National Aeronautics and
Space Administration

FY 2025
BUDGET ESTIMATES

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National Aeronautics and Space Administration

FY 2025 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2023	CR 2024	Request 2025	Fiscal Year 2026	2027	2028	2029
NASA Total	25,383.7	25,383.7	25,383.7	25,891.3	26,409.1	26,937.3	27,476.1
Deep Space Exploration Systems	7,447.6	7,468.9	7,618.2	7,803.7	7,959.8	8,119.0	8,281.4
Moon to Mars Transportation System	4,716.6	--	4,213.0	4,254.0	4,267.3	3,880.9	3,713.6
Moon to Mars Lunar Systems Development	2,630.5	--	3,288.1	3,285.7	3,389.5	3,868.8	3,712.3
Human Exploration Requirements & Architecture	100.5	--	117.1	264.1	303.0	369.3	855.5
Space Operations	4,266.7	4,250.0	4,389.7	4,497.6	4,587.6	4,679.4	4,773.0
International Space Station	1,286.2	--	1,269.6	1,267.8	1,262.8	1,259.4	1,259.4
Space Transportation	1,759.6	--	1,862.1	1,876.2	1,840.9	1,895.7	1,804.1
Space and Flight Support (SFS)	983.4	--	1,088.4	1,051.3	1,048.7	1,059.0	1,080.2
Commercial LEO Development	224.3	--	169.6	302.3	435.2	465.2	629.3
Exploration Operations	13.2	--	--	--	--	--	--
Space Technology	1,193.0	1,200.0	1,181.8	1,205.4	1,229.5	1,254.1	1,279.2
Science	7,791.5	7,795.0	7,565.7	7,717.0	7,871.3	8,028.7	8,189.3
Earth Science	2,175.0	--	2,378.7	2,396.3	2,446.1	2,489.7	2,543.4
Planetary Science	3,216.5	--	2,731.5	2,850.5	2,911.6	2,976.8	3,042.5
Astrophysics	1,510.0	--	1,578.1	1,587.0	1,613.6	1,647.1	1,673.4
Heliophysics	805.0	--	786.7	791.9	807.0	820.3	833.4
Biological and Physical Sciences	85.0	--	90.8	91.3	93.0	94.8	96.6
Aeronautics	935.0	935.0	965.8	985.1	1,004.8	1,024.9	1,045.4
STEM Engagement	143.5	143.5	143.5	146.4	149.3	152.3	155.3
Safety, Security, and Mission Services	3,136.5	3,129.5	3,044.4	3,105.3	3,167.4	3,230.7	3,295.3
Mission Services & Capabilities	2,067.4	--	2,058.1	2,099.2	2,141.3	2,184.1	2,227.6
Engineering, Safety, & Operations	1,069.1	--	986.3	1,006.1	1,026.1	1,046.6	1,067.7
Construction and Environmental Compliance and Restoration	422.4	414.3	424.1	379.3	386.9	394.6	402.5
Construction of Facilities	346.2	--	344.7	298.3	304.3	310.4	316.6
Environmental Compliance and Restoration	76.2	--	79.4	81.0	82.6	84.2	85.9
Inspector General	47.6	47.6	50.5	51.5	52.5	53.6	54.7
NASA Total	25,383.7	25,383.7	25,383.7	25,891.3	26,409.1	26,937.3	27,476.1

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NASA Total	**25,383.7**	**25,383.7**	**25,383.7**	**25,891.3**	**26,409.1**	**26,937.3**	**27,476.1**
Deep Space Exploration Systems	**7,447.6**	**7,468.9**	**7,618.2**	**7,803.7**	**7,959.8**	**8,119.0**	**8,281.4**
Moon to Mars Transportation System	**4,716.6**	**--**	**4,213.0**	**4,254.0**	**4,267.3**	**3,880.9**	**3,713.6**
Orion Program	**1,315.1**	**--**	**1,031.0**	**1,176.9**	**1,288.5**	**1,266.4**	**1,166.4**
Crew Vehicle Development	1,301.5	1,221.0	1,023.5	1,141.9	1,281.0	1,213.7	1,113.8
Orion Program Integration and Support	13.5	--	7.5	35.0	7.5	52.7	52.7
Space Launch System	**2,566.8**	**--**	**2,423.2**	**2,379.0**	**2,402.9**	**2,072.3**	**2,026.8**
Block 1B Capability Upgrade	648.3	462.5	285.8	275.1	54.3	--	--
SLS Operations	1,844.4	--	2,028.4	1,972.0	2,240.5	1,899.8	1,853.8
SLS Program Integration and Support	74.0	--	109.0	131.9	108.1	172.5	173.0
Exploration Ground Systems	**834.8**	**--**	**758.8**	**698.1**	**576.0**	**542.3**	**520.4**
Exploration Ground Systems Development	330.6	356.2	235.8	148.3	31.4	--	--
EGS Program Integration and Support	504.2	--	523.0	549.8	544.6	542.3	520.4
Moon to Mars Lunar Systems Development	**2,630.5**	**--**	**3,288.1**	**3,285.7**	**3,389.5**	**3,868.8**	**3,712.3**
Gateway	**779.2**	**--**	**817.7**	**627.9**	**586.8**	**746.0**	**635.4**
Gateway Initial Capability	493.0	516.6	431.8	181.3	--	--	--
xEVA and Human Surface Mobility Program	**324.9**	**--**	**434.2**	**483.9**	**644.7**	**673.6**	**571.2**
Human Landing System	**1,386.1**	**--**	**1,896.1**	**2,050.9**	**1,994.9**	**2,278.3**	**2,334.7**
HLS Initial Capability	807.3	526.3	647.1	703.3	607.2	252.1	--
Advanced Exploration Systems	**140.3**	**--**	**140.2**	**123.0**	**163.1**	**170.9**	**171.0**
Human Exploration Requirements & Architecture	**100.5**	**--**	**117.1**	**264.1**	**303.0**	**369.3**	**855.5**
Strategy & Architecture	**48.3**	**--**	**71.2**	**137.4**	**64.1**	**65.5**	**66.7**
Future Systems	**52.2**	**--**	**45.9**	**126.7**	**238.8**	**303.8**	**788.8**
Space Operations	**4,266.7**	**4,250.0**	**4,389.7**	**4,497.6**	**4,587.6**	**4,679.4**	**4,773.0**
International Space Station	**1,286.2**	**--**	**1,269.6**	**1,267.8**	**1,262.8**	**1,259.4**	**1,259.4**
International Space Station Program	**1,286.2**	**--**	**1,269.6**	**1,267.8**	**1,262.8**	**1,259.4**	**1,259.4**
ISS Systems Operations and Maintenance	1,034.4	--	1,008.5	1,008.5	1,003.5	1,000.0	1,000.0
ISS Research	251.8	--	261.1	259.3	259.3	259.4	259.4
Space Transportation	**1,759.6**	**--**	**1,862.1**	**1,876.2**	**1,840.9**	**1,895.7**	**1,804.1**
Crew and Cargo Program	**1,642.0**	**--**	**1,761.5**	**1,773.4**	**1,735.8**	**1,788.3**	**1,694.3**
Commercial Crew Program	**117.5**	**--**	**100.6**	**102.8**	**105.1**	**107.4**	**109.8**
Space and Flight Support (SFS)	**983.4**	**--**	**1,088.4**	**1,051.3**	**1,048.7**	**1,059.0**	**1,080.2**
Space Communications and Navigation	**532.0**	**--**	**627.7**	**585.4**	**582.6**	**591.5**	**605.5**
Space Communications Networks	424.8	--	543.5	499.7	491.2	495.1	509.2

FY 2025 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2023	CR 2024	Request 2025	2026	2027	2028	2029
Space Communications Support	107.2	--	84.2	85.7	91.3	96.4	96.4
Communications Services Program	**51.7**	**--**	**59.4**	**59.4**	**59.4**	**59.4**	**59.4**
Human Space Flight Operations	**101.5**	**--**	**105.0**	**105.8**	**105.8**	**105.9**	**108.0**
Human Research Program	**151.2**	**--**	**143.4**	**155.5**	**155.5**	**156.5**	**159.5**
Launch Services	**93.9**	**--**	**104.3**	**96.6**	**96.9**	**97.2**	**99.1**
Rocket Propulsion Test	**48.2**	**--**	**48.6**	**48.6**	**48.6**	**48.6**	**48.6**
21st Century Space Launch Complex	**5.0**	**--**	**--**	**--**	**--**	**--**	**--**
Commercial LEO Development	**224.3**	**--**	**169.6**	**302.3**	**435.2**	**465.2**	**629.3**
Exploration Operations	**13.2**	**--**	**--**	**--**	**--**	**--**	**--**
Space Technology	**1,193.0**	**1,200.0**	**1,181.8**	**1,205.4**	**1,229.5**	**1,254.1**	**1,279.2**
Early Stage Innovation and Partnerships	**122.0**	**--**	**140.1**	**145.1**	**149.6**	**154.2**	**160.4**
Agency Technology and Innovation	1.4	--	--	--	--	--	--
Early Stage Innovation	99.1	--	117.0	121.5	125.5	129.6	135.4
Technology Transfer	21.5	--	23.1	23.6	24.1	24.6	25.1
Technology Maturation	**323.9**	**--**	**340.8**	**353.2**	**363.1**	**370.4**	**377.8**
Technology Demonstration	**515.4**	**--**	**459.1**	**460.5**	**465.2**	**472.8**	**479.1**
Solar Electric Propulsion (SEP)	18.5	10.5	13.0	7.7	6.6	5.7	1.7
On-Orbit Servicing, Assembly, and Manufacturing Demonstration-1	227.0	--	11.0	--	--	--	--
Space Nuclear Propulsion	91.3	--	110.0	70.5	54.5	45.5	42.5
Small Spacecraft, Flight Opportunities & Other Tech Demo	178.6	--	325.1	382.3	404.1	421.6	434.9
SBIR and STTR	**231.7**	**--**	**241.8**	**246.6**	**251.6**	**256.7**	**261.9**
Science	**7,791.5**	**7,795.0**	**7,565.7**	**7,717.0**	**7,871.3**	**8,028.7**	**8,189.3**
Earth Science	**2,175.0**	**--**	**2,378.7**	**2,396.3**	**2,446.1**	**2,489.7**	**2,543.4**
Earth Science Research	**502.0**	**--**	**606.2**	**608.4**	**627.6**	**628.8**	**637.2**
Earth Science Research and Analysis	338.0	--	364.9	371.3	385.4	380.9	385.7
Computing and Management	164.0	--	241.2	237.1	242.2	248.0	251.4
Earth Systematic Missions	**915.0**	**--**	**854.4**	**868.7**	**888.2**	**869.9**	**757.8**
NASA-ISRO SAR	93.5	72.1	29.3	21.1	12.0	0.1	--
Sentinel-6	40.3	51.3	36.5	18.1	8.7	5.7	7.1
PACE	112.8	75.5	26.3	24.8	8.5	--	--
GRACE-Continuity	166.8	--	102.4	41.8	57.2	82.6	25.3
Other Missions and Data Analysis	501.6	--	660.0	762.9	801.7	781.4	725.5
Earth System Explorers	**2.5**	**--**	**19.6**	**59.0**	**99.5**	**130.6**	**194.7**
Responsive Science Initiatives	**55.0**	**--**	**167.7**	**173.9**	**176.4**	**177.9**	**179.5**
Earth System Science Pathfinder	**232.1**	**--**	**251.7**	**246.0**	**202.1**	**225.0**	**308.9**
Venture Class Missions	161.2	--	200.4	205.0	181.5	201.9	283.3
Other Missions and Data Analysis	70.9	--	51.3	41.0	20.6	23.1	25.6
Earth Science Data Systems	**291.1**	**--**	**263.2**	**257.6**	**268.3**	**269.8**	**276.3**
Earth Science Technology	**102.2**	**--**	**147.2**	**109.4**	**110.6**	**111.8**	**113.0**
Applied Sciences	**75.2**	**--**	**68.6**	**73.3**	**73.5**	**75.8**	**75.9**
Planetary Science	**3,216.5**	**--**	**2,731.5**	**2,850.5**	**2,911.6**	**2,976.8**	**3,042.5**

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Budget Authority ($ in millions)	Op Plan 2023	CR 2024	Request 2025	2026	2027	2028	2029
Planetary Science Research	**310.6**	**--**	**390.1**	**386.4**	**392.5**	**405.3**	**407.8**
Planetary Science Research and Analysis	205.1	--	249.3	249.2	252.2	260.9	264.4
Other Missions and Data Analysis	105.5	--	140.8	137.2	140.2	144.4	143.4
Planetary Defense	**135.5**	**--**	**276.6**	**369.3**	**299.6**	**81.0**	**78.1**
NEO Surveyor	90.0	301.9	235.6	327.3	257.6	39.0	36.1
Other Missions and Data Analysis	45.5	--	41.0	42.0	42.0	42.0	42.0
Lunar Discovery and Exploration	**486.3**	**--**	**458.3**	**456.8**	**467.8**	**479.1**	**488.5**
VIPER	97.2	69.3	33.0	--	--	--	--
Other Missions and Data Analysis	389.1	--	425.3	456.8	467.8	479.1	488.5
Discovery	**217.5**	**--**	**261.5**	**418.3**	**588.0**	**790.8**	**912.4**
DAVINCI	20.2	--	40.1	116.4	209.0	295.9	321.9
VERITAS	9.5	--	36.1	104.9	177.7	232.1	267.2
Other Missions and Data Analysis	187.7	--	185.3	197.0	201.3	262.7	323.3
New Frontiers	**488.2**	**--**	**500.5**	**533.0**	**484.2**	**471.6**	**298.3**
Dragonfly	400.1	--	434.6	496.8	434.2	317.6	32.5
Other Missions and Data Analysis	88.1	--	65.9	36.3	50.0	154.0	265.8
Mars Exploration	**248.1**	**--**	**324.5**	**298.6**	**305.8**	**353.3**	**390.7**
Other Missions and Data Analysis	248.1	--	324.5	298.6	305.8	353.3	390.7
Mars Sample Return	**818.8**	**--**	**200.0**	**100.0**	**100.0**	**100.0**	**100.0**
Outer Planets and Ocean Worlds	**356.8**	**--**	**119.0**	**97.4**	**97.1**	**126.3**	**204.3**
Europa Clipper	345.0	303.3	101.2	80.6	77.7	84.0	127.0
Other Missions and Data Analysis	11.8	--	17.8	16.8	19.5	42.3	77.3
Radioisotope Power	**154.9**	**--**	**201.1**	**190.7**	**176.6**	**169.4**	**162.5**
Astrophysics	1,510.0	--	1,578.1	1,587.0	1,613.6	1,647.1	1,673.4
Astrophysics Research	**284.8**	**--**	**300.5**	**378.7**	**390.5**	**390.3**	**377.1**
Astrophysics Research and Analysis	112.2	--	118.8	127.2	134.2	138.2	132.3
Balloon Project	52.6	--	56.1	61.0	63.0	59.0	58.2
Science Activation	52.0	--	52.0	52.0	52.0	52.0	52.0
Other Missions and Data Analysis	68.0	--	73.6	138.5	141.3	141.1	134.6
Cosmic Origins	**314.8**	**--**	**319.0**	**312.8**	**307.7**	**300.4**	**282.1**
Hubble Space Telescope (HST)	93.3	--	88.9	87.5	87.8	83.0	64.7
James Webb Space Telescope	162.5	--	187.0	187.0	187.0	187.0	187.0
Other Missions and Data Analysis	59.0	--	43.1	38.2	33.0	30.4	30.4
Physics of the Cosmos	**180.7**	**--**	**210.8**	**184.3**	**168.6**	**176.1**	**133.7**
Other Missions and Data Analysis	180.7	--	210.8	184.3	168.6	176.1	133.7
Exoplanet Exploration	**502.9**	**--**	**478.5**	**459.0**	**366.1**	**323.8**	**339.9**
Nancy Grace Roman Space Telescope	447.3	407.3	384.0	376.5	216.6	100.5	75.1
Other Missions and Data Analysis	55.6	--	94.5	82.5	149.5	223.4	264.8
Astrophysics Explorer	**226.8**	**--**	**269.3**	**252.2**	**380.6**	**456.4**	**540.6**
SPHEREx	81.6	65.4	38.7	6.0	1.6	0.5	--
Compton Spectrometer and Imager (COSI)	36.5	--	64.4	68.2	46.9	6.5	3.1
Other Missions and Data Analysis	108.7	--	166.3	178.0	332.1	449.4	537.5
Heliophysics	805.0	--	786.7	791.9	807.0	820.3	833.4
Heliophysics Research	**238.2**	**--**	**252.3**	**247.7**	**255.8**	**257.8**	**258.5**

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Heliophysics Research and Analysis	62.3	--	65.0	64.7	65.0	63.5	64.8
Sounding Rockets	60.4	--	75.3	69.2	74.2	69.5	69.2
Research Range	32.8	--	24.5	27.3	27.3	33.1	27.8
Other Missions and Data Analysis	82.8	--	87.5	86.5	89.4	91.8	96.7
Living with a Star	**155.2**	**--**	**107.7**	**100.1**	**112.1**	**106.3**	**101.4**
Other Missions and Data Analysis	155.2	--	107.7	100.1	112.1	106.3	101.4
Solar Terrestrial Probes	**198.0**	**--**	**133.2**	**82.9**	**64.9**	**56.1**	**38.1**
Interstellar Mapping and Acceleration Probe (IMAP)	123.3	137.4	63.9	39.5	23.9	15.3	--
Other Missions and Data Analysis	74.7	--	69.3	43.4	41.1	40.8	38.1
Heliophysics Explorer Program	**167.9**	**--**	**236.7**	**309.4**	**325.4**	**355.4**	**385.4**
HelioSwarm	10.9	--	39.3	126.8	138.2	109.0	86.0
Multi-Slit Solar Explorer	39.5	--	77.9	70.5	41.0	14.8	11.1
Other Missions and Data Analysis	117.5	--	119.5	112.0	146.2	231.6	288.4
Space Weather	**25.8**	**--**	**47.5**	**42.6**	**40.0**	**35.9**	**34.2**
Heliophysics Technology	**19.9**	**--**	**9.3**	**9.2**	**8.8**	**8.8**	**15.8**
Biological and Physical Sciences	85.0	--	90.8	91.3	93.0	94.8	96.6
Aeronautics	935.0	935.0	965.8	985.1	1,004.8	1,024.9	1,045.4
Aeronautics	935.0	--	965.8	985.1	1,004.8	1,024.9	1,045.4
Airspace Operations and Safety Program	**151.6**	**--**	**151.2**	**164.3**	**174.1**	**177.7**	**180.9**
Advanced Air Vehicles Program	**258.0**	**--**	**278.8**	**269.6**	**262.4**	**248.8**	**218.7**
Integrated Aviation Systems Program	**261.1**	**--**	**264.4**	**277.0**	**277.6**	**300.9**	**342.0**
Low Boom Flight Demonstrator	51.3	42.6	70.9	44.5	5.7	--	--
Electrified Powertrain Flight Demonstration	91.6	--	61.6	65.0	75.5	50.0	--
Other Projects	118.2	--	131.9	167.6	196.4	250.9	342.0
Transformative Aeronautics Concepts Program	**147.1**	**--**	**155.3**	**157.6**	**171.1**	**175.2**	**179.0**
Aerosciences Evaluation and Test Capabilities	**117.3**	**--**	**116.2**	**116.5**	**119.5**	**122.3**	**124.7**
STEM Engagement	143.5	143.5	143.5	146.4	149.3	152.3	155.3
Safety, Security, and Mission Services	3,136.5	3,129.5	3,044.4	3,105.3	3,167.4	3,230.7	3,295.3
Mission Services & Capabilities	2,067.4	--	2,058.1	2,099.2	2,141.3	2,184.1	2,227.6
Information Technology (IT)	**628.6**	**--**	**628.6**	**641.1**	**654.0**	**667.1**	**680.4**
Mission Enabling Services	**754.3**	**--**	**732.7**	**747.4**	**762.3**	**777.5**	**793.0**
Infrastructure & Technical Capabilities	**684.5**	**--**	**696.8**	**710.7**	**725.0**	**739.5**	**754.2**
Engineering, Safety, & Operations	1,069.1	--	986.3	1,006.1	1,026.1	1,046.6	1,067.7
Agency Technical Authority	**190.1**	**--**	**180.3**	**183.9**	**187.6**	**191.3**	**195.2**
Center Engineering, Safety, & Operations	**879.0**	**--**	**806.0**	**822.2**	**838.5**	**855.3**	**872.5**

FY 2025 PRESIDENT'S BUDGET REQUEST SUMMARY

Budget Authority ($ in millions)	Op Plan 2023	CR 2024	Request 2025	2026	2027	2028	2029
			Fiscal Year				
Construction and Environmental Compliance and Restoration	**422.4**	**414.3**	**424.1**	**379.3**	**386.9**	**394.6**	**402.5**
Construction of Facilities	**346.2**	**--**	**344.7**	**298.3**	**304.3**	**310.4**	**316.6**
Institutional CoF	**230.6**	**--**	**292.5**	**298.3**	**304.3**	**310.4**	**316.6**
Exploration CoF	**94.3**	**--**	**32.5**	**--**	**--**	**--**	**--**
Space Operations CoF	**17.8**	**--**	**19.7**	**--**	**--**	**--**	**--**
Science CoF	**3.6**	**--**	**--**	**--**	**--**	**--**	**--**
Environmental Compliance and Restoration	**76.2**	**--**	**79.4**	**81.0**	**82.6**	**84.2**	**85.9**
Inspector General	**47.6**	**47.6**	**50.5**	**51.5**	**52.5**	**53.6**	**54.7**
NASA Total	**25,383.7**	**25,383.7**	**25,383.7**	**25,891.3**	**26,409.1**	**26,937.3**	**27,476.1**

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023. Amounts include $8 million that was transferred to NASA's Information Technology Modernization Working Capital Fund.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

The funding levels for Planetary Science missions are subject to change. Given that the Mars Sample Return mission is a major part of NASA's Planetary Science budget, the Budget enables NASA's internal assessment of mission architecture options to be completed to address increases in mission cost estimates before providing final details for the $2.7 billion Planetary Science budget.

Totals may not add due to rounding.

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MESSAGE FROM THE ADMINISTRATOR

The President's Fiscal Year 2025 Budget request for NASA expresses the continued commitment from the Biden-Harris Administration to maintain and amplify America's preeminent place of leadership in humanity's quest to know the cosmos. The President's Budget prioritizes investments with a demonstrated return of value for the American taxpayer – investments in the future of deep space exploration, sustainable aeronautics, scientific endeavor, technological might, and inspiring the next generation, the Artemis Generation.

As history has proven, as the present has shown, and as the future will continue to demonstrate, to invest in NASA is to invest in the power, the principles, and the global leadership abilities of the United States. To invest in NASA is to benefit America and Americans.

We benefit America through NASA's Artemis campaign. The Artemis campaign represents the most diverse and broad coalition in space exploration. We are working with American companies and international partners to return astronauts to the Moon and then land the first astronauts on Mars.

Under NASA's leadership, humanity will make new scientific discoveries, test new technologies, and explore more of the lunar surface than ever before. The Artemis II crewed flight test, fully funded in the President's Budget, will, for the first time in over half a century, fly astronauts around the Moon. The budget makes investments in the long-term architecture for Artemis, including funding for human landing systems and extra-vehicular suits; lunar transportation, habitation and fission surface power that will enable humanity's sustainable presence on the Moon; and the Gateway lunar outpost, built with international partners, that will help enable operations on the surface of the Moon.

We benefit America through advancing our space technologies, which supports the growth and competitiveness of the U.S. space industry and will enable future Artemis missions. By developing lunar robotic missions, communications on and around the Moon, in-situ resource utilization demonstrations, Commercial Lunar Payload Services, and other key elements, NASA will deepen our understanding of the Moon to prepare for humanity's long-duration stays on the lunar surface, and later, Mars. Additionally, NASA is partnering with the Defense Advanced Research Projects Agency and industry to develop and demonstrate advanced nuclear propulsion, a technology that would enable more rapid crew transportation into deep space.

We benefit America through our leadership in Earth orbit. Last year, NASA celebrated 25 years of International Space Station (ISS) operations, including 23 years with continuous human presence. This year, we continue to use commercial services to safely transport cargo and astronauts to the ISS to conduct critical research, science, and technology demonstrations. These operations inform and reduce risk for future missions to the Moon and Mars and provide insight and breakthroughs that directly affect life on Earth, including NASA's contribution to curing cancer through the President's Cancer Moonshot initiative. The President's Budget supports NASA in maintaining critical operations in low Earth orbit while paving the way for a future sustained commercially-enabled American presence in space to continue creating scientific and economic opportunities for all.

We benefit America through our discoveries through the eye of NASA's James Webb Space Telescope, discoveries that represent a shift in our capacity to see the universe on an order of magnitude never before seen. In 2023, NASA's Webb Telescope continued to unfold the secrets of our universe and inspire the world through breathtaking images during its first year of operations. The

Webb telescope pulled back the curtain on some of the farthest galaxies, stars, and black holes ever observed; found methane and carbon dioxide in the atmosphere of a planet outside our solar system; and more. The President's Budget request for NASA science will continue supporting operations of groundbreaking missions like Webb, Hubble, and Perseverance. The request also invests in new missions and capabilities that will enable the next generation of great science, including the Nancy Grace Roman Space Telescope, Habitable Worlds Observatory Technology Maturation, and the Commercially Enabled Rapid Space Science Initiative, Near-Earth Object Surveyor, and Dragonfly.

We benefit America through NASA's leadership in climate and Earth science. Much of what we know about our changing planet is rooted in NASA's more than 40 years of Earth observations. With over two dozen instruments aboard the ISS complementing those in free-flyer orbits, NASA uses its unique vantage point of space to better understand our changing planet. With the President's Budget, NASA will continue to bring critical, life-changing climate data back down to Earth. NASA's new Earth Information Center at Headquarters in Washington DC, and online, helps fulfill the Biden-Harris Administration's call to make climate data more understandable and accessible for all people. Through current and future Earth science missions like Landsat Next and building out the multi-satellite Earth System Observatory, NASA will continue to help all humanity understand and address the impacts of climate change.

We benefit America through NASA's key role in improving air travel and reaching net-zero aviation greenhouse gas emissions by 2050, by accelerating research and development of aircraft technologies that are cleaner, quieter, and greener. NASA is working with American companies to develop next-generation aircraft and engines that would make commercial airliners 25 to 30 percent more efficient. That will benefit our planet, the U.S. commercial aviation sector, and passengers around the world. Through ambitious experimental projects like the X-66 Sustainable Flight Demonstrator and the X-59 Quiet Supersonic Technology Low Boom Flight Demonstrator, NASA will continue to help revolutionize the future of air travel.

We benefit America when NASA identifies, enables, and utilizes talents from across all of humanity. The President's Budget supports the Agency's commitment to reaching and engaging historically underserved populations and advancing diversity, equity, inclusion, and accessibility within our workforce as well as with our partners. This includes robust outreach effort to students of every background to pursue education in science, technology, engineering, and mathematics and then implement that education through public service at NASA or within America's space industry. With the launch of NASA's streaming platform NASA+, the Agency debuted Spanish content available for streaming along with steps to make NASA content more easily accessible for the public. NASA also took its "The Color of Space" documentary on a road tour, providing free in-person screenings at historically Black colleges and universities, conferences, and festivals Nationwide.

We benefit America when we invest in the future of America: the Artemis Generation. Through NASA initiatives like Earthrise, educators can provide their students with climate and science resources from across the Federal Government. President Biden's budget request will continue to help NASA inspire the STEM workforce of the future.

MESSAGE FROM THE ADMINISTRATOR

All of these benefits—for America, for humanity, and for the planet—add up to this: To invest in NASA advances our Nation's abilities and leadership in making the impossible possible, in making the unknown known, and in inspiring the world through discovery while creating competitive and good- paying jobs in all 50 states. The President's Budget will help bring our Nation, our economy, and our people deeper into a new era of American ingenuity, innovation, imagination, and leadership.

Bill Nelson

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($ in Billions)	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
NASA Budget	25.4	25.4	25.4	25.9	26.4	26.9	27.5

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023. Amounts include $8 million that was transferred to NASA's Information Technology Modernization Working Capital Fund.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

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The President's Fiscal Year 2025 Budget Request for NASA is $25.4 billion. With this proposed budget, NASA will fund the following efforts:

Agency Highlights

- Invests $7.8 billion to build on the success of Artemis I and return American astronauts to the Moon, including the first woman and first person of color, as part of the overall Artemis campaign; establish a sustainable lunar presence; and lay the groundwork for humanity's first crewed mission to Mars. This request supports activities related to Artemis missions II through XII, including the launches of Artemis II in 2025, Artemis III in 2026, and Artemis IV in 2028.
- Invests $4.4 billion to sustain human presence in low-Earth orbit (LEO) with operations of the International Space Station (ISS) until 2030 and then a transition to the use of commercial space stations thereafter. This includes $109 million for a U.S. deorbit vehicle that will enable the safe and responsible deorbit of the ISS at the end of this decade; and $170 million for U.S. industry to develop commercial LEO destinations that enable a continuous presence in LEO.
- Advances space technology research and development with $1.2 billion. With this investment in technology and innovation, the budget request will advance mission capabilities and technologies needed to grow the commercial space economy and support NASA's missions, including integrated Moon to Mars efforts, through strategic partnerships, and leveraging early- stage innovators.
- Includes $7.6 billion to conduct scientific exploration enabled by space-based observatories, which observe the Earth, perform fundamental research, visit other bodies in the solar system, and gaze out into the galaxy and beyond.
- Continues investments in Earth science and green aviation that will protect our home planet. Specifically, this request proposes $2.4 billion to fund Earth science and observations that enhance our understanding of the Earth system and continues efforts to make data more accessible and useful to a wide range of stakeholders, including scientists and policymakers. This request also includes over $500 million in Aeronautics to improve aircraft efficiency and reduce the climate impact of aviation.
- Broadens and diversifies student participation in Science, Technology, Engineering, and Mathematics (STEM) with $143.5 million for the Office of STEM Engagement to inspire

and develop the next generation of scientists, engineers, and explorers.

- Invests $3.5 billion in NASA's workforce and infrastructure including the vital functions that underpin the success of our missions, including NASA's facilities, information technology, core business, and technical services.
- Demonstrates NASA's commitment to advancing Diversity, Equity, Inclusion, and Accessibility (DEIA) throughout the workforce with a request of $22.4 million.
- Invests $41.2 million for space sustainability to better understand and mitigate the hazard of orbital debris.

Deep Space Exploration Systems - $7.6 billion

- $4.2 billion for Moon to Mars Transportation Systems (formerly Common Exploration Systems Development) to support lunar missions, with $1.0 billion to build Orion capsules for Artemis, $2.4 billion for the Space Launch System, and $758.8 million for Exploration Ground Systems, including Mobile Launcher-2.
- $3.2 billion for Moon to Mars Lunar System Development (formerly Artemis Campaign Development) to advance lunar exploration capabilities, with $1.8 billion for the Human Landing System program to develop and deploy multiple landing systems, $817.7 million for the Gateway, $434.2 million for space suits and lunar rovers, and $140.2 million for Advanced Exploration Systems for future lunar surface habitats.
- $117.1 million for Human Exploration Requirements and Architecture to support Moon and Mars strategy and architecture development, with $45.9 million for Future Systems to identify technologies as a precursor to Mars and $71.2 million for Strategy and Architecture to support requirements and manifest planning.

Space Operations - $4.4 billion

- $1.3 billion for ISS operations and research to continue leveraging the multi-national space platform to conduct research, identify risks to human health, test exploration technologies, and support the growth of a commercial economy in LEO. The ISS budget decreases in the outyears to support an increase in funding for the Commercial LEO Development program and for commercial development of the United States Deorbit Vehicle (USDV) that will safely de-orbit ISS at the end of operations.
- $1.9 billion for Space Transportation to continue NASA's partnership with the U.S. commercial space industry to operate safe, reliable, and affordable systems to transport crew and cargo to and from the ISS, including $109 million in funding for the USDV.
- $1.1 billion for Space and Flight Support to enable safe, reliable, and productive human space exploration, including funding to provide mission-critical space communications; provide launch and test services; and conduct astronaut training and research into the health of humans living and working in space.
- $170 million for Commercial LEO Development to partner with the U.S. commercial space industry to develop and deploy commercial space stations in LEO.

Space Technology - $1.2 billion

- $459 million for Technology Demonstration for ground and space flight testing, including a collaboration with the Defense Advanced Research Projects Agency (DARPA) to advance nuclear propulsion technologies; conducting two Cryogenic Fluid Management technology flight demonstrations; maturing and developing Fission Surface Power and Solar Electric Propulsion; and increasing the pace of space exploration with small spacecraft and flight opportunities. Funding for these technology demonstration missions is in part made possible by the close-out of OSAM-1.

- $341 million for Technology Maturation to advance revolutionary disruptive space technologies at mid-technology readiness levels in space transportation; entry, descent, and landing; in-situ resource utilization; power and energy storage; materials and structures; and robotic systems for sustainable exploration.
- $140 million for Early-Stage Innovation and Partnerships that source ideas from a broad, diverse base of innovators, and transfer space technology into the space economy.
- $242 million for Small Business Innovation Research and Small Business Technology Transfer to develop new technologies, drive investments in small businesses, and spur economic growth.

Science - $7.6 billion

- The request for Science invests in over 125 space science missions, including 54 that are currently preparing for launch and approximately 70 in operation. This request also funds U.S. scientists in universities, industry, and government labs through more than 4,000 openly competed research awards.
- $2.7 billion for Planetary Science to support innovative approaches to exploring new destinations in the solar system. This request continues development of numerous other missions, including the NEO Surveyor mission to detect potentially hazardous asteroids, the Dragonfly mission to explore a moon of Saturn, Europa Clipper which explores the icy moon of Jupiter, the VERITAS and DAVINCI missions to Venus, and contributions to the joint European EnVision mission to Venus, and Rosalind Franklin mission to Mars. The request also supports the Commercial Lunar Payload Services (CLPS) project to deliver scientific, exploration, and technology payloads to the Moon. The request includes $200M for Mars Sample Return that will allow the project to advance formulation of mission components and capabilities that have a high likelihood of being used in any future sample return architecture, and to evaluate and appropriately incorporate relevant findings from funded industry and center architecture studies.
- $2.4 billion for Earth Science to enhance understanding of the Earth system through continued investment in a broad portfolio of missions including Surface Biology and Geology, GRACE-Continuity, Landsat Next, and others; initiate the first Earth System Explorers mission; support the ongoing development of multiple innovative Venture Class missions; implement the Responsive Science Initiatives program, which consolidates and enhances current activities within Earth Science to increase the impact of NASA-funded observations and Earth system science; and continue robust support for research and applications related to wildland fire management and agriculture.
- $1.6 billion for Astrophysics to revolutionize our understanding of the origins and evolution of galaxies by supporting operation of the James Webb Space Telescope and the Hubble Space Telescope, as well as the development of the Nancy Grace Roman Space Telescope, a mission designed to unravel the secrets of dark energy and dark matter and to search for and image exoplanets; develop the Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer (SPHEREx); support initial selections for the first Astrophysics

Probe mission; and initiate important investments in precursor science, mission, and technology maturation efforts for a potential future Habitable Worlds Observatory, a Decadal Survey recommendation.

- $787 million for Heliophysics to study the Sun and its influence throughout the solar system, including the Interstellar Mapping and Acceleration Probe (IMAP) and the Carruthers Geocorona Observatory; support the competitive Explorer Program including recently selected missions Multi-slit Solar Explorer (MUSE) and HelioSwarm; expand the Space Weather Program focused on applied research and applications to enable the nation to better protect our technology and astronauts from space weather; continue the Diversify, Realize, Integrate, Venture, Educate (DRIVE) research initiative; and support orbital debris investments to enable characterization of the population of small debris in space.
- $91 million for Biological and Physical Sciences to better understand how biological and physical systems work from the unique vantage point of space and to develop transformative research capabilities with the commercial space industry to dramatically increase the pace of space-based research.

Aeronautics Research - $966 million

- $279 million for Advanced Air Vehicles to develop technologies and concepts that enable new generations of civil aircraft that are safer, faster, more energy-efficient, and have a smaller environmental footprint; demonstrate integrated small core aircraft engine technologies; develop techniques for high-rate manufacturing of composite structures; and advance long-term opportunities for supersonic and hypersonic flight.
- $264 million for Integrated Aviation Systems to explore, assess, and demonstrate the benefits of the most promising technologies at an integrated system level, including in flight; develop Electrified Powertrain Flight Demonstrations and a Sustainable Flight Demonstrator that will pave the way to reducing aviation emissions; and conduct test flights of the X-59 Low Boom Flight Demonstrator exploring quiet supersonic flight.
- $151 million for Airspace Operations and Safety to modernize and transform the national air traffic management system, in partnership with the Federal Aviation Administration and the aviation community; develop and explore advanced technologies for more efficient flight trajectories; lead research to integrate new advanced air mobility vehicles safely into the national airspace; provide tools to support in-time system-wide safety assurance; and develop a concept of operations to improve aerial responses to wildfires.
- $155 million for Transformative Aeronautics Concepts to support revolutionary aviation concepts development with opportunities focused on reducing aviation emissions, new computational tools, and experimental capability advancement.
- $116 million for Aerosciences Evaluation and Test Capabilities, supporting NASA’s 12 large wind tunnels across three centers.

STEM Engagement - $144 million

- NASA’s STEM engagement efforts will focus on broadening student participation, continuing K-12 student engagement in STEM pathways, and building partnerships and networks to magnify reach and impact. Investments include: $57 million for Space Grant, $24.8 million for Established Program to Stimulate Competitive Research (EPSCoR), $46.3 million for Minority

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University Research and Education Project (MUREP), and $15.4 million for Next Gen STEM.

Safety, Security and Mission Services (SSMS) - $3.0 billion

- $2.1 billion for Mission Services and Capabilities to advance NASA's Information Technology, Mission Enabling Services, and Infrastructure and Technical Capabilities. These programs will provide agency-wide business, technical, and infrastructure services that enable NASA's ambitious mission portfolio to help maintain U.S. leadership in space, aviation, science, and technology. This request includes critical funding for high priority areas such as managing cybersecurity risk and leveraging the innovation of Artificial Intelligence while ensuring our systems are safe and secure.
- $1.0 billion for Engineering, Safety, and Operations for nine NASA Centers, Headquarters, and component facilities. Center Engineering, Safety, and Operations ensures NASA's unique, technical, and innovative capabilities are mission ready. Through the Agency Technical Authority program, this funding provides independent oversight over NASA's missions and programs to ensure the health, safety, and security of NASA people and property as well as the public.

Construction and Environmental Compliance and Restoration (CECR) - $424 million

- $424.1 million to ensure agency infrastructure, laboratories, and critical facilities are safe, secure, environmentally sound, appropriately sized, efficiently operated, and mission-ready.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

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EXPLANATION OF BUDGET TABLES AND SCHEDULES

EXPLANATION OF PROJECT SCHEDULE COMMITMENTS AND KEY MILESTONES

Programs and projects follow their appropriate life cycle. The life cycle is divided into phases. Transition from one phase to another requires management approval at Key Decision Points (KDPs). The phases in program and project life cycles include one or more life cycle reviews, which are considered major milestone events.

Formulation

- Phase A: concept and technology development; and
- Phase B: preliminary design and technology completion.

Implementation

- Phase C: final design and fabrication;
- Phase D: system assembly, integration, test, launch and checkout;
- Phase E: operations and sustainment; and
- Phase F: closeout.

A life cycle review is designed to provide the program or project with an opportunity to ensure that it has completed the work of that phase and an independent assessment of a program or project's technical and programmatic status and health. The final life cycle review in a given life cycle phase provides essential information for the KDP that marks the end of that life cycle phase and transition to the next phase if successfully passed. As such, KDPs serve as gates through which programs and projects must pass to continue.

The KDP decision to authorize a program or project's transition to the next life cycle phase is based on a number of factors, including technical maturity; continued relevance to agency strategic goals; adequacy of cost and schedule estimates; associated probabilities of meeting those estimates (i.e., confidence levels); continued affordability with respect to the agency's resources; maturity and the readiness to proceed to the next phase; and remaining program or project risks (e.g., safety, cost, schedule, technical, management, and programmatic). At the KDP, the key program or project cost, schedule, and content parameters that govern the remaining life cycle activities are established.

For reference, a description of schedule commitments and milestones is listed below for projects in formulation or implementation. A list of common terms used in mission planning is also included.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Formulation

NASA places significant emphasis on project formulation to ensure adequate preparation of project concepts and plans and mitigation of high-risk aspects of the project essential to position the project for the highest probability of mission success. During formulation, the project explores the full range of implementation options, defines an affordable project concept to meet requirements, and develops needed technologies. The activities in these phases include developing the system architecture; completing mission and preliminary system designs; acquisition planning; conducting safety, technical, cost, and schedule risk trades; developing time-phased cost and schedule estimates and documenting the basis of these estimates; and preparing the project plan for implementation.

Formulation Milestone	Explanation
KDP-A	The life cycle gate at which the decision authority determines the readiness of a program or project to transition into Phase A and authorizes formulation of the project. Phase A is the first phase of formulation and means that: • The project addresses a critical NASA need; • The proposed mission concept(s) is feasible; • The associated planning is sufficiently mature to begin activities defined for formulation; and • The mission can likely be achieved as conceived.
System Requirements Review (SRR)	The life cycle review in which the decision authority evaluates whether the functional and performance requirements defined for the system are responsive to the program's requirements on the project and represent achievable capabilities.
System Definition Review or Mission Definition Review	The life cycle review in which the decision authority evaluates the credibility and responsiveness of the proposed mission/system architecture to the program requirements and constraints on the project, including available resources, and determines whether the maturity of the project's mission/system definition and associated plans are sufficient to begin the next phase, Phase B.
KDP-B	The life cycle gate at which the decision authority determines the readiness of a program or project to transition from Phase A to Phase B. Phase B is the second phase of formulation and means that: • The proposed mission/system architecture is credible and responsive to program requirements and constraints, including resources; • The maturity of the project's mission/system definition and associated plans is sufficient to begin Phase B; and • The mission can likely be achieved within available resources with acceptable risk.
Preliminary Design Review (PDR)	The life cycle review in which the decision authority evaluates the completeness/consistency of the planning, technical, cost, and schedule baselines developed during formulation. This review also assesses compliance of the preliminary design with applicable requirements and determines if the project is sufficiently mature to begin Phase C.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Implementation

Implementation occurs when agency management establishes baseline cost and schedule commitments for projects at KDP-C. The projects maintain the baseline commitment through the end of the mission. Projects are baselined for cost, schedule, and programmatic and technical parameters. Under Implementation, projects are able to execute approved plans development and operations.

Implementation Milestone	Explanation
KDP-C	The life cycle gate at which the decision authority determines the readiness of a program or project to begin the first stage of development and transition to Phase C and authorizes the Implementation of the project. Phase C is the first stage of development and means that: • The project's planning, technical, cost, and schedule baselines developed during formulation are complete and consistent; • The preliminary design complies with mission requirements; • The project is sufficiently mature to begin Phase C; and • The cost and schedule are adequate to enable mission success with acceptable risk.
Critical Design Review (CDR)	The life cycle review in which the decision authority evaluates the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. This review also determines if the design is appropriately mature to continue with the final design and fabrication phase.
System Integration Review (SIR)	The life cycle review in which the decision authority evaluates the readiness of the project and associated supporting infrastructure to begin system assembly, integration, and test. The life cycle review also evaluates whether the remaining project development can be completed within available resources, and determine if the project is sufficiently mature to begin Phase D.
KDP-D	The life cycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase C to Phase D. Phase D is the second phase in Implementation; the project continues in development and means that: • The project is still on plan; • The risk is commensurate with the project's payload classification; and • The project is ready for assembly, integration, and test with acceptable risk within its agency baseline commitment.
Launch Readiness Date (LRD)	The date at which the project and its ground, hardware, and software systems are ready for launch.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

Other Common Terms for Mission Planning

Term	Definition
Decision Authority	The individual authorized by the agency to make important decisions on programs and projects under their authority.
Formulation Authorization Document	The document that authorizes the formulation of a program whose goals will fulfill part of the agency's strategic plan and mission directorate strategies. This document establishes the expectations and constraints for activity in the Formulation Phase.
Key Decision Point (KDP)	The life cycle gate at which the decision authority determines the readiness of a program or project to progress to the next phase of the life cycle. The KDP also establishes the content, cost, and schedule commitments for the ensuing phase(s).
Launch Manifest	A list that NASA publishes (the "NASA Flight Planning Board launch manifest") periodically, which includes the expected launch dates for NASA missions. The launch dates in the manifest are the desired launch dates approved by the NASA Flight Planning Board and are not typically the same as the Agency Baseline Commitment schedule dates. A launch manifest is a dynamic schedule that is affected by real world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. Moreover, the launch dates are a mixture of "confirmed" range dates for missions launching within approximately six months, and contractual/planning dates for the missions beyond six months from launch. The NASA Flight Planning Board launch manifest date is typically earlier than the Agency Baseline Commitment schedule date to allow for the operationally driven delays to the launch schedule that may be outside of the project's control.
Operational Readiness Review	The life cycle review in which the decision authority evaluates the readiness of the project, including its ground systems, personnel, procedures, and user documentation, to operate the flight system and associated ground system(s), in compliance with defined project requirements and constraints during the operations phase.
Mission Readiness Review or Flight Readiness Review (FRR)	The life cycle review in which the decision authority evaluates the readiness of the project, ground systems, personnel, and procedures for a safe and successful launch and flight/mission.
KDP-E	The life cycle gate at which the decision authority determines the readiness of a project to continue in Implementation and transition from Phase D to Phase E. Phase E is the third phase in Implementation and means that the project and all supporting systems are ready for safe, successful launch and early operations with acceptable risk.
Decommissioning Review	The life cycle review in which the decision authority evaluates the readiness of the project to conduct closeout activities. The review includes final delivery of all remaining project deliverables and safe decommissioning of space flight systems and other project assets.
KDP-F	The life cycle gate at which the decision authority determines the readiness of the project's decommissioning. Passage through this gate means the project has met its program objectives and is ready for safe decommissioning of its assets and closeout of activities. Scientific data analysis may continue after this period.

EXPLANATION OF BUDGET TABLES AND SCHEDULES

For further details, go to:

- NASA Procedural Requirement 7102.5E NASA Space Flight Program and Project Management Requirements: https://nodis3.gsfc.nasa.gov/npg_img/N_PR_7120_005F_/N_PR_7120_005F_.pdf
- NASA Procedural Requirement NPR 7123.1C - NASA Systems Engineering Processes and Requirements: https://nodis3.gsfc.nasa.gov/npg_img/N_PR_7123_001C_/N_PR_7123_001C_.pdf
- NASA Launch Services Web site: https://www.nasa.gov/kennedy/launch-services-program/

COMMON ACRONYMS AND ABBREVIATIONS

NASA Centers

ARC	Ames Research Center
AFRC	Armstrong Flight Research Center
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
HQ	Headquarters
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LaRC	Langley Research Center
MSFC	Marshall Space Flight Center
SSC	Stennis Space Center

Mission Directorates

ARMD	Aeronautics Research Mission Directorate
ESDMD	Exploration Systems Development Mission Directorate
MSD	Mission Support Directorate
SMD	Science Mission Directorate
SOMD	Space Operations Mission Directorate
STMD	Space Technology Mission Directorate

Federal Agencies

DoD	Department of Defense
DoE	Department of Energy
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation

Partner Space Agencies

ASI	Italian Space Agency
CSA	Canadian Space Agency
DLR	German Aerospace Center
ESA	European Space Agency
ISRO	Indian Space Research Organization
JAXA	Japanese Aerospace Exploration Agency

Others

CDR	Critical Design Review
ISS	International Space Station
KDP	Key Decision Point
LCC	Life Cycle Cost
LEO	low-Earth orbit
PDR	Preliminary Design Review

DEEP SPACE EXPLORATION SYSTEMS

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Moon to Mars Transportation System	4,716.6	--	**4,213.0**	4,254.0	4,267.3	3,880.9	3,713.6
Moon to Mars Lunar Systems Development	2,630.5	--	**3,288.1**	3,285.7	3,389.5	3,868.8	3,712.3
Human Exploration Requirements & Architecture	100.5	--	**117.1**	264.1	303.0	369.3	855.5
Total Budget	**7,447.6**	**7,468.9**	**7,618.2**	**7,803.7**	**7,959.8**	**8,119.0**	**8,281.4**

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DEEP SPACE EXPLORATION SYSTEMS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Moon to Mars Transportation System	4,716.6	--	**4,213.0**	4,254.0	4,267.3	3,880.9	3,713.6
Moon to Mars Lunar Systems Development	2,630.5	--	**3,288.1**	3,285.7	3,389.5	3,868.8	3,712.3
Human Exploration Requirements & Architecture	100.5	--	**117.1**	264.1	303.0	369.3	855.5
Total Budget	**7,447.6**	**7,468.9**	**7,618.2**	**7,803.7**	**7,959.8**	**8,119.0**	**8,281.4**

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

Shown here, NASA's Space Launch System, carrying the Orion spacecraft, lifts off the pad at Launch Complex 39B at the agency's KSC in Florida at 1:47 a.m. EST on November 16, 2022.

The FY 2025 budget request includes $7.618 billion for the Deep Space Exploration Systems account. This funding directly supports the Moon to Mars (M2M) program, which is focused on returning humans to the Moon, conducting pioneering research and technology development activities on the lunar surface, and enabling eventual missions to Mars and beyond. In collaboration with its commercial and international partners, NASA will create the capabilities necessary to sustainably explore high priority destinations on the lunar surface, including in-situ science and resource utilization, surface transportation, and habitation capabilities. The operational knowledge, technological advances, and scientific discoveries NASA gains from exploring the Moon in collaboration with international and commercial partners will position the agency to take the next giant leap — sending astronauts to Mars and returning them safely back to Earth.

ESDMD will leverage the SMD's development of smaller landers for capabilities such as navigation and precision landing of cargo and data about the lunar surface. ESDMD will also leverage technological investments to prove and verify concepts through the STMD's lunar exploration activities. Finally, ESDMD will leverage the SOMD's capabilities, such as ISS and the Space Communications and Navigation Program, as a technology and human system testbed and communication capability provider, respectively.

The FY 2025 President's Budget Request manifest supports an Artemis II mission in September 2025, Artemis III mission in September 2026, Artemis IV mission in September 2028, and Artemis V mission in 2030 with subsequent flights on a yearly basis.

DEEP SPACE EXPLORATION SYSTEMS

The Deep Space Exploration Systems account consists of three themes which provide for the development of systems and capabilities needed for human exploration of deep space:

- M2M Transportation System;
- M2M Lunar Systems Development; and
- Human Exploration Requirements & Architecture (HERA).

M2M Transportation System programs work together to develop three of the key space transportation systems that will enable the agency's Artemis Campaign to land the first woman and first person of color on the Moon and extend human presence into the solar system. The systems being developed are the Orion crew vehicle, Space Launch System (SLS) launch vehicle, and Exploration Ground Systems (EGS). The first uncrewed launch of SLS and Orion occurred in November 2022 and the first launch returning humans to the lunar vicinity in fifty years will occur September 2025.

- The Orion Program is developing the spacecraft which will carry crew to deep space, sustaining the crew during space travel, providing emergency abort capability, and providing safe re-entry from deep space return velocities for Artemis missions.
- The SLS Program is developing the human-rated launch system capable of sending the crewed Orion spacecraft to the Moon, which will be used in each of the Artemis missions.
- The EGS Program is responsible for developing and operating the systems and facilities necessary to process, integrate, transport, and launch NASA's SLS rocket, Orion spacecraft, and any co-manifested SLS payloads for Artemis missions.

M2M Lunar Systems Development is developing the systems that will be used to land humans on the Moon, explore the lunar surface, and prepare for Mars exploration. The theme is developing and testing prototype systems and planning flight missions to the Moon to develop systems and operational practices that will enable an eventual mission to Mars. M2M Lunar Systems Development is comprised of four programs: Gateway; Exploration Extravehicular Activity (xEVA) and Human Surface Mobility Program (EHP); Human Landing System (HLS); and Advanced Exploration Systems (AES). The work done by these programs work will create the exploration infrastructure in lunar orbit and on the lunar surface that astronauts will utilize during Artemis missions and that will inform future missions to Mars.

- Gateway is a platform that will orbit the Moon and support orbital activities, lunar landers, and surface activities. Gateway will initially consist of a Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO); with later configurations including at least two modules contributed by NASA's international partners; and may be supported by U.S. commercial logistics services.
- EHP is formulating the systems that NASA will use to explore the surface of the Moon. These surface systems include: the Lunar Terrain Vehicle; the Pressurized Rover; and xEVA surface suits; providing lessons learned and expertise that will support future Mars missions.
- HLS utilizes commercial partnerships to develop and jointly deploy the integrated landing system that will transport crew to and from the lunar surface and conduct a series of lunar missions using that capability. The budget provides funding for the HLS program to maintain competition for lunar landing services by supporting the development of multiple different lunar landing systems.
- AES will continue work to identify and address knowledge gaps and deliver fundamental capabilities to provide astronauts a place to live and work with integrated life support systems, radiation

protection, food, fire safety, avionics and software, logistics management, and waste management systems.

HERA is identifying the exploration infrastructure required for Artemis missions that will inform future missions to Mars. It also works to ensure that lunar exploration systems are extensible to Mars exploration where technically feasible and cost-effective. HERA is comprised of the Strategy & Architecture Office (SAO) and Future Systems.

- SAO manages the architecture strategy activity that supports mission manifest planning and overall architecture requirements and capability identification.
- Future Systems is conducting trade studies to reduce risk and identify required technologies to be utilized as part of the Artemis Campaign and act as precursor systems for future missions to Mars.

EXPLANATION OF MAJOR CHANGES IN FY 2025

To fully implement the Moon to Mars Program Office concept and effectively manage content across the M2M portfolio, the following changes are being proposed:

- Rename Common Exploration Systems Development as M2M Transportation System;
- Rename Artemis Campaign Development as M2M Lunar Systems Development;
- Retire the Advanced Cislunar and Surface Capabilities (ACSC) program, with all follow-on M2M Integration, Moon and Mars Architecture, and Future Systems content previously in program being re-aligned to appropriate programs;
- Establish Future Systems as a stand-alone program under HERA theme;
- Rename Moon and Mars Architecture as Strategy & Architecture Office (SAO);
- Rename Exploration Capabilities as Advanced Exploration Systems (AES) and move to M2M Lunar Systems Development theme;
- Retire the Mars Campaign Development theme; and
- M2M Program Office and integration funding have been re-aligned across the M2M themes.

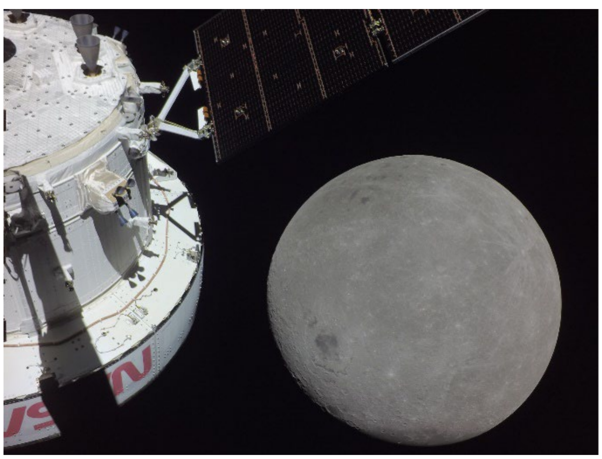
For more information, go to: https://www.nasa.gov/directorates/exploration-systems-development

MOON TO MARS TRANSPORTATION SYSTEM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Orion Program	1,315.1	--	**1,031.0**	1,176.9	1,288.5	1,266.4	1,166.4
Crew Vehicle Development	1,301.5	1,221.0	**1,023.5**	1,141.9	1,281.0	1,213.7	1,113.8
Orion Program Integration and Support	13.5	--	**7.5**	35.0	7.5	52.7	52.7
Space Launch System	2,566.8	--	**2,423.2**	2,379.0	2,402.9	2,072.3	2,026.8
Block 1B Capability Upgrade	648.3	462.5	**285.8**	275.1	54.3	0.0	0.0
SLS Operations	1,844.4	--	**2,028.4**	1,972.0	2,240.5	1,899.8	1,853.8
SLS Program Integration and Support	74.0	--	**109.0**	131.9	108.1	172.5	173.0
Exploration Ground Systems	834.8	--	**758.8**	698.1	576.0	542.3	520.4
Exploration Ground Systems Development	330.6	356.2	**235.8**	148.3	31.4	0.0	0.0
EGS Program Integration and Support	504.2	--	**523.0**	549.8	544.6	542.3	520.4
Construction & Envrmtl Compl Restoration	94.3	--	**32.5**	0.0	0.0	0.0	0.0
Exploration CoF	94.3	--	**32.5**	0.0	0.0	0.0	0.0
Total Budget	**4,810.9**	**--**	**4,245.5**	**4,254.0**	**4,267.3**	**3,880.9**	**3,713.6**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



On Flight Day 5 of the Artemis I mission, Orion takes a selfie, shown above, while approaching the Moon ahead of the outbound powered flyby — a burn of Orion's main engine that gets the vehicle into lunar orbit. During this maneuver, Orion came within 81 miles of the lunar surface.

The programs of NASA's Moon to Mars Transportation System, formerly Common Exploration Systems Development, are working together to build a space transportation system made up of the Orion crew vehicle, the Space Launch System (SLS) rocket, and the Exploration Ground Systems (EGS). The Transportation System program objectives support agency Strategic Goal 2 which will enable the agency's Artemis missions, seeking to extend and sustain human presence into the solar system by transporting crews to the Gateway or to the Moon's surface in the Human Landing System for long-term exploration and in preparation for future missions to Mars for sustainable long-term exploration, development, and utilization.

NASA's Orion spacecraft is designed to support human exploration missions to deep space, with a crew of four astronauts to cislunar space and beyond, as well as provide habitation and life support on-board for missions up to 21 days. Building upon more than 50 years of space flight research and development, Orion's versatile design will not only carry crew to space and sustain the crew during space travel, but also provide emergency abort capability, and provide safe reentry at deep space return

MOON TO MARS TRANSPORTATION SYSTEM

velocities for Artemis missions. The Orion systems are designed to operate in a contingency mode to augment life support systems in other space transport systems.

The SLS rocket is a heavy-lift launch vehicle that will launch astronauts in the Orion spacecraft on missions to cislunar space so they can return to the surface of the Moon and visit other destinations. The first three launches, including the Artemis I mission which successfully launched in November 2022, will feature the Block 1 configuration, standing at 322 feet tall and features a lift capability of 27 metric tons to translunar injection for Moon missions with 8.8 million pounds of maximum thrust. The evolution of the architecture, currently planned for first use on Artemis IV, will include an Exploration Upper Stage (EUS), associated Universal Stage Adapter, and Payload Adapter, which provides space for SLS to launch co-manifested payloads in addition to Orion. This Block 1B configuration will be capable of delivering at least 37.3 metric tons of net payloads to Trans-Lunar Injection on crewed missions. The 37.3 metric ton total includes Orion, which weighs 27 metric tons.

The objective of EGS is to process and launch Orion and SLS in support of the Artemis missions. To meet this objective, NASA is developing new ground systems, including Mobile Launcher 2 (ML-2), while refurbishing and upgrading infrastructure and facilities to meet tomorrow's demands.

The Artemis Campaign is the next step in human exploration of our solar system. It is a part of NASA’s Moon to Mars exploration approach, in which NASA will pursue its next giant leap, sustained human exploration of the Moon to develop the skills, systems, and operational capabilities required to enable human missions to Mars. As NASA works towards a sustainable Moon to Mars campaign, it is essential that the agency and its contractors reduce production and operations costs for Transportation systems. NASA is examining options to achieve this goal. Through a reduction in Transportation System program costs, the agency can focus on the many other capabilities needed for future deep space systems and successful exploration missions.

ORION PROGRAM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Crew Vehicle Development	1,301.5	1,221.0	**1,023.5**	1,141.9	1,281.0	1,213.7	1,113.8
Orion Program Integration and Support	13.5	--	**7.5**	35.0	7.5	52.7	52.7
Total Budget	**1,315.1**	**--**	**1,031.0**	**1,176.9**	**1,288.5**	**1,266.4**	**1,166.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Orion crew module pressure vessel for the Artemis III mission—the first vehicle under the Lockheed Martin OPOC contract—is undergoing assembly at NASA's KSC.

The Orion spacecraft will serve as an exploration vehicle that will carry crew to deep space, sustain the crew during space travel, provide emergency abort capability, and provide safe re-entry from deep space return velocities for Artemis missions. This spacecraft will enable extended duration missions beyond LEO, to the Moon, and eventually to Mars.

Orion's design, development, test (including flight tests), and evaluation will have the spacecraft ready to carry crew for the first time on Artemis II in September 2025. Development of the Orion spacecraft will be completed after the Artemis III mission, which incorporates the Rendezvous, Proximity Operations and Docking (RPOD) capability.

Orion is leveraging other capabilities, such as the Space Communications and Navigation program's Deep Space Network to enable communication capabilities between the spacecraft and mission control. Orion will leverage the Space Launch System's (SLS's) launch vehicle and Exploration Ground System (EGS) capabilities to safely launch and reach its desired orbit. The capabilities provided by the Orion Program enable the crews of the Artemis generation to safely travel to deep space, which promotes new technologies and systems needed for future Mars missions.

For more information, go to: http://www.nasa.gov/orion

Program Elements

ORION PROGRAM INTEGRATION AND SUPPORT

Orion Program Integration and Support activities manage the program interfaces between SLS and EGS. This effort is critical to ensuring the Orion systems' performance meets technical and safety specifications, and supports programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the Orion integration effort is vital to managing interfaces with other ESDMD activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across ESDMD are aimed at mitigating the impacts of potential design overlaps, schedule disconnects and delays, and cost overruns.

ORION PROGRAM

CREW VEHICLE DEVELOPMENT

Orion will be capable of transporting humans to orbit around the Moon, sustaining them for longer durations beyond LEO than ever before, providing emergency abort capability, and returning them safely to Earth. See the Crew Vehicle Development section starting on the next page for additional details.

CREW VEHICLE DEVELOPMENT

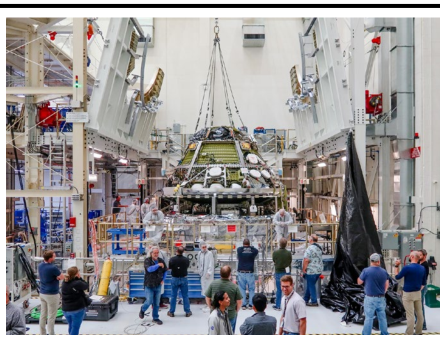
Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	4,509.6	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	4,509.6
Development/Implementation	8,378.6	602.1	336.6	**280.1**	25.0	0.0	0.0	0.0	0.0	9,622.4
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2024 MPAR LCC Estimate	**12,888.2**	**602.1**	**336.6**	**280.1**	**25.0**	**0.0**	**0.0**	**0.0**	**0.0**	**14,132.0**
Total Budget	**10,539.0**	**1,301.5**	**1,221.0**	**1,023.5**	**1,141.9**	**1,281.0**	**1,213.7**	**1,113.8**	**4,402.0**	**23,237.4**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



The second European Service Module was connected to the Crew Module to form the Orion spacecraft which will bring astronauts around the Moon and back during the Artemis II mission. The integration was done at KSC in Florida.

PROJECT PURPOSE

Orion is a deep space exploration vehicle that will be capable of transporting humans to orbit around the Moon, sustaining them for longer durations beyond LEO than ever before, providing emergency abort capability, and providing safe re-entry from deep space to Earth.

After the successful uncrewed launch of Artemis I on November 16, 2022, NASA is focusing on the completion of Artemis II, the first crewed Space Launch System (SLS) flight, and the preparation required for Artemis III and Artemis IV. The Artemis I mission was the first integrated flight test of the Orion spacecraft, the SLS launch vehicle, and ground systems.

For more information, go to http://www.nasa.gov/orion

EXPLANATION OF MAJOR CHANGES IN FY 2025

The proposed funding levels allow the program to support Artemis II and III launches as soon as is technically feasible. Due to the Artemis I launch delay, and to manage risk to the crew and ensure mission success, NASA re-assessed the Artemis II target launch date. The current target launch date for Artemis II in September 2025.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

PROJECT PARAMETERS

Orion is the vehicle that will fly astronauts from Earth to orbit around the Moon and back again. Orion will be able to carry a crew of four astronauts to cislunar space and beyond, as well as provide habitation and life support for up to 21 days. The spacecraft's four elements are the Crew Module (CM), the Crew Module Adapter (CMA), the European Service Module (ESM), and the Launch Abort System (LAS). Lockheed Martin is building the CM, also referred to as the capsule, providing a safe habitat from launch through landing and recovery. Lockheed Martin is also building the CMA, which connects the capsule to the ESM and houses electronic equipment for communications, power, and control. ESA is designing and developing the ESM, which provides in-space propulsion for orbital transfer, power and thermal control, attitude control, and high-altitude ascent aborts. While the ESM is mated with the CM, it will also provide water and air to support the crew. During launch, the ESM is attached to the spacecraft adapter which joins it to the SLS launch vehicle. Once SLS has delivered the Orion spacecraft to the desired orbit, the integrated Orion spacecraft separates from the SLS launch vehicle. The mounting of the CM, CMA, ESM, and spacecraft adaptor together is referred to as the Crew and Service Module (CSM). The LAS is positioned atop the Orion CM and can activate within milliseconds to propel the spacecraft to safety away from the launch vehicle in the event of an emergency during launch or ascent to orbit. The abort system also provides a protective shell that shields the CM from dangerous atmospheric loads and heating during ascent. Once Orion is out of the Earth's atmosphere and safely on its way to orbit, the spacecraft will jettison the LAS.

Orion's first mission was Artemis I, an uncrewed flight test that demonstrated many key Orion spacecraft capabilities. The capsule successfully splashed down on December 11, 2022. The next mission, Artemis II, is a crewed test flight, with a current mission profile that transports four crewmembers on a free return trajectory around the Moon. For Artemis III, the first Artemis mission to the Lunar surface, the Orion spacecraft will rendezvous and dock with the Human Landing System (HLS) spacecraft. The crew and necessary equipment will transfer from the Orion spacecraft into HLS, which will then undock, descend, and land on the Lunar surface. At the conclusion of the Lunar surface operations, HLS will lift off from the Lunar surface and re-dock to the Orion spacecraft where the crew will transfer back into Orion for their safe return to Earth.

The crew systems will provide a safe environment for astronauts to live and work for 21 days during missions far from Earth. Orion's advanced heat shield will protect the crew during a high-speed reentry into Earth's atmosphere. Temperatures will exceed that experienced by any human spacecraft in more than five decades. For Artemis IV and subsequent lunar missions, Orion will dock with the Gateway in a Near-Rectilinear Halo Orbit around the Moon, giving astronauts access to more areas of the Lunar surface and better communication capabilities than the Apollo Program.

ACHIEVEMENTS IN FY 2023

Artemis I was successfully launched on November 16, 2022. The Orion capsule splashed down in the Pacific Ocean off the coast of Baja, California on December 11, 2022, wrapping up its 25.5-day mission to lunar orbit and back. The mission took the Orion spacecraft beyond the Moon and demonstrated its performance capabilities during launch, transit to lunar orbit, return to Earth, re-entry, landing, and recovery.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

The Orion Program then began post-flight analyses to assess spacecraft performance against flight test objectives. The program recovered certain non-core avionics components from the returned spacecraft for reuse on the Artemis II mission. Those returned components were then refurbished and delivered to KSC for installation into the Artemis II CM. The re-use of components is planned for future missions to reduce assembly costs of subsequent Orion builds and is a key feature of the Orion Production and Operations Contract (OPOC).

The Flight Software/Integrated Test Lab (ITL) led by Lockheed Martin in Denver was reconfigured to support Artemis II and Artemis III testing in October 2022. ITL has an identical set of avionics, harnessing, sensors, and flight software to Orion, which supports robust flight simulations.

The heatshield fit check was completed in December 2022 for Artemis III. Artemis III CMA Primary and Secondary Structure installation were completed in Q1 FY 2023. The Artemis III CMA Initial Weld Operations were also completed in the same quarter.

The Artemis II CM functional tests continued throughout 2022 and were completed in December 2022. In June 2023, after the CM outfitting at KSC, Orion completed the installation of the heat shield for the Artemis II spacecraft inside the high bay of the KSC Operations and Checkout Building. The heatshield is vital to ensuring the safe return of the crew, as it protects them from the extreme heat of reentry.

CM and Service Module (SM) acoustic testing, which ensures that the Orion spacecraft for Artemis II mission can withstand the vibrations experienced throughout the mission, during launch, flight, and landing, was completed in 2023. The CM and SM production was completed in August 2023.

In June 2023, the Orion Program conducted an Artemis II Mission Integration Review (MIR) to review the mission specific objectives and requirements within the integrated flight and ground systems, detailed design capabilities, and hardware configuration.

Orion completed the first part of the Artemis III CMA Environmental Control and Life Support Systems (ECLSS) and Propulsion proof pressure and leak tests in June 2023. CMA wire harness and subsystem installations were completed in June 2023. The CM Reaction Control System (RCS) Thruster Pod was installed in June 2023.

In Q3 FY 2023, the Artemis II SM completed final hardware and Multi-Layer Insulation (MLI) installations. The MLI is installed in the Orion capsule to control the interior temperature environment while remaining lightweight.

The formal software developed for ascent/abort was released in September 2023 to support ITL testing and verifications. The Orion spacecraft uses a significant amount of software for commanding functions, monitoring and transmitting data, performing fault detection and response, and other tasks. Testing of the flight software is critical to safety and mission success. Formal release of software Build 205 to support ascent/abort scenarios was completed in September 2023.

Initial RPOD sensor system testing (static and open loop trajectory) was completed in FY 2023. The RPOD system enables critical rendezvous, proximity operations, docking, and undocking operations.

Orion has conducted integrated testing of ECLSS and the Orion Crew Survival System Suit in the Orion Life Support Integration Facility (OLIF) at NASA's JSC to further validate the performance of these systems in preparation for the crewed Artemis II mission. OLIF testing is in progress through FY 2023 and expected to complete in FY 2024.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2024

After the successful Artemis I mission, investigation teams were established to investigate the Power Conditioning Distribution Unit (PCDU) Latching Current Limiters (LCL) anomaly of downstream power switch off, heatshield performance due to unexpected loss of char layer, and CM/SM separation bolt. The PCDU LCLs are electronic circuit breakers controlling power from the PCDU to components in ESM and rest of the vehicle. The root cause determination work is in progress through FY 2024.

The Orion spacecraft for the Artemis II mission is continuing towards final assembly and testing. The Orion CM and SM completed all functional testing. CM and SM were then mated in October 2023 to form CSM. CSM has completed Initial Power On and is undergoing a suite of integrated functional tests.

The CSM Altitude Chamber test, which will put the spacecraft through conditions as close as possible to the environment it will experience in the vacuum of deep space, will be completed in Q2 FY 2024. Human-In-The Loop (HITL) testing of Artemis II displays and controls was in progress in FY 2023 and will continue into Q1 FY 2024. HITL ensures Orion's displays and controls are operable for all mission tasks and living space is adequately designed for astronauts. The HITL testing involves humans simulating and evaluating the tasks and interactions performing in CM.

Delivery of the Artemis II LAS tower assembly is complete. The Ogive panels and LAS hatch are targeting a readiness date of March 2024. The Ogive panels are protective panels that will shield CM from the severe vibrations and sounds it will experience during launch.

Artemis II Orion hardware qualification and verification will be in progress in FY 2024.

The Artemis II Orion software development work will also complete in FY 2024. The software build 205 formal ITL verification completion is planned for December 2023 with any needed updates to follow.

Environmental Test Article (ETA) (formerly the Artemis I Orion Crew Module) completed servicing and hardware removal and replacement in preparation for environmental testing in FY 2024. Functional testing is underway with planned ETA transport to Armstrong Test Facility (ATF) in December 2024 to begin abort environmental testing.

Artemis III's CM assembly, integration, and testing will continue throughout FY 2024. Installations of the secondary structure, and part one of ECLSS and propulsion components proof and leak testing will be completed in Q2 FY 2024. Additional subsystem and component installation will continue throughout FY 2024.

The Artemis III SM CMA wire-harness installations are in work. Testing and final closeouts are expected to complete in Q3 FY 2024.

Delivery of ESM-3 to KSC is planned for Q2 FY 2024. The Artemis III ESM and CMA will be mated to form SM and will undergo final integration and testing in the subsequent months. The Artemis III NASA Docking System (NDS) will be delivered to KSC in Q2 FY 2024. Following the delivery, NDS installation and acoustic testing is planned for the Q3 FY 2024. NDS provides the capability for the Orion spacecraft to dock to a Gateway or HLS element for Artemis III and later missions.

A key high-fidelity, Six-Degree-of-Freedom Test System of the RPOD system, complete with docking cameras and sensors, will be conducted at a Lockheed Martin facility in Denver, Colorado. These tests

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

will demonstrate the safety-critical operation of the RPOD hardware and software in the dynamic proximity operations environment.

The Artemis IV CM welding will be completed in Q2 FY 2024. Following delivery of the Artemis IV pressure vessel and primary structure parts to KSC, the Orion Program will continue through FY 2025.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The first crewed flight test launch, Artemis II, is scheduled for September 2025, and will send four astronauts around the Moon. The 10-day flight will test primarily test life support and other Orion systems that were not tested during the Artemis I mission. Post-mission operations, disassembly, and refurbishment will be in progress through FY 2025.

The Artemis III CM and SM will complete separate assembly and checkout and will be ready to mate to form CSM-3. The CSM and LAS Assembly, Integration and Procession (AI&P) will be completed. The DD250 handover to EGS is scheduled for late in FY 2025.

Artemis IV will be the second lunar landing of the Artemis program. The Artemis IV CM and SM AI&P will be in progress throughout FY 2025.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2025 PB Request
System Definition Review (SDR)	Aug 2007	Aug 2007
PDR	N/A	Aug 2009
KDP-A	Feb 2012	Feb 2012
Resynchronization Review	N/A	Jul 2012
KDP-B	Q1 FY 2013	Jan 2013
Delta PDR	Q4 FY 2013	Aug 2014
Exploration Flight Test-1 (EFT-1) Launch	Dec 2014	Dec 2014
KDP-C, Project Confirmation	FY 2015	Sep 2015
CDR	Oct 2015	Oct 2015
Ascent Abort-2 (AA-2) Flight Test	FY 2020	Jul 2019
Artemis I Launch Readiness	FY 2018	Nov 2022
Artemis II Launch Readiness	Apr 2023	NET Sep 2025

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Development Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2015	6,768.4	70	2024	9,622.4	+42.2	Artemis II	Apr 2023	NET Dec 2024	19

The above revised baseline cost and Launch Readiness Date were approved by the Agency Program Management Council per section 103 of the NASA Authorization Act of 2005 (P.L. 109-155)

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)*	Change from Base Year Estimate ($M)
TOTAL:	**6,768.4**	**9,622.4**	**+2,854**
Mission Operations	281.6	467.3	+185.7
Program Management	671.5	1,102.9	+431.4
Safety and Mission Assurance	191.4	226.4	+35
Spacecraft and Payload	3,205.1	6,311.4	+3,106.3
Systems Engineering and Integration	539.3	798.3	+259
Test and Verification	460.6	641.2	+180.6
Other Direct Project Costs	1,418.9	74.9	-1,344

Program unallocated future expenses (UFE) was held in "Other" category in the base year estimate and realigned to other elements as the program matured.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details
CM	CM provides a safe habitat for the crew, as well as storage for consumables and research instruments, and it serves as the docking port for crew transfers.	Provider: JSC Lead Center: JSC Performing Center(s): ARC, GRC, JSC, and LaRC Cost Share Partner(s): N/A
SM	SM, the powerhouse that fuels and propels the Orion spacecraft, will support CM from launch through separation before reentry.	Provider: ESA Lead Center: GRC Performing Center(s): ARC, GRC, JSC, and LaRC Cost Share Partner(s): ESA
LAS	LAS maneuvers CM to safety in the event of an emergency during launch or climb to orbit.	Provider: JSC Lead Center: LaRC Performing Center(s): JSC, LaRC, and MSFC Cost Share Partner(s): N/A

Project Risks

Risk Statement	Mitigation
If: The Artemis II CM Assembly Integration and Processing timeline is delayed, Then: The Artemis II CSM handover date to EGS will be impacted.	Teams are assessing opportunities to streamline the time from non-core avionics installation through CM completion by accelerating work while the non-core avionics are refurbished, resulting in overall schedule savings.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

Risk Statement	Mitigation
If: Artemis III+ Orion suppliers and/or Assembly Integration and Processing work experience delays, Then: Final integration and Orion spacecraft deliveries to EGS for launch processing could be delayed.	Over the past two and a half years, production efforts have been impacted by the pandemic’s direct effect on workforce as well as the workforce changes and attrition. This has been particularly noticeable in certain high skilled jobs, such as technicians. These same issues impact the Orion’s international partners and supply chain flow of parts and materials into the program. To minimize impacts, Orion’s integrated teams have adjusted the flow of activities and production/integration shifts to minimize delays in production and the integration critical path flow. The program will continue to reassess activity timing, opportunities to improve integration efficiency, and increased workforce in critical areas to maintain production and integration progress, but workforce and supply chain challenges remain.

Acquisition Strategy

NASA is using a contract with Lockheed Martin Corporation for Orion’s design, development, test, and evaluation. The contract was awarded in 2006 and reaffirmed in 2011 as part of reformulating the Orion Crew Exploration Vehicle as the Orion Program. Orion adjusted this contract to meet NASA and the Human Exploration and Operations Mission Directorate, now ESDMD, requirements to include the current flight test plan and the Artemis II flight readiness date. Additional Orion spacecraft have been ordered under OPOC, awarded in September 2019, which is an indefinite-delivery-indefinite-quantity contract that includes a commitment to order a minimum of six and the option for a maximum of 12 Orion spacecraft over the next 10 years. The first six spacecraft (Artemis III through Artemis VIII) will be acquired by cost-plus-incentive-fee orders. NASA will negotiate firm-fixed-price orders for future missions to take advantage of the anticipated spacecraft production cost decreases.

In addition, to further international cooperation, NASA has made agreements with ESA for the delivery of ESMs. In 2012, NASA signed an implementing arrangement with ESA to provide SMs for the Orion spacecraft for Artemis I and later added Annexes 1 and 2 for ESA to provide the ESM for Artemis II. Annex 3 was later added, and ESA is on contract with Airbus to build ESM-3. In October 2020, NASA and ESA signed the Gateway Memorandum of Understanding, committing ESA to ESM-4 and 5. NASA and ESA signed an Implementing Arrangement covering the details of the provision of ESM-4 and ESM-5 in May 2022. Incorporating the partnership with ESA also required a contract modification with Lockheed Martin to integrate the ESA-provided SM with the Lockheed Martin portion of the spacecraft.

For the SM main engines, Orion has enough Orbital Maneuvering System Engines (OMS-Es) remaining from the Space Shuttle Program to fly on the ESM through Artemis VI. OMS-E will be replaced by the Orion Main Engine (OME) starting with Artemis VII. The OME contract is a single-award, indefinite-delivery-indefinite-quantity contract with firm-fixed-price orders awarded to Aerojet Rocketdyne to produce these engines.

CREW VEHICLE DEVELOPMENT

Formulation	Development	Operations

The FY 2025 President's Budget does not mandate adjustments to contracts and agreements, and NASA expects contractors and partners to perform to their contract/agreement dates.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Orion Design Development, Test and Evaluation (DDT&E); Orion Production and Operations Contract (OPOC)	Lockheed Martin	Littleton, CO
Orion Main Engine	Aerojet Rocketdyne	Redmond, WA

INDEPENDENT REVIEWS

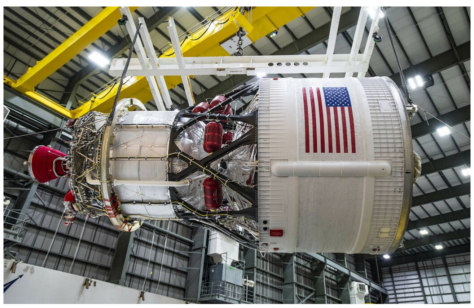
Review Type	Performer	Date of Review	Purpose	Outcome
Operational Readiness Review/ Flight Readiness Review (ORR/FRR) for Artemis II	Independent Assessment (IA) / Independent Review Team (IRT)	NET Mar 2024	To evaluate the readiness of the project to operate the flight system and associated ground system; and support systems for safe and successful launch and flight/mission.	N/A
Launch Readiness Date/Initial Operations Capability (LRD/IOC) for Artemis II	IA/IRT	NET May 2024	To assess all capabilities of the vehicle to support the readiness to launch.	N/A

SPACE LAUNCH SYSTEM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Block 1B Capability Upgrade	648.3	462.5	**285.8**	275.1	54.3	0.0	0.0
SLS Operations	1,844.4	--	**2,028.4**	1,972.0	2,240.5	1,899.8	1,853.8
SLS Program Integration and Support	74.0	--	**109.0**	131.9	108.1	172.5	173.0
Total Budget	**2,566.8**	--	**2,423.2**	**2,379.0**	**2,402.9**	**2,072.3**	**2,026.8**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Shown here is the interim cryogenic propulsion stage (ICPS) for Artemis III being delivered to United Launch Alliance (ULA) Delta Operations Center at Cape Canaveral in August 2023.

NASA demonstrated the launch capabilities of the Space Launch System (SLS) heavy-lift vehicle with the successful launch of Artemis I in November 2022. SLS precisely delivered the Orion spacecraft on its desired trajectory to the Moon.

SLS is the human-rated launch system capable of sending the crewed Orion spacecraft to the Moon. This launch system will be used in each of the Artemis missions, beginning with Artemis I, however its capabilities will evolve into more powerful configurations (i.e., Block 1B by Artemis IV, Block 2 by Artemis IX) to address major subsystem obsolescence issues and to meet the launch capability needs of future missions. The agency will continue to identify and implement affordability strategies to help SLS become a sustainable exploration capability used by subsequent Artemis missions. The proposed funding levels are sufficient to allow the program to support Artemis II and III launches as soon as is technically feasible. The current target Launch Readiness Date (LRD) for Artemis II is September 2025 and Artemis III is September 2026.

SLS relies on other capabilities, such as those provided by the SOMD's Space Communications and Navigation Program as its telemetry communications capability provider. SLS relies on the Exploration Ground System's capabilities to assemble and safely launch the vehicle. SLS's capabilities will enable the safe delivery of humans and larger volumes of cargo than ever before to deep space on future Artemis missions.

For more information, go to: http://www.nasa.gov/exploration/systems/sls/index.html

Program Elements

SLS PROGRAM INTEGRATION AND SUPPORT

SLS Program Integration and Support activities manage the program interfaces between Orion and the Exploration Ground Systems. This effort is critical to ensuring the SLS systems' performance meets technical and safety specifications, and supports programmatic assessments key to achieving integrated

SPACE LAUNCH SYSTEM

technical, cost, and schedule management. In addition, the SLS integration effort is vital to managing interfaces with other ESDMD and SOMD activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across ESDMD and SOMD are critical and aimed at mitigating the impacts of potential design overlaps, schedule disconnects and delays, and cost overruns.

LAUNCH VEHICLE DEVELOPMENT

The Launch Vehicle Development project developed the SLS launch vehicle to enable deep space exploration and support production and sustainment for future flights. See the Launch Vehicle Development section beginning on the next page for additional details.

BLOCK 1B CAPABILITY UPGRADE

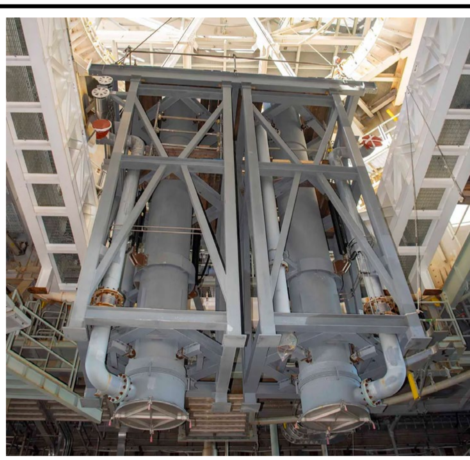
Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	1,278.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	1,278.0
Development/Implementation	1,035.0	648.0	604.0	**525.0**	470.0	305.0	87.0	0.0	0.0	3,674.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2024 MPAR LCC Estimate	**2,313.0**	**648.0**	**604.0**	**525.0**	**470.0**	**305.0**	**87.0**	**0.0**	**0.0**	**4,952.0**
Total Budget	**2,313.0**	**648.3**	**462.5**	**285.8**	**275.1**	**54.3**	**0.0**	**0.0**	**0.0**	**4,039.0**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Shown here, NASA Stennis teams lift and install large diffusers onto the Thad Cochran Test Stand.

PROJECT PURPOSE

The upgraded Space Launch System (SLS) Block 1B variant will carry cargos and astronauts on missions to land on the Moon. It will use a new and more powerful Exploration Upper Stage (EUS) to enable more ambitious missions beginning with Artemis IV.

For more information, go to: http://www.nasa.gov/exploration/systems/sls/index.html

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA established the Agency Baseline Commitment (ABC) for SLS Block 1B and its associated capabilities in December 2023.

PROJECT PARAMETERS

The Block 1B upgrade is for a crewed, co-manifested payload variant configuration that would be available for the Artemis IV mission through the Artemis VIII mission, enabling the delivery of the Orion space capsule and a broad range of large payloads to deep-space including elements of the Gateway and Lunar Lander programs.

BLOCK 1B CAPABILITY UPGRADE

Formulation	Development	Operations

The planned evolution of the SLS architecture to the SLS Block 1B configuration will increase the size and payload to support lunar orbital capabilities. The SLS Block 1B configuration will stand 365 feet and be capable of delivering at least 37 metric tons for crew and cargo to trans-lunar injection (TLI). As a result, the SLS Block 1B configuration can send Orion and up to 10.3 metric tons of additional payloads to TLI starting with the Artemis IV mission. To be able to do this, the Launch Vehicle Development team will exchange the Interim Cryogenic Propulsion Stage (ICPS) for an EUS, as well as the Launch Vehicle Stage Adapter (LVSA) for a Universal Stage Adapter (USA) and Payload Adapter (PLA) to support Co-Manifested Payloads.

When the flight manifest depletes the heritage Solid Rocket Booster (SRB) components currently available with the launch of the Artemis VIII mission, the SRB design for additional Block 2 performance upgrades will be accomplished primarily by producing new composite boosters in lieu of the heritage metallic casing used in the Shuttle Program, increasing motor pressure, and extending booster nozzle length through the Booster Obsolescence and Life Extension (BOLE) development work. The propellant will change from polybutadiene acrylonitrile (PBAN) to hydroxyl-terminated polybutadiene (HTPB). This is a major change to the design that also contributes to improved performance.

ACHIEVEMENTS IN FY 2023

The Block 1B CDR Board was successfully completed in November 2022. In addition, the RL-10 Sea Level Engines for Green Run testing were completed in September 2023 and are ready to deliver when needed.

WORK IN PROGRESS IN FY 2024

On October 12, 2023, the Agency Program Management Council (APMC) met and approved the Block 1B - SLS's EUS and its Associated Capabilities (EUS+CAPs) upgrades. An ABC and Management Agreement (MA) were established, and the Decision Memo was signed in December. This approval acknowledges that the program's planning, technical, cost, and schedule baselines developed during formulation are complete and consistent.

In December, crews at SSC completed a milestone with the installing of four large diffusers on the Thad Cochran Test Stand, a key component in preparation for future Green Run testing of EUS vehicle. The diffusers are critical as they direct engine exhaust away from the EUS during hot fire testing, minimizing heat exposure to sensitive vehicle systems.

A key focus in FY 2024 is the completion of the EUS Structure Test Article and PLA qualification unit builds. In addition, the production of the EUS flight unit, PLA flight unit, and the USA qualification/flight units will continue.

In other production and test activities, nine out of 10 Artemis IV Booster segments will complete fabrication and be placed in storage, Core Stage elements will be well into production, and test activities on the RS-25 engines will be completed in 2024.

BLOCK 1B CAPABILITY UPGRADE

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2025

Block 1B hardware development, production, and test for Artemis IV will continue. The first EUS flight unit (EUS-1) will complete assembly at Michoud Assembly Facility (MAF) and begin final integrated functional testing. It will then be transported to SSC for Green Run test which is planned for FY 2026.

The testing of the PLA qualification unit, USA qualification unit, and EUS STA will also be completed. The flight PLA will be ready to deliver to EGS. Flight hardware production of SLS elements for Artemis IV will continue.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2025 PB Request
KDP-C	Oct 2020	Oct 2020
CDR	Nov 2022	Nov 2022
Design Certification Review (DCR)	Nov 2027	Mar 2028*
Launch Artemis IV	Under Review	Under review

**Note: includes two months of supplemental schedule margin in cross-program interdependencies*

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2024	3,675.0	70	2024	3,675.0	0	Capability Readiness Date for Block 1B	Jan 2028	Jan 2028	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

BLOCK 1B CAPABILITY UPGRADE

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**3,675.0**	**3,675.0**	**0**
EUS	1,913.0	1,913.0	0
Spacecraft Payload Integration and Evolution (SPIE)/ USA	293.0	293.0	0
System Engineering & Integration	505.0	505.0	0
Other direct project cost	109.0	109.0	0
Program-managed Unallocated Future Expenses (UFE)	837.0	837.0	0

Totals may not add due to rounding

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Block 1B Development Office	Responsible for development, testing, and production of the initial EUS, as well as development for the Autonomous Flight Safety System (AFSS).	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC/MAF; SSC Cost Share Partner(s): N/A	NA
Stages	Responsible for development, testing, production, and support of hardware elements, including core and upper stages, liquid engine integration, and avionics integration.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC/MAF; SSC Cost Share Partner(s): N/A	NA

BLOCK 1B CAPABILITY UPGRADE

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: SLS suppliers and/or Assembly Integration and Processing work experience delays, Then: Final integration and SLS Launch Vehicle deliveries to Exploration Ground Systems for launch processing could be delayed.	Production efforts continued to be impacted by the workforce changes and attrition experienced in the years since the pandemic started. This has been particularly noticeable in certain high skilled jobs, such as technicians. These same issues impact the SLS's supply chain flow of parts and materials into the program. To minimize impacts, SLS's teams have adjusted the flow of activities and production/integration shifts to minimize delays in production and the integration critical path flow. The program will continue to reassess activity timing, opportunities to improve integration efficiency, and increased workforce in critical areas to maintain production and integration progress, but workforce and supply chain challenges remain.
If: Projected inflationary rise in prices for labor and materials is fully realized, Then: The purchasing power of the SLS Program could experience funding inefficiencies, cost, and schedule growth.	Purchasing power for the SLS Program has been affected by recent inflation experienced in all industries. Material and labor costs have the potential to see a steep rise over the upcoming years if the current trend continues. The program will continue to assess the cost and schedule and look for opportunities to save money to maintain the current activities as planned.

Acquisition Strategy

NASA is using contracts with Aerojet Rocketdyne, Boeing Aerospace, Northrup Grumman Innovation Systems, Teledyne Brown Engineering Inc., and United Launch Alliance for the production and design, development, test, and evaluation of the elements that make up the SLS launch vehicle. These elements include the Core and Upper stages, Solid Rocket Boosters, ICPS, the Core Stage Engines (RS-25s), the Upper Stage Engines (RL10s), Universal Stage Adaptor, and the Launch Vehicle Stage Adaptor as applicable to the various SLS Block configurations. SLS utilizes these contracts to meet the Artemis Campaign requirements for the Launch Vehicle. SLS is continuing to review options for future production contracts that will allow the program to procure launch vehicles on a service basis.

The FY 2025 President's Budget does not mandate adjustments to contracts and agreements, and NASA expects contractors and partners to perform to their contract/agreement dates.

MAJOR CONTRACTS/AWARDS

Procurement for SLS launch vehicle development meets the agency’s requirement to provide an evolvable launch vehicle within a schedule that supports various Artemis mission requirements. Procurements include use of existing assets to expedite development and further development of

BLOCK 1B CAPABILITY UPGRADE

Formulation	Development	Operations

technologies and future competitions for advanced systems and key technology areas specific to SLS launch vehicle needs.

The Stages Production and Evolution Contract (SPEC) was definitized in December 2022. Under this contract, Boeing will produce SLS Core Stages for Artemis III and IV, procure critical and long-lead material for the core stages for Artemis V and VI, and provide the EUS for Artemis V and VI, as well as tooling and related support and engineering services. The contract comes as Boeing optimizes manufacturing capabilities using KSC in Florida to perform some specific core stage assembly and outfitting activities beginning with the Artemis III rocket (a Memorandum of Agreement was signed in October 2022 allowing for this subset of core stage processing to occur at KSC). In tandem, teams will continue all remaining core stage manufacturing activities at MAF in New Orleans.

Element	Vendor	Location (of work performance)
Universal Stage Adapter	Dynetics, Inc.	Huntsville, AL
Stages (Core and Upper)	Boeing Aerospace	New Orleans, LA
Upper Stage Engines	Aerojet Rocketdyne	West Palm Beach, FL

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Block 1 B (B1B) CDR	SRB	Nov 2022	To evaluate the integrity of the project design and its ability to meet mission requirements with appropriate margins and acceptable risk within defined project constraints, including available resources. To determine if the design is appropriately mature to continue with the final design and fabrication phase.	The SRB evaluated the project and determined the project is sufficiently mature to progress to major manufacturing, assembly, and integration.
B1B JCL Review (Post CDR Closeout)	IRT	May 2023	To determine overall technical and programmatic status and health of the EUS+CAPs at CDR, evaluate the JCL model to assess potential risk pertaining to the program, and provide a recommendation regarding readiness-to-proceed to the next phase of the program/project life cycle.	The IRT evaluated the project model and concluded the readiness assessment to proceed to Phase C.

BLOCK 1B CAPABILITY UPGRADE

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome
B1B KPD-C	APMC	Dec 2023	To commence with KDP-C and Phase C activities for the Block 1B Vehicle Capability Upgrade and establish schedule and cost for Phases A-D.	The APMC Chair approved the SLS Block 1B capability upgrade to enter Phase C of the life cycle baselined for cost and schedule. Decision memo was signed in December 2023.

SLS OPERATIONS

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	1,844.4	--	2,028.4	1,972.0	2,240.5	1,899.8	1,853.8

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Shown here, all four RS-25 engines completed and installed into the Artemis II SLS Rocket Core Stage.

The Space Launch System (SLS) launch vehicle serves as the primary crew launch capability for the Artemis Campaign. After the successful uncrewed launch of Artemis I on November 16, 2022, NASA is focusing on the completion of Artemis II, the first crewed SLS flight that will carry three astronauts from NASA and one from CSA, and the preparation required for Artemis III. The Artemis I mission was the first integrated flight test of the agency's deep space exploration systems: the Orion spacecraft, the SLS launch vehicle, and the ground systems.

For more information, go to: http://www.nasa.gov/exploration/systems/sls/index.html

EXPLANATION OF MAJOR CHANGES IN FY 2025

The proposed funding levels sufficiently allow the program to support Artemis II and III launches as soon as is technically feasible. It also allows SLS to continue hardware development and production for Artemis III and beyond. The current target Launch Readiness Date (LRD) for Artemis II is September 2025 and Artemis III is September 2026.

ACHIEVEMENTS IN FY 2023

Following the successful Artemis I launch on November 16, 2022, the SLS Program conducted a comprehensive post-flight data reconstruction/assessment for SLS elements and completed the SLS Moon to Mars (M2M) Post-Flight Assessment Reviews (PFAR). In summary, SLS systems performed exceptionally well and successfully achieved all SLS-led flight test objectives.

Production and test of Artemis II SLS assemblies are in the completion phase and flight hardware is now being delivered to KSC for integration and test. Artemis II's ten booster motor segments arrived at KSC in September 2023. They will form the SLS's rocket's twin five-segment solid rocket boosters, which produce more than 75 percent of the total thrust at liftoff. In addition, the Launch Service Stage Adapter (LVSA) was completed in February 2023 and is ready to deliver to KSC when needed.

Significant progress was also made on the production and test of SLS elements for missions following Artemis II. The ICPS upper stage for the SLS rocket that will power the Artemis III mission and send

SLS OPERATIONS

Formulation	Development	Operations

astronauts to the Moon for a lunar landing arrived at the Cape Canaveral Space Force Station Poseidon Wharf in Florida in August 2023. SLS's ICPS provides Orion and the astronauts inside the big push – called a trans-lunar injection – to journey to the Moon on a precise trajectory during Artemis III.

For Artemis V and beyond, the Core Stage RS-25 liquid engines will be built using new design and manufacturing improvements. In June 2023, the Liquid Engine Office successfully completed the 12 certification tests for these new RS-25 production engines. This certification engine was the first engine of the re-started RS-25 assembly line.

WORK IN PROGRESS IN FY 2024

In October 2023, the program completed installation of the four RS-25 engines into the SLS Core Stage-2 (CS-2) at the Michoud Assembly Facility (MAF). The Core Stage continued into final assembly and test in preparation for delivery in 2024.

A key focus in FY 2024 will be delivery of flight hardware and performing the final testing, checkout, and preparations to support Artemis II launch in FY 2025. The CS, IPCS, LVSA, and Orion Stage Adapter (OSA) are scheduled to be delivered to KSC in 2024. The CS and its engines, form the backbone of the SLS rocket that will power the first crewed mission of the Artemis Campaign.

For Artemis III production and test activities, Booster aft skirts and forward assemblies will complete assembly and be placed in storage (motor segments are already in storage). Core Stage elements, LVSA, and OSA will be nearing completion.

All but one Booster segments will complete fabrication and Core Stage elements will continue their production.

The program began a second certification test series of RS-25 in October 2023 at NASA's SSC which includes a new nozzle. As of January 2024, four out of the twelve tests were successfully completed. This will help confirm manufacturing processes ahead of production for the SLS rocket. The tests are a key step to produce engines that will help power the SLS rocket, beginning with Artemis V. This series of twelve test will be conducted throughout FY 2024.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

A key focus of FY 2025 will be delivery of Artemis III flight hardware and performing the final testing, checkout, and preparations to support Artemis III launch in FY 2026. Artemis III CS production and test will be completed in FY 2025 along with elements including ICPS, LVSA, and OSA, will be ready for delivery to support KSC integration needs.

Critical activities for future mission will also continue. The initial deliveries of the first set of RS-25 production restart engines for Artemis V will occur.

The Booster Office plans to test the first full scale Booster Obsolescence and Life Extension (BOLE) test motor as part of the Booster Production and Operations Contract (BPOC) and conduct the PDR for BOLE in FY 2025.

SLS OPERATIONS

Formulation	Development	Operations

Project Schedule

Date	Significant Event
Sep 2025	Artemis II LRD
Sep 2026	Artemis III LRD

Project Management & Commitments

Element	Description	Provider Details
Booster	Responsible for development, testing, production, and support for the five-segment solid rocket motor to be used on initial capability flights.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A
Engines	Responsible for development and/or testing, production, and support for both core stage (RS-25) and upper stage liquid engines.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC; SSC Cost Share Partner(s): N/A
Stages	Responsible for development, testing, production, and support of hardware elements, including core and upper stages, liquid engine integration, and avionics integration.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC/MAF; SSC Cost Share Partner(s): N/A
Spacecraft Payloads and Integration	Responsible for development, testing, production, and support of hardware elements for integrating the Orion spacecraft and payloads onto SLS, including the ICPS, OSA, LVSA, Universal Stage Adapter (USA), and payload fairings.	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC, LaRC, GRC, and KSC Cost Share Partner(s): N/A

SLS OPERATIONS

Formulation	Development	Operations

Acquisition Strategy

NASA is using contracts with Aerojet Rocketdyne, Boeing Aerospace, Northrup Grumman Innovation Systems, Teledyne Brown Engineering Inc., and United Launch Alliance for the production and design, development, test, evaluation, and operation of the elements that make up the SLS launch vehicle. These elements include the Core and Upper stages, Solid Rocket Boosters, ICPS, the Core Stage Engines (RS-25s), the Upper Stage Engines (RL10s), USA, and the LVSA as applicable to the various SLS Block configurations. SLS utilizes these contracts to meet the Artemis Campaign requirements for the Launch Vehicle. SLS is continuing to review options for future production contracts that will allow the program to procure launch vehicles on a service basis.

The FY 2025 President's Budget does not mandate adjustments to contracts and agreements, and NASA expects contractors and partners to perform to their contract/agreement dates.

MAJOR CONTRACTS/AWARDS

Procurement for SLS launch vehicle development meets the agency's requirement to provide an evolvable launch vehicle within a schedule that supports various Artemis mission requirements. Procurements include use of existing assets to expedite and further the development of technologies and future competitions for advanced systems and key technology areas specific to SLS launch vehicle needs.

The Stages Production and Evolution Contract (SPEC) was definitized in December 2022. Under this contract, Boeing will produce SLS core stages for Artemis III and IV, procure critical and long-lead material for the core stages for Artemis V and VI, and provide the Exploration Upper Stage (EUS) for Artemis V and VI, as well as tooling and related support and engineering services. The contract comes as Boeing optimizes manufacturing capabilities using KSC in Florida to perform some specific core stage assembly and outfitting activities beginning with the Artemis III rocket (a Memorandum of Agreement was signed in October 2022 allowing for this subset of core stage processing to occur at KSC). In tandem, teams will continue all remaining core stage manufacturing activities at MAF in New Orleans.

Element	Vendor	Location (of work performance)
USA	Dynetics, Inc.	Huntsville, AL
Launch Vehicle Stage Adaptor	Teledyne Brown Engineering, Inc.	Huntsville, AL
Boosters	Northrop Grumman Innovation Systems	Magna, UT
Core Stage Engine	Aerojet Rocketdyne	Desoto Park, CA; SSC
ICPS	United Launch Alliance under contract to Boeing Aerospace	Huntsville, AL
Stages (Core and Upper)	Boeing Aerospace	New Orleans, LA
Upper Stage Engines	Aerojet Rocketdyne	West Palm Beach, FL

SLS OPERATIONS

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
LRD/Initial Operations Capability (IOC) for Artemis I	IA/IRT	Nov 2022	To assess all capabilities of the vehicle to support the readiness to launch.	Successful launch on November 16, 2022.
LRD/IOC for Artemis II	IA/IRT	Sep 2025	To assess all capabilities of the vehicle to support the readiness to launch.	TBD
LRD/IOC for Artemis III	IA/IRT	Sep 2026	To assess all capabilities of the vehicle to support the readiness to launch.	TBD

EXPLORATION GROUND SYSTEMS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Exploration Ground Systems Development	330.6	356.2	**235.8**	148.3	31.4	0.0	0.0
EGS Program Integration and Support	504.2	--	**523.0**	549.8	544.6	542.3	520.4
Total Budget	**834.8**	**--**	**758.8**	**698.1**	**576.0**	**542.3**	**520.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Shown here, the NASA Artemis II astronauts have suited up and are traveling to Pad 39B at NASA's KSC for a test demonstrating nominal launch day procedures.

The Exploration Ground Systems (EGS) Program enables integration, processing, and launch of the Space Launch System (SLS) and Orion spacecraft. The EGS Program, based at KSC, is responsible for developing and operating the systems and facilities necessary to process, integrate, transport, and launch NASA's SLS rocket, Orion spacecraft, and any co-manifested SLS payloads for Artemis missions. EGS's mission is to enable the future Artemis missions which will return astronauts to the Moon and eventually Mars.

EGS is responsible for the facility and ground support equipment at KSC which enables assembly, test, and launch of SLS and Orion, along with landing and recovery activities of the Orion spacecraft flight elements in support of Artemis missions. EGS is also modernizing communication and control systems to support these activities.

After successfully supporting the uncrewed flight test of Artemis I in November 2022, EGS continues to upgrade the Launch Complex-39B (LC-39B), crawler-transporters, Vehicle Assembly Building (VAB), Launch Control Center's Young-Crippen Firing Room 1, Mobile Launcher-1 (ML-1), and other ground facilities for crewed operations. EGS also continues to upgrade its infrastructure to support the SLS Block 1B launch vehicle configuration, which is the next evolution of the SLS launch vehicle, including the development of the Mobile Launcher-2 (ML-2). EGS enables the safe launch and recovery of Artemis missions.

For more information, go to: https://www.nasa.gov/exploration/systems/ground/index.html

Program Elements

EGS PROGRAM INTEGRATION AND SUPPORT

EGS Program integration and support activities manage program interfaces between the SLS and Orion. This effort is critical to ensuring the ground systems' performance meets technical and safety specifications and supports the programmatic assessments key to achieving integrated technical, cost, and

EXPLORATION GROUND SYSTEMS

schedule management. In addition, the EGS integration effort is vital to managing interfaces with other ESDMD and SOMD activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across ESDMD and SOMD are critical and aimed at mitigating the impacts of potential design overlaps, schedule disconnects and delays, and cost overruns.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

EGS Development is responsible for developing the necessary ground systems as well as refurbishing and upgrading infrastructure and facilities required for assembly, test, and launch of SLS and Orion. This includes LC-39B, VAB, MLs, other smaller facilities, and Orion landing and recovery activities. See the Exploration Ground Systems Development section beginning on the following page for additional details.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	974.7	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	974.7
Development/Implementation	2,700.4	30.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	2,730.4
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2024 MPAR LCC Estimate	**3,675.1**	**30.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3,705.1**
Total Budget	**3,609.3**	**330.6**	**356.2**	**235.8**	**148.3**	**31.4**	**0.0**	**0.0**	**0.0**	**4,711.6**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

PROJECT PURPOSE

Exploration Ground Systems (EGS) is responsible for safely launching the Space Launch System (SLS) and Orion spacecraft in support of the Artemis missions. EGS develops upgrades and maintains the necessary ground systems infrastructure and facilities required for assembly, test, and launch of SLS and Orion, along with the landing and recovery activities of Orion. This includes evolving several KSC infrastructures including the pad, known as Launch Complex-39B (LC-39B), the Vehicle Assembly Building (VAB), Mobile Launchers 1 and 2 (ML-1, ML-2), and other smaller facilities from a Space Shuttle focus to supporting Artemis missions. The modernization efforts maintain flexibility for LC-39B and VAB to accommodate other potential users and commercial partners, though no other users have been identified to date. ML-1, VAB, and LC-39B are undergoing additional modifications to accommodate crewed flight in preparation for future Artemis missions.

After the successful uncrewed launch of Artemis I on November 16, 2022, NASA is now focusing on the completion of Artemis II (the first crewed SLS flight) and the preparation required for Artemis III and Artemis IV. The Artemis I mission was the first integrated flight test of the agency's Deep Space Exploration Systems: the Orion spacecraft, the SLS launch vehicle, and the exploration ground systems.

For more information, go to: http://go.nasa.gov/groundsystems

EXPLANATION OF MAJOR CHANGES IN FY 2025

The proposed funding levels sufficiently allow the program to support Artemis II and III launches as soon as is technically feasible. The current target launch date for Artemis II is September 2025.

Additional funding since the last budget request has been added to support continued development and construction of ML-2. The additional funding is necessary to address increased material costs driven by

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

inflation, and some government contract changes. NASA is leveraging recommendations from multiple independent reviews to stabilize and maintain ML-2 construction as it is currently on the critical path to Artemis IV. ML-2 is the ground platform structure that will launch the SLS Block 1B (B1B) launch vehicle configurations into lunar orbit.

PROJECT PARAMETERS

EGS is focusing on the equipment, management, and operations required to safely mate Orion with the SLS, move the integrated SLS/Orion stack to the launch pad, and successfully launch it into space. The work entails use of facilities such as the VAB and LC-39B launch complex. For the Artemis missions, the EGS team is developing procedures and protocols to process the Orion spacecraft, the launch vehicle elements, and the launch abort system before assembly into an integrated vehicle. Additional ground system work required to launch astronauts into space on Artemis II includes modifying the ML-1 and crawler-transporters, preparing LC-39B at KSC, and modernizing computers, software, tracking systems, and other network communications.

The ML-1 is the ground structure used to assemble, process, and launch the SLS rocket and Orion spacecraft from LC-39B at KSC. ML-1 consists of a two-story base that is the platform for the launch vehicle and a tower equipped with several connection lines, called umbilicals, and launch accessories that will provide SLS and Orion with power, communications, coolant, fuel, and stabilization prior to launch. The tower also contains a walkway for personnel and equipment entering the crew module during launch preparations. ML-1 supported the agency's Artemis I launch and will also support the Artemis II and III launches.

ML-2 is the ground platform structure that will launch the SLS B1B launch vehicle configurations into lunar orbit. ML-2 is the primary interface between the ground launch control system and the SLS rocket and Orion spacecraft flight hardware. The ML-2 construction contract was awarded in July 2019 and is aligned to support the first launch of a B1B on Artemis IV.

Machines called crawler-transporters have carried the load of the launch vehicle and spacecraft to the launch pad for more than 50 years at KSC. Crawler-Transporter 2 (CT-2) will be used for launches of SLS and Orion.

ACHIEVEMENTS IN FY 2023

Artemis I was successfully launched on November 16, 2022. The Orion capsule splashed down in the Pacific Ocean off the coast of Baja California on Sunday, December 11, 2022, wrapping up its 25.5-day mission to lunar orbit and back. EGS completed post flight processing and de-servicing of Orion, followed by an Artemis I Post-Flight Assessment Review (PFAR) in April 2023.

EGS utilized the period between Artemis I and Artemis II to complete critical modifications, upgrades, and testing development to the launch pad, VAB, and ML-1 required to support the first crewed launch. The Launch Equipment Test Facility will complete testing of some critical ML-2 ground support equipment, such as the vehicle support posts and Exploration Upper Stage umbilical, in preparation for turnover to the ML-2 contractor for installation.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

The program completed construction activities of the new 1.4-million-gallon Liquid Hydrogen (LH2) Sphere at LC-39B which will enable multiple launch attempts with a quicker turnaround time for future missions. The new LH2 Sphere, in addition to the current LH2 Sphere, will supply an increased capacity of LH2 for Artemis II and beyond. The larger tank will allow NASA to attempt SLS launches on three consecutive days, instead of opportunities of two out of three days, in the event of a scrub. The newer technology reduces liquid hydrogen burn-off, allowing more launch attempts before having to refill the larger tank.

The Emergency Egress System (EES) Conveyance Modifications Construction Contract for ML-1 and LC-39B began on-site field installation in Q4 FY 2023. The EES system will provide crew and safety personnel emergency egress to safely exit from the launch vehicle in an emergency. Construction will be complete in time to support crewed Artemis missions. ML-1 rolled to Pad in August to start EES installation and Multi-element Validation & Verification (MEVV).

EGS continued fabrication of the Environmental Control System (ECS) in VAB and begin upgrades at LC-39B to support future Artemis missions and continue upgrades at the Compressor Converter Facility. Concrete pads for the Liquid Helium (LHe) vaporizers have been poured and concrete foundation for the LHe pump skids have been completed.

The program continued design of the LN2 RL-10 Chilldown system at LC-39B. The system will be used to chill down the propellants pre-launch for the RL-10 engines of the SLS B1B Exploration Upper Stage (EUS).

The integrated recovery team of NASA, Lockheed Martin, and DoD successfully completed the first recovery test for the crewed Artemis II mission in August 2023 off the coast of San Diego. During the test, the team practiced how they will extract the four astronauts who will venture around the Moon from their spacecraft after they land in the Pacific Ocean and recover the Orion crew module. NASA's landing and recovery team used a new crew module test article and personnel from the team as stands-ins for the four astronauts who will fly on the mission to demonstrate their procedures. The test included day and night recovery testing. The crew will participate in a future recovery test next year as part of their mission training.

ML-2 is the ground platform structure that will launch the SLS B1B launch vehicle configurations into lunar orbit. ML-2 is the primary interface between the ground launch control system and the SLS rocket and Orion spacecraft flight hardware. The ML-2 construction contract was awarded in July 2019 and is aligned to support the first launch of a B1B on Artemis IV. ML-2 construction phase started in August 2023.

The 10 booster motor segments for Artemis II arrived at KSC on September 25, 2023. EGS teams are now preparing to process each of the segments inside the Rotation, Processing and Surge Facility (RPSF) ahead of integrating them inside VAB. EGS will conduct seven verification and validation tests to ensure the EGS team and structures are ready to support Artemis II which begin in September 2023.

WORK IN PROGRESS IN FY 2024

EGS will utilize the period between Artemis I and Artemis II to complete critical modifications, upgrades, and testing of the launch pad, VAB, and ML-1 required to support the first crewed launch of Artemis. The

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

EES Conveyance Modifications Construction Contract for ML-1 and pad will continue site field installation followed by ML-1 Multi Element Verification and Validation (MEVV) in FY 2024. Following construction of ECS at VAB/ML/PAD, EGS will complete functional pre-testing and required MEVV activities to support Artemis II Core Stage (CS) stacking operations. The Artemis II Vehicle Integration and Operations, to include solid rocket booster (SRB) stacking, mating of the Space Launch System (SLS) CS, spacecraft offline operations, payload processing, integrated test and checkout, will all occur in FY 2024 in preparation for the Artemis II crewed launch in early FY 2025. The program will also complete the remaining Artemis II development, verification and validation efforts discussed above to support the Artemis II crewed launch. The Spaceport Command and Control System and Ground and Flight Application Software upgrades will be completed in FY 2024 to support Artemis II crewed missions.

The program conducted a water flow test with the mobile launcher in October FY 2024. It was the third in a series of six tests planned to verify the overpressure protection and sound suppression system is ready for launch of the Artemis II mission. The remaining three tests will be conducted in FY 2024

During liftoff, 400,000 gallons of water will rush onto the pad to help protect NASA’s Space Launch System rocket, Orion spacecraft, mobile launcher, and launch pad from any overpressurization and extreme sound produced during ignition and liftoff.

For Artemis IV and beyond, Launch Equipment Test Facility (LETF) will complete testing of critical ML-2 ground support equipment, such as the vehicle support posts and EUS umbilical, in preparation for turnover to the ML-2 Contractor for installation. In the spring of 2024, ML-2 will complete CDR and be making significant progress on construction of the ML-2 required for future B1B crewed missions, starting with Artemis IV. The establishment of an Agency Baseline Commitment for ML-2 will also be reviewed for final approval in 2024.

Other major construction projects, such as the construction for the Liquid Nitrogen Infrastructure Update and designs for VAB HB4 upgrades will begin in FY 2024. These efforts will support future crewed Artemis missions by upgrading the liquid nitrogen capabilities for quicker turnarounds for scrubbed launches, building the VAB HB4 EUS stand for engine servicing and the VAB Payload Environmental Access Room (PEAR) for cleanroom payload processing.

In the spring of 2024, ML-2 will complete CDR, having made significant progress on construction of the ML-2 required for future B1B crewed missions. The establishment of an Agency Baseline Commitment for ML-2 will also be reviewed for final approval in 2024.

The integrated recovery team of NASA, Lockheed Martin, and DoD, along with additional contractor support, will conduct Underway Recovery Test (URT)-11 in FY 2024 off the Pacific coast of San Diego, California to ensure safe recovery of the Orion crew module for future Artemis missions.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

EGS will complete Artemis II booster stacking, CS mate, and integrated test and checkout operations in the fall of 2024. Following final testing at Pad 39B and integration of Orion and SLS EGS in VAB, EGS will roll the integrated vehicle to the Pad for the Artemis II crewed launch in September 2025.

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

The integrated recovery team of NASA, Lockheed Martin, and DoD, along with additional contractor support, will conduct URT-12 in FY 2025 off the Pacific coast of San Diego, California to ensure safe recovery of the Orion crew module for future Artemis missions.

EGS will utilize the period between Artemis II and Artemis III to complete any remaining critical modifications, refurbishments, upgrades, and testing development to the launch pad, VAB, and ML-1 required to support Artemis III, NASA's first human mission to the lunar South Pole. FY 2025 Artemis III activities primarily include flight software updates, booster processing/stacking, core stage mate and integration operations.

EGS will complete the water flow test with the mobile launcher to verify the overpressure protection and sound suppression system is ready for launch of the Artemis III mission.

FY 2025 plans for Artemis IV center on completion of ML-2 base construction of decks, ground station equipment, and side panels. EGS will follow that with cyrogenic pipe installations, cold shock and umbilical range of motion testing to prepare for Crew Access Arm (CAA) commissioning, which is slated for the end of FY 2025.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2025 PB Request
KDP-A	Feb 2012	Feb 2012
Formulation Authorization	Apr 2012	Apr 2012
Systems Requirements Review (SRR) / System Definition Review (SDR)	Aug 2012	Aug 2012
KDP-B Agency Program Management Council (APMC)	Nov 2012	Nov 2012
PDR Board	Mar 2014	Mar 2014
KDP-C APMC	May 2014	May 2014
CDR Board	Dec 2015	Dec 2015
System Integration Review (SIR)	Apr 2018	Jun 2018
Operational Readiness Review / Flight Readiness Review (FRR)	Jul 2019	Jul 2019
Artemis I Launch Readiness	Nov 2018	Nov 2022
Mobile Launcher 2 PDR (Technical)	Mar 2021	Mar 2021
Mobile Launcher 2 PDR (Programmatic)	Jul 2021	Dec 2021
Mobile Launcher 2 CDR	Apr 2023	Apr 2023

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2015	1,843.5	80	2022	2,629.3	42.9	Artemis I Launch Readiness	Nov 2018	Nov 2022	48

NASA continues to review past reporting, and estimates do not necessarily accurately incorporate actual expenditures to date. Additionally, cost and confidence levels do not reflect the cost impacts of currently anticipated schedule delays. The estimates are expected to increase as NASA assesses the impacts of further delays and updates reporting on expenditures. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)*	Change from Base Year Estimate ($M)
TOTAL	**1,843.5**	**2,629.3**	**+785.8**
Mobile Launcher	213.1	501.8	+288.7
LC-39B Pad*	77.5	48.9	-28.6
VAB*	92.7	42.8	-49.9
Command, Control, and Communications	198.0	544.6	+346.6
Offline Processing and Infrastructure*	110.2	149.3	+39.1
Other	1,152.0	1,341.9	+189.9

Other includes Crawler Transporter, Launch Equipment Test Facility, Integrated Operations, Program Management, Logistics, Safety and Mission Assurance (S&MA), Integrated and Offline Operations, Construction of Facility and Systems Engineering and Integration (SE&I).

**The Agency Baseline Commitment for LC-39B Pad, VAB, and Offline Processing and Infrastructure previously integrated Operations cost which support Artemis I and later missions. EGS realigned those costs from each element and moved those costs to the other element, significantly lowering those elements' Current Year*

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Development Cost Estimate. In addition, the program removed $27 million in costs for the VAB Utility Annex from the VAB element estimate. Those costs were covered by Center Management and Operations as that work was determined to benefit all programs at KSC.

Totals may not add due to rounding.

Project Management & Commitments

EGS is developing ground systems infrastructure necessary to assemble, test, and launch SLS and Orion, as well as land and recover Orion flight elements.

Element	Description	Provider Details
Ground Systems Implementation (GSI)	GSI is responsible for the design, development, build, hardware/software integration, verification and validation, test, and transition to operations for program facility systems and Ground Support Equipment (GSE).	Provider: KSC Lead Center: KSC Performing Center(s): ARC Cost Share Partner(s): N/A
Operations and Test Management (O&TM)	O&TM is responsible for conducting overall planning and execution of both flight hardware and ground systems processing activities.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A
Command, Control, Communication (C3)	C3 is responsible for development, operation, and sustainment of End-to-End Command and Control and Communications services.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A
Program Management Team (PMT)	PMT includes project management, safety and mission assurance, logistics, systems engineering, utilities and facility operations, and maintenance.	Provider: KSC Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A

EXPLORATION GROUND SYSTEMS DEVELOPMENT

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The modifications to ML-1 are not completed in the planned 18-month window between Artemis I and Artemis II, Then: There is a possibility that the EES construction will not be completed in time to allow for Verification and Validation (V&V) prior to vehicle processing for Artemis II.	There is a dependency on the ML-1 being available and modifications being completed to complete the construction and activation of EES at the Pad. The dependencies with Artemis II ML-1 modifications may prevent timely installation and testing of EES with ML-1. Mitigation efforts being pursued include compressing the EES design schedule, compressing the construction schedule, exploring alternate implementation methods, initiating the construction earlier, and/or reducing the overall V&V schedule.
If: The modifications to the ECS ducting configuration and circuits are not completed in the planned 18-month window between Artemis I and Artemis II, Then: There is a possibility that the ECS construction will not be completed in time to allow for V&V prior to vehicle processing for Artemis II.	To support launches post Artemis I, modifications are planned to ECS that will enable it to support both Block 1 and B1B vehicles. This will require modifications to the existing circuits; however, these circuits had to be maintained throughout the entire Artemis I launch campaign. Mitigation efforts being pursued include compressing the design schedule, improving design package flexibility, identifying design scope that can be deferred, exploring alternate implementation methods, and/or reducing the overall V&V schedule.
If: ML-2 construction experiences design and construction delays, Then: ML-2 readiness for Artemis IV could be delayed.	EGS Program management is working with the prime contractor to shore up the discipline and rigor associated with project execution. NASA leadership has also increased oversight on the ML-2 project to ensure remaining development and construction work is executed as efficiently as possible. The program has seen challenges due to the COVID-19 pandemic, particularly in the areas of market pricing on materials/services and labor inefficiencies.

Acquisition Strategy

EGS serves as its own prime contractor for development activities. EGS executes SLS and Orion ground infrastructure and processing requirements by leveraging center and programmatic contracts. For more routine work, EGS also uses pre-qualified indefinite-delivery, indefinite-quantity contractors while exercising full and open competition for larger or more specialized projects, such as facility systems construction contracts and associated GSE fabrication firm-fixed-price contracts. A fixed-price contracting approach is the first choice whenever possible, as it provides maximum incentive for contractors to control costs because the contractors are subject to any losses incurred. In addition, a fixed-price contract imposes less administrative burden on the contracting parties.

The FY 2025 President's Budget does not mandate adjustments to contracts and agreements, and NASA expects contractors and partners to perform to their contract/agreement dates.

MAJOR CONTRACTS/AWARDS

EGS development activities will encompass projects of varying content and size. EGS uses the center's institutional contracts to execute the development, engineering, construction, and programmatic activities. If the project size or scope falls outside existing center capabilities, then a competitively bid firm-fixed-price contract will be used.

Element	Vendor	Location (of work performance)
ML-1 Structural and Facility Support Modification Contract	J.P. Donovan Construction, Inc.	KSC
VAB Platform Construction	Hensel Phelps Construction, Inc.	KSC
ML-2 Design Build	Bechtel National, Inc.	KSC

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Launch Readiness Date/Initial Operations Capability (LRD/IOC) for Artemis I	IA / IRT	Nov 2022	To assess all capabilities of the vehicle to support the readiness to launch.	Successful launch on November 16, 2022.
Mobile Launcher 2 CDR	IA / IRT	Apr 2023	To demonstrate that program design is mature; support full-scale fabrication, assembly, integration, and test; and meet overall performance requirements within cost and schedule constraints.	N/A

MOON TO MARS LUNAR SYSTEMS DEVELOPMENT

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Gateway	779.2	--	**817.7**	627.9	586.8	746.0	635.4
xEVA and Human Surface Mobility Program	324.9	--	**434.2**	483.9	644.7	673.6	571.2
Human Landing System	1,386.1	--	**1,896.1**	2,050.9	1,994.9	2,278.3	2,334.7
Advanced Exploration Systems	140.3	--	**140.2**	123.0	163.1	170.9	171.0
Total Budget	**2,630.5**	**--**	**3,288.1**	**3,285.7**	**3,389.5**	**3,868.8**	**3,712.3**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Virtual Reality (pictured above) is being used to help astronauts evaluate the Crew Cabin that is being developed for Artemis missions.

The overarching goal of the Moon to Mars Lunar Systems Development theme is to develop the systems that humans will use to live and operate in deep space, land humans on the Moon, explore the lunar surface, and prepare for Mars exploration. The theme comprises four programs: Gateway; the Human Landing System (HLS); Extravehicular Activity (xEVA) and Human Surface Mobility Program (EHP); and Advanced Exploration Systems (AES). In collaboration with commercial and international partners, the Moon to Mars program will create the necessary exploration infrastructure in lunar orbit and on the lunar surface that astronauts will use during Artemis missions. The Lunar Systems Development theme is responsible for developing and testing prototype systems, as well as planning and developing flight missions to lunar orbit and the lunar surface. In addition to expanding our lunar capabilities, these efforts will also inform and enable future missions to Mars. The theme's program objectives support the National Space Policy of 2020 and the 2021 Space Priorities Framework, as well as the agency's Strategic Goal 2, which seeks to extend human presence to the Moon and onto Mars for sustainable, long-term exploration, development, and utilization.

The Lunar Systems Development theme will leverage other capabilities, such as life support systems, within ESDMD for transportation of the crew to and from orbit around the Moon and technology development for future Mars systems. The theme will leverage SMD development of smaller landers for capabilities such as navigation and precision landing of cargo, as well as for data about the lunar surface. Finally, Lunar Systems Development will leverage SOMD's capabilities, such as the ISS and the Space Communications and Navigation program, as a technology and human system testbed and communication and navigation capability provider, respectively.

The theme's activities utilize a variety of agreement and contract types, such as Firm-Fixed-Price contracts, that enable NASA, private industry, academia, and international partners to share in the risks and rewards of government investments. These shared risks incentivize technical performance and building future commercial markets with entities other than NASA interested in using the new capabilities. These programs are also utilizing the unique skills of the NASA workforce to perform risk reduction, develop life support systems, and build and manage the missions that will take humanity back to the Moon and beyond.

Utilizing partnerships and competition to drive affordability, the HLS program will leverage commercial capabilities to develop integrated lunar landing systems. Artemis III's lunar landing demonstration will consist of landing two crew members on the lunar surface via the SpaceX Starship vehicle. Once the Orion spacecraft has docked to the Starship in lunar orbit, two crew members will board the Starship to continue their journey to the surface of the Moon for nearly a week, then return to lunar orbit and rendezvous with Orion for the return to Earth. As part of the Sustaining Lunar Development (SLD), Blue Origin's Mark 2 system will land on the Moon for Artemis V mission. NASA intends to support the development and use of multiple industry provided landing systems to maintain competition and enable redundancy in the HLS program.

xEVA and EHP develops and manages the systems that NASA will use to explore the surface of the Moon. These surface systems, including surface suits and mobility systems, will allow astronauts to reach of increasingly large areas of the surface of the Moon, maximizing the science and exploration value of the Artemis missions. Utilization of surface systems will also yield lessons learned that will be applied to the development and support of future Mars missions.

The Gateway will serve as a multi-purpose outpost orbiting the Moon, providing capabilities to enable a sustained deep space presence for NASA and its partners to conduct human exploration and scientific research on and around the lunar surface. Both in early and later stages of assembly, Gateway will enable crewed missions in lunar orbit, where astronauts will prepare for lunar surface missions and future crewed missions to Mars.

The Lunar Systems Development theme leads the next phase of lunar sustainability with the development activities occurring under AES. Development activities include high-priority technologies and capabilities to infuse them into prototype systems that will form the basis for human spaceflight missions and enable future long duration missions. Examples of AES activities include long-duration environmental control and life support systems (ECLSS); technology demonstrations on ISS and ground testing of integrated systems; crew health and performance; Earth independent operations software and systems tools to reduce crew's dependence on ground-based mission control; and advance habitat and life-support capabilities demonstrated and tested on Earth, in LEO, Near-Rectilinear Halo Orbit (NRHO), and the lunar surface.

The missions pioneered by this theme will enable the first intrepid crews of the new space age to travel safely to and from the surface of the Moon and mature the systems that can achieve sustainability on the Moon. These missions will enable new scientific discoveries and promote new technologies, research, and systems needed to sustain living in deep space for the benefit of all humankind and eventually feed into future Mars missions.

EXPLANATION OF MAJOR CHANGES IN FY 2025

Due to favorable commercial competition for HLS lander development, the agency reallocated HLS resources to meet other Moon to Mars (M2M) programs' realized risk priorities while continuing to fund human landing initial capability, sustaining lunar development capabilities and cargo lander development with two providers.

Gateway changes are due to refinement of Deep Space Logistics element requirements.

MOON TO MARS LUNAR SYSTEMS DEVELOPMENT

AES restructured the program to better align with the Moon to Mars architecture strategy by conducting risk reduction activities on the Moon in support of future long duration Mars missions.

GATEWAY

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Gateway Initial Capability	493.0	516.6	**431.8**	181.3	0.0	0.0	0.0
Gateway	286.2	--	**385.8**	446.6	586.8	746.0	635.4
Total Budget	**779.2**	**--**	**817.7**	**627.9**	**586.8**	**746.0**	**635.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Pictured above is the Gateway, which will serve as a multi-purpose outpost orbiting the Moon that provides essential support for long-term human return to the lunar surface.

The Gateway will serve as a multi-purpose outpost orbiting the Moon, providing capabilities to enable a sustained deep space presence for NASA and its partners to conduct human exploration and scientific research on and around the Lunar surface. Both in early and later stages of assembly, Gateway will enable crewed missions to lunar orbit, where astronauts will live, work, and prepare for and support lunar surface missions.

Gateway will host human lander systems enroute to the lunar surface. Gateway's unique near-rectilinear halo orbit (NRHO) will periodically (roughly weekly) bring Gateway within about 1,000 miles/1,500 kilometers (km) of the surface at its closest point. This orbit will allow NASA and its international and commercial collaborators to have unprecedented access to the north and south poles of the Moon to conduct deep space science and technology investigations and perform sustainable lunar exploration. Gateway will also serve as a platform for scientific research that require its unique location.

Elements of the Gateway will be developed and deployed incrementally. The Gateway Initial Capability architecture consists of the two foundational elements: the Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO). Maxar Technologies is developing and building the PPE, which will provide power, high-rate communications, attitude control, and orbital transfer capabilities for the Gateway. Northrop Grumman is building HALO, which is the first habitable module of Gateway, where astronauts will live and conduct research. HALO will provide command and control systems for the lunar outpost and docking ports for visiting spacecraft. PPE and HALO will be integrated and launched together on a SpaceX Falcon Heavy rocket no earlier than 2025.

As astronauts prepare for missions to the lunar surface, they will need deliveries of pressurized and unpressurized cargo, science experiments, and supplies, such as sample collection materials for the lunar surface. The Gateway Deep Space Logistics (DSL) project manages the Gateway Logistics Services (GLS) contract, which will deliver supplies and hardware to support Gateway's sustained lunar orbit operations and lunar landing missions.

International partners will provide important contributions to Gateway, including advanced external robotics and interfaces via the Gateway External Robotic System (GERS) from Canada; additional habitation via the International Habitat (I-Hab) from ESA and JAXA; lunar communications and a refueling capability via European Systems Providing Refueling, Infrastructure, and Telecommunications

(ESPRIT)-Refueler Module; and an airlock from the Mohammed bin Rashid Space Centre (MBRSC) of the United Arab Emirates (UAE) to support science and maintenance.

Gateway is leveraging and expanding upon the legal framework, knowledge, and relationships built via the ISS. It will leverage other SOMD capabilities, such as the Space Communications and Navigation program as a communication capability provider. Gateway will leverage the Space Launch System's (SLS) launch vehicle and Orion capsule capabilities to transport some of its elements into cislunar orbit, starting with the I-Hab as a co-manifested payload on Artemis IV. Gateway will be humanity's first space station in lunar orbit. It will support NASA's deep space exploration plans and the Moon and Mars exploration initiative by providing the infrastructure necessary for sustained lunar surface exploration. It also provides a research platform aimed at capabilities necessary for Mars exploration.

For more information, go to: http://www.nasa.gov/gateway

Program Projects

Power and Propulsion Element (PPE)

The PPE is a high-power, 60-kilowatt (kW) solar electric propulsion spacecraft that will provide power, high-rate communications, attitude control, orbit maintenance, and orbital transfer capabilities for the Gateway.

Habitation and Logistics Outpost (HALO)

HALO is where astronauts will initially live and conduct research while visiting the Gateway. The pressurized living quarters will provide command and control systems for the lunar outpost and docking ports for visiting spacecraft such as NASA's Orion spacecraft, lunar landers, and logistics resupply craft.

The HALO module will serve as the backbone for command and control and power distribution across Gateway and will perform other core functions, including hosting science investigations via internal and external payload accommodations and communicating with lunar surface expeditions. HALO also will enable the addition of the I-Hab habitable element and ESPRIT Refueler Module to expand Gateway capabilities. HALO leverages contributions from the Gateway international partners for robust capabilities. Batteries provided by JAXA will power HALO until PPE solar arrays can be deployed and during eclipse periods. Robotic interfaces provided by CSA will host payloads and provide base points for Canadarm3 robotic operations. ESA will provide a lunar communications system to enable high-data-rate communications between the lunar surface and Gateway.

Deep Space Logistics (DSL)

The DSL Project is the element of the Gateway Program charged with delivering cargo, equipment, consumables, and payloads to and removing waste from the Gateway. The functional reality of human habitation in any location on Earth or in space is that it involves the consumption of resources and the generation of waste. The development of a sustainable, repeatable, and reliable supply chain is critical to the success of the Artemis program.

The logistics spacecraft will have their own power, propulsion, and navigation systems to rendezvous autonomously with the Gateway in cislunar orbit and dock at a radial port. It will provide consumable resupply, outfitting equipment, and cargo delivery including utilization and spares. The logistics module is designed to serve as a large pantry where supplies can be easily accessed by the crew. The design of the spacecraft will accommodate the collection, storage, and eventual disposal of waste accumulated at Gateway. The cargo and supplies delivered by logistics spacecraft will support habitation of the Gateway as well as provide provisions for the lunar landers during the sustained lunar exploration phase.

The logistics flights are necessary to supply Gateway with critical cargo deliveries and to sustain the crew during stays on Gateway. The Gateway Logistics Services contract and technical capability are extensible to deliver unique payload configurations such as the GERS to the Gateway.

In March 2020, NASA awarded SpaceX as the provider under the Gateway Logistics Services contract to deliver cargo and other supplies to the lunar outpost. In addition to the logistics capability provided via the Gateway Logistics Services contract, JAXA has committed to providing logistics resupply capability via the HTV-XG spacecraft.

INTERNATIONAL HABITAT (I-HAB)

The I-Hab module is a contribution from ESA and will provide additional crew habitation and workspace, as well as additional environmental systems capability. This module will also provide additional docking ports and accommodations for internal and external science experiments.

I-Hab's environmental control and life support systems will augment the life support system capabilities provided by HALO and the docked Orion, enabling longer missions at the Gateway and on the lunar surface. JAXA will provide several capabilities for the Gateway's I-Hab, including I-Hab's environmental control and life support system, batteries, thermal control, and imagery components, which will be integrated into the module by ESA prior to launch on the SLS Block 1B launch vehicle on Artemis IV. Thales Alenia Space - Italy is under contract with ESA for the I-Hab module.

EUROPEAN SYSTEMS PROVIDING REFUELING, INFRASTRUCTURE, AND TELECOMMUNICATIONS (ESPRIT)

The ESPRIT provides additional capabilities that are realized in two components. HALO Lunar Communication System (HLCS) will be integrated and launched with HALO and will provide high-rate communications relay between Gateway and elements on the lunar surface. The second, separate module is the ESPRIT Refueling Module, which will incorporate crew observation windows and enable refueling of the PPE. Thales Alenia Space - France is under contract with ESA for both components of the ESPRIT.

GATEWAY EXTERNAL ROBOTICS SYSTEMS (GERS)

CSA will provide the Gateway's external robotics system, including a next-generation robotic arm, known as Canadarm3. Canadarm3 will move end-over-end to reach many parts of the Gateway's exterior, where its anchoring "hand" will plug into specially designed interfaces. CSA also will provide robotic interfaces for Gateway modules, which will enable payload installation including that of the first two scientific instruments launching on the foundational Gateway elements (PPE/HALO). Canadarm3 will be used to conduct maintenance, to berth and inspect vehicles, install science payloads, and support potential future Gateway EVAs. CSA will be responsible for end-to-end external robotics, including engineering and operations. CSA selected MDA for both the Canadarm3 and external robotic interfaces.

GATEWAY

GATEWAY AIRLOCK

The Gateway airlock module will support both crewed spacewalks as well a science airlock to transfer scientific experiments and Gateway hardware between the pressurized cabin and the exterior of Gateway. Canadarm3 would be an integral part of the science airlock operations moving the hardware into and out of the science airlock and deploying/retrieving around Gateway. The Mohammed bin Rashid Space Centre (MBRSC) of the United Arab Emirates (UAE) will provide the airlock.

EXPLANATION OF MAJOR CHANGES IN FY 2025

The proposed funding levels sufficiently allow the program to support development of Gateway's Initial Capability as soon as is technically feasible. While the confirmation baseline launch readiness date is December 2027, NASA is re-assessing the Gateway Initial Capability work-to launch date, which currently is targeted for no earlier than (NET) October 2025.

ACHIEVEMENTS IN FY 2023

The Gateway Program closed out the PDR sync review and successfully passed their KDP-I. This marked the transition from formulation to implementation for the whole tightly coupled program.

WORK IN PROGRESS IN FY 2024

CSA will hold GERS PDR. Gateway Deep Space Logistics received authority to proceed and awarded procurement of the first Logistics service mission in support of Artemis IV. Gateway will continue working with ESA on the development of I-Hab, the HLCS Engineering Module will be delivered, and ESA will hold an ESPRIT Refueling Module (ERM) PDR. It is anticipated that MBRSC will select a prime contractor for development of the Airlock.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

ESA and JAXA will hold an I-Hab CDR. Deep Space Logistics will be ready for KDP-C in support of Artemis IV.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2025 PB Request
KDP-I	Jul 2023	Jul 2023
CDR	Q2 CY 2024	Q4 CY 2024
Initial Capability LRD	Dec 2027	Dec 2027

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Gateway Formulation Synchronization Review (FSR)	Independent Review Team	Feb 2019	Equivalent to a SRR, the FSR evaluated the program's functional and performance requirements, ensuring proper formulation and correlation with agency and mission directorate strategic objectives.	Program cleared to proceed to next phase
Gateway Program SDR-informed Sync Review	Standing Review Board (SRB)	Jun 2020 Delta -Mar 2021	To evaluate the credibility and responsiveness of the proposed program requirements/architecture to the mission directorate requirements and constraints, including available resources, and allocation of requirements to projects. To determine whether the maturity of the program's mission/system definition and associated plans are sufficient to begin preliminary design.	Approval to proceed in Formulation at KDP-0
Gateway Program PDR-Informed Sync Review	SRB	May 2022, with close-out in May 2023	To evaluate the completeness/consistency of the program's preliminary design, including its projects, in meeting all requirements with appropriate margins, acceptable risk, and within cost and schedule constraints, and to determine the program's readiness to proceed with the detailed design phase of the program.	Approval to proceed to KDP-I
KDP-I	APMC	Jul 2023	To approve transition from formulation to implementation	Approval to proceed to implementation and Gateway Initial Capability

GATEWAY INITIAL CAPABILITY

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	1,719.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	1,719.0
Development/Implementation	0.0	776.0	843.8	**828.1**	630.8	387.6	95.5	0.0	0.0	3,561.8
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2024 MPAR LCC Estimate	**1,719.0**	**776.0**	**843.8**	**828.1**	**630.8**	**387.6**	**95.5**	**0.0**	**0.0**	**5,280.8**
Total Budget	**1,719.0**	**493.0**	**516.6**	**431.8**	**181.3**	**0.0**	**0.0**	**0.0**	**0.0**	**3,341.7**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Pictured above is construction of the Habitation and Logistics Outpost.

PROJECT PURPOSE

Gateway Initial Capability includes the Power and Propulsion Element (PPE), the Habitation and Logistics Outpost (HALO), the commercial launch vehicle for initial launch, and a portion of Program Mission Execution (PME). PPE and HALO will be integrated before launch on a Falcon Heavy as a single co-manifested vehicle. Both have contributions from international partners that are integrated pre-launch. Several elements for the full configuration are being provided by international partners, including I-Hab, ESPRIT Refueler Module, external robotics, and Airlock.

PROJECT PARAMETERS

The PPE will be the most powerful electric propulsion spacecraft ever flown, and it will maneuver Gateway around the Moon, opening more of the Lunar surface for exploration than ever before. The PPE project leverages Space Technology Mission Directorate investments in advanced electric propulsion systems. PPE will demonstrate an advanced solar electric propulsion system (SEP), which combines 12kW and 6kW SEP thrusters.

The PPE is being developed and built by Maxar Space Systems of Westminster, Colorado, and is managed out of NASA’s GRC in Ohio. PPE will be launched with HALO as an integrated vehicle on a

GATEWAY INITIAL CAPABILITY

Formulation	Development	Operations

SpaceX Falcon Heavy commercial rocket, and PPE will propel the co-manifested vehicle to cislunar space.

The HALO module is the initial habitation element where astronauts will live, exercise, prepare meals, rest, prepare for lunar surface missions, and conduct research while visiting Gateway. The pressurized living quarters will provide docking ports for visiting spacecraft like NASA's Orion spacecraft, lunar landers, and logistics resupply craft, and serve as the backbone for command and control and power distribution across Gateway.

Northrop Grumman's design for HALO, developed through NASA's Next Space Technologies for Exploration Partnerships (NextSTEP) contract vehicle, is based on its Cygnus spacecraft currently being used to deliver cargo to the ISS.

ACHIEVEMENTS IN FY 2023

In FY 2023, the Agency Baseline Commitment (ABC) was established for the Gateway Initial Capability. At the element level, HALO completed CDR close out. A CDR determines if the design is appropriately mature to continue with the final design and fabrication phase.

WORK IN PROGRESS IN FY 2024

In FY 2024, PPE's contractor will hold a CDR. The Assembly, Integration, and Test (AI&T) phase for HALO and PPE will be underway. The HALO habitable element, manufactured by Thales Alenia Space-Italia for Northrop Grumman, will be shipped, and delivered to the United States.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The Assembly, Integration, and Test (AI&T) phase for HALO and PPE will continue, as the spacecraft conduct verification and validation activities. Verification and validation testing will also be conducted for integrated ground labs and flight software. The Flight Operations Division at the JSC will be conducting flight control team training.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2025 PB Request
KDP-C	Jul 2023	Jul 2023
LRD	Dec 2027	Dec 2027

GATEWAY INITIAL CAPABILITY

Formulation	Development	Operations

Development Cost and Schedule

The establishment of Gateway Initial Capability Agency Baseline Commitments for Launch Readiness Date (LRD) represents a risk informed posture that encompass potential issues and not target launch dates. JCLs are used to track program performance. NASA continues to manage to a more aggressive schedule than the LRD.

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2024	3,561.8	70	2024	3,561.8	0	LRD	Dec 2027	Dec 2027	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**3,561.8**	**3,561.8**	**0**
Project Management	167.0	167.0	0
Systems Engineering	337.7	337.7	0
Science/ Technology/ Payloads	48.8	48.8	0
Safety	50.9	50.9	0
Spacecraft	1,632.8	1,632.8	0
Mission Operations	122.6	122.6	0
Launch Vehicle	191.1	191.1	0
UFE	1011.1	1,011.1	0

Totals may not add due to rounding

GATEWAY INITIAL CAPABILITY

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
PPE	Power Propulsion Element	Provider: Maxar Space Systems Lead Center: GRC Performing Center(s): GRC and JSC	N/A
HALO	Habitation and Logistics Outpost	Provider: Northrop Grumman Lead Center: JSC Performing Center(s): JSC	N/A
Commercial Launch Service	PPE & HALO co-manifested launch	Provider: SpaceX Lead Center: KSC Launch Services Program Performing Center(s): KSC	N/A

Project Risks

Risk Statement	Mitigation
If: PPE-HALO mass exceeds the mass allocation. Then: Further analysis and potential offloads will need to be conducted and/or identified.	Mass control boards have been established. Potential offloads will be identified and assessed. Design maturation, delivered component masses, and fidelity of performance models will impact these ongoing assessments and offer the most flexibility in optimizing the overall mission design.

Acquisition Strategy

Gateway Initial Capability major domestic procurements are firm fixed price contracts.

MAJOR CONTRACTS/AWARDS

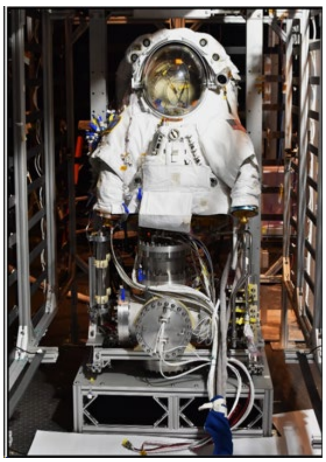
Element	Vendor	Location (of work performance)
PPE	Maxar Space Systems	California
HALO	Northrop Grumman	Arizona
PPE-HALO Launch Service	SpaceX	California

xEVA AND HUMAN SURFACE MOBILITY PROGRAM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**324.9**	**--**	**434.2**	**483.9**	**644.7**	**673.6**	**571.2**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Shown here, the Exploration Extravehicular Activity (xEVA) team conducts an Exploration Extravehicular Mobility Unit (xEMU) Design Verification Testing (DVT) thermal vacuum testing.

The NASA Extravehicular Activity (EVA) and Human Surface Mobility (HSM) Program (EHP) seeks to work with partners to advance the technologies associated with human mobility and lunar surface infrastructure in support of NASA's Artemis missions. The EHP vision provides safe, reliable, and effective EVA and HSM capabilities that allow astronauts to survive and work outside the confines of a spacecraft in space and on the Moon. Artemis missions will return humans to the surface of the Moon using innovative technologies to explore more of the lunar surface than ever before. The EHP will collaborate with commercial and international partners and establish the first long-term presence on the Moon. Eventually, the program will use what it learned on and around the Moon to develop surface systems that can be used by the first astronauts to land on Mars.

The EHP program and partners will collaborate on developing lunar capabilities to increase the productivity of crews on the lunar surface during Artemis missions. EHP focuses on high-risk technologies for lunar surface systems that will provide mission planners with more choices, thereby increasing mission success. In pursuing these types of capabilities, NASA and potential partners will develop new and improved technologies that will provide additional options for terrestrial applications in multiple industries.

Artemis astronauts exploring the Moon's South Pole will wear new spacesuits to keep them safe and productive in this harsh lunar environment. NASA is embracing commercial collaborations to optimize spacesuit technology and inspire innovation in the space industry. NASA has selected Collins Aerospace and Axiom Space to advance spacewalking capabilities in space and on the Moon, by buying services that provide astronauts with next generation spacesuit and spacewalk systems to work outside spacecraft, explore the lunar surface on Artemis missions, and prepare for human missions to Mars. The Exploration Extravehicular Activity (xEVA) System, which is required for astronauts to conduct moonwalks on the lunar surface, includes the Exploration Extravehicular Mobility Unit (xEMU) spacesuit development, vehicle interfaces to suit equipment, system servicing equipment, and specialized tools for these moonwalks.

The Lunar Terrain Vehicle (LTV) is an unpressurized surface transportation system that will significantly extend the range of crew excursions and enable more scientific research, resource prospecting, and exploration activities to be conducted. Because Artemis missions will be targeting the Lunar South Pole area, the new LTV must be able to withstand and operate in cold temperatures and unique lighting conditions. The Artemis LTV is expected to be able to be operated remotely when astronauts are not on the surface, enabling access to diverse locations that will facilitate science discoveries, resource prospecting, and exploration. It will also be available for commercial uses when not carrying out NASA research and operations.

Procuring services from industry partners allows NASA to leverage commercial innovation and provide the value to U.S. taxpayers while achieving its human spaceflight and exploration goals. The Lunar Terrain Vehicle Services (LTVS) contract will support continued science and long-term human exploration of the Moon during the Artemis Campaign.

Long duration mobility is a key enabler of more productive lunar exploration. The Pressurized Rover (PR) is a pressurized surface transportation system that would be used on the Moon to expand the range of excursions even further, allowing crews to perform longer-duration research and exploration activities. In addition, this capability would allow NASA to conduct analogs of Mars surface activities to reduce risk and optimize operational concepts. When NASA sends a pressurized rover to the surface of the Moon, it will serve as astronauts' living and working space, their life support system, and their means of transportation for up to a month at a time. As part of a study agreement with NASA, JAXA may provide a pressurized rover for Artemis missions.

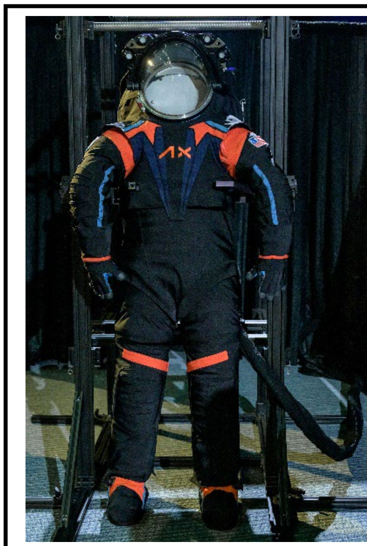
The capabilities provided by the EHP program enable the crews of the new space age the ability to safely explore the lunar surface and mature sustainability on the Moon. The ability to explore the lunar surface will enable new scientific discoveries and promote new technologies, research, and systems needed for future Mars missions.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

The EHP successfully wrapped up program formulation at the KDP-I in August 2023. This marks the transition from the formulation to the implementation phase for the program, which will lead to finalizing milestones, program implementation assignments, and acquisition strategy beyond the initial engagements.



Shown above, Axiom Space Picture of the Artemis III spacesuit prototype, the Axiom Extravehicular Extravehicular Mobility Unit (AxEMU).

The xEVA team awarded spacesuit contract task orders to two vendors: the Artemis III task order to Axiom Space and the ISS task order to Collins Aerospace. Subsequently, the vendors commenced work toward their proposed milestones. Each vendor has completed its Certification Baseline Review and is working toward completing its PDR. Axiom Space unveiled the first prototype spacesuit for NASA's Artemis III Moon surface mission. NASA selected Axiom Space to deliver the moonwalking system, including the spacesuit for the Artemis III mission. The spacesuit, called the Axiom Extravehicular Mobility Unit (AxEMU), builds on NASA's spacesuit prototype developments and incorporates the latest technology, enhanced mobility, and added protection from hazards. Training hardware for Artemis III has also been delivered. The Collins Aerospace designed suit will incorporate new technology that is efficient, durable, and requires less maintenance than the spacesuit used by NASA astronauts on ISS missions. Both new suits will accommodate a broader variation in astronaut size.

xEVA AND HUMAN SURFACE MOBILITY PROGRAM

Shown above, is the Collins Aerospace next-generation spacesuit prototype.

The LTV unpressurized rover team completed KDP-A. Later in the fiscal year, the team completed the LTV System Requirements Review and released a services model contract for proposal in May 2023. Instead of owning the vehicle, NASA plans to contract it as a service from industry. Proposals have been received and are under review for future selection.

The Pressurized Rover team completed a successful Mission Concept Review in partnership with JAXA. NASA continues to be actively engaged with JAXA to refine and coordinate on requirements and concept of operations for technologies needed to establish a long-term presence on the Moon with future Artemis missions.

WORK IN PROGRESS IN FY 2024

NASA is working with its two exploration space suit vendors, Axiom Space and Collins Aerospace, through PDR. Collins Aerospace will work toward a CDR and ground demonstration of their suit in a simulated space environment. NASA will have the option to extend the contract for an in-space demonstration outside the ISS. Axiom Space will be developing next-generation astronaut spacesuits to support the Artemis lunar missions, with a targeted demonstration of the new suit and tools capability on Artemis III.

NASA is also reviewing proposals received in response to the final LTVS request for proposals (RFPs). The LTV capability is an unpressurized mobility system to assist suited crew members in driving around the lunar surface and increasing the productivity of moon walks. It is also intended to be able to advance exploration goals via remote control from the ground during uncrewed phases on the lunar surface. The LTVS contract is anticipated to be awarded in FY 2024.

NASA will continue to define PR requirements and work toward an international partnership agreement for development and delivery of the PR to the lunar surface. By providing a pressurized mobile habitat in which humans can live and work, the pressurized rover will extend the range of explorable surface environments in future Artemis missions.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

In FY 2025, Collins Aerospace and Axiom Space will continue the development of the next generation astronaut spacesuits. EHP will continue to support the Extravehicular Activity Services (EVAS) contract developing new spacesuits for use in space and on the lunar surface.

EHP will manage the acquisition for LTVS, to include the Phase I task order for feasibility assessments. In addition, EHP will provide technical expertise to ensure LTV meets NASA's requirements.

NASA is also working towards approval of an international agreement that enables progress toward the design and development of a PR.

xEVA and Human Surface Mobility Program

Program Elements

EVA Development

The goal of the EVA development project is to provide a safe, reliable, and effective EVA capability that allows astronauts to survive and work outside the confines of the base spacecraft in orbit or on the lunar surface, in support of Artemis and other NASA human spaceflight programs.

The xEMU is designed to provide astronauts with enhanced mobility to accomplish their exploration tasks on the lunar surface. It is also designed to be more comfortable when worn by male and female astronauts with a wider range of physiological characteristics.

Lunar Terrain Vehicle

The LTV project will provide the unpressurized vehicle required for astronauts to explore the surface of the Moon. The project will also explore capabilities required to allow remote use of the vehicle to perform tasks on the Moon during periods where astronauts are absent from the lunar surface.

Pressurized Rover

The PR project will provide the means for astronauts to explore the surface of the Moon for long durations beyond any previous capability. Specifically, the habitable volume built into the surface PR will allow for long range reconnaissance missions.

Program Schedule

Date	Significant Event
Q4 FY 2023	EHP KDP-I
Q2 FY 2024	EHP Program Sync Review

Program Management & Commitments

ESDMD manages the xEVA and HSM Systems activities.

Program Element	Provider
xEVA	Provider: Collins, Axiom Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): TBD

XEVA AND HUMAN SURFACE MOBILITY PROGRAM

Program Element	Provider
LTV	Provider: TBD Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): TBD
Pressurized Rover	Provider: TBD Lead Center: JSC Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

Acquisition plans for all functions/elements of xEVA and HSM will be varied and depend upon specific activities as this effort includes risk-reduction activities and studies.

NASA is using contracts with Axiom Space and Collins Aerospace to advance spacewalking capabilities in LEO and on the Moon, by buying services that provide astronauts with next generation spacesuit and spacewalk systems to work outside spacecraft, explore the lunar surface on Artemis missions, and prepare for human missions to Mars.

The FY 2025 President's Budget does not mandate adjustments to contracts and agreements, and NASA expects contractors and partners to perform to their contract/agreement dates.

MAJOR CONTRACTS/AWARDS

NASA selected Axiom Space for the task order for developing a spacesuit to enable lunar surface activities, which has a base value of $228.5 million. A future task order will be competed for recurring spacesuit services to support subsequent Artemis missions. Axiom Space will be required to test the suits in a spacelike environment before Artemis III.

NASA has awarded a task order to Collins Aerospace to deliver a spacewalking system for use outside the ISS. This award – the second under NASA’s EVAS contract – is for design and development of a next-generation spacesuit and support systems. The task order has a base value of $97.2 million.

xEVA and Human Surface Mobility Program

Independent Reviews

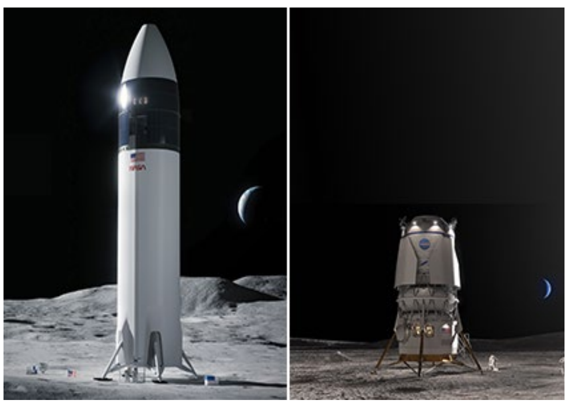
Review Type	Performer	Date of Review	Purpose	Outcome
System Requirements Review (SRR) / System Definition Review (SDR)	Standing Review Board (SRB)	Q3 FY 2023	To evaluate the program's functional and performance requirements, ensuring proper formulation and correlation with agency and mission directorate strategic objectives / To evaluate the proposed program requirements and architecture; allocation of requirements to projects; assess the adequacy of project pre-formulation efforts; determine if maturity of the program's definition and plans are enough to begin implementation	Program cleared to proceed to next phase

HUMAN LANDING SYSTEM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
HLS Initial Capability	807.3	526.3	**647.1**	703.3	607.2	252.1	0.0
Human Landing System	578.8	--	**1,249.0**	1,347.6	1,387.7	2,026.2	2,334.7
Total Budget	**1,386.1**	**--**	**1,896.1**	**2,050.9**	**1,994.9**	**2,278.3**	**2,334.7**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Left: Illustration of SpaceX's Starship HLS, for use on Artemis III and Artemis IV. Right: Illustration of Blue Origin's Blue Moon MK2 Lander, for use on Artemis V.

The Human Landing System (HLS) is the mode of transportation that will take astronauts to the lunar surface as part of Artemis. HLS program is working with U.S. industry to develop landers that will safely take Artemis astronauts from Orion or Gateway in lunar orbit to the surface of the Moon and back to the waiting spacecraft. The HLS program is also working with its industry providers to develop cargo variants for the delivery of large payloads such as pressurized rovers and habitats to the lunar surface. Partnering with American industry fosters a space-related economic marketplace and maintains America's high-tech industrial base while reducing costs to taxpayers. NASA shares its knowledge and expertise with industry and maintains oversight of safety while companies develop, test, and iterate their lander designs.

EXPLANATION OF MAJOR CHANGES IN FY 2025

Due to HLS award to Blue Origin being less than what NASA had estimated in the FY 2024 Budget, NASA was able to realign funding from HLS to address other risks in the Exploration Systems Development Mission Directorate portfolio without impact to the HLS program.

ACHIEVEMENTS IN FY 2023

In November 2022, NASA announced the exercise of Option B on SpaceX's existing HLS Next Space Technologies for Exploration Partnerships 2 (NextSTEP-2) Appendix H contract. Under this award, SpaceX will further develop its Starship Human Landing System to meet NASA's sustaining lander requirements for the Artemis IV mission.

NASA engaged in numerous product development and review activities to support the Sustaining Lunar Development (SLD). In May 2023, NASA awarded Appendix P to Blue Origin under NextSTEP-2 to develop a second commercial lander service that also meets NASA's extended set of lander requirements.

HUMAN LANDING SYSTEM

WORK IN PROGRESS IN FY 2024

For all HLS Capabilities, SpaceX and Blue Origin will continue to demonstrate that their human and cargo landing systems are maturing to meet all system requirements with acceptable risk and within cost and schedule constraints.

For Artemis III, NASA will continue to work with SpaceX to mature the Starship human landing system with a focus on the Propellant Transfer Flight Test. For Artemis IV, NASA will continue to work with SpaceX to mature its Starship human landing system including continuing the development of ECLSS environment for a four-person crew. For Artemis V, NASA will continue to work with Blue Origin to mature its Blue Moon Mark 2 human landing system.

NASA also authorized the execution of optional contract line items under both Appendix H and P to develop human-class cargo delivery landers that leverage the human landing system designs.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

For Artemis III, SpaceX will continue development of Starship leading to CDR. For Artemis IV, SpaceX will continue leveraging the Initial Capability development leading to a PDR of the Sustaining Capability Starship. For Artemis V, Blue Origin will continue development of Blue Moon Mark 2 system including CDR. Additionally, SpaceX and Blue Origin will continue development of large cargo landers with a Certification Baseline Review (CBR) and PDR, respectively.

Program Elements

HLS PROGRAM MANAGEMENT

HLS Program Management is responsible for executing programmatic roles assigned by ESDMD. The HLS Program Office will oversee all HLS verification, validation, and certification to ensure requirements for flight readiness satisfy NASA's standards for crew safety and human rating.

HLS Program Management is responsible for the insight and oversight activities in collaboration with commercial partners associated with human landing system hardware development, integration, and flight demonstration, leading to services that can be procured by NASA. HLS performs risk reduction activities and identifies and prioritizes upgrades to the human landing systems so they can support sustainable future exploration missions. HLS includes a lander ground operations office at KSC, and both a crew compartment office and a lander flight operations office at JSC. HLS prioritizes and coordinates collaboration resources across multiple NASA centers and manage major integrated system test activities, as applicable.

HUMAN LANDING SYSTEMS - INITIAL CAPABILITY

NASA currently has a contract (NextSTEP-2 Appendix H Option A) with SpaceX to develop its Starship HLS to land astronauts on the Moon during the Artemis III mission. Starship will dock with Orion in lunar orbit, two crew members will transfer from Orion to Starship, and descend to the surface. There, the crew will collect samples, perform science experiments, and observe the lunar environment before returning in Starship to Orion in lunar orbit. Prior to the crewed Artemis III mission, SpaceX will perform an uncrewed landing demonstration mission on the lunar surface.

HUMAN LANDING SYSTEMS - SUSTAINING CAPABILITY

NASA has also awarded a contract (NextSTEP-2 Appendix H Option B) to SpaceX to further develop its Starship HLS for the Artemis IV mission to meet an extended set of requirements, such as docking with Gateway for crew transfer and landing more mass on the lunar surface. Concurrently, NASA has awarded a contract (NextSTEP-2 Appendix P) to Blue Origin and its partners to develop its Blue Moon lander to meet the same set of extended requirements for use during the Artemis V mission. Blue Origin will also perform an uncrewed demonstration mission prior to the crewed Artemis V mission.

Program Schedule

Date	Significant Event
2025	Uncrewed HLS demonstration to the lunar surface with SpaceX Starship
Sep 2026	Artemis III: Crewed HLS demonstration to the lunar surface with SpaceX Starship
Sep 2028	Artemis IV: Crewed HLS demonstration to the lunar surface with SpaceX Starship that meets extended lander requirements

Program Management & Commitments

Program Element	Provider
HLS Program Management	Lead Center: MSFC Performing Center(s): ARC, GRC, LaRC, GSFC, SSC, JSC, KSC
HLS - Initial Capability	Provider: SpaceX (Artemis III) Lead Center: MSFC Performing Center(s): ARC, GRC, LaRC, GSFC, SSC, JSC, KSC
HLS - Sustaining Capability	Providers: SpaceX (Artemis IV) and Blue Origin (Artemis V) Lead Center: MSFC Performing Center(s): ARC, GRC, LaRC, GSFC, SSC, JSC, KSC
Cargo Landers	Provider: SpaceX and Blue Origin Lead Center: MSFC Performing Center(s): ARC, GRC, LaRC, GSFC, SSC, JSC, KSC

Acquisition Strategy

The HLS program utilizes the NextSTEP Broad Agency Announcement (BAA) contract vehicle. Through this approach, NASA can award firm-fixed-price, milestone-based proposals to enable rapid development of a crewed flight demonstration of the HLS.

MAJOR CONTRACTS/AWARDS

NextSTEP-2 Appendix H BAA Option A: Selected SpaceX of Hawthorne, California firm-fixed price, milestone-based contract total award value is $2.89 billion. SpaceX is developing the Starship – a fully integrated lander that will use the SpaceX Super Heavy rocket.

NextSTEP-2 Appendix H BAA Option B: Selected SpaceX of Hawthorne, California. NASA has awarded SpaceX a $1.15 billion contract to develop an upgraded version of its Starship lunar lander and fly a second crewed mission.

NextSTEP-2 Appendix N BAA: NASA awarded a total of $146 million to five U.S. companies to mature sustainable human landing system concepts, conduct risk-reduction activities, and provide feedback on NASA's requirements to cultivate industry capabilities for enabling a steady pace of crewed trips to the lunar surface under the agency's Artemis return to the Moon. The awardees include SpaceX, Blue Origin, Dynetics, as well as Lockheed Martin and Northrop Grumman.

NextSTEP-2 Appendix P BAA: Selected Blue Origin of Kent, Washington. The total award value of the firm-fixed price contract is $3.4 billion. Blue Origin is developing the Blue Moon lander to meet NASA's sustaining landing development requirement.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
HLS program	Standing Review Board (SRB)	Spring 2022	To evaluate the completeness / consistency of the planning, technical, cost, and schedule baselines developed during formulation; assess compliance of the preliminary design with applicable requirements; and determine if the project is sufficiently mature for HLS program KDP-C	Approved
HLS Initial Capability KDP-C	APMC	Nov 2023	To approve transition from formulation to implementation	Approved

HLS INITIAL CAPABILITY

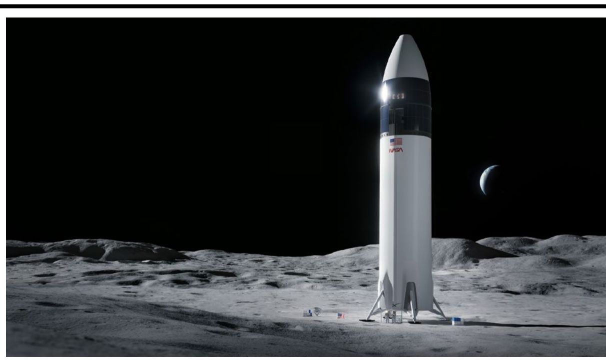
Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	1,860.2	678.9	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	2,539.0
Development/Implementation	0.0	166.3	232.2	**711.0**	600.7	359.3	269.5	0.0	0.0	2,339.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2024 MPAR LCC Estimate	**1,860.2**	**845.2**	**232.2**	**711.0**	**600.7**	**359.3**	**269.5**	**0.0**	**0.0**	**4,878.0**
Total Budget	**1,860.2**	**807.3**	**526.3**	**647.1**	**703.3**	**607.2**	**252.1**	**0.0**	**0.0**	**5,403.5**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Artist's rendering of SpaceX Starship human lander design.

PROJECT PURPOSE

The Human Landing System (HLS) Initial Capability supports Artemis III, the first Artemis lunar landing mission. In April, NASA awarded a contract for the full development of an initial lander capability to SpaceX (NextSTEP-2 Appendix H, Option A).

PROJECT PARAMETERS

The objective of the HLS Initial Capability is to facilitate the rapid development and demonstration of a U.S. landing system that will deliver the first astronaut crew to the surface of the Moon in more than 50 years. The Option A contract scope of work includes both an uncrewed and crewed lunar landing demonstration of the SpaceX Starship human landing system. For all Artemis missions, the agency's Space Launch System rocket will launch four astronauts aboard the Orion spacecraft for their multi-day journey to Lunar orbit. For the Artemis III lunar return mission, two crew members will transfer to the SpaceX Starship for the final leg of their journey to the surface of the Moon. The uncrewed demonstration will prove out landing capabilities prior to the crewed mission with astronauts. During the Artemis III mission, the HLS Starship will first dock with Orion spacecraft in lunar orbit to receive the crew, after which it will safely descend to the lunar surface with two astronauts for approximately a week. During this time, the crew will perform lunar surface extra-vehicular activity, conduct science objectives, and collect materials from the surface. The

HLS INITIAL CAPABILITY

Formulation	Development	Operations

HLS Starship will then ascend from the surface to lunar orbit to return to Orion and their colleagues before heading back to Earth.

ACHIEVEMENTS IN FY 2023

As part of the HLS Starship development activities, SpaceX conducted key design reviews and testing of various systems. SpaceX conducted Starship's first orbital launch attempt in April 2023.

WORK IN PROGRESS IN FY 2024

SpaceX conducted Starship's second orbital launch flight in November of 2023. SpaceX is targeting the third orbital test flight for early calendar year 2024. SpaceX will continue Starship's in-orbit fuel transfer capability development.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

For Artemis III, SpaceX plans to complete several test flights including propellant transfer no earlier than Nov 2024, long duration flight, and uncrewed lunar landing development.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2025 PB Request
KDP-C	Nov 2023	Nov 2023
CDR	Aug 2025	Aug 2025
ORR/FRR	Oct 2027	Oct 2027
LRD/IOC/IC	Feb 2028	Feb 2028

Development Cost and Schedule

The establishment of HLS Initial Capability Agency Baseline Commitments of Feb 2028 for HLS Lunar Orbit Checkout Review (LOCR) in support of Artemis III, represents a risk informed posture that encompass potential issues and not target launch dates. JCL are used to track program performance. NASA continues to manage to a more aggressive schedule than the LRD in the JCL.

HLS INITIAL CAPABILITY

Formulation	**Development**	Operations

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2023	2,338.9	70	2023	2,338.9	0	LOCR	Feb 2028	Feb 2028	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Launch Vehicle/ Services	2,338.9	2,338.9	0

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
HLS Starship	Initial Capability through services contract includes one uncrewed and one crewed human landing demonstrations	Provider: SpaceX Lead Center: MSFC Performing Center(s): ARC, GRC, LaRC, GSFC, SSC, JSC, KSC Cost Share Partner(s):	

HLS INITIAL CAPABILITY

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
In-space cryogenic propellant storage and transfer	Both SpaceX and Blue Origin use long duration storage and transfer of cryogenic propellants within their architectures to meet NASA requirements. Each provider is utilizing a combination of ground and flight tests along with NASA Tipping Point projects to gain understanding of the complexities and reduce the risks associated with cryogenic propellant storage and transfer.

Acquisition Strategy

NASA utilized the NextSTEP Broad Agency Announcement (BAA) contract vehicle with the Appendix H solicitation for the initial landing development. Option A, the firm-fixed-price, milestone-based procurement for flight and landing demonstrations of initial human landing systems was awarded to SpaceX.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Launch Vehicle/Services	SpaceX	California/Texas/Florida

ADVANCED EXPLORATION SYSTEMS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	140.3	--	140.2	123.0	163.1	170.9	171.0

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The CHAPEA mission 1 crew poses with a flag featuring their mission patch surrounded by their signatures (from left to right: Anca Selariu, Nathan Jones, Kelly Haston, Ross Brockwell). The flag will hang outside the habitat for the duration of their mission.

Advanced Exploration Systems (AES) is a portfolio of activities within the Mars Campaign Office (MCO) of the Moon to Mars (M2M) program that develops high-priority technologies and capabilities, which will be infused into prototype systems that will be used in future human spaceflight missions. These technologies and capabilities are developed using a combination of in-house activities and industry collaborations. The AES portfolio matures exploration capabilities and transit solutions to enable deep space missions, including capabilities that enable sustained surface missions on the Moon and Mars.

To enable NASA's Artemis program and eventual crewed missions to Mars, the MCO uses the AES portfolio to invest in the development and demonstration of high-priority technologies and capabilities to reduce risk, lower life cycle cost, and validate operational concepts for future human missions, with an emphasis on filling high priority technology gaps identified by the agency Strategic Capabilities and Leadership Teams (SCLT), Agency Principal Technologists, and the M2M program. The agency identifies and addresses potential risks by performing early validation and ground/flight testing of technologies in the Technology Readiness Level (TRL) three through five range prior to integration into planned operational systems. To evaluate the technologies, capabilities, and systems required for deep space missions, MCO is employing a phased approach in the AES portfolio by testing technologies on Earth, in LEO, in lunar orbit, and on the lunar surface. This approach is intended to accelerate technology development and infusion into operational programs while minimizing cost growth to improve affordability of future space exploration. AES focuses on advancing the technologies that will foster a sustainable presence on the Moon and Mars and enable a lasting presence utilizing reusable systems.

MCO will continue to coordinate with STMD on identifying and addressing knowledge gaps and delivering fundamental capabilities to enable the Moon to Mars Objectives.

EXPLANATION OF MAJOR CHANGES IN FY 2025

Content previously managed in Mars Campaign Development (MCD), has been reallocated between the MCO within the M2M program and the Strategy & Architecture Office (SAO) in ESDMD. All content associated with the Systems Engineering and Integration (SE&I) across ESDMD programs to support requirements development and configuration control of ESDMD level systems engineering and integration documentation, and early M2M Program Element initiation has been transferred to the SAO. The Exploration Capabilities program content was moved under the AES portfolio of activities within MCO and restructured into six Program Elements: Environmental Control and Life Support Systems (ECLSS), Crew Health and Performance (CHP), Earth Independent Operations (EIO), Transportation and Vehicle Systems, Surface Systems and Environments, and Science and Infrastructure, to be more reflective of Artemis mission needs, goals, and objectives, consistent with requirements identified by the M2M programs and the ESDMD SAO.

ACHIEVEMENTS IN FY 2023

In support of NASA's goal of extending human space exploration beyond LEO, AES continued development of reliable life support systems, deep space habitats, and overall capabilities reducing logistics requirements necessary to support sustainable human spaceflight missions and eliminating dependencies on frequent resupply from Earth.

AES continued upgrades to the Urine Processor Assembly (UPA) and Water Processor assembly (WPA) to improve reliability, maintainability, and mass reduction for the exploration ECLSS water revitalization system. The team completed analysis of two returned International Space Station (ISS) Brine Processor Assembly (BPA) bladders to verify the amount of water recovered from brine. By combining this data with data from the UPA and WPA water reclamation systems, the team was able to show that the three systems combined can achieve a 99 percent water recovery rate, meeting the requirements of 98 percent water recovery goal for future Mars transit missions.

On June 25, 2023, Crew Health and Performance Analog (CHAPEA) began their four-person crew, 378-day analog mission. The team reached the 100-day milestone on Oct. 3, 2023. This analog mission will assess crew health and performance during a typical Mars analog mission with prepackaged food and some fresh crops while carrying on typical Mars mission activities such as simulated Extra Vehicular Activities (EVA), controlling drones, doing science, meeting with flight surgeons, with a crew of the same four individuals. The data from the analog could tell us whether fresh crops significantly improve performance and should be designed into Mars vehicles and what type of performance we can expect from crews consuming the prepackaged foods on these missions.

The Ohalo III facility is being designed and built at KSC to fly on ISS in the FY 2026 timeframe to demonstrate plant growth approaches in micro and low gravity. Two grants were awarded through the Research Opportunities in Space Biology to develop plant growth trays that will utilize the Ohalo III facility to demonstrate novel approaches to plant growth in space and provide better nutritional and psychological benefits for crew on long duration missions.

ISS flight demonstrations of advanced CO_2 removal and the environmental monitoring system, as well as ground based advanced ECLSS testing, and development progressed. The Four Bed CO_2 ISS Tech Demonstration was successfully upgraded with new Calnetix blower. The Calnetix blower replaced the legacy obsolete Honeywell blower used in the carbon dioxide removal assembly and put the system within reach of its exploration CO_2 removal performance goal. Improvements planned for FY 2024 are expected to enable the system to fully reach its performance goal. AES Spacecraft Atmosphere Monitor (SAM) Technology Demonstration Unit (TDU)2 with Trace Gas Capability was completed and delivered on August 11, with an anticipated launch date in early FY 2024. SAM2 will be the first instrument capable of measuring the major constituents trace contaminants in the air.

ADVANCED EXPLORATION SYSTEMS

The BioMole Water Microbial testing flight demo launched on August 1, 2023 on NG-19. This technology leverages the MinION DNA sequencer which is already in use on ISS to test surfaces for microbial growth. This flight demo will expand the MinION's capability to the testing of potable water samples. Currently water samples are sent to the ground for analysis; having the capability to conduct microbial testing on orbit will fill an enabling gap for Mars transit. The tech demo usefully completed its first round of testing, demonstrating the on-orbit capability for potable water microbial testing for the first time.

The Spacecraft Fire Safety Project Saffire-VI experiment successfully launched August 1, 2023 on Northrop Grumman (NG)-19. Saffire-VI is the last in the line of Saffire fire safety experiments developed to continue investigating material flammability risks that will be faced by the crew on NASA's long duration exploration missions, especially at reduced pressure and higher oxygen concentrations. This data will be used to validate models of material flammability in zero-g. Spacecraft Fire Safety is working towards Lunar-g demonstrations on Flight Opportunities program sub-orbital flights and Commercial Lunar Payload Services (CLPS) flights for fire safety data in the lunar environment.

The Lunar Combustion Investigation (LUCI) will execute on a Flight Opportunities flight on New Shepard to study flammability in simulated lunar gravity. Fabrication of LUCI hardware was completed, and environmental testing began May 10th. The LUCI payload is expected to launch in summer 2024.

In partnership with ESA, AES continued flight unit build activities of the Enhanced European Exploration Exercise Device (E4D) multi-purpose exercise equipment and its associated vibration isolation system and software. This device is being developed for crew use to maintain physical fitness on long missions. Physical exercise is the most effective way to counteract the adverse effects of microgravity on the human body and is part of the daily routine for astronauts in orbit. E4D will be the first multi-modal exercise device used in space that has a servo motor as its force delivery system. Using electronics to deliver a load onto a human requires extra level of safety and testing. The team completed preliminary testing in accordance with a joint NASA/ESA Safety Review Board.

AES launched four CubeSats on Artemis I: BioSentinel, Near Earth Asteroid (NEA) Scout, Lunar IceCube, and Lunar Infrared Imaging (LunIR) to help answer strategic knowledge gaps associated with the Moon, asteroids, and effects of space radiation on biological systems; and develop capabilities for deep space CubeSats, enabling future missions for academia and industry. The BioSentinel CubeSat has continued in its solar orbit trailing Earth, collecting solar radiation data beyond its initial design life. It has completed mission operations and successfully conducted a communication beacon test and is scheduled for retirement in January 2024. The remaining CubeSats were not operational and project teams concluded mission operations.

The majority of the project Polaris activities have concluded. Polaris began with the selection of 10 proposals for small activities performed by the NASA centers to fill capability gaps and provide hands on experience to early career NASA employees. The teams completed a scale demonstration on Earth of the 50-meter robotic tower assembly. Completed integration with informatics into the heads-up display engine, which is now available for infusion into industry. Testing of the irradiated test displays to look for degradation was completed, and the work has transitioned into the Extravehicular Activity and Human Surface Mobility (EHP) program for additional system development. The Data Planning and Control Tool was completed and infused into the Huntsville Operations Support Center. Laser Processed Heat Exchanger coatings completed and qualified a vender and processes to fabricate silver coated heat exchangers that resist biofilm growth.

ADVANCED EXPLORATION SYSTEMS

WORK IN PROGRESS IN FY 2024

AES will continue development of ground and flight experiments to investigate long duration support for landing humans on the Moon and establishing a sustainable, long-term presence there.

AES will focus on the key critical technologies required to enable Mars missions, using Lunar missions and infrastructure as testbeds. Testing new ECLSS component options and conducting critical demonstrations for autonomous control of integrated ECLSS will continue. SAM2 TDU launched in November and will begin operations on ISS.

Technology such as the Biomole portable water microbial test flight developed to test surfaces for microbial growth on ISS will begin operations for the detection of microbial growth in the potable water.

Development and reliability testing of the ISS Universal Waste Management System (UWMS) toilet will progress in preparation for future exploration missions. The logistics reduction project will demonstrate trash compaction and processing options for make/buy decision in 2024. Space Radiation early detection models will be refined. The team will begin operations, flight data analysis and integration with Space Weather radiation analysis modeling tools for Gateway and HLS radiation shielding requirements.

The Fire Safety team began Saffire VI operations in December 2023 to investigate flammability of materials in microgravity. Four material samples are enclosed in the Saffire-VI chamber launched aboard NG-19 and will be ignited after Cygnus undock. Data and images will be captured and downlinked which will help validate models of flammability that can then be used by programs to assess material selections for spacecraft and suits in various Exploration Atmospheres.

The E4D multi-purpose exercise equipment and its associated vibration isolation system and software developed for crew use to maintain physical fitness on long missions will be delivered July 2024.

CHAPEA will complete its first mission, debrief, and begin preparation for mission 2 (including crew selection, and food production). Ohalo III will continue development of its ISS facility in preparation for launch in FY 2026. The Exploration Medical team will continue development and testing of exploration medical capabilities to support long term crew health needs, e.g., medical systems such as on demand generation of IV fluids and in-flight Exploration Electronic Health Record (xEHR) system on ISS use on long-duration missions and perform radiation testing of pharmaceuticals.

In FY 2024, AES will complete CAPSTONE operations. CAPSTONE is a CubeSat weighing 55 pounds, designed to test innovative navigation technologies in a dynamic halo-shaped orbit in Near Rectilinear Halo Orbit (NRHO) for risk reduction of future spacecraft.

Remaining Polaris activities extended into FY 2024 will sunset. ASTRA will fly as a guest on a commercial satellite scheduled for launch in early 2024. The goal is to mirror fault detection isolation and controls of the spacecraft to ground controllers. Multi-function nano sensors will be testing against KSC's launch leak detection systems to baseline performance against field designed systems. The bioremediation project is targeted to fly to the ISS in late 2024. Spaceflight Autonomous Multigenerational Microbial Gene Sequencer is continuing its efforts and will be completed in March 2024. Radiation Assessment During Exposure and Long Duration Spaceflight (RadReads) continues development and is scheduled to complete bench testing this fiscal year.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

In FY 2025, AES will continue current developments of ground and flight experiments to investigate long duration support for landing humans on the Moon and establishing a sustainable, long-term presence there and it will add key critical technologies identified by the architecture team required to enable Mars missions, using Lunar missions and infrastructure as testbeds.

AES will expand technology development requiring lunar precursors into Communications, Position, Navigation, and Timing, including development of reliable, long-distance, and high-bandwidth surface to surface communications. AES will also add development into dust mitigation, Earth-independent operations, and crew health and performance for years in microgravity.

For Mars-unique technology investments, AES intends to increase activities and partnership opportunities in Earth-Mars transportation systems, including nuclear, chemical, and hybrid systems. Growth areas also include entry, descent, and landing technologies, an optimized EVA suit for Martian environments, and zero-boil off cryogenic storage and transfer.

ISS flight demonstrations for the smaller version of the mini-Total Organic Carbon Analyzer (MiniTOCA), and upgrades to the ISS oxygen generation and CO_2 resource recovery systems are planned for 2025.

On orbit utilization of E4D on ISS is expected to begin in 2025.

Development efforts of Ohalo III in preparation for launch to ISS in FY 2026. Ohalo III will demonstrate a potential Mars Exploration crop growth facility for Transit Hab.

Program Elements

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM (ECLSS)

Habitation Systems delivers the fundamental capability to provide integrated life support systems, environmental and crew health monitoring, radiation forecasting and protection, fire-safety, and systems to manage food, waste, clothing, and tools that enable astronauts to carry out NASA's mission in space and on other worlds. AES focuses on developing key habitation systems to enable the crews to live and work safely in space, with an initial focus on lunar missions, and extensibility to Mars. Activities include life support systems and logistics reduction.

CREW HEALTH AND PERFORMANCE

These activities include development of countermeasures such as exercise equipment to maintain crew fitness on long missions, food systems such as crop production to provide nutritious food for the crew, development of diagnostic sensors for remote medical care, and models of human physiology to predict crew fatigue and injuries when performing EVA.

Experiments to improve spacecraft fire-safety are also under way to better understand how fire spreads and how to recover from fire events in lunar gravity. These investments will progressively move from habitation subsystems to integrated systems and then be infused into deep space exploration elements and system designs.

AES works with the ECLSS-CHP Strategic Capabilities Leadership Team (SCLT) to follow road maps developed within the SCLT that show planned infusion into future exploration systems, such as Surface Habitat and Mars Transit Habitat. The Road Maps show clear paths of development and testing leading to adoption by future missions, aligned with agency program milestones, and contain both funded and unfunded work. These Road Maps assist in prioritization and assessing the impacts of development delays to agency milestones.

EARTH INDEPENDENT OPERATIONS (EIO)

For Mars EIO will deliver technologies to provide capabilities to mitigate risks associated with reduced ground support. The missions to Mars will incur significant round-trip communication delays (as long as 40-70 minutes), lack of resupply opportunities, and no evacuation options. Human rating requirements state that crew and vehicle systems must be able to perform certain critical operations independent of support from the ground. The EIO portfolio will pursue a hybrid approach, combining current large data analytics with traditional rule-based system modeling approaches to provide situational awareness and diagnostics support to crew for time- and safety-critical operations.

EIO will deliver technologies that provide for integrating systems for data, sensing, in-space analytics, diagnostics support, and procedure execution. The developed operational products will use state of the art technologies in artificial intelligence, machine learning, sensor fusion, and data visualization.

Program Schedule

Date (FY)	Significant Event
Under Review	Demonstrate trash compaction and processing options
Dec 2023	Conducted Saffire–VI fire safety experiment
Apr 2024	Ohalo Engineering Unit assembly complete
Jul 2024	Complete CHAPEA Mission 1
Aug 2024	Execute LUCI experiment in simulated lunar gravity on New Shepard
FY 2024	Complete CAPSTONE operations in Near Rectilinear Halo Orbit (NRHO) to demonstrate pathfinder lunar operations for Gateway

Program Management & Commitments

Exploration Systems Development Mission Directorate’s Associate Administrator delegated management authority, responsibility, and accountability to the MCO via the M2M Program at NASA HQ. The MCO establishes overall direction and scope, budget, and resource allocation for activities implemented by the NASA centers.

Program Element	Provider
ECLSS	Provider: NASA Centers Lead Center: HQ Performing Center(s): JSC, MSFC, ARC, GRC, LaRC, KSC, and JPL Cost Share Partner(s): Bigelow Aerospace, Boeing, Lockheed Martin, Orbital ATK, Sierra Nevada, NanoRacks (NextSTEP), Dynetics, and UTC Aerospace Systems (UTAS)

Program Element	Provider
Crew Health & Performance	Provider: NASA Centers Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A
EIO	Provider: NASA Centers Lead Center: Various NASA Centers Performing Center(s): JSC, MSFC, ARC, GRC, KSC, SSC and JPL
Vehicle Systems	TBD
Surface Systems and Environments	TBD
Science and Infrastructure	TBD

Acquisition Strategy

Each year, MCO evaluates how the AES portfolio aligns with human exploration priorities and technology gaps and either terminates or realigns activities that do not demonstrate adequate progress. MCO also adds new activities to the AES portfolio, as appropriate. MCO will continue to utilize this process to identify and evaluate risk-reduction activities needed in support of lunar and future Mars missions. The AES portfolio strives to maximize specialized skills within the civil service workforce, but it may also utilize contractor effort in areas where NASA can leverage external skills and knowledge in a cost-efficient manner. AES will also use the Small Business Innovation Research program to engage small businesses for risk reduction and technology maturation. AES continues the use of competitively selected external awards and industry collaborations. Upgrades to existing ISS life support systems will use existing contracts.

ADVANCED EXPLORATION SYSTEMS

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Habitation Systems (ECLSS): Brine Water Processor	Paragon	Tucson, AZ; MSFC
Habitation Systems (ECLSS): Thermal Amine CO_2 Scrubber	Collins Aerospace	Windsor Locks, CT
Habitation Systems (ECLSS): Oxygen Generation Assembly	Collins Aerospace	Windsor Locks, CT
Habitation Systems (ECLSS): Water Processor Assembly	Collins Aerospace	Windsor Locks, CT
NextSTEP Broad Agency Announcement Awards	Boeing, Bigelow Aerospace, Lockheed Martin, Orbital ATK, and Dynetics	JSC; MSFC; KSC

INDEPENDENT REVIEWS

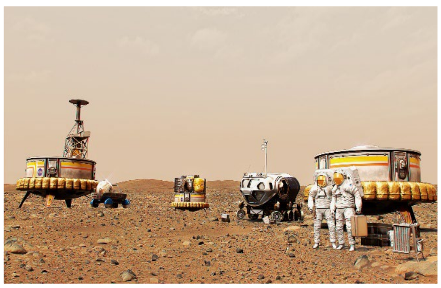
The MCO undergoes quarterly Directorate Program Management Council reviews, annual M2M Control Board status briefing, and periodically, representatives from the Office of Chief Engineer, the Office of Safety and Mission Assurance, and the Office of Chief Financial Officer will assess AES performance during agency-level Baseline Performance Reviews. In addition, the MCO provides briefing reports to, and seeks feedback on planning and development activities from, the NASA Advisory Council's Human Exploration and Operation Committee and Technology Committee on the AES portfolio.

HUMAN EXPLORATION REQUIREMENTS & ARCHITECTURE

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Strategy & Architecture	48.3	--	**71.2**	137.4	64.1	65.5	66.7
Future Systems	52.2	--	**45.9**	126.7	238.8	303.8	788.8
Total Budget	**100.5**	**--**	**117.1**	**264.1**	**303.0**	**369.3**	**855.5**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Shown here is an artist's rendition of astronauts utilizing systems on the surface of Mars.

The overarching goal of the Human Exploration Requirements & Architecture (HERA) theme is to identify the exploration objectives, systems, and infrastructure required for Artemis missions that will inform future missions to Mars. It also works to ensure that lunar exploration systems are extensible to Mars exploration where technically feasible and cost-effective to do so. These program objectives support the National Space Policy of 2020, the Space Priorities Framework of 2021, as well as the agency's Strategic Goal 2, which seeks to extend human presence to the Moon and onto Mars for sustainable long-term exploration, development, and utilization.

HERA manages the architecture strategy activity that supports NASA's Moon to Mars Goals & Objectives and overall architecture requirements and capability identification. HERA conducts an annual Agency Architecture Concept Review to gain concurrence on the current state of architecture planning, driven by Moon to Mars Objectives, which were formally established in September 2022. This program is responsible for the configuration management, definition, and development of the human exploration strategy in support of ESDMD including the integration and support of other mission directorates, centers, and both internal and external stakeholders.

Future Systems leads the pre-formulation of elements identified by the architecture strategy to enable consistent initiation processes. These elements are managed by Future Systems through their initial program or project formulation milestone and then transitioned to implementing programs for development.

EXPLANATION OF MAJOR CHANGES IN FY 2025

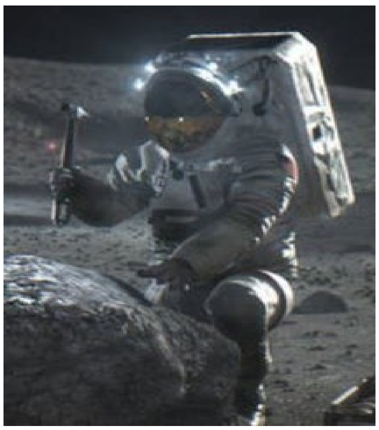
Content previously managed in Strategy & Architecture that is more closely associated with the Systems Engineering and Integration (SE&I) of the Moon to Mars effort have been transferred to that office to better align the support. Functions associated to support requirements development, configuration control of ESDMD level systems engineering and integration documentation, and support to technology projects specific to ESDMD have been transferred to the Advanced Exploration Systems, Mars Capability Office, and SE&I programs.

STRATEGY & ARCHITECTURE

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**48.3**	**--**	**71.2**	**137.4**	**64.1**	**65.5**	**66.7**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Strategy & Architecture will collaborate with programs across NASA to design the roadmap for future long-term human exploration.

The Strategy & Architecture program is responsible for the integration of the Moon to Mars architecture and the human spaceflight exploration strategy across ESDMD. Strategy & Architecture is responsible for defining the agency's approach for lunar and Mars exploration. This includes the integration across many key components of human space such as transportation, habitats, robotics and mobility, and landing. This program is responsible for maintaining the configuration control and management of the overall baseline exploration architecture for the agency and the engagement and integration with other mission directorates, international partners, and external stakeholders among others in service of that effort. In the near term, Strategy & Architecture is conducting trade studies to reduce risk and identify required technologies to be utilized as part of the Artemis Campaign and act as precursor systems for potential future Mars missions.

Strategy & Architecture also maintains the science, technology, utilization, and integration required to support ESDMD in Artemis missions and future exploration planning, which includes the following activities:

- Capability integration for planning and gap analyses of capabilities required for future exploration missions; and
- Science and technology utilization for coordination and planning for future exploration missions.

The Strategy & Architecture team also oversees the agency's habitation strategy using the Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement (BAA) process, a public-private partnership model seeking commercial development of deep space exploration capabilities to support human spaceflight missions. The multiple phases of NextSTEP are informing NASA's notional future deep space, long duration habitation capability.

EXPLANATION OF MAJOR CHANGES IN FY 2025

Content previously managed in Strategy & Architecture more closely associated with the Systems Engineering and Integration (SE&I) of the Moon to Mars effort have been transferred to better align the support. Functions associated to support requirements development and configuration control of ESDMD level systems engineering and integration documentation, and support to technology projects specific to ESDMD have been transferred to the Advanced Exploration Systems, Mars Capability Office, and SE&I programs.

STRATEGY & ARCHITECTURE

ACHIEVEMENTS IN FY 2023

The inaugural Architecture Concept Review was held in January 2023, with the purpose of helping unify the agency, promote advocacy for the architecture, and generate inputs from across NASA. It focused on the initial capabilities, systems, and operations necessary to re-establish human presence on and around the Moon by synchronizing the Moon and Mars architecture, documenting the functional needs of the architecture, and in some cases, identifying gaps in current system capabilities necessary to accomplish the functional needs. This effort resulted in the publication of the Architecture Definition Document and supporting material to communicate the agency strategy across the multitude of stakeholders.

The Architecture Concept Review process and results were published in April 2023.

A Strategic Analysis Cycle (SAC) was also conducted in FY 2023 with the goal of prioritizing the work and studies, coordinate with industry and international partners, and identify and resolve gaps in the architecture to achieve progress.

NASA led architecture workshops in June and August 2023 in which the agency invited international space agencies, U.S. companies, academic institutions, and other government agencies to review and provide feedback on the agency's Moon to Mars architecture approach. This feedback was considered and addressed in preparation for the update and revision of the agency architecture approach and in support of the 2023 Architecture Concept Review.

WORK IN PROGRESS IN FY 2024

The Strategy & Architecture program will continue developing the detailed, integrated systems design studies needed to prepare for a human mission to Mars. Through a rigorous systems engineering focused process, Strategy & Architecture will identify potential lunar surface systems, operations, and technologies that will help NASA and industry identify a commercial logistics capability path to support future lunar surface activities. In addition, extensions of NextSTEP Appendix A are informing NASA’s conceptual future deep space, long-duration habitation capability.

In November 2023, the annual Architecture Concept Review will provide an updated Moon and Mars architecture with the goal of documenting additional details for missions, including elements provided by international partners and industry providers by focusing on the initial capabilities, systems, and operations to establish human presence on Mars and continued exploration. The program will also continue to address trade studies, analysis, and assessments to support the definition of Mars driving decisions, architectural alternatives, and strive to inform the agency technology and development processes to ensure efficiency and prioritization of efforts.

Program efforts will determine the concepts and potential solutions that will best support accomplishing the Moon to Mars objectives and initiate activities for pre-formulation as opportunities allow. Element initiation will occur when achievable solutions are identified to address the needs of the exploration enterprise. In addition, the effort will conduct risk-reduction studies to identify required lunar surface technologies to be utilized on the lunar surface and act as precursor systems for potential future missions.

STRATEGY & ARCHITECTURE

KEY ACHIEVEMENTS PLANNED FOR FY 2025

Strategy & Architecture will conduct risk reduction activities to identify risks, capability gaps, and requirements to ensure mission success across NASA.

The yearly Architecture Concept Review will provide an updated Moon and Mars architecture with increasing definition and evolution as formulation and acquisition activities occur. The process will ensure continuity in the architecture evolution and incorporation of new technologies, opportunities and best practices as systems develop and progress.

Program Schedule

No formal commitment dates.

Program Management & Commitments

ESDMD manages the Strategy & Architecture activities.

Acquisition Strategy

None.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

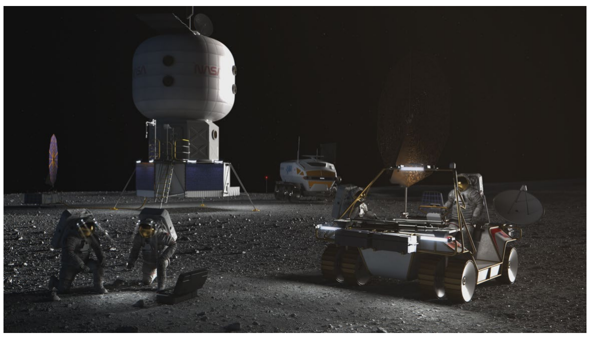
To be determined.

FUTURE SYSTEMS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**52.2**	**--**	**45.9**	**126.7**	**238.8**	**303.8**	**788.8**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Shown here is an artist rendition of future systems including the Foundation Surface Habitat to enable long duration stays on the lunar surface.

The Future Systems program manages and integrates the systems that NASA will use throughout the Artemis Campaign to access and explore the surface of the Moon.

Future Systems formulates the systems necessary to achieve the Moon to Mars Objectives as identified through architectural analysis. These systems, including transportation, habitation, or other supporting infrastructure, will provide capabilities to enable future Artemis missions and exercise analog capabilities to prepare for future Mars missions. Future Systems will utilize initial studies and pre-formulation activities to establish initial element system requirements. As these technologies and systems mature, they will be the building blocks for the capability to extend stays on or around the Moon. Future Systems is responsible for the pre-formulation phases of elements to support the Moon to Mars Architecture through integration of mission concepts, identification of key driving requirements, and analysis of alternatives to enable consistent project or program definition for ESDMD. Once they enter into the formulation phase of the project development lifecycle, management of new systems will be transferred to the Moon to Mars Program Office.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

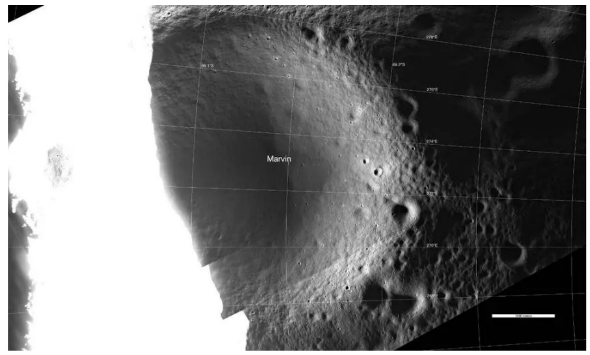
ACHIEVEMENTS IN FY 2023

The Strategy & Architecture Office initiated studies to provide context for how near-term lunar activities will inform future missions to Mars. The office successfully conducted the Element Initiation review for both an initial surface habitation capability and small-scale partner-provided lunar surface cargo lander. These elements were derived from the needs articulated in the Moon to Mars Architecture Definition Document, with potential to support the Artemis missions through further definition and formulation.

Through a partnership with the Korea Aerospace Research Institute (KARI), the ShadowCam flight instrument launched on the Korea Pathfinder Lunar Orbiter (KPLO), also known as Danuri, in 2022. By collecting high-resolution images of the Moon's permanently shadowed regions, ShadowCam will provide critical information about the distribution and accessibility of water ice and other volatiles at spatial scales required to mitigate risks and maximize the results of future exploration activities. NASA provided ShadowCam with Deep Space Network lunar navigation and trajectory assistance. Since Danuri entered lunar orbit in December 2022, ShadowCam has been routinely capturing images of the lunar North and South Pole regions with standout images in unprecedented detail.

WORK IN PROGRESS IN FY 2024

Future Systems will continue formulation of key elements required for sustainability. Efforts will focus on definition and project integration leading to Mission Concept Reviews and element definition to support transition to the Moon to Mars Program or appropriate parties for implementation in addition to completion of the initial project milestones for an initial lunar surface habitation element and partner provided small lunar surface cargo lander.



The image above shows the broader area surrounding the Marvin crater, which is about 16 miles (26 kilometers) from the South Pole.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

Future Systems will continue conducting risk-reduction activities to further develop key elements of the Artemis plan for the lunar missions, as well as continue to leverage commercial and international interest. As element definition is completed, Future Systems efforts will transition to the next highest priorities as defined by the Strategy & Architecture office and approved by the Associate Administrator for ESDMD for development. Potential activities include enabling systems and capabilities necessary to achieve the Moon to Mars objectives and expand the capabilities in the Artemis program for exploration.

Program Elements

PROGRAM INTEGRATION AND SUPPORT

The Program Integration and Support activities manage the program interfaces between ESDMD. This effort is critical to ensuring the performance meets technical and safety specifications and supports the programmatic assessments key to achieving integrated technical, cost, and schedule management. In addition, the integration effort is vital to managing interfaces with other ESDMD and SOMD activities, including strategic studies, feasibility studies, and small-scale research tasks that feed into future human exploration. Coordination and timely integration across ESDMD and SOMD are critical and aimed at mitigating the impacts of potential design overlaps, schedule disconnects and delays, and cost overruns.

FUTURE SYSTEMS

The Future Systems effort conducts activities that will lead directly to the development of capabilities based on the needs articulated in the Moon to Mars Architecture Definition Document, as well as other systems required for NASA to continue to advance human exploration. The effort leverages the ESDMD Strategy & Architecture Office to coordinate, integrate, and manage the pre-project development and

FUTURE SYSTEMS

formulation in conjunction with cross-directorate teams from the Moon to Mars Program Office and relevant programs and project support. The effort includes integration and support from other NASA mission directorates and NASA center personnel as to ensure the efforts are effective and the resulting element formulation achieves agency needs.

Program Schedule

By definition, all systems managed by Future Systems are in pre-formulation and therefore their schedules have not been defined.

Program Management & Commitments

ESDMD manages the Future Systems activities.

Program Element	Provider
Future Systems	Provider: NASA Centers Lead Center: HQ Performing Center(s): MSFC, JSC, JPL, KSC, ARC, GRC, LaRC, GSFC Cost Share Partner(s): N/A

Acquisition Strategy

No acquisition planned for this program.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None.

SPACE OPERATIONS

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
International Space Station	1,286.2	--	**1,269.6**	1,267.8	1,262.8	1,259.4	1,259.4
Space Transportation	1,759.6	--	**1,862.1**	1,876.2	1,840.9	1,895.7	1,804.1
Space and Flight Support (SFS)	983.4	--	**1,088.4**	1,051.3	1,048.7	1,059.0	1,080.2
Commercial LEO Development	224.3	--	**169.6**	302.3	435.2	465.2	629.3
Exploration Operations	13.2	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**4,266.7**	**4,250.0**	**4,389.7**	**4,497.6**	**4,587.6**	**4,679.4**	**4,773.0**

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

SPACE OPERATIONS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
International Space Station	1,286.2	--	**1,269.6**	1,267.8	1,262.8	1,259.4	1,259.4
Space Transportation	1,759.6	--	**1,862.1**	1,876.2	1,840.9	1,895.7	1,804.1
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Commercial LEO Development	224.3	--	**169.6**	302.3	435.2	465.2	629.3
Exploration Operations	13.2	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**4,266.7**	**4,250.0**	**4,389.7**	**4,497.6**	**4,587.6**	**4,679.4**	**4,773.0**

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The Space Operations account is dedicated to sustained human presence in LEO, enabling future exploration and advanced operations in our solar system, and advancing scientific discoveries that benefit life on Earth. In the near term, this includes support of ISS operations and research, while laying the foundation for America to develop and maintain a commercial economy in LEO. This budget request continues to prepare for a smooth transition in 2030 from ISS operations to new LEO destinations that are commercially owned and operated and to safely deorbit the ISS.

NASA astronauts, Loral O'Hara (left) and Jasmin Moghbeli (right), pose for a portrait while installing helmet lights on spacesuits and checking the functionality of their spacesuit's components - (October 27, 2023).

Space Operations is comprised of four themes:

- ISS;
- Space Transportation;
- Space and Flight Support; and
- Commercial LEO Development.

Collectively, these themes are developing and operating American-led space infrastructure enabled by a commercial market, enhancing space access and services to both government and commercial entities, and researching and developing capabilities to safeguard astronaut explorers. These activities, which support existing and future space operations for both NASA and non-NASA missions, are catalysts for economic development and lay the groundwork for a commercial future in LEO in which NASA is one of many customers for commercial services. Additionally, these activities continue to return medical and environmental benefits to humanity, advance scientific knowledge, and foster new technologies that improve American lives.

SPACE OPERATIONS

ISS continues to demonstrate American leadership in global space exploration, enabling a U.S.-led multinational partnership to advance shared goals in space. As a testbed for deep space exploration, ISS is helping us learn how to keep astronauts healthy during long-duration space travel and demonstrating technologies for human and robotic exploration beyond LEO, to the Moon, and to Mars. The ISS:

- Promotes commerce in space as new commercialization concepts are explored and stimulates non-NASA demand to support development of commercial destinations under the Commercial LEO Development Program;
- Enables scientists to identify and quantify risks to human health and performance, develop countermeasures, and develop and test technologies that protect astronauts during extended human space exploration;
- Supports NASA research and development in the areas of biological and physical science, as well as Earth and space science missions;
- Conducts research to benefit humanity through the ISS National Lab;
- Continues American leadership in LEO in the face of increased human spaceflight activity by foreign competitors; and
- Maintains the ISS international partnership that has brought together astronauts and scientists from dozens of spacefaring nations in peaceful and cooperative activity.

Space Transportation's objective is to transport U.S. Orbital Segment (USOS) astronauts and cargo safely to and from space, including the ISS. Working with industry to develop and provide human transportation services to and from space lays the foundation for more affordable and sustainable future human space transportation. These commercial partnerships bolster American leadership in space, have ended sole reliance on foreign providers for crew transportation services, help stimulate the American aerospace industry, and allow NASA to focus on building the capabilities and expertise necessary for missions to the Moon and Mars. This theme includes the Commercial Crew Program (CCP) and Crew and Cargo Program, which includes the ISS U.S. Deorbit Vehicle (USDV).

- The CCP partners with the U.S. commercial sector to develop and operate safe, reliable, and affordable crew transportation systems capable of carrying humans to and from the ISS and other LEO destinations. Working with industry to develop and provide human transportation services to and from space lays the foundation for more affordable and sustainable future human space transportation.

- The Crew and Cargo Program manages transportation services provided by both international partners and domestic commercial providers. Through the program, NASA has greatly strengthened U.S. competitiveness by awarding ISS cargo resupply contracts to multiple vendors, as well as continuing to advance commercial spaceflight and support American jobs. The Crew and Cargo Program also includes funding for the ISS USDV that will be competitively awarded to U.S. industry.

The Space and Flight Support Theme (SFS) continues to provide mission critical space communication and navigation services, launch and test services, and astronaut training to support its customer missions. The theme is comprised of the Space Communications and Navigation (SCaN) Program, Communications Services Program, Launch Services Program, Rocket Propulsion Test Program, Human Space Flight Operations Program, and Human Research Program.

- The SCaN Program provides communication to missions in LEO, including ISS, suborbital missions, and some lunar orbital missions, utilizing the Near Space Network. The Deep Space Network communicates with missions most distant from Earth and will initially provide primary communication links to early Artemis missions. SCaN is planning for expanded services for missions to the Moon, including lunar relay capability for missions that cannot communicate directly with Earth and enhanced position, navigation, and timing services that are less dependent on tracking stations on Earth.

- The Communications Services Program focuses on demonstrating the feasibility of using commercially provided satellite communications (SATCOM) services to support NASA missions near Earth.
- The Launch Services Program provides expertise and active launch mission management for more than 70 NASA and other government missions in various stages of development.
- The Rocket Propulsion Test Program manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions.
- The Human Space Flight Operations Program provides the training and readiness to ensure crew health and safety and mission success.
- The Human Research Program improves astronauts' ability to collect data, solve problems, respond to emergencies, and remain healthy during and after extended space travel.

NASA's Commercial LEO Development effort focuses on the development of a robust commercial space economy in LEO. It is stimulating development of commercially owned and operated LEO destinations from which NASA can purchase services to meet enduring LEO human spaceflight and research requirements. The program:

- Ensures NASA can meet its needs in LEO as it transitions in 2030 from ISS operations to new LEO destinations that are commercially owned and operated. NASA’s future requirements that will persist beyond the lifetime of the ISS include crew accommodation and training, human research, physical and biological research, technology demonstration and science, and a National Laboratory;
- Prepares for a sustained human presence in LEO and U.S. leadership in LEO after the ISS;
- Ensures the capability to maintain an American presence in LEO;
- Drives down costs through LEO commercialization so NASA can free up resources to be used for future human space operations and exploration; and
- Utilizes inventive, non-traditional agreements for acquiring commercial space goods and services to meet NASA requirements.

The Budget funds ISS operations and research, a vehicle to safely de-orbit ISS after it is retired in 2030, and commercial space stations that NASA will use as soon as they become available. The Budget gradually reduces research and other activities on board the ISS in the outyears, beginning in FY 2026, to provide the funding necessary for USDV development and Commercial LEO Development efforts. As a result of this budget re-balancing, an assessment will be carried out to determine the full trade space of potential changes needed to meet outyear funding levels; such options should include discussion of reducing the number of science payloads/investigations to ISS and/or decreasing the number of astronauts on board the USOS, among other options.

For more information, visit: https://www.nasa.gov/directorates/space-operations-mission-directorate

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

INTERNATIONAL SPACE STATION PROGRAM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
ISS Systems Operations and Maintenance	1,034.4	--	**1,008.5**	1,008.5	1,003.5	1,000.0	1,000.0
ISS Research	251.8	--	**261.1**	259.3	259.3	259.4	259.4
Total Budget	**1,286.2**	**--**	**1,269.6**	**1,267.8**	**1,262.8**	**1,259.4**	**1,259.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

NASA astronaut Loral O'Hara is shown here performing a spacewalk to replace a trundle bearing assembly, which allows the solar arrays to track the Sun and generate electricity (November 1, 2023).

The ISS is the largest and most complex space-based research facility ever constructed. The ISS enables distinct research opportunities, including research supporting the Artemis human lunar exploration missions and future Mars human exploration programs. Returns from the investment in ISS are not limited to scientific discovery and technology advancement. The ISS international partnership is composed of five space agencies representing 15 nations, led by the United States. NASA's international partners include the Canadian, European, Japanese, and Russian space agencies. Engineers, scientists, and managers from around the world have directed their resources for the peaceful use of space and are now reaping the benefits to humanity. ISS provides a high visibility opportunity for American leadership in LEO.

ISS orbits the Earth about every 90 minutes and has been continuously occupied since 2000. November 3, 2023, marked the 23rd anniversary of continous human occupation aboard the ISS. The ISS spans the area of a U.S. football field (with end zones) and weighs approximately 925,335 pounds (419,725 kilograms). Its solar arrays, which help power the vehicle, are longer than a Boeing 777's wingspan at 240 feet. The ISS has eight docking and berthing ports for visiting vehicles delivering crew and cargo. Orbiting Earth 16 times per day at a speed of 17,500 miles per hour, the ISS maintains an altitude range of 230 to 286 miles. The complex has more livable room than a conventional five-bedroom house, with two bathrooms, fitness equipment, a 360-degree bay window, and state-of-the-art scientific research facilities. The U.S. Orbital Segment (USOS) is the portion of the ISS operated by the United States and its Canadian, European, and Japanese partners. Russia exclusively operates the Russian segment. In addition to external test beds, the USOS houses three major science laboratories: the United States Destiny, European Columbus, and Japanese Kibo. NASA's current crew size on the USOS averages four astronauts.

This budget request funds the civil service and contractor staff, as well as the facilities and equipment, required to support U.S. obligations for the USOS and enable vehicle operations and research in the harsh conditions of space with constant, around-the-clock support. The requested funding enables four major focus areas of activity for the ISS Program, including: (1) serving as a key steppingstone on the pathway to deep space exploration; (2) maintaining U.S. global leadership of space exploration; (3) enabling the development and advancement of a commercial marketplace in LEO; and (4) returning benefits to humanity on Earth through space-based research; technology development; and Science, Technology, Engineering, and Mathematics (STEM) education for students of all ages.

The ISS plays an essential role in facilitating the expanding sphere of human space exploration from LEO to the Moon (via the Artemis and eventually Mars missions). The ISS is currently the only microgravity platform capable of long-term testing of new life support and crew health systems, advanced habitation modules and other technologies needed to expand NASA's exploration horizons. This research and development program will continue to focus on capabilities needed to maintain a healthy and productive crew in deep space, including the Gateway and future missions to the Moon and Mars. Manifested or planned experiments and demonstrations include tests of improved long-duration life support technologies, advanced fire safety equipment, on-board environmental monitors, techniques to improve logistics efficiency, in-space additive manufacturing, advanced exercise and medical equipment, radiation monitoring and shielding, human-robotic operations, and autonomous crew operations.

NASA will maintain research and technology efforts in LEO using the ISS to enable exploration with humans to the Moon and Mars, while continuing to perform research that benefits humanity and leads to a robust ecosystem in LEO.

NASA is working to implement a stepwise transition of ISS from the current model of NASA sponsorship and direct NASA funding to a model where NASA is one of many customers purchasing services from a LEO human spaceflight enterprise via the Commercial LEO Development Program. NASA will transition from current ISS operations to this new model when the commercial platforms and services become available. Following the completion of ISS operations in 2030, the ISS will be safely de-orbited via a controlled reentry into an unpopulated region of the Pacific Ocean. The Crew and Cargo Program is developing this de-orbit capability (the U.S. Deorbit Vehicle or USDV) with U.S. industry through a competitive procurement.

The ISS Program aims to provide direct research benefits to the public through its operations, research, and technology development activities. As a National Laboratory, the USOS allocates 50 percent of the U.S. portion of resources to enable other U.S. government agencies, academia, and industry to utilize its unique environment and advanced facilities to perform investigations. Observing from and experimenting aboard ISS provides the opportunity to learn about Earth, life, and the solar system from a very different perspective. The ISS serves as an innovation laboratory for experiments that cannot be accomplished on Earth. Earth observation instruments on ISS expand our Nation's understanding of the climate and carbon cycle. It also allows other NASA mission directorates to conduct research and demonstrate technologies. This includes technology demonstrations sponsored by STMD and Biological and Physical Sciences, and Earth Science research funded by SMD. The results of the research completed on ISS can be applied to many areas of science, improving life on Earth.

NASA and its partners also use this unique asset to advance STEM education efforts to inspire youth to pursue those fields. Over 10 million U.S. students have designed, launched, operated, or used data from more than 800 student experiments launched to ISS, including a 30 percent representation from underserved communities. ISS inspires future generations and helps foster greater interest in STEM careers.

The Budget gradually reduces research and other activities on board the ISS in the outyears, beginning in FY 2026, to provide the funding necessary for USDV development and Commercial LEO Development efforts. As a result of this budget re-balancing, an assessment will be carried out to determine the full trade space of potential changes needed to meet outyear funding levels; such options should include discussion of reducing the number of science payloads/investigations to ISS and/or decreasing the number of astronauts on board the USOS, among other options

For more on the ISS Program, visit: https://www.nasa.gov/mission_pages/station/main/index.html

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	1,034.4	--	1,008.5	1,008.5	1,003.5	1,000.0	1,000.0

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

NASA astronaut Stephen Bowen replaces charcoal filters in the Destiny laboratory module as part of life support maintenance (Aug 8,2023)

The ISS is a complex research facility and human outpost in LEO developed in a collaborative, multinational effort led by the United States with partners in Canada, Europe, Japan, and Russia. It is supported by the commercial industry via the Crew and Cargo Program and Commercial Crew Program (CCP). The ISS Systems Operations and Maintenance (O&M) project funds civil service and contractor labor, as well as facilities and equipment necessary to enable vehicle operations in the harsh conditions of space with constant, around-the-clock support. The ISS systems operate in extreme temperatures, pressures, and energies that challenge engineering techniques with minimal margin for error. The risks associated with operating the ISS are significant and must be effectively managed to protect against catastrophic consequences to mission success and human life. Successful risk mitigation activities on ISS in LEO pave the way for more successful Artemis and Mars missions.

Safely operating the ISS in the severe conditions of space and ensuring the crew always have a sufficient supply of food, water, oxygen, and repair parts demands precise planning and logistics. The 463-ton vehicle requires routine maintenance and is subject to unexpected mechanical failures, given its highly complicated systems and the harshness of space. Resolving problems can be challenging and often requires the crew to make repairs in space with support from ground teams on Earth. Astronauts aboard the ISS must rely on the materials available to them on board. This requires the support team on Earth to monitor and meticulously plan for replacement parts and consumables, such as filters and gases, as well as Orbital Replacement Units (ORUs) like the Inlet De-ionizing Bed, Microbial Check Valves, and Multi-Filtration Beds, which are key components of the Regenerative Environmental Control Life Support System (Regen ECLSS). The coordination and support necessary for the ISS crew to live and work comfortably in space requires intensive Earth-based mission operations. Ground teams continually monitor ISS performance, provide necessary vehicle commands, and communicate with the crew.

Even before the astronauts leave Earth, the ISS Systems O&M project, in conjunction with the Human Space Flight Operations Program, provides the crew training to prepare them for their stay aboard the ISS. One example includes operating the Neutral Buoyancy Laboratory, an indoor underwater training facility, where astronauts, in a safe environment, can simulate specific extravehicular activities (EVAs) to repair, replace, or install new instruments and operational systems. During training exercises, neutral-buoyancy diving is used to simulate the weightlessness of space operations.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

The ISS Program considers all aspects of the mission when developing operations plans to meet program objectives. These include scheduling crew activities, choreographing docking and undocking of visiting crew and supply ships, evaluating supplies of consumables, managing flight plan variability, and resolving stowage issues. The ISS Systems O&M project is responsible for keeping ISS operational and available to perform its research mission.

A critical component of the ISS Systems O&M project is immediate emergency services and analyses conducted by mission control teams on Earth, known as vehicle and program anomaly resolution. Engineers and operators diagnose system failures and develop solutions, while program specialists respond to changing program needs and priorities through re-planning efforts. These teams ensure appropriate redundancy, training, and procedures are in place to respond to any type of failure at any time. The project requires sparing and repairing nine highly complex on-orbit systems made up of hundreds of unique ORUs. Additionally, software sustainment manages and executes millions of lines of flight code to support operation and control of the ISS.

Because the ISS is an international partnership, program decisions are not made in isolation. Rather, they require coordination with multiple countries to ensure all technical, schedule, and resource supply considerations and commitments are taken into account. The experience NASA is gaining through integration with its ISS partners is helping the agency better prepare for future missions in human space exploration, such as on the Gateway or the lunar surface.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

The ISS Systems O&M project continued to maintain resources both on-orbit and on the ground to operate and utilize the ISS. The ISS Systems O&M project funded Mission Control Center (MCC) operations, monitoring the safety of crew and integrity of ISS 24/7. This is required to maintain success in providing all necessary resources, including power, data, crew time, logistics, and accommodations, to support research while operating safely with a typical crew of seven astronauts, four USOS crew and three Russian crew.

The ISS Systems O&M project supported the arrival and departure of 19 flights, including domestic commercial and international crew and cargo missions to the ISS. This resulted in supporting over one flight per month. Each flight required extensive planning and analyses to support on-orbit operations, as well as launching, docking, undocking, berthing, unberthing, deorbiting, packing, manifesting, hardware processing, and on-orbit configuration.

NASA ground teams continued to monitor overall vehicle health and oversee general maintenance and performance of all the ISS vehicle systems, including command and data handling, communication and tracking, crew health care, environmental control and life support, electrical power, EVAs, robotics, flight crew equipment, propulsion, structures and mechanisms, thermal control, guidance, navigation, and control. These individual teams worked together to support the crew in quick resolution of several unexpected anomalies, including continued support to identify and mitigate a small ISS atmosphere leak in the transfer tunnel of the Zvezda module, which launched to space in 2000 and forms part of the Russian region of the ISS. Zvezda supports the ISS's life support systems (which have some backup in the U.S. orbital side of the ISS) and contains living quarters for two cosmonauts. The leak has been reduced by patching identified small cracks. Both Roscosmos and USOS continue to monitor the air pressure, search for root cause, and ensure that the ISS is supplied with sufficient consumables.

In FY 2023, the team supported launch and installation of four ISS Roll Out Solar Arrays (iROSAs). The combination of the eight original arrays and the smaller, more efficient, new iROSA arrays will provide a 20 to 30 percent increase in power for space station research and operations. This upgrade ensures the ISS will be able to support the anticipated power demand of future utilization and commercialization activities, while preserving for the expected increase in research and exploration technology demonstrations for Artemis and beyond.

In FY 2023, the Systems O&M project successfully integrated the second private astronaut mission (PAM), Axiom Mission-2 (Ax-2). The integration of the second PAM mission occurred in approximately 10 months, which was enabled by the NASA, Axiom, SpaceX, and International Partner teams who have put in the hard work in support of NASA's vision to commercialize LEO. Ax-2 completed 21 ISS National Lab sponsored and one NASA-Human Research Program sponsored investigations, including an ambitious Life Sciences Glovebox (LSG) plan with over 65 hours of LSG use by Ax-2 and USOS crew.

Within the ECLSS category, the ISS Systems O&M project procured essential consumables and spares for the Waste and Hygiene Compartment (WHC) to meet demand through FY 2026. The Regen ECLSS and the Brine Processor Assembly successfully demonstrated 98 percent water recovery on ISS. Water recovery in LEO is vital, as reuse diminishes the need for resupply via cargo launches.

The ISS Systems O&M project began working on the software changes necessary to incorporate the new encryption hardware to ensure secure communications to the ISS. Software changes to support the Axiom Commercial Space Station began in 2023. Overall, the software and avionics team supported over 450 integrated test shifts, which supported 350 software transitions, 50 visiting vehicle flights, and the remaining supported Mission Control upgrades, multiple payloads, and technology demonstrations.

WORK IN PROGRESS IN FY 2024

Throughout the year, NASA ground teams will continue to monitor overall vehicle health and oversee general maintenance and performance of all the ISS vehicle systems. The ISS Systems O&M project will continue to manage resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. The ISS Systems O&M project is expected to support at least two U.S. Commercial Crew post-certification missions; the first crewed test flight of Boeing's Starliner spacecraft; and the third PAM, Axiom Mission 3. In addition to the U.S Commercial Crew flights, the ISS System O&M project is planning six U.S. Commercial Resupply Services cargo flights, including the first Sierra Space Dream Chaser cargo flight, the first Japanese cargo flight on the new H-II Transfer Vehicle (HTV)-X vehicle, four Progress flights, and two crewed Soyuz flights.

The ISS Systems O&M project will deliver critical spares and consumables, including: the Anomaly Gas Analyzer for use during an emergency response for fire or ammonia, Oxygen Gas Assembly with quick disconnect for improved shelf life, and launch and installation of the improved Cycle Ergometer with Vibration Isolation & Stabilization, enabling cycling activities via leg or arm ergometry in order to provide aerobic exercise as a countermeasure to cardiovascular deconditioning. In addition to hardware deliverables, the ISS Systems O&M project is working to complete the FGB life extension through 2030 and complete U.S. Airlock modifications necessary to support Exploration EVAs demonstration and operations. The ISS System O&M project is making significant progress toward the launch and installation of the seventh and eighth iROSA wings.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

ISS continues to develop and install software vital to its on-orbit safety and day-to-day operations. The team will transition and install the Forward Link project on ISS to update the encryption algorithms. Removal and return of the failed Radio Frequency Group will be completed via an EVA in January. The Space Communication and Navigation Integrated Laser Communications Relay Demonstration Low-Earth Orbit User Modem and Amplifier Terminal (ILLUMA-T) will be installed, which will demonstrate the benefits of laser communications systems and offer missions higher data rates and expedited data transfer. At 1.2 Gigabits per second, ILLUMA-T will send data to NASA's first-ever laser relay and complete NASA's first end-to-end laser communications system. Procurement of a new audio bridge unit will provide connectivity between the legacy ISS audio system and more modern systems supporting commercial activity. Axiom Mission 3 will be integrated and continue its use of PAM-Net, a specific virtual private network devoted to enable PAM investigations and research separate from the ISS-crew.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The Budget funds ISS operations and research, a vehicle to safely de-orbit ISS after it is retired in 2030, and commercial space stations that NASA will use as soon as they become available. The Budget gradually reduces research and other activities on board the ISS in the outyears, beginning in FY 2026, to provide the funding necessary for USDV development and Commercial LEO Development efforts. Reductions are currently bookkept in the Space Transportation theme but will eventually be allocated across ISS Operations & Maintenance, Research, and Transportation as appropriate. As a result of this budget re-balancing, an assessment will be carried out to determine the full trade space of potential changes needed to meet outyear funding levels; such options should include discussion of reducing the number of science payloads/investigations to ISS and/or decreasing the number of astronauts on board the USOS, among other options.

The ISS Program will continue to work closely with CCP and commercial crew providers to ensure any challenges with the initial missions are addressed with minimal impact to ISS operations and research. NASA plans to work with international partners to maintain a continuous ISS crew member capability by coordinating and managing resources, logistics, systems, and operational procedures. The ISS Systems O&M project will continue to manage resource requirements and changes, including vehicle traffic, cargo logistics, stowage, and crew time. In addition to providing anomaly resolution and failure investigation (as needed), they will provide real-time support for activities, such as EVAs and visiting vehicles. The ISS Systems O&M project plans to support the launch of two U.S. crew flights, five U.S. cargo flights, one PAM mission, two Russian crew flights, three Russian cargo flights, and the second HTV-X mission.

The ISS Program protects for four EVAs to install hardware and/or payloads and four EVAs to address external anomalies. Until the cargo vehicle manifests are finalized, specific EVA hardware installations are under review.

ISS SYSTEMS OPERATIONS AND MAINTENANCE

PROJECT SCHEDULE

The table below provides a schedule for FY 2024 and FY 2025 completed and planned EVAs. Only currently planned EVAs are included in the table and additional EVAs will be added as needed. The ISS conducts near-term, real-time assessments of EVA demands, along with other program objectives, to efficiently plan all required ISS activities. NASA remains postured to conduct EVAs on short notice in response to specific contingency scenarios. In addition, the ISS Program balances routine maintenance EVAs against overall astronaut availability to maintain focus on utilization and research.

Date	Significant Event
Oct 2023	Russian EVA
Nov 2023	USOS EVA
Dec 2023	USOS EVA
Apr 2024	Russian EVA
Sep 2024	Two USOS EVAs
Oct 2024	USOS EVA
TBD	USOS EVA

Project Management & Commitments

While NASA maintains the integrator role for the entire ISS, each partner has primary authority for managing and operating the hardware and elements they provide. Within NASA, JSC, located in Houston, TX, leads the project management of the ISS Systems O&M Program.

Acquisition Strategy

The current Boeing vehicle sustaining engineering contract extends through September 2024. ISS is planning for at least a one-year contract extension and is evaluating a follow-on option. Requirements of this contract include sustaining engineering of U.S. on-orbit segment hardware and software, technical integration across all the ISS segments, end-to-end subsystem management for most of the ISS subsystems and specialty engineering disciplines, and U.S. on-orbit segment and integrated system certification of flight readiness.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
U.S. on-orbit segment Sustaining Engineering Contract	The Boeing Company	JSC

ISS SYSTEMS OPERATIONS AND MAINTENANCE

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Other	NASA Aerospace Safety Advisory Panel	Nov 2023	Provides independent assessments of safety with recommendations to the NASA Administrator.	No open recommendations
Other	NASA Advisory Council/	Dec 2023	Provides independent recommendations for the NASA Administrator.	No new recommendations

ISS RESEARCH

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**251.8**	**--**	**261.1**	**259.3**	**259.3**	**259.4**	**259.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The ISS is an orbiting platform that astronauts and researchers use to understand the effects of space on human health and to develop technologies to mitigate those effects that are a barrier to future human exploration missions. The unique microgravity environment enables scientific investigation of physical, chemical, and biological processes in an environment very different from Earth.

NASA Astronaut Frank Rubio, pictured here, uses a glovebag and services the BioFabrication Facility, replacing and installing components inside the research device, which is designed to print organ-like tissues in microgravity and learn how to manufacture whole, fully functioning human organs in space (September 25, 2023).

During the past 23 years, the orbiting platform has evolved into a dynamic laboratory that hosts an increasing variety of government and privately-owned science facilities, external testbeds, and observatory sites. The ISS provides the only current U.S. capability for human-assisted space-based research and is a foundation for efforts to expand commercial use of LEO and to enable a sustained U.S. presence in this region of space.

The ISS Research budget funds support for all research users of the ISS through NASA's multi-user systems support (MUSS) and the ISS National Laboratory.

The ISS National Laboratory has been managing non-NASA utilization of ISS since it was designated by Congress in 2005. The 2010 Authorization Act subsequently required national laboratory managed experiments be guaranteed not less than 50 percent of the U.S. research capacity. Since 2012, more than 700 payloads have flown under the ISS National Lab allocation. For the past three fiscal years, 80 percent of the ISS National Lab payloads launched represent investigations from the private sector, fostering economic growth to fuel a new innovation ecosystem in LEO.

MUSS provides strategic, tactical, and operational support to all ISS research, whether sponsored by NASA, international partners, or the ISS National Lab. Through MUSS, ISS Research supports the execution of the broader portfolio of research and technology development activities on the ISS, funded through other NASA organizations (e.g., SMD, Biological and Physical Sciences [BPS], Human Research Program [HRP], ESDMD, and STMD). ISS external research platforms enable research recommended by the National Academies Decadal Survey and funded by NASA's SMD to provide access to Earth and space vantage points. Research conducted aboard ISS has made fundamental contributions to human knowledge and has advanced scientific goals set by the National Academy of Sciences through a series of Decadal Surveys.

ISS RESEARCH

ISS research also supports development of technologies for potential use in exploration missions, such as Artemis, and longer-duration missions to Mars and beyond. ISS provides a means to demonstrate technology and system readiness for use on a human-occupied exploration vehicle by documenting performance in a spacecraft environment with humans-in-the-loop; piloting operational procedures and training requirements; and determining logistics requirements, safety, and interoperability concerns with respect to overall space systems infrastructure. ISS is host to multiple long-duration flight experiments and projects, which include investigations in water purification, recovery, and utilization; oxygen generation and filtration systems; carbon dioxide filtration systems; crop production; and mitigation of known medical issues, all of which contribute to closing the technology and knowledge gap of future long duration space exploration missions.

ISS Research also contributes to agency efforts to spur economic growth of LEO and to enable a sustained U.S. presence in this region of space. In Space Production Applications awards help companies raise the technological readiness level of their products and move them to market, propelling U.S. industry toward the development of a sustainable, scalable, and profitable non-NASA demand for services and products in LEO. These commercialization awards provide opportunities for NASA to reduce future costs in LEO, enabling deep-space missions farther from Earth, including the Moon and Mars.

NASA's plans for expanding activities in LEO build on and apply the lessons learned from over a decade of work and experience with private companies in ISS research. For example, research facilities onboard ISS continue to evolve from primarily government funded and operated to privately owned and operated. Since 2012, privately owned research facilities have greatly increased access, capability, and use-inspired science return from ISS-supported research. Currently, there are 24 such facilities in operation supporting approximately 60 percent of ISS National Lab-sponsored payloads. In addition, 36 companies provide services as implementation partners, guiding researchers to build and ship flight hardware to be executed on the ISS. These activities validate business models and expand the numbers of entities with experience in conducting business in space.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None

ACHIEVEMENTS IN FY 2023

FY 2023 saw upgraded research facilities come online, new capabilities piloted, an increase in crew hours dedicated to science, and new solar panels added to increase ISS power capacity.

Research facility updates included an upgraded version of Redwire Space's BioFabrication Facility (BFF) to further human tissue printing research and a new facility from BioServe Space Technologies, called the BioServe Centrifuge, that can be used to separate substances of different densities.

FY 2023 also saw an increasingly diverse portfolio of commercial, fundamental science, and technology demonstration investigations conducted. The ISS Research budget supported, either directly or through MUSS integration services, over 400 active investigations across all ISS partners. NASA and the ISS National Lab combined to sponsor more than 250 U.S. research investigations. These totals included 148 payloads for the ISS National Lab.

Examples of fundamental research and technology demonstration research included:

ISS RESEARCH

Studies of Bose-Einstein condensates using one of ISS's newer research facilities, NASA Cold Atom Laboratory (CAL). CAL supports studies that require atom-interferometry measurement capability, a first of its kind in LEO. Atom interferometry can be used to precisely measure a host of phenomena, including gravity, acceleration, rotation, electric fields, magnetic fields, and chemical interactions (see: https://www.jpl.nasa.gov/missions/cold-atom-laboratory-cal).

The National Institutes of Health (NIH) and the NSF continued to fund ISS National Lab-sponsored fundamental research, including two tissue chip studies to improve heart failure disease models and develop new treatments, a project to improve the efficiency of heat pipes (used to prevent electronics overheating), and an investigation to produce superior graphene aerogels (lightweight materials for applications such as improved energy storage in batteries, better oil spill cleanup methods, and next-generation space suits).

Research utilizing the upgraded BFF on board ISS in the fields of tissue engineering and regenerative medicine, resulting in production of a 3D-printed human meniscus construct. Tearing of the meniscus, a cartilaginous structure in the knee, is one of the most common orthopedic injuries, and current treatments can ultimately lead to increased risk of knee replacement or arthritis.

The ISS National Lab continued to drive upward trends for industry involvement in supply, demand, and investment related to its research and development (R&D) portfolio. ISS National Lab R&D-sponsored activities in FY 2023 included projects from industry, startup companies funded in collaboration with Boeing, and research entities.

- Bristol Myers Squibb conducted research to improve the crystallization of biotherapeutic medicines so they can be given as a quick injection rather than a lengthy infusion.
- Biomedical startup RevBio (formerly LaunchPad Medical) built upon a previous project to advance its proprietary, patented Tetranite® bone adhesive that helps bone fractures heal more quickly.
- Public data shows $230.5 million of private capital and grant funding was raised during FY 2023 by startups that have completed a flight project with the ISS National Lab. Since 2014, startups have raised nearly $2.1 billion after completion of their flight projects. These funds were raised from public equity markets, venture/private capital, and public and private grants.

Additional examples of accomplishments in FY 2023, representing both MUSS support and ISS National Lab efforts, include:

- 39 peer-reviewed publications related to ISS National Lab-sponsored research were identified. 24 were related to projects awarded through NSF/CASIS joint solicitations (14 on tissue engineering, and 10 on transport phenomena, combustion, and fluid dynamics); one was related to an NIH-funded tissue chip investigation; four were from rodent research on wound healing, microgravity's effects on the brain, and testing a new osteoporosis drug; four were related to the Materials International Space Station Experiment (MISSE) flight facility investigations testing new spacecraft materials; two were related to spaceflight hardware, one for gene editing and the other for protein crystallization; one was related to Hewlett Packard Enterprise's Spaceborne Computer; two were related to the Alpha Magnetic Spectrometer; and one was related to an archaeological study on the ISS to understand how people adapt to life in space.

ISS RESEARCH

- Five patents related to ISS National Lab-sponsored research were identified: Micro-gRx filed a patent for a tissue chip system to culture and electrically stimulate human skeletal muscle cells, Astrobotic Technology Inc. has a patent pending for a machine-learning algorithm to detect anomalies in machinery by "making sense" of distinctive audio patterns they emit, researchers from UCLA filed a patent for a systemic therapy to treat osteoporosis, adidas has a patent pending for a strategically weighted ball that induces a "spin flip" under high enough rotations, and Cam Med (now Qlibrium™) was granted a patent for an electrochemistry system and method to generate gas bubbles in a microfluidic device for improved drug delivery.

A new product resulted from ISS National Lab-sponsored research: Felix and Paul Studios released the virtual reality series "Space Explorers: Blue Marble" that was created using imagery taken from the ISS.

The ISS National Lab Space Station Explorers community gained three new education partners: Club for the Future (Blue Origin's educational foundation), Limitless Space Institute, and Luminary Labs. In FY 2023, more than 10.4 million individuals participated in ISS National Lab education and outreach programs and projects, and more than 25.8 million people used online ISS National Lab educational products.

For more information, visit: https://www.nasa.gov/mission_pages/station/research/index.html and https://www.issnationallab.org/

WORK IN PROGRESS IN FY 2024

Planned activities will continue to increase the number of commercial research facilities onboard the ISS. Those facilities will be enabling an increasingly diverse portfolio of commercial, academic and other government agency, fundamental science, and technology demonstration investigations. In the first half of FY 2024, 274 investigations are scheduled to be active, 140 of which are NASA and ISS National Lab sponsored and 68 are new.

Highlights of research planned, representing both NASA and the ISS National Lab efforts include:

- ISS National Lab-sponsored research funded by NSF will continue to fly in FY 2024. Beginning in 2016, CASIS partnered with the NSF Engineering Directorate to issue annual research solicitations in fundamental science. This partnership has resulted in eight annual solicitations in the physical sciences topic area of transport phenomena and six annual solicitations in the biomedical topic area of tissue engineering and mechanobiology.
- The University of California, San Diego will launch ISS National Lab-sponsored research to improve understanding of neurological disease by growing brain organoids in space. Microgravity-induced alterations in brain organoids may trigger inflammation that accelerates aging, providing a unique model for neurological disease. This research builds on a previous ISS National Lab-sponsored project to improve disease models for late-onset neurological conditions and could aid in the discovery of new treatments for patients on Earth.
- Biomedical startup LambdaVision will continue ISS National Lab-sponsored research to advance its protein-based artificial retina to restore vision in patients with degenerative eye diseases. This research builds on a previous project that was awarded a grant through the Technology in Space Prize, funded by CASIS and Boeing in partnership with the MassChallenge startup accelerator program.
- The ISS National Lab and NASA continue to partner to advance the key area of in-space production applications by supporting applied research and development that demonstrates space-based

manufacturing and production activities in microgravity. The objective of R&D in this focus area is to use the unique microgravity environment to develop, test, or mature products and processes that have a demonstrated potential to produce positive economic impact in the near term.

- The ISS National Lab is continuing to support commercial research and technology development through private astronaut missions in the new era of privatized utilization of the orbiting laboratory. This support contributes to building a solid customer base for a robust and sustainable LEO economy.
- The SMD sponsored Atmospheric Waves Experiment (AWE) will begin operations in FY 2024 and explore the global distribution of atmospheric gravity waves in the upper atmosphere and how they travel upward and vary with the seasons. AWE investigates how atmospheric gravity waves affect space weather, which can affect both space and ground-based communications, navigation, and tracking systems.
- NASA's Biological and Physical Science Division sponsored Cold Atom Lab, continues operations through FY 2024, allowing scientists to study fundamental behaviors and quantum characteristics of atoms at one ten billionth of a degree above absolute zero.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The Budget funds ISS operations and research, a vehicle to safely de-orbit ISS after it is retired in 2030, and commercial space stations that NASA will use as soon as they become available. The Budget gradually reduces research and other activities on board the ISS in the outyears, beginning in FY 2026, to provide the funding necessary for USDV development and Commercial LEO Development efforts. Reductions are currently bookkept in the Space Transportation theme but will eventually be allocated across ISS Operations & Maintenance, Research, and Transportation as appropriate. As a result of this budget re-balancing, an assessment will be carried out to determine the full trade space of potential changes needed to meet outyear funding levels; such options should include discussion of reducing the number of science payloads/investigations to ISS and/or decreasing the number of astronauts on board the USOS, among other options.

NASA will continue to innovate, implementing new processes for payload development and integration that are focused on sending investigations to ISS as soon as they are ready, including renewed focus on cancer research that supports the President's Cancer Moonshot (an initiative to prevent more than four million cancer deaths by 2047 and improve the experience of people touched by cancer). ISS is working with research sponsors on the transition of research to Commercial LEO Destinations (CLDs), including designing new payloads to be modular wherever possible. The ISS National Lab is partnering with NASA’s BPS Division on the Igniting Innovation solicitation to fund multiflight translational and transformative research focused on cancer and other diseases. Because multiple flights can lead to faster iterations and improved timelines, payload development and integration processes can better meet the demands of its users, resulting in quicker payload deliveries to ISS (within months in some cases). Thus, private sector users looking to leverage space-based activities to accelerate time to market for product enhancements have a rapid path from project concept to flight. This bolsters the value proposition for space-based R&D. Similarly, R&D sponsored by NASA, private companies, or other government agencies can be executed within a timeline that enhances the relevance of the research projects. For these cutting-edge projects, scientific discovery and technological advancement moves quickly and will benefit by optimized timelines to flight.

Under the streamlined payload development and integration processes, the flight manifest for FY 2025 is still in development. As a result, the majority of specific investigations that will be conducted on ISS in

FY 2025 have not yet been identified. However, known upcoming investigations planned to fly in FY 2025 include:

- Tissue engineering and regenerative medicine to improve human health and longevity and flight projects supported by other government agencies, including NSF, will explore a range of related topics from stem cell biology to cancer research to 3D printing of tissue.
- Multiple ISS National Lab-sponsored physical science projects funded by NSF, projects selected and funded by the Technology in Space Prize funded by CASIS and Boeing in collaboration with the MassChallenge startup accelerator program, and projects selected through the NASA Vascular Tissue Challenge.
- Multiple projects awarded through ISS National Lab research announcements in the areas of in-space production applications and technology development/demonstration, including projects to advance stem cell biology, optical fiber production, and crystal growth.
- The Zero Boil-Off Tank payload, funded by the BPS Division, will use an experimental fluid to test active heat removal and forced jet mixing as an alternative means for controlling tank pressure for volatile fluids. Long term storage of cryogenic fluids is necessary for spacecraft propulsion and life support and results from the investigation will improve models used to design tanks for both space and Earth applications. In FY 2025 the Solid Fuel Ignition and Extinction (SoFIE) hardware insert for the Combustion Integrated Rack (CIR) will be used in a wide variety of solid material combustion and fire suppression studies.

Project Schedule

An increment, or expedition, is a period of time for ISS operations that spans from one crew return mission to another. Three to five expeditions typically span a calendar year, and each consists of cargo ship arrivals and departures, extensive research investigations, and standard crew maintenance and logistical tasks. The table below provides a schedule for FY 2024 through FY 2026 with completed and planned start dates for the upcoming increments to ISS.

Date	Significant Event
Mar 2024	Increment 71
Sep 2024	Increment 72
Mar 2025	Increment 73
Sep 2025	Increment 74
Mar 2026	Increment 75
Sep 2026	Increment 76

Project Management & Commitments

The ISS Program Office meets commitments to international partners for utilization access under the ISS agreements and follows statutory guidance in the NASA Authorization Act of 2010 in providing access to on-orbit capabilities for ISS National Lab research. The ISS Program interfaces with the ISS National Lab and personnel from a wide variety of NASA organizations to integrate objectives into strategic plans and implement research.

Within NASA, mission directorates also prioritize their research investments for ISS based on exploration roadmaps for technologies needed to support NASA's exploration goals, the Human Research path to risk reduction, and recommendations from the relevant National Academies of Science decadal surveys. These are demonstrated in non-ISS budgets of HRP, some activities in STMD, and specific SMD divisions including BPS.

Element	Description	Provider Details
MUSS	MUSS activities support all research on ISS (NASA sponsored and non-NASA sponsored).	Provider: ISS Program and contractors Lead Center: JSC Performing Center(s): MSFC, ARC, GRC, KSC, JPL Cost Share Partner(s): N/A
ISS National Lab	Manages the ISS National Laboratory through the National Laboratory Cooperative Agreement	Provider: Center for the Advancement of Science in Space, Inc. (CASIS)

Acquisition Strategy

NASA awards contracts and grants for conducting research on ISS. NASA prioritizes ISS research based on an established agency process that prioritizes NASA's use for exploration critical research needs (human research for exploration and technology research for systems to support long-duration lunar and Mars missions) followed by research that aligns with the National Academies' Decadal Surveys that are related to science and can be done in space. NASA manages non-NASA ISS research activities through the ISS National Lab in cooperation with CASIS and that research is prioritized separately from the NASA research. Peer review is practiced in each selection and is the means to ensure a high-quality research program. Engaging leading members of the research community to assess the competitive merits of submitted proposals is essential to ensuring the productivity and quality of ISS research.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Vehicle Sustaining Engineering Contract	The Boeing Company	Houston, TX
Huntsville Operations Support Center	COLSA Corporation	Huntsville, AL
Mission Operations and Integration (MO&I) Contract	Teledyne Brown Engineering	Huntsville, AL
ISS National Lab Management Entity	CASIS	Melbourne, FL

SPACE TRANSPORTATION

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Crew and Cargo Program	1,642.0	--	**1,761.5**	1,773.4	1,735.8	1,788.3	1,694.3
Commercial Crew Program	117.5	--	**100.6**	102.8	105.1	107.4	109.8
Total Budget	**1,759.6**	**--**	**1,862.1**	**1,876.2**	**1,840.9**	**1,895.7**	**1,804.1**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Shown here, a SpaceX Falcon 9 rocket lifts off the pad at Launch Complex 39A at 12:34 a.m. EST on March 2, 2023, carrying the Dragon spacecraft Endeavour for NASA's Crew-6 mission to the ISS.

Space Transportation's objective is to transport astronauts and cargo safely to and from the ISS and to safely deorbit the ISS after it is retired in 2030. This theme includes the Commercial Crew Program (CCP) and the Crew and Cargo Program. Maintaining ISS requires a fleet of vehicles and launch locations to transport astronauts, science experiments, critical supplies, and maintenance hardware; replenish air and water supplies; and dispose of waste.

CCP partners with the U.S. commercial sector to develop and operate safe, reliable, and affordable crew transportation to LEO. NASA awarded Commercial Crew Transportation Capability (CCtCap) contracts to Boeing and Space Exploration Technologies Inc. (SpaceX) in September 2014. Through its certification efforts, NASA will ensure the selected commercial transportation systems meet NASA's safety and performance requirements for transporting crew to ISS.

Within the Crew and Cargo Program, NASA purchases cargo transportation to ISS under Commercial Resupply Services (CRS) contracts with Northrop Grumman, Sierra Space (a subsidiary of Sierra Nevada Corp [SNC]), and SpaceX. The Budget also supports other space transportation-related activities, such as integration work required to ensure that these visiting vehicles can safely dock or berth to ISS.

As of September 30, 2023, NASA had allocated approximately $25.5 billion towards service providers under the Commercial Crew and Cargo programs. These funds have supported the completion of two rockets, two cargo vehicles, and one crew vehicle; the ongoing development of one other crew vehicle and one other cargo vehicle; 47 successful cargo flights; and seven successful crew flights to ISS. Of that amount, NASA contributed $5.9 billion towards the development of the commercial crew and cargo systems. This is the amount NASA refers to as its "investment" in the systems. The $5.9 billion includes NASA's share of the commercial cargo development costs, as well as all NASA CCP development costs (Commercial Crew Development Phases 1 and 2, the Commercial Crew Integrated Capability initiative, Certification Products Contract, and CCtCap). The remaining $19.5 billion is the amount NASA has contracted for services (i.e., the transportation of cargo and crew to ISS). This amount includes the current contract values for both CRS-1 and CRS-2 cargo contracts, as well as CCtCap crewed missions to the ISS. Within the current maximum contract value, NASA can still award another $6.1 billion under the CRS-2 contracts. Of the $25.5 billion NASA has allocated to these programs, $19.4 billion has been paid to the companies as of September 2023.

At the completion of ISS operations in 2030, the ISS will be safely de-orbited via a controlled re-entry into an unpopulated region. This budget request includes $109 million in FY 2025 towards the development of this capability, the U.S. Deorbit Vehicle (USDV). NASA intends to pursue this capability with U.S. industry through a competitive procurement.

The Budget funds ISS operations and research, a vehicle to safely de-orbit ISS after it is retired in 2030, and commercial space stations that NASA will use as soon as they become available The Budget gradually reduces research and other activities on board the ISS in the outyears, beginning in FY 2026, to provide the funding necessary for USDV development and Commercial LEO Development efforts. As a result of this budget re-balancing, an assessment will be carried out to determine the full trade space of potential changes needed to meet outyear funding levels; such options should include reducing the number of science payloads/investigations to ISS and/or decreasing the number of astronauts on board the USOS, among other options.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

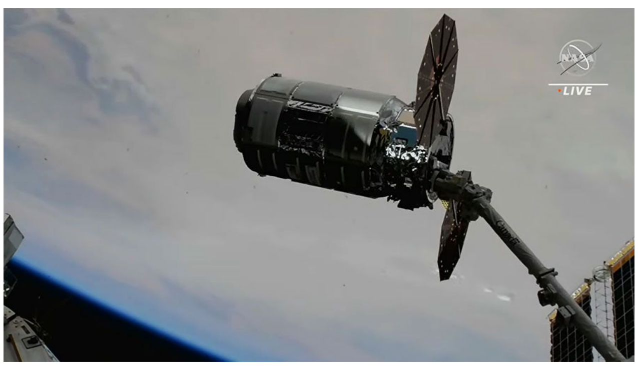
CREW AND CARGO PROGRAM

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**1,642.0**	**--**	**1,761.5**	**1,773.4**	**1,735.8**	**1,788.3**	**1,694.3**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Northrop Grumman's Cygnus space freighter is pictured in the grips of the Canadarm2 robotic arm following its capture as both spacecraft orbited above Africa. (August 2023)

Maintaining the ISS requires a fleet of spacecraft to sustain a constant supply line of both crew and cargo that is crucial to operations and research. Deliveries not only provide science experiments, supplies, and maintenance hardware, but also rotate crewmembers, return research and equipment for repair, and dispose of waste.

The Crew and Cargo Program manages transportation services provided by both international partners and domestic commercial providers. NASA's commercial service contracts to resupply the ISS have changed the way the agency does business in LEO. With these contracts, NASA continues to advance commercial spaceflight while simultaneously supporting the American jobs created by this industry.

The Crew and Cargo Program budget supports all milestone payments for Commercial Resupply Services (CRS)-2 contracted flights to provide cargo transportation for a multitude of users, including transportation for National Laboratory science research payloads. Northrop Grumman, Space Exploration Technologies Inc. (SpaceX), and Sierra Space are working under CRS-2 contracts with missions that began in FY 2020. Under CRS-2, Sierra Space will launch CRS missions from Cape Canaveral, FL, as SpaceX does today. Both of these providers also have or will have the capability to return science experiments to Earth. SpaceX uses its Falcon 9 rocket to launch the Dragon-2 docking cargo vehicle, while Sierra Space will use United Launch Alliance's Vulcan rocket to launch its Dream Chaser Cargo (DCC) berthing vehicle. Northrop Grumman previously launched its Cygnus berthing cargo vehicle on the Antares rocket from the Mid-Atlantic Regional Spaceport at NASA's Wallops Flight Facility (WFF) in Virginia. Beginning in FY 2024, Northrop Grumman will launch its Cygnus spacecraft from KSC in Florida on SpaceX's Falcon 9 rocket until an upgraded version of the Antares rocket is available. Northrop Grumman provides trash disposal and may conduct additional experiments before the Cygnus spacecraft burns up in the atmosphere after leaving ISS. These capabilities enable studies of fire

CREW AND CARGO PROGRAM

Formulation	Development	Operations

suppression, deployment of small satellites, and other activities that may not be suited for ISS on-board operations.

For years after the Space Shuttle was retired in 2011, crew transportation to ISS was provided using the Russian Soyuz vehicle. However, beginning with the SpaceX commercial crew Demo-2 flight in May 2020, the United States is again launching astronauts into space and to ISS. The Commercial Crew Program (CCP) manages these activities to develop and provide domestic crew transportation to the ISS under the Commercial Crew transportation Capability (CCtCap) contracts with Boeing and SpaceX.

The Crew and Cargo Program also funds activities supporting visiting vehicles that provide transportation for the ISS, including integration activities.

At the completion of ISS operations in 2030, the ISS must be safely de-orbited via a controlled re-entry over an unpopulated region. Existing U.S. Orbital Segment transportation vehicles do not have sufficient propulsive capabilities (e.g., thrust) or propellant quantities to meet the de-orbit needs. A much more extensive vehicle redesign or new development would be needed to meet the de-orbit requirements. NASA intends to pursue this capability with U.S. industry through a competitive procurement. Based on the extent of this development, NASA estimates it would take industry four to five years to develop this capability once the contract is awarded.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

Northrop Grumman completed 13 mission milestones in support of seven commercial resupply flights, including milestones for successful completion of two CRS-2 flights in FY 2023. SpaceX completed 16 mission milestones in support of eight commercial resupply flights, including milestones for successful completion of three CRS-2 flights in FY 2023.

Northrop Grumman completed two CRS-2 integration milestones required to demonstrate new contract capabilities and design enhancements to support science and payload research objectives.

The program funded CCtCap contract milestones for post-certification crew missions that will be flown by Boeing and SpaceX. The program supported three SpaceX Commercial Crew missions (Crew-5, Crew-6, and Crew-7). More information on CCtCap progress can be found under the CCP portion of this document.

The program supported the second private astronaut mission (PAM) with Axiom Space of Houston, TX. In addition, the program supported two crewed Soyuz launches, and four launches of Progress, a Russian cargo vehicle.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

In September 2023, NASA released a request for proposal from U.S. industry for the U.S. Deorbit Vehicle, a spacecraft meant to safely de-orbit the ISS as part of its planned retirement.

In November 2023, NASA released a request for proposal from existing CRS-2 contractors. These extensions will cover missions from January 2027 through December 2030.

WORK IN PROGRESS IN FY 2024

NASA expects six commercial resupply flights to deliver research and logistics hardware in FY 2024. Northrup Grumman plans to launch two flights and complete 10 mission milestones in support of six CRS-2 flights. SpaceX plans to launch three flights and complete 12 mission milestones in support of seven CRS-2 flights. Sierra Space plans to launch DCC-1 and complete seven mission milestones in support of five CRS-2 flights.

The program will also continue funding CCtCap contract milestones for post-certification crew missions with Boeing and SpaceX. The program will support two SpaceX Commercial Crew missions (Crew-8 and Crew-9). NASA expects to launch two commercial crew flights carrying four crew each flight. More information on CCtCap progress can be found under the CCP portion of this document.

The program will support a PAM with Axiom Space and the Boeing Crew Flight Test (CFT). The PAM, AX-3, launched on January 21 and Boeing CFT is planned no earlier than mid-April 2024. In addition, the program will also support two Soyuz crew launches, and four Progress cargo launches, not funded by NASA.

Contract award for U.S. Deorbit Vehicle is planned for 2024. The de-orbit vehicle will attach (via docking) to the ISS at least one year prior to the planned ISS re-entry date to enable adequate time for on-orbit tests and checkouts. Although nominal ISS end of life is late 2030, the government requires that this de-orbit capability be available as soon as possible to protect for contingencies that could drive early re-entry.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The Crew and Cargo Program will enable continued research and technology development by providing a stable crew and cargo flight plan.

NASA expects five commercial resupply flights to deliver research and logistics hardware in FY 2025. Northrop Grumman plans to launch three commercial resupply flights and complete nine mission milestones in support of five CRS-2 flights. SpaceX plans to launch one commercial resupply flight and complete nine mission milestones in support of four CRS-2 flights. Sierra Space plans to launch one commercial resupply flight and complete seven mission milestones in support of five CRS-2 flights. These resupply flights will be vital for delivering not only the day-to-day supplies needed, but also the experiments that enable the astronauts to continue important research on ISS.

CREW AND CARGO PROGRAM

Formulation	Development	Operations

The program will also continue funding CCtCap contract milestones for post-certification crew missions with Boeing and SpaceX. NASA is planning for at least two commercial crew missions annually. The program is also preparing to support a fourth PAM. The flight schedule also includes two Soyuz crew launches, three Progress cargo launches, and one H-II Transfer vehicle (HTV)-X, that are not funded by NASA.

The FY 2025 Budget request includes $109 million in funding to begin work to develop a U.S. de-orbit capability for ISS.

PROJECT SCHEDULE

Maintaining a regular rate of cargo delivery on a mix of NASA and international partner vehicles ensures the ISS can sustain nominal operations and maintenance, while allowing the program to respond to any anomalies that might occur. The table below shows all 30 scheduled ISS flight plans for FY 2024 and FY 2025. Of these 31 planned flights, 15 are funded by NASA. NASA funds SpaceX, Northrop Grumman, and Sierra Space cargo missions, as well as Boeing and SpaceX crew missions. The planned spacing of the Commercial Crew and Soyuz crew rotation flights ensures a continuous crew presence on the ISS and smooth transitions between crews.

Date	Significant Event
Nov 2023	SpaceX (SpX) CRS-29
Dec 2023	Progress 86*
Jan 2024	AX-3 (PAM)*
Jan 2024	Northrop Grumman (NG) 20
Feb 2024	Progress 87P*
Mar 2024	SpX Crew 8
Mar 2024	SpX CRS-30
Mar 2024	Soyuz 71S*
Apr 2024	Boeing CFT
Jun 2024	Progress 88P*
Jun 2024	Sierra Space DCC-1
Aug 2024	SpX Crew 9
Aug 2024	Progress-89P*
Aug 2024	NG 21

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Date	Significant Event
Sep 2024	SpX CRS-31
Sep 2024	Soyuz-72S*
No Earlier Than Oct 2024	AX-4 (PAM)*
Nov 2024	Progress-90P*
Dec 2024	SpX CRS-32
Feb 2025	NG 22
Feb 2025	Progress-91P*
Mar 2025	Soyuz-73S*
Mar 2025 - Under Review (UR)	JAXA HTV-X 1*
Spring 2025	Commercial Crew Mission
May 2025	PAM*
Jun 2025	Progress-92P*
Jul 2025	Sierra Space DCC-2
Fall 2025	Commercial Crew Mission
Aug 2025	NG 23
Sep 2025	Soyuz-74S*

**Missions are not funded by NASA*

Project Management & Commitments

JSC is responsible for management of the Crew and Cargo Program.

Element	Description	Provider Details
Crew transportation	Commercial crew transportation will be provided by Boeing and SpX and managed by the CCP.	Provider: Boeing; SpX Lead Centers: JSC, KSC Performing Center(s): N/A Cost Share Partner(s): CSA, ESA, and JAXA

CREW AND CARGO PROGRAM

Formulation	Development	Operations

Element	Description	Provider Details
Cargo transportation	NG, SpX, and Sierra Space will provide cargo transportation to the ISS via the major contracts described below. JAXA will provide additional cargo transportation as part of the ISS partnership.	Provider: NG, SpX, Sierra Space, and JAXA Lead Center: JSC Performing Center(s): GSFC, KSC Cost Share Partner(s): CSA, ESA, and JAXA

Acquisition Strategy

The ISS Program competitively procures all ISS cargo transportation services, excluding services obtained via barter arrangements with our international partners or nominal cargo transportation provided by Soyuz. On January 14, 2016, NASA competitively awarded CRS-2 contracts to Orbital ATK (now Northrop Grumman), Sierra Space, and SpaceX, with cargo transportation services that began in November 2019. Like the preceding CRS contracts, CRS-2 contracts are milestone-based, fixed-price, indefinite-delivery-indefinite-quantity contracts.

In September 2014, NASA's CCP awarded two Federal Acquisition Regulation (FAR)-based fixed-price CCtCap contracts to Boeing and SpaceX for commercial crew transportation services to ISS that began in FY 2021. CCP will continue to manage and provide technical insight on these contracts even though the Crew and Cargo Program will fund remaining milestones in FY 2024 and beyond. These crewed vehicles provide a minimum of 220 pounds of cargo, as specified by the ISS Program.

The USDV Request for Proposal was issued to U.S. industry in FY 2023 with award planned in FY 2024.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Crew transportation	Boeing	Houston, TX
Crew transportation	SpX	Hawthorne, CA
Cargo transportation	NG	Dulles, VA
Cargo transportation	Sierra Space	Louisville, CO
Cargo transportation	SpX	Hawthorne, CA

CREW AND CARGO PROGRAM

Formulation	Development	Operations

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Other	NASA Advisory Council	Jan 2023	Provides independent recommendations for the NASA Administrator	No new recommendations
Other	NASA Aerospace Safety Advisory Panel	Nov 2023	Provides independent assessments of safety and recommendations to the NASA Administrator	No open recommendations

COMMERCIAL CREW PROGRAM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**117.5**	**--**	**100.6**	**102.8**	**105.1**	**107.4**	**109.8**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Shown here, a SpaceX Falcon 9 rocket soars upward after liftoff at the pad at 3:27 a.m. EDT on Saturday, August 26, 2023, from KSC's Launch Complex 39A in Florida, carrying NASA's SpaceX Crew-7 crew members to the ISS.

The Starliner crew module is shown here being hoisted in Boeing's Commercial Crew and Cargo Processing Facility at KSC in Florida on January 19, 2023, before being mated to a new service module for NASA's Boeing Crew Flight Test.

With technical guidance and support from NASA, the U.S. private sector is developing and operating safe, reliable, and affordable crew transportation to space. Partnership with the commercial space industry for access to ISS and other LEO destinations bolster American leadership, eliminate our reliance on foreign providers for this service, and help stimulate the American aerospace industry. Crew transportation to ISS is currently provided using the SpaceX Crew Dragon, which was certified in 2020, and the Russian Soyuz vehicle. The Boeing Starliner spacecraft is still in the development and test phase but making significant strides towards certification by NASA for crew transportation to ISS. By supporting development of U.S. human spaceflight capabilities, NASA is also contributing to the foundation of a more affordable and sustainable future for human spaceflight in LEO and beyond.

Through the Commercial Crew Program (CCP) and the Commercial Crew Transportation Capability (CCtCap) contracts that they manage, NASA provides technical insight/oversight and financial support to industry partners as they develop and operate their crew transportation systems using milestone-based contracts and certifies them to carry astronauts to and from the ISS, which ended the nation's reliance on foreign crew transportation to ISS. Under this acquisition model, NASA defines requirements up-front and pays the partner only once contract milestones are successfully completed. This approach reduces financial risk to taxpayers and incentivizes the private sector to provide increased cost-control and decreased systems development cost. In addition, this approach helped stimulate growth of new space transportation industry capabilities available to all potential customers, strengthened America's space industrial base, and provided a catalyst for future business ventures that can capitalize on affordable, globally competitive U.S. space access. Returning these launches to American soil has significant economic benefits, with more than 1,000 suppliers working across nearly every state. A total of 14 Post Certification Missions (PCMs) have been awarded to SpaceX and six PCMs to Boeing.

In FY 2020, NASA initiated the Suborbital Crew (SubC) activity under the CCP to develop a safety case assessment for commercial suborbital space transportation services. This assessment will support procurement of commercial suborbital space transportation services for NASA Astronauts and other NASA personnel. However, this activity does not include funding to procure services. The funding is to support a safety assessment designed to ensure evaluate whether the systems are safe enough to fly NASA personnel. After several years of development, the first commercial suborbital human space transportation systems have entered commercial operations. The flight profiles of these vehicles include flying to altitudes of approximately 100 kilometers, which results in periods of microgravity longer than drop towers and parabolic aircraft flights create. Potential uses include human-tended microgravity research, astronaut training, and testing and qualification of spaceflight hardware. Suborbital human spaceflight has the potential to provide an effective and affordable way to meet the agency’s needs.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

SpaceX has launched three PCMs in FY 2023. SpaceX Crew-5 successfully launched on October 5, 2022, carrying NASA astronauts Nicole Mann and Josh Cassada, JAXA astronaut Koichi Wakata, and Roscosmos cosmonaut Anna Kikina. After staying 157 days in orbit, the Crew-5 astronauts returned to Earth in a splashdown near the coast of Florida on March 12, 2023. On March 2, 2023, SpaceX Crew-6 launched from KSC, carrying NASA astronauts Stephen Bowen and Warren "Woody" Hoburg, United Arab Emirates astronaut Sultan Alneyadi, and Roscosmos cosmonaut, Andrey Fedyaev. The Crew-6 astronauts spent approximately six months aboard the space station before returning to Earth on September 4, 2023. Before Crew-6 departed, SpaceX Crew-7 launched on August 26, 2023, carrying NASA astronaut Jasmin Moghbeli, ESA astronaut Andreas Mogensen, JAXA astronaut Satoshi Furukawa, and Roscosmos cosmonaut Konstantin Borisov.

NASA and Boeing teams continued to make progress in preparing for Starliner's first crewed flight to and from the ISS. NASA and Boeing completed a joint Crew Flight Test (CFT) checkpoint review in May 2023. During the checkpoint, mission teams discovered two technical issues with the spacecraft that delayed the launch planned for July 2023. One issue was risk from a specific type of tape used on the spacecraft to protect wires from chafing. The adhesive properties of the tape could present a flammability risk under certain conditions. Boeing has been working to complete tape remediation as engineering teams conduct flammability assessments on what remains. The second issue was with the efficiency of certain joints within the parachute system. Boeing has redesigned the joints (i.e. soft link), which are undergoing testing. Boeing has completed the Starliner spacecraft build and approximately 98 percent of the certification products required for the flight test. NASA completed its rocket readiness assessment, which evaluates all CFT launch vehicle segment flight critical items prior to integration activities. All rocket hardware is at the Cape Canaveral Space Force Station in Florida, awaiting processing ahead of rocket stacking at the launch site. The NASA astronauts who will fly on CFT completed the critical Crew Equipment Interface Test in February and March 2023. SubC continued progress towards refining the approach for a safety case and determining how NASA will assess commercial suborbital crew systems for NASA personnel safety.

WORK IN PROGRESS IN FY 2024

Crew-7 will spend several months aboard the ISS conducting new scientific research, including the ISS external microorganisms investigation, which scientists hope will better our understanding of microorganisms' ability to survive and reproduce in space. The crew will also perform ESA's sleep in orbit investigation, where they will examine the physiological differences between sleep on Earth and in space. SpaceX Crew-8 mission to the ISS is targeted to launch no earlier than early March 2024. The mission will carry NASA astronauts Matthew Dominick, commander; Michael Barratt, pilot; and Jeanette Epps, mission specialist, as well as Roscosmos cosmonaut mission specialist, Alexander Grebenkin to join Expedition 70 and 71 crew members aboard the ISS to conduct a wide range of operational and research activities. Crew-8 is expected to return to Earth in late August 2024. The SpaceX Crew-9 mission is targeted to launch no earlier than mid-August 2024. NASA and SpaceX will announce the crew of four at a later date.

NASA and Boeing will conduct a parachute drop test in early 2024 and will continue to make progress towards the first crewed flight of the Boeing CFT, planned for no earlier than mid-April 2024. CFT will send NASA astronauts and test pilots Butch Wilmore and Suni Williams on a demonstration flight to prove the end-to-end capabilities of the Starliner system. Starliner will launch atop a United Launch Alliance Atlas V rocket from Cape Canaveral Space Force Station in Florida, spend approximately eight days docked to the ISS, and return to Earth with a parachute and airbag-assisted ground landing in White Sands, New Mexico.

NASA will support the Commercial LEO Development Program's Collaborations for Commercial Space Capabilities (CCSC)-2 Space Act Agreements awardees by contributing technical expertise, assessments, lessons learned, technologies, and data.

SubC will continue refining the approach to its safety case and determining how NASA will assess commercial suborbital crew systems.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

CCP will continue to focus on mission planning and preparations for future CCP missions, as well as remain actively engaged with the providers as they continue space hardware manufacturing, critical testing, and qualification and verification events.

Having multiple U.S. domestic crew launch capabilities supports uninterrupted access to ISS, incentivizes performance through competition, and reduces risk. Therefore, it is imperative that NASA achieve its goal of certifying the Boeing Starliner crew transportation system. Once Boeing CCtCap certification is

COMMERCIAL CREW PROGRAM

complete, both partners' space transportation systems will begin regularly flying astronauts to and from ISS. NASA is planning for two Commercial Crew missions in 2025.

CCP will transition to sustaining operations at a level needed to safely operate with two commercial providers. CCP will continue to manage the CCtCap contracts, including providing technical oversight and managing modifications and upgrades to both crew transportation systems and potentially certifying new launch vehicles or spacecraft to other LEO destinations in the future.

CCP will continue to support the CCSC-2 Space Act Agreements awardees by providing extensive infrastructure, experience and knowledge in spaceflight development, and operations support.

Program Schedule

NASA funds SpaceX and Boeing crew missions related to United States Orbital Segment crew requirements. Commercial crew flights planned for FY 2024 and FY 2025 are included in the table below.

Launch Date	Significant Event
No Earlier Than (NET) March 2024	SpaceX (SpX) Crew-8
NET Apr 2024	Boeing CFT
Aug 2024	SpX Crew-9
Spring 2025	Commercial Crew Mission
Fall 2025	Commercial Crew Mission

Program Management & Commitments

The SOMD team at NASA HQ performs strategic management and oversight of CCP, while KSC is responsible for day-to-day CCP management, in collaboration with JSC. CCP partnered with industry leaders and utilized a combination of Space Act Agreements and Federal Acquisition Regulation (FAR)-based fixed-price contracts to stimulate efforts to develop and demonstrate crew transportation capabilities.

Program Element	Provider
Commercial Crew Program	Providers: Boeing, SpX Lead Center: KSC Performing Center(s): All Cost Share Partner(s): Industry Partners (Boeing, SpX)

COMMERCIAL CREW PROGRAM

Acquisition Strategy

CCP facilitates development of a U.S. commercial crew space transportation capability with the goal of achieving safe, reliable, and cost-effective access to and from space and the ISS. Under the CCP's partnership approach, NASA engineers have insight into a company's development process and evaluate systems for overall safety, reliability, and performance. The agency's technical expertise and resources are also accessible to partner companies. Because companies are only paid a fixed amount, they are incentivized to reduce costs and apply their most efficient and effective manufacturing and business operating techniques throughout the process. Additionally, the partners own and operate their completed transportation systems.

The current and final stage of the acquisition lifecycle began with the award of two FAR-based fixed-price CCtCap contracts in September of 2014 for development, test, evaluation, and final NASA certification of a Crew Transportation System. CCtCap contracts include demonstration of crewed ISS missions and subsequent service missions. The contracts also include a Special Studies Services section for special studies, tests, or analyses, as needed by NASA to reduce program risk. NASA's FAR based fixed-price contracts during this phase allow for compliance with NASA's existing mission and safety requirements for transporting crew to and from ISS.

NASA measures partner progress against fixed-price milestones based on performance of agreed upon entrance and success criteria. Although the content varies by partner, milestones are designed to demonstrate progress toward completing crew transportation system development, such as risk reduction testing, design reviews, hardware development, and flight tests. The government pays for milestones only after completion.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
CCtCap	Boeing	Houston, TX
CCtCap	SpX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Other	NASA Advisory Council	Jan 2023	Provide independent recommendations for the NASA Administrator	No new recommendations
Other	NASA Aerospace Safety Advisory Panel	Nov 2023	Provide independent assessments of safety and recommendations to the NASA Administrator	No open recommendations

SPACE COMMUNICATIONS AND NAVIGATION

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Space Communications Networks	424.8	--	**543.5**	499.7	491.2	495.1	509.2
Space Communications Support	107.2	--	**84.2**	85.7	91.3	96.4	96.4
Total Budget	**532.0**	**--**	**627.7**	**585.4**	**582.6**	**591.5**	**605.5**

Pursuant to P.L. 105-261, Division A, Title X, Section 1064(d), this budget incurs no costs for frequency allocations.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

NASA's Psyche mission launched from KSC, shown here, on October 13, 2023, aboard a SpaceX Falcon Heavy rocket. Psyche is carrying the Deep Space Optical Communications (DSOC) technology demonstration, which will test deep space laser communications for future exploration missions.

NASA's Space Communications and Navigation (SCaN) capabilities provide mission-critical communications and navigation services required by all NASA human and robotic missions. These missions range from high-altitude balloons to the ISS in LEO to Voyager 1, the most distant humanmade object currently more than 14 billion miles from Earth. SCaN retrieves science, spacecraft, and crew health data for all these missions; uploads commands; and sends data to individual control centers. Navigation services determine the precise location of a satellite so it can control its trajectory through space, gather valid scientific data, and avoid other spacecraft or space debris.

SCaN provides planning and integration of current and future network capabilities to meet customer mission needs, while reducing costs. It provides systems engineering, architecture planning, communications data standards, technology development, testbeds for future capabilities, radio frequency spectrum management, and navigation policy.

In addition to providing communication services to NASA missions, SCaN supports external customers, including foreign governments, international partners, commercial entities (e.g., launch service providers), and non-NASA U.S. missions, to which SCaN provides services on a reimbursable basis.

The Near Space Network (NSN) provides communication services to NASA users and missions using a combination of commercially-owned and government-owned ground assets and relay spacecraft, which allow for near real-time, low latency support, including support for human spaceflight operations. This allows SCaN to offer global telecommunication services via the NSN for telemetry, tracking, and command of LEO spacecraft such as the Hubble Space Telescope and ISS and vehicles from international partners and commercial entities. SCaN's goal is to migrate the NSN away from government owned assets by leveraging the diverse space communications capabilities provided by private industry to provide new technology and capabilities for NASA missions. A key part of this migration includes commercial service demonstrations managed by the Communications Services Program (CSP). The goal is to begin migration to these commercial services after the CSP demonstrations are complete in FY 2026.

The Deep Space Network (DSN) is focused on supporting deep space missions by utilizing its global network of large antenna ground assets. Both networks support Commercial Crew providers and Artemis missions. The DSN is a keystone of NASA's exploration of the solar system. This international network supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the broader universe.

Both networks require maintenance, replenishment, modernization, and capacity expansion to ensure continued operation and to meet new mission needs. Human and robotic exploration of the Moon requires communications to support video, telemedicine, and advanced instruments that locate and identify exploitable resources on the Moon (e.g., subsurface ice). SCaN is engaged in the planning of the Artemis lunar exploration and science missions to ensure that communications and navigation capabilities meet mission needs. SCaN is planning for expanded services for missions to the Moon, including a lunar relay capability for missions that cannot communicate directly with Earth; additional lunar Direct-to-Earth assets; and enhanced position, navigation, and timing services that are less dependent on tracking stations on Earth.

SCaN participates in several U.S. and international organizations that coordinate compatibility and interoperability in space communications and navigation. SCaN also promotes new technologies and provides technical leaders and domain experts who ensure appropriate space communication standards are available to NASA missions. The research and technology avenues within SCaN aim to predict the needs of future communications missions in a manner that will yield performance advancements and reduced costs.

SCaN is responsible for ensuring access to portions of the electromagnetic spectrum — a valuable, highly regulated, and limited natural resource that all NASA missions require — necessary to support NASA's mission needs, including ensuring interference-free operations and bandwidth availability.

For more information, go to http://www.nasa.gov/scan

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
SCaN	Standing Review Board	Dec 2022	Program Implementation Review with focus on interdependencies, implementation planning, and risk gaps or shortfalls.	SCaN is tracking and working nine issues identified by the Independent Review Team.

SPACE COMMUNICATIONS NETWORKS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**424.8**	**--**	**543.5**	**499.7**	**491.2**	**495.1**	**509.2**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Launch Communications Station (LCS), shown here and located at KSC, supported the Artemis I launch and is being upgraded to support Artemis missions, including the upcoming Artemis II mission.

Space Communications Networks provide 24/7, global, near-Earth and deep space communications capability, plus tracking and navigation services to more than 100 NASA missions and other U.S. government missions, international civil space agencies, and commercial missions. This capability ensures reliable and near-continuous communication with NASA and customer spacecraft. The Space Communication and Navigation (SCaN) Program continuously examines and integrates commercial capabilities and services to meet NASA's space communications and navigation requirements.

NASA's space communications networks provide ongoing services to agency and customer missions, nominally averaging approximately 600 tracking passes per day. Customer missions include, but are not limited to, James Webb Space Telescope; Parker Solar Probe; Joint Polar Satellite System; Interior Exploration using Seismic Investigations, Geodesy and Heat Transport Mars Lander; Ice, Cloud and land Elevation Satellite; Lucy; Landsat 9; Lunar Reconnaissance Orbiter; Mars Perseverance; Mars Reconnaissance Orbiter; Origins, Spectral Interpretation, Resource Identification, and Security – Regolith Explorer (OSIRIS-REx); Psyche; and Commercial Crew and Cargo. NASA would not be able to deliver key science data or advance exploration goals without SCaN's network capabilities.

The Near Space Network (NSN) provides near-continuous communication services to users from ground level up to cislunar distances via commercial and government assets. The NSN enables the utilization of a reliable, robust, and cost-effective set of commercial space-to-ground communications services in which NASA is one of many customers. The NSN supports an extensive, diverse customer base from suborbital to Lagrangian orbits by providing direct-to-ground data transfer from spacecraft at S-, X-, and Ka-band frequencies up to data rates of 3.5 gigabits per second. The relay component is comprised of a constellation of government owned Tracking and Data Relay Satellites (TDRSs) and a mix of ground antennas owned by NASA, universities, and private companies to maximize the network's geographic coverage. NSN government assets, including the TDRS system, are maintained and operated by the Advanced Communications Capabilities for Exploration and Science Systems (ACCESS) project. NSN is the prime user interface for current and future missions to ensure compatibility, complete pre-mission planning, and provide communication services during mission operations. NSN serves as the NASA interface to commercial service providers in the United States and internationally.

SPACE COMMUNICATIONS NETWORKS

As a part of the NSN, NASA's TDRS system is a constellation of government-owned, contractor-operated communications satellites in geosynchronous orbit (more than 22,000 miles above the Earth's surface) matched with a set of space-to-ground link terminals located at NASA's White Sands Complex (WSC) in New Mexico, Guam, and Blossom Point, MD. NASA will maintain government-owned ground stations necessary to communicate with geosynchronous, lunar, and highly elliptical Earth orbits, as well as spacecraft launched from certain suborbital launch locations, supported by the Launch Communications Segment (LCS). The LCS provides pre-launch, launch, ascent, and landing communication services to various users through three modern ground stations: the Kennedy Uplink Station on site at KSC; the Ponce de Leon Station 40 miles north in New Smyrna Beach, Florida; and the Bermuda Tracking Station. Additionally, there are NASA-owned Direct-to-Earth ground stations located at WSC, Alaska Satellite Facility, U.S. McMurdo Antarctic Station, and Wallops Flight Facility (WFF) in Wallops Island, VA.

The Deep Space Network (DSN), which has operated for 60 years, provides reliable and high performing communication and tracking services to approximately 40 NASA and non-NASA missions beyond geosynchronous orbit. It is a worldwide network of 34-meter and 70-meter antennas that supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the universe. The DSN currently consists of three deep-space communications facilities located approximately 120 degrees of longitude apart around the world: at Goldstone in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. The site separation ensures any spacecraft in deep space can always communicate with at least one DSN facility as the Earth rotates and the spacecraft continues to move along its trajectory. Additionally, NASA uses the Goldstone Solar System Radar (GSSR) capability to track and characterize near-Earth objects that pass within nine million miles of Earth. The orbits of the near-Earth objects are determined and utilized by the SMD's Planetary Science Division to assess the probability of a conjunction between the object and the Earth. Investments in GSSR, such as installation of a new klystron, are underway to increase its capability for supporting planetary defense research. The installation of new radar equipment, planned for completion in FY 2026, will extend the radar's capability,which will increase the time to develop viable solutions to avoid orbital collision for planetary defense.

NSN and DSN support a different set of customer requirements for spacecraft orbit, signal strength, and real-time coverage. Both networks provide services to customer missions at a proficiency greater than 95 percent. To continue providing this level of support, each network requires regular maintenance, modernization and capacity expansion, and IT security upgrades to combat the ever-growing cybersecurity threats toward U.S. assets.

SCaN continues implementing the DSN "Road to Green" activity to improve the long-term maintenance posture and network health requirements that ensure reliability and meet future agency needs.

The ongoing DSN Aperture Enhancement Project (DAEP) is modernizing and upgrading the DSN to expand capacity, improve flexibility to support customer missions, and reduce operations and maintenance costs. The project is augmenting the capabilities of the existing 70-meter antennas by completing arrays of four 34-meter Beam Waveguide (BWG) antennas at each of the three DSN facilities: California by 2026, Spain by 2027, and Australia by 2029. The BWG antennas allow for antenna arraying and are less complicated, more flexible, and more cost-effective to maintain than the 70-meter antennas. Antenna arraying combines the signals received by two, three, or four 34-meter antennas to offer performance beyond that of one 34-meter antenna and up to the equivalent of a 70-meter antenna. When missions do not require all four 34-meter antennas to be arrayed, the 34-meter antennas can support multiple spacecraft individually, offering greater flexibility than a single 70-meter antenna. The new

SPACE COMMUNICATIONS NETWORKS

34-meter antenna construction efforts use Construction of Facilities funds appropriated in NASA's Construction and Environmental Compliance and Restoration account. As part of future DAEP requirements, ScaN plans to install an 80-kilowatt transmitter on one 34-meter BWG antenna per DSN facility to match the transmit capabilities of a 70-meter antenna and plans to be operational at all facilities by 2029.

SCaN will continue to work on acquiring lunar communications relay services and an interoperable lunar network through commercial service procurements and international partnerships. The network is required to meet the communication and navigation needs for lunar missions and support mission objectives such as human landing, sustained human presence, and scientific exploration on and around the Moon. The Lunar Exploration Ground System (LEGS), a dedicated new set of 18-meter class antennas, will provide additional capacity in support of lunar exploration and other missions, while preserving DSN capacity for Mars and outer planet missions. SCaN is increasing its infrastructure to support human and robotic exploration of the Moon, including providing a lunar communications capability and enhanced position, navigation, and timing services. The Lunar Communications Relay and Navigation Systems (LCRNS) is an infrastructure that will meet NASA's mission needs; enable a sustainable, long-term approach to human and robotic exploration; and embody an extensible solution for supporting future travel to Mars and beyond.

In alignment with lunar interoperability and standardization goals, ScaN is in the process of implementing Delay Tolerant Networking (DTN) to both the NSN and DSN. DTN will provide an internet-like approach to spacecraft communications and the ability to handle greater data rates and volumes, up to 1.2 Gigabits per second (Gbps). Mission implementation of DTN began with the successful test of the DSN and the Korea Pathfinder Lunar Orbiter (KPLO), and will continue with the NSN and the Plankton, Aerosol, Cloud, Ocean Ecosystem (PACE). DTN will also be a part of optical communications experiment on the Laser Communications Relay Demonstration (LCRD) and the Integrated LCRD LEO User Modem and Amplifier Terminal (ILLUMA-T).

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

Consistent with prior years' successes, SCaN Networks continued to provide communications, tracking, and navigation services at a 95 percent or greater proficiency rate to more than 100 entities, including NASA and other U.S. government agencies, international civil space agencies, and commercial missions.

The DSN continued site preparations for Deep Space Station (DSS)-33 at the Canberra Deep Space Communications Complex (CDSCC) for DAEP and completed pedestal construction and the facilities installation for DSS-23 at the Goldstone Deep Space Communications Complex (GDSCC). The DSS-23 upgrades supported the Psyche/Deep Space Optical Communications mission and other optical communication opportunities. DSN Lunar Exploration Upgrades (DLEU) continued for two more antennas, DSS-24 and DSS-36, with DSS-36 Ka-band installation completed.

In June 2023, the construction of a solar farm was completed at the CDSCC through a Solar Power Purchase Agreement, allowing for the generation of renewable energy. The DSN continued to complete key Road-to-Green tasks, including completion of GDSCC and CDSCC medium-priority fire and life safety systems and procurement of antenna uplink spares.

An upgraded fencing system at the Apollo GDSCC site was completed in September 2023, with final closeout planned for Q1 FY 2024. The enhanced fencing will significantly improve security measures at the GDSCC location.

NASA released a Request for Proposal in February 2023 to support SCaN's commercialization goals and the agency's lunar exploration plans, with awards planned for the Spring of 2024. These awards will define the detailed milestones and validation for commercial lunar relay services. In addition to these awards, LEGS will support lunar missions by providing a dedicated new set of antennas designed to help alleviate the user load on the current 34-meter subnet and to allow DSN to focus on deep space support. The LEGS project successfully completed an overall PDR in December 2022.

DTN demonstrations were successful between the DSN and KPLO, including the first formal in-flight test and demonstration of video transfer, which took place in October 2023. The NSN is scheduled to complete the first DTN experiment on LCRD in FY 2024 and continue preparing for PACE implementation.

The ACCESS Project completed the fourth and final Operational Readiness Review (ORR) for the Network Initiative for Ka-band Advancement (NIKA) antenna located at WFF in December 2022. With completion of this ORR, all NIKA tri-band stations are operational.

WORK IN PROGRESS IN FY 2024

SCaN networks will continue to provide communications, tracking, and navigation services to more than 100 NASA and other U.S. government, international civil space agencies, and commercial missions at a 95 percent or greater proficiency rate.

The DSN will continue the DLEU effort, with DSS-24 and DSS-34 scheduled for completion in FY 2024.

The LEGS project will conduct an Antenna PDR in Q1 FY 2024, an Antenna CDR in Q2 FY 2024, and a Signal Processing CDR in Q2 FY 2024. Radiofrequency (RF) compatibility testing is also scheduled to be completed in Q3 FY 2024.

DSN sustainment and maintenance activities and the Road-to-Green initiative will continue, resolving recommendations from the fire safety review team and additional sparing for critical uplink systems. Obsolescence tasks for antenna subsystems will continue during FY 2024.

NIKA will provide high-rate downlink services to NASA-ISRO Synthetic Aperture Radar and PACE, launching in FY 2024. The NSN DTN implementation is also scheduled to complete the first demonstration with the PACE mission.

DSS-54 pedestal build and installation of mirrors will be completed by Q4 FY 2024. The DSS-23 Antenna build will be completed, and electronics will be delivered.

SCaN continues to lead LCRNS requirements and interoperability specification refinement for lunar relay services. SCaN released revision five of the LCRNS interoperability specification draft and received feedback from relevant industry, academia, and international stakeholders. SCaN continues to support Source Evaluation Board (SEB) evaluations of the Lunar Relay Service proposal with awards anticipated in Q2 of FY 2024.

SPACE COMMUNICATIONS NETWORKS

KEY ACHIEVEMENTS PLANNED FOR FY 2025

SCaN Networks will continue to provide communications, tracking, and navigation services to more than 100 NASA and other U.S. government agencies, international civil space agencies, and commercial missions at a 95 percent or greater proficiency rate, including the crewed Artemis II mission and Europa Clipper science mission, both launching in FY 2025.

DLEU is committed to understanding future missions' requirements for upcoming lunar activities. Upgrades to the DSN will be a critical communications component to achieve human spaceflight on and around the lunar surface. The DLEU will improve communications and navigation by upgrading and expanding the network to provide higher data rates and higher latency. In FY 2025, upgrades to DSS-24 and DSS-34 will be completed, will begin and complete upgrades to DSS-56. By the end of FY 2025, three of six antenna upgrades will be complete. LEGS validation efforts will continue in FY 2025, while Lunar Relay validation will continue through FY 2025 and beyond. LEGS is scheduled to complete a Global CDR in Q1 FY 2025. Delivery of LEGS antenna 1 to WSC is planned for Q3 FY 2025. Initial preparatory activities for the potential LEGS site 2 in South Africa will also continue.

Following award of the lunar relay services contract(s) and kickoff, SCaN will manage vendor validation and verification milestones to prepare for the eventual launch and on-orbit validation of an initial lunar relay satellite.

Project Schedule

The table below includes significant SCaN network milestones in FY 2024 and FY 2025.

Date	Significant Event
Q1 FY 2024	DSS-24 DLEU Upgrade Complete
Q1 FY 2024	LEGS Antenna PDR
Q2 FY 2024	LEGS Antenna CDR
Q4 FY 2024	DSS-34 DLEU Upgrade Complete
Q1 FY 2025	LEGS Global CDR
Q3 FY 2025	DSS-56 DLEU Upgrades Complete

Project Management & Commitments

Element	Description	Provider Details
ACCESS	ACCESS provides the project management and subject matter expertise required to operate, maintain, and sustain assigned Government Owned / Contractor Operated ground- and flight-based systems and assigned facilities to provide NASA, other government agencies, and partners optimal communications and navigation mission services through its alignment to and interfaces with the NSN.	Provider: ACCESS Project Office Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers

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Element	Description	Provider Details
NSN	NSN provides the project management and subject matter expertise required to provide continuous LEO communication services to users via commercial and government assets and providers. NSN will act as the government interface to the commercial service providers located in the United States and internationally.	Provider: NSN Project Office Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers
Commercialization Innovation and Synergies (CIS)	CIS functionally will provide project management leadership and subject matter expertise required to identify opportunities, extend invitations, implement collaborative solutions, and nurture diverse relationships to leverage commercial capabilities across the space communications industry.	Provider: CIS Project Office Lead Center: GSFC Performing Center: N/A Cost Share Partner(s): Non-NASA customers
DSN	DSN provides communication and navigation services to customer missions in deep space.	Provider: DSN Project Office Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): Non-NASA customers

Acquisition Strategy

Acquisition methods utilized to provide operational network capabilities include competitive procurements and international partnerships. JPL provides the management of the DSN. NSN issued a solicitation to provide Lunar communication and navigation services to directly support of Artemis.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
DSN	JPL/California Institute of Technology	Pasadena, CA
NSN	Peraton	Herndon, VA
DSN	Commonwealth Scientific and Industrial Research Organization	Canberra, Australia
DSN	Instituto Nacional de Tecnica Aeroespacial	Madrid, Spain

SPACE COMMUNICATIONS SUPPORT

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**107.2**	**--**	**84.2**	**85.7**	**91.3**	**96.4**	**96.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

On November 9, 2023, SCaN's optical communications demonstration mission, ILLUMA-T, launched aboard the SpaceX CRS-29 resupply mission (shown here) to the ISS. ILLUMA-T will be installed outside the ISS, where it will test laser relay communications with SCaN's LCRD mission.

The projects in Space Communications Support provide the Space Communications and Navigation (SCaN) Program with planning, management, systems engineering, spectrum and data standards management, and advanced technology development that will enable, improve, and mature available spacecraft communication and navigation technologies for ground and space-based use. Technology development efforts are created and tested in laboratory settings before they are taken into space for further testing and demonstration.

The SCaN Program leverages technical expertise in radio frequency (RF) and optical communications, navigation, and networking to develop solutions critical to providing communication and navigation capabilities across the agency, for use with commercial satellite communication providers. These technologies will demonstrate using a common radio to provide cross-service support for NASA, commercial, and other U.S. government networks.

A combination of government and commercial investments enable technology development, such as development of a lunar Global Navigation Satellite System (GNSS) receiver that will substantially reduce network loading and improve navigation autonomy and accuracy, which are critical capabilities for Artemis and Moon to Mars missions. Lunar surface communications and navigation will be advanced with fourth generation long-term evolution cell phone technology in collaboration with Nokia. SCaN is also reducing risk to future missions as the Tracking and Data Relay Satellite system is gradually retired by investing in user terminal technology that will enable missions to use satellite services from a variety of commercial providers.

As the space user community expands and data demand grows, SCaN is leading the development of high data rate communications through optical technology. Optical communications, also known as laser communications, is highly efficient compared to RF, offering higher data rates and reduced power and mass requirements, but currently at a higher cost. This long-term investment has yielded successful flight demonstrations in near-Earth, cislunar, and deep space. An optical terminal will fly on the Artemis II mission for additional demonstrations of the viability of optical communications for missions seeking higher data volume than achievable with RF alone.

SCaN serves as the NASA representative to the Interagency Operations Advisory Group and Consultative Committee for Space Data Systems and provides the secretariats for both entities. Space communications

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data standards enable world space agencies and industry to interoperate and provide each other primary and backup communications services, reducing mission risk and alleviating the need to build and deploy additional space and ground assets. These standards provide significant cost savings to NASA without reducing the services or coverage available to space missions and serves as a compatibility and interoperability guide for industry.

SCaN is responsible for ensuring NASA has access to the electromagnetic (EM) spectrum, and that sufficient, free from interference bandwidth is available. The EM spectrum is a valuable, highly regulated, and limited natural resource that all NASA missions require. SCaN serves as the agency's Spectrum Manager and provides NASA representatives to advocate for NASA's requirements at domestic spectrum governing bodies, including the Interdepartment Radio Advisory Committee within the National Telecommunications and Information Administration and at international spectrum governing bodies.

SCaN represents NASA's interests at multiple international technical forums, including the World Radiocommunication Conferences (WRCs). These conferences review and revise the International Telecommunication Union's Radio Regulations, which govern international use of the electromagnetic spectrum. NASA's delegates lead several key WRC working groups and regional committees throughout the year. In both the domestic and international arenas, NASA continues to engage with the commercial sector to identify more flexibility in using spectrum resources that will meet mission objectives for the entire space community.

NASA spacecraft in Earth orbit can employ the U.S. Global Positioning System (GPS) and other GNSS signals for precision positioning, navigation, and timing (PNT), allowing NASA to minimize network tracking burdens while maximizing spacecraft autonomy and improving operations. SCaN manages NASA’s policy on GPS use, represents NASA at the U.S. PNT Executive Committee, works with the United States Space Force to continue improving GPS capabilities to support space users, and leads U.S. efforts at the United Nations International Committee on GNSS to facilitate interoperability of GNSS capabilities to support space users.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

NASA's STMD and SCaN jointly developed the Laser Communications Relay Demonstration (LCRD) Project, with SCaN funding the ground operations and STMD funding the spacecraft payload. LCRD was launched in December 2021 and was NASA's first long-duration optical communications project demonstrating technologies that could be used on future missions. SCaN continued to operate the LCRD payload and experiments throughout the two-year experiment period, which included an experiment to verify the collection of metric-tracking data from optical links. LCRD is scheduled to complete its experimental phase in Q3 FY 2024. The experimental phase will demonstrate the unique capabilities of optical communications, which include data rates 10 to 100 times faster than RF systems and improve metric tracking performance.

The TeraByte InfraRed Delivery (TBIRD) is a CubeSat payload capable of delivering 200 gigabits per second (Gpbs) from LEO to Earth. The TBIRD payload technology is based on 1,550 nanometer wavelength commercial components used for terrestrial fiber optic connections. The TBIRD continued

SPACE COMMUNICATIONS SUPPORT

demonstrations, supported by the Optical Communications Telescope Laboratory (OCTL) at JPL's Table Mountain Facility. On April 28, 2023, TBIRD achieved a milestone of 200 Gpbs throughput on a space-to-ground optical link, the highest data rate ever achieved through optical communications technology.

The Deep Space Optical Communications (DSOC) integrated payload on the Psyche spacecraft was also developed through a joint SCaN/STMD collaboration. The DSOC payload was integrated onto the Psyche spacecraft in Q3 FY 2023 and launched on October 13, 2023.

SCaN is leading NASA efforts on the Lunar GNSS Receiver Flight Experiment (LuGRE), which is launching on the Blue Ghost Mission-1 (Commercial Lunar Payload Services [CLPS] Mission 19D) in FY 2024. The LuGRE payload includes a GPS-Galileo receiver, furnished by the ASI, that will be used to validate the use of GPS and Galileo signals throughout cislunar space and on the nearside of the Moon. The LuGRE payload was delivered to Firefly Aerospace in Q2 FY 2023 for integration on the Blue Ghost Mission-1 lunar lander. LuGRE completed a Ground Segment Design Review in Q4 FY 2023.

SCaN's Wideband Polylingual Experimental Terminal (PExT) mission made major progress from an early concept review to development of payload hardware through payload integration. This included CDRs and environmental testing of the antenna, power amplifier, and radio. The PExT flight mission also developed payload scheduling software focused on demonstrating the operation of the payload across multiple service providers. The team leveraged the NextSTEP Broad Agency Announcement (BAA) Appendix L (titled CIS Capability Studies II: Wideband/Phased Array/Crosslink) to begin working with commercial industry to make similar terminals available for users.

In December 2022, the NavCube3 mini (NC3m) GNSS receiver passed a Technology Readiness Level 6 assessment. This low size, weight, and power (SWaP) receiver will demonstrate a capability to operate in all Earth orbit regimes and cislunar/lunar space. NC3m has already demonstrated excellent performance on high fidelity LEO, Geosynchronous Equatorial Orbit (GEO), and lunar hardware in the loop simulations

WORK IN PROGRESS IN FY 2024

The Integrated LCRD LEO User Modem and Amplifier Terminal (ILLUMA-T) optical demonstration payload launched to ISS on November 9, 2023. This includes continued operations of the LCRD payload and ground station support via the OCTL. ILLUMA-T will demonstrate LEO to GEO optical communications crosslink via the operational LCRD payload in GEO, demonstrating a 1.244 Gpbs relay link.

DSOC launched onboard the Psyche spacecraft on October 13, 2023, with a two year demonstration period. DSOC will demonstrate deep-space optical communication uplink data rates of 1.6 kbps for multiple ranges between 0.25 and 1 astronomical units. It will also present key capabilities related to pointing accuracy and implementation of the High Photon Efficiency signaling standard.

The Optical-to-Orion (O2O) terminal on the Artemis II Orion spacecraft will provide 260 megabits per second of bandwidth. The O2O payload is scheduled to complete all Ground Readiness Tests and Mission Readiness Tests by the end of Q3 FY 2024. The O2O Ground Terminal at Table Mountain will conduct an Operational Readiness Review (ORR) in Q3 FY 2024 in preparation for supporting the Artemis II launch.

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Low-Cost Optical Terminal (LCOT) is an optical ground station utilizing commercial-off-the-shelf and modified hardware. LCOT will conduct a CDR, finalize integration and testing, and conduct a more sophisticated demonstration with LCRD in Q4 FY 2024.

The LuGRE GPS-Galileo flight experiment will conduct an ORR in Q4 FY 2024 and then launch as part of the Blue Ghost Mission-1 lunar lander. This experiment will validate the use of GPS and Galileo signals for positioning, navigation, and timing at lunar distance.

SCaN is also leading efforts to validate multi-GNSS use for range safety applications, including the Space Loft 15 GPS-Galileo flight experiment, which will launch in FY 2024.

The Wideband PExT mission plans to complete payload environmental testing, bus integration, and launch on SpaceX Transporter 11. The Wideband PExT mission will have six months of planned operations extending into FY 2025.

SCaN will also support WRC-23 in Q1 FY 2024.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

NASA will continue the DSOC optical demonstrations. O2O will successfully support Artemis II and Orion, transmitting high-resolution images and video from the Moon to Earth at rates up to 260 megabits per second, a rate not available with the current Orion communications system.

NASA will complete its series of optical communications technology demonstrations ILLUMA-T, DSOC, and O2O, having demonstrated optical communications for spacecraft in LEO, GEO, and Deep Space. LCOT will conduct a demonstration with O2O in Q1 FY 2025.

The LuGRE will complete its mission in Q1 FY 2025.

The Wideband PExT mission will continue operations into FY 2025.

Project Schedule

The table below includes significant Space Communication Support milestones in FY 2024 and FY 2025.

Date	Significant Event
Q1 FY 2024	Psyche Launch - DSOC begins demonstration
Q1 FY 2024	WRC 2023 conference
Q1 FY 2024	ILLUMA-T Launch
Q1-Q3 FY 2024	ILLUMA-T demonstration with LCRD
Q2 FY 2024	Wideband PExT launch on SpaceX Transporter 11
Q4 FY 2024	LuGRE ORR
Q4 FY 2024	Blue Ghost Mission-1 CLPS-19D Launch
Q4 FY 2024	LCOT Demonstration Lunar Relay CDR

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Date	Significant Event
Q4 FY 2024	LCOT Demonstration with LCRD
Q1 FY 2025	LCOT Demonstration with O2O
Q1-Q2 FY 2025	Wideband PExT operations complete

Project Management & Commitments

The SCaN Program office at NASA HQ manages Space Communications Support functions.

Element	Description	Provider Details
Space Communications Support	Provides critical communication and navigation architecture planning, technology development, data standards development and management, and spectrum management for NASA. Includes program management, business management, navigation policy support, and external communications.	Provider: NASA Responsible Center: HQ

Acquisition Strategy

Space Communications Support functions use multiple small, contracted efforts, most of which are support services functions.

MAJOR CONTRACTS/AWARDS

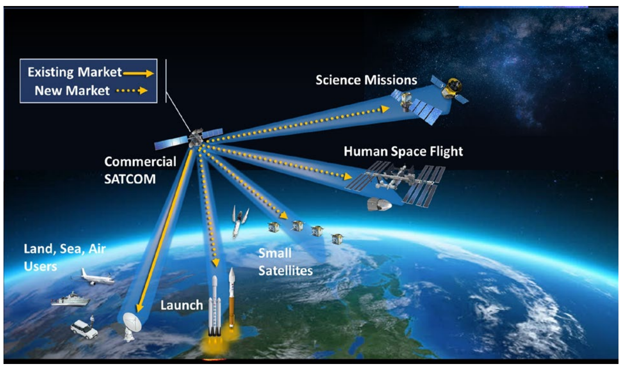
Element	Vendor	Location (of work performance)
Wideband	Applied Physics Laboratory	Laurel, MD

COMMUNICATIONS SERVICES PROGRAM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**51.7**	**--**	**59.4**	**59.4**	**59.4**	**59.4**	**59.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



The Communications Services Program will collaborate with industry to demonstrate the commercially provided data relay services, shown here, available for NASA space missions.

The Communications Services Program (CSP) focuses on demonstrating the feasibility of commercially provided satellite communications (SATCOM) services to NASA missions. CSP is pursuing demonstrations that will allow future NASA missions to use flight qualified commercial communications services. Ultimately, near-Earth users will begin transitioning from using NASA owned networks to commercially provided services.

The CSP effort is a component of the larger NASA strategy to migrate near-Earth missions from communications and navigation services provisioned by government-owned networks to commercial networks. This transition to commercial services, and particularly commercial SATCOM, is driven by the state of current NASA network assets, National Space Policy, and long-standing federal procurement policies that direct the government to make use of, rather than duplicate, commercially provided services. NASA will not replenish the Tracking and Data Relay Satellites (TDRS), as aging spacecraft assets are decommissioned in the 2030's. NASA will continue to support existing users but seeks to transition future space-relay users to commercial providers. This approach is consistent with federal policies intended to increase the cost-effectiveness of government operations and leverage investments that have already been made by the private sector.

The SCaN Program has overarching agency responsibility to ensure operational NASA missions receive required communications and navigation support. CSP retains responsibility to execute demonstrations of commercial SATCOM services and provide assessments and recommendations for service acquisition to the agency. SCaN will ensure that the transition to commercial services is managed in concert with the gradual phase out of the existing NASA-owned network resources.

NASA has a diverse set of users and communications needs against which commercial capabilities will be evaluated, such as launch vehicle support, visiting vehicles to ISS, human space flight, and science missions in Earth orbit ranging from flagship observatories to SmallSats and CubeSats. CSP intends to leverage SATCOM capabilities developed for terrestrial users to bring flexibility and functionality of commercial service to the space domain. CSP will work with the commercial market to identify requirements and explore opportunities that are mutually beneficial to NASA and industry. NASA expects to work with multiple commercial entities to demonstrate capabilities that best fulfill NASA's requirements, while also being compatible with a larger market where NASA can be one of many customers. These agreements will be designed to bolster American industry and reduce the cost of communication services to NASA, while promoting a diverse commercial market and maximizing interoperability between government and commercial service providers.

The CSP budget will support multiple agreements between NASA and commercial SATCOM companies to develop and demonstrate capabilities that can meet NASA's needs and begin the initial planning for acquisition of commercial SATCOM services. The goal is to begin migration to these commercial services after the demonstrations are complete in FY 2026.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

CSP has completed an Analyses of Alternatives (AoA) assessment to explore systems engineering trades and evaluate operational approaches for provisioning future commercial services. CSP began formal engagement with the Near Space Network to include their participation in the AoA.

On April 20, 2022, NASA selected six satellite communications (SATCOM) providers to begin developing and demonstrating, near-Earth space communication services that may support future agency missions: Inmarsat Government Inc., Kuiper Government Solutions (KGS) LLC, SES Government Solutions, Space Exploration Technologies (SpaceX), Telesat U.S. Services LLC, and Viasat Incorporated. Each of the six partners have unique milestones. Current schedules for all six partners conclude the demonstration phase in FY 2026. Inmarsat Government, Inc. has achieved four milestones, including the ELERA Network Enhancements CDR. KGS has completed six milestones, including a Mission Concept Review. SES Government Solutions has completed three milestones, including an Architecture CDR. SpaceX has completed two milestones, including an Optical Communications Package Technical Interchange Meeting (TIM). Telesat U.S. Services, LLC has completed five milestones, including an Architecture CDR. Viasat Incorporated has completed four milestones, including a Spaceflight Demo System Requirements Review.

CSP will continue formal engagement with the mission community and stakeholders to review the progress and results of the demonstrations. The most recent mission engagement forum, held on October 12, 2023, included participation by all six CSP partners and over 200 members of the NASA mission community.

WORK IN PROGRESS IN FY 2024

CSP plans to continue monitoring partner progress through the demonstration period. CSP will identify capabilities gaps, if any, using NASA use cases and through direct mission engagement. The AoA activity will continue into FY 2024 and be a key input for future acquisition planning. CSP will initiate planning for subsequent acquisition of services by leveraging knowledge gained during demonstrations, the AoA, assessment of commercial provider readiness date, and coordination with the Near Space Network. The planning work completed by CSP will inform an agency decision to formally end new mission commitments to TDRS service.

While each partner has unique milestones, FY 2024 will encompass milestones such as CDRs/Interim Design Reviews or the launch of test network infrastructure. Inmarsat Government, Inc. is expected to complete six milestones, including ELERA Space Relay CDR. KGS is scheduled to complete five milestones, including the Test Readiness Review. SES Government Solutions is scheduled to complete an Electronically Steered Array (ESA) Ground Demo and four milestones including a Pre-Shipment Readiness Review (PSRR). SpaceX is scheduled to complete two milestones, including a Service Level Agreement (SLA) Coordination TIM. Telesat U.S. Services, LLC is scheduled to complete seven milestones, including an Interim Design Review. Viasat Incorporated is scheduled to complete seven milestones, including a Spaceflight Demonstration CDR.

CSP will continue to manage the overall demonstration portfolio to stay within the project's allocated funding profile and to mature the set of capabilities to support a service solicitation.

KEY ACHIEVEMENT PLANNED FOR FY 2025

CSP plans to continue to monitor and manage the partner progress through the demonstration period, execute biannual mission engagement forums, and complete an updated assessment of commercial readiness. CSP will continue to identify capabilities and gaps as applicable during vendor milestone reviews. In FY 2025, planned major accomplishments include the KGS Pre-Production Network Development Launch; an Interim Design Review provided by SES Government Solutions; a Mission Readiness Review with Inmarsat Government Inc.; a Spaceflight Demonstration Flight Readiness Review with Viasat Incorporated; and a High-Rate Data Relay Demonstration TIM with SpaceX. Additionally, Telesat U.S. Services will provide an ESA Ground Demo.

By leveraging demonstration knowledge, CSP will prepare for subsequent acquisition of services and TDRS transition. CSP will utilize the outcomes of the AoA to help define the future architecture and the role of NASA for commercial services. CSP will continue coordinating and collaborating on the infusion of commercial services with the Near Space Network.

Program Schedule

The table below includes significant Communication Services Program milestones in FY 2024 and FY 2025.

Date	Significant Event
Q1 FY 2024	KGS LLC: Test Readiness Review (Phase 2.2)
Q2 FY 2024	Viasat Incorporated: Spaceflight Demonstration CDR
Q3 FY 2024	SES Government Solutions: PSRR

COMMUNICATIONS SERVICES PROGRAM

Date	Significant Event
Q3 FY 2024	SpaceX: SLA Coordination TIM
Q4 FY 2024	Inmarsat Government Inc.: ELERA Space Relay CDR
Q4 FY 2024	Telesat U.S. Services LLC: Interim Design Review
Q1 FY 2025	KGS LLC: Pre-Production Network Development Launch
Q1 FY 2025	SES Government Solutions: Interim Design Review
Q1 FY 2025	SpaceX: High-Rate Data Relay Demonstration TIM
Q2 FY 2025	Inmarsat Government Inc.: Secondary Launch Partner Mission Readiness Review
Q4 FY 2025	Telesat U.S. Services LLC: ESA Ground Demo Complete
Q4 FY 2025	Viasat Incorporated: Spaceflight Demonstration Flight Readiness Review

Program Management & Commitments

Program Element	Provider
Communications Services	Provider: CSP Project Office Lead Center: GRC Performing Center(s): N/A Cost Share Partner(s): N/A

Acquisition Strategy

Similar to the approach used for the Commercial Orbital Transportation Services and Commercial Crew, NASA used funded Space Act Agreements (SAAs) for the CSP demonstration awards. By using funded SAAs, CSP will stimulate industry to demonstrate end-to-end capability leading to operational service. These demonstrations will inform the future acquisition strategy for transitioning near-Earth NASA users to suitable commercially provided services. This acquisition strategy could include commercial service contracts, hosted payloads, and/or public-private partnerships to obtain commercially provided satellite communications services.

COMMUNICATIONS SERVICES PROGRAM

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
SATCOM Demonstration	Inmarsat Government Inc.	Reston, VA
SATCOM Demonstration	KGS LLC	Arlington, VA
SATCOM Demonstration	SES Government Solutions	Reston, VA
SATCOM Demonstration	SpaceX	Hawthorne, CA
SATCOM Demonstration	Telesat U.S. Services LLC	Arlington, VA
SATCOM Demonstration	Viasat Incorporated	Carlsbad, CA

INDEPENDENT REVIEWS

In FY 2022, CSP completed a peer level Formulation-Systems Requirement Review (F-SRR), tailored from NASA engineering best practices and a key milestone in support of the funded SAA solicitation and awards. Individual demonstration reviews will be held according to industry best practices and individual milestones definitized in demonstration contracts.

HUMAN SPACE FLIGHT OPERATIONS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**101.5**	**--**	**105.0**	**105.8**	**105.8**	**105.9**	**108.0**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Human Space Flight Operations (HSFO) Program supports the astronaut corps, space flight readiness training, and health of crew members before, during, and after each spaceflight mission to the ISS and will support future Artemis missions. All crews on board ISS have undergone rigorous preparation, which is critical to mission success. Within the HSFO Program, the Space Flight Crew Operations (SFCO) Project provides astronaut selection and space flight readiness training, while the Crew Health and Safety (CHS) Project manages all aspects of NASA astronaut crew health.

Pictured here, NASA astronauts Reid Wiseman, Victor Glover, and Christina Koch, with CSA astronaut Jeremy Hansen, are announced as members of the Artemis II crew that will travel around the Moon (April 4, 2023).

To pave the way to the Moon and on to Mars, NASA is working with industry to develop the transportation, habitation, and exploration systems that will enable crewed exploration of destinations beyond Earth's orbit. NASA must also prepare the human system for living and working for extended periods in the hostile environment of space. As astronauts explore further from Earth, many different issues may arise that require investigation. Questions that should be considered are:

- What health risks will astronauts face and how are they resolved?
- What type of training will crews need to prepare for months of travel in the harsh space environment?
- How will the crew deal with medical emergencies or technical anomalies when Earth is no longer within reach?
- How will NASA keep crews operating at peak performance during their mission to ensure mission success?

CHS, in collaboration with NASA's Office of Chief Health and Medical Officer and the Human Research Program (HRP), answers these and other questions to ensure crew health, safety, and mission success. SFCO and CHS are responsible for astronaut space flight readiness training and health, while HRP funds research of human health and performance countermeasures, the human response to space, and technologies that enable safe, reliable, and productive human space exploration.

HUMAN SPACE FLIGHT OPERATIONS

Scientifically Calibrated In-Flight Imagery (SCIFLI) will collect real-time visual, infrared, and spectral data on vehicles while they are in-flight to improve effectiveness and safety of commercial and NASA missions.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

- SFCO directed and managed the astronaut corps and provided trained astronauts for NASA human space flight efforts, including for Expeditions 68 and 69.
- SFCO provided support to the crew during launch, landing, and recovery operations for ISS Expeditions. This included the validation of Extravehicular Activity (EVA) and Intravehicular Activity (IVA) tool interfaces to ensure on-orbit functionality for 10 different missions.
- SCIFLI acquired airborne and ground-based imaging data during Space Launch System (SLS) ascent and Orion entry, descent, and landing.
- CHS maintained the Astronaut Occupational Health Plan that includes clinical certification for 40 Active U.S. government Astronauts and health and fitness through training, flight, post-mission recovery, medical and behavioral health management, physical conditioning, radiation exposure reports and baseline occupational surveillance, as well as medical risk modeling through Probabilistic Risk Assessment tools.
- CHS continued to implement all aspects of the TREAT Astronauts Act to monitor, diagnose, and treat former U.S. government Astronauts.
- Data obtained under the TREAT Astronauts Act, as well as all CHS activities, continued to be added to the Information Management Platform for Data Analytics and Aggregation (IMPALA) data analysis tool for informing current and future operational programs and paradigms for crew health, safety, and performance.

WORK IN PROGRESS IN FY 2024

- SFCO will direct and manage the astronaut corps and provide trained astronauts for NASA human space flight efforts, including for Expedition 70 and 71 and Boeing's Crew Flight Test (CFT) mission. In addition, SFCO will continue training astronauts for the Artemis II mission. SFCO will begin the recruitment and selection process for the 2025 Astronaut Candidate (ASCAN) class.
- SFCO will continue to operate and maintain the T-38 high performance jets in support of space flight readiness training, Gulfstream aircraft in support of direct crew return after completion of ISS Expeditions and the Boeing CFT mission, Super Guppy aircraft in support of oversized cargo transportation for NASA's programs, and WB-57 aircraft in support of high-altitude imagery for NASA's human space flight and science programs.
- SFCO will provide support to the crew during launch, landing, recovery, and rescue operations for ISS Expeditions and the Boeing CFT mission. This includes vehicle hardware inspections for ISS

Cargo resupply and Axiom 3 missions; launch and landing operations support for Crew-7, Crew-8, Crew-9, and Boeing CFT missions; Human in the Loop Testing support for Commercial Crew Program (CCP), Commercial LEO Development Program (CLDP), Human Landing System, Gateway, EVA and Human Surface Mobility Program, and Lunar Terrain Vehicle.

- CHS will maintain the Astronaut Occupational Health Plan that includes clinical certification for 45 active U.S. government Astronauts and health and fitness through training, flight, and post-mission recovery.
- CHS will continue to implement all aspects of the TREAT Astronauts Act, including the TREAT Astronauts Act Board, which assists in determining whether medical conditions are associated with spaceflight.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

- SFCO will direct and manage the astronaut corps and provide trained astronauts for NASA human space flight efforts, including for ISS and Artemis missions. SFCO is targeting 2025 and 2027 for the next ASCAN class selections.
- The current T-38 fleet is projected to be retired in the 2030s. Because replacing the T-38 would require a budgetary expenditure in the hundreds of millions of dollars (even to procure a smaller high-performance fleet), NASA is evaluating more cost-effective alternatives. Additionally, NASA is evaluating options to replace the one-of-a-kind Super Guppy aircraft.
- SFCO will provide support to the crew during launch, landing, recovery, and rescue operations for ISS and Artemis missions. SFCO will support the vehicle hazard safety process to ensure they account for crew and operations safety for all NASA human space flight missions. This includes the completion of Artemis II Safety Hazard Assessment, continued support for Phase II Level Safety Hazard Assessments for all Artemis III and IV elements and all cross program required aspects, development and review of ISS Deorbit Vehicle Safety Hazard Assessment, and the development for CLDP and CCP transportation services and sub-orbital flights.
- SCIFLI team anticipates supporting the Artemis II launch and landing, the SLS Booster descent, all ISS missions (crew and cargo), and several upcoming commercial missions.
- CHS will maintain the Astronaut Occupational Health Plan that includes clinical certification for 41 active U.S. government Astronauts and health and fitness through training, flight, and post-mission recovery in support of ISS mission increments, Artemis II and Artemis III.
- CHS will provide medical and behavioral screening expertise to SFCO in support of the 2025 Astronaut Candidate selections.
- CHS will medically monitor and support U.S. government Astronaut training activities for ISS EVAs, Exploration EMU (xEMU) development, and Artemis lunar surface EVAs. CHS will provide the selected ASCANs training in fundamentals of expeditionary skills and competencies to prepare them to become highly successful astronauts.
- CHS will generate IMPALA data deliverables required for the evaluation of human system risks to enable lunar and Mars missions.
- CHS will support transition to operations of Informing Mission Planning via Analysis of Complex Tradespaces (IMPACT) for exploration missions and programs.

- CHS will maintain the Flight Medicine Clinic tools, resources, equipment, and IT infrastructure, including the Electronic Health Record, to medically certify and maintain the health of the Astronaut Corp.
- CHS will continue the Lifetime Surveillance of Astronaut Health (LSAH) exams with the goal of obtaining a 75 percent participation rate. LSAH exams facilitate the collection of vital retired astronaut data for informing future space missions.

Program Elements

SPACE FLIGHT CREW OPERATIONS (SFCO)

SFCO directs and manages the astronaut corps activities, assigns flight crew, is responsible for human space flight readiness training, and maintains and operates the JSC aircraft fleet, including the T-38 high-performance aircraft, Gulfstream V, and Super Guppy cargo aircraft.

SFCO also determines the need for and selects astronaut candidates. It takes approximately two years from the decision to select a new astronaut class until the selection process is completed. Once selected, new astronauts must complete two years of training for eligibility and then 30 months of ISS training before qualifying for an ISS mission. The number of spacecraft seats U.S. astronauts will fill in the next four years of human space flight determines the manifest requirement. The manifest includes projected Commercial Crew flights to ISS, Commercial Crew test flights, and Artemis flights. Requirements for future missions, for example to Gateway and the Moon, will be planned as those missions become better defined.

Astronaut space flight readiness training activities implemented by SFCO put the crew into operational environments which share some aspects of the fast dynamics, physical stress, and risk found in spaceflight. The training develops the skills and ability to work as a team in an environment that is fast-paced, stressful, and carries potentially severe penalties for failure. The training also includes developing the skills necessary to respond in an emergency/high-stress environment and operate high-performance aircraft and spacecraft.

SCIFLI collects data on in-flight vehicles and can provide mission planning support. They play a part in ensuring the safety of parachutes in SpaceX and Boeing spacecraft, documenting heat shields from high-speed aircraft returning from beyond the Moon, and will be collecting data on important future missions such as Artemis 2, Sierra Space’s DreamChaser, and SpaceX’s Starship. While experimental ground testing and simulations provide incredibly useful data, nothing can replicate the actual conditions of flight. With remote imagery, SCIFLI can collect data on in-flight vehicles in real-time.

CREW HEALTH AND SAFETY (CHS)

CHS enables healthy and productive NASA crew during all phases of spaceflight missions, implements a comprehensive NASA astronaut occupational health care program, and works to understand, prevent, and mitigate negative long-term health consequences from exposure to the spaceflight environment. Using HRP research and other findings, CHS implements enhancements to astronaut occupational health protocols to ensure crew health and safety. In this collaboration, HRP concentrates on the research aspects of crew health, whereas CHS focuses on implementing the research results and mitigation plans into occupational health protocols. As research continues on ISS, CHS is actively seeking new approaches to apply research findings to improve NASA health protocols, including collaborative opportunities with other federal agencies and academia. Further, CHS is implementing the TREAT Astronauts Act for former NASA astronauts. This Act enables NASA to provide monitoring, diagnosis, and treatment to astronauts for spaceflight-related medical issues following retirement from NASA. In addition, NASA will be able to obtain more medical data to supplement the occupational surveillance program for former NASA astronauts and better assess the long-term effects of spaceflight on the human body to enable exploration.

CHS is also responsible for maintaining the health of active NASA astronauts during non-mission periods, focusing on three aspects of health care: preventive care, risk factor management, and long-term health monitoring. CHS integrates and coordinates information relevant to human health before, during, and after spaceflight. CHS documents and assesses all emerging health risks, such as Spaceflight Associated Neuro-ocular Syndrome, a spaceflight condition that affects astronauts eye structure and can lead to impaired vision, and the risk of venous flow changes. CHS continues to collaborate with several non-NASA organizations, including the National Academies, to inform the risk decisions associated with long-duration and exploration missions.

Program Schedule

Date	Significant Event
FY 2024	Continue the annual LSAH exams with the goal of reaching 75 percent of former astronauts.
FY 2025	Select new ASCAN Class

Program Management & Commitments

Program Element	Provider
SFCO	Provider: SFCO Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A
CHS	Provider: CHS Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): N/A

Acquisition Strategy

The section below identifies the current contracts that support SFCO and CHS.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Aircraft Logistics, Integration, Configuration and Engineering	Yulista Tactical	Ellington Field, Houston, TX El Paso, TX
Human Health and Performance Contract	Kellogg Brown & Root	Houston, TX

INDEPENDENT REVIEWS

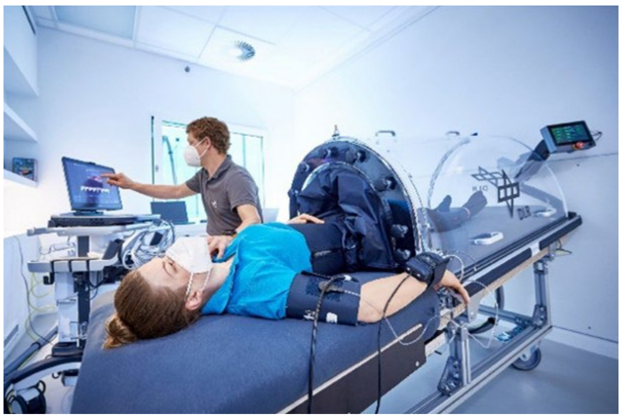
Review Type	Performer	Date of Review	Purpose	Outcome
Performance	JSC AS9100 NQA Audit	Nov 2022	Recertification to AS9100, ensuring quality and safety in Spaceflight Hardware.	JSC was recertified to AS9100

HUMAN RESEARCH PROGRAM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**151.2**	**--**	**143.4**	**155.5**	**155.5**	**156.5**	**159.5**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



A volunteer at the DLR's :envihab facility lies with her head tilted down to simulate the weightlessness of space. A recent study conducted by HRP's researchers had volunteers at :envihad stay in bed with their heads tilted down for 30 days at a time. Data collected is allowing researchers to scrutinize how microgravity on the ISS could affect eye function. (Credit: DLR).

Sending astronauts into space involves a multitude of complicated systems, but perhaps the most complex is the human system: human health, crew interactions, and human factors, which includes how crews interact with their environment, spacecraft, habitat, and systems during missions. While NASA has more than 50 years of crew experience in LEO, researchers are continuing to unravel the mysteries of how the human body responds to the harsh environment of space. The Human Research Program (HRP) is responsible for understanding and mitigating the highest risks to astronaut health and performance to ensure that crews remain healthy and productive during long-duration missions beyond LEO.

Space poses significant health risks for crew members, including the possibility of long-term health effects manifesting later in life from space radiation exposure, health and performance decrements developing during the mission, and decrements in capabilities immediately upon return to Earth. Current research on ISS in LEO and in ground-based analog laboratories is expanding NASA's capabilities to enhance crew performance and protect the health and safety of astronauts. Investigations regarding space radiation protection, deep space habitat systems, behavioral health, innovative medical technologies, advanced food and pharmaceutical systems, space suit requirements, and validated countermeasures are evolving to ensure crew health. HRP also collaborates with NASA’s Office of the Chief Health and Medical Officer (OCHMO), as well as the Crew Health and Safety (CHS) and Spaceflight Crew Operations (SFCO) projects to ensure crew health, safety, and mission success. SFCO and CHS are responsible for astronaut training, readiness, and health, while HRP funds research development on human health and performance countermeasures and technologies that enable safe, reliable, and productive human space exploration. The knowledge gained through HRP’s work and through partnerships will enable NASA’s plans for long-duration human space missions beyond LEO. In addition, as is the case with many space-based medical investigations, this research may lead to significant advancements in treating patients on Earth.

As NASA prepares to conduct crewed Artemis missions to the Moon and to lunar orbiting stations, HRP is using research to develop the scientific and technological capabilities to facilitate these exploration missions. In support of the risk reduction strategy for human space exploration contained in NASA’s

Human Research Roadmap, HRP is coordinating with the National Academies, the National Council on Radiation Protection and Measurements (NCRP), and other domestic and international partners to deliver products and strategies to protect crew health and performance during and after exploration spaceflight missions.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

To accomplish HRP Artemis research goals, HRP strengthened key partnerships at NASA associated with all aspects of spaceflight: from launch and landing to life support systems, task management, and the full Human Health System. Also, HRP worked closely with the Biological and Physical Science Program (BPS) within SMD to build strategic roadmaps related to recommendations within their recently released BPS Decadal Survey.

HRP continued to manage data gathering for all HRP studies on NASA, international, commercial, and private astronaut missions. Most notably, HRP's signature study, called the Complement of Integrated Protocols for Human Exploration Research (CIPHER), began collecting data. CIPHER is the first study to integrate multiple physiological and psychological measures, allowing NASA to assess the whole human response to time spent in space.

A high-priority for NASA is understanding risks to eye health (i.e., Spaceflight Associated Neuro-ocular Syndrome [SANS]). In 2023, HRP 1) completed data collections and began data processing from ground-based bedrest studies conducted at the DLR's :envihab facility; 2) uncovered details about SANS-induced grooves in eye tissue that can impair vision and progressively worsen with duration and repeat flights; and 3) identified structures that could be predictive of eye swelling, known as optic disc edema.

Future deep-space crews must be able to autonomously handle mission tasks and medical emergencies despite communication delays with Earth. Through tests on analog crews, HRP discovered communications systems that allow users to give feedback as communications unfold (human-in-the-loop evaluations) can offset effects of communication delays and keep conversations highly organized. HRP also delivered procedures and tools that can serve as a foundation for medical systems at the future Gateway lunar outpost, effectively transitioning medical authority from terrestrial to space-based assets. HRP is working to integrate this foundation into NASA's current and future medical system design processes.

A crew of four volunteers simulated a trip to the Martian moon, Phobos, without leaving Earth. They entered the Human Exploration Research Analog (HERA) on January 27, 2023, for campaign 6 mission 4. They lived and worked like astronauts for 45 days during their Phobos mission simulation.

HRP select eight research projects chosen from 60 proposals submitted in response to the 2023 Human Exploration Research Opportunities (HERO) Solicitation. They will address numerous spaceflight risks related to muscle and bone health, sex differences, crew autonomy and behavior, balance and disorientation, and inflammation of the brain or spinal cord.

HRP formed partnerships that strengthen our understanding of how radiation exposure affects human health and performance. For example, NASA's BPS Program is collaborating with HRP to support the

Research Opportunities in Space and Earth Sciences research solicitations. To help fill knowledge gaps, new collaborations were also established with the U.S. Navy to perform epidemiological studies on submariners stationed on nuclear submarines and with the U.S. Air Force to examine radiation impact on mini pigs, which are thought to be a more robust model to human responses.

Through the HRP-funded partnership with the Baylor College of Medicine, called the Translational Research Institute for Space Health (TRISH), HRP has funded tissue engineering projects, exploring systems that need not be tended by humans, but are instead analyzed autonomously on future spaceflights. In addition, TRISH's Enhancing eXploration Platforms and Analog Definition (EXPAND) database and biorepository has collected data and bio samples from five commercial spaceflight missions. HRP also forged a Space Act Agreement with SpaceX to conduct research on orbital free-flyers.

WORK IN PROGRESS IN FY 2024

HRP released NASA Research Announcement (NRA), titled HERO–2024, to solicit applied research. The research will fall into one or more categories corresponding to the HRP's five programmatic elements: Space Radiation, Human Health Countermeasures, Exploration Medical Capability, Human Factors and Behavioral Performance, and Research Operations and Integration.

HRP will continue to maximize research through utilization of the Crew Health and Performance Exploration Analog, domestic bedrest facilities, commercial partners, international partners, and the ISS National Lab. HERA Campaign 7, which includes four 45-day missions, 12 HRP studies, six United Arab Emirates studies, and one ESA study, will begin.

Mitigating Artemis-relevant risks—such as injury due to dynamic loads, impact to sensorimotor systems after gravity-transition, and extravehicular activities—remain a science priority for HRP. In FY 2024, researchers have begun developing injury assessments for the neck and spine. These studies will enable more precise prediction of neck and spine injury in a wider range of loading.

Research across the board will also continue to yield information on knowledge gaps and provide recommendations on architecture design. Additional HRP research further assessing SANS, nutrition, immune function, sleep, team dynamics and pharmaceutical stability will also provide deliverables that will help inform crew health and performance for space exploration missions. Radiation quality assessments will enhance research capabilities for individual susceptibility studies. Key partnerships between HRP and the DoD on health surveillance can lead to early detection of long-term health complications after radiation exposure.

In addition, HRP is increasing its participation in the Established Program to Stimulate Competitive Research and the Minority University Research and Education Project. HRP firmly believes that investing in such programs will help acquire new perspectives, ideas, and technologies from new communities that can enhance HRP science.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

HRP plans to deliver models to help predict if spacecraft landing loads will injure crewmembers. For example, calculations using these values will be able to assess the impact of dynamic loads on the neck and spine that crew will experience when landing on the lunar surface.

HRP will advance crew health and medical autonomy by completing testbed scenarios that validate procedure execution and information management. Following this accomplishment, HRP will facilitate joint technology demonstrations of medical capabilities for simulation-based verification and operational performance metrics. These planned outcomes will provide the foundation needed to simulate, model, test and train operators on tasks associated with autonomous medical and performance capabilities. Deliverables from these tasks will provide recommendations on mission architecture, design, and mitigation strategies. Additionally, requirements will be established for Earth-independent medical care and an interactive system that helps ensure crew health.

Key partnerships with the Air Force Research and Navy Research labs that started in FY 2023 will begin to yield results that will provide valuable insight on the impact of human health after exposure to radiation. These results will enhance the characterization of and mitigation strategies for chronic exposure. Radiation research will continue to build on additional long-term health studies, focusing on cancer, cardiovascular disease, and neurocognitive disorders. Utilizing cutting-edge technologies, including omics (e.g., geonomics, microbiome), precision health, pharmacogenomics, and tissue engineering, will help drive HRP research, especially for radiation.

CIPHER will continue to be implemented on ISS missions, providing a full research complement to the impact of microgravity on human bodies over time.

Because fluid shifts in the body can lead to SANS and reductions in cognitive performance, NASA is prioritizing research efforts to better understand how microgravity affects human health. As a result, HRP has extensively investigated viable options for domestic bedrest facilities. Domestic bedrest facilities will enhance research associated with fluid shifts, saving time and money while providing more opportunities to U.S. institutions. The initial research plan is to use these capabilities to study countermeasures for SANS and test exercise technologies that should mitigate fluid shifts on Artemis missions. HRP will also continue to partner with DLR’s :envihab facility for additional bedrest studies needed for SANS research.

Both external and internal partnerships will be critical for meeting HRP objectives. Integration of HRP research into Artemis platforms will involve deep coordination with Orion, Gateway, and Human Landing System programs. Novel technologies and research from BPS and TRISH, particularly on tissue engineering, will help HRP address some human health risks. HRP will extend outreach and collaboration opportunities across government agencies that share common interests in data analysis, behavioral health, 3D tissue models, and radiation.

HRP is strategically aligning itself for working in a new era of commercial space exploration. Significant coordination with NASA and commercial partners will continue as HRP plans for future LEO research. HRP will ensure that future commercial LEO space stations will support important work needed to enable future exploration missions to the Moon and Mars, while also informing NASA on how to overcome the risks of spaceflight under remote and longer duration conditions. HRP will also be poised to support a community of non-NASA astronauts flying in space.

Program Elements

EXPLORATION MEDICAL CAPABILITY

As NASA makes plans to extend human exploration beyond LEO, identifying and testing next generation medical care and crew health maintenance technologies is vital. Healthcare options evolve based on experience, anticipated needs, and input from flight surgeons and crew offices. During future Mars missions, crews will not be able to rely on real-time conversations with Earth-based medical experts due to communication lag-time associated with the distance between Earth and deep space. Therefore, crew and relevant systems will have to be able to facilitate autonomous medical care operations. Teams in this area draft requirements for medical equipment and clinical care, develop remote medical technologies, and assess medical requirements unique to long-duration space missions.

HUMAN HEALTH COUNTERMEASURES

Countermeasures are the procedures, medications, devices, and other strategies that offset the impacts of spaceflight stressors (e.g., low gravity, closed environment) and help keep astronauts healthy and productive during space travel and after their return to Earth. Researchers are responsible for understanding normal physiologic effects of spaceflight and provide biomedical expertise and develop countermeasures to harmful effects on human health and performance. These experts define health and medical standards; validate human health prescriptions and exercise system requirements; develop injury and sickness prevention standards; integrate and validate physiological countermeasures; and establish criteria for NASA fitness for duty, as well as crew selection and performance standards.

HUMAN FACTORS AND BEHAVIORAL PERFORMANCE

Just as the space environment poses physical risks to crewmembers, the unique stresses and challenges of spaceflight, as well as vehicle design, can affect cognitive and mental performance. Considering external factors is essential when designing a spacecraft, habitat, or spacesuit. Human factors experts develop new equipment, procedures, and technologies designed to make the space environment more livable. Behavioral health researchers assess the impact of space travel on human behavioral health and develop interventions and countermeasures to ensure optimal health and performance. Experts in this area make extensive use of analogs, which are experimental environments created to simulate certain aspects of space travel. By duplicating space conditions, such as altered day and night cycles, heavy workloads, social isolation, and close living quarters, scientists gain insight into the impact of these circumstances on human behavior and performance. Scientists then work to develop countermeasures, equipment, and other interventions to minimize these risks.

SPACE RADIATION

As NASA expands human presence beyond the Earth's protective magnetic field, it is critical that astronauts be able to manage the risks associated with living and working in a space radiation environment. Space radiation researchers develop the knowledge base necessary to determine the biological effects of space radiation. This information can then be used for standards for health and habitability and the requirements for radiation protection. They also develop tools to assess and predict risks due to space radiation exposure and strategies to mitigate exposure effects. The deep space radiation environment is far different from that on Earth or in LEO. NASA and the DoE have partnered on a facility at Brookhaven National Laboratory in Upton, NY, to simulate the deep space radiation environment, which researchers use to help understand its biological effects.

RESEARCH OPERATIONS AND INTEGRATION

The ISS provides a unique testbed for HRP activities. The Research Operations and Integration element plans, integrates, and implements HRP-approved biomedical flight experiments on ISS, as well as research studies that use ground-based spaceflight analog facilities to accomplish program objectives.

HUMAN RESEARCH PROGRAM

These experiments and studies pertain to pre- and post-flight activities, and program objectives include coordinating flight or ground resources with our international partners, maintaining the Human Research Facility biomedical research racks on ISS and flight hardware, and developing crew training for both flight and ground investigations. Teams also operate a Telescience Support Center (TSC), which provides real-time support and data services to all HRP flight experiments. Strong interfaces with external implementing organizations, such as the ISS Research Integration office, analog coordination offices, and international partners, are critical to maintaining a robust research program. This group is also responsible for operating the HERA facility and for arranging access to other analog facilities required by HRP researchers, including NSF Antarctic facilities and international partner facilities.

MATURATION AND INTEGRATION OFFICE

The Maturation and Integration Office (MIO) has the responsibility for coordinating HRP research and technology deliverables with its stakeholders. This office provides strategic planning for Artemis, Mars, and Commercial Spaceflight research opportunities. This office further fosters relationships with OCHMO, Artemis missions, and Flight Operations Directorate to ensure HRP is addressing high priority operational research questions that can reduce risks or provide additional trade space for those organizations. As OCHMO and the agency stand up a recognized "Crew Health and Performance System" for exploration missions, this office will integrate models and technology deliverables along with our operational spaceflight partners.

Program Schedule

Date	Significant Event
Jan 2024	HERA Campaign 7 begins
Jun 2024	HERO 2024 selections announced
Jul 2024	HERO 2025 release of NRA
Apr 2025	HERO 2025 selections announced

Program Management & Commitments

The program office is located at JSC with support from ARC, GRC, LaRC, and KSC.

The SOMD Associate Administrator delegated the authority, responsibility, and accountability of HRP management to the Human Spaceflight Capabilities Division at NASA HQ. Working closely with the Office of the Chief Scientist and the OCHMO, the Division establishes overall direction, scope, budget, and resource allocation for the program, which NASA centers then implement.

Program Element	Provider
Exploration Medical Capability	Provider: JSC Lead Center: JSC Performing Center(s): GRC, ARC, and LaRC Cost Share Partner(s): N/A

Program Element	Provider
Human Health Countermeasures	Provider: JSC Lead Center: JSC Performing Center(s): ARC and GRC Cost Share Partner(s): N/A
Human Factors and Behavioral Performance	Provider: JSC Lead Center: JSC Performing Center(s): ARC, GRC, and KSC Cost Share Partner(s): N/A
Space Radiation	Provider: JSC Lead Center: JSC Performing Center(s): LaRC Cost Share Partner(s): N/A
Research Operations and Integration	Provider: JSC Lead Center: JSC Performing Center(s): N/A Cost Share Partner(s): N/A
Maturation and Integration Office (MIO)	Provider: JSC Lead Center: JSC Performing Center(s): ARC and GRC Cost Share Partner(s): N/A

Acquisition Strategy

Based upon National Academies' recommendations, external peer reviews, and agency human exploration plans, NASA HRP awards contracts and grants to further efforts in mitigating risks to crew health and performance by providing essential biomedical government research and technologies for human space exploration. HRP uses a peer review process that engages leading members of the research community to competitively assess the merits of submitted proposals to assure a high-quality research program.

HRP releases the HERO umbrella NRA that requests research proposals across all its research elements throughout the year. This NRA provides opportunities for universities, other agencies, and industry researchers from across the nation to develop NASA's high-priority ground and spaceflight experiments, which directly contribute to NASA's exploration mission.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Program Management	Translational Research Institute for Space Health	Baylor College of Medicine

Element	Vendor	Location (of work performance)
Research Operations and Integration	DLR	:envihab facility in Cologne, Germany
Space Radiation	U.S. DoE	Brookhaven National Laboratory

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Quality	National Council on Radiation Protection and Measurements (NCRP)	Jan 2022	Sex-differences in Lung Cancer Radiation Risks for use in Project Models	Reduced uncertainties and improved information for cancer risk projections.
Quality	Peer Review Panel	Feb 2022	Peer review of NRA	Selected grantees

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FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**93.9**	**--**	**104.3**	**96.6**	**96.9**	**97.2**	**99.1**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

A SpaceX Falcon Heavy rocket, with the Psyche spacecraft onboard, is launched from Launch Complex 39A on October 13, 2023, at KSC in Florida. NASA's Psyche spacecraft will travel to a metal-rich asteroid by the same name orbiting the Sun between Mars and Jupiter to study its composition. Psyche is the first LSP-managed mission to launch on a Falcon Heavy rocket.

NASA's science and discovery missions, civil communications, geographic survey, and civil weather missions provide key services for our nation and the world. The Launch Services Program (LSP) ensures access to space for the nation's civil sector satellite and robotic planetary missions.

National Space Transportation Policy identifies the NASA Administrator as the launch agent for the nation's civil sector. LSP enables the Administrator to execute this role by acquiring and managing domestic commercial launch services for assigned missions, certifying new commercial launch vehicles for readiness to fly high-value spacecraft, performing mission design and launch integration activities, and directing launch mission assurance efforts to ensure the greatest probability of launch mission success. While no space mission is routine, LSP has unique launch system expertise involving payloads containing nuclear power sources for launching one-of-a-kind science exploration missions to other planets, the Sun, or other locations in space. NASA relies on LSP to provide robust, reliable, and cost-effective launch services via commercial launch providers. NASA achieves assured access to space through a competitive mixed-fleet approach utilizing the breadth of U.S. industry capabilities. In addition, LSP provides launch-related expertise to other NASA programs, such as Commercial Resupply Services, Commercial Crew Program (CCP), and programs supporting the Artemis missions. LSP also provides launch advisory support to NASA payload missions using launch services through other government agencies, the launch industry, or international partners.

In addition to acquiring the commercial launch service, LSP arranges pre-launch spacecraft processing facility support and communications and telemetry during ascent for its customers. LSP offers insight into the commercial space launch industry, which has been utilized by CCP. LSP also tracks lessons learned to identify and mitigate risks for future managed launches and certifies readiness of new commercial launch vehicles for NASA and other civil sector, uncrewed spacecraft. The program also conducts engineering analyses and other technical tasks to maximize launch success for every assigned payload.

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Further, as part of NASA's launch site risk mitigation efforts, NASA is studying safety issues associated with a new generation of launch vehicles that use liquid oxygen and methane propellants. The Liquid Oxygen and Methane Assessment (LMA) Project is responsible for assembling data collection, which is beneficial for risk-based considerations of spacecraft survivability. The LMA project will coordinate with NASA mission directorates and U.S. government agencies to run concurrent testing, share the data, and gain access to previously tested raw data to further understand hazards and risks associated with liquid oxygen and methane propellants.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

LSP provided expertise and active launch mission management for over 70 NASA scientific spacecraft missions in various stages of development. LSP continuously works with the U.S. commercial launch industry to assess their designs and provide advice, which expands the selection of domestic launch vehicles available to NASA's missions and nurtures a competitive commercial launch service environment. LSP successfully launched one weather satellite for NOAA and two science missions as shown in the table below.

Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
Nov 2022 Vandenberg Space Force Base, CA	Atlas V	Joint Polar Satellite System (JPSS)-2 and LEO Flight Test of an Inflatable Decelerator (LOFTID)	NASA NOAA/ SMD and LaRC	JPSS-2 is the second of NOAA's latest generation of U.S. polar-orbiting, non-geosynchronous, environmental satellites. The satellite provides global observations that serve as the backbone of both short- and long-term forecasts, including those that help us predict and prepare for severe weather events. LOFTID flew with JPSS-2 as a secondary to demonstrate inflatable heat shield technology.
Dec 2022 Vandenberg Space Force Base, CA	Falcon 9	Surface Water and Ocean Topography (SWOT)	NASA SMD	The SWOT mission is focused on a better understanding of the world's oceans and its terrestrial surface watery. The satellite will collect detailed measurements of how water bodies on Earth change over time.

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Launch Date/Location	Launch Vehicle	Payload	Customer	Mission Objectives
May 2023 New Zealand	Electron	Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS)	NASA SMD	A constellation of 3U CubeSats, that will measure temperature and moisture profiles and precipitation in tropical systems with unprecedented temporal frequency.

LSP acquired a new launch service for one future mission, Sentinel-6B, through a competitively awarded launch services task order under the NASA Launch Services (NLS) II contract. In addition, LSP acquired four new Class D launch services under the Venture-Class Acquisition of Dedicated and Rideshare (VADR) contract. Under VADR, LSP provides a broad range of commercial launch services capable of delivering NASA's high risk tolerant payloads, ranging from Class D payloads to higher risk-tolerant payloads, including CubeSats, to a variety of orbits. These Federal Aviation Administration (FAA) licensed Class D and small satellite payloads tolerate relatively high risk and serve as an ideal platform for technical and architecture innovation, contributing to NASA's science research and technology development, in addition to fostering a growing U.S. commercial launch market.

LSP continued partnering with universities, non-profits, and NASA centers to launch small research satellites through the CubeSat Launch Initiative (CSLI), which provides rideshare opportunities for small satellite payloads to fly on upcoming launches when excess capacity is available. These partnerships have provided regular educational opportunities for students in Science, Technology, Engineering, and Mathematics (STEM) disciplines, which help strengthen the nation's future workforce. As of the end of FY 2023, over 150 CubeSats have been launched from 34 states, the District of Columbia, and Puerto Rico, with 55 CSLI-sponsored CubeSats preparing for upcoming launches on NASA, other U.S. agencies, ESA, and commercial missions. In FY 2023, nine CSLI-sponsored CubeSats were launched.

The 2022 NLS II on-ramp activity commenced in Q1 FY 2022 and evaluations of proposals are underway. An on-ramp synopsis for the 2023/2024 NLS II on-ramp activity was released Q4 FY 2023 to gauge industry interest. A number of companies have expressed intent to on-ramp new launch services. The Delta II Closeout/Space Launch Complex (SLC) 2 Demolition work continued at Vandenberg Space Force Base (VSFB) in California. Demolition of the Mobile Service Tower was completed in December 2020, and the SLC-2 launch pad was turned over to the Space Force who then leased the pad to Firefly. Along with the launch pad, there are 16 real properties (buildings across the greater SLC-2 complex) that need to be demolished at NASA's cost. A contract was awarded by the 30th Space Wing in September 2021 to demolish three of the 16 buildings that NASA is responsible to demolish per the cost sharing agreement signed between NASA and the United States Air Force (now the United States Space Force) in May 2019. The contract for demolishing the remaining thirteen buildings was awarded in November 2022. The final cost sharing agreement memorandum (Delta II Facilities Disposition Cost Sharing Project Completion) was signed by the VSFB Space Force commander on April 23, 2023. The purpose of the signed letter was to validate that NASA has fulfilled its obligation to fund the demolition of assigned facilities per the renegotiated cost sharing agreement signed on May 1, 2019. NASA's portion of the cost sharing agreement has hereby been met with no further funding/obligation required for any Delta II facilities disposition.

WORK IN PROGRESS IN FY 2024

LSP will continue to execute the role of launch agent for the NASA Administrator on behalf of the U.S. civil sector, as described in the National Space Transportation Policy. The program will provide management of NLS contracts, launch mission assurance, mission design, and launch integration support to scientific and technology spacecraft missions in various development phases. The TROPICS mission is one example of how LSP supports and manages launch services. On February 10, 2022, Astra Space Inc. failed to deliver the Mission One TROPICS payload to orbit. In July 2022, Astra formally notified NASA LSP of their intention to discontinue Rocket 3.3 and move directly into development of Rocket 4.0. In August 2022, NASA decided to de-manifest the remaining TROPICS payloads from Astra's Rocket 3.3 under the Venture Class Launch Services (VCLS) Demo 2 contract, and to seek alternative launch opportunities through the VADR contract process. On November 23, 2022, the task order for the remaining two TROPICS payloads was awarded to Rocket Lab USA Inc. of Long Beach, California, under the VADR contract. In May 2023, the pair of TROPICS-2 and TROPICS-3 spacecraft successfully launched aboard two Electron rockets from Rocket Lab's Launch Complex 1 Pad B in Māhia, New Zealand, completing the constellation. The current manifest for FY 2024 shows LSP will manage and conduct launch activities for three NASA missions contracted under NLS II, one VCLS Demo 2 mission, and two NASA missions under VADR, as shown in the table below.

Contract Mechanism	Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
NLS II	Oct 2023 KSC, FL	Falcon Heavy	Psyche	NASA SMD	The Psyche mission will journey to a unique metal-rich asteroid, also named Psyche, which orbits the Sun between Mars and Jupiter. The asteroid is considered unique, as it appears to largely be made of the exposed nickel-iron core of an early planet – one of the building blocks of our solar system.

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Contract Mechanism	Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
NLS II	Jan 2024 Cape Canaveral Space Force Station, FL	Falcon 9	Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)	NASA SMD	The PACE mission represents the nation's next great investment in understanding and protecting our home planet. The mission will provide global ocean color, cloud, and aerosol data that will provide unprecedented insights into oceanographic and atmospheric responses to Earth's changing climate. PACE will help scientists investigate the diversity of organisms fueling marine food webs and the U.S. economy and deliver advanced data products to reduce uncertainties in global climate models and improve our interdisciplinary understanding of the Earth system.
NLS II	Apr 2024 KSC, FL	Falcon Heavy	Geostationary Operational Environmental Satellite U (GOES-U)	NOAA and NASA SMD	GOES-U is a planned weather satellite, the fourth and last of the GOES-R series of satellites, operated by NOAA. The GOES-R series will extend the availability of the Geostationary Operational Environmental Satellite system until 2036.
VCLS Demo 2	No Earlier Than (NET) Mar 2024 Under Review Vandenberg Space Force Base, CA	Firefly Black LLC Alpha	VCLS Demo 2 (Mission Two: [1] 75 kg payload, 550 km Sun Synchronous Orbit (SSO); and [2] 20 kg to 550 km SSO w/ min 10-degree plane change)	NASA, one STEM school, and multiple universities	VCLS is a demonstration flight to determine if new small launch vehicles can deliver NASA payloads to orbit at a fixed price.

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Contract Mechanism	Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
VADR	May 2024 Māhia, New Zealand	Electron	Polar Radiant Energy in the Far-InfraRed Experiment (PREFIRE)	NASA SMD	PREFIRE will quantify the radiative processes effected by changing temperatures in the Arctic and will reveal new aspects of the Arctic climate by measuring the full spectrum of polar radiant energy.
VADR	Aug 2024 Cape Canaveral Space Force Station, FL	New Glenn	Escape and Plasma Acceleration and Dynamics Explores (ESCAPADE)	NASA SMD	The Escape and Plasma Acceleration and Dynamics Explorers (EscaPADE) are a dual-spacecraft mission to study ion and sputtered escape from Mars.

**FY 2024 Launch Dates shown in this table correspond to launch dates listed as Management Agreements elsewhere in this document.*

Psyche, the first LSP managed mission on a Falcon Heavy, successfully launched from KSC on October 19, 2023.

LSP will continue work towards certifying new commercial launch vehicles to launch high-value payloads, as needed, and will continue launch service acquisition activities necessary to support NASA and other approved government missions.

Along with full end-to-end launch service management of awarded missions, LSP continues to offer advisory support, expertise, and knowledge to NASA programs and projects utilizing launch services not procured and managed by LSP. The program is currently providing these advisory and informational services to several programs and missions, including:

- Gateway;
- Human Landing Systems;
- ISS Commercial Resupply Services;
- Commercial Crew Program; and
- NASA-ISRO Synthetic Aperture Radar mission (NISAR).

The LMA Project will continue to conduct tests and generate data to further understand the hazards and risk associated with liquid oxygen and methane through the various test series.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

LSP will continue to execute the role of launch agent for the NASA Administrator on behalf of the U.S. civil sector, as described in the National Space Transportation Policy. LSP will work with the U.S. commercial launch industry to assess their designs and provide advice, which expands the selection of domestic launch vehicles available to NASA's missions and nurtures a competitive commercial launch service environment. The program will provide management of NLS contracts, launch mission assurance,

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mission design, and launch integration support to scientific spacecraft missions in various development phases. The current manifest for FY 2025 shows LSP will manage and conduct launch activities for three NASA missions contracted under NLS II and two NASA missions contracted under VADR.

Contract Mechanism	Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
NLS II	Oct 2024 KSC, FL	Falcon Heavy	Europa Clipper	NASA SMD	NASA's Europa Clipper will conduct detailed reconnaissance of Jupiter's moon, Europa, and investigate whether the icy moon could have conditions suitable for life.
NLS II	Feb 2025 Cape Canaveral Space Force Station, FL	Falcon 9	Interstellar Mapping and Acceleration Probe (IMAP), with Space Weather Follow-On L1 (SWFO-L1) 2nd and Carruthers 2nd	NASA SMD (IMAP and Carruthers) NOAA and NASA SMD (SWFO-L1)	IMAP will simultaneously investigate two important and coupled science topics in the heliosphere: the acceleration of energetic particles and interaction of the solar wind with the local interstellar medium.
NLS II	Feb 2025 Vandenberg Space Force Base, CA	Falcon 9	Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx), with Polarimeter to Unify the Corona and Heliosphere (PUNCH 2nd)	NASA SMD	SPHEREx will survey hundreds of millions of galaxies near and far, some so distant their light has taken 10 billion years to reach Earth. Astronomers will use the mission to gather data on more than 300 million galaxies, as well as more than 100 million stars in our Milky Way.
VADR	Feb 2025 Vandenberg Space Force Base, CA	Falcon 9	Total and Spectral Solar Irradiance Sensor 2 (TSIS-2)	NASA SMD	TSIS-2 will measure the Sun's energy input to Earth.

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Contract Mechanism	Launch Date/Location*	Launch Vehicle	Payload	Customer	Mission Objectives
VADR	NET Apr 2025 Vandenberg Space Force Base, CA	Falcon 9	Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS)	NASA SMD	TRACERS aims to answer long-standing questions critical to understanding the Sun-Earth system. The spinning satellites will study how solar wind, the continuous stream of ionized particles escaping the Sun and pouring out to space, interacts with the region around Earth dominated by our planet's magnetic field.

**FY 2025 Launch Dates shown in this table correspond to launch dates listed as Management Agreements elsewhere in this document.*

The LMA project will close out activities and provide the final optimized data analysis and recommendation on the safety issues associated with the new generation of launch vehicles that use liquid oxygen and methane propellants.

Program Management & Commitments

Program Element	Provider
Commercial Launch Vehicle (CLV) Launch Services	Provider: ULS, Northrop Grumman Innovation Systems (NGIS, formerly Orbital ATK), SpaceX, Rocket Lab USA, Virgin Orbit, Firefly Black, Relativity Space, Blue Origin, ABL Space Systems, Astra Space Inc., L2 Solutions, LLC, Phantom Space Corporation Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A

ACQUISITION STRATEGY

LSP's acquisition strategy was created for the original NLS contracts for procuring CLV launch services from domestic commercial launch service suppliers. To meet the needs of science and technology customers who typically spend three to seven years developing a spacecraft mission, NASA created a contractual approach providing multiple competitive launch service options to cover small-, medium-, intermediate-, and heavy-sized missions. The follow-on contract mechanism, NLS II, has similar contract features. These features include not-to-exceed prices, indefinite-delivery-indefinite-quantity contract terms, and competitive firm-fixed-price launch service task order-based acquisitions. The NLS II ordering period has been extended to June 30, 2030, to ensure active competition for NASA customers and encourage new launch capability development through these long-term contracts, NASA provides annual

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opportunities to U.S. industry to add new commercial launch service providers and/or launch vehicles to the contract.

LSP is also able to contract separately from the NLS contract mechanism if such an approach is necessary to meet a mission or customer need. For instance, the launch service for the Europa Clipper mission funded by NASA SMD was competed outside and separate from the NLS II contract due to the special needs of that mission. In addition, VCLS awards for very small launch vehicles were conducted outside and separate from the NLS II contract to provide more flexibility to the new, small class launch providers.

NASA has also made efforts to provide a complete launch service, including payload processing at the launch site. LSP uses firm-fixed-price indefinite-delivery-indefinite-quantity contracts for commercial payload processing capabilities on both the east and west coasts. The Payload Processing Facility contracts were recompeted and the Spacecraft Processing Operations Contract (SPOC) was awarded on February 7, 2023. SPOC is a five-year contract with a five-year option (10 years total). The contract currently has two providers, SpaceX and Astrotech, with an on-ramp option to bring more qualified providers.

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MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
NLS II-Blue	Blue Origin	Kent, WA KSC, FL
NLS II-O	Northrop Grumman Systems Corporation	Chandler, AZ
NLS II-S	SpaceX	Hawthorne, CA
NLS II-U	United Launch Services, LLC	Centennial, CO
East Coast Commercial Payload Processing	Astrotech Space Operations	Titusville, FL
Expendable Launch Vehicle Integrated Support 3	a.i. Solutions, Inc.	KSC, FL Cape Canaveral Space Force Station, FL Vandenberg Space Force Base, CA
Europa Clipper Launch Services	SpaceX	Hawthorne, CA
SPOC	SpaceX Astrotech Space Operations	Hawthorne, CA Titusville, FL
Venture Class Demonstration 2 (VCLS Demo 2)	Astra Space Inc. Relativity Space Inc. Firefly Space Transport Services	Alameda, CA Long Beach, CA Cedar Park, TX
Venture-Class Acquisitions of Dedicated and Rideshare (VADR)	ABL Space Systems Astra Space Inc. Blue Origin Florida LLC Firefly Space Transport Services, LLC L2 Solutions LLC Northrop Grumman Systems Corporation Phantom Space Corporation Relativity Space Inc. Rocket Lab USA Inc. SpaceX United Launch Services LLC Virgin Orbit LLC	El Segundo, CA Alameda, CA Merritt Island, FL Cedar Park, TX Houston, TX Chandler, AZ Tucson, AZ Long Beach, CA Long Beach, CA Hawthorne, CA Centennial, CO Long Beach, CA

ROCKET PROPULSION TEST

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	48.2	--	48.6	48.6	48.6	48.6	48.6

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Shown here, NASA conducts an RS-25 hot fire test on the Fred Haise Test Stand at SSC in south Mississippi on June 22, 2023.

Developing and testing rocket propulsion systems is foundational to spaceflight. Whether the payload is a robotic science experiment or a crewed mission, the propulsion system used to launch it must be safe and reliable. A rigorous engine test program is a critical component of any rocket propulsion development activity.

NASA's Rocket Propulsion Test (RPT) program maintains and manages a wide range of facilities capable of ground testing rocket engines and components under controlled conditions. This test infrastructure includes facilities located across the United States, and the program provides a single-entry point for any user of NASA rocket test stands. RPT retains a skilled workforce capable of performing tests on all modern-day rockets and supporting complex rocket engine development. RPT evaluates customer test requirements and desired outcomes while minimizing test time and costs. It also streamlines facility usage and eliminates redundant capabilities by closing and consolidating NASA's rocket test facilities, as appropriate.

RPT is NASA's implementing authority for rocket propulsion testing. It approves and provides direction on test assignments, capital improvements, and facility modernization and refurbishment to reduce propulsion test costs. RPT integrates multi-site test activities, identifies and protects core capabilities, and develops advanced testing technologies.

The agency has designated RPT as the NASA representative for the National Rocket Propulsion Test Group (NRPTG), an inter-agency collaboration with the DoD, to facilitate efficient and effective use of the federal government's rocket propulsion test capabilities. The NRPTG is a standing group within the Range Commanders Council.

For more information, go to: https://rpt.nasa.gov/

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

In 2023, RPT test facilities continued to support NASA, commercial, DoD, and NASA international partner requirements for purposes of component, engine, and rocket stage level of testing. RPT delivered test capabilities to support technology advancement, capability demonstration, risk retirement, and hardware qualification and launch readiness for more than 700 tests (over 57,000 seconds).

RPT placed priority on testing rocket engines and components for NASA and its collaborative commercial partners on the Artemis missions and continued to provide testing of the Space Launch System (SLS) RS-25 core stage engines in the A-1 Test Stand at SSC in Mississippi. This testing provided performance data on redesigned engines to be used beginning with Artemis V. Modifications were made to the SSC B-2 Test Stand throughout FY 2023, in support of an integrated four-engine stage test of the Exploration Upper Stage (EUS) and its plume management system. The 75-ton interstage test article, an important element of this planned test, arrived and was mounted into the test stand in preparation of integration of the continued RL-10 EUS engines.

At MSFC, testing supported both NASA internal and NASA collaborative projects to advance manufacturing and development techniques through the testing of engine components, including rocket nozzles. MSFC conducted testing in evaluation of liquid rocket engines for landers, on-orbit stages, and spacecraft, as well as solid rocket motors. White Sands Test Facility (WSTF) supported NASA, international partners, and commercial and defense customers with hot firings, acceptance testing, and qualification of thrusters and thruster system components. Testing at WSTF also supported developmental thrusters that advanced low-temperature operations and nano-satellite propulsion. Demilitarization support for Minuteman III propulsion stages deactivation also continued. At GRC's Armstrong Test Facility (ATF), preparations for proto-qualification testing of the Sierra Space Dream Chaser Cargo System (DCCS) in the In-Space Propulsion Facility (ISPF) continued, as well as vacuum testing to support a federal partner. The first DCCS ISS cargo mission is currently planned to launch in FY 2024.

The expanding commercial space market drew on RPT capabilities. Companies supported included: Axiom Space, Boeing, Blue Origin, Dynetics, Vast, Relativity Space, Rocket Lab, Sierra Space, and Ursa Major. Commercial industry also expanded the number of test facilities leased from the agency. With NASA requirements for large engine testing diminishing, two legacy large engine test stands (A2 and A3) at SSC, with no known near-term government demand, were leased to commercial tenants. Elsewhere at SSC, test activity in the E-Complex, a versatile multi-user complex for development testing, supported a variety of commercial engine, turbo-pump, thruster, and component test requirements. The partnering agreements will facilitate substantial capital investment in upcoming years, provide cost sharing offsets (savings) in operations and maintenance of common test support, and create dozens of jobs, which in turn helps to transition SSC to a vibrant multi-user RPT Center.

Investments in FY 2023 predominately supported multi-year projects, such as the High-Pressure Gas Facility and the High-Pressure Industrial Water control system upgrades and data acquisition system upgrades at multiple centers.

WORK IN PROGRESS IN FY 2024

RPT continues testing of the RS-25 engines used in powering the SLS rocket in support of Artemis missions. Building off previous hot fire testing, RPT will conduct a final certification series of 12 tests in the A1 Test Stand at SSC beginning in the fall of 2023 and extending into 2024. Six of the 12 tests have been completed. This test series will collect data on new key components, including the nozzle, hydraulic actuators, flex ducts, and turbopumps. The test series will help confirm that new manufacturing processes reliably support production engine requirements for the new set of the engines for the SLS. Work also continues at SSC to ready the B-2 Test Stand for the integrated stage test of the EUS, enabling the SLS to send large cargos to the Moon and Mars. In late 2023, at the E-1 complex at SSC, a high-pressure hydrogen vent line was discovered to have shifted from its original position. Repair of the line may impact two commercial customers planning testing in 2024. The RPT program and SSC are evaluating options to adjust operations to meet minimum test requirements, as well as options to minimize any downtime and return the stand to full operations within current resources.

NASA continues advancing technologies and innovative production processes using various additive manufacturing techniques to develop lightweight, reliable combustion chambers, nozzles, and injectors. Hot fire testing is used to validate operability, performance, and reusability. RPT test facilities at MSFC continue to conduct testing on innovative designs and technologies such as the Rotating Detonation Rocket Engine, a project which integrates advance technology and additive manufacturing techniques. SLS subscale RS-25 oxidizer pre-burner testing will also be performed at MSFC to identify the performance of additively manufactured component designs relative to the traditionally machined processes. Commercial requirements, such as planned testing of a Blue Origin turbopump assembly, will be conducted as well.

RPT testing at WSTF, principally centered on testing and evaluating potentially hazardous materials, spaceflight components, and in-space propulsion systems, remains very active. Preparatory work is underway on a multi-year effort for evaluation of Gateway propellant vent freezing in advance of later Test Stand 405 testing. Other demand in 2024 includes initiation of a multi-year effort for Orion main engine development, qualification, and acceptance testing at Test Stand 403.

At GRC's ATF, proto-qualification testing of the Sierra Space DCCS in the ISPF is planned to be completed.

The above content is a representative capturing of testing demand. Additional requirements exist and more will come in during the year as has been the historical trend. FY 2024 looks to have a stable and high level of engine/component test requirements across the breadth of RPT's test regimes. However, RPT does continue to right-size its facilities, consistent with where it sees future demand, and is working with GRC to develop alternative plans for the Lewis Field Altitude Combustion Stand (ACS) and Cell 32 rocket test facility, both of which have been mothballed for several years.

Multi-year multi-center control system and data acquisition investments continue to represent the highest priority usage of modernization resources in 2024.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

Testing to support Artemis launches and flight systems will continue to be the predominant focus of the RPT Program. Readiness of the B-2 Test Stand for EUS testing will be paramount. EUS stage testing, like the Green Run test performed on the first SLS core stage prior to its initial launch, will be the first integrated test of the EUS. Multiple firings of the four RL-10 engine set are planned to demonstrate engine restart capability.

In support of the Human Landing System program, modifications to meet qualification test requirements for the Blue Origin Lunar Lander propulsion system will be underway at the GRC ATF ISPF. FY 2025 work includes restoration activities associated with the ISPF steam system and condensing water systems to restore the ability to hot fire test an engine with up to 30,000 pounds of force and implementation of other test-specific integration requirements.

The multi-year requirements, such as those supporting Orion, Gateway, and long-term efforts in support of demilitarization of Minuteman III propulsion stages at WSTF, will continue through 2025. Testing of advanced technologies and newly developed NASA and commercial engines, thrusters, and components is expected to be remain strong and will introduce new requirements yet to be defined for the utilization schedules provided below.

The timing and nature of the test support needs of commercial test providers, including the Pre-Exploration Production and Operations Contract implementation phase, will be better understood in FY 2025.

RPT pricing and cost recovery policies, resulting from changes in sharing the cost of RPT provided test support services, and decisions on how to apply the cost of maintenance to test customers, should be in place, posturing RPT to apply a greater level of its resources toward strategic investments. Specific requirements for enabling services to be provided (such as high-pressure water, high-pressure gas, and cryogenics) in support of commercial testing stemming from the lease of test stands A2 and A3 at SSC are not mature enough to project at this time.

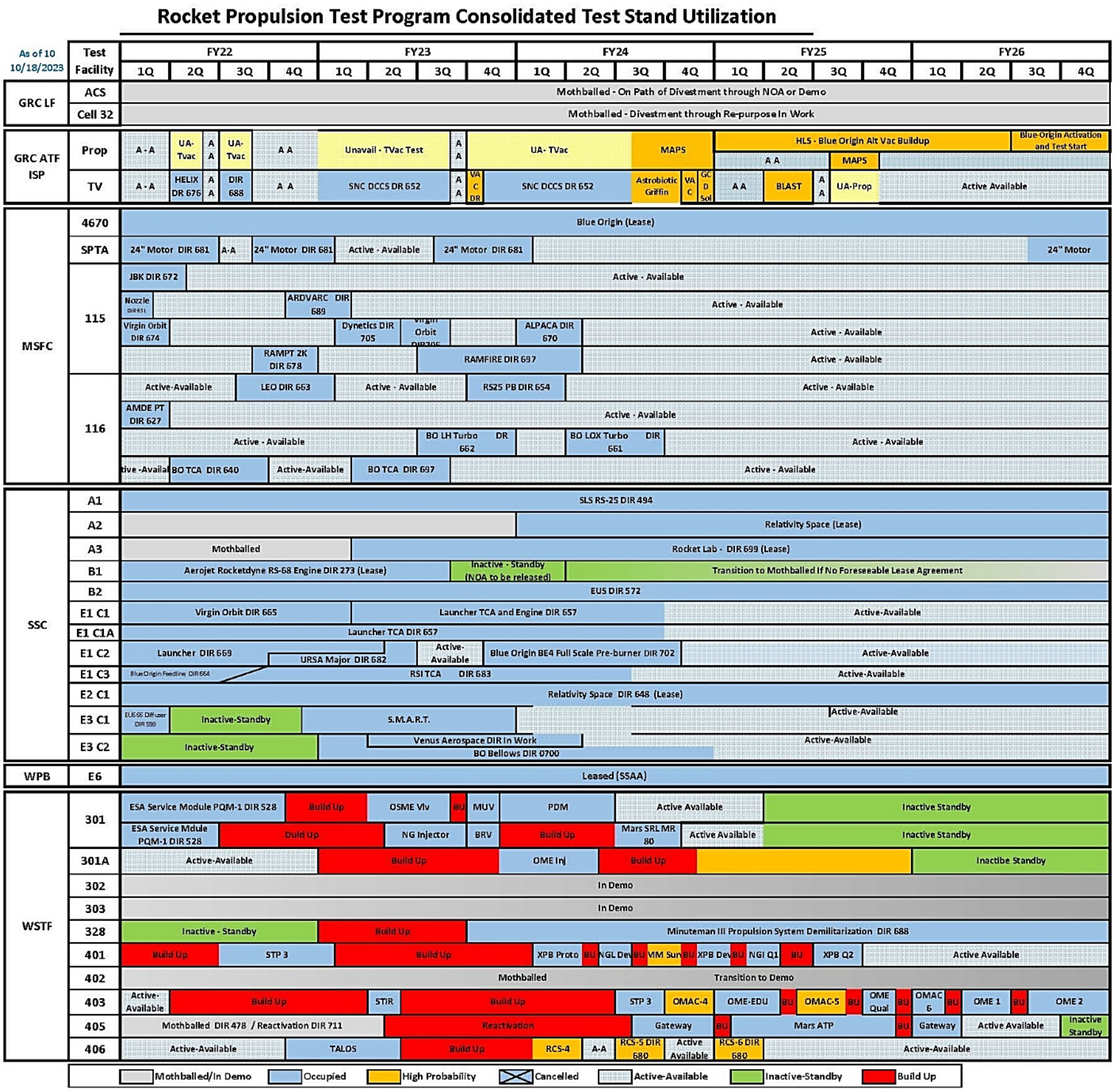
Reassessment of the RPT test infrastructure to posture it best for agency continuing needs remains a focused long-term planning effort. The ability for RPT to re-architecture the very-aged test support facilities at SSC to increase affordability and reliability will depend on additive resources. The RPT program budget has historically required institutional, and/or mission/customer cost-sharing to fund major repair or modernization projects. RPT design architecture development studies to inform decisions for architecture reinvestment will support future agency decisions and budget requests that may enable reduction in future Operations and Maintenance burden to RPT and its test customers.

Program Schedule

The following chart shows past, current, and planned test campaigns at SSC, MSFC, GRC, and WSTF rocket propulsion test facilities. The designations at the far left of the chart refer to the facility, the top of the chart shows time by quarter of fiscal and calendar year, and the key to the status of each facility appears at the bottom of the chart.

Most test stands and facilities are scheduled 18 months in advance. Defining the scope of work, selecting test stands and fuel, and estimating labor and total cost to customers is a complex process that can take 18 to 36 months. RPT is working now with internal and external customers to design testing programs for FY 2025 and beyond.

ROCKET PROPULSION TEST



ROCKET PROPULSION TEST

PROGRAM MANAGEMENT & COMMITMENTS

Program Element	Provider
RPT	Provider: RPT Lead Center: N/A Performing Center(s): SSC, JSC, GRC, MSFC, KSC, Wallops Flight Facility (WFF) Cost Share Partner(s): Various other NASA programs, DoD, and commercial partners

ACQUISITION STRATEGY

None.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None. In the governance structure, the RPT program is assessed for performance through the SOMD Program Management Council. All Capability Portfolio programs are also assessed annually by the MSD Strategic Investment Board.

COMMERCIAL LEO DEVELOPMENT

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**224.3**	**--**	**169.6**	**302.3**	**435.2**	**465.2**	**629.3**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Commercial LEO Destinations are shown here. CDISS: a) Axiom Space, Inc (far left); CDFF: b) Blue Origin's Orbital Reef (middle), c) Nanoracks, Voyager Space, and Airbus (far right) Credit: Axiom Space, Inc, Blue Origin, Nanoracks, and Voyager Space.

NASA seeks to maintain access to a LEO human-rated platform to continue U.S. human presence – with both government astronauts and private citizens – to support the utilization of space by U.S. citizens, companies, academia, and international partners, as well as to expand the American foothold in space. To successfully meet NASA's Strategic Goals and Objective 2.2, to “Develop a human spaceflight economy enabled by a commercial market", NASA established the Commercial LEO Development Program as a focused effort to ensure there will be a U.S. space station in LEO that meets NASA’s enduring requirements, even after the ISS is retired. In meeting NASA’s requirements, this program will also help develop a robust commercial space economy in LEO that supports good-paying jobs.

The Commercial LEO Development Program supports the development of commercially owned and operated LEO destinations from which services can be purchased that meet NASA’s requirements and those of other customers. As commercial LEO destinations (CLDs) become available, NASA intends to implement an orderly transition from ISS operations to new CLDs. The current strategy builds on and applies lessons learned from over a decade of partnerships with commercial companies. The transition of LEO operations to the private sector will yield efficiencies in the long term, enabling NASA to shift resources towards other objectives.

NASA has pursued several avenues to enable the LEO economy. These include offering use of an ISS berthing port to Axiom Space to deploy a new commercial element on the ISS, Commercial Destinations for ISS (CDISS); supporting development and use of Commercial Destinations Free Flyers (CDFF); offering use of the ISS for Private Astronaut Missions; and fostering development of crucial technologies that enable a robust LEO economy through the Collaborations for Commercial Space Capabilities (CCSC) initiative.

NASA is utilizing a two-phase award approach to ensure a seamless transition of activity from the ISS to commercial destinations. In the first phase, NASA is partnered with three companies (Blue Origin, Nanoracks, and Axiom Space) to formulate and design commercial LEO destination capabilities suitable for potential government and private sector needs. The first phase is expected to continue through 2025.

NASA awarded Space Act Agreements (SAAs) to three companies (Blue Origin, Nanoracks, and Northrop Grumman) in December 2021 to develop CLDs that are launched directly to orbit (i.e., free-flyers). In FY 2023, Northrop Grumman agreed to withdraw from its own funded SAA so the company could join Nanoracks in providing cargo logistics services and engineering services.

Nanoracks' commercial LEO destination, in collaboration with Voyager Space, is called Starlab. Starlab consists of a large habitat with a docking node, power and propulsion element, and external robotic arm. The Starlab architecture will consist of a single launch, targeted for 2027, with an initial operating capability of four crew. In FY 2023, Voyager Space and Airbus announced an agreement paving the way for a joint venture to develop, build, and operate Starlab. Northrop Grumman is teaming with Nanoracks to provide services to support the Starlab station.

Blue Origin and Sierra Space are partnered to develop Orbital Reef, a commercially owned and operated space station to be built in LEO, which will start operating in the second half of this decade. Orbital Reef teammates include Boeing, Redwire Space, Genesis Engineering, and Arizona State University. Orbital Reef will feature spacious modules with large Earth-facing windows and extensive pressurized volume for the crew and multiple external payload sites.

Axiom Space is partnered with NASA to reconfigure the ISS port, provide new ISS utilities and resources to the port, integrate the commercial elements onto ISS, and recertify new docking port locations for Commercial Resupply Services and Commercial Crew Program vehicles. These CDISS support activities will be funded by the Commercial LEO Development Program.

NASA's Commercial LEO Development budget request supports and advances the nation's goals in LEO and deep space exploration by furthering the development and maturity of the commercial space market. This development will enable private industry to assume roles that have been traditionally government-only, thereby creating new opportunities for economic growth in LEO and potentially yielding long-term cost savings to the government by leveraging industry innovation and commercial market incentives.

EXPLANATION OF MAJOR CHANGES IN FY 2025

Budgetary resources have been rephased to increase support for Phase 2 award(s) and certification activities and given those adjustments, near-term milestones are under review.

ACHIEVEMENTS IN FY 2023

Axiom Space continued development of the commercial segment, CDISS. Axiom continued the first phase of a CDR, which included systems such as avionics, structures, environmental control, and payloads. Axiom also completed a Financial Health Review in FY 2023.

Blue Origin completed the Creep Test and the Orbital Reef Financial Report #1. The Creep Test ensures a sub-scale test article passes short duration proof and leak tests as part of Orbital Reef's soft goods certification program.

Nanoracks completed seven milestones, including the Mission Concept Review, the Payload Systems Requirements Review, and the Starlab Stations Systems Requirement Review. These reviews ensure that the proposed functional and performance requirements meet Commercial LEO needs.

The second private astronaut mission with Axiom, Axiom Mission 2 (Ax-2), took place in May 2023 aboard ISS. Ax-2 Commander Peggy Whitson, Pilot John Shoffner, and Mission Specialists Ali Alqarni and Rayyanah Barnawi flew to the ISS aboard SpaceX Dragon Freedom on a SpaceX Falcon 9 rocket from Launch Complex 39A at NASA's Kennedy Space Center in Florida. The Axiom private astronauts completed 10 days in space at the conclusion of their mission. The spacecraft returned to Earth with 20 research projects covering physical science, life science, human research, Science Technology Engineering and Mathematics, and technology demonstrations.

In March 2023, NASA announced the selection of Axiom Space for the third private astronaut mission to the ISS, which launched January 18, 2024. In August 2023, NASA announced the selection of Axiom Space for the fourth private astronaut mission to ISS, targeting launch in 2025.

In June 2023, NASA awarded seven CCSC-2 unfunded SAAs. CCSC-2 continues the pursuit of goals set in the U.S. National Space Policy and NASA's strategic plan that will benefit human spaceflight and the U.S. commercial LEO economy by meeting future business and government needs. These agreements are designed to advance commercial space-related efforts through NASA contributions of technical expertise, assessments, lessons learned, technologies, and data. Structured sharing of NASA expertise demands minimal government resources but fosters development of technologies crucial to development of a robust LEO economy. The seven selected companies are:

- Blue Origin, Kent, WA;
- Northrop Grumman Systems Corporation, Dulles, VA;
- Sierra Space Corporation, Broomfield, CO;
- Space Exploration Technologies Corporation, Hawthorne, CA;
- Special Aerospace Services, Boulder, CO;
- ThinkOrbital Inc., Lafayette, CO; and
- Vast Space LLC, Long Beach, CA.

WORK IN PROGRESS IN FY 2024

In October 2023, NASA released a request for information (RFI) to industry, which included a draft set of requirements for end-to-end services on future Commercial LEO Destinations. The purpose of the RFI is to seek feedback from industry as the agency refines its requirements set for new Commercial LEO Destinations. In FY 2024, NASA will complete and publish a requirements document that will define NASA's safety and services requirements for CLDs.

Progress will continue on provider agreements and near-term milestones are under review for both CDISS and CDFF. Axiom Private Astronaut Mission 3 (Ax-3) launched from NASA's KSC on January 18, 2024. Once docked to ISS, the Axiom astronauts spent 18 days aboard the orbiting laboratory conducting in-orbit activities in coordination with ISS crew members and flight controllers on the ground. The Ax-3 crew members trained for their flight with NASA, international partners, and SpaceX, which Axiom contracted with as the launch provider for transportation to and from ISS, and who familiarized the private astronauts with systems, procedures, and emergency preparedness for ISS and the Dragon spacecraft.

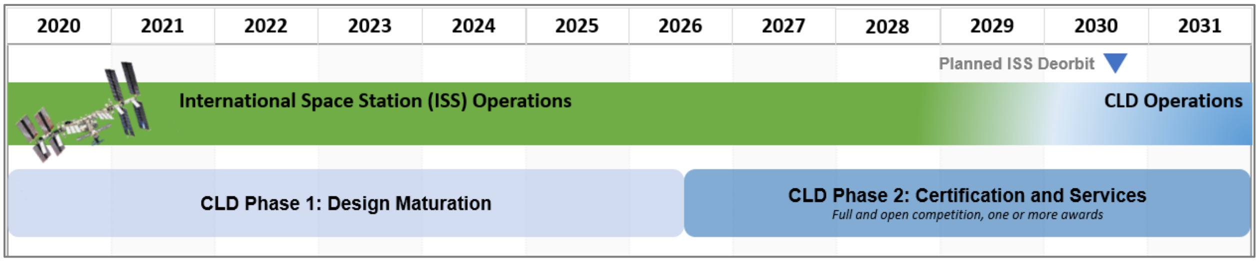
KEY ACHIEVEMENTS PLANNED FOR FY 2025

Progress will continue on provider agreements and near-term milestones are under review. NASA plans to launch Axiom Private Astronaut Mission (Ax-4) in FY 2025.

COMMERCIAL LEO DEVELOPMENT

Program Schedule

The following chart depicts the near-term roadmap of planned Commercial LEO Development efforts.



Program Management & Commitments

Program Element	Provider
Commercial LEO Development Program	Providers: Axiom Space, Inc.; Blue Origin; Nanoracks LCC Lead Center: JSC Performing Center(s): JSC Cost Share Partner(s): Industry Partners (shown as providers above)

Acquisition Strategy

NASA uses multiple acquisition tools for Commercial LEO Development. The established Next Space Technologies for Exploration Partnerships Broad Agency Announcement contract vehicle was used for the CDISS contract to initiate development of the commercial segment. Similar to the approach used for the Commercial Orbital Transportation System and Commercial Crew Program, NASA used SAAs for Phase 1 of the CDFF. FAR-based contracts will be utilized for Phase 2 to perform certification activities and purchase destination services. NASA is using unfunded SAAs in the CCSC-2 initiative to advance commercial space-related efforts through NASA contributions of technical expertise, assessments, lessons learned, technologies, and data. To enable private astronaut missions, NASA uses a NASA Research Announcement to solicit private astronaut missions to the ISS.

Major Contracts/Awards

Element	Vendor	Location (of work performance)
CDISS	Axiom Space, Inc.	Houston, TX
CDFF	Blue Origin	Kent, WA
CDFF	Nanoracks LLC	Houston, TX
Private Astronaut Mission Ax-1	Axiom Space, Inc.	Houston, TX
Private Astronaut Mission Ax-2	Axiom Space, Inc.	Houston, TX
Private Astronaut Mission Ax-3	Axiom Space, Inc.	Houston, TX

Element	Vendor	Location (of work performance)
Private Astronaut Mission Ax-4	Axiom Space, Inc.	Houston, TX
CCSC-2	Blue Origin	Kent, WA
CCSC-2	Northrop Grumman Systems Corporation	Dulles, VA
CCSC-2	Sierra Space Corporation	Broomfield, CO
CCSC-2	Space Exploration Technologies Corporation	Hawthorne, CA
CCSC-2	Special Aerospace Services	Boulder, CO
CCSC-2	ThinkOrbital Inc.	Lafayette, CO
CCSC-2	Vast Space LLC	Long Beach, CA

Independent Reviews

Review Type	Performer	Date of Review	Purpose	Outcome
Other	NASA Advisory Council	Jan 2023	Provide independent recommendations for the NASA Administrator	No new recommendations.
Other	NASA Aerospace Safety Advisory Panel	Nov 2023	Provide independent assessments of safety and recommendations to the NASA Administrator	No open recommendations

SPACE TECHNOLOGY

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Early Stage Innovation and Partnerships	122.0	--	**140.1**	145.1	149.6	154.2	160.4
Technology Maturation	323.9	--	**340.8**	353.2	363.1	370.4	377.8
Technology Demonstration	515.4	--	**459.1**	460.5	465.2	472.8	479.1
SBIR and STTR	231.7	--	**241.8**	246.6	251.6	256.7	261.9
Total Budget	**1,193.0**	**1,200.0**	**1,181.8**	**1,205.4**	**1,229.5**	**1,254.1**	**1,279.2**

Pursuant to P.L. 115-10 Title VII Sec 702(e), this budget is formulated in such a manner to avoid duplication of projects, programs, or missions conducted by other projects, programs, or missions conducted by another office or directorate of the Administration.

FY 2023 reflects funding amounts specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

SPACE TECHNOLOGY

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Early Stage Innovation and Partnerships	122.0	--	**140.1**	145.1	149.6	154.2	160.4
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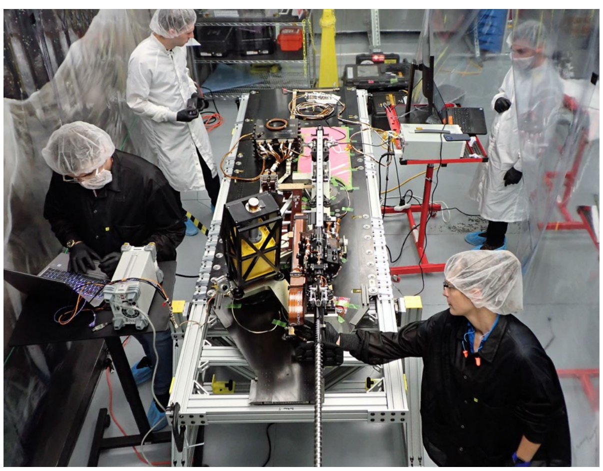


Shown here, teams with NASA, Honeybee Robotics, and Intuitive Machines work to install The Regolith and Ice Drill for Exploring New Terrain (TRIDENT) drill and the Mass Spectrometer Observing Lunar Operations (MSOLO) instrument with Intuitive Machines' Nova-C lander for NASA's Polar Resources Ice Mining Experiment-1 (PRIME-1) demonstration.

STMD serves as the national technology base for civil space. STMD transforms NASA missions and ensures American leadership in the space economy, rapidly developing, demonstrating, and transferring revolutionary, high-payoff space technologies that enhance mission capabilities and reduce cost. NASA partners with the nation's aerospace industry, including small and large businesses, as well as academia, in its high-risk, high-reward investment activities across the technology development spectrum.

EXPLANATION OF MAJOR CHANGES IN FY 2025

This budget funds the close-out of the On-orbit Servicing, Assembly, and Manufacturing (OSAM-1) project, which was cancelled in FY 2024. Please see the Technology Demonstration section for more details.

This request proposes to establish Space Nuclear Propulsion Technology as a stand-alone program and is consistent with Public Law 117–167 of August 2022.

SPACE TECHNOLOGY

KEY ACHIEVEMENTS PLANNED FOR FY 2025

Early-Stage Innovation and Partnerships (ESIP)

- Space Technology Research Grants supports a robust portfolio across academic researchers, from graduate students to senior faculty members. This program challenges academic researchers to examine the theoretical feasibility of ideas and approaches that are critical to making science and space activities more effective, affordable, and sustainable. In FY 2025, STMD plans to issue over 300 grants similar to prior fiscal years.
- Early Career Initiative engages the early-career NASA workforce in the management and development of two-year, $2.5 million technology projects. In addition to providing leadership opportunities for the early-career NASA workforce, it also helps build and maintain unique skillsets in support of NASA missions. In FY 2025, STMD expects to have nine active awards, an increase of four over FY 2023.
- Center Innovations Fund provides low-cost seed funding to develop new technologies and capabilities at all NASA centers including JPL. Partnerships with academia, industry, other NASA centers, as well as other government agencies are encouraged. In FY 2025, STMD plans to grant over 120 awards, about 20 awards fewer than FY 2023.
- NASA Innovative Advanced Concepts nurtures highly innovative, visionary ideas that could one day change the possible in aerospace over the next 10 to 20 plus years. In FY 2025, STMD expects about 38 active awards, an increase of about 20 over FY 2023.
- Prizes, Challenges, and Crowdsourcing conducts public-facing challenges in support of all NASA mission directorates, addressing several agency priorities. Using a wide variety of avenues, including the NASA Tournament Lab, NASA@WORK, and Centennial Challenges, nearly every U.S. state has provided solutions. In FY 2025, STMD is planning for nearly 50 new awards, similar to prior years.
- Early-Stage Innovation and Commerce provides the ability for ESIP programs to jointly explore innovative methods to increase the impact of NASA early-stage technology development. Examples include innovative pilots including enhanced support to underrepresented communities, evidence-driven programs, academic research to market, and partnerships. In FY 2025, STMD is planning for 10 awards, similar to prior fiscal years.
- Technology Transfer provides agency-level management and oversight of NASA-developed and NASA-owned intellectual property and manages the transfer of these technologies to external entities. NASA is seeking to accelerate commercialization through entrepreneurial initiatives and partnerships. In FY 2025, STMD has the goal to manage over 5,000 patents and software use agreements and to increase technology transfer activities to all NASA centers.

Technology Maturation

- Game Changing Development (GCD) aims to advance exploratory concepts and deliver transition-ready solutions that enable new capabilities or radically alter current approaches such as High Performance Spaceflight Computing. GCD advances a broad range of mid-TRL technologies, including in the areas of entry, descent, and landing (e.g., Safe and Precise Landing – Integrated Capabilities Evolution and Dragonfly Entry Aerosciences Measurements (DrEAM); power and energy storage (e.g., Tipping Points In-Situ Resource Utilization [ISRU] power on the Moon and

Harmonia Radioisotope power supply); propulsion systems (e.g., Liquid Oxygen/Liquid Hydrogen demonstration engine Announcement of Collaboration Opportunity); materials and structures (e.g., Superlight Aerospace Components); and robotic systems (e.g., ISRU Pilot Excavator).

- Lunar Surface Innovation Initiative develops transformative capabilities for lunar surface exploration across the Space Technology portfolio. Focus areas include in-situ resource utilization, sustainable surface power, excavation and construction, dust mitigation, and ability to operate in extreme environments. The Lunar Surface Innovation Consortium brings together NASA, universities, industry, non-profits, and other government agencies to ensure the United States is the leader in sustainable lunar exploration. In FY 2025, STMD expects to continue to mature technologies critical for a sustained human presence on the Moon. For example, the Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) will utilize lunar in-situ materials for the on-demand construction of large-scale infrastructure elements such as habitats, berms, landing pads, and blast shields. Lunar Infrastructure Foundational Technologies (LIFT-1) will be an ISRU lunar surface demonstration of oxygen extraction technologies from lunar regolith for eventual production, capture, and storage of oxygen on the lunar surface.

Technology Demonstration (TDM)

TDM matures crosscutting system-level technologies through demonstration in operational environments. Examples of projects in TDM include high-power solar electric propulsion; cryogenic fluid management; sustainable lunar surface power; and space nuclear propulsion. These technologies are critical for a long-term, sustainable presence on the Moon and deep space exploration.

- The Solar Electric Propulsion project seeks to develop and qualify an advanced 12 kilowatt-class Electric Propulsion thruster applicable to exploration and commercial spaceflight, and the Qualification System Acceptance Review 1 is planned for FY 2025.
- The Eta Space CFM Tipping Point launch is scheduled for November 2024 and the United Launch Alliance CFM Tipping Point launch readiness review is planned for July 2025.
- Research in both Nuclear Thermal Propulsion (NTP) and Nuclear Electric Propulsion (NEP) will enable robust and reliable energy to both human and scientific exploration missions.
    - Subscale integrated NEP concept design is targeted for completion in FY 2025
    - Final design and initial fabrication of a high-power electric thruster that could be used in a NEP system will be delivered in FY 2025
    - NASA is partnering with DARPA on a cislunar demonstration of NTP technologies, planned for FY 2027, and the mission CDR is scheduled in early FY 2025

Flight Opportunities (FO) and Small Spacecraft Technology (SST) will continue to increase the pace of space exploration and discovery by leveraging small spacecraft and responsive launch capabilities. By 2025, the 12 current SST demonstrations, including the Starling mission and space traffic management experiment currently on orbit, will be completed. In FY 2024, SST is evaluating four industry-led mission concept studies for transition to one or more orbital demonstrations. During FY 2025, those new missions will be undergoing rapid hardware development in preparation for a target launch before the end of 2026. In FY 2025, FO anticipates using newly awarded Indefinite Delivery / Indefinite Quantity contracts to continue its rapid pace of technology demonstrate activities in partnership with the U.S. commercial space transportation industry.

Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR)

SBIR and STTR will continue efforts to encourage participation of underrepresented groups across the nation to expand inclusive innovation. In FY 2025, STMD plans to select over 600 new awards, grants, and contracts to small businesses, as well as continue to incubate and mature NASA commercial partnerships through post Phase II activities through sequential Phase II awards. Additionally, STMD will pilot ways to reduce barriers to entry and streamline the experience throughout the program phases, including strategies to encourage transition to NASA, government, and/or commercial use beyond SBIR/STTR awards.

EARLY STAGE INNOVATION AND PARTNERSHIPS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Agency Technology and Innovation	1.4	--	**0.0**	0.0	0.0	0.0	0.0
Early Stage Innovation	99.1	--	**117.0**	121.5	125.5	129.6	135.4
Technology Transfer	21.5	--	**23.1**	23.6	24.1	24.6	25.1
Total Budget	**122.0**	**--**	**140.1**	**145.1**	**149.6**	**154.2**	**160.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Pictured above is the ECI Rotating Detonation Rocket Engine (RDRE), which is developing an efficient, high specific impulse engine to meet NASA's Moon to Mars transportation requirements.

Early Stage Innovation and Partnerships (ESIP) empowers a community of innovators in aerospace research and transformative technology ventures to enable NASA's mission and invigorate the nation's economic future.

Early Stage Innovation supports concept studies, applied research, and early technology development that germinate revolutionary ideas, expand innovation, and transform future capabilities. Open innovation capabilities support NASA's research and development (R&D) objectives and leverage the agency's connection with the American and global public to support NASA's objectives. NASA awards early-stage efforts through Space Technology Research Grants, NASA Innovative Advanced Concepts, the Center Innovation Fund, the Early Career Initiative (ECI), and open innovation efforts through the Prizes, Challenges and Crowdsourcing program. Within Technology Transfer, NASA promotes the commercialization of technologies that emerge from NASA's R&D activities to promote economic development through commercial expansion in space and tangible Earth applications.

EARLY STAGE INNOVATION

The ESIP portfolio includes the following program elements:

Space Technology Research Grants (STRG)

STRG conducts a series of annual and biennial competitive solicitations targeting strategic technology gaps and stimulating innovative space technology research that engage the entire spectrum of academic researchers, from graduate students to early career and senior faculty members. STRG emphasizes technology that can make space activities more effective, affordable, and sustainable. In the process, close collaborations between U.S. universities and NASA centers are established and nurtured. Also, via the students who support these awards, these efforts cultivate the pipeline of the next generation of technologists and innovators who will go on to support the aerospace and other industries with roles in industry, academia, and government.

EARLY STAGE INNOVATION AND PARTNERSHIPS

- The NASA Space Technology Graduate Research Opportunities (NSTGRO) solicitation seeks to sponsor graduate researchers who show significant potential to contribute to NASA's goal of creating innovative new space technologies for the nation's exploration, science, and economic future.
- The topics featured in the Early Career Faculty (ECF), Early Stage Innovations (ESI), Lunar Surface Technology Research (LuSTR), and Space Technology Research Institutes (STRI) solicitations are of high priority to NASA and the aerospace community and focus on areas where academia is ideally suited to provide significant contributions.
    - ECF is uniquely focused on supporting outstanding faculty researchers early in their careers as they conduct space technology research.
    - ESI efforts are slightly larger efforts that are university-led but allow for teaming within academia as well as some external entities including industry.
    - LuSTR are university-led efforts addressing high priority lunar surface challenges that encourages larger teaming.
    - STRIs are STRG's largest multi-year awards, which support university-led institutes that require diverse, multidisciplinary, multi-institutional participants researching high-priority early-stage space technologies.

NASA Innovative Advanced Concepts (NIAC)

NIAC offers NASA the opportunity to collaborate with any U.S. entity in search of the most visionary and transformative technology concepts. NIAC executes annual solicitations seeking exciting, unexplored, but technically credible new concepts that could one day create breakthroughs in space and aeronautics. These efforts keep the agency and our nation on the cutting edge of aerospace research, enabling long-term capabilities and disruptive innovations that make aeronautics and space exploration more effective, affordable, and sustainable.

Initiated in 2011 as an internal NASA program, NIAC Phase I and continuation Phase II solicitations are open to NASA centers, other government agencies, universities, industry, and individual entrepreneurs. NASA implemented a Phase III solicitation in 2019 to complement its portfolio of Phase I and Phase II concepts. Phase III studies continue to mature Phase II transformative ideas, allowing NASA to strategically transition the most promising NIAC concepts to other NASA programs, other government agencies, or commercial partners.

Center Innovation Fund (CIF)

CIF provides annual seed funding to each NASA center, including NASA's JPL, to stimulate aerospace creativity and workforce innovation to transform future missions and advance national aerospace capabilities. CIF activities are competitively proposed by researchers at NASA centers with concurrence by NASA HQ to explore alternative technology approaches or develop enhanced technology capabilities that will advance NASA mission capabilities. Partnerships with academia, private industry, individual innovators, as well as among NASA centers and government agencies, are highly encouraged.

Early Career Initiative (ECI)

ECI provides the opportunity for NASA early career civil servants to propose and work on two-year technology projects with industry and academic partners, engage in hands-on technology development opportunities, and learn different approaches to project management. To maximize the effectiveness of the early career projects, each team is mentored by senior NASA center personnel and NASA STMD subject matter experts. Several ECI projects target technology demonstrations or flight opportunities that support lunar surface operations, which provides NASA civil servant innovators the opportunity to have their technologies demonstrated on the lunar surface. Designed to invigorate NASA's technology base and champion innovative management processes, ECI successfully partners NASA early career leaders with external world-class innovators to deliver transformative national space capabilities.

Prizes, Challenges, and Crowdsourcing (PCC)

PCC has a toolkit consisting of three parts. The NASA Tournament Lab is operated by the Center of Excellence for Collaborative Innovation (CoECI) and manages a contract that makes a wide variety of commercial open innovation platforms available to NASA employees to conduct challenge and crowdsourcing projects to support their work. CoECI also supports NASA Spark (formerly NASA@WORK), an internal crowdsourcing and challenge platform designed to improve the ability of NASA employees to connect with others within the agency to solve technical and non-technical problems. Centennial Challenges offer incentive prizes to generate revolutionary solutions to support advanced NASA technology needs and, where appropriate, partners with both private or public organizations to maximize return on investment.

Early Stage Innovation and Commerce (ESIC)

ESIC addresses the ESIP portfolio joint priorities and implements innovative pilots to advance technology-driven economic growth through engagement, evidence-based implementation, and addressing barriers to promote inclusivity as a key component to ensuring American global leadership in space technology. ESIC addresses several ESIP/STMD gaps complementing other existing programs, including increasing the emphasis on and impact of inclusive innovation and participation by non-traditional and diverse communities across ESIP programs, increasing the rate of transition from university labs to market by actively supporting entrepreneurship in university-based research, and building capability for evidence-driven evaluation and technology transition. ESIC provides the ability for ESIP programs to jointly explore innovative methods to increase the impact of NASA early stage technology development, including testing the potential of non-profit partnerships to leverage philanthropic capital to advance space technology research.

TECHNOLOGY TRANSFER

Technology Transfer provides agency-level management and oversight of NASA-developed and NASA-owned intellectual property and manages the transfer of these technologies to external entities. Activities include active collection and assessment of all NASA inventions, strategic management and marketing of intellectual property, negotiation and management of licenses, software releases, and development of technology transfer-focused partnerships. The team tracks and reports metrics related to these activities (e.g., numbers of new inventions, patents, licenses, cooperative research and development agreements, or software use agreements).

NASA's Technology Transfer Expansion (T2X) initiative accelerates commercialization of NASA technologies through outreach, strategic partnerships, and entrepreneurial projects that expand NASA's presence, create an entrepreneurial workforce, and increase national economic impact. Focused in regions across the nation where there is evidence of highly concentrated resources to support and stimulate high-tech sustainable startup ecosystems, T2X engages in innovative entrepreneurial activities and with institutions of higher education to increase licensing and commercialization success. These expansion efforts employ regionally-tailored engagements to promote venture creation and growth, support the U.S.

EARLY STAGE INNOVATION AND PARTNERSHIPS

economy (including the space industry), and help companies across the country successfully bring new technologies to market.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

- NIAC selected 14 Phase I studies and six Phase II visionary studies, worth $175,000 and $600,000 respectively. Examples include a lunar pipeline to efficiently transport oxygen manufactured at the Moon's South Pole to a future Artemis base, advanced propulsion systems capable of rapid flights to Mars and beyond, and a rapid defense system for planetary protection from dangerous asteroid impacts.
- ECI continued four second-year activities and initiated five new ones at different NASA centers, each worth up to $2.5 million. New ECI awards include the advanced development of efficient new rocket engines, instruments to measure lunar volatiles and planetary atmospheres, and a system for carbon capture and utilization for terrestrial and lunar applications.
- CIF competitively selected 123 innovative seedling activities across the NASA centers. Highlights of selected projects include methodologies for machine learning of agriculture crop damage after severe storms and high precision relative position sensing system to mitigate and track orbital debris.
- STRG funded 74 new projects with universities. STRG also released its first solicitation that leveraged the double anonymous peer review approach in 2023 based on SMD's evidence of the approach advancing inclusive innovation. These activities cover a range of technical topics including orbital debris mitigation, materials and manufacturing advancements for the next generation of higher-powered spacecraft, and advancements in hypersonic transition, turbulence, and spacecraft stability, including entry and descent modeling that will help enable the exploration of Mars, Titan, and gas giant planets and the safe return to Earth.
- The PCC Deep Space Food Challenge Phase 2 awarded a total of $750,000 to five U.S. teams (and recognized three international teams) for building and demonstrating prototypes for in-space food production. Four teams won a total of $1.6 million in Phase 2, level 2, of the Watts on the Moon Challenge to develop systems to store and distribute power on the lunar surface. Through its Crowdsourcing Contenders solicitation, PCC also awarded $830,000 for 13 crowdsourcing projects proposed by members of the NASA workforce to support NASA technology needs ranging from astronaut medical care on the lunar surface to miniaturized sensors to detect methane on the Earth and other planets.
- Technology Transfer licensed over 143 patents and 12 copyrights, fulfilled over 5,300 new software usage agreements, and recorded 1,564 new inventions.
- STMD, in partnership with SMD and NSF, released the Innovation-Corps (I-Corps) pilot solicitation, an immersive, entrepreneurial training program, and selected the first participant from a minority serving institution. ESIC released NASA's first community building prize that will support deeper engagement with diverse ecosystem of innovators who are unfamiliar with ESIP's funding opportunities as well as identify best practices for outreach to untapped communities.

EARLY STAGE INNOVATION AND PARTNERSHIPS

WORK IN PROGRESS IN FY 2024

- NIAC selected 13 new Phase I awards in January 2024, each worth $175,000. Some concepts include: a new technique to maintain cryogenic hydrogen propellant for long duration space missions; a unique method to search for life signatures in mined lunar and Martian water; and a concept to bring back a sample from the surface of Venus. NIAC will also select up to eight new Phase II awards and one Phase III award in FY 2024.
- ECI selected four new activities for FY 2024 and continued the five initiated in FY 2023. The new ECI projects include an advanced ground-based sensor to monitor the development and transport of greenhouse gasses in the Earth’s atmosphere, development with industry partners of several technologies required for in-space servicing of spacecraft, and a rapid method to detect and mitigate destructive arcing in solar arrays on spacecraft and on the lunar surface. CIF funded 106 highly innovative activities across the centers including JPL, including robotic construction methods, sensors and instruments for planetary and Earth-science applications, power and propulsion concepts, and methods to mitigate the hazards of operating on the lunar surface.
- STRG’s plans to make additional awards for graduate fellowships, early career faculty, research institutions and teams pursuing lunar surface innovations in FY 2024. New activities include novel methods of a "gecko roller" to remove lunar dust from spacesuits and instruments, the development of space refrigeration systems without hazardous refrigerants for a potential range of needs spanning from crew health to space biology and geology needs, and research into innovative approaches using multiple robots to access and explore challenging lunar terrain.
- PCC will conclude the final phases of the Watts on the Moon, Break the Ice Lunar, and Deep Space Food Challenges. PCC will open a new Centennial Challenge in FY 2024 intended to incentivize the design, development, and demonstration of novel solutions and technologies for sustainable waste management, reuse, and recycle on the lunar surface. PCC will also collaborate with the NASA and NOAA SBIR/STTR programs to develop a $200,000 challenge to promote the development of business models to provide climate decision support tools using NASA and NOAA climate data. The intent is that the challenge will stimulate and prepare competitors to submit proposals to future SBIR/STTR solicitations in NASA and NOAA on climate topics.
- ESIC will continue to offer I-Corps grant awards and the Space Tech Catalyst Prize will announce winners, offering an opportunity for prize winners to share best practices and potential collaboration opportunities to increase inclusion in ESIP programs. ESIC will continue to pilot methods for increasing engagement and awards with minority serving institutions (MSIs) and other diverse awardees to enable breakthrough technology innovation. ESIC will implement an evaluation on transition strategies consistent with the FY 2024 Agency Evaluation Plan in the NASA Learning Agenda.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

- NIAC will continue to nurture visionary ideas that could transform future NASA missions through Phase I, II, and III awards.
- ECI plans to increase the number of annual early career development awards in FY 2025 with a goal of eventually funding at least one new ECI activity annually at each NASA center. The CIF Program will continue to invest in highly innovative center activities to further enhance and enable future

EARLY STAGE INNOVATION AND PARTNERSHIPS

agency capabilities, adding to the more than 90 patents, 350 New Technology Reports, dozens of commercial licenses, and two spin-off companies already generated by the program.

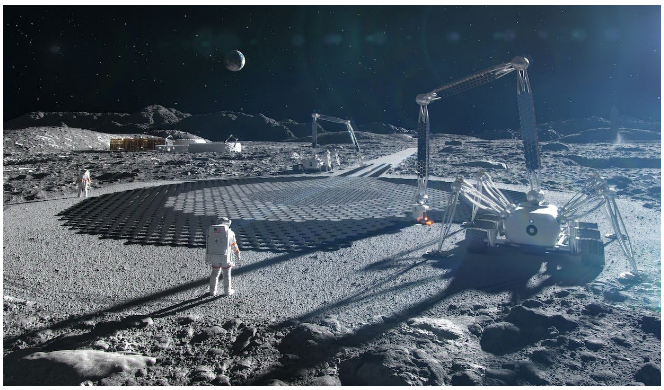
- While the majority of STRG solicitations traditionally focus on specific topics of study in known emerging areas or that address known technology needs, the program is evaluating a pilot of a solicitation that will allow for the proposal of disruptive aerospace technologies, generated by academia, that potentially enable new capabilities or new fields of aerospace technology study. Additionally, STRG is also planning to potentially pilot an approach to a set of funded extensions and continuations on prior STRG awards, potentially including but not limited to LuSTR, ECF, and ESI awards, which focus on enabling greater pipelines for technology infusion and/or transitions of early stage technologies from academia to industry.
- PCC will conduct the waste management challenge while formulating and preparing to launch an additional Centennial Challenge. PCC will also conduct its next Crowdsourcing Contenders solicitation. PCC will continue to make the NASA Spark platform available to all NASA employees, while supporting public challenges and crowdsourcing projects to meet NASA mission needs. PCC will also collaborate with other STMD programs on projects to fund, transition, and advance technologies of strategic value to NASA.
- The Technology Transfer Program will expand T2X beyond the initial three pilot centers to increase licensing and commercialization successes while engaging local and regional partners and will increase T2X agreements, with an emphasis on MSIs and historically black college and universities.
- ESIP aims to increase the rate of transition from university labs to market through formalizing I-Corps as an activity and piloting entrepreneurial fellowships in partnership with NSF. In addition, ESIP will continue to promote efforts to streamline and create efficiencies for proposers and partners. Through strategic investments in institutional capacity building as well as proposer development, ESIP anticipates strategic investments in capacity growth to yield greater participation by non-traditional and diverse communities across ESIP programs.

TECHNOLOGY MATURATION

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**323.9**	**--**	**340.8**	**353.2**	**363.1**	**370.4**	**377.8**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



ICON is illustrating the autonomous on demand 3D printing of a notional large-scale structure on the lunar surface using in-situ regolith-based materials developed under the Technology Maturation Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) project.

The Technology Maturation portfolio provides transformative and crosscutting technologies that contribute to U.S. leadership in space technology and support NASA missions. The program is committed to developing a global lunar utilization infrastructure for sustained operations on the lunar surface. Critical to this effort are industry partnerships that enable NASA and the private sector to share the risk and benefit of common technology interests and investments. These industry partnerships are primarily developed through NASA's Tipping Point (TP) and Announcement of Collaboration Opportunity (ACO) solicitations.

EXPLANATION OF MAJOR CHANGES IN FY 2025

The Budget includes $10 million to support an FY 2025 round of ACO awards to increase NASA's ability to engage with private industry.

PROJECT OVERVIEWS

Technology Maturation has a broad portfolio of approximately 100 activities, with the majority of these activities including partnerships and collaborations with industry, academia, and/or other government agencies. The portfolio includes a combination of mid-TRL ground-based and flight demonstration developments.

SPACE TRANSPORTATION

NASA advances technologies that support rapid, efficient in-space transportation and reduce transit times. Propulsion investments focus on higher thrust and efficiency, including alternatives to traditional chemical propulsion systems for deep space exploration spacecraft systems, and advancement of additive manufacturing techniques. Specific investments include:

- Refractory Alloy Additive Manufacturing Build Optimization (RAAMBO) and Optimized and Repeatable Components in Additive Manufacturing (ORCA), which will advance additive manufacturing using refractory alloys;
- Composite Technologies for Exploration -- Thermoplastic Development for Exploration Applications (CTE-TDEA) is advancing thermoplastic composite capabilities by developing structural joining solution methods for aerospace structures (e.g., lunar landers, on-orbit assembly of large-scale structures, and launch vehicle applications); and
- Fully Additively Manufactured Liquid Oxygen/Liquid Hydrogen Engine demonstration (FAMLLE) ACO partnership with industry to produce an additively manufactured thrust chamber assembly and validate the structural integrity and reliability through a series of tests. If successful, this innovative approach will reduce manufacturing time and costs for space-grade components.

ENTRY, DESCENT, AND LANDING (EDL)

STMD is working to develop capable EDL systems, materials, and computer modeling capabilities necessary to land increased mass more accurately on planetary bodies and to improve capabilities to return spacecraft from LEO and deep space. More specifically, NASA is focusing on precision landing and hazard avoidance; design, analysis, and testing of advanced materials for thermal protection; and EDL architectures for future exploration vehicles and planetary entry missions. Stereo Camera for Lunar Plume-Surface Studies (SCALPSS), a collaboration with SMD, is an example, and it is composed of tiny cameras placed around the base of the commercial lunar lander that monitor crater formation from the precise moment a lander’s hot engine plume begins to interact with the Moon’s surface. SCALPSS data will be used by future lunar lander vehicle and surface system designs.

SUSTAINABLE EXPLORATION

Space Technology is also working on capabilities for sustainable living and working farther from Earth to support routine crewed operations beyond LEO. Technologies demonstrated will enable humans to live and operate on the Moon and eventually on Mars. Additionally, these capabilities provide the ability to reach challenging sites and resources on the Moon and Mars and to survive and operate through the lunar night.

Lunar Surface Innovation Initiative (LSII)

Through LSII, Space Technology is developing the essential capabilities required for humans and systems to successfully live and operate in multiple environments on the lunar and other planetary body surfaces. These technologies will result in the capability to extract and utilize local resources, generate surface power and store energy, access and navigate a variety of terrains, autonomously excavate lunar surface materials for manufacturing and construction, and mitigate lunar dust. Also included in LSII is the Lunar Surface Innovation Consortium, which is facilitated by Johns Hopkins Applied Physics Laboratory and supports a nationwide alliance of universities, industry, non-profits, NASA, and other government agencies with a vested interest in establishing a sustained presence on the Moon. Since its inception in 2019, LSII has engaged over 800 organizations across 50 states, the District of Columbia, Guam, Puerto Rico, and 48 countries to advance the technologies needed to explore the lunar surface and stimulate economic development.

TECHNOLOGY MATURATION

Key activities and elements of LSII are described below.

In-Situ Resource Utilization (ISRU)

ISRU will develop and demonstrate technologies to use the Moon's resources to produce water, fuel, and other supplies. Following development and maturation of ISRU technologies at the component, subsystem, and scaled system levels, this effort will demonstrate the ability to produce propellants, other mission consumables, and infrastructure from regolith and atmospheric resources at a variety of destinations.

- Polar Resources Ice Mining Experiment-1 (PRIME-1) will be the first ISRU demonstration on the Moon. The project includes a flight-ready instrumentation package that will robotically sample and analyze ice from below the surface. PRIME-1 is a critical instrument suite that will be integrated on the SMD Commercial Lunar Payload Services (CLPS) Intuitive Machines commercial lunar lander to land at the lunar South Pole to assess the volatiles and determine water content. PRIME-1 will help provide the knowledge necessary to find critical resources to produce propellant, water, and oxygen for lunar missions.
- Lunar Infrastructure Foundational Technologies (LIFT-1) is a flight demonstration that will leverage collaboration with industry, academia, and other government agencies, to increase technology readiness for most of the Moon-to-Mars Infrastructure Objectives. The primary objective will be an ISRU lunar surface demonstration of oxygen extraction technologies from lunar regolith for eventual production, capture, and storage of oxygen on the lunar surface.

Sustainable Surface Power

STMD is making critical advancements in power generation and energy storage that will provide the capability for continuous power throughout day and night operations on the lunar surface. Solar array technology under development can generate energy in extreme environments, including low-light intensity and low temperature. In addition, Space Technology is developing and demonstrating a primary fuel cell system to support operations with long discharge times, including applications on rovers, powering of habitats, powering ISRU systems, and for general energy storage:

- Vertical Solar Array Technology (VSAT) is a partnership with industry to develop lightweight solar arrays capable of autonomous 10-meter vertical deployment on uneven terrain and will enable near continuous capture of sunlight by the solar arrays at the lunar South Pole region.
- The ISRU-Based Power on the Moon (ISRU Power) TP project will develop a commercial end-to-end system that produces solar power from simulated lunar regolith using molten regolith electrolysis.
- The Harmonia radioisotope power supply (Harmonia RPS) for Artemis TP project will deliver a novel radioisotope power system that will enable lunar night operations through an electrically heated 10-Watt electric Stirling generator.
- The LunaGrid-Lite TP demonstration is a tethered, scalable lunar power transmitter that will enable power distribution to remote, hazardous, and permanently shadowed regions on the lunar surface and will remove the burden of rovers needing to carry a power source around the lunar surface.

Dust Mitigation

Lunar dust is one of the principal issues that NASA must address before returning to the surface of the Moon. It has the potential to affect every lunar surface system. STMD is developing technologies and concepts to mitigate lunar dust hazards to enable sustained operations both on the lunar surface and with transfers to and from the Lunar Gateway or other orbital platforms. Electrodynamic Dust Shield (EDS) is an active dust mitigation technology demonstration that uses electric fields to move dust from surfaces and to prevent accumulation on surfaces. Potential applications include thermal radiators, spacesuit fabrics, visors, camera lenses, solar panels, and many other technologies.

Excavation and Construction

Space Technology is developing technologies that enable affordable, autonomous manufacturing and construction using lunar surface materials. The ability to excavate regolith under lunar environmental conditions, which include lunar dust, extreme temperatures, and minimal gravity is critical to NASA's ISRU subscale demonstration construction plant.

- Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) utilizes lunar in-situ materials for the on-demand construction of large-scale infrastructure elements such as habitats, berms, landing pads, and blast shields. These structures will provide protection for crewmembers, hardware, and electronics while on the surface of an extraterrestrial body and enable sustained surface exploration.
- The ISRU Pilot Excavator (IPE) will demonstrate a regolith robot excavator capable of supplying raw materials to an ISRU pilot construction plant.

Extreme Environments

STMD is advancing rovers, manipulators, and other systems that can operate throughout the full range of lunar surface conditions, including lunar noon (up to 150 degrees Celsius), lunar night (down to negative 180 degrees Celsius), multiple day/night cycles, and permanently shadowed regions (down to negative 240 degrees Celsius).

TRANSFORMATIVE MISSIONS AND DISCOVERIES

Extreme Access

STMD is developing technologies that enable humans or robotic systems, particularly autonomous systems, to efficiently access, navigate, and explore previously inaccessible lunar or planetary surface or subsurface areas.

- Cooperative Autonomous Distributed Robotic Exploration (CADRE) will evolve technology developed by the Pop Up Flat Folding Exploration Robot (PUFFER) project and demonstrate collaborative autonomous exploration on the lunar surface by navigating, communicating, computing, perceiving, and decision-making without human interaction.
- Inspired by terrestrial technology, STMD will deploy the first LTE/4G communication system that will deploy on the lunar surface as part of a TP contract. The system aims to support lunar surface communications at greater distances and increased speeds.
- The Micro-Nova TP project is a small deployable hopper lander that will access lunar craters and enable high-resolution surveying of the lunar surface over a short distance.

- High-TRL Light Detection and Ranging (LiDAR) is a vision mapping system that will enable rovers to venture beyond benign planetary and lunar surfaces into dark, high-contrast, confined, or low-texture (i.e., extreme) environments. The main electronics box will fly on the Dragonfly mission to the Saturn moon Titan and potentially future lunar surface missions.

Servicing, Assembly, Manufacturing, and Crosscutting

- Super-lightweight Aerospace Composites (SAC) will scale up the manufacturing and use of high-strength carbon nanotube composite materials leading to significant mass savings in rocket and spacecraft structures such as EDL systems, hypersonic vehicles, and propulsion systems.
- Precision Assembled Space Structure (PASS) technologies are autonomously assembled structures and high-precision joints for effective and efficient on-orbit assembly of large structures, such as next generation science telescope. The project is a collaboration with the Department of Defense and SMD.
- The 2023 ACO Robotically Assembled Light Bender (RALB) system will redirect sunlight to individual solar power systems to generate electricity in regions without sunlight.

Avionics, Communication, and Navigation

- High Performance Spaceflight Computing (HPSC) is intended to develop a next-generation flight computing system that can improve in-space computing performance to 100 times the computational capacity of current flight processors for the same amount of power.
- Distributed Spacecraft Autonomy (DSA), flown on the Small Spacecraft Technologies Starling mission, is a multi-spacecraft mission autonomous decision-making technology which will significantly increase the effectiveness of missions by operating them as a collective rather than individually.

INDUSTRY AND COMMERCE INNOVATION OPPORTUNITY

NASA stimulates the commercial space industry through collaborative partnerships that foster the technology development required for future NASA, commercial, and government sector capabilities and missions. STMD employs a novel, merit-based competition model to ensure that NASA maintains a crosscutting portfolio that spans a range of technical disciplines and market readiness levels.

- Through TP proposals, NASA seeks industry-developed space technologies that can foster the development of commercial space capabilities and benefit future NASA missions. A technology is considered at a tipping point if an investment in a demonstration will significantly mature the technology, increase the likelihood of infusion into a commercial space application, and bring the technology to market for both government and commercial applications. The partnerships established through TP selections combine NASA resources with an industry contribution of at least 25 percent of the total project resources (10 percent minimum for companies with 500 or fewer employees), shepherding the development of critical space technologies/capabilities to stimulate commercial space economy while also saving the agency, and American taxpayers, money.

- Through ACO awards, NASA helps reduce the development cost of space technologies and accelerate the infusion of emerging commercial capabilities into future missions. Resulting in unfunded Space Act Agreements, NASA centers partner with selected companies to provide expertise, facilities, hardware, and software at no cost.

ACHIEVEMENTS IN FY 2023

STMD made 16 new ACO and 11 TP selections to advance capabilities and technologies related to NASA's Moon to Mars objectives.

Mission payload highlights include:

- DSA launched onboard the Starling mission in July 2023, and successfully demonstrated the autonomous ability to collect and analyze science data from a swarm of spacecraft which are currently monitoring Earth's ionosphere and utilizing the DSA software to communicate with each other and autonomously react to collectively reorient as required.
- SCALPSS completed hardware development and delivered flight hardware to the CLPS provider Firefly Aerospace for integration into the lunar lander in support of a launch and demonstration in 2024.
- MMPACT continued to advance the technology necessary for lunar surface construction through successful development and test of the construction material Laser Vitreous Material Transformation (Laser VMX).
- Vertical Solar Array Technology completed detailed design reviews and started prototype fabricating.
- SAC successfully manufactured large quantities of high-strength carbon nanotube yarn required for future technology infusion into other applications such as Nuclear Thermal Propulsion components, nozzle extensions, and composite pressure vessels.

WORK IN PROGRESS IN FY 2024

Technology Maturation is currently executing over 95 projects including 41 ACO and TP projects. Many of these technology payloads are preparing for flight hardware delivery or completing integration and testing with the various launch providers:

- STMD plans to release a Request for Information for LIFT-1 and is developing Request for Proposal requirements for launch, landing, and operations of the payloads on the lunar surface. LIFT-1 selection is currently planned by early FY 2025.
- PRIME-1, LTE/4G Communications, and Micro-Nova TP project are in process of final integration and testing with the NOVA-C Intuitive Machines (IM) lunar lander for launch on the CLPS IM-2 mission.
- EDS completed payload development and delivered to Firefly in early FY 2024 to support a launch and flight demonstration in early to mid-FY 2024.
- CADRE will deliver the flight hardware to IM in preparation for launch and landing in 2024 onboard the CLPS IM-3 mission.
- SCALPSS will also deliver flight hardware to Blue Origin for integration into their lunar lander.

- The ISRU Pilot Excavator (IPE) critical design review (CDR) and qualification testing on the prototype unit is in progress and the team will launch a multi-year university challenge that will give students the chance to develop autonomy code and simulations using the IPE as the subject case study.
- VSAT vendors will compete testing of the components and system prototypes in a simulated lunar environment and once complete, the system will be ready for subsequent testing in an operational environment.
- RALB ACO team will fabricate and ground test a robotically assembled tandem reflector mirror system at NASA test facility.
- HPSC will complete its CDR and begin qualification testing on prototype chips.
- PASS will complete a 20-meter autonomous assembly ground demonstration.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

STMD will continue to focus technology developments on both lunar surface payloads and multi-application technologies.

Plans for flight payloads include:

- SCALPSS and EDS will support the CLPS 19D Firefly launch and landing.
- CADRE will enter the operations phase as it roams the lunar surface.
- Safe and Precise Landing - Integrated Capabilities Evolution (SPLICE) will complete a low-altitude flight test of an integrated hazard detection and avoidance system.
- Dragonfly Entry Aerosciences Measurements (DrEAM) hardware acceptance review will be complete for all flight hardware for the SMD New Frontiers mission Dragonfly to Titan, Saturn's largest moon.

Plans for multi-application technologies include:

- HPSC will complete evaluation of chip prototype shock and radiation testing, and work will conclude by documenting multi-core flight computing system in order to facilitate transition into commercial applications.
- The FAMLLE ACO team will integrate the partner-provided thrust chamber assembly into an engineering test unit and complete a hot fire test.

Plans for ISRU, power, and construction projects include:

- Carbothermal Reduction Demonstration (CaRD) will test the concentrated solar energy prototype to heat simulated regolith high enough to melt it and create the reaction to extract oxygen from the regolith.
- The MMPACT activity will complete with a technical assessment of the key performance parameters to help enable the technology to transition to flight opportunities (e.g., LIFT-1, CLPS).
- Harmonia Radioisotope Power Supply for Artemis will complete final design of the electrically heated Stirling generator.

- LunaGrid-Lite will fabricate and test an engineering model of an integrated electric transmission cable and reel subsystem and a universal modular interface converter with a CubeRover.
- LIFT-1 will make selection(s) for award of a lunar surface technology demonstration mission.
- ISRU power on the Moon TP will complete ground demonstrations of melting simulated regolith and purification of silicon as a steppingstone to larger scale subsystem demonstrations and eventually a fully integrated system demonstration of molten regolith electrolysis.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
2022 Announcement of Collaboration Opportunity (ACO) For information, go here. https://www.nasa.gov/news-release/nasa-selects-12-companies-to-collaborate-on-key-technology-development/	Aerojet Rocketdyne, Inc. Blue Origin, LLC Boeing Company Canopy Aerospace Inc. Lockheed Martin Inc. Maxar Phase Four, Inc. Psionic, LLC Roccor, LLC Sierra Space Corporation Stratolaunch, LLC Venturi Astrolab, Inc.	El Segundo, California Kent, Washington Arlington, Virginia Denver, Colorado Bethesda, Maryland Westminster, Colorado El Segundo, California Hampton, Virginia Erie, Colorado Louisville, Colorado Mojave, California Hawthorne, California
2022 Tipping Points (TP) For information, go here. https://www.nasa.gov/general/2023-nasa-tipping-point-selections/	Astrobotic Technology Big Metal Additive Blue Origin, LLC Freedom Photonics Lockheed Martin Inc. Redwire Protoinnovations Psionic United Launch Alliance (ULA) Varda Space Industries Zeno Power Systems	Pittsburgh, Pennsylvania Denver, Colorado Kent, Washington Santa Barbara, California Littleton, Colorado Jacksonville, Florida Pittsburgh, Pennsylvania Hampton, Virginia Centennial, Colorado El Segundo, California Washington, D.C.

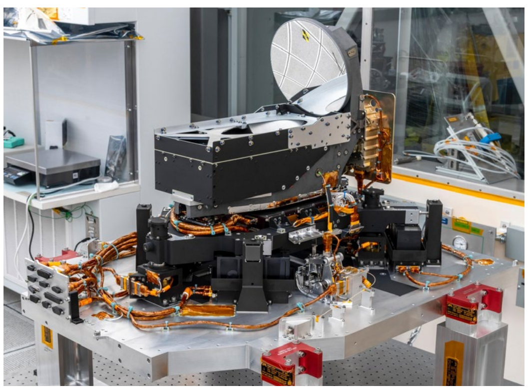
Note – Some of these activities may conclude in FY 2024 and may not be active in FY 2025.

TECHNOLOGY DEMONSTRATION

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Solar Electric Propulsion (SEP)	18.5	10.5	**13.0**	7.7	6.6	5.7	1.7
On-Orbit Servicing, Assembly, and Manufacturing Demonstration-1	227.0	--	**11.0**	0.0	0.0	0.0	0.0
Space Nuclear Propulsion	91.3	--	**110.0**	70.5	54.5	45.5	42.5
Small Spacecraft, Flight Opportunities & Other Tech Demo	178.6	--	**325.1**	382.3	404.1	421.6	434.9
Total Budget	**515.4**	**--**	**459.1**	**460.5**	**465.2**	**472.8**	**479.1**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Shown above is the Deep Space Optical Communications transceiver assembly before it was integrated and launched with the Psyche spacecraft.

The Technology Demonstration Program matures crosscutting system-level technologies through demonstration in operational environments. The program does this through both ground-based testing and space flight demonstrations in relevant or operational environments. Ground-based testing is performed to advance technologies from component validation to system model or prototype demonstration. Space flight demonstrations further advance system level technologies with the goal to transition these new capabilities to operational use by NASA missions, industry, and other government agencies.

The Technology Demonstration (TDM) portfolio technology investments include high-power solar electric propulsion; cryogenic fluid management; sustainable lunar surface power; lunar infrastructure, advanced communications, and navigation; in-space servicing, assembly, and manufacturing. Commercial sector collaborations continue to be used to share the risk and financial interest and better leverage government investments.

The Space Nuclear Propulsion (SNP) Program's goal is to advance more robust deep-space propulsion systems with higher propellant efficiencies that can enable future NASA mission sets. Technology maturation and demonstration projects managed within the SNP Program will focus principally on nuclear electric propulsion (NEP) and nuclear thermal propulsion (NTP) system concepts. More advanced nuclear-powered concepts could be incorporated as engineered systems become feasible.

The Flight Opportunities and Small Spacecraft projects rapidly develop and demonstrate technologies through partnerships with U.S. industry for suborbital flight testing and small spacecraft missions. These programs leverage agile spacecraft platforms and responsive launch capabilities to increase the pace of space exploration, scientific discovery, and the expansion of space commerce. These emerging capabilities have the potential to enable new mission architectures, enhance conventional missions, and promote development and deployment on faster timelines. The programs partner with U.S. industry and academia to target technology gaps that market forces would not otherwise fill. The two programs address the advancement of technologies that support national efforts in cislunar space and breakthrough capabilities that ensure national leadership in space and help the commercial space industry grow.

EXPLANATION OF MAJOR CHANGES IN FY 2025

This request proposes to establish Space Nuclear Propulsion Technology as a stand-alone program and is consistent with Public Law 117–167 of August 2022.

This request reflects a delay to the Fission Surface Power (FSP) delivery from FY 2029 and supports a 2032 delivery to the launch site. NASA will work to complete the design and development of a modular FSP source that supports lunar and Mars surface exploration.

This budget request reflects NASA's decision to cancel and close out the On-orbit Servicing, Assembly, and Manufacturing Demonstration-1 (OSAM-1) Project in FY 2024, due to spacecraft bus delivery delays, supply chain issues, significant cost growth, other persistent technical performance challenges, and surveys of industry members have revealed no dependence on OSAM-1 technologies nor technology gaps that OSAM-1 uniquely fills. The project name was changed from Restore-L to OSAM-1 when the Space Infrastructure Dexterous Robot payload was added to the mission. When the project baseline was established in May 2020, baseline development costs were $974.4 million with a Launch Readiness Date (LRD) of September 2025. NASA established a new baseline in October 2022 with development costs of $1.244 billion and an LRD of December 2026. In September 2023, NASA notified Congress it anticipated that OSAM-1 would exceed the October 2022 baseline development estimate by more than 15 percent and the new LRD by more than six months. In January 2024, NASA held an independent review board which recommended cancellation of the project. Closeout activities will continue in FY 2025 to cover residual workforce closeout costs.

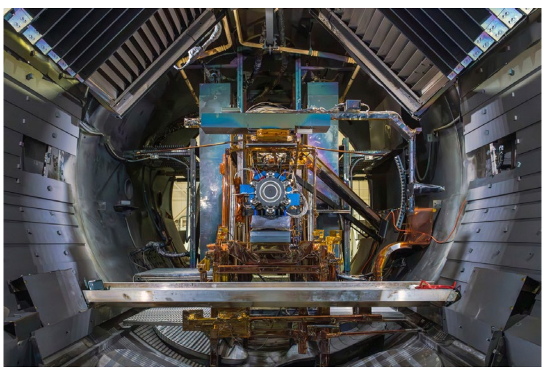
SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	179.2	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	179.2
Development/Implementation	130.1	27.1	16.5	**19.0**	13.7	9.5	5.7	1.7	0.0	223.3
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	0.0
2024 MPAR LCC Estimate	**309.3**	**27.1**	**16.5**	**19.0**	**13.7**	**9.5**	**5.7**	**1.7**	**0.0**	**402.5**
Total Budget	**296.6**	**18.5**	**10.5**	**13.0**	**7.7**	**6.6**	**5.7**	**1.7**	**0.0**	**360.2**

The FY 2024 MPAR LCC Estimate for SEP reflects the total LCC reported by NASA in January 2024. The requested budget authority is inclusive of Space Technology only.



Shown above is the Solar Electric Propulsion project's first qualification thruster installed in thermal vacuum facility test chamber.

PROJECT PURPOSE

NASA will continue the development of SEP with higher-power, longer-life thrusters, which are nearly three times as powerful as current technology. In collaboration with ESDMD, the first operational demonstration of the SEP 12-kilowatt (kW) thruster will be on the Power and Propulsion Element (PPE) to place Gateway into its highly elliptical lunar orbit. This demonstration and operational mission will provide NASA with experience in electric propulsion around the Moon, while demonstrating operational approaches as Gateway interfaces with visiting crew and robotic vehicles. SEP will also enable more efficient orbit transfer of spacecraft and accommodate the increasing power demands for government and commercial satellites.

Visit https://www.nasa.gov/tdm/solar-electric-propulsion/ to learn more about SEP.

EXPLANATION OF MAJOR CHANGES IN FY 2025

This budget reflects PPE required modifications to the SEP thruster harnesses for the three flight models, Qualification Model-2 thruster, a rough order of magnitude estimate of future changes to the Aerojet Rocketdyne harness qualification retest, and the associated project costs and schedule implications.

PROJECT PARAMETERS

The goal of SEP is to qualify a 12-kW solar electric propulsion thruster to use as the primary propulsion for a spaceflight demonstration during an operational mission. Objectives include:

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

- Qualify high-power SEP thruster technology for operational use through continuous long-term operation of the system in a relevant environment, sufficient to characterize and predict the performance and lifetime of the system; and
- Qualify a 12-kW electric propulsion thruster for extended operations in deep space.

ACHIEVEMENTS IN FY 2023

The Aerojet Rocketdyne team completed the first qualification thruster assembly in April 2023 and delivered it to NASA's GRC in May 2023. Flight thrusters work continued to progress toward assembly completion and the project also held a successful KDP-D in May 2023.

WORK IN PROGRESS IN FY 2024

The second qualification thruster assembly will be complete in the third quarter of FY 2024.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The Qualification System Acceptance Review 1 (QSAR-1) is scheduled for December 2024.

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2025 PB Request
Formulation Authorization	Mar 2015 (as part of Asteroid Redirect Robotic Mission [ARRM])	Mar 2015 (as part of ARRM)
KDP-A	Mar 2015 (as part of ARRM)	Mar 2015 (as part of ARRM)
PDR	Aug 2017	Aug 2017
KDP-C	Oct 2019	Oct 2019
Delta KDP-C	-	May 2021
CDR	Mar 2022	Mar 2022
Re-baseline	Mar 2022	Mar 2022
KDP-D	Apr 2022	May 2023
QSAR-1	Jun 2024	Dec 2024
QSAR-2	Jun 2025	Aug 2026
Advanced Electric Propulsion System Life Qualification Test Report	Oct 2028	Jan 2029

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2022	203.2	70	2024	223.2	9.8	Electric Propulsion Thruster Life Qual Test Report	Oct 2028	Jan 2029	3

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**203.2**	**223.2**	**+20.0**
Science/Technology	159.7	172.8	+13.1
Other Direct Project Costs	43.5	50.4	+6.9

Project Management & Commitments

Element	Description	Provider Details
Project Management	Manages Aerojet Rocketdyne contract, thruster development life testing and qualification testing	Lead Center: GRC
Thruster Development	Thruster development and life qualification testing support	Lead Center: JPL
Thruster Design	Thruster design and qualification	Provider: Aerojet Rocketdyne Lead Center: N/A

SOLAR ELECTRIC PROPULSION (SEP)

Formulation	Development	Operations

Acquisition Strategy

All major acquisitions are in place.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Advanced Electric Propulsion System Contract	Aerojet Rocketdyne	Redmond, WA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
QSAR-1	SRB	Dec 2024	Assess/approve environmental test results for Qualification Module-1	TBD
QSAR-2	SRB	Aug 2026	Assess/accept preliminary life test data for Qualification Module-2	TBD

SPACE NUCLEAR PROPULSION

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Nuclear Thermal Propulsion	90.0	--	**92.5**	53.0	37.0	28.0	25.0
Nuclear Electric Propulsion	1.3	--	**17.5**	17.5	17.5	17.5	17.5
Total Budget	**91.3**	**--**	**110.0**	**70.5**	**54.5**	**45.5**	**42.5**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Shown above is an artist's depiction of the DRACO NTP flight demonstration concept.

NASA is investing in Space Nuclear Propulsion to explore propulsion systems that may prove useful for human exploration missions beyond the Moon. Space nuclear systems are a potential alternative to traditional chemical propellants that offer a combination of propellent mass efficiency and high thrust. NASA has made strides to advance solutions to long-existing technology gaps necessary for the design of safe and reliable propulsion systems. These solutions included advancing high-temperature reactor fuel, materials, and designs, as well as methods for managing cryogenic propellants. While more technology improvements will be required for an operational system, NASA is now poised to experimentally demonstrate the combined performance of these technologies in subcomponents, subsystems, and an integrated nuclear thermal propulsion capability.

NUCLEAR THERMAL PROPULSION (NTP)

NTP systems offer the benefits of high thrust, high specific impulse, and reduced propellant mass. Nuclear thermal rockets can produce thrust levels comparable to chemical systems with a propellant mass efficiency two or more times than that of conventional chemical propulsion. The high thrust capability of NTP eliminates the need for a chemical stage to conduct gravity maneuvers. The combination of propellent mass efficiency and high thrust for NTP offers unique benefits as a deep space propulsion system in terms of increased payloads, fast deep-space transit, and improved mission flexibility. NTP also offers a competitive ability to execute a Mars exploration mission with reduced Earth staging logistics, round-trip fueling at Earth, and high-mass payload delivery. However, NTP systems are significantly more expensive to develop and operate than chemical propulsion systems.

DEMONSTRATION ROCKET FOR AGILE CISLUNAR OPERATIONS (DRACO)

In January 2023, NASA and the Defense Advanced Research Projects Agency (DARPA) announced a collaboration to demonstrate a nuclear thermal rocket engine (NTRE) in space. Under the agreement, STMD will lead technical development of the nuclear thermal engine to be integrated with DARPA's experimental spacecraft. DARPA is acting as the contracting authority for the development of the entire stage and the engine, which includes the reactor. DARPA will lead the overall mission including rocket systems integration and procurement, approvals, scheduling, and security, cover safety and liability, and ensure overall assembly and integration of the engine with the spacecraft. Over the course of the development, NASA and DARPA will collaborate on assembly of the engine before the in-space demonstration as early as 2027.

While DRACO will demonstrate a prototype NTRE, extending those developments into a reliable operational capability will require further technology development. These developments include active cryogenic fluid management, a mass-optimized reactor design, fuel qualification testing, ground testing of subsystem components, and ground testing of integrated engine systems.

NUCLEAR ELECTRIC PROPULSION (NEP)

NEP offers electric power provided by a fission reactor combined with a power conversion system and high propellant mass efficiency provided by the electric thrusters. Combined, these can gradually increase vehicle velocity and support the higher power needs of a Mars human exploration mission or a high-value deep-space science mission to outer planets. An integrated NEP vehicle is complex and the success of a design, particularly a large-scale Mars transportation system, relies on the successful development of several critical subsystems. When compared to solar electric powered systems, nuclear electric systems can offer greater power for lower mass and not suffer loss in power as mission distance from the sun increases. A nuclear reactor can allow deep-space operation where solar energy is lower or solar power production is impractical. Compared to traditional chemical systems, electric propulsion offers efficiencies that are four-to-ten times higher, which can mean fewer supply launches to Mars from Earth with the ability to complete a round trip without the added logistics and risk of refueling at Mars. However, as with NTP, NEP systems are significantly more expensive to develop and operate than chemical propulsion systems

ACHIEVEMENTS IN FY 2023

NASA and DARPA finalized their NTP partnership in January 2023. NASA realigned its investment strategy to support the DRACO partnership and the mission successfully entered the formulation phase in July 2023.

NASA extended the NTP industry-led contracts for Phase 1 reactor designs to demonstrate manufacturability and operational feasibility.

NASA completed the internal review of the NEP Technology Maturation Plan for high power development, executed initial NEP investments in power generator thruster development, and initiated technology investments to advance high-power NEP electric thrusters and power management systems.

WORK IN PROGRESS IN FY 2024

The DRACO NTRE PDR is planned for February 2024. DRACO project will enter the implementation phase by the end of FY 2024.

Nuclear technology maturation efforts include complete installation of a hydrogen test loop at the Idaho National Laboratory Transient Reactor Test facility. Industry partners plan to reduce reactor design risks through feasibility demonstrations by the end of the third quarter of FY 2024, and limited investments in fuel fabrication development will continue as feasible.

The NEP Technology Maturation Plan will be baselined and used to guide NASA's investment strategy. The team is developing preliminary design requirements for a low-power NEP flight demonstration.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

DRACO CDR is scheduled in early FY 2025.

Subscale integrated NEP concept design is targeted for completion in FY 2025. Final design and initial fabrication of a high-power electric thruster that could be used in a NEP system is also scheduled to be delivered in FY 2025.

DRACO Estimated Project Schedule

Milestone	FY 2025 PB Request
Signed Interagency Agreement	Jan 2023
Start Formulation	Jul 2023
NTRE PDR	Feb 2024
Start Implementation	Sep 2024
NTRE CDR	Oct 2024
Reactor to Engine Integration Completion	Mar 2027

DRACO Formulation Estimated LCC Range and Schedule Range Summary

LCC estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation, which follows a non-advocate review and/or PDR.

Formulation KDP Date	Estimated LCC Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Jul 2023	293.2 - 360.0	Reactor to Engine Integration Completion	Mar 2027 - Sep 2028

DRACO Project Management & Commitments

NASA manages the design, development, and test of the nuclear thermal propulsion engine. DARPA manages: the design and development of the flight vehicle; all assembly, integration, and testing of the integrated vehicle-engine system; launch of the demonstrator; in-space flight operations; and all nuclear launch safety and approval processes. MSFC manages the DRACO project for NASA.

Element	Description	Provider Details
NTRE	Propulsion system for the rocket demonstration	Provider: Lockheed Martin Lead Center: MSFC Performing Center(s): MSFC; GRC Cost Share Partner(s): DARPA

DRACO Acquisition Strategy

The NASA-DARPA Interagency Agreement defines roles and responsibilities in a jointly managed effort for the NTRE demonstration. NASA utilizes an Interagency Assisted Acquisition to fund development of the NTRE under the DARPA DRACO Other Transaction Agreement contract with industry. DARPA owns the contract with the industry performer and will administer the overall DRACO contract for the demonstration, including NASA's programmatic and technical direction for the NTRE.

DRACO MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Nuclear Thermal Rocket Engine	Lockheed Martin	Denver, CO

DRACO INDEPENDENT REVIEWS

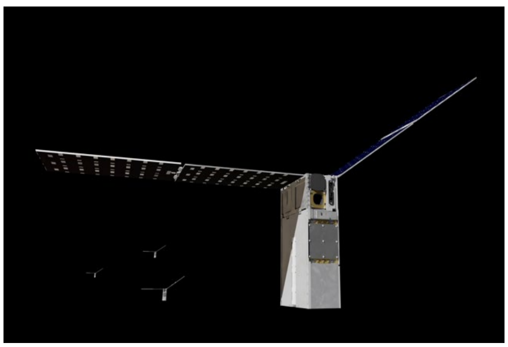
Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Independent Review Team (IRT)	Feb 2024	PDR	TBD
Performance	IRT	Oct 2024	CDR	TBD

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**178.6**	**--**	**325.1**	**382.3**	**404.1**	**421.6**	**434.9**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Shown here is a depiction of the Starling mission which is advancing the readiness of technologies for multi-spacecraft distributed missions. Starling 1.0 launched in July 2023.

FLIGHT OPPORTUNITIES (FO) AND SMALL SPACECRAFT TECHNOLOGY (SST)

The FO and SST portfolio supports disruptive technology innovation and the execution of unique missions to change the pace of space exploration, discovery, and the expansion of space commerce. The portfolio's speed, flexibility, and access to a wide array of commercial suborbital and orbital capabilities provides opportunities to rapidly address technology gaps and emerging needs.

Leveraging Emerging Commercial Capabilities to Accelerate Technology Development

The FO and SST portfolio engages in collaborations with U.S. commercial industry and academia to support American global competitiveness and leadership in space. The portfolio makes use of a flights-of-opportunity- and missions-of-opportunity-based approach to rapidly move technology from benchtop to flight test. This approach leverages commercial capabilities and best practices alongside rapid acquisition approaches that improve the ability to work effectively with the entrepreneurial space industry.

In addition to purchasing commercial space flight testing services, FO and SST also invest directly in U.S. commercial space flight capabilities. The portfolio partners with commercial flight providers on the development of new space test capabilities and aims to provide researchers access to emerging commercial space test offerings. The portfolio also utilizes its flights-of-opportunity and missions-of-opportunity acquisition approach to further this aim. For example, the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) mission is not only a technology demonstrator and precursor for lunar exploration but is also intended to lay the groundwork for future commercial support of missions beyond Earth.

Addressing Critical Technology Gaps for NASA and the Nation

By flight testing technologies with commercial flight providers, FO and SST mature capabilities needed for space exploration, scientific discovery, and commercial applications, while strategically investing in the growth of the U.S. commercial space flight industry. These tests take technologies from ground-based laboratories into relevant flight environments to increase technology readiness and validate feasibility, while reducing the costs and technical risks of future missions. Technology investment capability gaps identified by STMD's Strategic Technology Architecture Roundtable inform future NASA missions, national needs, and U.S. commercial interests. Current investment areas include:

- Testing space-based manufacturing technologies that address both future NASA needs and opportunities for commercial industry. Capabilities for in-space manufacturing, as well as technologies that further commercial in-space biological and physical research capabilities, not only assist NASA with plans for the next wave of human exploration beyond Earth but also enable companies to innovative products that can only be discovered or produced in microgravity.
- Advancing commercial microsatellite and orbital maneuvering vehicle systems for continued expansion of small, risk-tolerant missions further beyond Earth and for advanced near-Earth applications. Such systems can support cislunar operations, science, planetary defense, and orbital debris mitigation.
- Enabling lunar utilization infrastructure via commercial flight-testing opportunities for lunar communication, positioning, navigation, and timing capabilities as well as in-situ resource utilization and advanced manufacturing.

ACHIEVEMENTS IN FY 2023

- FO tested 31 payloads via 20 flights from six commercial providers and, in January 2023, nine technologies were selected as part of the 2022 TechFlights solicitation.
- The CAPSTONE technology demonstration mission entered lunar orbit on November 13, 2023, becoming the first CubeSat to fly to and operate at the Moon. Over the course of CAPSTONE's primary mission, the spacecraft tested multiple navigation technologies that could provide autonomous onboard navigation information for future missions, reducing the burden lunar activities may place on already overtaxed ground systems. The spacecraft also gathered operational data in the near-rectilinear halo orbit for the Artemis program.
- On April 28, 2023, the TeraByte InfraRed Delivery (TBIRD) communications system achieved 200 gigabit per second (Gbps) throughput between a satellite in LEO and the ground. This is the highest data rate ever achieved by space-based optical communications technology. The TBIRD communications system was developed with NASA's Space Communication and Navigation program and was demonstrated on Pathfinder Technology Demonstrator-3 (PTD-3). PTD-3 is part of a series of missions that will test the operation of a variety of novel CubeSat technologies in orbit.
- CubeSat Infrared CrossLink A (CLICK-A) successfully demonstrated the precision laser pointing performance of the spacecraft's fine steering mirror control system, an element of a compact optical crosslink communications system. The fine steering mirror control system enables use of a lower power laser and will support alignment of two-way optical communication between small spacecraft in orbit.
- In May 2023, three winners of NASA's first TechLeap Prize Autonomous Observation Challenge No.1 completed a re-flight of their technologies less than one year after their initial flights. TechLeap is designed to quickly identify and test technologies of interest to NASA and the nation and increases access to flight tests for small and entrepreneurial organizations.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

- The Starling mission's four small spacecraft launched on July 17, 2023, on an FAA-licensed Rocket Lab Electron rocket from Launch Complex 1 in Māhia, New Zealand. Upon successful deployment, mission operators achieved operational two-way communications with each spacecraft and completed payload commissioning.

WORK IN PROGRESS FOR FY 2024

- FO's Suborbital/Hosted Orbital Flight and Payload Integration Services 4 solicitation seeks commercial providers to test technology payloads in the space environment. This solicitation adds new capabilities, including hosting payloads in orbit in cooperation with the SST Program and flying NASA researchers on suborbital flights. Selection decisions and first use of the new contracts is anticipated in early 2024.
- The Starling primary mission continues in 2024. It will demonstrate autonomous maneuver planning, ad hoc communications networking, relative navigation, and autonomous coordinated science measurements, all with minimal intervention from operators on the ground. Starling 1.5, the extended mission, will demonstrate technologies and processes for autonomous conjunction assessment and collision avoidance between spacecraft in LEO.
- TechFlights 2023 was released in May 2023, seeking proposals from industry, academia, and non-profit research institutes for space technologies that can be advanced through flight tests. FO partnered with the Commercially Enabled Rapid Space Science (CERISS) initiative from SMD, to advance biological and physical sciences research capabilities with the commercial space industry. In addition to offering suborbital flight tests with industry providers, the solicitation also included access to commercial platforms hosting payloads in orbit in cooperation with the SST Program. Final selection decisions and work on the new projects began in early 2024.
- The three winners of the second TechLeap challenge, Nighttime Precision Landing Challenge No. 1, are developing their unique innovations to detect hazards in the dark from an altitude of 250 meters (820 feet) or higher. By processing their sensing system data in real time, these technologies are designed to help spacecraft land safely in areas of great scientific interest on the Moon. Flight testing is scheduled for early 2024 in Mojave, California aboard Astrobotic's Xodiac lander testbed.
- The University SmallSat Technology Partnerships (USTP) initiative selected eight U.S. university teams to begin projects in early 2024 to advance technologies for navigation and timing, edge computing and machine-learning architectures, as well as power and thermal control for small spacecraft. The university teams received awards from the SST Program to mature new systems and capabilities in these areas, with support from a partnering NASA Center. As in past years, some USTP projects may be selected for a subsequent flight demonstration through the CubeSat Launch Initiative or FO.
- With the aim of providing persistent communications for wildland fire first responders, researchers at flight provider Aerostar, the U.S. Forest Service, and NASA's ARC are collaboratively developing the Strategic Radio and Tactical Overwatch (STRATO) technology. A full proof-of-concept flight test over an active wildland fire will take place no earlier than spring 2024. This is a key step in demonstrating the potential for a stratospheric platform to give firefighters the communications capabilities and real-time observation data they need.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The FO and SST portfolio will continue its solicitation and flight cadence with industry and academia, as well as its flights-of-opportunity- and missions-of-opportunity-based approach to rapidly move technology from benchtop to flight test.

- Four industry-led mission concept studies executed in 2023 will transition during FY 2025 to an orbital demonstration, targeting launch before the end of 2026.
- By 2025, 12 current SST demonstrations, including the Starling mission and space traffic management experiment, both currently on orbit, will be completed.

OTHER TECH DEMO

Cryogenic Fluid Management (CFM)

CFM is an enabling technology that holds the potential to support a human presence on a planetary surface as well as long-duration space flight by optimizing the preservation of chemical propellants. Improved cryogenic fluid management helps enable in-space transportation systems, such as human lander systems and lunar and, eventually, Mars surface operations, including in-situ resource utilization. Missions that involve durations ranging from months to multiple years are far beyond the current state-of-the-art capabilities for in-space cryogenic fluid management. The goal of CFM is to advance and demonstrate technologies enabling storage, autonomous transfer, and gauging of cryogenic propellants, capable of scaling to tens of metric tons, with negligible losses for long durations in space and on the lunar surface.

As part of the 2020 Tipping Point solicitation process, NASA selected four companies in 2021 for milestone-based firm-fixed price contracts to demonstrate cryogenic fluid technologies in the areas of passive thermal control, tank pressure control, active cooling, and tank-to-tank propellant transfer. The four Tipping Point teams are expected to launch between FY 2024 and FY 2025.

CFM also maintains NASA contracts to advance cryocoolers, a technology critical to long duration storage of cryogens, as well as a variety of in-house work related to the storage, transfer, and mass gauging of cryogenic fluids.

Fission Surface Power (FSP)

FSP is developing a small, lightweight fission power system that will enable long-duration lunar surface operations that is extensible for use on Mars. The goal is to demonstrate an integrated fission power system on the lunar surface to verify the engineering function, power performance, and operational reliability of the capability. Following a successful demonstration, this power technology could form a key capability for long-duration human surface missions on the Moon and eventually Mars. The technology could enable mission operations in harsh environments, such as permanently shadowed craters and the 14-day lunar night near the poles, and satisfy mission needs for continuous solar-independent power operations. This work is being conducted in collaboration with the Department of Energy and industry to optimize the use of common technology found in terrestrial fission power systems. NASA will explore technology synergies for NEP and potential collaborations with the United States Space Force, other government agencies, or international partners.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Deep Space Optical Communications (DSOC)

DSOC technologies are considered essential for future human missions to Mars and have a wide range of applications for planetary science missions including those to Mars and the Jovian systems, as well as other deep space distance exploration missions. The DSOC project developed key technologies for demonstration of a deep space optical flight transceiver and ground receiver that provide greater than 10 times the data rate of a state-of-the-art deep space radio frequency system (Ka-band). This capability will enable advanced instruments, live high-definition video, and telepresence that allow for deep space human exploration of the solar system. DSOC was delivered on schedule in June 2021 and integrated onto Psyche in FY 2022. It launched on Psyche on October 13, 2023, completed check out and commissioning, and successfully sent and received its first data in November 2023. It will continue these demonstrations over the next two years during Psyche's cruise toward Mars.

Selected Announcement of Collaboration Opportunity (ACO) and Tipping Point

As part of the 2022 ACO and Tipping Point solicitation process, NASA selected one ACO and three Tipping Points that align with work in the Technology Demonstration Missions (TDM) Program:

- **Aerojet Rocketdyne Electrically Actuated Quick-Disconnect Coupling for Cislunar and Lunar Surface Cryogenic Propellant Transfer ACO**
  NASA partners with Aerojet Rocketdyne in this activity to design, analyze, and test an electrically actuated quick-disconnect cryogenic coupling and increase it from TRL 2 to 5. The effort will result in a detailed design for a cryogenic coupler and two-tested prototype sets of couplers.
- **Redwire Infrastructure Manufacturing with Lunar Regolith (Mason) Tipping Point**
  Mason is a grader, compactor, and microwave emitter scalable to a system capable of removing rocks, compacting loose regolith, and sintering (melting) regolith into a solid surface. The team will develop three subsystems in a relevant environment (simulated regolith) by FY 2026 to demonstrate viability to design and build systems for lunar operations.
- **United Launch Alliance Vulcan Engine Reuse Scale (VERS) Hypersonic Inflatable Aerodynamic Decelerator Technology Demonstration Tipping Point**
  VERS will continue to evolve a proven Hypersonic Inflatable Aerodynamic Decelerator (HIAD) technology design, developing a 10-meter HIAD, enabling even larger inflatable decelerators for future exploration use. This team will build multiple development units using different commercial vendors to expand the potential supplier base for HIAD manufacturing, perform structural and inflation system testing on an engineering development unit, perform gas generator development that will reduce mass/volume on an operational system, and perform risk reduction testing to support model validation. This will culminate in a ground demo in FY 2026.
- **Lockheed Martin Joining Demonstrations In-Space (JOINS) Tipping Point**
  JOINS will advance in-space joining and inspection technologies through a series of ground and flight demonstrations, culminating in a flight module to be demonstrated on ISS in 2026. The in-space demonstrations will be in an automated module with welding and inspection capabilities in the Bishop Airlock on ISS. The joining and inspection demonstrations will be on multiple joint configurations, materials, and processes. The welded and inspected on-orbit samples will return to Earth for ground testing to assess the performance of the welding and inspection technologies.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

Lunar Infrastructure Flight Demonstrations (LIFD)

LIFD will enable lunar infrastructure integrated system-level demonstrations. It will demonstrate a bi-directional power microgrid with multiple sources and loads. Initial investments in 2025-2027 will target multiple industry contracts and internal developments with the goal of pursuing partnerships towards a potential integrated power management and distribution flight demonstration in the 2030s.

ACHIEVEMENTS IN FY 2023

- The CFM team delivered and installed the Radio Frequency Mass Gauge (RFMG) demonstration on Commercial Lunar Payload Services (CLPS) Intuitive Machines-1 (IM-1) in February 2023.
- The LEO Flight Test of an Inflatable Decelerator launched on November 10, 2022, as a rideshare with the Joint Polar Satellite System-2 (JPSS-2) spacecraft on an Atlas V. The mission completed its flight demonstration with a successful atmospheric reentry. The reentry vehicle and eject-able data module ocean recovery was a success and the operations phase close-out occurred in September 2023.
- The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE), selected as one of TIME's best inventions of 2023, completed its 17th and final oxygen production run on Mars in September 2023.
- Industry completed the FSP phase I designs for an integrated lunar fission power system in September 2023.

WORK IN PROGRESS IN FY 2024

- DSOC launched on Psyche on October 13, 2023, and is sending and receiving data with transmission rates 10 to 100 times greater than current state-of-the-art radio frequency systems. The first test transmission, known as "first light", occurred on November 14, 2023. The Post Launch Assessment Review occurred in early 2024, closing out the commissioning phase and beginning the official DSOC demonstration.
- A new nationwide alliance focused on in-space servicing, assembly, and manufacturing (ISAM) called the Consortium for Space Mobility and ISAM Capabilities (COSMIC) held a successful kickoff in November 2023, with participation from government, academia, and industry. COSMIC's objective is to make ISAM a routine part of space architectures and mission life cycles. Over 550 parties with vested interest in ISAM participated in the kick-off. An executive steering committee was formed, and the next full meeting of the consortium will take place in May 2024 in Logan, Utah.
- The CFM RFMG flew in February 2024 on IM-1.
- The SpaceX CFM Tipping Point launch is planned for a no-earlier-than March 2024 and will demonstrate tank-to-tank transfer operations for liquid oxygen.
- The FSP mission concept review is planned for late FY 2024.
- Selected ACO and Tipping Points:
    - The VERS PDR is in February 2024;
    - The Mason PDR is in May 2024; and
    - The JOINS CDR is in June 2024.

SMALL SPACECRAFT, FLIGHT OPPORTUNITIES & OTHER TECH DEMO

KEY ACHIEVEMENTS PLANNED FOR FY 2025

- The DSOC demonstrations continue in FY 2025 as Psyche continues its cruise, allowing DSOC to send and receive data to and from the Earth at distances as far away as Mars.
- The Eta Space CFM Tipping Point launch is scheduled for November 2024 and will demonstrate unsettled liquid oxygen transfer operations and two-stage cooling operations.
- The United Launch Alliance CFM Tipping Point launch readiness review is planned for July 2025 and will demonstrate tank-to-tank transfer for liquid hydrogen and main propellant tank and system line chill-down operations.
- The FSP phase II contract award is targeted in the third quarter of FY 2025.
- Selected ACO and Tipping Points:
    - The Aerojet Rocketdyne ACO final test report will be complete in February 2025;
    - The Mason CDR is in March 2025;
    - VERS engineering development unit development testing is in August 2025; and
    - The JOINS ground demo will be in June 2025 with the suborbital demo in December 2025.
- LIFD mission concept review is in September 2025.

Acquisition Strategy

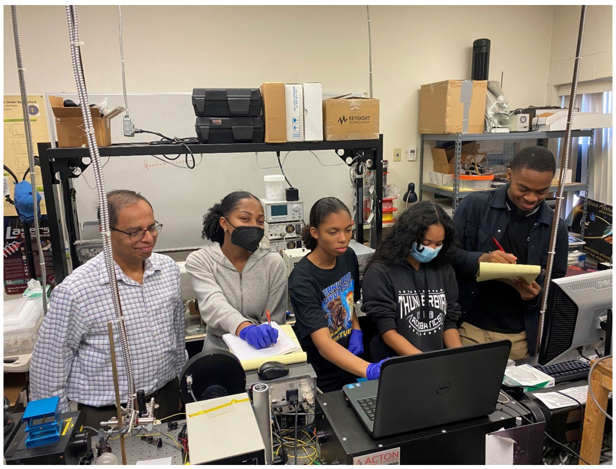
These critical technology projects are defined as part of the strategic framework and capabilities, and through STMD's Strategic Technology Architecture Roundtable process. In addition, Space Technology embraces competition and external partnerships. As such, some of the technologies are selected through annual Tipping Point, ACO, and other NASA solicitations. For more information, go to https://techport.nasa.gov/opportunities/stmd.

SBIR AND STTR

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	231.7	--	241.8	246.6	251.6	256.7	261.9

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Shown above, Dr. Patel (left) and four Oakwood University students record data related to their NASA STTR research to develop ultraviolet protective coating for photovoltaic solar cells in space. Photo credit: Oakwood University

NASA’s Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs leverage the nation’s innovative small business community to fund research and development in support of NASA's mission in space technology, human exploration, science, and aeronautics. These programs will also support NASA's Artemis program objectives by identifying and accelerating relevant technologies throughout all phases (i.e., Phase I, II, and Post Phase II). Post Phase II awards may involve matching funding from investors and encourages the advancement of innovations and commercialization of technologies developed through Phase I and Phase II. These programs provide the small business sector with an opportunity to develop and commercialize technology for NASA to spur economic growth. The SBIR/STTR programs are also intended to foster and encourage participation in innovation and entrepreneurship by women and socially or economically disadvantaged persons.

The SBIR and STTR program elements are as follows:

SBIR

The SBIR program was established by statute in 1982 and was most recently reauthorized in 2022 to increase research and development opportunities for small businesses. The program stimulates U.S. technological innovation, employs small businesses to meet federal research and development needs, increases the ability for small businesses to commercialize innovations they derive from federal research and development, and encourages and facilitates participation by socially disadvantaged small businesses. The SBIR program budget is based on a level of at least 3.2 percent of NASA’s extramural research and development budget. The maximum value for an SBIR Phase I contract is $150,000 for a period of performance of six months and the maximum value of an SBIR Phase II is $850,000 over a 24-month period of performance. NASA also supports several Post Phase II vehicles:

- Phase II-E is a contract opportunity on Phase II awards that provides incentives for cost sharing with non-SBIR investors to extend the research and development efforts of the current Phase II contract.

- Civilian Commercialization Readiness Pilot Program (CCRPP) contracts with non-SBIR investors with incentives for cost sharing to extend the research and development efforts of previous Phase II contracts with strong customer pull for technology maturation and commercialization.
- Phase II sequential contracts help accelerate the TRL of technologies to a point that other investors can infuse the technology into other NASA programs.

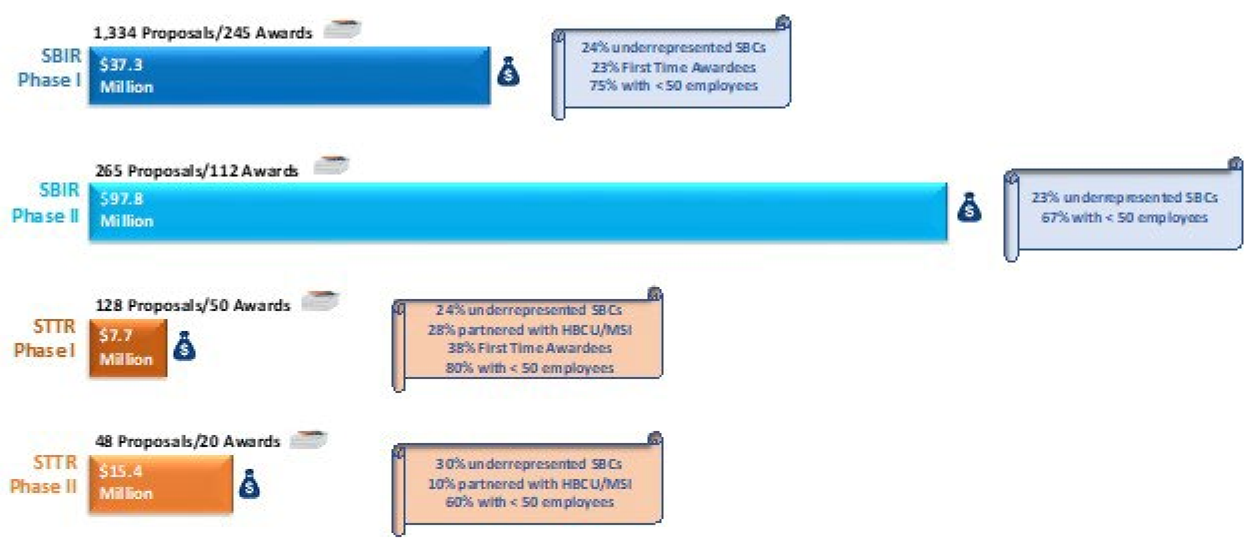
STTR

The STTR program was established by statute in 1992 and reauthorized in 2022 to award contracts to small businesses for cooperative research and development with a non-profit research institution, such as a university. NASA's STTR program facilitates the transfer of technology developed by a research institution through the entrepreneurship of a small business, resulting in technology to meet NASA's core competency needs in support of its mission programs. Modeled after the SBIR program, STTR is funded based on 0.45 percent of the NASA extramural research and development budget. The maximum value for an STTR Phase I contract is $150,000 for a period of performance of 13 months and the maximum total value of an STTR Phase II is $850,000 over a 24-month period of performance. Phase II-E, CCRPP, Phase II sequential contracts can be available to STTR participants.

EXPLANATION OF MAJOR CHANGES IN FY 2025

The SBIR and STTR programs will explore ways to reduce barriers to entry and streamline the experience throughout the program phases, including strategies to encourage transition to NASA, government, and/or commercial use beyond SBIR/STTR awards.

ACHIEVEMENTS IN FY 2023



- Overall, the SBIR and STTR programs awarded nearly 450 new projects to small business across the nation. Some new activities include a retro-braking propulsion system focused initially on deorbit of spacecraft in LEO to mitigate the potential risk from orbital debris, a novel approach to automate the DNA monitoring of microbes to help quickly identify those which might pose a

threat to astronauts, and a lightweight, compact, and high-performance lidar, making it faster and more efficient for many applications spanning science missions, space exploration systems, and aeronautics.
- Four STTR awards were made to selections that had previously received NASA M-STTR planning grants which are now part of the Minority University Research and Education Project Partnership Annual Notification created to incentivize partnerships between minority serving institutions and small businesses.
- NASA selected its first Tribal College and University, Navajo Technical University, as part of an STTR Phase II award for work on a Digital Twin Data Acquisition System for Institutional Facility Management.
- NASA also selected 12 firms for Phase II awards under the pilot solicitation SBIR Ignite, which focuses on commercially viable technology ideas with an emphasis on entrepreneurial engagement to encourage commercialization and economic impact.

WORK IN PROGRESS IN FY 2024

- The Intern Diversity Supplement is a pilot to develop an opportunity to support diversity in STEM through a combined research/ business internship experience as an eligible expense covered in SBIR/STTR awards.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

- SBIR and STTR will continue efforts to encourage participation of underrepresented groups across the nation to expand inclusive innovation.
- SBIR and STTR intend to select over 600 new awards, grants, and contracts to small businesses, as well as continue to incubate and mature NASA commercial partnerships through post Phase II activities through sequential Phase II awards.
- The program will pilot ways to reduce barriers to entry and streamline the experience throughout the program phases, including strategies to encourage transition to NASA, government, and/or commercial use beyond SBIR/STTR awards.

SBIR AND STTR

Program Management & Commitments

Program Element	Provider
SBIR and STTR	Provider: Various Small Businesses and their research partners Lead Center: NASA HQ; Level 2: ARC Performing Center(s): All centers play a project management and implementation role. Cost Share Partner(s): SBIR/STTR Phase II-E matches cost share funding with SBIR and STTR up to $375,000 of non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, other government agency, or third-party commercial investor to extend an existing Phase II project to perform additional research. SBIR/STTR CCRPP matches cost share funding up to $2,500,000 of non-SBIR and non-STTR investment(s) from a NASA project, NASA contractor, other government agency, or third-party commercial investor to continue a former Phase II project to perform additional research for strong customer pull for the technology maturation, commercialization, and ultimately utilization versus incremental development.

Acquisition Strategy

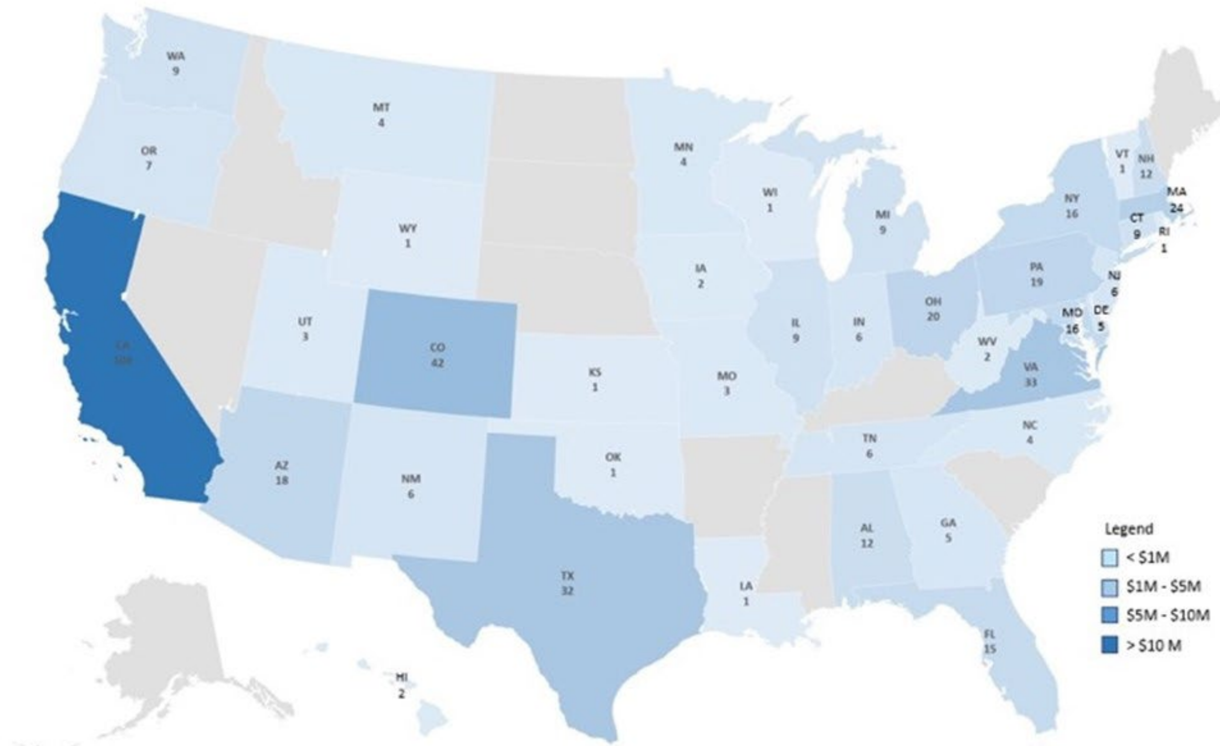
NASA issues annual SBIR and STTR program solicitations, setting forth a substantial number of topic areas open to qualified small businesses. There are three phases for SBIR and STTR funding awards. Phase I awards give small businesses the opportunity to establish the scientific, technical, and commercial merit of the proposed innovation in alignment with NASA interests. The most promising Phase I projects are selected for Phase II awards through a competitive selection process based on scientific and technical merit, expected value to NASA, and commercialization potential. Phase II awards focus on the development, demonstration, and delivery of the proposed innovation. SBIR Ignite is a new experiment in Phase I and II awards seeking to fund ideas that are relevant in the commercial market with a proposal process more closely aligned with what firms would see through a venture financing process. Phase II Sequentials, Phase II-E, and CCRPP support advancement of innovations developed under Phase II. Phase III supports the commercialization of innovative technologies, products, and services that result from a Phase I or Phase II contract. Commercialization includes further development of technologies and getting feedback to discover infusion opportunities into NASA programs, other government agencies, or the private sector. Phase III contracts receive funding from sources other than the SBIR and STTR programs and may be awarded without further competition.

SBIR and STTR program management work collaboratively with NASA center Chief Technologists (for STTR) and the mission directorates (for SBIR) during the acquisition process. This collaboration, from topic development through proposal review and ranking, supports the final selection of proposals of high value to NASA. Mission directorates and center program personnel interact with SBIR and STTR award winners to maximize alignment and implementation of the SBIR and STTR products with NASA's future missions and systems.

SBIR AND STTR

Award Distribution

The map below represents the FY 2023 SBIR and STTR investments through Phase I, Phase II, Phase II-E, Sequential, and CCRPP awards.



SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Earth Science	2,175.0	--	**2,378.7**	2,396.3	2,446.1	2,489.7	2,543.4
Planetary Science	3,216.5	--	**2,731.5**	2,850.5	2,911.6	2,976.8	3,042.5
Astrophysics	1,510.0	--	**1,578.1**	1,587.0	1,613.6	1,647.1	1,673.4
Heliophysics	805.0	--	**786.7**	791.9	807.0	820.3	833.4
Biological and Physical Sciences	85.0	--	**90.8**	91.3	93.0	94.8	96.6
Total Budget	**7,791.5**	**7,795.0**	**7,565.7**	**7,717.0**	**7,871.3**	**8,028.7**	**8,189.3**

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

SCIENCE

Planetary Science

Astrophysics

SCIENCE

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Earth Science	2,175.0	--	**2,378.7**	2,396.3	2,446.1	2,489.7	2,543.4
Planetary Science	3,216.5	--	**2,731.5**	2,850.5	2,911.6	2,976.8	3,042.5
Astrophysics	1,510.0	--	**1,578.1**	1,587.0	1,613.6	1,647.1	1,673.4
Heliophysics	805.0	--	**786.7**	791.9	807.0	820.3	833.4
Biological and Physical Sciences	85.0	--	**90.8**	91.3	93.0	94.8	96.6
Total Budget	**7,791.5**	**7,795.0**	**7,565.7**	**7,717.0**	**7,871.3**	**8,028.7**	**8,189.3**

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NASA's SMD conducts scientific exploration enabled by space-based observatories, which observe the Earth, perform fundamental research, visit other bodies in the solar system, and gaze out into the galaxy and beyond. NASA's scientific exploration will inform human exploration of the Moon, Mars, and the solar system, providing valuable scientific data for such human missions. NASA also strives to drive discovery by studying biological and physical phenomena in space. SMD utilizes technological advances and partnership opportunities, including public-private partnerships that leverage commercial investments, to further NASA's science objectives.

This massive Wolf-Rayet star, WR 124, is 15,000 light-years away in the constellation Sagittarius. It is 30 times the mass of the Sun and has shed 10 Suns worth of material so far. As the ejected gas moves away from the star and cools, cosmic dust forms and glows in the infrared light, detectable by the James Webb Space Telescope.

NASA's science programs also help protect and improve life on Earth through research that enables innovative and practical applications for decision-makers, including disaster response, natural resource management, and planetary defense.

SMD uses the recommendations of the National Academies' decadal surveys as important inputs in planning and prioritizing the future of its science programs. SMD uses these recommendations to prioritize future flight missions (including space observatories and probes), as well as technology development and proposals for theoretical and suborbital supporting research.

The current decadal surveys informing mission priorities include the Decadal Survey for Earth Science and Applications from Space 2018 to 2027; the Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032; the Pathways to Discovery in Astronomy and

Astrophysics for the 2020s; and the Decadal Survey on Biological and Physical Sciences Research in Space 2023-2032. The Heliophysics Division is expecting an updated decadal in 2024.

In determining the content of the Science portfolio, NASA also considers national priorities and policies, budgets, existing technological capabilities, partnership opportunities, and other programmatic factors.

EXPLANATION OF MAJOR CHANGES IN FY 2025

The budget provides $7.6 billion for Science, a $229.3 million decrease from the FY 2023 enacted level. Within Earth Science, NASA is restructuring missions within the Earth System Observatory. The Atmosphere Observing System (AOS) missions will be restructured to retain the partnership with JAXA on their Precipitation Measurement Mission, formerly part of AOS-Storm. NASA is assessing options for implementing the remainder of the Aerosol and Cloud, Convection, and Precipitation designated observables. Similarly, the Surface Biology and Geology (SBG) mission will be split into two projects, Surface Biology and Geology (SBG)-Thermal Infrared (TIR) and SBG-hyperspectral visible to shortwave infrared (VSWIR), to maximize execution flexibility and reduce near-term budget requirements. The budget provides $150 million for Landsat Next. NASA will not be able to reliably estimate the launch readiness date until there is a final FY 2024 appropriation but expects the launch date to be delayed compared to the prior estimate of CY 2030. NASA has established a new Responsive Science Initiatives program in Earth Science. This program consolidates and enhances current activities within Earth Science to increase the impact of NASA's observations, Earth system science, and applied science by aligning, scaling and connecting with user needs.

Within Planetary Science, the budget proposes an updated profile for the Near-Earth Object (NEO) Surveyor mission to support a June 2028 launch readiness date. NASA has also increased the Dragonfly budget request, consistent with the updated mission cost estimate expected to be reviewed at the upcoming mission confirmation, and consistent with a launch readiness date of July 2028. Given the need to increase the Dragonfly budget, NASA has delayed the New Frontiers 5 Announcement of Opportunity (AO) from November 2023 to no earlier than 2026. This budget request also extends the New Horizons mission until the spacecraft exits the Kuiper Belt in the 2028 to 2029 timeframe. NASA has also significantly expanded support for the ESA Rosalind Franklin ExoMars Rover mission in the wake of Russia's exit from the mission. The request includes $200M for Mars Sample Return that will allow the project to advance formulation of mission components and capabilities that have a high likelihood of being used in any future sample return architecture, and to evaluate and appropriately incorporate relevant findings from funded industry and center architecture studies.

Within Astrophysics, the budget supports increased investment in the Habitable Worlds Observatory Technology Maturation project, in direct alignment with the Great Observatories Mission and Technology Maturation Program (GOMAP) recommendation in the Astro2020 Decadal Survey. NASA has reduced the Explorer Future missions budget which will preclude the selection of Missions of Opportunity for the 2021 and 2025 AOs. NASA proposes to reduce the budgets of the Hubble and Chandra observatories in order to balance investments in future Astrophysics missions and missions in operations.

Within Heliophysics, the budget proposes the cancellation of Geospace Dynamics Constellation mission to fund higher priorities and increases funding for the Space Weather program. Within Biological and Physical Sciences, NASA has prioritized funding for the Commercially Enabled Rapid Space Science Initiative (CERISS) project, which, while reduced in scope compared to the FY 2024 Request, will expand suborbital or orbital demonstrations compared to what was funded in FY 2023.

SCIENCE

KEY ACHIEVEMENTS PLANNED FOR FY 2025

In FY 2025, NASA plans to launch Europa Clipper; Volatiles Investigating Polar Exploration Rover (VIPER); The Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer; The Interstellar Mapping and Acceleration Probe; Polarimeter to Unify the Corona and Heliosphere; The Sun Radio Interferometer Space Experiment; and Total and Spectral Solar Irradiance Sensor-2. In FY 2025, the Lunar Discovery & Exploration Program anticipates the launch and delivery of multiple new lunar science payloads to the surface of the Moon through the Commercial Lunar Payload Services project. The agency will make final selections for the next Heliophysics Small Explorers mission, the first Earth System Explorers missions, and the first Astrophysics Probe mission.

NASA will continue formulation of the Surface Biology & Geology and Gravity Recovery and Climate Experiment-Continuity (GRACE-C) missions and will reformulate the Atmosphere Observing System missions. The Responsive Science Initiatives program will release its first research solicitation. Biological and Physical Sciences will analyze tissue chip samples returned from the Artemis II mission and share insights across NASA and with other government agencies.

NASA will continue development of the Dragonfly and the NEO Surveyor missions. The Lucy mission will continue its journey to explore the Jupiter Trojan asteroids and will encounter the main asteroid belt and observe asteroid Donaldjohansen in April 2025. The Roman Space Telescope will continue development activities and is expected to begin integration and testing as it progresses toward launch in 2027. The Heliophysics division will evaluate the recommendations from the Heliophysics Decadal Survey, expected in 2024.

Themes

NASA's Science budget, managed by SMD, includes five major science areas.

EARTH SCIENCE

NASA's unique capabilities as a space and science agency ultimately enable decision makers to address the most pressing challenges posed by our rapidly changing planet such as changing agricultural conditions, and severe weather challenges, including droughts, tropical storms, and wildfires. NASA develops innovations in instrument, flight, data, and mission technology to improve capability, resolution, and frequency of our remote sensing and in-situ Earth observations. NASA missions use the vantage point of space to observe our planet and continuously improve our scientific understanding of Earth's interconnected systems, from Earth's core to its atmosphere. Missions include continuity measurements made for decades, and advances in observations to advance understanding of the Earth system. NASA selects and funds innovative research enabling the nation's scientific community to build an ever-improving understanding of global-scale changes, connecting causes to effects.

This budget supports translating Earth science into actionable data and information via investments in Applied Sciences, which will support applications and user engagement related to disaster response, wildfires, environmental justice, energy, and agriculture. NASA will work jointly with the Environmental Protection Agency and other agencies to integrate greenhouse gas data from a variety of sources with a goal of making data more accessible to federal, state, and local governments, as well as other users. Visualization of the information and partnerships in a comprehensive Earth system framework will be enabled by open science and cutting-edge data science techniques. NASA will continue development of the Earth Information Center, a physical and virtual space that provides easily accessible, readily usable, and scalable Earth information – enabling global understanding of the Earth system.

The budget supports continued formulation of the Earth System Observatory missions and Landsat Next, continues the Earth System Explorers program, and supports sustained climate observations. The budget also supports the ongoing development of multiple missions in development within the Earth Venture element. The Applied Sciences program will continue to leverage Earth Science satellite measurements and new scientific knowledge to enable innovative and practical uses by public and private sector organizations, including expanded applications development work in support of agriculture.

PLANETARY SCIENCE

To answer questions about the solar system and the origins of life, NASA sends robotic space probes to the Moon, other planets and their moons, asteroids and comets, and the icy bodies beyond Neptune. NASA is operating spacecraft at Mars, Jupiter, and the Moon. NASA is preparing to deliver new instruments to the lunar surface; will launch the Europa Clipper mission to explore Jupiter's moon, Europa; will develop the Dragonfly mission to explore Saturn's moon, Titan; and will send two missions to explore Venus. The budget funds the Lunar Discovery and Exploration Program that supports Artemis science, commercial collaborations, and innovative approaches to achieving human and science exploration goals. The budget supports future competitive mission selections within Discovery and New Frontiers and a robust research program to support the scientists who use NASA mission data to make discoveries about our solar system.

The budget supports the Open Source Science initiative, an SMD-wide activity that advances open science, supports data science innovation, and increases the accessibility of scientific data through the development of efficient data and computing system capabilities for all SMD divisions.

ASTROPHYSICS

NASA stands on the threshold of new endeavors that will transform not only our understanding of the universe and the processes and physical paradigms that govern it, but also humanity's place in it. Progress in understanding pathways to habitable worlds, opening new windows on the dynamic universe, and unveiling the drivers of galaxy growth require the essential vantage point of space. Building on the revolutionary advances in our observations of exoplanets, NASA now seeks to identify and characterize Earth-like exoplanets orbiting Sun-like stars, with the ultimate goal of obtaining imaging and spectroscopy of potentially habitable worlds.

NASA aims to exploit the new observational tools of gravitational waves and particles, along with temporal monitoring of the sky across the electromagnetic spectrum and wide-area surveys to probe the most energetic processes in the universe and address the nature of dark matter, dark energy, and cosmological inflation. By linking observations and modeling of the stars, galaxies, and the gas and energetic processes that couple their formation, evolution, and destinies, NASA can revolutionize our understanding of the origins and evolution of galaxies, from the nature of the tenuous cosmic webs of gas that feed them, to the nature of how this gas condenses and drives the formation of stars.

The budget supports operation of the James Webb Space Telescope and the Hubble Space Telescope, as well as the development of the Nancy Grace Roman Space Telescope. Within the Explorers program, the budget includes funding for SPHEREx and initial selections of the first Astrophysics Probe mission. This budget expands precursor science and technology efforts in planning and preparing for the GOMAP recommendation contained in the Astro2020 Decadal Survey.

SCIENCE

HELIOPHYSICS

The Sun, a typical small star midway through its life, governs our solar system. The Sun wields its influence through its gravity, radiation, solar wind, and magnetic fields, all of which interact with the Earth and its space environment. These processes are crucial for our understanding of the universe, and they relate directly to our ability to live in space as they produce space weather, which can affect technological infrastructure and human activities in space. Using a fleet of sensors on various spacecraft in Earth orbit and throughout the heliosphere, NASA seeks to understand the fundamental processes of how and why the Sun varies in many ways, how Earth and our solar system respond to the Sun, how the Sun and the solar system interact with the interstellar medium, and how human activities are affected by these processes. The science of heliophysics, including space weather, enables the predictions necessary to safeguard life and society on Earth and the outward journeys of human and robotic explorers.

The budget supports the development of the Interstellar Mapping and Acceleration Probe, the Carruthers Geocorona Observatory, and a competitive Explorers Program, including the recently selected Multi-slit Solar Explorer and HelioSwarm missions. The budget increases funding for the Space Weather program, which is focused on applied research and applications to enable the nation to better protect our technology and astronauts from space weather. The budget includes funding for the Diversify, Realize, Integrate, Venture, Educate initiative and funds orbital debris investments to enable characterization of the populations of small debris and dust in space to protect space-based critical infrastructure and humans working in space.

BIOLOGICAL AND PHYSICAL SCIENCES

NASA is a leader in performing fundamental biological and physical sciences research that contributes to transformational discoveries, improves life on Earth and in space, and enables sustained deep-space human exploration. NASA achieves this by pioneering research to understand how spaceflight affects living and physical systems in space and to prepare for future human exploration missions far from Earth. The experiments NASA conducts on the ISS and other platforms examine how astronauts, plants, animals, and physical systems respond to the extreme conditions of space, including microgravity, ionizing radiation, and altered atmosphere.

NASA examines processes of metabolism, reproduction, and development and studies how organisms repair cellular damage and protect themselves from infection and disease in the conditions of deep space. In addition to providing useful information on how living organisms respond and adapt to spaceflight, the discoveries NASA makes in space have significant implications for life on Earth.

NASA also conducts research to understand the fundamental laws of the universe, including quantum science, and determine how physical systems react in spaceflight environments. This research provides basic scientific knowledge and results leading to societal benefit, including contributions to the fundamental understanding of underlying space exploration technologies, such as power generation, storage, and fuel transfer; space propulsion; life support systems; and environmental monitoring and control. NASA research also contributes to scientific discoveries in novel areas, such as the fifth state of matter, known as Bose-Einstein Condensates, material sciences, and soft matter. This physical sciences research has led to improved space systems and new products on Earth.

EARTH SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Earth Science Research	502.0	--	**606.2**	608.4	627.6	628.8	637.2
Earth Systematic Missions	915.0	--	**854.4**	868.7	888.2	869.9	757.8
Earth System Explorers	2.5	--	**19.6**	59.0	99.5	130.6	194.7
Responsive Science Initiatives	55.0	--	**167.7**	173.9	176.4	177.9	179.5
Earth System Science Pathfinder	232.1	--	**251.7**	246.0	202.1	225.0	308.9
Earth Science Data Systems	291.1	--	**263.2**	257.6	268.3	269.8	276.3
Earth Science Technology	102.2	--	**147.2**	109.4	110.6	111.8	113.0
Applied Sciences	75.2	--	**68.6**	73.3	73.5	75.8	75.9
Total Budget	**2,175.0**	**--**	**2,378.7**	**2,396.3**	**2,446.1**	**2,489.7**	**2,543.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Earth Science

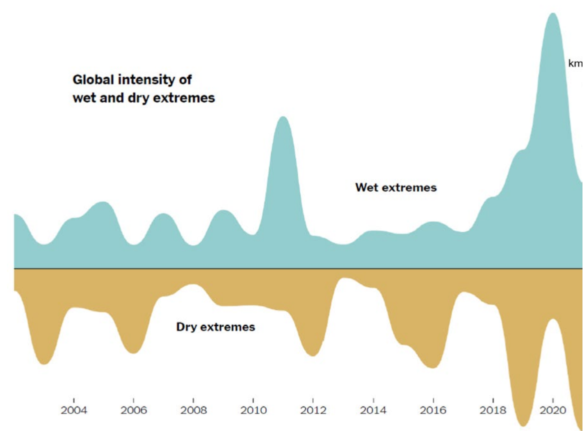
EARTH SCIENCE RESEARCH

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Earth Science Research and Analysis	338.0	--	**364.9**	371.3	385.4	380.9	385.7
Computing and Management	164.0	--	**241.2**	237.1	242.2	248.0	251.4
Total Budget	**502.0**	**--**	**606.2**	**608.4**	**627.6**	**628.8**	**637.2**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Earth Science Research program addresses complex, interdisciplinary Earth science problems in pursuit of a comprehensive understanding of the Earth system. This strategy involves six interdisciplinary and interrelated science focus areas, including:



The graph above shows the global total intensity of extreme dry events and wet events from 2002 to 2021 based on data from NASA's Gravity Recovery and Climate Experiment (GRACE) and GRACE-FO missions. Total intensity is strongly correlated with global mean temperature. (Image: The New York Times 03/14/2023)

- Water and Energy Cycle: quantifying the key reservoirs and fluxes in the global water cycle, assessing water cycle change, and assessing water quality.
- Weather and Atmospheric Dynamics: enabling improved predictive capability for weather and extreme weather events.
- Earth Surface and Interior: characterizing the dynamics of the Earth's surface and interior and forming the scientific basis for the assessment and mitigation of natural hazards and response to rare and extreme events.
- Climate Variability and Change: understanding the roles of ocean, atmosphere, land, and ice in the climate system and improving our ability to predict future changes.
- Atmospheric Composition: understanding and improving our predictive capability for changes in the ozone layer, Earth's radiation budget, and air quality associated with changes in atmospheric composition.
- Carbon Cycle and Ecosystems: quantifying, understanding, and predicting changes in Earth's ecosystems and biogeochemical cycles, including the global carbon cycle, land cover, and biodiversity.

NASA's Earth Science Research program is critical to the advancement of the interagency United States Global Change Research Program (USGCRP), established in 1989 and mandated in the Global Change Research Act of 1990 to develop and coordinate "a comprehensive and integrated U.S. research program which will assist the nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." This program also makes extensive contributions to international

EARTH SCIENCE RESEARCH

science programs, such as the World Climate Research Program, and greenhouse gas (GHG) measurement and calibration efforts.

EXPLANATION OF MAJOR CHANGES IN FY 2025

The request transfers $22 million from Earth Science Research program to the new Responsive Science Initiatives Program for the following components starting in FY 2025: Greenhouse Gas Center, Earth Information System, Wildfires, NASA contributions to the Joint Center for Satellite Data Assimilation, and Short-term Prediction Research and Transition Center (SPoRT). Funding from Research and Analysis (R&A) for the Student Airborne Research Program is transferred to the Early Career Research project.

The Directorate Support budget increases in FY 2025 reflect the consolidation of select labor costs of the Science workforce and funding to support the development of mission proposals by NASA centers.

ACHIEVEMENTS IN FY 2023

A NASA-funded study suggests that extreme Australian wildfires caused an increase in organic matter in the atmosphere, leading to more cloud cover and less sunlight reaching the Earth’s surface, with subsequent decrease in humidity and temperatures, all triggering a La Niña that lasted three years up until 2023. A La Niña is a climate event in which an oceanic phenomenon characterized by the presence of cooler than normal sea-surface temperatures in the central and eastern tropical Pacific.

In FY 2023, the joint NASA-NOAA Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas field campaign conducted research in urban air quality, marine emissions, climate feedbacks, and atmospheric interactions at the marine-urban interface.

The Space Geodesy program continued development, deployment, and operation of its next-generation network of co-located Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Global Navigation Satellite System (GNSS), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) stations. Space Geodesy installed the first new SLR gimbal and telescope in Maryland, while the second was prepared for shipment to Ny-Ålesund, Norway. NASA also delivered the first two Laser Retroreflector Array flight units for GPS-III to the U.S. Space Force to provide an independent tool for improved positioning, navigation, and timing.

The Global Learning and Observation to Benefit the Environment (GLOBE) project supported four U.S. Student Research Symposia where 218 students presented 86 projects and also presented at the 78th United Nations (UN) General Assembly Science Summit to highlight how GLOBE implementation supports sustainable development goals.

Scientific Computing and HECC projects expanded computing and storage at their centers, which will allow NASA to create machine learning or physics-based Earth system model projections to increase fidelity in simulating launch and space flight vehicles’ propulsion systems and provide climate model impacts at city scales.

WORK IN PROGRESS IN FY 2024

In FY 2024, Airborne Science will fly the NASA-South African National Space Agency (SANSA) joint Biodiversity Survey of the Cape campaign across South Africa’s Greater Cape Floristic Region and

EARTH SCIENCE RESEARCH

execute the Airborne and Satellite Investigation of Asian Air Quality mission working to improve understanding of the factors controlling local Asian air quality.

The Space Geodesy program will install the Ny-Ålesund VLBI gimbal and telescope and deploy the Brazil VLBI antenna.

GLOBE will strengthen its infrastructure by performing a major upgrade to the website platform, including launching a learning activity database that will accelerate discovery, collaboration, and innovation of the program's educational resources. GLOBE will formalize the U.S. GLOBE Evaluator Community of Practice in preparation for the next five-year strategic plan outlining GLOBE's science and education goals.

Scientific Computing and HECC projects will continue to expand computing and storage and improve the facilities at NASA centers. NASA will use the General Purpose Graphics Processing Units deployed in FY 2023 to train a foundation Earth Science model and will develop codes that can exploit the DoE exascale (a thousand more speed and power than previous supercomputers) systems to facilitate advancements in artificial intelligence (AI) and machine learning (ML). The Scientific Computing project will expand on-site use of Graphics Processing Units (GPUs) for Artificial Intelligence and Machine Learning (AIML) science and atmospheric modeling; expand to commercial clouds; continue modernization and porting the NASA GEOS atmospheric model to GPU-based systems; and prototype a hybrid high performance computing and storage environment using both on-premises and commercial cloud computing capabilities. The HECC project will complete facility expansions for the new hyperwall at NASA ARC and compute module-providing exploration environments to scientists and engineers across NASA. Scientific Computing and HECC are engaging in supercomputing workforce development discussions with Minority Serving Institutions and Historically Black Colleges and Universities.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

NASA's Boeing 777-200ER (B777) airplane will reach initial operating capability for science research. This aircraft will nearly double the payload and range capacity of the platform it replaced, creating opportunities for interdisciplinary studies not available on any other research aircraft with the capacity to carry a wide array of instruments across the globe.

The Early Career Research (ECR) program will fully transition all solicitations to dual anonymous peer review and request inclusion plans. ECR will also have an ECR Tour to increase awareness of ECR opportunities, targeting minority serving institutions and underrepresented groups, and conduct a series of workshops/educational content to help early career researchers submit proposals.

The Space Geodesy Project plans to finish installing the new SLR system at Ny-Ålesund and continue developing new SLR systems in Maryland and Texas, while upgrade-work at other sites continue. NASA expects these upgrades to improve accuracy for precision orbit determination for missions such as Ice, Cloud, and Land Elevation Satellite (ICESat-2), GRACE-Follow-on (FO), and Sentinel-6 Michael Freilich, and increase data product accuracy for processes including ice sheet mass change and estimates of sea level rise rate and its acceleration.

The GLOBE program will observe its 30th anniversary on Earth Day, April 22, 2025. Key achievements in FY 2025 include: a new five-year strategic plan and an associated evaluation strategy and implementation plan; completing the competitive selection of an organization(s) to operate the GLOBE Implementation Office; and expansion of the U.S. GLOBE Country Coordinating Office to strengthen U.S. GLOBE implementation.

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Scientific Computing and HECC will continue to expand on-site computing and storage at NASA centers. HECC will build an on-site data module to support the supercomputer usage. Both computing centers will continue to expand cloud usage to support open science and will continue to build on the hybrid architecture to work toward an operational capability by the end of FY 2025 that leverages both on-site and commercial cloud computing to support high performance computing research, collaboration, and open science. They will also continue to expand on-premise use of GPUs for AIML science and atmospheric modeling.

Program Elements

GLOBAL MODELING AND ASSIMILATION OFFICE

The Global Modeling and Assimilation Office creates global Earth system component models using data from Earth Science satellites and aircraft. Investigators can use these products worldwide to further their research.

AIRBORNE SCIENCE

The Airborne Science project is responsible for providing aircraft systems to further science and advance the use of satellite data. NASA uses these assets worldwide in campaigns to investigate extreme weather events, observe Earth system processes, obtain data for Earth Science modeling activities, and calibrate instruments flying aboard Earth Science spacecraft. NASA Airborne Science platforms support mission definition and development activities. These activities include:

- Conducting instrument development flights.
- Gathering ice sheet observations as gap fillers between missions.
- Serving as technology test beds for Instrument Incubator Program missions.
- Serving as the observation platforms for research campaigns, such as those competitively selected under the suborbital portion of Earth Venture.
- Calibrating and validating space-based measurements and retrieval algorithms.

OZONE TRENDS SCIENCE

The Ozone Trends Science project produces a consistent, calibrated ozone record used for trend analyses and other studies.

INTERDISCIPLINARY SCIENCE

Interdisciplinary Science includes science investigations as well as calibration and validation activities that ensure the utility of space-based measurements. In addition, this project supports focused fieldwork (e.g., airborne campaigns) and specific facility instruments which fieldwork depends on.

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EARTH SCIENCE RESEARCH AND ANALYSIS

Earth Science Research and Analysis is the core of the research program and funds the analysis and interpretation of data from NASA's satellites. This project funds the scientific activity needed to establish a rigorous foundation for the satellites' data and their use in computational models.

EARLY CAREER RESEARCH

The Early Career Research project (formally named Fellowships and New Investigators) supports graduate and early career research in the areas of Earth system research, applied science, data systems, and technology.

SPACE GEODESY

Geodesy is the science of measuring Earth's shape, gravity, orientation, and rotation and how these properties change over time. The Space Geodesy Project (SGP) encompasses the development, operation, and maintenance of a global network of space geodetic technique instruments, a data transport and collection system, data analysis, and the public dissemination of data products required to maintain a stable terrestrial reference system. SGP provides the data and analysis essential for fully realizing the measurement potential of the current and coming generation of Earth-observing spacecraft.

EARTH SCIENCE DIRECTED RESEARCH AND TECHNOLOGY

The Earth Science Directed Research and Technology project funds the civil service staff who work on emerging Earth Science flight projects, instruments, and research.

GLOBAL LEARNING AND OBSERVATIONS TO BENEFIT THE ENVIRONMENT

GLOBE is a worldwide, hands-on primary and secondary school-based project that promotes collaboration among students, teachers, and scientists to conduct inquiry-based investigations about our environment. The program centers on the study of dynamics of Earth's environment, focused on atmosphere, hydrosphere, pedosphere (i.e., soil), and biosphere. Students take measurements, analyze data, and participate in research in collaboration with scientists. NASA initiated a citizen science component, called GLOBE Observer, in 2016 that makes four protocols available for use by anyone in a GLOBE country. NASA sponsors the GLOBE project and partners with NSF, NOAA, and the United States Department of State.

SCIENTIFIC COMPUTING

The Scientific Computing project funds NASA's Earth Science Discover supercomputing system, high-end storage, network, software engineering, and user interface projects, including climate assessment modeling and data analysis, and commercial cloud computing. Scientific Computing supports Earth system science modeling activities based on data collected by Earth Science spacecraft. The system is separate from the High-End Computing Capability program at NASA ARC, so it can be close to the satellite data archives at GSFC while also providing cloud computing environments specifically

Earth Science Research

engineered for Earth Science collaborations. The proximity to the data and the focus on satellite data assimilation makes the Discover cluster unique in its ability to analyze large volumes of satellite data quickly. The system currently has approximately 170,000 central processing unit cores and 415,000 graphical processing unit cores.

High-End Computing Capability

HECC supports the Endeavour, Cabeus, Pleiades, Electra, and Aitken supercomputer systems and the associated network connectivity, data storage, data analysis, visualization, and application software support. It serves the supercomputing needs of all NASA mission directorates and NASA-supported principal investigators at universities. The funding supports the operation, maintenance, upgrade, and expansion of NASA's supercomputing capability. These five supercomputer systems, with approximately 727,000 central processing unit cores and 4.8 million graphical processing unit cores, support NASA's aeronautics, human exploration, and science missions. For example, the systems perform first-of-a-kind simulations, helping engineers designing the Mars landing vehicle's propulsion system reduce risk from dust interference. The systems also run simulations created with unprecedented resolution, helping scientists understand how galaxies co-evolve with extensive reservoirs of gas around them.

Directorate Support

The Directorate Support project funds the NASA SMD's institutional and crosscutting activities including National Academies studies, proposal peer review processes, printing and graphics, information technology, the NASA Postdoctoral Fellowship Program, working group support, independent mission assessments, NASA Center bid and proposal, Center and HQ performance awards, Center and HQ lump sum payments, HQ civil servant labor, procurement support for the award and administration of all grants, and other administrative tasks.

Program Schedule

Date	Significant Event
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation release
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation release
Q1 FY 2026	ROSES-2025 selection within six to nine months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation release
Q1 FY 2027	ROSES-2026 selection within six to nine months of receipt of proposals
Q2 FY 2027	ROSES-2027 solicitation release
Q1 FY 2028	ROSES-2027 selection within six to nine months of receipt of proposals
Q2 FY 2028	ROSES-2028 solicitation release

EARTH SCIENCE RESEARCH

Date	Significant Event
Q1 FY 2029	ROSES-2028 selection within six to nine months of receipt of proposals
Q2 FY 2029	ROSES-2029 solicitation release

Program Management & Commitments

Program Element	Provider
Global Modeling and Assimilation Office	Provider: Various Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): N/A
Airborne Science	Provider: Various Lead Center: HQ Performing Center(s): AFRC, ARC, WFF, JSC, LaRC Cost Share Partner(s): N/A
Scientific Computing	Provider: GSFC Lead Center: HQ Performing Center(s): GSFC Cost Share Partner(s): N/A
Ozone Trends Science	Provider: Various Lead Center: HQ Performing Center(s): LaRC, GSFC Cost Share Partner(s): USGCRP and Subcommittee on Ocean Science and Technology (SOST) agencies
Interdisciplinary Science	Provider: Various Lead Center: HQ Performing Center(s): HQ, JPL, GSFC, ARC, AFRC, GRC, LaRC, MSFC, JSC Cost Share Partner(s): USGCRP and SOST agencies
Earth Science Research and Analysis	Provider: Various Lead Center: HQ Performing Center(s): All NASA centers Cost Share Partner(s): USGCRP and SOST agencies
High-End Computing Capability	Provider: ARC Lead Center: HQ Performing Center(s): ARC Cost Share Partner(s): N/A

EARTH SCIENCE RESEARCH

Program Element	Provider
Directorate Support	Provider: Various Lead Center: HQ Performing Center(s): All NASA centers Cost Share Partner(s): N/A
Early Career Research	Provider: Various Lead Center: HQ Performing Center(s): All NASA centers Cost Share Partner(s): N/A
Space Geodesy	Provider: Various Lead Center: GSFC Performing Center(s): GSFC, JPL Cost Share Partners: N/A
Global Learning and Observations to Benefit the Environment	Provider: University Corporation for Atmospheric Research Lead Center: HQ Performing Center(s): HQ, GSFC Cost Share Partner(s): N/A

Acquisition Strategy

NASA implements the Earth Science Research program via competitively selected research awards. NASA releases research solicitations each year in the ROSES NASA Research Announcements. All proposals in response to NASA ROSES are peer reviewed and selected based on defined criteria. The program competitively awards funds to investigators from academia, the private sector, NASA centers, and other government agencies.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Earth Science Advisory Committee	October 2023	Annual review to assess progress against Earth Science performance goals and overarching strategic objective.	Expectations for the research program fully met.
Performance	Earth Science Advisory Committee	TBD	Annual review to assess progress against Earth Science performance goals and overarching strategic objective.	TBD

EARTH SYSTEMATIC MISSIONS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
NASA-ISRO SAR	93.5	72.1	**29.3**	21.1	12.0	0.1	0.0
Sentinel-6	40.3	51.3	**36.5**	18.1	8.7	5.7	7.1
PACE	112.8	75.5	**26.3**	24.8	8.5	0.0	0.0
GRACE-Continuity	166.8	--	**102.4**	41.8	57.2	82.6	25.3
Other Missions and Data Analysis	501.6	--	**660.0**	762.9	801.7	781.4	725.5
Total Budget	**915.0**	**--**	**854.4**	**868.7**	**888.2**	**869.9**	**757.8**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The NASA-ISRO Synthetic Aperture Radar (NISAR) mission is shown here undergoing testing in the ISRO high bay.

The Earth Systematic Missions (ESM) program includes a broad range of multi-disciplinary science investigations aimed at understanding the Earth system and its response to natural and human-induced forces and changes. Understanding these will help determine how to predict future changes and mitigate or adapt to these changes.

More than half of the projects in formulation or development under ESM have an international or interagency contribution, and several on-orbit missions provide data products in near real-time for use by the United States and international meteorological and other agencies and disaster responders.

ESM includes the next generation of remote-sensing satellite missions, the Earth System Observatory (ESO), to address the high-priority Earth observation needs of the research and applications communities, as identified by the National Academies 2017 Decadal Survey. Each ESO mission will advance observational capabilities within its scientific field. NASA will integrate these missions into a single observatory to deliver an unprecedented holistic, four-dimensional view of our planet's climate systems. that will advance our ability to measure, predict and improve our response to evolving natural hazards, changing agricultural conditions, and severe weather challenges, including droughts, tropical storms, and wildfires.

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA is restructuring the AOS missions to retain the partnership with JAXA on their Precipitation Measurement Mission, formerly part of AOS-Storm. The remainder of the Aerosol and Cloud, Convection, and Precipitation (ACCP) designated observables will be selected through a combination of directed and competed opportunities (see AOS sections). The funding for these mission elements is transferred from the AOS-Sky and AOS-Storm projects to ESO Future Missions.

EARTH SYSTEMATIC MISSIONS

This budget separates the Surface Biology and Geology mission into two projects: SBG-TIR and SBG-VSWIR. This new architecture maximizes execution flexibility and reduces near-term budget requirements (see SBG sections on pages ES-34 and ES-35).

This budget includes $150 million for Landsat Next, providing a $128 million increase from the 2023 operating plan level to ramp up development of instruments that will be significantly more capable than existing Landsat capabilities. NASA will not be able to estimate the launch date with more certainty until there is a final FY 2024 appropriation and instrument contracts are awarded.

NASA renamed the Mass Change mission to the Gravity Recovery and Climate Experiment-Continuity mission. This budget includes an additional $151 million to support launch readiness in FY 2029.

In December 2023, Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL) entered the final design and fabrication activity phase. NASA established the CRISTAL budget profile supporting cooperation between NASA and ESA, targeting a launch readiness date no earlier than 2030.

NASA consolidated the out-year extended mission operations budget in ESM and established a new project named Earth Science Senior Review to fund operating mission extensions after 2026.

NASA consolidated mission research science teams into a more integrated project to encourage development of proposals built around science questions by combining the EOS Research and Precipitation Science Team projects into ESM Research and by consolidating the budget for all ocean science teams (Ocean Salinity Science Team, Ocean Surface Topography Science Team, and Ocean Winds Science Team) into a new project, Ocean Measurements Research.

NASA renamed Earth Radiation Budget Science to Earth Radiation Data Continuity.

NASA approved a replanned cost and schedule for the CLARREO Pathfinder mission. Pursuant to Section 521 of P.L. 113-235, NASA has notified Congress that the CLARREO Pathfinder mission has experienced total development cost growth of greater than 10 percent of the Agency Baseline Commitment established at KDP-C in July 2019.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	117.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	117.0
Development/Implementation	769.4	84.5	47.3	**0.0**	0.0	0.0	0.0	0.0	0.0	901.1
Operations/Close-out	0.0	0.0	21.7	**25.4**	21.1	11.6	0.1	0.0	0.0	79.9
2024 MPAR LCC Estimate	**886.3**	**84.5**	**69.0**	**25.4**	**21.1**	**11.6**	**0.1**	**0.0**	**0.0**	**1,098.0**
Total Budget	**920.3**	**93.5**	**72.1**	**29.3**	**21.1**	**12.0**	**0.1**	**0.0**	**0.0**	**1,148.4**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

PROJECT PURPOSE

The NASA-ISRO Synthetic Aperture Radar (NISAR) mission will provide an unprecedented, detailed view of the Earth using advanced radar imaging and a dual frequency (L-band and S-band) Synthetic Aperture Radar (SAR). NISAR will be NASA's first dual frequency radar imaging satellite and will observe processes including ecosystem disturbances, ice sheet collapse, and natural hazards (e.g., earthquakes, tsunamis, volcanoes, and landslides). The mission will reveal information about the evolution and state of Earth’s crust, broaden scientific understanding of our planet's changing processes and their effect on Earth's climate, and aid future resource and hazard management.

Both the 2007 and 2017 Earth Science Decadal Surveys endorsed the NISAR science objectives. NISAR is a collaborative mission with ISRO.

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA reduced the LCC for NISAR by $20 million due to excellent cost performance since the KDP-D rebaseline (in August 2022).

PROJECT PARAMETERS

NISAR consists of a dual frequency (L-band and S-band) SAR. NASA will provide the L-band SAR (L-SAR), the engineering payload, the payload integration, and payload operations. ISRO will provide S-band SAR (S-SAR), the spacecraft bus, the launch vehicle, observatory integration and testing, and spacecraft operations. NISAR has a prime mission of three years.

NASA-ISRO Synthetic Aperture Radar (NISAR)

Formulation	Development	Operations

NISAR will implement enhanced data acquisition and data downlink capability as well as a global soil moisture product for agricultural, forest, and modeling efforts, as recommended by the interagency Satellite Needs Working Group (SNWG). The SNWG identified multiple other agencies that would benefit from NISAR systematically collecting data over North America in Quad-pol 40-megahertz mode, thus requiring additional data acquisition and downlink capability. NASA will track the cost of these additional capabilities outside of the Agency Baseline Commitment for cost, as approval of the scope enhancements took place after mission confirmation.

Achievements in FY 2023

During the first half of FY 2023, NISAR completed system integration and test (SIT-3) activities at JPL including environmental tests, science operation mode testing, antenna and boom assembly tests, deployment activities, and fully integrating the payload assembly. The project packed and delivered the fully integrated payload to ISRO in to continue the system integration and test (SIT-4) activities. During SIT-4 the NASA and ISRO teams are integrating the payload with the ISRO-provided spacecraft bus.

Work in Progress in FY 2024

The NASA team is supporting the SIT-4 activities in India per the jointly-developed plan. SIT-4 activities will continue to prepare for launch in FY 2024.

Key Achievements Planned for FY 2025

NISAR will complete commissioning and in-orbit-checkout and begin prime operations.

Schedule Commitments/Key Milestones

Milestone	Confirmation Baseline Date	FY 2025 PB Request
KDP-C	Aug 2016	Aug 2016
CDR	Oct 2018	Oct 2018
KDP-D	Mar 2021	Mar 2021
Payload Delivery to ISRO	Mar 2023	Mar 2023
Launch Readiness Date (LRD)	Oct 2024	Oct 2024

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2022	921.1	70	2024	901.1	-2	LRD	Oct 2024	Oct 2024	+0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost. NASA originally baselined NISAR in 2016 and conducted a re-plan in 2022 which will become a new reporting baseline in the FY 2024 appropriation. The original baseline is provided in the Supporting Data section.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**921.1**	**901.1**	**-20.0**
Aircraft/Spacecraft	143.6	145.6	+2.0
Payloads	369.6	370.4	+0.8
Systems I&T	104.8	107.0	+2.2
Launch Vehicle	0.2	0.2	+0
Ground Systems	97.1	97.1	+0
Science/Technology	35.4	35.4	+0
Other Direct Project Costs	170.4	145.4	-25.0

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Project Management & Commitments

The ESM program at NASA GSFC has program management responsibility for NISAR. NASA assigned project management responsibility to JPL. NISAR is a partnership between NASA and ISRO.

Element	Description	Provider Details	Change from Baseline
L-SAR	Radar imaging payload	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
S-SAR	Radar imaging payload	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A
Spacecraft	Provides platform for the payload	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A
Launch Vehicle	Geosynchronous Satellite Launch Vehicle (GSLV); delivers observatory to orbit	Provider: ISRO Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ISRO	N/A

Project Risks

Risk Statement	Mitigation
If: The Reflector Deployment operations are not successful, Then: The observatory will not function as planned.	The project will exercise and test the critical functionality during system integration and test activities and ensure the risk is retired before launch.
If: The Boom Deployment operation is not successful, Then: The observatory will not function as planned.	The project will exercise and test the critical functionality during system integration and test activities and ensure the risk is retired before launch.

NASA-ISRO SYNTHETIC APERTURE RADAR (NISAR)

Formulation	Development	Operations

Acquisition Strategy

The design and build of L-SAR radar is an in-house build at JPL with competed subcontracts.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Solid State Recorder	Airbus	Germany
Reflector Antenna	Astro Aerospace	California

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	SRB	Jan 2024	Operational Readiness Review (ORR)	TBD

SENTINEL-6

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	15.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	15.5
Development/Implementation	235.7	34.1	47.8	**30.3**	15.6	0.0	0.0	0.0	0.0	363.5
Operations/Close-out	9.7	6.2	3.5	**6.2**	2.5	8.7	5.7	7.1	17.9	67.5
2024 MPAR LCC Estimate	**260.9**	**40.3**	**51.3**	**36.5**	**18.1**	**8.7**	**5.7**	**7.1**	**17.9**	**446.5**
Total Budget	**260.9**	**40.3**	**51.3**	**36.5**	**18.1**	**8.7**	**5.7**	**7.1**	**17.9**	**446.5**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

PROJECT PURPOSE

The Sentinel-6 mission will provide continuity of ocean topography measurements beyond the Topography Experiment (TOPEX)/Poseidon (launched in 1992), Jason-1 (2001), Ocean Surface Topography Mission/Jason-2 (2008), and Jason-3 (2016) missions. It consists of two satellites, Sentinel-6 Michael Freilich (S6-MF) and Sentinel-6B (S6-B), that will launch five years apart (2021 for S6-MF and 2026 for S-6B) to extend ocean topography measurements for ocean circulation and climate studies for at least another decade.

Sentinel-6 will also characterize atmospheric temperature and humidity profiles and make them available for incorporation into National Weather Service models to support weather forecasting capabilities.

Sentinel-6 is a collaborative mission with NOAA, ESA, and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT).

EXPLANATION OF MAJOR CHANGES IN FY 2025

This budget reflects an LCC reduction of approximately $39 million due to lower than planned launch vehicle costs.

PROJECT PARAMETERS

NASA will provide the launch vehicle and launch services as well as the Advanced Microwave Radiometer-Climate Quality (AMR-C), the Global Navigation Satellite System-Radio Occultation (GNSS-RO) receiver, and the Laser Retroreflector Array (LRA) for each spacecraft. NASA will also provide support for instrument integration and testing on the satellites, mission operations support for

SENTINEL-6

Formulation	Development	Operations

NASA-developed instruments, an operational AMR-C science data processor for EUMETSAT, near real-time and offline data processing for GNSS-RO data, and mission data product archiving and distribution. The S6-MF and S-6B observatories each have a five-and-a-half-year prime mission.

ACHIEVEMENTS IN FY 2023

S6-MF continued to produce high-accuracy science data products, contributing to hundreds of scientific publications per year. The Ocean Surface Topography Science Team (OSTST) assessed the quality of S6-MF data compared to its predecessor mission, Jason-3, and determined that inter-mission biases could be determined to within ± 0.3 millimeter (mm). This ensures the integrity of the long-term sea level change record from space, beginning in the early 1990s. The NASA GNSS-RO team has further enhanced the data processing and improved products performance and quality leading to positive impacts on weather forecasting.

The S6-B satellite is currently in storage in preparation for a launch in 2026. In September 2023, S6-B was temporarily removed from storage and completed a successful annual checkout.

In December 2022, NASA selected SpaceX to provide launch services for the S-6B mission. This budget reflects the reduction for launch vehicle savings of approximately $39 million in LCC for the Sentinel-6 mission.

WORK IN PROGRESS IN FY 2024

S6-B will launch on the same type of launch vehicle (SpaceX Falcon 9) reducing the risk of differing launch environments from the S6-MF satellite. The project will have sufficient time for additional analysis and testing of the S6-B satellite in time to support a 2026 launch. In early November 2023, the OSTST held its annual meeting with further assessments of the Sentinel-6 data and presentations of new science results. The project will make detailed plans to conduct updates of the ground and operations systems to support the future launch of S6-B. The project will also conduct an annual checkout of the S6-B satellite.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

Sentinel-6 expects to continue to produce high-accuracy science data products from S6-MF. The project will refresh ground systems to maintain consistent and reliable mission operations, perform health checks of the stored S6-B satellite, and conduct detailed planning to prepare S6-B launch by early 2026.

SENTINEL-6

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2025 PB Request
KDP-C	Apr 2017	Apr 2017
CDR	Oct 2017	Oct 2017
Sentinel-6 Michael Freilich U.S. Payload delivery to ESA	Mar 2020	Mar 2020
Sentinel-6B U.S. Payload delivery to ESA	Oct 2020	Oct 2020
Launch (Sentinel-6 Michael Freilich)	Nov 2021	Nov 2020
Start Phase E (Sentinel-6 Michael Freilich)	Feb 2022	Feb 2021
End Prime Mission (Sentinel-6 Michael Freilich)	Aug 2027	Aug 2026
Launch (Sentinel-6B)	Nov 2026	Nov 2026
Start Phase E (Sentinel-6B)	Feb 2027	Feb 2027
End Prime Mission (Sentinel-6B)	Aug 2032	Aug 2032

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2017	465.9	>70	2024	363.5	-22	LRD of S6-MF	Nov 2021	Nov 2020	-12
N/A	N/A	N/A	N/A	N/A	N/A	LRD of S-6B	Nov 2026	Nov 2026	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

SENTINEL-6

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**465.9**	**363.5**	**-102.4**
Aircraft/Spacecraft	0	0	0
Payloads	65.8	77.1	+11.3
Systems I&T	8.8	6.2	-2.6
Launch Vehicle	280.7	190.6	-90.1
Ground Systems	9.7	14.0	+4.3
Science/Technology	4.4	19.9	+15.5
Other Direct Project Costs	96.5	55.7	-40.8

Project Management & Commitments

The ESM program at JPL has program management responsibility for Sentinel-6. NASA also assigned project management responsibility to JPL. Sentinel-6 is a partnership with NOAA, ESA, and EUMETSAT.

Element	Description	Provider Details	Change from Baseline
AMR-C	Provides high spatial resolution wet tropospheric path delay corrections for the ESA-supplied Ku/C-Band Altimeter	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
GNSS-RO	Supports secondary mission objectives for weather modeling and forecasting	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
LRA	Provides orbit determination	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A

SENTINEL-6

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Ku/C-Band Altimeter	Measures Jason-heritage ocean surface topography at nadir	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)	Provides orbit determination	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Spacecraft Bus	Provides instrument platform	Provider: ESA Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Launch Vehicle	Delivers spacecraft to orbit	Provider: NASA Lead Center: JPL Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

Project Risks

None.

Acquisition Strategy

Sentinel-6 leverages Jason heritage by using JPL legacy instrument designs (e.g., AMR-C, GNSS-RO, and LRA) and an in-house build with a combination of sole source and competitive procurements. NASA selected SpaceX to provide a Falcon 9 launch vehicle through a competitive Launch Service Task Order evaluation under the NASA Launch Services II contract.

SENTINEL-6

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
GNSS-RO Electronics	MOOG	Golden, CO
AMR-C Antenna	Northrop Grumman Innovation Systems	San Diego, CA
LRA	ITE	Laurel, MD
Launch Services (S-6 Michael Freilich and S-6B)	SpaceX	Los Angeles, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	SRB	Aug 2025	Sentinel-6B ORR	TBD

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	260.3	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	260.3
Development/Implementation	439.9	112.8	52.5	**0.0**	0.0	0.0	0.0	0.0	0.0	605.2
Operations/Close-out	0.0	0.0	22.9	**26.3**	24.8	8.5	0.0	0.0	0.0	82.5
2024 MPAR LCC Estimate	**700.2**	**112.8**	**75.5**	**26.3**	**24.8**	**8.5**	**0.0**	**0.0**	**0.0**	**948.1**
Total Budget	**700.2**	**112.8**	**75.5**	**26.3**	**24.8**	**8.5**	**0.0**	**0.0**	**0.0**	**948.1**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

PROJECT PURPOSE

The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission will improve our understanding of how the ocean and atmosphere exchange carbon dioxide; reveal how aerosols fuel phytoplankton growth in the surface ocean; and provide the first-ever global measurements to identify phytoplankton composition and growth. This will improve our ability to understand Earth's changing marine ecosystems, manage natural resources (e.g., fisheries), and identify harmful algal blooms.

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA reduced the LCC for PACE by $16 million due to excellent cost performance.

PROJECT PARAMETERS

NASA GSFC is responsible for the design and fabrication of the spacecraft, development of the Ocean Color Instrument (OCI), and the mission operations center. GSFC will collect, process, archive, and distribute PACE data. OCI consists of a cross-track rotating telescope, thermal radiators, along with half-angle mirror and solar calibration mechanisms. Its signal-to-noise ratios will rival or exceed previous ocean color instruments.

The Hyper-angular Rainbow Polarimeter 2 (HARP-2) is a wide-swath imaging polarimeter capable of characterizing atmospheric aerosols for the purposes of sensor atmospheric correction and atmospheric

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

science. The Spectro-Polarimeter for Exploration (SPEXOne) provides atmospheric aerosol and cloud data at high temporal and spatial resolution.

PACE launched in 2024 with a minimum mission duration of three years.

ACHIEVEMENTS IN FY 2023

PACE successfully entered the system assembly, integration and test, and launch and checkout phase in February 2023. PACE completed its environmental test campaign in July 2023.

WORK IN PROGRESS IN FY 2024

PACE held its Pre-Ship Review (PSR) in October 2023 and shipped to the launch site in November 2023. The team held its Operational Readiness Review (ORR) in November 2023 in preparation for KDP-E in January 2024. PACE launched from KSC on a Space X Falcon 9 on February 8, 2024.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The PACE team expects to be in on-orbit operations.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2025 PB Request
KDP-B	Jul 2017	Jul 2017
KDP-C	Aug 2019	Aug 2019
KDP-D	Aug 2021	Feb 2023
Launch Readiness (or equivalent)	Jan 2024	Feb 2024
End Prime Mission	Apr 2027	Aug 2027

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2020	558.0	>70	2024	605.2	+8	LRD	Jan 2024	Feb 2024	+4

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**558.0**	**605.2**	**+47.2**
Aircraft/Spacecraft	103.6	136.3	+32.7
Payloads	79.2	189.2	+110.0
Systems I&T	18.8	27.1	+8.3
Launch Vehicle	105.0	78.6	-26.4
Ground Systems	19.3	28.8	+9.5
Science/Technology	50.0	59.1	+9.1
Other Direct Project Costs	182.1	86.2	-95.9

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
Polarimeter (HARP-2) - Contribution	Measures how the oscillation of sunlight changes by passing through clouds, aerosols, and the ocean.	Provider: University of Maryland Baltimore County (UMBC) Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): UMBC	N/A
Polarimeter (SPEXOne) - Contribution	Measures how the oscillation of sunlight changes by passing through clouds, aerosols, and the ocean.	Provider: Netherlands Institute for Space Research (SRON) Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): SRON	N/A
Ocean Color Instrument	Highly advanced optical spectrometer that will measure properties of light over portions of the electromagnetic spectrum.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Spacecraft	Provides a platform for instruments.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Provides launch services for the PACE Observatory.	Provider: SpaceX Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mission Operations and Ground system	Provides software and system with capabilities for command and control, mission scheduling, long-term trending, and flight dynamics analysis. Collects, processes, archives, and distributes PACE data.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

PLANKTON, AEROSOLS, CLOUDS, OCEAN ECOSYSTEM (PACE)

Formulation	Development	Operations

Acquisition Strategy

GSFC built the spacecraft and OCI instrument in-house. UMBC contributed the HARP-2 polarimeter. SRON contributed the SPEXOne polarimeter. The PACE project worked with the NASA Launch Services Program (LSP) to award the launch services contract to SpaceX in February 2020.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Launch Vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	SRB	Nov 2022	Systems Integration Review (SIR)	Successful
Performance	SRB	Nov 2023	ORR	Successful

GRACE-CONTINUITY

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**166.8**	**--**	**102.4**	**41.8**	**57.2**	**82.6**	**25.3**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

PROJECT PURPOSE

The primary goal of the Gravity Recovery and Climate Experiment - Continuity (GRACE-C) (previously named Mass Change) mission is to better understand the global water cycle through large-scale mass changes. This will inform drought assessment and forecasting, and agricultural water use planning, as well as understanding the drivers of sea level rise, Earth's energy imbalance, and ice mass loss from the world's ice sheets.

GRACE-C will advance ESO goals by providing continuity of the 20-plus-year record of monthly measurements of Earth's mass change established by the GRACE and GRACE-FO missions.

NASA leads work on GRACE-C in partnership with DLR, building on a relationship established in the 1990s for GRACE and GRACE-FO. It is targeting a launch in a near-polar orbit in 2028 to maintain continuity with GRACE-FO.

EXPLANATION OF MAJOR CHANGES IN FY 2025

GRACE-C entered Preliminary Design and Technology Completion Activities phase (Phase B) in September 2023 and NASA renamed the Mass Change mission to GRACE-C. This budget includes an additional $151 million to support a launch readiness date in FY 2029.

PROJECT PRELIMINARY PARAMETERS

GRACE-C consists of a pair of satellites in co-planar, low altitude polar orbits. Accurate measurements of the range change between the two satellites combined with precise measurements of their position and orientation and non-gravitational forces they feel will provide the mission data. Each satellite carries Global Navigation Satellite System receivers, attitude determination sensors, a laser ranging interferometer (LRI), high accuracy accelerometers, and laser retroreflectors for orbit determination.

NASA is responsible for the GRACE-C project, providing the project manager and project scientist; project management; system engineering and mission design; safety and mission assurance; delivery of the integrated LRI; LRI electronics subsystems; accelerometers; spacecraft; instrument integration and on orbit operations; science and applications data processing; and delivery of calibrated/validated science and applications data products to a NASA archive for public distribution and long-term preservation.

DLR is responsible for providing LRI optics subsystems; mission operations and telemetry; tracking and command; the ground data system; laser retro-reflectors for ground-to-satellite ranging; and the launch vehicle and launch services.

GRACE-CONTINUITY

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2023

In March 2023, GRACE-C successfully entered the concept and technology development phase.

In September 2023, GRACE-C successfully demonstrated that the proposed mission/system architecture is credible and responsive to program requirements and constraints, including resources and that the maturity of the project's mission/system definition and associated plans is sufficient to enter Phase B for preliminary design and technology completion activities.

WORK IN PROGRESS IN FY 2024

The project is completing a series of inheritance reviews for the spacecraft subsystems and preparing for PDR scheduled for March 2024. Following PDR, the project will present the results of the PDR at KDP-C and request approval to proceed into the development phase to begin fabrication and system assembly.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The project will prepare for and complete CDR in Spring 2025.

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2025 PB Request
Formulation Authorization	Mar 2023	Mar 2023
KDP-C	NLT Summer 2024	Jul 2024
CDR	Apr 2025	Jul 2025
KDP-D	Jan 2026	Mar 2027
Launch (or equivalent)	May 2028	Dec 2028

Formulation Estimated LCC Range and Schedule Range Summary

LCC estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (i.e., KDP-C), which follows a non-advocate review and/or PDR.

KDP-B Date	Estimated LCC Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Sep 2023	587.8 – 617.8	LRD	May 2028 – Dec 2028

GRACE-CONTINUITY

Formulation	Development	Operations

Project Management & Commitments

The ESM program at the JPL has program management responsibility for GRACE-C. NASA assigned project management responsibility to JPL. GRACE-C is a partnership with DLR.

Element	Description	Provider Details
Spacecraft	Provides platform for the instruments	Provider: Airbus Defence & Space (Germany) Lead Center: N/A Performing Center(s): JPL Cost Share Partner(s): N/A
Accelerometers	Measures all nongravitational accelerations of the satellite(s)	Provider: French Office National d'Etudes et Recherches Aérospatiales (ONERA) Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
Laser Ranging Interferometer	Heterodyne interferometric laser will measure the distance between the two spacecraft as a function of time	Provider: JPL and DLR Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): JPL and DLR
Launch Vehicle	Delivers spacecraft to orbit	Provider: DLR Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): DLR
Project Management	Overall management; system engineering and mission design; safety and mission assurance	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
Science and Applications Data Processing	Delivery of calibrated/validated science and applications data products	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): DLR

GRACE-CONTINUITY

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: The expected delivery of the LRI components contributed by DLR are delayed, Then: The critical path schedule will be impacted.	DLR is finalizing subcontracts and will work with JPL in Phase B to align schedules and determine potential LRD impacts.

Acquisition Strategy

NASA will conduct GRACE-C acquisitions consistent with the workshare and heritage approaches used successfully on the GRACE and GRACE-FO missions. The implementation strategy will include the key teams and U.S./German partnership roles from those missions as well as utilizing heritage satellite and instrument architectures.

JPL will procure two spacecraft from Airbus (Germany); procure the flight spare accelerometers from GRACE-FO; and implement and deliver the integrated LRI. The JPL LRI components are subcontracts with Tesat and Ball Aerospace. DLR will provide the German components of the LRI; the laser retro-reflectors; launch services; the mission operations and ground system; and the telemetry, tracking, and commanding support necessary to operate the mission.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft	Airbus	Germany
Accelerometer	ONERA	France

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Standing Review Board (SRB)	Apr 2023	Systems Requirement Review (SRR)	Successful
Performance	SRB	Jul 2023	Mission Definition Review (MDR)	Successful
Performance	SRB	Spring 2024	PDR	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Surface Biology and Geology - VSWIR	0.0	--	**19.0**	71.0	97.0	101.0	71.0
Atmosphere Observing System-Sky	33.7	--	**0.0**	0.0	0.0	0.0	0.0
Precipitation Measuring Mission (PMM)	20.9	--	**19.8**	20.2	21.1	24.3	18.0
Landsat Next	22.5	--	**150.0**	183.8	182.4	180.4	211.7
Surface Biology and Geology - TIR	46.9	--	**30.0**	52.0	72.0	48.0	49.0
Sustained Climate Observations Future Mi	1.3	--	**12.4**	13.7	10.6	14.8	7.6
Earth Systematic Missions (ESM) Research	23.3	--	**46.0**	42.8	41.5	41.6	41.6
Surface Water and Ocean Topography Mission	20.1	--	**16.2**	15.1	0.8	0.0	0.0
Ocean Surface Topography Science Team	5.3	--	**0.0**	0.0	0.0	0.0	0.0
Earth Observations Systems (EOS) Research	9.5	--	**0.0**	0.0	0.0	0.0	0.0
Landsat 9	2.9	--	**3.0**	3.1	3.1	0.0	0.0
Sage III	4.6	--	**4.2**	4.2	0.0	0.0	0.0
Radiation Budget Instrument (RBI)	0.2	--	**0.0**	0.0	0.0	0.0	0.0
Sustainable Land Imaging	4.6	--	**0.0**	0.0	0.0	2.7	2.6
Earth from ISS	1.7	--	**0.9**	0.0	0.0	0.0	0.0
Total Solar Irradiance Sensor-2 (TSIS-2)	11.2	--	**43.1**	6.4	6.0	6.5	3.6
Earth Radiation Data Continuity	12.4	--	**15.9**	15.9	15.9	15.9	15.9
Ozone Mapping and Profiler Suite (OMPS)	2.1	--	**2.9**	1.4	1.5	1.5	1.6
Total Solar Irradiance Sensor-1 (TSIS-1)	4.3	--	**3.9**	3.9	0.0	0.0	0.0
CLARREO Pathfinder	9.4	--	**15.7**	13.6	9.8	2.5	0.0
Earth System Observatory Future Missions	17.4	--	**48.7**	114.0	140.3	145.6	111.3
Earth Science Program Management	67.6	--	**66.5**	63.8	64.5	65.3	65.9
Precipitation Science Team	5.9	--	**0.0**	0.0	0.0	0.0	0.0
Ocean Winds Science Team	2.9	--	**0.0**	0.0	0.0	0.0	0.0
Land Cover Science Project Office	1.2	--	**0.0**	0.0	0.0	0.0	0.0
Ocean Salinity Science Team	6.9	--	**0.0**	0.0	0.0	0.0	0.0
Soil Moisture Active and Passive (SMAP)	18.0	--	**11.5**	11.4	0.0	0.0	0.0
Deep Space Climate Observatory	1.5	--	**1.6**	1.5	0.0	0.0	0.0
Global Precipitation Measurement (GPM)	20.5	--	**18.6**	18.4	0.0	0.0	0.0
Suomi National Polar-Orbiting Partnership (Suomi NPP)	3.5	--	**4.0**	4.1	4.2	4.3	4.3
Terra	22.1	--	**15.6**	16.1	17.2	9.5	9.5
Aqua	27.6	--	**17.7**	16.2	11.4	6.9	6.9
Aura	18.8	--	**12.7**	9.2	4.2	1.7	0.0
ICESat-2	26.0	--	**20.1**	20.3	0.0	0.0	0.0
GRACE Follow-On	12.7	--	**8.8**	9.1	0.0	0.0	0.0
Ocean Measurements Research	0.0	--	**17.4**	17.9	18.3	18.6	18.6
Earth Science Senior Review	0.0	--	**0.0**	0.0	68.5	82.5	81.7
Copernicus Polar Ice and Snow Topography	12.1	--	**33.8**	14.0	11.6	7.7	4.8
Total Budget	**501.6**	**--**	**660.0**	**762.9**	**801.7**	**781.4**	**725.5**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

OTHER MISSIONS AND DATA ANALYSIS

Earth Systematic Missions (ESM) Other Missions and Data Analysis includes operating missions and their science teams and competed research projects. Mission science teams define the scientific and applications requirements for their missions and generate algorithms used to process the data into useful data products. The research projects execute competitively selected investigations related to specific mission measurements.

Also included are Sustainable Land Imaging activities, as well as smaller instruments and missions in formulation and development, such as the Ozone Mapping and Profiler Suite Limb Sounder and Total and Solar Irradiance Sensor-2.

Mission Planning and Other Projects

ATMOSPHERE OBSERVING SYSTEM (AOS)-SKY

AOS was designed to measure ACCP designated observables from the 2017 Decadal survey and their interactions. Observing these parameters is key to improving climate modeling, weather forecasts, and air quality predictions.

The AOS architecture is composed of two projects: AOS-Sky and Precipitation Measuring Mission (PMM) (previously named AOS-Storm) that leverage multiple orbit planes, sub-orbital components, complementary instrumentation, and international contributions to optimize measurements and enable new discoveries.

AOS-Sky passed KDP-A and entered formulation in January 2023. NASA awarded spacecraft study contracts and radar and polarimeter study contracts to industry in late FY 2023. NASA has changed the architecture and acquisition approach in this budget request to increase competitive opportunities while achieving maximum science (see ESO Future Missions section) with launches targeted for no earlier than 2030. The funding for these mission elements is transferred from the AOS-Sky and AOS-Storm projects to ESO Future Missions.

PRECIPITATION MEASURING MISSION (PMM)

NASA reduced the scope of the AOS-Storm directed mission and renamed it the Precipitation Measurement Mission.

This mission is comprised of a JAXA contributed Ku-band Doppler Radar, hosted on a JAXA spacecraft. NASA will provide launch services, system engineering, and science support for this mission. NASA will also leverage a partnership with ASI for an advanced lidar capability (see ESO Future Missions).

PMM will provide continuity of critical precipitation measurements from the Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement (GPM), and advance science by providing improved sensitivity doppler observations with scanning capabilities. It will fly in an inclined orbit that offers more frequent sampling, increasing our understanding of all stages of storm development, to enable more accurate predictions of convective rainfall and severe weather. PMM contributes to the enhancement of weather and disaster management, and provision of long-term information on water resources infrastructure contributing to global scale climate and water issues.

NASA is targeting a launch for PMM no earlier than FY 2029.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

NASA completed Mission Concept Review in May 2022 for PMM as part of AOS. PMM passed KDP-A (Completing Concept and Technology Development) in January 2023.

SURFACE BIOLOGY & GEOLOGY-THERMAL INFRARED RADIOMETER (SBG-TIR)

The SBG element of the ESO will revolutionize scientific understanding of climate change, agriculture, terrestrial and marine habitats, the surface water cycle, and the distribution of natural resources on land. SBG will answer open questions about how carbon, water, nutrients, and energy move within and between the atmosphere, the oceans, the landscape, and ecosystems. NASA has separated the SBG mission into two projects to maximize execution flexibility and cost control. The SBG-TIR instrument is a wide-swath infrared thermal imager based on the successful ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) architecture and will be in an early-afternoon Sun synchronous orbit.

ASI will provide the spacecraft and launch vehicle. The target launch date for SBG-TIR is no earlier than CY 2028.

Recent Achievements

SBG held its KDP-A in November 2022 and entered the formulation phase where the project is working on completing concept and technology development.

SURFACE BIOLOGY & GEOLOGY-VISIBLE & SHORTWAVE INFRARED SPECTROMETER (SBG-VSWIR)

SBG-VSWIR will provide global mapping measurements of the surface reflectance from the Earth’s land, inland water, and coastal regions. The VSWIR element will be in a morning Sun synchronous orbit to minimize cloud contamination of scenes with sufficient frequency to measure ecosystem function at sub-seasonal and yearly time scales and with sufficient detail to quantify variation in plant functional diversity, aquatic ecosystems, coastal benthic cover, soils and minerals and snow in complex mountain landscapes. The data will also allow observation of real-time events such as oil spills and smoke plumes. NASA will provide the instrument, spacecraft, and launch vehicle for VSWIR.

This budget supports a launch readiness for the SBG-VSWIR payload no earlier than FY 2032 to achieve a minimum one-year overlap of TIR and VSWIR observations.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

SBG held its KDP-A in November 2022 and entered the formulation phase where the project is working on completing concept and technology development.

LANDSAT NEXT

Landsat Next is the successor mission to Landsat 8 and 9. The U.S. Geological Survey (USGS) and NASA have collected Landsat imagery since 1972, resulting in the longest continuously acquired collection of space-based terrestrial observations. Landsat derived information allows federal agencies, land managers, and policymakers to make informed decisions about natural resources, including agriculture, water, and forests, and the environment.

Landsat Next data will help decision makers pinpoint and minimize environmental health and human safety risks and support emergency response and post-disaster assessment. Landsat Next will also support wildland fire management, assessment of harmful algae bloom severity, and famine warning.

Landsat Next is a constellation of three identical satellites in a phased orbit to yield a system revisit of six days. Its instruments will provide Superspectral Coincident Visible and Short Wave Infrared plus Thermal Infrared imaging bands for simultaneous measurements in 26 bands (vs 11 bands of Landsat 8 and 9). These additional bands enable new applications, including water quality, mineral mapping, snow hydrology, and soil conservation assessments.

NASA will develop, launch, and check-out space systems. USGS will develop the ground systems; operate the on-orbit spacecraft; and collect, archive, process, and distribute data to users. NASA will manage mission operations from launch through the on-orbit checkout, and then transition Landsat Next to USGS.

Recent Achievements

Landsat Next entered Phase A of formulation in November 2022. In May 2023, NASA released a Request for Proposal (RFP) for the competitive procurement of the Landsat Next Instrument Suite. Proposals were received in July 2023 and award is anticipated in May 2024, pending the outcome of the FY 2024 appropriations process.

NASA also initiated spacecraft-studies contracts with multiple vendors in February 2023 to identify potential modifications to commodity spacecraft for Landsat Next.

SUSTAINED CLIMATE OBSERVATIONS FUTURE MISSIONS

Sustained climate observations support climate change prediction and inform adaptation and mitigation measures. Current sustained climate observation missions focus on observing and improving predictions of sea level rise. NASA will work with international and commercial stakeholders to identify opportunities for achieving these observations through effective and cost-efficient collaborations. Currently, NASA is contributing to ESA's Sentinel-6C mission, which will extend the Sentinel-6 series of sea level observations with an additional Advanced Microwave Radiometer (MR) hosted on an ESA provided satellite.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The Sentinel-6C study team initiated an accommodations study to support ESA's RFP for the spacecraft and long-lead procurements.

EARTH SYSTEMATIC MISSIONS (ESM) RESEARCH

ESM Research funds science teams that are composed of competitively selected investigators who analyze data from ESM projects to address key science questions. Most selected activities focus on science data analyses; however, some activities continue algorithm improvement and validation.

NASA consolidated the Earth Observation Systems (EOS) Research project for the Terra, Aqua, Aura, and Ice, Cloud, and Land Elevation Satellite (ICESat-2) missions and the Precipitation Science project for the TRMM and GPM missions into ESM Research.

Recent Achievements

Researchers used Atmospheric Infrared Sounder (AIRS) carbon monoxide observations to confirm an increase in both long-term trends and extremes of wildfire occurrence in the northern hemisphere over the last 20 years (i.e., 2002 to 2021).

Scientists used remote sensing observations of tree canopy height collected by Global Ecosystem Dynamics Investigation (GEDI) and ICESat-2 to characterize the spatial diversity of global forest structure and quantify the implications for forest carbon stocks and fluxes. In a related study, researchers combined GEDI data with data from the DLR TerraSAR-X add-on for Digital Elevation Measurement (TanDEM-X) satellites to develop a 25-meter (m) forest height map for the entire island of Tasmania and validated it against an airborne lidar survey of the area.

Scientists applied AIML methods to Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data to automatically detect thermal features that typically require manual analysis at five different volcanoes with a 93 percent accuracy. This paves the way for the development of an automated thermal analysis system for future TIR missions, such as SBG.

Researchers analyzed drought-induced food crises globally in the Soil Moisture Active Passive (SMAP) record (since 2015; approximately five per year). They demonstrated that SMAP retrievals of soil moisture, integrated with food prices, provide an early warning for food crises caused by droughts three to six months in advance. This suggests that in the future, drought response could be predictively scaled to anticipate the size of the food crisis.

OCEAN SURFACE TOPOGRAPHY SCIENCE TEAM (OSTST)

NASA consolidated OSTST in the Ocean Measurements project starting in FY 2024.

EARTH OBSERVATION SYSTEMS (EOS) RESEARCH

NASA consolidated EOS Research in the ESM Research project starting in FY 2024.

OTHER MISSIONS AND DATA ANALYSIS

SUSTAINABLE LAND IMAGING (SLI)

SLI enables the development of a multi-decade, space-borne system that will provide U.S. users with high-quality global land-imaging measurements that will be compatible with the existing Landsat record and will address near and long-term issues of continuity risk. The program will evolve flexibly and responsibly through investment and introduction of new sensor and system technologies. Under the SLI framework, NASA will maintain responsibility for developing, launching, and initial checkout of space systems. USGS will be responsible for collecting and documenting user needs, developing the associated ground systems, and operating the on-orbit spacecraft. USGS will also collect, calibrate, archive, process, and distribute SLI system data to users. The development costs for the next series of Landsat satellites is funded out of the Landsat Next budget line, leaving only funding for technology development for future Landsat concepts in the SLI line.

The SLI-Technology program will demonstrate improved, innovative, full-instrument concepts for potential infusion into the next generation of Landsat missions and for technology transfer to commercial imagery providers. SLI-Technology develops technologies at the component and breadboard-level. NASA will solicit instrument and subsystem development activities in coordination with the Landsat science community.

SLI will also engage with international partners to ensure access to high-quality data and fusion of those measurements with those from the U.S. Landsat missions. The USGS, supported by NASA and other agencies, is serving as the primary United States government point of contact to ensure access to, and archiving of, Sentinel-2 data products for U.S. research and operational users.

The SBG missions will serve as a pathfinder for sustainable land imaging, therefore, this budget includes reductions to SLI-Technology. The SLI-Technology budget for subsequent Landsat missions will resume in FY 2028.

Recent Achievements

NASA worked with USGS to define a commercial imagery pathfinder for SLI. This pathfinder will explore the development of high spatial resolution and high revisit commercial Visible and Near-Infrared Reflectance (VNIR) imagery data products that can augment the Landsat data archive and provide additional value in meeting user needs.

The SLI-Technology program funded an on-orbit demonstration of a new instrument – the Multiband Uncooled Radiometer Imager (MURI) – developed under the Earth Science Technology Instrument Incubator project. MURI, an uncooled long-wavelength infrared bolometer-based imager, launched on January 3, 2023, as a hosted payload.

TOTAL SOLAR IRRADIANCE SENSOR-2 (TSIS-2)

TSIS-2 will maintain and extend the 41-year measurement record of total solar irradiance and spectral solar irradiance beyond 2023. Researchers use solar irradiance data to understand how solar energy affects the Earth system over an 11-year cycle and longer time scales. The TSIS-2 launch readiness date is May 2025 and the mission will operate for no less than three years.

Recent Achievements

NASA approved the final spacecraft design in October 2022 and the spacecraft provider started assembly of key spacecraft components. The instrument vendor delivered the Spectral Irradiance Monitor (SIM) into safe storage in September 2023. The Total Irradiance Monitor (TIM) is undergoing final testing in preparation for storage in early FY 2024.

EARTH RADIATION DATA CONTINUITY (ERDC)

NASA renamed Earth Radiation Budget Science to ERDC in this budget request. ERDC uses data from the multiple radiation budget instruments in orbit (e.g., the Clouds and the Earth's Radiant Energy System (CERES), Terra, Aqua, Suomi National Polar-Orbiting Partnership [Suomi NPP], NOAA-20, and geostationary instruments) and ancillary measurements to produce integrated data products over the entire suite of radiation budget instruments. In total, scientists have used 32 instruments on 26 spacecraft thus far to produce an accurate, temporally consistent description of the radiation budget at the top of the atmosphere, within the atmosphere, and at the surface. ERDC is the only project worldwide whose prime objective is to produce global, climate-quality Earth radiation budget data from dedicated Earth radiation budget satellite instruments.

Recent Achievements

In FY 2023, the ERDC team developed new Angular Distribution Models (ADMs) for radiance to flux conversion using the CERES Flight Model 5 (FM5) instrument flying on the Suomi National Polar-orbiting Partnership (S-NPP) satellite. The new ADMs will improve the accuracy of CERES data products from S-NPP and NOAA-20 and will also be used to determine shortwave and longwave radiative fluxes from the Libera instrument that will fly on the Joint Polar Satellite System (JPSS-4) satellite in 2027.

Members of the ERDC team also used measurements from the recent Arctic field campaign, Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC), to evaluate CERES surface fluxes and published the findings in a peer-reviewed scientific journal. This provides users a quantitative assessment of the uncertainties associated with the CERES surface radiative flux product over the Arctic.

OZONE MAPPING AND PROFILER SUITE LIMB SOUNDER (OMPS-L)

OMPS is a three-part instrument that tracks the health of the ozone layer and measures the concentration of ozone in the Earth's atmosphere: a nadir mapper that maps global ozone with about 50-kilometer (km) ground-resolution; a nadir profiler that measures the vertical distribution of ozone in the stratosphere; and OMPS-L, a limb profiler that measures ozone in the lower stratosphere and troposphere. NASA provided OMPS-L for integration on the OMPS instrument that currently operates on the Suomi NPP spacecraft. These measurements fulfill the U.S. treaty obligation to monitor global ozone concentrations for the Montreal Protocol. Therefore, to ensure data continuity, NASA provided a copy of this suite for NOAA's Joint Polar Satellite System-2 (JPSS-2) mission, now called NOAA-21, which launched in November 2022. The project budget also supports OMPS-L profilers for JPSS-3 and JPSS-4.

Recent Achievements

In FY 2023, the OMPS team successfully completed installation of the JPSS-3 OMPS onto the spacecraft. The OMPS team also successfully completed the JPSS-4 OMPS-L, and integrated sensor suite testing will complete in FY 2024.

OTHER MISSIONS AND DATA ANALYSIS

CLIMATE ABSOLUTE RADIANCE AND REFRACTIVITY OBSERVATORY (CLARREO) PATHFINDER (CPF)

CPF will measure sunlight reflected by the Earth and Moon with up to ten times better accuracy than current sensors. This improved accuracy will make it possible to detect subtle climate change trends decades sooner than otherwise possible.

Recent Achievements

In FY 2023, final design and fabrication activities progressed including the completion of the HyperSpectral Imager for Climate Science instrument independent absolute radiometric testing in the thermal vacuum chamber. Upon completion of all other payload subsystems, the project was ready to enter system assembly, integration and test, and launch and checkout at the start of FY 2024.

NASA approved a replanned cost and schedule for CPF in September 2023, increased the budget to reflect these updated estimates, and updated the instrument delivery date to May 2025. These changes are based on the inability of the project to meet the SpaceX-29 launch in December 2023 as a result of schedule erosion due to technical problems in CY 2022/CY 2023. Due to the availability of ISS accommodations and SpaceX payload launch space, CPF must be placed in extended storage. The new development cost estimate exceeds the development cost in the Agency Baseline Commitment established at KDP-C in July 2019 by more than 10 percent, requiring a congressional notification. Pursuant to Section 521 of P.L. 113-235, NASA has notified Congress that CPF has experienced total development cost growth of greater than 10 percent.

EARTH SYSTEM OBSERVATORY FUTURE MISSIONS

NASA has adjusted the architecture and acquisition strategy for the AOS missions to address ongoing affordability concerns and to maximize the achievable science. The new approach to AOS will be a disaggregated architecture and acquisition approach to increase competitive opportunity and contain costs, while maintaining critical international partnerships. PMM, the renamed AOS-Storm mission, will maintain NASA's international contribution commitment to the JAXA PMM and provide continuity of global precipitation observations. The remainder of the budget from the AOS missions moved to this line will support the remaining elements of new acquisition approach. NASA will continue the international partnership with ASI to develop an advanced lidar mission flown on an Italian spacecraft and on an Italian launch that will make critical aerosol and cloud observations.

The remaining ACCP content will be achieved through a combination of competed and directed opportunities. Studies underway now will inform the content of these opportunities and approaches to retain critical science synergies from the disaggregated architecture. In this approach, NASA will provide competitive opportunities for industry to participate in portfolio content, leverage relevant technologies available in the private sector, and better retain programmatic content by distributing associated instrumentation to common platforms.

NASA will also continue Surface Deformation and Change (SDC) studies for a future mission to make deformation measurements that are a fundamental tool for understanding the dynamics of earthquakes, volcanoes, landslides, glaciers, ground water, and the deep interior of the Earth. SDC will not move beyond pre-formulation as NASA will capture and incorporate lessons learned from the NISAR mission.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

In FY 2023 the SDC study team completed the down selections to five candidate architectures and have extensively engaged the science communities including Cryosphere, Ecosystems, Hydrology, and Solid Earth. The team has also established a joint study with ESA to evaluate a potential future development of an L-band Synthetic Aperture Radar architecture.

Starting in FY 2024, NASA initiated a low-cost lidar partnership opportunity with ASI. Currently under study, this is a multi-wavelength lidar instrument that strengthens capability for atmosphere, ocean, and land lidar measurements.

EARTH SCIENCE PROGRAM MANAGEMENT

The Earth Science Program Management budget supports critical flight project management functions executed by the ESM program offices at NASA GSFC and JPL. This budget supports:

- The GSFC conjunction assessment risk analysis function, which determines maneuvers required to avoid potential collisions between spacecraft and to avoid debris.
- The technical and management support for the international Committee on Earth Observation Satellites, which coordinates civil space-borne observations of Earth.
- Senior Review Board teams, who conduct independent reviews of the various flight projects in Earth Science.
- Earth Science division communications and public engagement activities.
- Management and infrastructure for the Earth Information Center (EIC). The budget for EIC moves to the Responsive Science Initiatives Program starting in FY 2025.

Recent Achievements

EIC is a physical and virtual space at NASA HQ where visitors can explore how NASA and its partners study our home planet. EIC opened in June 2023, hosting dignitaries, student groups, and other visitors. NASA also developed a second EIC for the National Museum of Natural History, complete with a 30-foot by nine-foot hyperwall. The EICs showcase large, awe-inspiring visualizations, interactive media, stories, and narratives that communicate actionable science about Earth's land, water, atmosphere, and biosphere to the public. An accompanying interagency website, https://www.earth.gov, launched in November 2023 to deliver critical Earth data directly to people in ways that they can immediately use for their lives and livelihoods.

PRECIPITATION SCIENCE TEAM

NASA consolidated the Precipitation Science Team project in the ESM Research project starting in FY 2024.

OCEAN WINDS SCIENCE TEAM (OWST)

NASA consolidated OWST into the new Ocean Measurements Research project starting in FY 2024.

OTHER MISSIONS AND DATA ANALYSIS

LAND COVER PROJECT SCIENCE OFFICE (LCPSO)

NASA moved LCPSO to the Crosscutting Activities project in the Responsive Science Initiatives Program starting in FY 2025.

OCEAN SALINITY SCIENCE TEAM (OSST)

NASA consolidated OSST into the new Ocean Measurements Research project starting in FY 2024.

OCEAN MEASUREMENTS RESEARCH

Ocean Measurements Research combines the Ocean Surface Topography Science Team (OSTST), Ocean Salinity Science Team (OSST), and Ocean Vector Wind Science Team (OVWST) projects into one.

OSTST uses data from the Ocean Surface Topography Mission, Jason, Sentinal-6 Michael Freilich (S6-MF), and others to measure global sea surface height and study oceanography, climate science, weather, and extreme events. The OSTST is the official science team for the Jason and Sentinel-6 missions.

OSST supports the development and construction of surface salinity products from Aquarius, SMAP, and ESA’s Soil Moisture and Ocean Salinity (SMOS) mission. The team studies upper-ocean processes that impact variability of sea surface salinity and its role in the Earth’s water cycle, climate variability, and extreme weather events.

OWST uses data from the Quick Scatterometer (QuikSCAT) satellite, RapidScat instrument, and other international missions, which measure ocean surface winds by sensing ripples caused by winds at the ocean’s surface. Scientists use this data to acquire global observations of surface wind velocity each day.

Recent Achievements

S6-MF monitored the development of this year’s El Niño, capturing bursts of high sea level moving eastward along the equator and building up warm water in the far eastern Pacific, which typically precedes an El Niño event. S6-MF continues to track its development as the event unfolds.

OSST produced a 12-year-long, multi-mission, satellite salinity climate data record to advance research of ocean physics and ocean-water cycle linkages. OSST members completed a first-of-its-kind field, in-situ plus airborne campaign in the Arctic Ocean studying the role of summer-time salinity in sea ice edge advance in the subsequent fall.

OVWST used observations from the recently launched the Compact Ocean Wind Vector Radiometer (COWVR) and Temporal Experiment for Storms and Tropical Systems (TEMPEST) observatory installed on ISS to examine connections between surface winds and convective events, such as where surface air converges to cause upward motion. OVWST also used simultaneous wind and current measurements from NASA's Sub-Mesoscale Ocean Dynamics Experiment (SMODE) airborne platform to show that ocean and atmosphere models demonstrate remarkable sensitivity to the multiple aspects of the physics represented in these models.

EARTH SCIENCE SENIOR REVIEW

Every three years, the Earth Science division conducts a Senior Review to evaluate missions that have completed, or will soon complete, their prime mission operation phase. The 2023 Senior Review concluded in September 2023. Budget for mission extensions after 2026 will depend upon recommendations by the next Senior Review in 2026.

Recent Achievements

In 2023, the Senior Review evaluated extension proposals for 12 missions. Review results and a final report were presented to NASA. NASA approved the extension requests and used the panel findings to formulate mission programmatic direction for the extension period (FY 2024 to FY 2026).

COPERNICUS POLAR ICE AND SNOW TOPOGRAPHY ALTIMETER (CRISTAL)

CRISTAL is a joint ESA-NASA mission based on Sentinel-6 heritage that will measure surface elevation of glaciers and ice caps, ensuring continuous monitoring of sea ice thickness, snow depth, ice sheet height change, change in sea level, and ocean circulation. CRISTAL will also address why sea ice of the polar ocean is shrinking; why sea level is rising; and why the ice sheets of Greenland and Antarctica are losing mass.

NASA will develop and deliver two Advanced Microwave Radiometer (AMR-CR) instruments to ESA, one each for the CRISTAL-A and CRISTAL-B spacecrafts. ESA will launch CRISTSAL-A and CRISTAL-B sequentially no earlier than 2027 and 2030 respectively with overlapping operations.

Recent Achievements

CRISTAL completed a three-year study for potential NASA radiometer contribution, associated accommodations, and operations support. CRISTAL successfully completed a combined mission concept review, system requirement review, and mission design review in March 2023. CRISTAL also completed a successful PDR in October 2023 and entered the final design and fabrication activity phase in December 2023.

Operating Missions

SURFACE WATER AND OCEAN TOPOGRAPHY MISSION (SWOT)

SWOT will make high-resolution measurements of ocean circulation, kinetic energy, and dissipation to improve ocean circulation models and predictions of weather and climate. SWOT will also measure the water levels in millions of lakes and water bodies and the discharge of all major rivers to obtain a surface water inventory on the continents and allow for deeper understanding of the natural water cycle and improved water management.

SWOT will complement the Jason oceanography missions, as well as Sentinel-6, GPM, SMAP, and Gravity Recovery and Climate Experiment Follow-On (GRACE-FO). SWOT is an international collaborative mission with the French space agency Centre National d’Études Spatiales (CNES), CSA, and United Kingdom Space Agency (UKSA).

Recent Achievements

The mission successfully completed its calibration phase in July 2023, enabling the satellite to move into its final orbit and begin the global science mapping phase.

OTHER MISSIONS AND DATA ANALYSIS

Preliminary results have shown that the random noise of the sea surface height measurement exceeds requirements by a large margin, revealing small-scale variability of sea surface height never observed from space before. Additionally, the initial hydrology (freshwater) results are meeting/exceeding expectations and match well with ground-based calibration/validation sites.

LANDSAT 9

The Landsat data series, initiated in 1972, is the longest continuous record of changes in Earth's surface as seen from space and the only U.S. satellite system designed and operated to make repeated observations of the global land surface at moderate resolution. Landsat data is available at no cost to users, providing a unique resource for people who work in agriculture, geology, forestry, regional planning, education, mapping, and climate research.

Landsat 9, launched in September 2021, extends the record of multi-spectral, moderate resolution Landsat quality data and meets operational and scientific requirements for observing land use and land change. Landsat 9 is a collaboration between NASA and the USGS and is a cornerstone of the SLI effort. Landsat 9 is currently in prime mission operations through December 2026.

Recent Achievements

NASA continued to support Landsat 9 data calibration, validation, and characterization, including cross-calibration of Landsat 9 and Landsat 8 to ensure a seamless extension of the 50-plus-year Landsat record.

The Landsat science communication and outreach team supported 23 science conferences and public events including Landsat's 50th Celebration at the Pecora conference, two events on Capitol Hill, and the opening of NASA's EIC.

STRATOSPHERIC AEROSOL AND GAS EXPERIMENT III (SAGE-III)

SAGE-III, launched in February 2017, operates on ISS, and provides global, long-term measurements of key components of Earth's atmosphere. SAGE-III also provides unique measurements of temperature in the stratosphere and mesosphere and profiles of trace gases, such as water vapor and nitrogen dioxide, which play significant roles in atmospheric radiative and chemical processes. These measurements are vital inputs to the global scientific community for improved understanding of climate and human-induced ozone trends.

The 2023 Senior Review approved extended mission operations for SAGE III through FY 2026.

Recent Achievements

The project released an additional 12 months of SAGE-III data products for a total of 75 months from the mission thus far. Data from the Contamination Monitoring Package (CMP) sub-system that records the external contamination environment at the location of SAGE-III payload on ISS was shared with the ISS space environment team following recent leaks from visiting vehicles (Soyuz and Progress). This dataset was instrumental in assessing the impact to and guiding the safe operation of other external payloads following these contamination events. These unique data are rewriting how the ISS space environment team models the behavior of contamination that can impact external payloads.

OTHER MISSIONS AND DATA ANALYSIS

EARTH FROM ISS

Earth from ISS ensures appropriate processing and availability of data collected by the Land Information System (LIS) and other ISS instruments. Earth from ISS invests in algorithm development, data production and distribution, as well as data analysis and modeling for planned ISS Earth science payloads.

LIS makes space-based global lightning observations to support research of weather and extreme storms, climate, atmospheric chemistry, and lightning physics. LIS data also helps calibrate and validate the observations from the Geostationary Lightning Mapper operating on NOAA's Geostationary Operational Environmental Satellites (GOES) weather satellites.

In November 2023, LIS was decommissioned and removed from its location due to limited site availability on ISS.

Recent Achievements

LIS successfully completed six years on orbit in FY 2023. Publication of additional scientific results occurred in major research journals, including an estimate of global nitrogen oxide production by lightning.

TOTAL SOLAR IRRADIANCE SENSOR-1 (TSIS-1)

Launched in December 2017, TSIS-1 is providing absolute measurements of total solar irradiance and spectral solar irradiance which is important for accurate scientific models of climate change and solar variability, allowing scientists to better understand solar variability at both short and long-time scales. TSIS-1 was in prime operations through March 2023.

The 2023 Senior Review approved extended mission operations for TSIS-1 through FY 2026.

Recent Achievements

TSIS-1 extended the solar irradiance reference spectrum to a range of 115 nanometers (nm) to 200 micrometers (μm), to support applications and research needs from the international science community, including satellite and ground-based remote sensing and radiative transfer and climate modeling.

SOIL MOISTURE ACTIVE AND PASSIVE (SMAP)

SMAP, launched in January 2015, maps soil moisture with unprecedented accuracy, resolution, and coverage to improve monitoring and forecasting of water resources and weather. Although SMAP's active radar instrument failed in July 2015, its radiometer continues to provide global mapping of soil moisture with accuracy, resolution, and coverage that exceeds the capability of other on-orbit systems.

The 2023 Senior Review approved extended mission operations for SMAP through FY 2026.

Recent Achievements

SMAP is significantly expanding the coverage of global land area where land surface models can be helpful to water-resource monitoring and forecasting. In FY 2023, over 184 studies using SMAP data appeared in peer-reviewed scientific journals.

Additionally, the Google Earth Engine, an open-source cloud-computing platform, included the SMAP soil moisture products. Private sector agriculture companies also used SMAP soil moisture products from

Google. The United States Department of Agriculture Foreign Agricultural Service used SMAP soil moisture products from Google in their International Production Assessment system (https://ipad.fas.usda.gov/). The U.S. Air Force HQ 557th Weather Wing uses information from SMAP in the Global Hydro-Intelligence system that provides weather forecasts, warnings and advisories for the Army and Air Force. The 14th Weather Squadron uses this information in war gaming and strategic planning efforts.

DEEP SPACE CLIMATE OBSERVATORY (DSCOVR)

DSCOVR, launched in February 2015 to an orbit between the Earth and Sun, is a NOAA, The United States Air Force (USAF), and NASA mission that provides a 45-minute early warning for adverse space weather events. NASA provided the two Earth-observing instruments, the Earth Polychromatic Imaging Camera (EPIC) and National Institute of Standards & Technology Advanced Radiometer (NISTAR), to the DSCOVR satellite. Publicly available EPIC and NISTAR data includes color images of the full sunlit disk of the Earth; maps of ozone, clouds, aerosols, and vegetation; and measurements of sulfur dioxide from volcanic eruptions.

The 2023 Senior Review approved extended mission operations for the DSCOVR NASA-provided instruments through FY 2026.

Recent Achievements

In 2023 NASA recovered the calibration of EPIC and NISTAR after a gyro failure from 2019 to 2020. DSCOVR also showed that the GISS ModelE2 Global Climate Model overestimates clouds over oceans and underestimates clouds over land. A unique observation from EPIC showed the seasonal and long-term variations in leaf area of the Congolese rainforest that is of interest in this era of climate change.

GLOBAL PRECIPITATION MEASUREMENT (GPM)

GPM, launched in February 2014, provides a three-dimensional view of tropical storm structural and microphysical properties and provides estimates of storm rainfall accumulations for major storm events. The GPM Microwave Imager (GMI) measures energy from different types of precipitation within clouds to estimate heavy to light rain and to detect falling snow. The Dual-frequency Precipitation Radar (DPR) provides three-dimensional information about precipitation particles, including their size distributions and associated rainfall rates. GPM is a joint mission with JAXA.

The 2023 Senior Review approved extended mission operations for GPM through FY 2026.

Recent Achievements

GPM extended its datasets and research through satellite operations, data processing and delivery, and science activities. The project's Mission Operations worked with industry and ISS to coordinate close approaches between the GPM core observatory and other spacecraft.

The GPM Ground Validation partnered with the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms field campaign that studies snowstorms along the U.S. eastern seaboard. It flew its third field campaign during January 2023 and is assembling datasets that will be available for the scientific community.

OTHER MISSIONS AND DATA ANALYSIS

The GPM held the GPM Mentorship program, which provided background training to 179 participants, as well as one-on-one mentoring to 34 international students and early-career hydrometeorological professionals in applying GPM data for real-world research problems.

SUOMI NATIONAL POLAR-ORBITING PARTNERSHIP (SUOMI NPP)

Suomi NPP, launched in October 2011 as a partnership between NASA and NOAA, provides visible and infrared multi-spectral global imagery, atmospheric temperature and moisture profiles, total ozone and stratospheric ozone profiles, and measurements of Earth’s radiation balance. Suomi NPP products have provided critical near-real time and continuity data, extending the EOS observation long time-series in monitoring changes in land, ocean, and atmosphere as well as Earth’s radiation budget. NASA built and launched Suomi NPP. NOAA operates the spacecraft and instruments.

Suomi NPP is currently in extended operations; a Joint Steering Group meeting with NOAA in early 2024 will confirm plans for the project's future.

Recent Achievements

In FY 2023, the NASA Suomi NPP team continued to add to the existing data records from Earth Observing System missions, enabling scientists to build multi-satellite, multidecadal (greater than 31 years) time series with high accuracy and long-term stability suitable for studies of Earth systems science.

Suomi NPP products offered near real-time information of smoke loading, active fire, and locations during the wildfire events over Canada and the U.S. western states in the summer of 2023. These products helped track and predict the evolutions of the intense smoke plumes that led to hazardous air quality conditions over major cities in the United States.

In addition, Suomi NPP's nighttime lights product helped to provide disaster response support after the Türkiye/Syria Earthquake in February 2023, the Morocco Earthquake in September 2023, and Hurricane Idalia in the United States in August 2023.

Suomi NPP observations provide high-resolution land surface temperature information to monitor extreme heat events in urban areas around the globe. They also provide critical data for detecting and tracking harmful algal blooms on the West Florida Shelf and impact critical fisheries and human health.

TERRA

Terra, launched in December 1999, is an EOS flagship mission that studies atmospheric composition, carbon cycle, ecosystems, biogeochemistry, climate variability and change, water and energy cycles, and weather. Terra has provided over 23 years of continuous data collection and is a joint mission with Japan and Canada.

Terra is currently in extended operations. The 2023 Senior Review for Operating Missions approved extended mission operations for Terra with the end of science data acquisition estimated to occur in FY 2027 due to power limitations as the spacecraft orbit drifts with respect to the Sun.

Recent Achievements

In FY 2023, the Terra mission entered its 24th year of operations. Multiple U.S. and international agencies used Terra's products for volcanic ash monitoring, weather forecasting, forest fire monitoring, carbon management, and global crop assessment. Direct broadcast and near-real-time data products from

OTHER MISSIONS AND DATA ANALYSIS

Terra sensors were especially critical for predictions of local air quality and smoke transport as well as fire management. Weather prediction models use Terra near real-time products to provide added data for tropical storms and hurricanes. Terra's five instruments enabled synergistic studies of clouds, aerosols, and land cover to understand sources and variability of air pollution such as fires and industrial emissions and increased knowledge and reduced uncertainty in vegetation monitoring.

AQUA

Aqua, launched in May 2002, is an EOS flagship mission that monitors atmospheric, land, ocean, and ice properties. The Aqua Earth observing instruments that continue to operate –AIRS, Advanced Microwave Sounding Unit (AMSU), CERES, and Moderate Resolution Imaging Spectroradiometer (MODIS) – provide data to federal agencies and the science community for research and applications ranging from improved weather forecasting to monitoring forest fires, crop yields, volcanic ash plumes, and ice-infested waters. Aqua is a joint mission with Japan and Brazil.

Aqua is currently in extended operations. The 2023 Senior Review for Operating Missions approved extended mission operations for Aqua with the end of science data acquisition estimated to occur in FY 2026 due to power limitations as the spacecraft orbit drifts with respect to the Sun.

Recent Achievements

During FY 2023, researchers used Aqua data for a variety of investigations including: AIRS data were used to show the Arctic is becoming progressively warmer and wetter and also that methane is increasing in the mid-upper troposphere; CERES data were used to show that Earth has a stabilizing feedback only via thermal infrared radiation and not for absorbed solar radiation, allowing the heat due to the latter to accumulate; and MODIS data were used to show that ship fuel regulations have led to global reductions in visible ship emission signatures on clouds called "ship tracks", that the color of the global oceans is becoming greener due to more phytoplankton, and that cropland expansion may not be the primary driver of reductions in global burned area and fire activity.

In late FY 2023 Aqua reduced the number of operations personnel in half by limiting in-person operations coverage to only daytime hours. This cut costs with only a modest reduction in data capture.

Throughout FY 2023, Aqua data and imagery monitored major environmental events around the world, such as wildfires in Canada, southeastern Australia, and eastern Russia; typhoon Lan lashing Japan; the rapid growth of hurricane Hillary affecting California; flooding along Australia's Fitzroy River; the massive seaweed bloom in the Atlantic; and the atmospheric rivers that battered California in early 2023. The Aqua Mission team received USGS's prestigious Pecora Group Award "for its significant contributions to scientific studies of the Earth over two decades and related applications."

AURA

Aura, launched in July 2004, is an EOS flagship mission that measures atmospheric chemical composition, tropospheric/stratospheric exchange of energy and chemicals, and chemistry-climate interactions to understand changes in the Earth's radiation balance, air quality, and the ozone layer. Two of Aura's four instruments are operational: the Microwave Limb Sounder and the Ozone Monitoring Instrument. Aura is a joint mission with the Netherlands, Finland, and the United Kingdom.

OTHER MISSIONS AND DATA ANALYSIS

Aura is currently in extended operations. The 2023 Senior Review for Operating Missions approved extended mission operations for Aura with the end of science data acquisition estimated to occur in FY 2025 due to power limitations as the spacecraft orbit drifts with respect to the Sun.

Recent Achievements

More than 19 years into its mission, Aura continued to provide data for scientific research and societal benefit in FY 2023. By monitoring the products of fossil fuel burning, Aura data helped to assess economic activity worldwide (including in countries without reliable economic data) and to assess the effectiveness of pollutant emission controls. Climate scientists used Aura data to quantify volcanic emissions effects on the stratosphere. Volcanologists used these measurements to understand long-term changes in global volcanic processes.

This year, the Aura team led efforts to quantify the 2022 Hunga Tonga-Hunga Ha'apai undersea volcanic eruption's effects on Earth's ozone layer. Aura data showed that in the months following the eruption, enhanced aerosol and water vapor from the volcanic plume promoted conversion of now-banned industrially produced compounds into forms that cause ozone destruction. Although the Aura team did not observe appreciable ozone loss at the latitudes of the eruption or the 2022 Antarctic ozone hole, the team is studying its effects on the 2023 Antarctic ozone hole.

ICE, CLOUD, AND LAND ELEVATION SATELLITE (ICESAT-2)

ICESat-2, launched in September 2018, measures global elevation to determine sea ice thickness and ice sheet mass change. It also provides topography and vegetation data around the globe, supporting estimates of biomass and carbon in aboveground vegetation, measurements of ocean topography, inland water body elevation, and cloud properties. ICESat-2 has one instrument, the Advanced Topographic Laser Altimeter System, which measures the round-trip time of laser light from the observatory to Earth and back as the basis for the mission's elevation measurements.

The 2023 Senior Review approved extended mission operations for ICESat-2 through FY 2026.

Recent Achievements

ICESat-2 continues to operate nominally, measuring the record low minimum and maximum extents of Antarctic Sea ice observed in 2023. Rapid release data products from the mission assisted icebreaker navigation through sea ice covered regions of Antarctica in December 2022. In conjunction with ESA's CryoSat-2 mission, the Cryo2 Ice campaign maintained an orbital alignment with ICESat-2 that is allowing for cross-cutting measurements of ice change with new joint NASA and ESA data products expected in 2024.

Analysis shows that the green laser light of ICESat-2 can penetrate up to 15 meters (i.e., nearly 50 feet) of water, enabling shallow water bathymetry (i.e., the measurement of depth of water in oceans, seas, or lakes). Work is progressing on a new on-demand mission bathymetry data product.

To date, over 6,892 users have downloaded over 38.2 million IceSat-2 data files spanning 19 data products and yielding more than 366 peer-reviewed publications in the scientific literature. As the ICESat-2 data volume continues to grow, the ICESat-2 project has developed tools for cloud-based data access and analysis and sponsored several workshops dedicated to introducing users to these new tools.

OTHER MISSIONS AND DATA ANALYSIS

GRAVITY RECOVERY AND CLIMATE EXPERIMENT FOLLOW-ON (GRACE-FO)

GRACE-FO, launched in May 2018, provides mass change observations and high-resolution global models of Earth's gravity field, allowing scientists to gain new insights into the dynamic processes of Earth's water cycle. GRACE-FO also maps large earthquakes and tectonic processes. GRACE-FO data is vital to ensuring there is a minimal gap in mass change measurements following the decommissioning of the original GRACE mission in 2017. GRACE-FO is a partnership with the German Research Center for Geosciences and was in prime mission operations through May 2023.

The 2023 Senior Review approved extended mission operations for GRACE-FO through FY 2026.

Recent Achievements

GRACE-FO data feeds into several climate indicators of NASA's Vital Signs of the Planet Web site as well as into the U.S. Drought Monitor to assess the current state of drought, and to generate seasonal forecasts of groundwater and soil moisture for the contiguous United States. GRACE-FO observations accurately measured the massive increase of water stored in California's snowpack and freshwater reservoirs during the exceptionally wet 2022/2023 winter and is now providing vital data points for groundwater recharge over California's Central Valley aquifer system. Globally, the long-term data record provided unique insights into increasing drought and flood events as the water cycle intensifies in a warmer climate.

During 2023, GRACE-FO also made progress to mitigate the risks associated with the increasing intensity of the 11-year solar cycle and its aging flight systems.

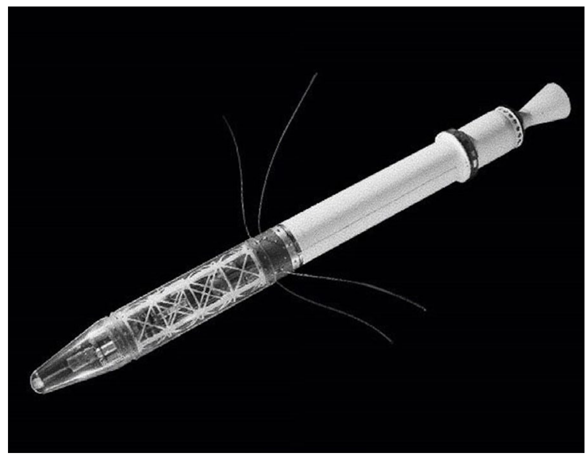
EARTH SYSTEM EXPLORERS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**2.5**	**--**	**19.6**	**59.0**	**99.5**	**130.6**	**194.7**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

NASA's Earth System Explorers (ESE) program provides competitive opportunities for medium-sized instruments and missions that address specific science and application needs identified in the 2017 National Academies' report, "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space."



NASA's Earth System Explorers will continue the tradition of the first U.S. satellite Explorer 1 (illustrated above), which was launched in 1958.

These Principal Investigator-led projects will employ innovative, streamlined, and efficient management approaches to constrain design, development, and operations costs. Distinct from Earth Venture (EV) instruments and missions, Earth System Explorers will focus on one or more of the seven identified targeted observables important to our understanding of Earth system science:

- atmospheric winds;
- greenhouse gases;
- ice elevation;
- ocean surface winds and currents;
- ozone and trace gases;
- snow depth and snow water equivalent; and
- terrestrial ecosystem structure.

The cost cap is set at $320 million (in FY 2024 dollars) excluding the cost of standard launch vehicle services.

EXPLANATION OF MAJOR CHANGES IN FY 2025

In this budget request, NASA integrated and updated ESE mission cadence with EV to balance large, medium, and small EV and ESE opportunities. This budget request changes the cadence for releasing an ESE announcement of opportunity (AO) from every two years to twice a decade (2023 and 2029), with up to two selections made against each AO.

EARTH SYSTEM EXPLORERS

ACHIEVEMENTS IN FY 2023

The ESE Program Office successfully completed the system requirements review/system definition review held in March 2023.

NASA released the final version of the first ESE AO in Q3 FY 2023 and received responses in Q4 FY 2023. NASA expects the first ESE launch no later than spring 2030.

WORK IN PROGRESS IN FY 2024

NASA plans to make selections for competitive Phase A studies in Q3 FY 2024.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

NASA plans to make final mission selections in Q4 FY 2025. Missions selected to continue will proceed to Phase B formulation activities.

Program Elements

EARTH SYSTEM EXPLORERS FUTURE MISSIONS

Earth System Explorers Future Mission funding supports the selection of new missions through AO solicitations every three years, beginning in 2029, which will support the goal of launching three missions within a decade. This funding supports proposals selected during Step 1 of the proposal process with conducting Phase A formulation studies. Selected proposals will move to Step 2 for full mission implementation.

EARTH SYSTEM EXPLORERS PROGRAM MANAGEMENT

ESE Program Management provides funding for the ESE Program Office, development of AO solicitations, and the technical, management, and cost evaluations of proposals received in response to the AO solicitations. It also supports the management of missions conducting formulation studies and missions in implementation (per the two-step selection process).

Program Schedule

Date	Significant Event
Q3 FY 2024	Selection of candidates to move into Step 1 within nine months of receipt of proposals
Q4 FY 2025	Select proposals for Step 2
Q3 FY 2029	AO Release

EARTH SYSTEM EXPLORERS

Program Management & Commitments

Program Element	Provider
ESE Program Management	Provider: GSFC Lead Center: GSFC Performing Center(s): TBD Cost Share Partner(s): TBD

Acquisition Strategy

NASA will select all ESEs through full and open competition using a two-step proposal process.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

None.

RESPONSIVE SCIENCE INITIATIVES

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	55.0	--	167.7	173.9	176.4	177.9	179.5

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

NASA FireSense project partnered with the U.S. Forest Service (USFS) for a fall prescribed burn, pictured here in October 2023. USFS conducts prescribed burns biannually for ecosystem restoration and to reduce hazardous fire fuels. USFS and NASA collect data at these burns to help improve models of fire and smoke behavior.

Responsive Science Initiatives (RSI) includes projects that connect user needs with NASA remote sensing observations and Earth system science. RSI encourages synergies amongst projects, providing focused support for user-centered research activities and attending to the complex managerial requirements and stakeholder arrangements of projects that involve other agencies or commercial satellite data.

RSI is currently comprised of six major projects: Crosscutting Activities, Interagency Satellite Observation Needs (ISON), Agriculture, Wildland Fires, Responsive Science Research (RSR), and Commercial SmallSat Data Acquisition (CSDA).

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA established RSI as a new program in Earth Science in this budget request. With the exception of Responsive Science Research (RSR), all of the RSI projects or activities contained therein existed elsewhere in the Earth Science Division's budget prior to FY 2025. Some of the projects represent combinations of related activities budgeted in different programs but unified under RSI.

This budget request includes an additional $8 million above the FY 2023 enacted level to support data needs of other agencies, identified through the U.S. Group on Earth Observations Satellite Needs survey process, and enables the Greenhouse Gas Center to support new use cases and measurement, data validation, and/or standards efforts aligned with the goals of the National Strategy to Advance an Integrated U.S. Greenhouse Gas measurement, Monitoring and Information System.

In FY 2025, the following elements move in their entirety from other Earth Science programs to RSI: Agriculture, the Health and Air Quality Science Team (HAQAST), and the Western Water Applications Office (WWAO) from Applied Sciences (HAQAST and WWAO become components of the Crosscutting Activities project); ISON (which houses NASA's response to the U.S. Group on Earth Observations Satellite Needs Working Group) and CSDA from Earth Science Data System (ESDS); short-term Prediction Research and Transition (SPoRT) center, the Climate Adaptation Science Investigators (CASI), and the Goddard Institute for Space Science's (GISS) Climate Impacts Group from R&A; and the

Landcover Project Science Office from Earth Systematic Missions. In addition, in FY 2025, the following elements coalesce from multiple programs across Earth science to RSI: wildland fires (including Wildland Fire Applications, FireSense and FireTech); efforts included in the GHG Center; the Earth Information System (EIS), NASA Earth eXchange (NEX); Global Partnerships; and the Earth Information Center (EIC).

ACHIEVEMENTS IN FY 2023

NASA's Agriculture project established a new domestic consortium, A Climate Resilient Ecosystem Approach in March 2023. Additionally, Harvest, NASA's consortium on global food security, worked in partnership with the Ukraine Ministry of Agriculture to provide wheat production estimates over the Russian occupied territories using remote sensing techniques. The Ukrainian government used these estimates to inform their decision to not put in place a wheat export ban in 2022, which impacted global food availability assessments and pricings.

HAQAST continued to engage hundreds of stakeholders across environmental health and air quality communities to utilize NASA data and tools for societal benefit. The first round of short-term, high-impact joint efforts between HAQAST members and stakeholders concluded with advancements in the use of satellite data for environmental justice, assimilation of new geostationary satellite data into the Environmental Protection Agency's (EPA's) AirNow system, and enhancements in stakeholder access and utilization of data products.

The CSDA project completed the one-year scientific evaluation of "On-ramp #2" vendors. SMD is currently finalizing a summary report based on these findings and recommendations. In addition, the project competitively selected Principal Investigators via NASA ROSES 22 to evaluate the data utility for longer term purchase. The purchase of commercial satellite data augments or compliments the suite of Earth observations acquired by NASA, other U.S. government agencies, and international partners.

The SpoRT project deployed products related to lightning and convection, tropical cyclones, drought monitoring, and flood forecasting. SpoRT continued development on three artificial intelligence products related to dust storms, lightning risk, and flooding.

The EIS team developed multi-mission synthesis of the terrestrial water cycle to support several stakeholders including the World Meteorological Organization, U.S. Fish and Wildlife Service, EPA, The Nature Conservancy, and the Bangladesh Water Development Board.

EIC, a physical and virtual space where visitors can explore how NASA and its interagency partners study our home planet, opened to the public at NASA HQ in June 2023. The EIC showcases awe-inspiring visualizations, interactive media, stories, and narratives that communicate actionable science about Earth's land, water, atmosphere, and biosphere to the general public.

The Wildland Fires effort completed the first full year of funding a portfolio of activities. Several activities provided direct support to wildfire management practitioners (e.g., Truckee Fire Department, U.S. Forest Service, Burned Area Emergency Response rehabilitation teams, and other Department of the Interior agencies), including a rapid response support tool for the Lahaina, HI fires in August 2023.

The CASI Workgroup, in close collaboration with NASA's Office of Strategic Infrastructure, studied downscaled climate projections and their impacts on NASA facilities, workforce, and local and regional environments to help NASA facilities managers adapt to increasing climate risks.

The Synthesis Report of the IPCC Sixth Assessment Report featured the work of the Climate Impacts Group (CIG). The Agricultural Model Intercomparison and Improvement Project (AgMIP) hosted a

Global Workshop in June 2023, with more than 200 people from 44 countries. Hosted by CIG, the Urban Climate Change Research Network contributed to a Massive Open Online Course, with over 1,700 students enrolled.

WORK IN PROGRESS IN FY 2024

HAQAST will see results from the second round of short-term tasks on topics including reducing uncertainty in regional air quality modeling, oil and gas emissions, environmental justice, and supporting Tropospheric Emissions: Monitoring of Pollution (TEMPO) applications for surface ozone.

NASA, along with its implementing partners EPA, NOAA and the National Institute of Standards and Technology (NIST), will have a “soft launch” of the U.S. GHG Center. In its initial (i.e., prototype) phase, the U.S. GHG Center is a partnership of federal agencies with a virtual portal. The beta portal release will occur in FY 2024. The initial demonstration areas leveraged to prototype the U.S. GHG Center are: 1) providing more accessible anthropogenic emission inventories; 2) improving understanding of natural sources and sinks of methane and carbon dioxide; and 3) demonstrating the ability to reliably observe and estimate point source GHG emissions.

The CSDA project is finalizing the long-term data preservation processes for the commercial data acquired by NASA for ingest, archive, catalog, and distribution of the purchased commercial data. NASA also expects completion of the one-year scientific evaluations of the "on-ramp #3" vendors’ commercial data. The CSDA five year Multiple-Award Indefinite Delivery Indefinite Quantity (IDIQ) contract with firm-fixed task orders will be in place to continue the project objectives to support NASA's Earth science research and applications activities.

The Satellite Needs Working Group (SNWG) Management Office at MSFC is overseeing the formulation, implementation, and operation of products and activities based on solutions identified in the SNWG-2016, 2018, and 2020 assessment cycles. The SNWG-2024 assessment cycle will commence and NASA, USGS, and NOAA will begin an in-depth evaluation process of agency satellite data needs identified through a survey conducted by the U.S. Group on Earth Observations.

SPoRT will continue to develop value added products related to weather forecasting, water resources, and air quality, with a focus on artificial intelligence. SPoRT will continue to provide NASA value added datasets in real-time to partners, NASA centers, and NASA programs.

NEX will continue to engage with the scientific community to evaluate, compare, and improve statistical downscaling of climate projections, with emphasis on use of NASA data and models to improve resilience.

The EIS team will develop a high-resolution land analysis environment of North America to support downstream applications related to improved drought monitoring, water resource management, water quality forecasting, and hydrometeorological prediction.

The Wildland Fires team will work with stakeholders to provide useful NASA data, models, and tools by hosting focused science-user group workshops. The team will focus on the critical stakeholder needs to ensure future funding solicitations are prioritizing the crucial gaps in wildfire knowledge. The FireSense effort will work with agency wildland fire management partners, including the U.S. Forest Service, to execute an airborne campaign over prescribed fires and wildfires.

AgMIP will spearhead the design of the Virtual Agricultural Innovations Laboratory with the Iowa Corn Growers Association. The prototype is a digital twin for Iowa agriculture that utilizes remote sensing data, field observations, crop modeling, and machine learning.

RESPONSIVE SCIENCE INITIATIVES

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The Responsive Science Research project will begin in FY 2025 and release its first solicitation.

Within the Crosscutting Activities project, multiple efforts will increase the uptake of the latest Earth science research by key stakeholders. In FY 2025, following the completion of needs assessments for each western U.S. water basin, the Western Water Applications Office will establish a liaison and provide support services for water managers, utilizing freshwater data from Earth observations at the basin, state, and local scales. NASA's CASI team will continue to integrate climate science from the Earth Science Division with requirements, master plans, and projects of the Office of Strategic Infrastructure. The EIS team will develop a high-resolution soil moisture monitoring system for agricultural production over the continental United States, leveraging current and upcoming missions. The U.S. GHG Center will develop practices for refining and disseminating information with mature datasets and modeling capabilities. Additionally, the center will continue to solicit user needs and develop a process for evaluating and integrating new data and capabilities.

In FY 2025, the ISON project anticipates continued operation and implementation of the successful solutions identified in the SNWG 2016-2020 assessment cycles with several activities becoming operational. Successful solutions from SNWG 2022 will be in either formulation or implementation. SNWG-2024, the 5th Assessment, will conclude and NASA will present the findings to the U.S. Group on Earth Observations (USGEO) and other federal stakeholders.

The CSDA five year Multiple-Award IDIQ contract with firm-fixed task orders will be in place to continue the project objectives of identifying, evaluating, and acquiring data from commercial sources to support NASA's Earth science research and applications activities. The IDIQ contract is the next on-ramp opportunity for new companies and for sustained CSDA vendors. CSDA will continue to support the ISON project during their assessment of SNWG-generated commercial data requests.

Within the Agriculture project, NASA Harvest will complete a standing system and methodology in FY 2025, based on the Ukraine food supply assessment processes, for Rapid Action for Agriculture Policy. This system will deliver actionable agriculture assessments in the face of natural and man-made food supply disruptions. The NASA A Climate Resilient Ecosystem Approach (ACRES) Consortium will establish Essential Agriculture Variables from Earth observations such as crop residue and tillage mapping, which the agriculture community will use as science-based measurements for climate-smart measurements and policy in FY 2025.

Within the Wildland Fires project, the current round of activities in the Applied Sciences Wildland Fires portfolio will finish in FY 2025. The Wildland Fires project will focus on funding a new round of research and activities based on identified stakeholder needs. The project will work with agencies, states, and communities to provide useful NASA data, models, and tools (in response to guiding workshops) that focus on communicating; guiding; and transitioning science, tools, and models to operational agencies and communities. This will enhance NASA’s usefulness to communities as fire response becomes increasingly challenging.

Program Elements

RESPONSIVE SCIENCE RESEARCH

The RSR project sponsors interdisciplinary research driven by user needs of NASA's remote sensing and Earth system science. Outcomes address societal challenges and support decision-making by policymakers, governmental organizations, private sector, or the general public. Theme areas are determined by considering emerging questions from NASA's other projects and programs in applied sciences, mission outcomes, recent results, and community reports and other feedback to NASA. The project generally competes individual awards through NASA ROSES, but also involves directed support to NASA centers.

CROSSCUTTING ACTIVITIES

The Crosscutting Activities project brings recent developments from NASA's efforts in research and remote sensing to federal and state agencies, the private sector, the public, and other partners. Activities are crosscutting in two ways: they build on outcomes from across the Earth Science Division (ESD), including the R&A element and the RSR project; and/or they combine results and data from across the federal government to offer a complete view of an aspect of Earth science.

CA's primary goals are to develop and support products and tools that meet user-determined needs. Examples include weather forecast improvements for NOAA, West Nile virus spreading projections for state public health officials, and numerical models of Earth systems to support construction standards. This project also accelerates the uptake of Earth science and improves accessibility to data and tools through development of portals such as the Earth Information Center and the U.S. GHG Center. Both of these portals are interagency collaborations which aim to put relevant information in the hands of users, including federal agency partners, local and state decisionmakers, and the general public.

The U.S. GHG Center provides GHG data through a web portal to inform climate action for a range of stakeholders. The center involves partnerships with the EPA, NOAA, and NIST, each of which provide critical contributions to the portal, located at https://earth.gov/ghgcenter. NASA provides satellite and aircraft data, modeling capabilities, and leads portal development and operation. The center activities serve as a focal point of collaboration with networks of stakeholders and users, including those from federal agencies, the private sector, and international and intergovernmental entities. By managing these efforts collectively, the Crosscutting Activities project encourages efficiencies in management and implementation. Lessons learned, external partnerships, and other synergies can be capitalized on to increase NASA's overall impact.

INTERAGENCY SATELLITE OBSERVATION NEEDS

The ISON project supports NASA's participation in the U.S. Group on Earth Observation's Satellite Needs Working Group, which identifies high priority, sustained, and unmet needs for satellite Earth observation. The SNWG conducts a biennial survey of federal civil agencies to formally document and communicate satellite Earth-observing needs to NASA. Through the ISON project, NASA, in partnership with USGS and NOAA, assesses each submitted satellite need, and proposes potential solutions that help satisfy the agencies' observational needs. The ISON project's analysis of other agency observational needs and recommendations of potential solutions inform agency planning and budgeting. The ISON project also oversees the implementation of the solutions. Examples of solutions that have been successfully implemented include enhanced data acquisition and data downlink capability for the NISAR mission and products that combine data from multiple satellites to meet the data needs of multiple agencies.

AGRICULTURE

The Agriculture project promotes the use of Earth observations for understanding the functioning and resilience of food systems. The area supports multi-organizational consortia to enhance domestic productivity, international food security, and improved agricultural practices, especially for economic progress and humanitarian pursuits. The Agriculture project comprises two consortia: NASA Harvest, focusing on global food security issues, and NASA ACRES, focusing on domestic agricultural needs. ACRES is NASA's first consortium that focuses on domestic agriculture and bridges the gap from space-to-farm and workforce-to-impact together with U.S. farmers, ranchers, and other agrifood system decision makers who address the most pressing challenges to sustainable, productive, and resilient agriculture, both today and into the next generation. NASA's Harvest and ACRES agriculture consortia focus on applying satellite Earth observation information to the most pressing agricultural and food security challenges facing U.S. farmers and the global agriculture community. These consortia bring public and private sectors together to enable flexible partnerships that enable rapid delivery of Earth observation solutions to agriculture decision makers.

WILDLAND FIRES

The Wildland Fires project supports the improved prediction, management, and mitigation of overall impacts of wildfires within the United States and around the world. Activities include developing and transitioning research, technology, and applications to operational fire management agencies and organizations in the United States and across the globe. This project focuses on four functional themes: improved forecasting and mitigating pre-fire risk; improved detection and monitoring of active fires; improved prediction of post-fire hazards, including landslides; and air quality impacts.

COMMERCIAL SMALLSAT DATA ACQUISITION

The CSDA project identifies, evaluates, and acquires data from commercial sources to support NASA's Earth science research and applications activities. This will provide a cost-effective means to augment and/or complement the suite of Earth observations acquired by NASA and other U.S. government agencies, as well as those acquired by international partners and made available to NASA and its stakeholders.

RESPONSIVE SCIENCE INITIATIVES

Program Schedule

Date	Significant Event
Q1 FY 2024	ROSES-2023 selections within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation release
Q1 FY 2025	ROSES-2024 selections within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation release
Q1 FY 2026	ROSES-2025 selections within six to nine months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation release
Q1 FY 2027	ROSES-2026 selections within six to nine months of receipt of proposals
Q2 FY 2027	ROSES-2027 solicitation release
Q1 FY 2028	ROSES-2027 selections within six to nine months of receipt of proposals
Q2 FY 2028	ROSES-2028 solicitation release
Q1 FY 2029	ROSES-2028 selections within six to nine months of receipt of proposals
Q2 FY 2029	ROSES-2029 solicitation release

Program Management & Commitments

Program Element	Provider
Crosscutting Activities	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): None
ISON	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): None
Agriculture	Provider: HQ Lead Center: HQ Performing Center(s): ARC, GSFC, MSFC Cost Share Partner(s): USDA, USAID, BMGF, ESA, Swiss Re
Wildland Fires	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): None

RESPONSIVE SCIENCE INITIATIVES

Program Element	Provider
Responsive Science Research	Provider: HQ Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): None
CSDA	Provider: Various Lead Center: GSFC Performing Center(s): GSFC, JPL, MSFC Cost Share Partner(s): None

Acquisition Strategy

NASA bases the Earth Science Responsive Science Initiative acquisitions on full and open competition to the greatest extent possible. Approximately one quarter of the portfolio is directed rather than competed. Grants are peer reviewed and selected based on NASA research announcements and other related announcements. NASA may acquire certain research, instruments, or services without competition if there is a clear scientific, technological, or programmatic benefit to NASA.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
CSDA	IDIQ vendors per awarded task orders	Various (vendor location)
SNWG	University of Maryland	Maryland

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Relevance	Earth Science Advisory Committee and Applied Sciences Advisory Committee	Spring 2024	Discuss Earth Science to Action Strategy	TBD

Earth System Science Pathfinder

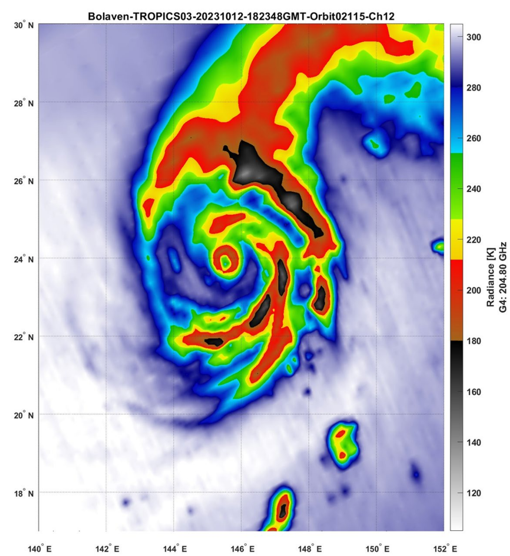
FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Venture Class Missions	161.2	--	**200.4**	205.0	181.5	201.9	283.3
Other Missions and Data Analysis	70.9	--	**51.3**	41.0	20.6	23.1	25.6
Total Budget	**232.1**	**--**	**251.7**	**246.0**	**202.1**	**225.0**	**308.9**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Earth System Science Pathfinder (ESSP) program provides regular opportunities for competitively selected low-cost and targeted Earth science investigations that accommodate new and emerging scientific priorities and measurement capabilities. Principal investigators lead these focused projects that contribute to studies of the atmosphere, oceans, land surface, polar ice regions, or solid Earth.

ESSP projects include space missions, remote sensing instruments for space-based missions of opportunity, and extended duration airborne-science missions. The ESSP program also supports the conduct of science research utilizing data from these missions. ESSP projects may involve partnerships with other U.S. agencies and/or international organizations. This portfolio of missions and investigations provides opportunity for investment in innovative Earth science that enhances NASA's capability for better understanding the current state of the Earth system.



The Time-Resolved Observations of Precipitation Structure and Storm Intensity With a Constellation of Smallsats (TROPICS) constellation satellite took this image of Super Typhoon Bolaven, which reached peak intensity on October 12, 2023, with wind speeds of approximately 180 miles per hour.

Explanation of Major Changes in FY 2025

NASA selected the Polarized Submillimeter Ice-cloud Radiometer (PolSIR) mission from the Earth Venture Instrument 6 AO. This budget supports updated instrument and science cost and schedule estimates for Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR) as the project entered the final design and fabrication phase, after a successful KDP Review-C in March 2023.

NASA consolidated funding for extended mission operations in the Venture Class Future Missions project to hold future funding for Senior Reviews for ESSP mission extensions after 2026.

This budget request aligns with the updated Earth Venture Announcement of Opportunities (AO) cadence which will balance large, medium, and small (SmallSat/CubeSat) opportunities. Please see the Venture Class Missions section for more information.

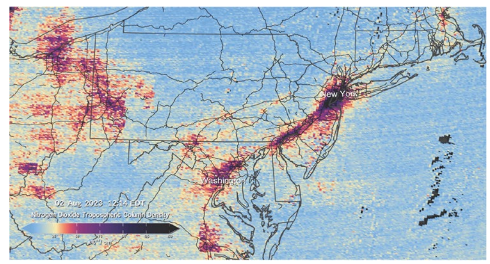
VENTURE CLASS MISSIONS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**161.2**	**--**	**200.4**	**205.0**	**181.5**	**201.9**	**283.3**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

NASA's Earth Venture Class Missions provide frequent flight opportunities for high-quality, low-cost Earth science investigations that can be developed and flown in five years or less. NASA selects the investigations through open competitions to ensure broad community involvement and encourages innovative approaches. Successful investigations enhance our capability to understand the current state of the Earth system and enable continual improvement in the prediction of future changes. Solicitations include both space-borne and airborne/suborbital opportunities.



This image shows nitrogen dioxide levels over the DC/Philadelphia/New York region at 12:14 p.m. on August 2, 2023, as measured by TEMPO for hourly air quality at the neighborhood scale.

NASA established Venture Class Missions in response to recommendations in the 2007 National Academies' report, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond." The 2017 National Academies' report, "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space," also endorsed the Venture Class Missions.

All Earth Venture-class missions and instruments are cost and schedule constrained and openly competed. Adherence to cost caps and schedule constraints is critical to the success of the Earth Venture Program to ensure availability of funding for frequent solicitations and programmatic flexibility and responsiveness. Earth Venture missions complement the directed elements of NASA's Earth Science Program, enabling more frequent launch opportunities and demonstration of innovative ideas and higher-risk technologies outside of Earth Systematic class missions.

Earth Venture Class Missions include the following components:

- Earth Venture Suborbital (EVS) investigations support suborbital-science investigations. NASA releases EVS solicitations every four years and selects multiple investigations within each call, individually cost-capped at no more than $30 million.
- Small Earth Venture (S-EV)/Medium Earth Venture (M-EV)/Large Earth Venture (L-EV) are missions of opportunity that can be hosted on space-borne platforms, be small space-based missions, or will fly on-orbit demonstrations. The updated cadence of solicitations will begin in FY 2026 for every two years. The size of Earth Venture opportunities will vary and will be based on budget availability. The average costs for different Earth Venture Class are: $150 million for S-EV, $250 million for M-EV, and $300 million for L-EV. Costs are inclusive of Principal Investigators (PI)-managed mission cost, access to space, and accommodations.

VENTURE CLASS MISSIONS

EXPLANATION OF MAJOR CHANGES IN FY 2025

Earth Venture has renamed Earth Venture Instruments (EVI), Earth Venture Continuity (EVC), and Earth Venture Missions (EVM) to Small, Medium, and Large EVM. Consistent with the National Academy of Sciences, Engineering, and Medicine (NASEM) recommendation to "consider discontinuing the distinction between EV Mission and EV Instrument proposals," NASA updated the EV AO cadence to balance large, medium, and small (SmallSat/CubeSat) opportunities while keeping EV opportunities stable. The planned Earth Venture Announcement of Opportunity (AO) in 2026 will address the ACCP designated observables.

Program Element

VENTURE CLASS FUTURE MISSIONS

Earth Venture Class Future Mission funding supports the selection of new missions through AO solicitations at intervals of every two years for Small-EV, Medium-EV, and Large-EV, beginning in FY 2026. The planned Earth Venture AO in 2026 will address the ACCP designated observables. EVS maintains a four-year cadence for AO solicitations. The project also contains the budget for extended missions.

Planned Future Achievements

NASA is currently evaluating proposals for EVS-4 and expects selections in the winter of 2024.

NASA will conduct the next Senior Review in the Spring of 2026 to determine mission extensions for FY 2027 through FY 2029.

CYCLONE GLOBAL NAVIGATION SATELLITE SYSTEM (CYGNSS) (EVM-1, SELECTED IN 2012)

CYGNSS data enables scientists to probe from space key air-sea interaction processes that take place near the inner core of storms and play large roles in the genesis and intensification of hurricanes. The CYGNSS measurements provide information to the hurricane forecast community and seek to improve models to predict the strength of hurricanes as they develop. CYGNSS also makes measurements over land that scientists use to image flood inundation, wetland extent, and surface soil moisture.

CYGNSS's eight micro-satellite observatories receive both direct and reflected signals from Global Positioning System (GPS) satellites. The direct GPS signals pinpoint CYGNSS observatory positions and track fluctuations in GPS power, while the reflected signals are indicative of ocean surface roughness. Scientists use both measurements to derive the critical measurement of wind speed over ocean and water properties over land. CYGNSS launched in December 2016 and entered its extended mission phase in March 2019. The 2023 Senior Review for Operating Missions approved extended mission operations for CYGNSS through FY 2026.

Recent Achievements

The CYGNSS project developed a new version of an engineering data product which improved the science instrument calibration, resulting in more accurate windspeed measurements over oceans and more accurate soil moisture measurements over land.

The Rongowai-sustained airborne campaign in partnership with the New Zealand Space Agency supports validation of CYGNSS soil moisture and flood inundation products. Rongowai is an autonomous CYGNSS-like sensor installed on an Air New Zealand commercial aircraft which takes data continuously when airborne and provides extensive underflight validation of CYGNSS observations. A citizen science company which collected in-situ water samples during an 89-day South Indian Ocean passage from Australia to Africa is helping with validation of the CYGNSS ocean microplastic product. The CYGNSS project team are analyzing these water samples for surfactant concentration levels and will then compare those with CYGNSS observations.

Planned Future Achievements

The CYGNSS project will complete production of a near real-time version of its high wind speed data product and work with forecast personnel in the National Hurricane Center (NHC) and Joint Typhoon Warning Center (JTWC) operational centers to evaluate its use by them. Additionally, the CYGNSS project will support an Observing System Experiment conducted jointly by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and United Kingdom (UK) Met Office to assess the potential impact to their operational weather forecasting capabilities of assimilating ocean wind speed and soil moisture measurements made by CYGNSS and other, newer, missions which use the remote sensing technique pioneered by CYGNSS.

The budget request includes extended mission operations for CYGNSS through FY 2027.

TROPOSPHERIC EMISSIONS: MONITORING OF POLLUTION (TEMPO) (EVI-1, SELECTED IN 2012)

The TEMPO instrument measures atmospheric pollution covering most of North America. A commercial communications satellite, Intelsat-40e, hosts the instrument and launched in April 2023. On an hourly basis, TEMPO measures atmospheric pollution spanning from Mexico to Canada, and from the Atlantic Ocean to the Pacific Ocean. TEMPO provides measurements that include the key elements of air pollution chemistry (e.g., ozone, nitrogen dioxide) in the lowest part of the atmosphere. Measurements from geostationary orbit capture the inherent high variability in the daily cycle of emissions and chemistry. Measuring across both time and space creates a revolutionary dataset that provides understanding and improves prediction of air quality and climate forcing.

Maxar Technologies of Westminster, Colorado provided satellite integration, launch, and data transmission services for TEMPO.

Recent Achievements

In FY 2023, TEMPO successfully completed its Operational Readiness Review (ORR). TEMPO successfully launched on April 7, 2023. The TEMPO instrument completed first light on August 2, 2023, and NASA released the first public image on August 24, 2023.

Planned Future Achievements

In FY 2024, TEMPO will complete commissioning activities and begin normal operations.

VENTURE CLASS MISSIONS

ECOSYSTEM SPACEBORNE THERMAL RADIOMETER EXPERIMENT ON SPACE STATION (ECOSTRESS) (EVI-2, SELECTED IN 2014)

ECOSTRESS launched in June 2018 to help scientists observe changes in global vegetation from ISS. The sensors give scientists new ways to see how changes in climate or land use affect agriculture, forests, and ecosystems. ECOSTRESS uses a high-resolution thermal infrared radiometer to measure plant evapotranspiration, the loss of water from growing leaves, and evaporation from the soil. These data reveal how ecosystems change with climate and provide a critical link between the water cycle and effectiveness of plant growth, both naturally and agriculturally. ECOSTRESS began extended operations in August of 2019 and proposed to the 2020 Senior Review for extension through September 2023. NASA conducted an out-of-cycle Senior Review in December 2022 and approved ECOSTRESS to continue operations through September 2026 to align with the 2026 Senior Review. ISS extended site accommodations for ECOSTRESS through September 2028.

Recent Achievements

ECOSTRESS collected over 397,000 scenes (images that are 400 km by 400 km in size) and achieved an acquisition rate that is more than double the proposed acquisition rate. The data show variations in plant water use and plant stress over different regions, together with differences in plant water uptake over the daily cycle. Companies incorporated ECOSTRESS data into systems used by farmers to optimize irrigation schedules for crops throughout the world. Large cities, such as Los Angeles, are using ECOSTRESS data for heat island assessment and mitigation strategies, and scientists are using the data to study droughts throughout the world. A heat island is an urbanized area that experiences higher temperatures than outlying areas. Three new missions that are under development by NASA and other international space agencies, with planned launches towards the end of the decade, have all adopted the ECOSTRESS design.

Planned Future Achievements

The project will continue extended operations at least through the next Senior Review in September 2026. An expanded science team will use the ECOSTRESS data for a variety of studies in agriculture, forestry, geology, and the urban environment.

GLOBAL ECOSYSTEM DYNAMICS INVESTIGATION (GEDI) LIDAR (EVI-2, SELECTED IN 2014)

GEDI is a geodetic-class laser ranging system that provides three-dimensional measurements of the Earth's forests from ISS. GEDI measures the height of the Earth's temperate and tropical forests and their vertical structure. This data will help scientists determine, for the first time, how much carbon forests store as biomass, and the net impact of deforestation and subsequent regrowth on atmospheric carbon dioxide that results from human-influenced activities and climate variations. GEDI is the first mission optimized for vegetation measurements from space and provides the first global and transparently available data set that various U.S. agencies can use at relevant scales for both policy and land management.

Launched in December 2018, GEDI completed its prime mission in April 2021. NASA conducted an out-of-cycle Senior Review in December 2022 and approved GEDI to continue operations through September 2026 to align with the 2026 Senior Review. GEDI is currently temporarily stowed until Fall 2024 on an

ISS storage site while another mission operates at its location. Once reinstalled at its current location, NASA has requested site accommodations for GEDI through the end of life of the ISS.

Recent Achievements

GEDI has collected over 21 billion observations of the Earth's forests and topography through March 2023. The project continues to collaborate with DLR to fuse GEDI observations with the commercial archive of the DLR TanDEM-X radar satellites and has produced high resolution maps of height and biomass over Gabon, Mexico, Australia, the Amazon Basin, and parts of the United States. In 2023 alone, there have been six publications in Nature journals reflecting the enormous scientific impact of the GEDI data sets.

Future Achievements

The mission is currently in hibernation until Fall 2024, at which point it will be reinstalled and continue collecting data at least through the next Senior Review in 2026. During this hibernation period, GEDI is reprocessing its archive of data to provide more accurate estimates of canopy height, structure, biomass, and topography. GEDI is also producing a canopy structural complexity index that should be extraordinarily useful for habit and biodiversity studies; data products that blend observations from the ICESat-2 mission and GEDI; fusion of its data with those from TanDEM-X that goes beyond height to 3D canopy structure; and ecosystem modeling that predicts annual land surface carbon sources and sinks. GEDI is working closely with the U.S. Forest Service toward the use of GEDI data for wildfire prediction, habitat management, and other activities. Lastly, GEDI has had several meetings with the Association of Southeast Asian Nations (ASEAN) member countries in Southeast Asia, at the request of the U.S. State Department, on facilitating the use of NASA data in their national carbon accounting activities.

EARTH VENTURE MANAGEMENT

Earth Venture Management supports the development of AO solicitations and the technical, management, and cost evaluations of proposals received in response to the solicitations. The budget supports critical flight project management functions executed by the Earth System Science Pathfinder (ESSP) program office, and Senior Review Board teams, who conduct independent reviews of the ESSP flight projects. Additionally, this project supports the airborne assets that the EVS investigations rely on for their airborne campaigns, as well as large aircraft procurements.

Recent Achievements

SMD has purchased and begun modifications of the B777-200ER aircraft, to become the new large aircraft science platform for the directorate.

Planned Future Achievements

Science modifications for the large aircraft will continue in FY 2024 with an anticipated ready for science date in FY 2025.

MULTI-ANGLE IMAGER FOR AEROSOLS (MAIA) (EVI-3, SELECTED IN 2016)

The MAIA investigation will use a spaceborne multi-angle imager to remotely determine aerosol characteristics and assess linkages between different airborne particulate matter (PM) types and human health (including adverse birth outcomes, cardiovascular and respiratory disease, and premature death).

This project will measure concentrations of fine and coarse particles, sulfate, nitrate, organic and elemental carbon, and mineral dust particles in major urban areas around the globe at one-kilometer spatial resolution. The MAIA science team will use established epidemiological methodologies to associate human exposure to particulate matter with adverse health outcomes.

MAIA's primary spaceborne instrument consists of a specialized digital camera mounted on a two-axis gimbal on an LEO spacecraft, which will collect multi-angle spectropolarimetric imagery over a globally distributed set of major metropolitan areas. It will use this data in conjunction with surface-based pollution monitors and atmospheric models to map PM concentrations and types and conduct epidemiological studies. Surface-based PM monitoring equipment deployments, overseen by the MAIA project, include instruments that collect particles on filters for subsequent chemical and gravimetric analyses; aethalometers, which measure black carbon concentrations; low-cost PM sensors to extend spatial coverage in selected areas; and aerosol sunphotometers. MAIA's Instrument Operations and Science Data Systems will be located at JPL. The baseline (prime) mission is three years.

ASI will contribute a PLATiNO satellite to host the MAIA instrument. As an additional part of the partnership, ASI is also providing a launch vehicle for access to space along with part of the ground services to support MAIA during operations. Launch is currently planned for November 2025.

Recent Achievements

In FY 2023, NASA completed testing of the entire instrument and then placed the instrument into storage while the satellite development continues. Accommodations continue apace to ensure compatibility with the launch vehicle and to satisfy ASI-required spacecraft review requirements. The science team continues to prepare for operations by creating simulated Level 1 data products to ensure data product accuracy.

The project hosted a science team meeting with broad representation from all targeted areas, where the science team confirmed adjustments to the primary target areas and discussed further localized collaborative efforts around those target areas. NASA supported ASI in their spacecraft PDR.

The budget request includes funding for mission operations through FY 2029.

Planned Future Achievements

NASA plans to deliver the MAIA instrument to ASI in FY 2024 for integration onto the satellite where it will also undergo testing to ensure the system can withstand the launch and space environments.

The budget request includes funding for extended mission operations for MAIA.

TIME-RESOLVED OBSERVATIONS OF PRECIPITATION STRUCTURE AND STORM INTENSITY WITH A CONSTELLATION OF SMALLSATS (TROPICS) (EVI-3, SELECTED IN 2016)

TROPICS will make measurements over the tropical latitudes to observe the thermodynamics and precipitation structures of Tropical Cyclones (TCs), like hurricanes, over much of the storm systems' life cycles. TROPICS observations will include the temperature within the atmosphere, spatially and vertically resolved, as well as humidity, cloud ice, precipitation horizontal structure, and instantaneous surface rain rates. These measurements and the increased temporal resolution provided by the constellation are contributing to a better understanding of the TC life cycles and the environmental factors that affect the intensification of TCs. The TROPICS mission consists of five CubeSats, which will each have a cross-track scanning multiband passive microwave radiometer in an IU payload (IU, a CubeSat unit, is equivalent to a four-inch cubic box).

NASA pursues better understanding of basic storm processes where this improved knowledge will result in better weather modeling, which allows meteorologists to improve forecasts of storm tracks and intensity, ultimately enabling better warnings to the general population and more effective disaster management.

Recent Achievements

In FY 2022, TROPIC's commercial launch provider was unsuccessful in the first launch, resulting in the loss of the first pair of CubeSats. Recognizing the urgent science and application needs, NASA selected a new launch provider, Rocket Lab USA, Inc., and through two separate launches deployed the remaining four TROPICS constellation cubesats in FY 2023. NASA provided TROPICS imagery to both the National Hurricane Center and Joint Typhoon Warning Centers throughout the 2023 Atlantic Hurricane Season, aiding in the protection of life and property.

The TROPICS Pathfinder, a qualification unit launched in FY 2021, demonstrated the effectiveness of the end-to-end system identical to constellation. This satellite continues its risk reduction mission and provides daily global coverage.

Planned Future Achievements

The TROPICS Pathfinder will continue its risk reduction mission and TROPICS will continue their primary mission in FY 2024. TROPICS will conduct mission operations through FY 2026.

EARTH VENTURE SUBORBITAL-3 (EVS-3; SELECTED IN 2018)

In 2020, NASA initiated five investigations spanning a range of pressing research areas such as intense East Coast snowfall events and the impact of small-scale ocean currents on global climate. These investigations are:

- Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) studies the formation of snow bands in East Coast winter storms. Better understanding of the mechanisms of snow band formation and the factors that influence the location of the most intense snowfall will help improve forecasts of these extreme weather events.
- Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment (ACTIVATE) identifies how aerosol particles change cloud properties in ways that affect Earth's climate system. The investigation will focus on marine boundary layer clouds over the western North Atlantic Ocean that have a critical role in Earth's energy balance.
- Delta-X investigates the natural processes that maintain and build land in major river deltas threatened by rising seas. The project will improve models that predict loss of coastal land from sea level rise by improving estimates of how deltas add land, a process that involves trapping sediments and creating organic soils as plants grow.
- Dynamics and Chemistry of the Summer Stratosphere (DCOTSS) explores how strong summertime convective storms over North America can change the chemistry of the stratosphere. These storms regularly penetrate deep into the lower stratosphere, carrying pollutants that can change the chemical composition of this atmospheric layer, including ozone levels.

- Sub-Mesoscale Ocean Dynamics and Vertical Transport (S-MODE) examines the potentially large influence that small-scale ocean eddies have on the exchange of heat between the ocean and the atmosphere. The project will collect a benchmark data set of climate and biological variables in the upper ocean that influence this exchange.

Recent Achievements

During FY 2023, the EVS-3 investigations completed the deployment phase of their investigations. All the investigations are actively involved in data analysis and publication of their science research.

The IMPACTS investigation completed the deployment phase in FY 2023. During the three deployments, IMPACTS flew 240.6 flight hours on the NASA ER-2, and 272.3 flight hours on the NASA P-3, all for a total of 88 science research flights.

The S-MODE investigation completed the deployment phase in FY 2023. During the two deployments (and a pilot campaign), S-MODE flew 232.1 flight hours on the NASA B200, 60.5 flight hours on the NASA Gulfstream III (G-III), and ~140 flight hours on the TOI Twin Otter, all for a total of 95 science research flights. The science team on the research cruise, the Oceanus, collected 1,396 profiles of upper-ocean temperature, salinity, oxygen, and chlorophyll fluorescence.

Planned Future Achievements

With the completion of the deployment phases for the EVS-2 investigations, these investigations will focus on data analysis, archive, open data workshops and science team meetings. This is the last year that NASA will include EVS-3 investigations in the budget request.

EARTH SURFACE MINERAL DUST SOURCE INVESTIGATION (EMIT) (EVI-4; SELECTED IN 2018)

EMIT uses a sensor mounted to the exterior of ISS to map the mineral composition of regions that produce dust aerosols around the world. Scientists do not currently have a global inventory of the mineral sources of dust, and as a result, the global impacts of dust on atmospheric heating and cooling, weather, and other aspects of Earth's environment are not well established.

EMIT's hyperspectral instrument measures the different wavelengths of light emitted by minerals on the surface of deserts and other dust sources to determine their composition. By measuring in detail which minerals make up the dust, EMIT helps answer the critical question of whether mineral-based dust has a cooling or warming effect on the atmosphere. EMIT's modeling component uses the data collected to advance the understanding of the role of atmospheric dust in Earth's climate and better predict how it can change in the future. EMIT began its prime mission in October 2022 to obtain one year of global dust observations. At the end of its prime mission, the EMIT team will propose to an out-of-cycle Senior Review for mission extension through September 2026 to align with the 2026 Senior Review.

Recent Achievements

EMIT has demonstrated an important capability to measure methane and carbon dioxide point source emissions across six continents. Due to these valuable methane imaging results, NASA has requested, and the ISS program approved, EMIT site accommodations through the end of life of ISS. NASA has also identified additional value-added contributions from EMIT including mapping critical minerals, wildfire fuel, ecosystem properties, and water quality signatures.

The EMIT team began delivering data products to the NASA Land Processes Distributed Active Archive Center (LP DAAC) on February 2, 2023.

EMIT's accuracy and fidelity are state-of-the-art in Earth orbit and continue to meet or exceed the science requirements. EMIT maps the prevalence of key minerals in the planet's dust-producing deserts, information that will advance our understanding of airborne dust's effects on climate. Researchers are beginning to use the data available at the NASA LP DAAC to examine other properties of the Earth surface, including geology, ecology, snow properties and more.

EMIT has detected hundreds of "super-emitters" of methane in facilities, equipment, and other infrastructure which include the fossil-fuel, landfill/waste processing, or agriculture sectors that emit methane at high rates in Central Asia, the Middle East, and the Southwestern United States. Methane is a potent greenhouse gas, making early detection of these emissions important to slowing climate change. The EMIT team, in partnership with the LP DAAC, initiated data product deliveries for methane products on an extremely expedited timeline to support the broad scientific and public interest in these datasets, completing the process in under two months. This information is being made available in public NASA archives and through the U.S. Greenhouse Gas Center web portal.

Planned Future Achievements

EMIT will continue collecting data under the prime mission period until the end of November 2023 and then continue under extended operations for greenhouse gas emission detection and other observations that support NASA and our nation. EMIT will continue to expand its relevance by exploring the utility of its mineral maps for assessing risks to water quality from abandoned mines, as well as through assessing the ability to contribute to direct assessment of water quality issues associated with harmful algal blooms.

NASA approved the extended mission operations for EMIT through FY 2026.

POLAR RADIANT ENERGY IN THE FAR INFRARED EXPERIMENT (PREFIRE) (EVI-4; SELECTED IN 2018)

PREFIRE will fly miniaturized thermal spectrometers on a pair of small CubeSat satellites to measure far-infrared emissions and how they change throughout the day and over seasons. These CubeSats will orbit Earth's poles to probe a little-studied portion of the radiant energy emitted by Earth for clues about Arctic warming, sea-ice loss, and icesheet melting. These observations will allow scientists to assess how changes in thermal infrared emissions at the top of Earth's atmosphere are related to changes in cloud cover and surface conditions below, such as the amount of sea ice and meltwater on the surface of ice.

Recent Achievements

The PREFIRE project delivered the instruments to the CubeSat vendor for integration in early FY 2023. The project held a Pre-Ship Review for the CubeSats in April 2023. This review marked the delivery of one of the CubeSats from the vendor.

Planned Future Achievements

NASA will hold a second review for delivery of the final CubeSat from the vendor in FY 2024. The launches are planned for May 2024. This budget request supports mission operations for PREFIRE through FY 2025.

VENTURE CLASS MISSIONS

GEOSYNCHRONOUS LITTORAL IMAGING AND MONITORING RADIOMETER (GLIMR) (EVI-5; SELECTED IN 2019)

GLIMR will provide unique observations of ocean biology, chemistry, and ecology in the Gulf of Mexico, portions of the southeastern United States coastline, and the Amazon River plume where the waters of the Amazon River enter the Atlantic Ocean. It will closely monitor the health of the oceans and assess risks for coastal communities to protect our environment.

NASA will integrate GLIMR on a NASA-selected platform and launch into a geosynchronous orbit, where it will monitor a wide area centered on the Gulf of Mexico for up to 15 hours a day. From this vantage point, the hyperspectral ocean color radiometer will measure the reflectance of sunlight from optically complex coastal waters in narrow wavebands. GLIMR will gather observations of a given area each day in a way that would not be possible from a satellite in an LEO. These observations are a critical capability in studying phenomena such as the life cycle of coastal phytoplankton blooms and oil spills. GLIMR is a competitively selected, cost-capped, PI-led EVI development, with a cost cap of $107.9 million for the instrument and science investigation. The access to space solution for GLIMR is the responsibility of NASA and has not yet been determined. As an EVI development, GLIMR is a higher-risk innovative project intended to achieve cutting-edge science through strictly cost-capped implementation.

Recent Achievements

The GLIMR instrument team successfully completed their KDP-C review in March 2023, indicating that the project was sufficiently mature to begin final design and fabrication activities for the instrument alone.

This budget includes an updated cost and schedule for GLIMR instrument and science. NASA will establish the formal Agency Baseline Commitment for the GLIMR mission after finalizing the access to space cost range. The instrument team held their CDR in June 2023.

Planned Future Achievements

GLIMR will hold a review of instrument readiness no later than Q1 FY 2025 to inform approval of the initiation of access to space procurements, including spacecraft and spacecraft operations, associated ground systems, and launch vehicle.

LIBERA (EVC-1; SELECTED IN 2020)

Libera is NASA's first mission selected under the EVC element. The project, named for the daughter of Ceres in ancient Roman mythology, provides continuity of the Clouds and the Earth's Radiant Energy System (CERES) Earth Radiation Budget (ERB) observations. Its primary goal is to extend the ERB record seamlessly, which is essential for recognizing changes to Earth's climate system and for constraining future predictions. The project will deliver the Libera instrument in 2025 to NOAA for hosting on the JPSS satellite named NOAA-22, targeted for launch in 2027.

Recent Achievements

Libera held the CDR in June 2023. Libera is moving forward with build, assembly, and testing of the instrument components.

Planned Future Achievements

Libera will continue to work on building, assembling, and testing instrument components prior to holding a KDP-D review and delivering the instrument to NOAA-22 for integration in 2025.

INVESTIGATION OF CONVECTIVE UPDRAFTS (INCUS) (EVM-3, SELECTED IN 2021)

INCUS will study the behavior of tropical storms and thunderstorms, including their representation in weather and climate models, by directly addressing why convective storms, heavy precipitation, and clouds occur and exactly when and where they form. This investigation of the vertical transport of air and water will address objectives laid out in the 2017 Earth Science Decadal Survey and fills an important niche to help understand and better predict extreme weather and its impact on climate models, all of which serve to provide crucial information needed to mitigate weather and climate effects on our communities. INCUS means anvil in Latin and is a reference to the anvil-shaped cumulonimbus thunderstorm clouds it will study.

Recent Achievements

The INCUS mission successfully completed the system requirements review, mission definition review, and mission PDR in FY 2023.

Planned Future Achievements

INCUS will conduct a confirmation review in FY 2024 that will allow the project to begin final design and fabrication activities. Subsequent to the confirmation review, the mission CDR is also planned in FY 2024.

POLARIZED SUBMILLIMETER ICE-CLOUD RADIOMETER (POLSIR) (EVI-6, SELECTED IN 2023)

The PolSIR investigation will study and characterize the diurnal variability of tropical and sub-tropical ice clouds and will provide key observational constraints on ice properties in climate models to enable modelers to develop more accurate cloud parameterizations. These new observations will lead to reduced model uncertainty and increased fidelity of climate forecasts in support of critical climate change adaption decisions such as infrastructure development and hazard mitigation. The PolSIR project itself will consist of two CubeSats each equipped with a polarized submillimeter radiometer, that will fly in separate orbits to examine ice clouds and their microphysical properties in the sub-tropics and tropics.

Recent Achievements

NASA selected PolSIR in May 2023 from the competed EVI-6 AO and initiated formulation activities at the beginning of FY 2024.

Planned Future Achievements

In FY 2024, PolSIR will conduct the system requirements review, mission definition review, mission PDR, and confirmation review for authorization to proceed into implementation phase where the project will begin fabrication and assembly.

VENTURE CLASS MISSIONS

Program Schedule

Following the National Academies' recommendation, NASA is "discontinuing the distinction between EV Mission and EV Instrument proposals." In the schedule below NASA has marked those Earth Venture solicitations as simply "EVX" and will decide the size/type of the solicitation when it releases the AO. This will allow better tailoring to the needs of the division and available resources.

Date	Significant Event
FY 2024	PREFIRE CubeSat delivery
FY 2024	PREFIRE launch readiness
FY 2026	EVX-1 solicitation released
FY 2026	MAIA launch readiness
FY 2026	Libera instrument delivery
FY 2026	PolSIR instrument delivery
FY 2027	EVS-5 (suborbital) solicitation released
FY 2027	GLIMR instrument delivery
FY 2027	INCUS launch readiness
FY 2028	EVX-2 solicitation released
FY 2029	PolSIR launch readiness

Program Management & Commitments

The ESSP program at LaRC manages the Venture Class projects. The “Provider” in the following table lists the PI institution for each project.

Program Element	Provider
EVS-3: IMPACTS	Provider: University of Washington Lead Center: LaRC Performing Center(s): ARC, AFRC, GSFC Cost Share Partner(s): N/A
EVS-3: ACTIVATE	Provider: University of Arizona Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A
EVS-3: DCOTSS	Provider: Texas A&M University Lead Center: LaRC Performing Center(s): AFRC, ARC, GSFC Cost Share Partner(s): N/A

VENTURE CLASS MISSIONS

Program Element	Provider
EVS-3: S-MODE	Provider: Woods Hole Oceanographic Institute Lead Center: LaRC Performing Center(s): JPL, JSC Cost Share Partner(s): N/A
EVS-3: Delta-X	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
EVM-1: CYGNSS	Provider: University of Michigan Lead Center: LaRC Performing Center(s): N/A Cost Share Partner(s): N/A
EVM-3: INCUS	Provider: Colorado State University Lead Center: LaRC Performing Center(s): JPL Cost Share Partner(s): N/A
EVI-1: TEMPO	Provider: Smithsonian Astrophysical Observatory Lead Center: LaRC Performing Center(s): LaRC, GSFC Cost Share Partner(s): N/A
EVI-2: ECOSTRESS	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): USDA
EVI-2: GEDI	Provider: University of Maryland Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
EVI-3: TROPICS	Provider: MIT Lincoln Laboratory Lead Center: LaRC Performing Center(s): GSFC Cost Share Partner(s): N/A
EVI-3: MAIA	Provider: JPL Lead Center: LaRC Performing Center(s): JPL Cost Share Partner(s): ASI

VENTURE CLASS MISSIONS

Program Element	Provider
EVI-4: EMIT	Provider: JPL Lead Center: JPL Performing Center(s): GSFC, JPL Cost Share Partner(s): N/A
EVI-4: PREFIRE	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A
EVI-5: GLIMR	Provider: University of New Hampshire Lead Center: LaRC Performing Center(s): LaRC, GSFC Cost Share Partner(s): N/A
EVC-1: LIBERA	Provider: University of Colorado Laboratory for Atmospheric and Space Physics Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A
EVI-6: PolSIR	Provider: Vanderbilt University Lead Center: LaRC Performing Center(s): GSFC Cost Share Partner(s): N/A

Acquisition Strategy

NASA will issue Venture Class solicitations at intervals of every two years for EV missions and will decide the size/type of the solicitation when it releases the AO. NASA will select all Venture Class missions through full and open competition.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
CYGNSS	PI Institution: University of Michigan Instrument Provider: Southwest Research Institute Launch Vehicle Provider: NASA	PI: Ann Arbor, MI Instrument: San Antonio, TX Launch Vehicle: Cape Canaveral, FL
TEMPO	PI Institution: Smithsonian Astrophysical Observatory Instrument Provider: Ball Aerospace & Technologies Corp. Host Services Provider: Maxar Technologies	PI: Cambridge, MA Instrument: Boulder, CO Host Services: Westminster, CO

VENTURE CLASS MISSIONS

Element	Vendor	Location (of work performance)
GLIMR	PI Institution: University of New Hampshire Instrument provider: Raytheon Host Services Provider: TBD	PI: Durham, New Hampshire Instrument: El Segundo, CA Host Services: TBD
Libera	PI Institution: University of Colorado Laboratory for Atmospheric and Space Physics Instrument provider: LASP Host Services Provider: NOAA (NOAA-22)	PI: Boulder, CO Instrument: Boulder, CO Host Services: TBD
PolSIR	PI Institution: Vanderbilt University Instrument provider: NASA Host Services Provider: TBD	PI: Nashville, TN Instrument: Greenbelt, MD Host Services: TBD

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	SRB	Q2 FY 2023	TEMPO ORR	Successful
Performance	SRB	Q4 FY 2023	Libera CDR	Successful
Performance	SRB	Q4 FY 2023	INCUS PDR	Successful
Performance	SRB	Q1 FY 2024	GLIMR CDR	TBD
Performance	SRB	Q2 FY 2024	PREFIRE ORR	TBD
Performance	SRB	Q3 FY 2024	PolSIR PDR	TBD
Performance	SRB	Q1 FY 2025	GLIMR SIR	TBD
Performance	SRB	Q2 FY 2025	Libera SIR	TBD
Performance	SRB	Q3 FY 2026	INCUS ORR	TBD
Performance	SRB	Q3 FY 2027	PolSIR ORR	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
ESSP Missions Research	17.5	--	**25.3**	24.6	20.6	23.1	25.6
Orbiting Carbon Observatory-3	8.7	--	**7.2**	7.2	0.0	0.0	0.0
OCO-2	9.7	--	**9.2**	9.2	0.0	0.0	0.0
CloudSat	8.0	--	**4.4**	0.0	0.0	0.0	0.0
Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)	6.9	--	**5.3**	0.0	0.0	0.0	0.0
GeoCarb	20.0	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**70.9**	**--**	**51.3**	**41.0**	**20.6**	**23.1**	**25.6**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Earth System Science Pathfinder (ESSP) Other Missions and Data Analysis projects include operating missions and mission-specific research. These innovative missions will enhance understanding of the current state of the Earth system and enable continual improvement in the prediction of future changes.

Mission Planning and Other Projects

ESSP MISSIONS RESEARCH

ESSP Missions Research provides funds for the science teams supporting ESSP operating missions, and Principal Investigator-led Earth Venture-Instruments, operating onboard ISS. The science teams are comprised of competitively selected individual investigators who analyze data from the missions to address relevant science questions.

Recent Achievements

NASA scientists combined data from GPS and GRACE to infer changes in groundwater storage in the Central Valley as well as the Sacramento-San Joaquin-Tulare River basin, its source watershed. They found that from 2006 to 2021 the Central Valley has been losing an average 2.2 km3 per year (0.6 giga-gallons) with two-thirds of the groundwater loss concentrated in the southern third of the valley. This study is impactful in that it provides a quantitative value for changes in total water storage in this area. Additionally, the scientists inferred changes in bedrock groundwater by removing signals from snow water and soil moisture by creating a composite model using GPS and GRACE data.

Researchers studying extreme water events applied a novel approach with terrestrial water storage observations from the GRACE and GRACE-FO satellites to delineate and characterize 1,056 extreme events (i.e., droughts and floods) from 2002 to 2021. They found that the largest event identified was an ongoing pluvial (i.e., heavy rain flooding) that began in 2019 and engulfed central Africa. The magnitude was such that Lake Victoria rose over one meter, with flooding in the surrounding region. The second largest event was a 2018-2021 pluvial over central and eastern North America. The third largest event was a 2011-2012 Australian pluvial that ended the Millennium Drought and even caused sea level to decline for a brief period. They found the intensity of extreme water events was strongly correlated to high terrestrial soil temperatures, suggesting that continued warming will cause more frequent, more severe, longer and/or larger droughts and pluvials (i.e., floods).

Scientists used column carbon dioxide (CO_2) observations from OCO-2 and OCO-3 missions on 10 occasions from March 2017 to June 2022 to quantify CO_2 emissions from Europe's largest fossil fuel power plant, the Bełchatów Power Station in Poland. They found that the space-based CO_2 emission changes with a trend that is consistent with the independently reported hourly power generation trend that results from both permanent and temporary unit shutdowns. OCO-2 and OCO-3 emission estimates agree with the bottom-up emission estimates for nine of the 10 occasions. These results demonstrate the ability of the OCO-2 and OCO-3 missions to quantify emission reductions for a large facility and their ability to quantify short-term emission changes.

Operating Missions

OCO-3

OCO-3, which launched in May 2019, is a complete stand-alone payload, built using the spare OCO-2 flight instrument, with additional elements added to accommodate installation and operation on ISS. The OCO-3 instrument consists of three high-resolution grating spectrometers that collect space-based measurements of atmospheric carbon dioxide with the precision, resolution, and coverage needed to assess the spatial and temporal variability of carbon dioxide over an annual cycle.

OCO-3 started extended operations in September 2022. NASA conducted an out-of-cycle Senior Review in December 2022 and approved OCO-3 to continue operations through its next Senior Review in 2026. ISS is temporarily stowing OCO-3 for about six months on an ISS storage site, while another mission operates at its location. Once reinstalled at its current location in approximately May 2024, NASA has requested OCO-3 site accommodations through the end of life of ISS.

Recent Achievements

The OCO-3 mission completed four-and-a-half years of successful operations on ISS. The data products consist of atmospheric carbon dioxide measurements that are complementary to the OCO-2 mission, spanning latitudes from 52 degrees North to 52 degrees South. Researchers have used this data to detect changes in emissions that are occurring due to drastic societal shifts in urban/industrialized areas and capture emissions from sectors, such as on-road, off-road transportation, power generation, and heavy industry. The OCO-3 mission continues to provide a solar-induced chlorophyll fluorescence (SIF) data product. SIF is a measure of photosynthesis activity, an indicator of plant health, and particularly valuable for farmers and agricultural communities. Researchers published several articles that OCO-3 data can provide sectoral information (CO_2 from industry vs. transportation, for example) within cities, which can eventually provide actionable data for city administrators to use to develop targeted greenhouse gas policies. OCO-3 data are not only serving the needs of scientists and researchers, but also supporting the science applications community and organizations like the World Bank Group and the C40 Cities Climate Leadership Group.

OCO-2

OCO-2 launched in July 2014 and collects precise CO_2 measurements across the globe every day from its vantage point in LEO. OCO-2 also collects measurements of SIF, a proxy for plant photosynthesis, which provides additional information on the uptake of carbon dioxide by plants. Data scientists are gaining greater insight into how much CO_2 the Earth emits by natural sources and human activities, and the natural process for removing CO_2 from the atmosphere. This information may help decision makers manage CO_2 emissions and reduce the human impact on the environment.

The OCO-2 instrument has collected almost one million soundings globally each day since September 2014. OCO-2 is currently in extended mission operations. The 2023 Senior Review for Operating Missions approved extended mission operations for OCO-2 through FY 2026.

Recent Achievements

OCO-2 has created a high-quality record of the changes in the global distribution of carbon dioxide and SIF across seasons and through various global and regional climate changes such as El Niño and La Niña cycles. Scientists use the data to study the response of the natural carbon cycle to these changes, as well as extreme regional events including droughts, floods, and wildfires. On regional scales, these studies show large year-to-year variability in the land biospheric-carbon sink in the tropics and a strong land-carbon sink at mid-to-high latitudes. At high northern latitudes, OCO-2 data have shown strong responses of the carbon cycle to climate change, including shifts in the timing and magnitude of summer carbon uptake and fall carbon release. OCO-2 observations also quantify carbon dioxide emissions from human activities including large power plants and urban centers. Respected, peer reviewed journals continue to publish these science findings and contribute to national and international assessment studies. The continued nominal performance and operations of the spacecraft and instrument facilitated the long-term record of CO_2 observations. In addition, the project has taken advantage of new opportunities to use small-scale ground networks and airborne observation to validate the OCO-2 products in key regions where traditional validation measurements are sparse, such as tropical Africa. OCO-2 measurements provide a unique contribution to U.S. and international needs for a greenhouse gas observing network to enhance scientific understanding, inform climate mitigation efforts, and assess mitigation goals. Intercomparisons have demonstrated good agreement between datasets from OCO-2 and OCO-3.

CLOUDSAT

CloudSat, launched in April 2006, measures cloud characteristics to increase understanding of the role of clouds in Earth's radiation budget. This mission provides estimates of the percentage of Earth's clouds that produce rain, provides vertically resolved estimates of how much water and ice are in Earth's clouds, and estimates how efficiently the atmosphere produces rain from clouds. CloudSat collects information about the vertical structure of clouds and aerosols that other Earth-observing satellites do not collect. This data improves models and provides a better understanding of the human impact on the atmosphere.

CloudSat is currently in mission close-out (Phase F).

Recent Achievements

During the past year, international and other agency operational systems continued to adopt CloudSat observations. Now part of the European Centre for Medium Range Weather Forecasts forecast system, CloudSat shows positive impacts to both the analysis fit of other observations and to the subsequent forecast skill of the forecast system. The science community continues to use CloudSat data in formulating important improvements to the operational cloud layer height algorithms used by weather forecasters and derived from the Advanced Baseline Imager on the Geostationary Operational Environmental Satellites. CloudSat also provides critical verification data for global snowfall products produced by NASA's Global Precipitation Measurement (GPM) mission. The project exploits synergies with other NASA missions beyond GPM, as highlighted by the recently released cloud product that combines Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) and the OCO-2 data with CloudSat. CloudSat has also been foundational to the Earth Cloud, Aerosol and Radiation Explorer (EarthCARE) mission launching in 2024, and data products from CloudSat will link to EarthCARE products to produce a new climate data record.

During this past year, analysis of CloudSat data has served as the basis for i) calibrating cloud profile information derived from operational sensors for use in aviation forecasts, ii) improving hurricane intensification forecasts specifically through the use of CloudSat ice measurements and its impacts on the hurricane environment, iii) the creation of a climate data record that is showing statistically significant changes in cloud heights over the multi-decadal record, as well as iv) providing essential information and clarity on aerosol-cloud interactions that remain a major source of uncertainty in the projected climate warmings. CloudSat observations of lighter rains and snow at higher latitudes continue to be a vital measurement, especially because no other observing system reproduces this information. CloudSat observations of rain and snow not only underpin research that concerns the hydrological cycle and how it is changing, particularly in middle and higher latitudes, but also water resource applications centered around snow melt as its source. These and previously reported examples demonstrate the continued wide utility of CloudSat to the applications and science communities. This is the last year NASA will include this mission in its budget because the mission is in the decommissioning and closeout phase.

CLOUD-AEROSOL LIDAR AND INFRARED PATHFINDER SATELLITE OBSERVATION (CALIPSO)

The CALIPSO mission, launched in April 2006, provides the first comprehensive three-dimensional measurement record of aerosols, helping to better understand how aerosols form, evolve, and transport over the globe. The mission provides data on the vertical structure of clouds and the geographic and vertical distribution of aerosols, and further detects sub-visible clouds in the upper troposphere. CALIPSO also indirectly estimates the contribution of clouds and aerosols to atmospheric temperature.

In late FY 2023, the spacecraft's orbital drift reached a point where it can no longer generate enough power to continue to operate the instrument. The mission started decommissioning activities for the spacecraft and instrument. CALIPSO is currently in mission close-out (Phase F).

Recent Achievements

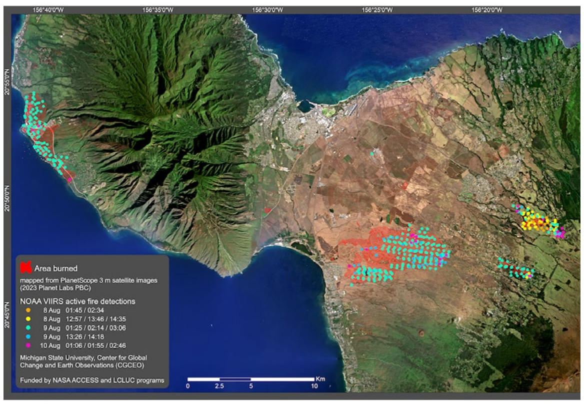
CALIPSO continued to provide unique vertical profile observations of clouds and atmospheric particle (aerosol) layers over the globe. During FY 2023, the mission released two new major versions of existing lidar data products, which include several enhancements that will contribute to a better understanding of aerosol optical properties and their contributions to the Earth's radiation budget. In addition, the project also released an updated polar stratospheric cloud product, providing better insights on the composition, formation, and impact of these phenonium on the ozone layer. The mission completed its science phase in August after more than 16 years of successful operations. This is the last year NASA will include this mission in its budget request because the mission is in the decommissioning and closeout phase.

EARTH SCIENCE DATA SYSTEMS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**291.1**	**--**	**263.2**	**257.6**	**268.3**	**269.8**	**276.3**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



This image of Maui, Hawaii, showing fire development and movement between August 8 and 10, 2023, was created through the application of artificial intelligence (AI) to high-resolution commercial satellite data overlain with data from NASA's Fire Information for Resource Management System. The resulting three meter resolution imagery enables scientists, managers, and local governments to better assess post-fire impacts, study burned areas, and help plan mitigation efforts.

The Earth Science Data Systems (ESDS) program oversees the lifecycle of Earth science data with the principal goal of maximizing the scientific return from NASA's missions and experiments for research and applied scientists, decision-makers, and the nation.

ESDS acquires, processes, preserves, and distributes observational Earth science data from spacecraft, aircraft, and in-situ sensors to support Earth Science research focus areas. The ESDS program primarily accomplishes this via the Earth Observing System Data and Information System (EOSDIS), which has been in operation since 1994.

EOSDIS has continuously evolved to take advantage of improved technology to meet the increasing demands of data providers and users. Following the addition of data from several new missions, NASA expects the EOSDIS data archives to grow substantially in size between 2023 and 2029, from its current size of 96 petabytes (PB) to approximately 600 PB in 2029.

EOSDIS has a history of actively evolving its capabilities through communication with users, rapid adoption of new technologies, and by supporting competitive research elements within the Data System Evolution (DSE) component of the program. These activities ensure effective prioritization of investments to manage user needs, while simultaneously identifying new technologies to improve the preservation of, and access to, the diverse and valuable data NASA collects.

EXPLANATION OF MAJOR CHANGES IN FY 2025

This budget transfers several components of the ESDS program to the new Earth Science Program, Responsive Science Initiatives: The Commercial SmallSat Data Acquisition (CSDA) project (renamed Commercial Satellite Data Acquisition), responsible for identifying, evaluating, and acquiring data from commercial sources that support NASA's Earth science research and application goals; and the Satellite Needs Working Group (SNWG), renamed Interagency Satellite Observations Needs, previously funded within the DSE project in ESDS.

EARTH SCIENCE DATA SYSTEMS

The Open Source Science project is transferred to the Planetary Science division starting in FY 2024, per notification in the 2023 Congressional operating plan. This request also proposes reductions to the ESDIS project in order to migrate existing ESDIS capabilities into the Open Source Science project so that those capabilities can be leveraged across SMD.

ACHIEVEMENTS IN FY 2023

EOSDIS archives grew to over 96 PB in FY 2023, with 44.23 PB in the commercial cloud, and distributed 2.6 billion data files to 2.8 million users worldwide. In five years, the amount of data archived grew 249 percent with the system stewarding over 15,000 data products and growing by approximately 61 TB daily. EOSDIS serves over 1.4 million registered users; a 40 percent increase over FY 2022. The EOSDIS Common Metadata Repository (CMR) data catalog contains approximately 1.4 billion data files, allowing users to search through over 59,000 NASA and partner data collections in under one second.

Planned growth of data ingest rates and archive volumes in support of new NASA missions poses challenges for managing data in cloud and backup systems. ESDS assessed cloud archive practices, data governance, and usage patterns, and continues to invest in developing future-focused architectures to meet processing needs and increase efficiency.

The NASA Sentinel Gateway continued to serve data from the ESA partnership, averaging 60 TB per week from ESA to EOSDIS. During FY 2023, NASA distributed over 220 million data files from Sentinel missions. Additionally, the team accesses Sentinel-3 near real-time data products in support of its Land, Atmosphere Near real-time Capability for EOS (LANCE) system, specifically targeting communities using the Fire Information and Resource Management System.

ESDS played a significant role in creating the Earth Information Center, developing dynamic data visualization components and completing significant development for the U.S. Greenhouse Gas Center.

ESDS published a new Geographic Information System (GIS) Portal, improving user experience and enhancing resource discovery while leveraging commonly used GIS community platforms.

The SNWG Management Office led NASA's review of over 100 surveys from 25 agencies. The SNWG is instrumental in identifying and implementing new data products, including the Harmonized Landsat Sentinel-2 (HLS) product developed by ESDS, one of the most popular NASA data sets with a total archive of five PB.

In FY 2023 ESDS partnered with commercial, interagency, and international partners to develop the HLS Geospatial Foundation Model, a first of its kind AI tool with wide-ranging potential applications, including tracking land use changes, monitoring natural disasters, and predicting crop yields.

The largest uncertainty in future projections of sea level change comes from the response of the Antarctic Ice Sheet to the warming oceans and atmosphere. Numerous studies show the ice sheet is out of long-term equilibrium and losing mass at an accelerated rate, increasing sea level rise. The longest observational record available to study the mass balance of the Earth's ice sheets comes from disparate satellite altimetry missions. Measurements must be cross-calibrated and integrated into a consistent record of change. Scientists presented an intuitive approach, applying improved topography removal, cross-calibration, and normalization of seasonal amplitudes from different missions to derive elevation change estimates. They processed the full archive record of satellite altimetry data, providing a seamless record of elevation change for the Antarctic Ice Sheet that spans the period 1985 to 2020, and produced and distributed the data as part of the NASA MEaSUREs ITS_LIVE project.

EARTH SCIENCE DATA SYSTEMS

WORK IN PROGRESS IN FY 2024

Several new missions will deliver data in FY 2024, with the launch of PACE and the planned launch of NISAR. The NISAR mission will produce over 27 PB of synthetic aperture radar data per year. ESDS will maintain its focus on open-source, cloud-native software and data services, responsive to user needs. The program will continue to develop and enable standardized and optimized tools that work across diverse operational and heritage Earth data, with a continued migration of datasets and services into the commercial cloud.

In the coming year, the CSDA (moving to RSI) program will continue to rely on ESDS to implement long-term data preservation processes for commercial data acquired by NASA, ingesting, archiving, cataloging, and distributing the purchased data and making it discoverable using standard search interfaces.

Similarly, the SNWG (also moving to RSI) will depend on ESDS for data development and stewardship activities and will work closely with stakeholder engagement personnel and programs to ensure developed products are communicated and adopted.

With the announcement of the ESO, the ESDS program engaged the missions to identify and assess potential architectures that can meet the ESO mission science processing objectives, enable data system efficiencies, promote open science principles, and enhance Earth system science. ESDS will continue its investigations in developing future-focused architectures to meet mission science processing needs, increase efficiency, and embrace open science practices through its ongoing Multi-Mission Data Processing System Study.

ESDS will release a solicitation for the Citizen Science for Earth Systems Program (CSESP) element. This activity will focus on developing and implementing projects that harness contributions from members of the public to advance our understanding of the Earth as a system.

While investing in future mission processing systems, ESDS is also taking a forward-looking approach to its user support as well. ESDA will conduct a study and begin prototypes to re-orient the EOSDIS Distributed Active Archive Centers (DAACs) to efficiently cater to NASA's growing influx of data and software and its expanding and evolving user community. This study will pave the way for ESDS to expand its focus to support both foundational research, and applications of that research.

ESDS will expand and deepen its partnerships with external organizations to strengthen its capabilities in AIML by exploring public-private partnerships to address data discoveries and access challenges, by collaborating to develop a foundation model for weather and climate applications and developing a large language model in collaboration with other science divisions to enhance scientific discovery.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

ESDS will expand its capabilities to support efficient technology infusion and streamline current data management processes and service functions, including the assessment of an enterprise ingest and archive architecture.

ESDS data systems will also evolve to support open science policies and initiatives to ensure accessibility and reproducibility of NASA funded data. In addition, ESDS will prepare for the final mission data processing and preservation of artifacts from the Aura mission.

EARTH SCIENCE DATA SYSTEMS

ESDS will continue to support the partnerships established through the non-reimbursable Space Act Agreements with commercial vendors.

ESDS will continue to work as a liaison between different NASA science divisions to support AI and ML adoption. The team will also develop generalizable ML pipelines for rapid prototyping of science problems. ESDIS will begin a significant transition from DAACs to Science Enabling Centers.

Program Elements

EARTH SCIENCE DATA AND INFORMATION SYSTEM (ESDIS)

The ESDIS project manages the geographically distributed science systems of EOSDIS, including DAACs, Science Investigator-led Processing Systems (SIPS), LANCE, and core systems. Together, these systems support the processing of satellite data and seamless interdisciplinary access to EOSDIS data, including data products, data services, and data handling tools for a broad range of user communities that include scientists, government agencies, commercial users, and the public.

- SIPS generate high-quality science products from Terra, Aqua, Aura, S-NPP, and JPSS missions at facilities under the direct control of the instrument principal investigators and team leaders. Products produced at SIPS undergo extensive quality assurance before the program transfers them to DAACs for archiving and distribution to users.
- DAACs archive, document, and distribute data and provide user support for NASA's past and current Earth-observing satellites: Sentinel's 1, 3, 5P, and 6 satellites; airborne investigations; and field measurement programs. Acting in concert, the DAACs provide reliable, robust services to users whose needs may cross the traditional boundaries of a science discipline, while continuing to support the unique needs of users within specific science discipline communities. The DAAC facilities, hosted at NASA or other institutions, each specialize in a science discipline (i.e., atmosphere, calibrated radiance, solar radiance, cryosphere, human dimensions, land, or ocean science).
- LANCE generates and provides access to near real-time products from the Atmospheric Infrared Sounder, Advanced Microwave Scanning Radiometer 2, Microwave Limb Sounder, Moderate Resolution Imaging Spectroradiometer, Measurement of Pollution in the Troposphere, Ozone Monitoring Instrument, Ozone Mapping Profiler Suite, and Visible Infrared Imaging Radiometer Suite (VIIRS) (VIIRS-Land and VIIRS Atmosphere) instruments. LANCE provides the data within three hours of observation. The data supports NASA applications users who are interested in monitoring and analyzing a wide variety of natural and man-made phenomena.

The EOSDIS system supports several core systems to provide a common entry point to discover, access, and visualize data from the distributed DAACs and SIPS. The program developed core systems to reduce duplication and improve user access to EOSDIS data, including:

- CMR, which is a high-performance, high-quality, continuously evolving metadata system that catalogs all data and service metadata records for EOSDIS and is the authoritative management system for all EOSDIS metadata.
- Global Imagery Browse Services (GIBS), which provides visual representations of NASA Earth science data at full resolution in a free, open, and interoperable manner. Through responsive and highly available Web services, it enables interactive exploration of data to support a wide range of

applications, including scientific research, applied sciences, natural hazard monitoring, and outreach. GIBS provides much of the LANCE near real-time imagery, as well as present-day and historical imagery.

- NASA-compliant General Application Platform, which is a cloud-based platform that provides a scalable and flexible application platform solution that offers the cost benefits of hardware consolidation with the safety and security of application sandboxing and resource management.
- Cumulus, which is a cloud optimized software package for performing Earth science data ingest, archive, and distribution capabilities to support all EOSDIS missions.
- Earth Observing System Networks, which provides effective access to EOSDIS. They depend on end-to-end network connectivity between users and geographically distributed DAACs. The NASA Earthdata website integrates information from across EOSDIS. Earthdata is the entry point for EOSDIS data, articles, documentation, and collaboration. It leverages CMR to provide comprehensive search capabilities. Earthdata offers new and experienced users an organized view of EOSDIS resources and the latest events.
- The NASA Sentinel Gateway, which transfers data from a dedicated interface to the European Commission's Copernicus Programme Sentinel 1, 3, and 5P satellite ground system. The Sentinel Gateway transfers data from the Sentinel satellites to DAACs for archival and distribution to users.

For more information, see https://earthdata.nasa.gov.

DATA SYSTEM EVOLUTION (DSE)

The Data System Evolution project funds research opportunities, interagency initiatives, and promotion of data and service interoperability through the development and implementation of standards. DSE is composed of one competitive component, CSESP, and supports the Interagency Implementation and Advanced Concepts Team (IMPACT) activity, which is responsible for the development of long-term data records needed by NASA scientists. CSESP consists of two elements: the collection and analysis of data by citizen scientists across all Earth Science focus areas, and technological development and production of low-cost sensors for measurement and monitoring. NASA solicits proposals in this competitive program element every three years.

IMPACT works with other government agencies to increase the use of NASA Earth observations. This team assesses, independently evaluates, and makes recommendations to improve EOSDIS services and processes; manages archiving of airborne science observations; and develops proof of concept data system capabilities. NASA continues to design and implement a common system to host greenhouse gas monitoring measurements from a variety of data sources.

DSE activities support the widespread use of NASA Earth science observations through the development and implementation of standards, collaborations with other space agencies, and by leading activities to improve the discoverability of NASA data.

EARTH SCIENCE DATA SYSTEMS

MAKING EARTH SYSTEM DATA RECORDS FOR USE IN RESEARCH ENVIRONMENTS (MEASUREs)

The overall objective of MEaSUREs is to provide Earth science higher-level data products and services driven by NASA's Earth science goals. These data products, called Earth Science Data Records, are critical for understanding Earth System processes; assessing variability, long-term trends, and changes in the Earth System; and providing input and validation means to modeling efforts. MEaSUREs is a competitive program element solicited every five years.

MEaSUREs emphasizes linking together multiple satellites into a constellation, developing the means of utilizing a multitude of data sources to form a coherent time series, and facilitating the use of NASA's extensive data in the development of comprehensive Earth system models. In addition, MEaSUREs activities include infusion or deployment of applicable science tools that contribute to data product quality improvement, consistency, merging or fusion, or understanding.

Program Schedule

The ESDS program solicits research opportunities approximately every three years for ACCESS and every five years for MEaSUREs. The ESDIS project continuously delivers software to improve functionality and improve efficiency.

Date	Significant Event
Q2 FY 2024	ROSES CSESP Solicitation Released
Q1 FY 2026	ROSES CSESP Solicitation Released
Q2 FY 2027	ROSES MEaSUREs Solicitation Released
Q2 FY 2028	ROSES MEaSUREs Solicitation Released
Q2 FY 2029	ROSES CSESP Solicitation Released
Q2 FY 2029	ROSES MEaSUREs Solicitation Released

EARTH SCIENCE DATA SYSTEMS

Program Management & Commitments

The ESM program at GSFC provides program management for the ESDIS project. NASA HQ manages the DSE and MEaSUREs projects.

Program Element	Provider
EOSDIS core system	Provider: Various Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Alaska Synthetic Aperture Radar Facility Distributed Active Archive Center (DAAC) (Fairbanks, AK)	Provider: University of Alaska Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Atmospheric Science Data Center (Hampton, VA)	Provider: LaRC Lead Center: LaRC Performing Center(s): LaRC Cost Share Partner(s): N/A
Goddard Earth Science Data and Information System Center (Greenbelt, MD)	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Land Processes Data Center (Sioux Falls, SD)	Provider: U.S. Geological Service (USGS) Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
National Snow and Ice Data Center (NSIDS) (Boulder, CO)	Provider: University of Colorado Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Oak Ridge National Laboratory DAAC (Oak Ridge, TN)	Provider: Oak Ridge National Laboratory Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Physical Oceanography DAAC (Pasadena, CA)	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A

Earth Science Data Systems

Program Element	Provider
Socio-economic Data and Applications Center (SEDAC) (Palisades, NY)	Provider: Columbia University Lead Center: N/A Performing Center(s): N/A Cost Share Partner(s): N/A
Crustal Dynamics Data Information System (Greenbelt, MD)	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
Global Hydrology Research Center (Huntsville, AL)	Provider: University of Alabama Lead Center: MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A
Interagency Implementation and Advance Concepts Team (Huntsville, AL)	Provider: MSFC Lead Center: MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A

Acquisition Strategy

Research opportunities within DSE are available through NASA's ROSES announcements. NASA competitively selects ESDIS support contracts through full and open competition.

Major Contracts/Awards

Element	Vendor	Location (of work performance)
EOSDIS Evolution & Development	Raytheon	Riverdale, MD
NSIDC	University of Colorado	Boulder, CO
Alaska SAR Facility	University of Alaska	Fairbanks, AK
SEDAC	Columbia University	Palisades, NY

EARTH SCIENCE DATA SYSTEMS

INDEPENDENT REVIEWS

The American Customer Satisfaction Index (ACSI) measures customer satisfaction with the NASA EOSDIS at a national level for each DAAC on an annual basis. NASA EOSDIS scored a 79 on the ACSI survey in 2022. It also identifies the key areas that NASA can leverage across its DAACs to continuously improve its service to its customers.

Review Type	Performer	Date of Review	Purpose	Outcome
Quality	ACSI	2023	Survey current EOSDIS users to assess satisfaction with current services	Pending Release
Performance	Earth Science Advisory Committee	2023	Annual review to assess progress against Earth Science performance goals and overarching strategic objective	The program fully met expectations for the research program
Quality	ACSI	2024	Annual survey of EOSDIS users to assess satisfaction with services	TBD
Quality	ACSI	2025	Annual survey of EOSDIS users to assess satisfaction with services	TBD

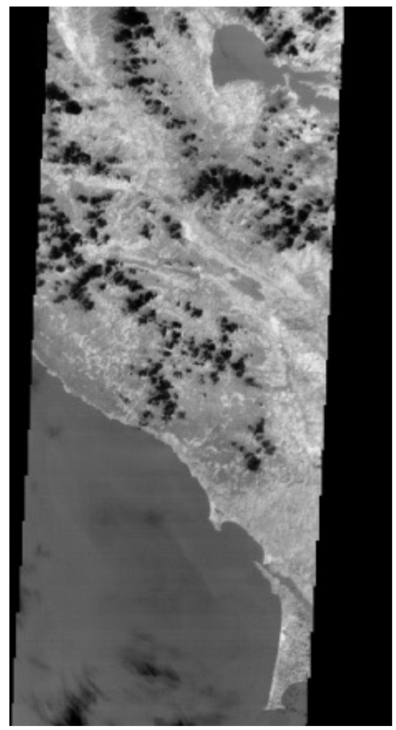
EARTH SCIENCE TECHNOLOGY

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	102.2	--	147.2	109.4	110.6	111.8	113.0

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Advanced technology plays a major role in enabling Earth science research and applications. The Earth Science Technology Program (ESTP) enables previously infeasible science investigations, improves existing measurement capabilities, and reduces the cost, risk, and/or development times for Earth science instruments and information systems.



The ESTP's Multiband Uncooled Radiometer Imager (MURI) instrument was launched by the SpaceX Transporter 6 on January 3, 2023, as one of several hosted payloads within the Loft Orbital YAM5 SmallSat. MURI is testing a new two-band longwave infrared (10.8um and 12.0um) radiometric imager that utilizes an uncooled focal plane array, which does not require a bulky, heavy cryogenic cooler. Above is an image from MURI on July 8, 2023, showing a portion of the Los Angeles basin in California. (Credit: Leonardo DRS)

EXPLANATION OF MAJOR CHANGES IN FY 2025

The request includes $40 million in FY 2025 to begin work to develop the first space-borne gravity gradiometer. This new technology will make use of atomic interferometry to measure gravity with unprecedented sensitivity and has the potential to both continue the measurements made by NASA's Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On missions while substantially improving gravity measurements to address new and critically important science questions.

ACHIEVEMENTS IN FY 2023

ESTP executed 175 active tasks in 2023, awarded to a variety of institutions including NASA centers, industry, and academia as well as other government agencies, Federally Funded Research and Development Centers, and nonprofit organizations. Within the portfolio, 31 percent of the tasks advanced at least one Technology Readiness Level (TRL) and at least 10 tasks advanced more than one TRL. Historically, student participation in ESTP tasks has been substantial, with a cumulative total of at least 1,179 students from 171 institutions participating in the program. 157 students from 48 institutions participated in technology development efforts in FY 2023.

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The ESTP infused at least 18 tasks into science measurements, airborne campaigns, data systems, or other operational activities during the year. For example, in Spring 2023 NASA deployed two new atmospheric radar instruments, CloudCube and the Vapor In-Cloud Profile Radar (VIPR), to the Scripps Pier in La Jolla, CA, to support the DoE’s Eastern Pacific Cloud Aerosol Precipitation Experiment (EPCAPE). A year-long, campaign, EPCAPE seeks to characterize the cloud cover, cloud thickness, cloud altitude, radiative properties, aerosol interactions, and precipitation of stratocumulus clouds in the eastern Pacific. VIPR, a 2016 Instrument Incubator Program (IIP) investment, is obtaining humidity profiling inside of clouds, as well as precipitation with high vertical resolution. CloudCube, a 2019 IIP award, is measuring the vertical profile of clouds and precipitation, as well as Doppler velocities.

In another example of technology infusion, the real-time radio frequency interference processing demonstrated by ESTP's CubeSat Radiometer Radio Frequency Interference Technology (CubeRRT) validation project is being applied to two ESA missions: The Copernicus Imaging Microwave Radiometer (CIMR) mission, which will carry a wide-swath conically-scanning multi-frequency microwave radiometer to provide observations of sea-surface temperature, sea-ice concentration and sea-surface salinity; and the Meteorological Operational series of satellites, which provides weather data services.

As a final example, the program is transitioning the Ecological Spectral Information System, a set of open-source software tools and data-derived spectral models developed under ESTP's Advanced Information Systems Technology (AIST) project, to operational use at the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC). ORNL DAAC, one of several NASA data archives, specializes in terrestrial biogeochemistry, ecology, and environmental processes.

In January 2023, the ESTP also successfully launched a technology demonstration, the MURI instrument, as a hosted payload on the Loft Orbital YAM5 SmallSat. This technology will enable future low-cost instruments for thermal imaging of Earth.

WORK IN PROGRESS IN FY 2024

ESTP will continue ongoing technology tasks and fund new ones under solicitations that will be issued during the fiscal year. Awards will continue to reflect the full breadth of NASA Earth science needs, while also supporting the NASA Wildland FireSense, Earth Information Center (EIC), and Greenhouse Gas (GHG) efforts and initiating the Quantum Gravity Gradiometer.

ESTP's FireSense Technology element, which is part of the NASA Wildland FireSense effort, released a second solicitation in late FY 2023 and expects to make selections in mid-FY 2024. The FY 2023 solicitation included the leveraging of existing commercial capabilities, particularly in low-cost, scalable, infrared sensing. NASA released a solicitation for the In Space Validation of Earth Science Technologies (InVEST) element in late FY 2023. Those awards, which will aim to validate emerging technologies on orbit, are expected in FY 2024.

ESTP plans to solicit proposals for the IIP element, the AIST program element, and the Decadal Survey Incubation (DSI) program elements, with awards expected in late FY 2024 or early FY 2025.

ESTP has two upcoming space validation launches for FY 2024, both tentatively scheduled for March 2024: the Hyperspectral Thermal Imager 6-unit CubeSat and the SigNals-Of-Opportunity P-band Investigation 6-unit CubeSat.

ESTP's AIST project will continue to develop a digital twin Earth prototype framework leveraging several tasks. The digital twin Earth prototype will mirror localized Earth science systems and utilize the

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combination of data analytics, machine learning, and state-of-the-art models to conduct "what if" investigations that can result in actionable predictions and relate natural and physical events to human activities.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

ESTP technology development will continue to reflect the full breadth of NASA Earth science needs, while incorporating requirements from the Earth Science Decadal Survey as well as the NASA Wildland FireSense, GHG, EIC, and Quantum Gravity Gradiometer efforts.

ESTP plans to select new awards under the IIP element, the AIST program element, the DSI program element, and the FireSense Technology program elements. The program will also release a solicitation for the Advanced Component Technologies (ACT) program element, with awards made by early FY 2026.

NASA expects three launches of ESTP validation missions as hosted payloads: the Geodetic Reference Instrument Transponder for Small Satellites, the Global L-band Active/Passive Observatory for Water Cycle Studies, and the Aerosol Radiometer for Global Observation of the Stratosphere.

Program Elements

ADVANCED TECHNOLOGY INITIATIVES (ATI)

This project enables development of critical component and subsystem technologies for instruments and platforms, mostly in support of the Earth Science Decadal Survey, through the Advanced Component Technology element. Current awards focus on areas such as laser transmitters, passive optical technologies, and microwave and calibration technologies. Other awards support measurements of solar radiance, ozone, aerosols, and atmospheric gas columns for air quality and ocean color, and for coastal ecosystem health and climate emissions.

The InVEST activity selects new technologies to validate in space prior to use in a science mission. This is necessary because the space environment imposes stringent conditions on components and systems, some of which cannot be tested on the ground or in airborne systems. Validation of Earth science technologies in space will further reduce the risk of new technologies in future Earth Science missions.

Technology development for support of Wildfire Science, Management, and Disaster Mitigation (FireSense Technology), will seek new, innovative Earth system observation capabilities to predict and manage wildfires and their impacts. The FireSense Technology element collaborates with the Earth Science Applied Science, Responsive Science Initiatives and the Research and Analysis programs, the ARMD, and the Small Business Innovative Research program. FireSense Technology will work closely with interagency partners such as NOAA, the U.S. Forest Service, the California Department of Forestry and Fire Protection, the National Interagency Fire Center, and others. In doing so, FireSense Technology will leverage NASA resources to improve the end-to-end management of wildfires in the United States and around the world. Over the next four to five years, FireSense Technology will execute a series of airborne field campaigns to test novel technologies for reducing impact of wildfires, while demonstrating their usefulness to operational wildland fire management agencies. These technologies will make use of broad capabilities in instrument and information technology, along with new observing platforms in space, in the air, and on the ground.

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INSTRUMENT INCUBATOR

This project develops instruments, instrument concepts, and measurement techniques at the system level, including laboratory breadboards and operational prototypes that often lead to ground or airborne demonstrations. These instrument prototypes provide multiple measurements to support the broad needs of Earth science, such as greenhouse gases, ocean color, and solar spectrum (from ultraviolet to infrared). Instrument Incubator supports the development of instrument design and prototyping through laboratory and/or airborne demonstrations for innovative measurement techniques that have the highest potential to meet the measurement capability requirements of the NASA Earth science community across the optical and the microwave spectrum.

A major change planned for the Instrument Incubator project is the formulation of the Atomic Interferometer – Gravity Gradiometer Technology Demonstration. Under this effort, a new capability will be enabled for mass change measurements, which are critical for monitoring key aspects of global change. Conventional techniques, which involve the measurement of relative gravitational differences between two satellites, provide science data at a resolution of about 300km. The most recent decadal survey states a desire for resolution of about 100km to enable measurements of water-storage change in very large drainage basins and to understand the implications of glacial isostatic adjustment. The purpose of the demonstration mission is to advance the evolution of ultracold atoms in a microgravity environment such that a detailed understanding of sensor-platform interactions can be realized, to validate the long-term stability performance of atomic sensors, and to provide raw atomic sensor measurement data for evaluation by the science community to enable a future mission. Such a mission is expected to achieve long-term cost reduction and provide an order of magnitude improvement in sensitivity.

DECADAL INCUBATION

NASA created this project in response to the recommendation of the 2017 Earth Science Decadal Survey. It focuses on maturing observing systems, instruments, technologies, and measurement concepts to address high priority science for the decade 2027-2037 decade in two targeted observable areas. These observable areas are the Planetary Boundary Layer and Surface Topography and Vegetation. Anticipated developments in this project include various observation and information system technologies, modeling/system design, analysis activities, and small-scale pilot demonstrations in support of the two observable areas. NASA currently funds 35 awards made from the DSI-21 solicitation.

ADVANCED INFORMATION SYSTEMS TECHNOLOGY (AIST)

This project develops end-to-end information systems technologies that enable new Earth observation measurements, information products, and information system frameworks. The technologies help access, fuse, analyze, and visualize Earth science data and integrate them into cross-cutting information systems that facilitate science investigations, decision making and dissemination to all potential users. Currently, AIST activities focus on three primary areas needed to support future Earth science measurements.

- Novel Observing Strategies (NOS): NOS projects dynamically coordinate and collaborate observations across multiple platforms (space, air, ground) to optimally acquire a more complete picture of Earth Science phenomena. NOS can be described as a federated Observing System, a generalized SensorWeb concept in which each node can be an individual sensor, a group of sensors, a constellation of satellites (e.g., the ESO concept), a model or integrated models, or even database(s)

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or any other source of relevant information, that have varying degrees of coordination to achieve a common science objective.

- Earth System Digital Twins (ESDTs): ESDTs represent an emerging capability for understanding, forecasting and conjecturing the complex interconnections among Earth systems, including anthropomorphic forcings and impacts to humanity. The ESDT thrust will develop capabilities toward the development of future digital twins of the Earth or of subcomponents of the Earth, as well as toward the development of an overarching framework that will continuously evolve and connect the various components developed by Research and Analysis, Applied Sciences, Data Systems, and Computational Capabilities from other Earth Science programs.
- Analytic Collaborative Frameworks (ACF): The development of the third area, ACF, complements the first two areas. ACF technology tasks aim to harmonize tools, data, and computing environments to meet the needs of Earth science investigations of physical processes and natural phenomena through a reusable, common architecture. ACF systems provide the tools to handle the large amounts of diverse data provided by NOS systems and to address previously intractable scientific questions, potentially providing a feedback loop to NOS, determining needs for additional observations. The ACF thrust will also develop the capabilities needed to develop the digital replicas that are at the heart of ESDTs. Additionally, ACF projects generalize custom or unique tools to make them accessible and useful to a broader community.

Program Schedule

Date	Significant Event
Q1 FY 2024	ROSES-2023 selection no earlier than six months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation
Q1 FY 2025	ROSES-2024 selection no earlier than six months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation
Q1 FY 2026	ROSES-2025 selection no earlier than six months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation
Q1 FY 2027	ROSES-2026 selection no earlier than six months of receipt of proposals
Q2 FY 2027	ROSES-2027 solicitation
Q1 FY 2028	ROSES-2027 selection no earlier than six months of receipt of proposals
Q2 FY 2028	ROSES-2028 solicitation
Q1 FY 2029	ROSES-2028 selection no earlier than six months of receipt of proposals
Q2 FY 2029	ROSES-2029 solicitation

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Program Management & Commitments

Program Element	Provider
Instrument Incubator	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, MSFC, AFRC Cost Share Partner(s): N/A
AIST	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, MSFC, ARC, JSC Cost Share Partner(s): N/A
ATI	Provider: Various Lead Center: HQ Performing Center(s): GSFC, JPL, LaRC, ARC Cost Share Partner(s): N/A
Decadal Incubation	Provider: Various Lead Center: HQ Performing Center(s): GSFC, LaRC, JPL Cost Share Partner(s): N/A

Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as through the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA centers, industry, and academia, as well as other government agencies, Federally Funded Research and Development Centers, and nonprofit organizations.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Assessment	External reviewers from academia and industry, To Be Determined	Mid-FY 2024	Provide an independent technical assessment of the goals and strategy for the execution of the quantum gravity gradiometer experiment	To Be Determined; expected late FY 2024

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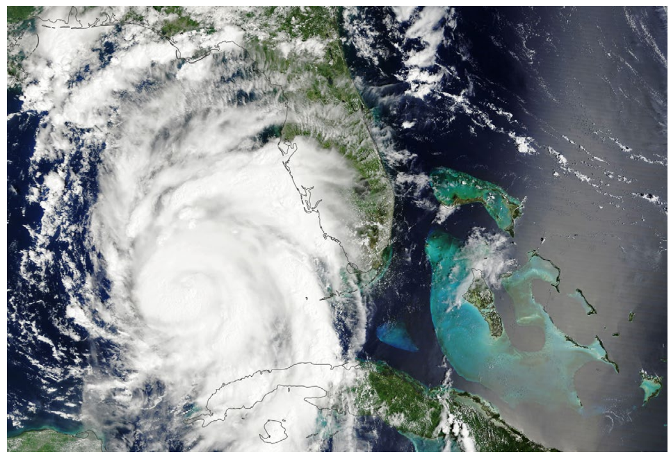
FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	75.2	--	68.6	73.3	73.5	75.8	75.9

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Applied Sciences program leverages NASA Earth Science satellite measurements and new scientific knowledge to enable innovative and practical uses by public and private sector organizations. It supports near-term uses of Earth science knowledge, discovers and demonstrates new applications, facilitates adoption of applications, and builds capabilities.



The Moderate Resolution Imaging Spectroradiometer on NASA's Terra satellite acquired this image of Hurricane Idalia on August 29, 2023, as the hurricane approached the Gulf Coast. Idalia was a Category 3 hurricane when it made landfall and brought a devastating storm surge with it. NASA's Disasters program activated to support response efforts for the coastal area, with the program sharing Earth observing data and imagery to help identify damage and assess impacts.

Applied Sciences projects improve decision-making activities to help the United States better manage its resources, improve quality of life, and strengthen the economy. NASA develops Earth science applications in collaboration with end-users in public, academic, and private organizations.

The program supports activities in thematic Earth science applications areas, in capacity building with uses of Earth observations, and in planning for future NASA missions.

Examples of these include:

- Disaster-response and aid organizations use data from multiple Earth-observing satellites to identify damaged areas following disasters, such as hurricanes, floods, and wildfires.
- The U.S. Department of Veterans Affairs uses NASA Earth observations of smoke and other air pollution to study the health impacts on veterans deployed to Afghanistan, Iraq, and other areas of Southwest Asia.
- State and local governments use satellite-based water quality data to assess algal bloom magnitude, frequency, duration, and extent to map indicators and threats to human health from harmful algal blooms.
- Tourism industries, coastal resource managers, and others use satellite data to identify the amount and location of Sargassum seaweed in the Atlantic and the Gulf of Mexico to mitigate Sargassum beaching events that cause serious problems for the environment, human health, and economy.

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- Local governments use satellite-based land-surface temperature data, emissivity data, and imagery to identify populations most vulnerable to extreme heat and guide service efforts.
- The Navajo Nation uses satellite observations as part of a Drought Severity Evaluation Tool to target interventions and allocate drought relief funding more efficiently and equitably.

The program supports the development of these products in the decision-making process of user organizations. The program encourages potential users to envision and anticipate possible applications from upcoming satellite missions and to provide input to mission development teams to increase the societal benefits of NASA missions.

For more information, go to: https://appliedsciences.nasa.gov/

EXPLANATION OF MAJOR CHANGES IN FY 2025

Starting in FY 2025, NASA moved the following elements from the Applied Sciences program to the new Responsive Science Initiative (RSI) program:

- All contributions made to broader Earth Science Division (ESD) efforts (e.g., ESD Global Partnerships and NEX) and division-wide contracts.
- Western Water Applications Office, the Health and Air Quality Science Team, and all Applied Sciences contributions to the U.S. Greenhouse Gas Center and the Earth Information System.
- the Agriculture project, including support for the Harvest and Acres consortia.
- the Wildland Fires project, including support for wildland fire applications and the Firesense project that support U.S. wildland fire management.

The amount transferred from the Applied Sciences program to the Responsive Science Initiative program for these program elements is approximately $26 million. The request also reduces the number of new grants in competed application areas, including Climate Resilience, Ecological Conservation, Health and Air Quality, and Water Resources. Previously awarded grants will continue to be funded.

ACHIEVEMENTS IN FY 2023

The Disasters project significantly advanced the state of disaster science while simultaneously enabling decisions for disaster response around the world. Novel results included the use of artificial intelligence to understand the impact of disasters on critical infrastructure, while other teams used satellite data to inform agricultural insurance assessments for hail globally. The project supported response activities for key partners including the Federal Emergency Management Agency, United States Agency for Internal Deployment (USAID) Bureau of Humanitarian Affairs, World Central Kitchen, and The International Federation of Red Cross and Red Crescent Societies. In FY 2023, the NASA Disasters Mapping Portal posted 79 data services, featuring more than 2,000 images and datasets, for 18 different supported disasters domestically and abroad.

The Health and Air Quality effort within the Applications project supported critical resources to disseminate important information and data covering health surveillance, the effects of global climate change on public health, and air quality management. Demonstrating this impact, a health and air quality task successfully tested a portal to help air quality management assess the risk of poor air quality due to wildfire smoke. During fire season, this team additionally held weekly briefings on air quality impacts for 21 stakeholder organizations in state and federal air quality management.

The Water Resources effort within the Applications project addressed critical water challenges in the United States and globally. The NASA developed tool, OpenET, supported data needs for federal water accounting systems and processes, regional water resource managers, and individual landowners in FY 2023. In the State of California, farmers and water rights holders were able to, for the first-time, use OpenET to meet the State Water Use Control Board reporting requirements, replacing complicated and expensive monitoring systems and automating onerous reporting requirements.

The Capacity Building project continued to build greater knowledge of remote sensing in the United States and around the globe. The SERVIR program (managed jointly with USAID) worked with its global network to conduct 65 projects and 101 trainings that reached over 2,900 individuals from 54 countries. In January 2023, SERVIR launched its Southeast Asia hub, expanding geographically from the Mekong region.

The Applied Remote Sensing Training (ARSET) program element conducted 15 trainings that netted a reach of 13,345 instances of participation from 158 countries, 53 U.S. states and territories, and more than 5,100 organizations. The Digital Earth Virtual Environment and Learning Outreach Program (DEVELOP) program element, a workforce development effort that partners early career professionals with user organizations to apply Earth science data, conducted 63 feasibility projects and engaged 269 young professionals.

Capacity Building's Community Action Equity and Environmental Justice element onboarded a team of associate program managers who are managing 41 tasks. These tasks support domestic environmental justice efforts in 21 U.S. states and territories across a broad range of thematic topics, such as extreme heat and urban heat islands, health and air quality, urban greenspace, flooding, wildfires, urbanization, and agriculture.

WORK IN PROGRESS IN FY 2024

In FY 2024, NASA is competing the establishment of a new initiative called Catalyst to catalyze biodiversity conservation at large scales, starting in the State of California. This solicitation will establish a central resource center; support cutting-edge technological development combining next generation in situ and airborne datasets with NASA Earth observing capability to enable conservation decision-making; leverage existing integrated datasets, platforms, and tools to address the immediate needs of conservation decision-makers; and demonstrate the ability of cross-leveraged platforms to visualize the complex natural histories of California and the surrounding western United States

The Disasters project is launching the Disaster Response Coordination System (DRCS), which will formalize NASA's approach for leveraging the best available science, technology, and expertise in support of domestic and international disaster response. The DRCS will provide an all-of-NASA approach to disaster response by leveraging all of NASA's assets to provide data and decision support and evolve into a consistent, reliable partner for federal, state, local, and tribal disaster responders. The Disasters project will also direct several new tasks to advance the science of disaster risk reduction, recovery, and resilience and develop a new generation of researchers focused on the connections between disasters and extreme events and the communities exposed to the increasing impacts of these events.

Within the Capacity Building project, Community Action will continue 39 environmental justice science tasks with the goal of assessing the potential applications of and feasibility to use and to integrate

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socioeconomic data and Earth observations. These efforts are informing solutions related to environmental justice issues directly impacting underserved communities, consistent with the Administration's environmental justice and equity goals. SERVIR's fourth Applied Sciences team will continue collaborating with the hubs in southeast Asia, Hindu Kush Himalaya, West Africa, and Amazonia, and with stakeholders in eastern and southern Africa. SERVIR will start serving the sixth region, Central America, deepening the program impact and scaling services within the region. SERVIR will additionally begin expanding a new service area in air quality and health.

ARSET plans to conduct 17 trainings with learning materials available in both English and Spanish. DEVELOP will conduct over 50 project activities and engage more than 200 young professionals.

In FY 2024, The Prediction of Worldwide Energy Resources (POWER) task will release a new version of its data services that will improve the usability of NASA observations in support of renewable energy and energy efficiency.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

Within the Capacity Building project, FY 2025 will complete the first full year of operations for the SERVIR Central America hub. The SERVIR hubs and their partners will be able to use the results of 20 grants conducted by the competitively selected SERVIR Applied Sciences Team and NASA will select the next SERVIR Applied Sciences Team. ARSET will expand trainings in additional topic areas and DEVELOP will increase participants and projects.

In FY 2025, the Disasters project will advance disaster science to better inform cascading, compound, and complex events that lead to billion-dollar disasters and render communities incapable of recovering to their fullest.

As a part of the Ecological Conservation task, the Catalyst initiative will complete its first year of activities, demonstrating the ability of cross-leveraged platforms to visualize the complex natural histories of the western United States.

In FY 2025, the POWER Project will enhance its data services to the energy efficiency and renewable energy community by incorporating observations from new NASA satellite missions. POWER will also build on a pilot task supporting energy efficiency planning efforts at NASA centers and facilities by expanding the availability of climate projection information in its data services to a global domain.

Program Elements

CAPACITY BUILDING

The Capacity Building project enhances the United States and developing countries' capacity (e.g., human, scientific, technological, institutional, and resource capabilities) to make decisions informed by Earth science data and models. Capacity Building develops skills in current and future workforce and creates opportunities in under-served areas to broaden the benefits of Earth observations. This project supports training, information product development, experiential learning to co-develop demand-driven products, data access tools, short-term application test activities, user engagement, and partnership development. This project has four primary elements:

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- SERVIR: A joint venture with USAID that enables emerging economy countries to improve their environmental management and resilience to climate change through uses of Earth observations in development decision-making.
- ARSET: A professional-level training program for accessing and using Earth observations data through computer-based webinars and hands-on courses for all types of organizations.
- DEVELOP: A national training and development program for individuals to gain experience applying Earth observations through 10-week interdisciplinary activities co-developed with users to address community needs.
- Community Action: Activities focused on advancing equity and environmental justice, strengthening skills of Indigenous groups to use Earth observations for land management decisions and actions, and prizes and challenges to reach new communities with new ideas to address Earth science applications needs.

MISSION AND APPLIED RESEARCH

The Mission and Applied Research project enables involvement by applications-oriented users in the planning and development of Earth Science satellite missions. It enables end-user engagement to identify applications early in and throughout the mission life cycle and integrates end-user needs in design and development, enabling user feedback and broadening advocacy. Mission and Applied Research organizes community workshops to identify priority needs as well as studies to inform design trade-offs and identify ways to increase the applications value of missions. This project advises flight projects on activities to develop the applications dimension of a mission in development to help broaden benefits and maximize the return from the investment in the mission.

DISASTER SUPPORT

The Disaster Support project enables the development of innovative and time-relevant applications using NASA satellite mission data in concert with novel approaches to understanding community exposure and vulnerability to a range of hazards and extreme events. The project sponsors the use and integration of Earth observations in the decisions and actions of disaster-management and disaster-financing organizations, including the pursuit of feasibility studies and needs assessments, in-depth engagements, and workshops. The project also sponsors a Disaster Response Coordination System that coordinates across NASA centers to enhance the value and usability of NASA Earth Science products in support of domestic and international disaster response across a wide range of disaster types, including floods, fires, earthquakes, volcanoes, and landslides. Furthermore, this project pursues strategic partnerships with disaster groups that can carry forward NASA-developed information and tools to support the disaster management communities they serve. The project will begin to place a greater focus on disaster risk reduction, improving early warning, and helping partners take anticipatory action and build resilience to complex and cascading disasters.

APPLICATIONS

The Applications project sponsors the integration of Earth observations in the decisions and actions of community organizations. There are formal Applications program elements in Climate Resilience,

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Ecological Conservation, Energy and Infrastructure, Health and Air Quality, and Water Resources. Two formal program elements that had been in the Applications project of the Applied Sciences program, Agriculture and Wildland Fires, have moved to the RSI program.

The Applications program elements support feasibility studies, in-depth activities, applied science teams, consortia, workshops, and needs assessments. Each Applications program element participates in major conferences and events that their partners attend to meet and engage managers and users.

- Climate Resilience: promotes uses of Earth science information to provide communities and stakeholders with enhanced information, tools, applications, and resources that improve societal resilience to current and future climate stressors. This area will conduct work through solicitation efforts for applied research and applications development.
- Ecological Conservation: promotes the use of Earth observations and models to analyze and forecast changes that affect ecosystems and to develop effective resource management strategies. Primary user communities are natural resource managers (both land and marine) and those involved in conservation and sustainable ecosystem management.
- Energy and Infrastructure: provides solar, meteorological, and other types of Earth information to aid with decision-making related to renewable energy, building energy efficiency, and resilient infrastructure. A major component of the energy and infrastructure Application program element is the POWER tool.
- Health and Air Quality: promotes the use of Earth observation data and models in the implementation of air quality standards, policy, and regulations for economic and human welfare. Additionally, the element addresses issues related to environmental health, infectious/vector-borne diseases, toxic and pathogenic exposures, and other health-related hazards and their effects for risk characterization and mitigation.
- Water Resources: supports the use of Earth observations in water resources management related to water demand, supply, and quality. The program element includes five functional themes: drought, streamflow and flood forecasting, evapotranspiration and irrigation, water quality, and climate effects on water resources.

In addition to these activities, the Applied Sciences program supports the following initiatives:

- Group on Earth Observations (GEO) Work Programme: Applied Sciences supports specific elements in the GEO Work Programme to further U.S. and NASA interests internationally, leveraging resources of other countries and organizations. This initiative specifically fosters a broader involvement of domestic organizations in a national approach to the GEO Work Programme, increasing opportunities for these organizations.
- NASA Lifelines Consortium: This consortium seeks to improve the use of Earth science information in humanitarian decision-making so the most vulnerable and hardest-to-reach communities can meet their immediate needs. NASA Lifelines is a community- and capacity-building initiative that connects a wide range of experts across Earth science and humanitarian organizations to foster innovation that helps communities better prepare for, respond to, and recover from wide-ranging events that negatively impact lives and livelihoods.
- The Collaborative Network for Valuing Earth Information (CONVEI) Consortium: This multi-organizational consortium advances the approaches used for assessing the economic and societal benefits of Earth observations in supporting decisions related to agriculture, water resources,

disasters, health, conservation, environmental justice, and climate change. CONVEI focuses on creating a collaborative network of Earth scientists and social scientists to share new approaches across disciplines, build new capacities to assess the value of Earth science information, and advance the next generation of satellite information to better support society's most pressing decisions for people and the planet.

Program Schedule

Date	Significant Event
Q1 FY 2024	ROSES-2023 selections within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation release
Q1 FY 2025	ROSES-2024 selections within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation release
Q1 FY 2026	ROSES-2025 selections within six to nine months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation release
Q1 FY 2027	ROSES-2026 selections within six to nine months of receipt of proposals
Q2 FY 2027	ROSES-2027 solicitation release
Q1 FY 2028	ROSES-2027 selections within six to nine months of receipt of proposals
Q2 FY 2028	ROSES-2028 solicitation release
Q1 FY 2029	ROSES-2028 selections within six to nine months of receipt of proposals
Q2 FY 2029	ROSES-2029 solicitation release

Program Management and Commitments

Program Element	Provider
Applications	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): U.S. Forest Service, National Park Service (NPS), U.S. Department of Agriculture (USDA), NOAA), USGS, U.S. Fish and Wildlife Service, Environmental Protection Agency (EPA), Bureau of Land Management, Centers for Disease Control and Prevention

APPLIED SCIENCES

Program Element	Provider
Capacity Building	Provider: Various Lead Center: Various Performing Center(s): ARC, GSFC, JPL, MSFC, LaRC Cost Share Partner(s): Groundwork USA, University of Georgia, Idaho State University, Boston University, Colorado State University, University of Virginia, University of Wyoming, Skidmore College, Arizona State University, NOAA, USGS, USDA, USAID, State Department
Disaster Support	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): USACE, BLM, USFS, USGS, NOAA, USDA Foreign Agriculture Service, Earth Observatory of Singapore, Pacific Disaster Center, Willis Towers Watson, MDA, U Colorado Boulder, Geotechnical Extreme Events Reconnaissance Organization, Tonkin and Taylor Ltd
Mission and Applied Research	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, JPL, LaRC, MSFC Cost Share Partner(s): USDA, CNES, ISRO, Joint Research Centre, ESA, NOAA, European Centre for Medium-Range Weather Forecasts

Acquisition Strategy

NASA bases the Earth Science Applied Science acquisitions on full and open competition. Grants are peer reviewed and selected based on NASA research announcements and other related announcements.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Relevance	Earth Science Advisory Committee and Applied Sciences Advisory Committee	Jan 2024	Review strategic planning efforts	TBD

PLANETARY SCIENCE

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Planetary Science Research	310.6	--	**390.1**	386.4	392.5	405.3	407.8
Planetary Defense	135.5	--	**276.6**	369.3	299.6	81.0	78.1
Lunar Discovery and Exploration	486.3	--	**458.3**	456.8	467.8	479.1	488.5
Discovery	217.5	--	**261.5**	418.3	588.0	790.8	912.4
New Frontiers	488.2	--	**500.5**	533.0	484.2	471.6	298.3
Mars Exploration	248.1	--	**324.5**	298.6	305.8	353.3	390.7
Mars Sample Return	818.8	--	**200.0**	100.0	100.0	100.0	100.0
Outer Planets and Ocean Worlds	356.8	--	**119.0**	97.4	97.1	126.3	204.3
Radioisotope Power	154.9	--	**201.1**	190.7	176.6	169.4	162.5
Total Budget	**3,216.5**	**--**	**2,731.5**	**2,850.5**	**2,911.6**	**2,976.8**	**3,042.5**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Planetary Science

PLANETARY SCIENCE

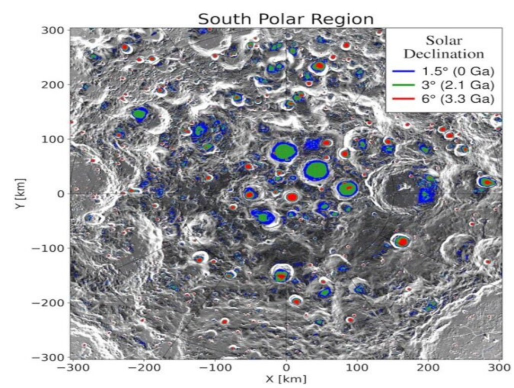
PLANETARY SCIENCE RESEARCH

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Planetary Science Research and Analysis	205.1	--	**249.3**	249.2	252.2	260.9	264.4
Other Missions and Data Analysis	105.5	--	**140.8**	137.2	140.2	144.4	143.4
Total Budget	**310.6**	**--**	**390.1**	**386.4**	**392.5**	**405.3**	**407.8**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Planetary Science Research program is at the heart of NASA's planetary science objectives. It informs and inspires future missions and maximizes the return of existing ones. The Planetary Science Research program supports the scientists who use NASA mission data to make discoveries about our solar system. Scientists study NASA mission data to understand the planets and small bodies that inhabit our solar system, to answer questions about its formation, how it reached its current diverse state, how life evolved on Earth and possibly elsewhere in the solar system, and what characteristics of the solar system lead to the origins of life. The program also supports development of analytical and theoretical tools, as well as laboratory data, to complement analyses of flight mission data. The research program achieves this by supporting research grants solicited annually and subjected to a competitive peer review before selection and award. The Planetary Science Research program focuses on five key research goals:



Researchers studied the permanently shadowed regions of the lunar poles, with the south polar region shown here, to understand the history of the Moon’s tilt and guide the search for ice deposits for future landed lunar missions.

- Advance the understanding of how the chemical and physical processes in our solar system operate, interact, and evolve;
- Explore and observe the objects in the solar system to understand how they formed and evolve;
- Explore and find locations where life could have existed or could exist today;
- Improve our understanding of the origin and evolution of life on Earth to guide our search for life elsewhere; and
- Identify and characterize objects in the solar system that pose threats to Earth or offer resources for human exploration.

EXPLANATION OF MAJOR CHANGES IN FY 2025

This budget establishes a new Planetary Technology project, consistent with a recommendation in the Decadal Survey to provide integrated technology development for high-priority science missions. Managing planetary technology development in one project allows NASA more flexibility and agility to enable timely hardware solutions, minimize sustainability costs, and support an enhanced technology strategy. This project includes the Planetary Exploration Science Technology Office, Entry System

PLANETARY SCIENCE RESEARCH

Modeling, and Global Reference Atmospheric Models activities, which were previously budgeted in the Discovery Program.

ACHIEVEMENTS IN FY 2023

During FY 2023, NASA selected over 300 new research grants for funding across the United States, with approximately 1,800 active grants total. Core elements of the Research &Analysis Program, such as Solar System Workings, Emerging Worlds, Habitable Worlds (HW), Exobiology, and Yearly Opportunities in Research for Planetary Defense directly address the five key research goals.

- The Solar System Workings element funded approximately 40 new research activities of the various bodies in the solar system using techniques including laboratory experiments, analysis of observational data, and theoretical modeling.
- The Emerging Worlds element funded approximately 20 new research awards that address individual topics ranging from the earliest stages of solar system formation to the events that led to today's solar system.
- The Habitable Worlds element funded approximately 10 new research awards focusing on topics related to the presence of water or exotic solvents, sources of energy for life, the presence of organics and their reactivity, water body physics and chemistry as they pertain to habitability, and space weather signatures that may be indicative of planetary habitability.
- The Exobiology element funded approximately 20 new investigations in five major sub-themes: Prebiotic Chemistry, Early Evolution of Life and the Biosphere, Evolution of Advanced Life, Large Scale Environmental Change and Macro-Evolution, and Biosignatures and Life Elsewhere.
- The Near-Earth Object Observations element funded approximately 10 new selections, including both large-scale observing programs designed to detect and track near-Earth objects and smaller research programs aimed at characterizing the physical properties of such bodies.

In 2023, researchers adapted an Earth lava flow model to the Venus environment to track how each variable, such as gravity, temperatures, and wind speed impacted its emplacement. The results indicate that a basaltic channelized lava flow would travel approximately 75 percent further on Venus than on Earth, due to a decrease in heat loss to the atmosphere of Venus. This improves our understanding of physical processes across the solar system and impacts planning for future Venus missions.

In 2023, researchers developed a new experimental method to trace the migration of liquid metal through the mantle of a generic “terrestrial” planet. The results demonstrated that iron melts could have filtered through grain boundaries and exchanged chemical elements along the way, explaining the presence of metal-loving elements in Earth's mantle today and advancing our understanding of how materials migrate in planetary interiors and the chemical consequences of this process.

The data analysis program elements will continue ensuring scientific return from NASA's investments in missions. Participating scientist activities will continue, including an investment in the Martian Moons eXploration (MMX) mission, a Japanese mission with NASA collaboration to survey the moons of Mars (Deimos and Phobos). NASA began funding the Here to Observe program to broaden participation in planetary science research by pairing undergraduates with planetary missions. NASA also began a partnership with NSF exploring an Ideas Lab to enhance collaborative discussions and broaden participation in achieving common research goals.

PLANETARY SCIENCE RESEARCH

FY 2023 saw the selection of 10 new Planetary Science Enabling Facilities across the United States at NASA centers, Educational Organizations, and Non-Profit Organizations. These experimental and analytical research facilities are available to the Planetary Science Division research community. These facilities enabled increased access to users conducting research related to planetary aeolian and atmospheric processes, space weathering and, of critical importance given the arrival of the extraterrestrial samples returned by the Origins, Spectral Interpretation, Resources Identification, Security-Regolith Explorer (OSIRIS-REx) mission, laboratory analysis of extraterrestrial materials.

WORK IN PROGRESS IN FY 2024

In pursuit of fundamental science that guides planetary exploration, the Planetary Science Research Program will continue to select highly rated Research and Analysis (R&A) proposals that support planetary missions and goals. The individual program elements within the R&A portfolio directly address the major scientific themes identified for Planetary Science and these program elements will continue in the coming year. Planetary Science will also continue archiving and distributing relevant mission data to the science community and the public in a timely manner. Planetary Research will add new participating scientist activities for the Hera mission with ESA, which will investigate the Didymos binary asteroid, impacted by NASA's successful Double Asteroid Redirection Test (DART) mission in 2022.

The Advanced Multi-Mission Operations System (AMMOS) ground data system in the Cloud is scaling up its capability to support more complex missions.

In addition to creating a centralized Web presence for the Planetary Data System (PDS), the team is implementing strategies to significantly improve data usability and accessibility of the complete planetary data archive for all users. A cloud migration strategy has been developed, which will enable more modern and innovative data sharing, computation, and analysis methods. Further, PDS is continuing to convert all data products to a data standard (i.e., PDS4) that enables improved software interoperability and search capabilities and supports the integrated use of both current and historic planetary datasets by both the research community and general public.

In September 2023, Astromaterial Curation received the OSIRIS-REx sample, collected from the asteroid Bennu. The team is focusing a large portion of their efforts on preliminary examination and characterization of these samples and developing the catalogue to make these samples publicly available to the larger scientific community in FY 2024. Furthermore, the Curation project will continue to work with Columbia University to ensure data from the OSIRIS-REx mission as well as other various astromaterials is included in the database, Astromat, which is publicly accessible and searchable. The Curation project will continue to support future Mars Sample Return, MMX, and Artemis efforts while maintaining the integrity and availability of their current collections.

In the Robotics Alliance project, NASA organizers will increase participation of students from underserved and underrepresented communities in challenging applications of engineering and science, including national robotic competitions.

In Planetary Technology, the Optically Pumped Solid State Quantum Magnetometer team is developing a quantum sensor that operates with optically addressable quantum centers in silicon carbide and nitrogen-vacancy center diamond. NASA's Global Reference Atmospheric Model (GRAM) team will develop updates of Venus and Mars GRAMs to support atmospheric modeling for the Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) and Mars missions, as well as a Titan GRAM to support the Dragonfly mission. The NASA Entry Systems Modeling team will develop

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and validate multiscale Thermal Protection System heat shield material failure simulations and validate parachute simulation capabilities for Mars Sample Return (MSR) and Dragonfly. The Entry Systems Modeling team will also develop and demonstrate novel guidance, navigation, and control schemes by combining multiple atmospheric trajectory analyses for potential future New Frontiers and Discovery missions.

Open Source Science, which was transferred from the Earth Science Division in FY 2023, will deploy a search platform for scientific publications covering multiple disciplinary areas across NASA's SMD. They are developing a large language model (LLM) for applications across NASA science. This development includes a retrieval augmented generation platform that leverages different types of LLMs and supports rapid development of applications. These applications will help to enable discovery, access, and use of NASA's science data. Finally, they will be releasing the "Transform to Open Science 101" curriculum. This curriculum introduces open science concepts in a manner that is appropriate for early career researchers and those new to open science ideas.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The Planetary Science Research Program will continue to select highly rated R&A proposals that support planetary missions and goals. Planetary science will also continue archiving and distributing relevant mission data to the science community and the public in a timely manner.

This budget implements new activities to strengthen broad participation in planetary science research. The "Here to Observe" program will continue to broaden participation in planetary science research by pairing teams of undergraduates with specific PSD mission research teams and expanding the number of participants in the program. Participants will observe and learn about planetary science missions in order to spark and maintain interest in STEM careers. They will participate in NASA-led activities like workshops and field trips, as well as create their own supplemental activities. NASA will select and fund an Ideas Lab team in collaboration with NSF. Participating scientist activities will also continue and specific missions participating will depend on planetary mission timelines.

PDS expects to have 90 percent of its data converted to a more complete data standard (PDS4) by FY 2025.

Private industry will leverage use of Glenn Hall thruster technology, developed in Planetary Technology, in a commercial mission called Mission Extension Pod planned for launch in 2025.

Open Source Science will expand search and discovery tools for scientific information and publications, provide a research data and software repository, and continue development of an enterprise-level cloud computing framework for SMD. They will also expand their Artificial Intelligence (AI) Foundation Model to other science divisions and train approximately 4,000 researchers in open science principles.

Program Elements

PLANETARY SCIENCE RESEARCH AND ANALYSIS (R&A)

Planetary Science R&A enhances the scientific return from on-going and completed space flight missions and provides the foundation for the formulation of new scientific questions and strategies for answering those questions. R&A develops new theories and instrumentation concepts that enable the next generation

PLANETARY SCIENCE RESEARCH

of space flight missions. R&A funds research tasks in areas such as astrobiology and cosmochemistry; the origins and evolution of planetary systems; the observation and characterization of extra-solar planets (i.e., exoplanets); and the atmospheres, geology, and chemistry of the solar system's bodies other than the Earth or the Sun.

Program Schedule

The Planetary Science Research Program solicits proposals as part of the SMD's annual Research Opportunities in Space and Earth Sciences (ROSES) research calls. The program issues solicitations every year. A Senior Review process assesses all missions in the extended operations phase every three years and all data archives every five years.

Date	Significant Event
Q1 FY 2024	ROSES-2023 NRA selection within six to nine months of receipt of proposals
Feb 2024	ROSES-2024 NRA solicitation release
Q1 FY 2025	ROSES 2024 NRA selection within six to nine months of receipt of proposals
Feb 2025	ROSES-2025 NRA solicitation release
Mar-Apr 2025	Senior Review Operating Missions
Q1 FY 2026	ROSES-2025 NRA selection within six to nine months of receipt of proposals
Q4 FY 2026	Senior Review Data Archives Discipline Nodes
Q3 FY 2027	Senior Review Data Archives Support Nodes

Program Management & Commitments

Program Element	Provider
R&A	Provider: NASA Lead Center: HQ Performing Center(s): ARC, GRC, GSFC, JPL, JSC, LaRC, MSFC Cost Share Partner(s): N/A

Acquisition Strategy

The R&A budget will fund competitively selected activities from the ROSES omnibus research announcement.

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Advanced Multi-Mission Operation System	40.5	--	**38.9**	40.4	41.1	41.9	41.3
Planetary Data System	28.8	--	**28.7**	33.5	35.8	38.7	38.7
Astromaterial Curation	12.1	--	**13.6**	15.2	15.7	15.5	15.6
Robotics Alliance	5.0	--	**5.0**	5.0	5.0	5.1	5.1
Open Source Science	19.0	--	**49.7**	37.6	37.6	37.6	37.5
Planetary Technology	0.0	--	**5.0**	5.4	5.1	5.6	5.2
Total Budget	**105.5**	**--**	**140.8**	**137.2**	**140.2**	**144.4**	**143.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The image above shows members of NASA JSC's Curation team alongside colleagues from Lockheed Martin looking into the science canister glovebox in a cleanroom after successful removal of the OSIRIS-REx sample return canister lid. The OSIRIS-REx sample return capsule landed in the Utah desert on September 24, 2023, and the science canister was transported to JSC for processing the next day.

Other Missions and Data Analysis includes activities and infrastructure that support NASA Planetary Science Research and missions, such as the Advanced Multi-Mission Operation System, Planetary Data System, and Astromaterial Curation.

Mission Planning and Other Projects

ADVANCED MULTI-MISSION OPERATION SYSTEM (AMMOS)

AMMOS is a system of reusable software tools and services comprising a mission ground operations and ground data system used across multiple NASA missions. AMMOS provides multi-mission operations, navigation, design, and training tools and services for Planetary Science flight missions, as well as other SMD missions, and invests in improved communications and navigation technologies. The AMMOS project will continue to provide and develop multi-mission software tools for spacecraft navigation, command, control, assessment, mission planning, and data archiving. Utilizing the AMMOS common tools and services lowers individual mission costs and risks by providing a mature base for mission operations systems at significantly reduced development times. AMMOS also provides support to our international space agency partners on an as-needed basis. This support typically pertains to navigation assistance and scheduling of NASA’s Deep Space Network (DSN) assets.

AMMOS currently provides multi-mission operations tools and services to 88 missions, and includes support to Planetary Science, Heliophysics, Earth Science, and Astrophysics missions within NASA and critical operations services to 14 international missions. AMMOS continues to provide critical NASA support to international missions from CSA, DLR, ESA, ISRO, JAXA, the Korea Aerospace Research Institute (KARI), and United Arab Emirates Space Agency.

Operating missions enabled by AMMOS include the Mars 2020 Perseverance rover, Parker Solar Probe, Chandrayaan-2, Chandra X-ray Observatory, Lucy, the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment, and the Korean Pathfinder Lunar Orbiter, among many others. Missions currently in development enabled by AMMOS, include Europa Clipper, Volatiles Investigating Polar Exploration Rover, and Lunar Trailblazer.

Recent Achievements

AMMOS supported the Psyche mission, which launched on October 13, 2023, by providing several mission system functions including planning and sequencing, mission control, mission navigation, and mission system security. Psyche leveraged 22 software products from the AMMOS catalog to construct its ground data system used to operate the spacecraft. Psyche used the software with minimum adaptation which saved costs during the mission development phase. AMMOS will continue to support Psyche during its prime mission with regular updates to ensure the mission operates with bug-free, reliable, and secure software.

AMMOS Multi-Mission Time Correlation (MMTC) software launched into operations for the first time alongside the Psyche mission. Numerous missions across NASA, including Europa Clipper and Interstellar Mapping and Acceleration Probe (IMAP), have already baselined and begun testing MMTC as part of their ground system to track and analyze drift between time measured onboard the spacecraft and standard terrestrial time scales used for planning and scientific analysis back on Earth. Mars mission operators used AMMOS Mars Relay Operations Service (MaROS) to coordinate the relay of over a Terabit of data from landed Mars assets over the course of FY 2023. Finally, implementation started on a new subsystem called “Where’s My Relay Data” (WMRD) – a customizable dashboard where operators can analyze the flow of their relay data in real-time.

Some of the AMMOS navigation team used the AMMOS-developed Monte software to perform an independent navigation of the Artemis I mission to the Moon. The team presented the paper "Independent Verification and Validation Orbit Determination for the Artemis I Mission" (AAS 23-235) at the Astrodynamics Specialists Conference in August 2023. NASA plans to use Monte to navigate the FY 2025 Artemis II mission as a result.

As of August 2023, the number of AMMOS Monte software licensees reached 120 (combined government, government contractor, research, and commercial licenses). One notable use of Monte was by the Japanese company ispace, which used Monte to navigate its Hakuto mission to the Moon in 2023.

PLANETARY DATA SYSTEM (PDS)

PDS is an online data archive that furthers NASA’s Planetary Science goals by efficiently collecting, archiving, and making accessible digital data produced by, or relevant to, NASA’s planetary missions, research programs, and data analysis. This curated archive includes raw and fully calibrated orbital and surface observations from hundreds of NASA missions and instruments exploring the solar system planets, asteroids, and small bodies. The PDS archives now span more than 50 years of NASA-funded research, and they are expanding to include ground-based observations of Near-Earth objects (NEOs). The PDS archives are publicly available through the PDS website. NASA is incorporating new PDS enhancements including a plan for unifying the PDS website, intended to make data easier to find and access, adopting a cloud computing strategy that will increase access to super-computing time and continuing to create training modules for finding and using PDS data.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The PDS received and released data from 23 active planetary missions since October 2022 and continues to release enhanced legacy data. The PDS website has served over 1.5 million unique visitors, domestic and international, who downloaded nearly 360,000 files and over 2,100 tools. The PDS currently contains approximately three petabytes of data from over 70 missions and works with a variety of data providers, including NASA mission teams and Commercial Lunar Payload Service (CLPS) payload providers. The PDS practices open science and findability, accessibility, interoperability, and reusability (FAIR) principles. The PDS also continued to support data providers from over 300 NASA research program investigations, including archive support for data from ground-based observations, laboratory analyses, field observations, and the restoration of old datasets. Migration of data from PDS3 to PDS4 standards continued, enhancing future users' interactions with the PDS. As a result, the PDS archive grew by approximately 320 terabytes to total approximately three petabytes. The PDS achieved the NASA 2022 Silver Group Award for PDS4 development.

ASTROMATERIAL CURATION

The Astromaterials Acquisition and Curation Office curates extraterrestrial material under NASA control. Curation is an integral part of sample return missions. Activities conducted by the Curation office include: (1) research into advanced curation techniques to support future missions; (2) sample return mission planning; (3) archiving of witness, engineering, and reference materials related to sample return missions; (4) recovery and transport of returned materials; (5) initial characterization of newly received samples; (6) preparation and allocation of samples for research; and (7) providing clean and secure storage of samples for the benefit of current and future generations.

Materials currently curated include: Antarctic meteorites; cosmic dust; samples collected from the Moon; samples of the solar wind; samples from comet 81P/Wild; dust collected in interstellar space; particles from asteroids Itokawa, Ryugu, and Bennu; cosmic dust collected in Earth’s stratosphere; microparticle-impacted flight hardware; witness materials (i.e., small foils and plates placed in spacecraft assembly cleanrooms to collect particles); and coupons (i.e., representative pieces of materials used in construction of spacecraft). Curated materials come from past, present, and future sample-return missions: Apollo, Luna, Long Duration Exposure Facility, Genesis, Stardust, Hayabusa, Hayabusa2, OSIRIS-REx, and Mars 2020 Rover. Planning and research efforts are currently underway to develop the technologies and procedures for proper curation of samples from current and future missions to the Moon, such as Artemis; to Mars; and to Mars’ moon, Phobos, such as Martian Moons eXploration (MMX). NASA plans to receive MMX samples through cooperation with JAXA. New laboratory space is currently under construction to be the long-term home of witness materials and coupons for NASA's portion of the MMX samples, and for cold sample processing of Apollo samples.

The project maintains ten existing collections of astromaterials in pristine condition for scientific research within ten cleanroom suites at JSC and White Sands Complex. JSC curation also maintains numerous high efficiency particulate air (HEPA)-filtered air handling systems, an ultrapure water system, high-purity gaseous and liquid nitrogen systems, and a precision cleaning facility to support these sample storage laboratories. The suite of advanced imaging instruments continues to non-destructively characterize the current astromaterials collections, allowing more efficient use of the samples and more robust scientific results.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

In 2023 NASA announced that new samples were available by request to the research community, including newly classified Antarctic meteorites, recently opened Apollo samples, and new collections of cosmic dust. NASA also published updates on NASA's portion of the Hayabusa2 collection.

Construction for new cleanrooms for sample processing for future missions is underway as part of the B31 Annex design and build at JSC. The Curation project conducted laboratory readiness reviews in FY 2023 to ensure labs are safe and technically ready to receive samples and conduct advanced curation research. The Curation team led and participated in rehearsals to prepare for the OSIRIS-REx sample delivery in September 2023.

Finally, the Curation project continues to work directly with Columbia University to develop methods for archiving the data produced through the analysis of astromaterials so the data can be publicly accessible and searchable. The goal is to link the astromaterials database to curation catalogs and databases in support of open science initiatives.

ROBOTICS ALLIANCE PROJECT (RAP)

RAP increases interest in engineering, technology, science, and mathematics disciplines among youth in the United States to create an inspired, experienced, and technical workforce for the aerospace community. Annual activities and events expose students to challenging applications of engineering and science, including national robotic competitions in which high school students work with engineering and technical professionals from government, industry, and universities to gain hands-on experience and mentoring.

Recent Achievements

In FY 2023, RAP sponsored approximately 315 U.S.-based teams (approximately 11,000 students) in the For the Inspiration and Recognition of Science and Technology (FIRST) Robotics Competition; 55 VEX Robotics Competition teams (approximately 500 students); and sponsored and/or supported 19 FIRST Robotics Competition events (affecting approximately 55,000 students). During the past year, RAP also added pilot competition programs focusing on Unmanned Aerial Vehicles, embedding robotics efforts with younger students, and implementing a robotics intern project with underserved communities. During the upcoming year, the team will conduct effectiveness assessments of these pilot projects and consider expanding them into long-term, sustained elements of RAP.

OPEN SOURCE SCIENCE (OSS)

The OSS initiative is an SMD-wide activity that advances open science, supports data science innovation, and increases the accessibility of scientific data through the development of efficient data and computing system capabilities for all SMD divisions. The primary goal of OSS is to create an efficient open science data and computing ecosystem to dramatically accelerate scientific discovery and to expand access to petabytes of public data, software, publications, and scientific knowledge produced by SMD missions and research. OSS is guided by the goals described in the “Strategy for Data Management and Computing for Groundbreaking Science 2019-2024.” The primary elements of OSS are:

The Core Data and Computing Services (CDCS) component (CDCSP) is crafted with dual objectives. Firstly, it is dedicated to the development of an efficient data and computing framework to meet the demands of SMD and its affiliated communities. Secondly, the program works to alleviate the challenges

OTHER MISSIONS AND DATA ANALYSIS

associated with adhering to open science policies. It concurrently aspires to elevate the transparency of SMD data, software, publications, and associated information.

The Data Science Innovation component entails the evaluation and prototyping of emerging data science technologies and methodologies to ascertain their applicability across diverse use cases. Data Science Innovation is instrumental in exploring strategic partnerships with industry and academia, supporting the continuous upskilling of individuals in the realm of data science, and ensuring the ethical deployment of data science technology for scientific endeavors.

The Open Science Implementation (OSI) facet is dedicated to advancing open science endeavors. This involves the formulation of open science policies, provision of support to the scientific community through incentives and grants, and the facilitation of targeted open science training for researchers. Through these initiatives, OSI seeks to cultivate a culture of transparency and collaboration within the scientific community while promoting responsible and transparent sharing of scientific knowledge.

Recent Achievements

CDCS completed a data and computing architecture study to evaluate how a coordinated cloud-High End Computing (HEC) infrastructure can meet the data and computing needs of SMD and support the entire mission directorate's transition to open-source science. The team also released a beta version of the Science Discovery Engine, a search platform for NASA's scientific data, documentation, and code that allows users to search over 80,000 records and discover 85 percent of NASA's scientific data holdings.

Data Science Innovation released the open geospatial artificial intelligence (AI) foundation model and successfully applied it to flood mapping, burn scar detection, and crop classification. The Data Science Innovation team released ethical AI best practices and guidelines and large, curated AI training datasets and benchmarks.

OSI released a new SMD Policy Directive "Scientific Information Policy for SMD." This policy focuses on sharing scientific information including data, software, and publications and was the first policy to be in line with the Office of Science and Technology Policy 2022 memo "Ensuring Free, Immediate, and Equitable Access to Federally Funded Research." OSI also awarded 15 proposals to support developing open science curriculum and training through summer schools and virtual cohorts.

PLANETARY TECHNOLOGY

Planetary Technology funds promising mission-specific technology investments, such as NASA's Global Reference Atmospheric Model (GRAM) and Entry Systems Modeling as well as non-mission specific, non-nuclear investments in planetary technology which will enable future Planetary Science missions. These activities are managed by the Planetary Exploration Science Technology Office (PESTO), which also coordinates planetary-relevant technology investments across the agency and maximizes technology infusion into specific missions.

Recent Achievements

The Hot Operating Temperature Technology (HOTTech) team completed high temperature technology testing in the Glenn Extreme Environment Rig (GEER) chamber, which simulates Venus-surface conditions. Planetary Technology also enabled researchers from around the country to gather at an ocean worlds cryobot mission concept technology workshop about drilling through the icy crusts of Europa and Enceladus to support the search for life. The NASA Entry Systems Modeling teams developed modeling tools to: assess vehicle stability of both Dragonfly and Mars Sample Return Earth Entry System

OTHER MISSIONS AND DATA ANALYSIS

(MSR-EES); improve models of parachute deployment at Mars; and characterize heatshield response and failure criteria for MSR-EES and Artemis I. NASA's GRAM team released updates of Venus and Earth to support atmospheric modeling required for the DAVINCI and the ESA EnVision missions.

PLANETARY DEFENSE

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
NEO Surveyor	90.0	301.9	**235.6**	327.3	257.6	39.0	36.1
Other Missions and Data Analysis	45.5	--	**41.0**	42.0	42.0	42.0	42.0
Total Budget	**135.5**	**--**	**276.6**	**369.3**	**299.6**	**81.0**	**78.1**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

For three decades, NASA has engaged in studying near-Earth objects (NEOs), asteroids, and comets that orbit the Sun and come within 30 million miles of our planet's orbit. While NEOs have the potential to help planetary scientists better understand the birth and formation of our solar system and perhaps the origins of life, some travel in orbits that bring them close enough to Earth's vicinity to make them potential impact hazards.

An astronomer took this time-lapse photograph near his home in London, Ontario, Canada, after NASA's Scout system accurately predicted the entry of 2022 WJ1 on November 19, 2022. The resulting fireball streaked directly overhead and continued east until it broke up. Credit: Robert Weryk

To address this, NASA established its Planetary Defense Coordination Office in 2016 to manage agency efforts to find; track; characterize; and, if necessary, mitigate against NEO impacts.

Planetary Defense encompasses all the capabilities needed to detect and warn of potential asteroid or comet impacts with Earth and then to either prevent or mitigate their possible effects. The effort involves:

- Finding and tracking NEOs that pose a hazard of impacting Earth (greater than 10 meters in size are considered hazardous).
- Characterizing each potentially hazardous NEO found, predicting its precise trajectory, and also determining its size, shape, mass, composition, rotational dynamics, and other parameters to assess the likelihood and severity of devastation if it has a potential Earth impact.
- Warning of the impact timing, potential effects, and advise of possible means to mitigate the impact.
- Planning and testing of measures to deflect or disrupt (break up) an object on an impact course with Earth, or to mitigate the effects of an impact.

Significant progress in NEO detection has been made in recent years and the recently confirmed NEO Surveyor mission, designed to improve detection capabilities to find greater than 90 percent of NEOs 140 meters (m) or larger within about a decade of being launched in 2028, will roughly triple NASA's current capability. In 2022, the DART mission successfully impacted an asteroid almost seven million miles from

PLANETARY DEFENSE

Earth, altering its orbit and demonstrating NASA's ability to respond to a potential asteroid threat for the first time via a kinetic impactor spacecraft.

The Planetary Defense Coordination Office (PDCO) manages the Planetary Defense Program.
PDCO administers the Near-Earth Object Observations (NEOO) project, which funds, and coordinates efforts across multiple agencies and space institutions to find, track, and characterize any asteroid or comet that could become an impact hazard to Earth. Scientists supported by NASA conduct these NEOO efforts at observatories on the ground and in space, as well as with partnerships for data from assets of NSF and space situational awareness facilities of the United States Space Force.

In addition to finding, tracking, and characterizing NEOs, NASA also researches techniques for deflecting or disrupting, if possible, NEOs that are determined to be on an impact course with Earth to provide options for government response to any detected impact threat. If deflection or disruption of the NEO is not possible due to insufficient time available before impact, the PDCO is responsible for providing expert input to other government agencies, such as the Federal Emergency Management Agency, for emergency response operations. The PDCO is a key participant in implementing the United States Preparedness Strategy and Action Plan for NEO Hazards and Planetary Defense.

EXPLANATION OF MAJOR CHANGES IN FY 2025

The budget proposes an updated profile for the NEO Surveyor mission to support a June 2028 launch readiness date with no impact to the total LCC.

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	165.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	165.0
Development/Implementation	18.6	90.0	301.9	**235.6**	327.3	255.1	0.0	0.0	0.0	1,228.6
Operations/Close-out	0.0	0.0	0.0	**0.0**	0.0	2.5	39.0	36.1	123.9	201.5
2024 MPAR LCC Estimate	**183.6**	**90.0**	**301.9**	**235.6**	**327.3**	**257.6**	**39.0**	**36.1**	**123.9**	**1,595.1**
Total Budget	**183.6**	**90.0**	**301.9**	**235.6**	**327.3**	**257.6**	**39.0**	**36.1**	**123.9**	**1,595.1**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The NEO Surveyor spacecraft, depicted above, will detect, track, and characterize asteroids and comets moving across the sky against the stationary stars in the background.

PROJECT PURPOSE

The Near-Earth Object Surveyor (NEO Surveyor) addresses NASA's objective to find, track, and characterize the asteroids and comets that could potentially impact Earth and cause significant damage. NEO Surveyor consists of ground and space-based segments that constitute a system searching the sky for significant potential impact hazards.

The NEO Surveyor will make significant progress toward the objective given to NASA in Public Law 109-155 Sec. 321, the George E. Brown, Jr. Near-Earth Object Survey Act, which requires detecting, tracking, cataloging at least 90 percent of NEOs equal to or larger than 140 meters in size, and characterizing a representative subset.

The National Academies study (2019) concluded that a space-based mid-infrared survey is the most effective, timely option for meeting the congressional NEO survey completeness and size determination requirements. The most recent Planetary Science and Astrobiology Decadal Survey 2023-2032 (2022) recommended that NASA should fully support the development, timely launch, and subsequent operation of NEO Surveyor to achieve the highest priority planetary defense goals.

NEO Surveyor will find potentially hazardous objects because of its optimized sensitivity in the infrared part of the spectrum and observation cadence. The mission's primary goals are to: (1) identify impact hazards to the Earth posed by NEOs by performing a comprehensive survey of the NEO population; (2) obtain detailed physical characterization data for individual objects that are likely to pose an impact

Formulation	Development	Operations

hazard; and (3) advance the understanding of potential impact energies of potentially hazardous NEOs through characterizing physical properties, including object size, to inform potential mitigation strategies.

EXPLANATION OF MAJOR CHANGES IN FY 2025

The budget proposes an updated profile for the NEO Surveyor mission to support a June 2028 launch readiness date with no change to LCC.

PROJECT PARAMETERS

NEO Surveyor consists of a single scientific instrument: a 50-centimeter (nearly 20 inch) diameter telescope that operates in two heat-sensing infrared wavelengths. It will be capable of detecting both bright asteroids and dark asteroids - the most difficult type to find.

The NEO Surveyor Observatory will travel in a large-amplitude halo orbit around the Sun-Earth Lagrange point 1 (L1). The L1 orbit has the advantages of a flexible launch date and a stable, cold thermal environment that supports passive cooling, and enables high data rates needed to downlink full-frame images for asteroid detection and recovery using ground processing and analysis.

After launch, NEO Surveyor will carry out a five-year baseline survey to find at least two-thirds of the undetected NEOs larger than 140 meters (460 feet). These are the potentially hazardous objects large enough to cause major regional damage in the event of an Earth impact. By using two heat-sensitive infrared imaging channels, NEO Surveyor can make accurate measurements of both NEO position and sizes to gain valuable information about their composition, shapes, rotational states, and orbits.

ACHIEVEMENTS IN FY 2023

The project successfully passed KDP-C on November 29, 2022, and continued to finalize design and fabrication activities.

WORK IN PROGRESS IN FY 2024

The project continues instrument subsystems design maturation and will complete CDR for the mission’s only critical instrument, the infrared telescope system. The project will also mature the overall spacecraft design and procure the spacecraft components.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The project will conduct the mission-level CDR to demonstrate that the maturity of the design is ready to proceed with full-scale fabrication, assembly, integration, and test.

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2025 PB Request
KDP-C	Nov 2022	Nov 2022
CDR	Feb 2025	Feb 2025
KDP-D	Aug 2026	Aug 2026
LRD	Jun 2028	Jun 2028
EOM	Sep 2033	Sep 2033

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2023	1,228.6	86	2024	1,228.6	0	LRD	Jun 2028	Jun 2028	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**1,228.6**	**1,228.6**	**0.0**
Aircraft/Spacecraft	338.0	338.0	0.0
Payloads	221.7	221.7	0.0
Systems I&T	4.1	4.1	0.0
Launch Vehicle	134.0	134.0	0.0
Ground Systems	25.2	25.2	0.0
Science/Technology	71.7	71.7	0.0
Other Direct Project Costs	433.9	433.9	0.0

Project Management & Commitments

Element	Description	Provider Details	Change from Baseline
NEO Surveyor Director and Investigation Team	NEO Surveyor science and operations leadership	Provider: University of Arizona (UA) Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Flight System Management	Project management, systems engineering, safety and mission assurance, and system integration	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
NEO Surveyor Spacecraft	Spacecraft bus with all flight subsystem capabilities	Provider: Ball Aerospace, Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Telescope	50-centimeter aperture telescope (waveguide and reflectors)	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Camera Assembly Enclosure	Houses the Sensor Chip Assemblies (SCA), Sensor Chip Electronics (SCE), and focal plane modules	Provider: Space Dynamics Laboratory Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Sensor Chip Assemblies (SCA) and Sensor Chip Electronics (SCE)	Digital image sensor and electronics. Two 16-megapixel mercury cadmium telluride focal plane modules	Provider: Teledyne Scientific & Imaging Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mission Operations	NEO Surveyor Spacecraft operations at existing facility with DSN connectivity and existing cybersecurity authorization capability	Provider: Laboratory for Atmospheric and Space Physics (LASP), UC Boulder Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	Yes, trade study performed and LASP selected
NEO's Survey Data System (SDS)	Process, analyze, archive, and distribute NEO Surveyor instrument data.	Provider: Caltech IPAC Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Launch Vehicle	Launch vehicle and all launch services to deliver mission to orbit	Provider: TBD Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: Teledyne does not deliver a sufficient number of SCAs meeting flight requirements by schedule need dates due to production challenges, Then: There will be an impact to schedule/cost or technical margins.	The project began early SCA design work and completed flight pathfinder SCAs to develop and validate the build process, along with formally documenting the detector selection process. Margin assessment is ongoing to better understand threshold acceptance quality criteria. The team is working though testing the SCAs identified as flight and spare candidates and is waiting on output of additional SCA lots.

NEAR EARTH OBJECTS SURVEYOR

Formulation	Development	Operations

Risk Statement	Mitigation
If: Planned tests and model validation campaign is insufficient to produce a fully validated flight model due to the complexity of the individual tests and the difficulty of stitching test results together to emulate an end-to-end test, Then: The project will need additional cost and time to augment the model or replan the test sequence.	The project completed early risk reduction prototype activities and is developing a detailed test plan campaign, followed by a review of the test campaign focusing on test implementation, model validation, and detailed modeling of the test configuration. After these activities, the project will conduct a test readiness review prior to the testing and evaluate success criteria after each test result during testing.

Acquisition Strategy

JPL has initiated subcontracts for the major flight and ground support components. NASA contracted directly with UA for the survey director, investigation team and associated efforts, and focal planes. UA initiated subcontracts for the components of the focal plane and will deliver those to the flight project. NASA contracted directly with Caltech/IPAC for SDS.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Survey director, investigation team, and focal planes	University of Arizona	Tucson, AZ
Instrument CEA, CEU, and instrument I&T	Space Dynamics Laboratory (SDL)	Logan, UT
Instrument components, spacecraft bus, and observatory I&T	Ball Aerospace	Boulder, CO
Mission Operations	Laboratory for Atmospheric and Space Physics (LASP)	Boulder, CO

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	SRB	Feb 2025	CDR	TBD
Performance	SRB	Jul 2026	SIR	TBD

OTHER MISSIONS AND DATA ANALYSIS

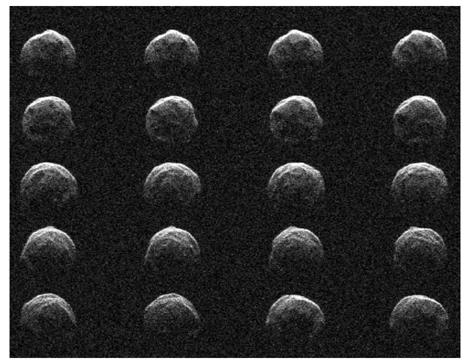
FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Double Asteroid Redirection Test	3.1	--	**0.0**	0.0	0.0	0.0	0.0
Near Earth Object Observations	42.4	--	**41.0**	42.0	42.0	42.0	42.0
Total Budget	**45.5**	**--**	**41.0**	**42.0**	**42.0**	**42.0**	**42.0**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Mission Planning and Other Projects

NEAR-EARTH OBJECT OBSERVATIONS (NEOO)



Shown here are the NASA Goldstone Solar System Radar observations of near-Earth asteroid 2006 HV5 on April 25, 2023, less than one day before a 1.5-million-mile-close approach with Earth. The radar images show it to be about 1,000 feet across, roughly the height of the Eiffel Tower, confirming size estimates from infrared observations collected by NASA's NEO Wide-Field Infrared Survey Explorer (WISE) mission. 2006 HV5 is classified as a potentially hazardous asteroid but currently poses no impact threat. (NASA/JPL-Caltech)

The NEOO project funds work that uses ground and space-based assets to search for Near-Earth Objects (NEOs) that have potential to collide with Earth and characterize them to assess if any could do significant damage at the surface of our planet. NEOs range in size from a few meters to approximately 34 kilometers. There are over 33,000 known NEOs, and over 10,600 of them are larger than 140 meters in size. NASA estimates that there are still over 14,000 NEOs left to find in this size range.

The NEOO project supports a network of activities including search and characterization observatories and the data processing and analysis required to understand the orbits and nature of the near-Earth population of small bodies. In accordance with the findings and recommendations of the Planetary Science and Astrobiology Decadal Survey (2022), as well as NASA's action plan in response to the White House's updated National Preparedness Strategy and Action Plan for Planetary Defense (2023), NASA continues to:

- Increase collection of NEO detection and characterization data by the Catalina Sky Survey, the Panoramic Survey Telescope and Rapid Reporting System (Pan-STARRS), and the United States Space Force’s (USSF) Space Surveillance Telescope.
- Support the operation of the four small telescope wide field survey sites called the Asteroid Terrestrial-impact Last Alert System (ATLAS), designed to detect smaller asteroids as they approach the Earth and warn of any imminent impact, two of which now operate at southern hemisphere sites.
- Support data processing and analysis activities critical for planetary defense: The Minor Planet Center (MPC), which is the internationally recognized repository for small body position measurements

operated as a sub-node of NASA's Planetary Data System Small Bodies Node, and the Center for Near-Earth Object Studies (CNEOS), which utilizes MPC data to calculate precise orbits for NEOs and identify any NEO impact threats to Earth.

- Support the continued and enhanced operation of planetary radar capabilities at NASA’s Goldstone Deep Space Network facility and support the processing and archiving of radar data from the decommissioned 305-meter telescope at the NSF’s Arecibo Observatory.
- Utilize NASA's Infrared Telescope Facility for targeted measurement of physical characteristics of NEOs.
- Support NEO research teams at multiple universities and space science institutes using their access to research telescopes to observe and characterize the nature of asteroids and comets which can closely approach Earth.
- Investigate both ground and space-based concepts for increasing capacity to detect, track, and characterize NEOs of all sizes.

Since NASA’s NEO search efforts started in 1998, NEOO research has found over 96 percent of the estimated population of these objects that are one kilometer and larger, and about 44 percent of all those larger than 140 meters in size. NEOs discovered and characterized by the project may also be viable targets for future robotic and human exploration, and possible eventual candidates for asteroid resource utilization operations.

The Infrared Telescope Facility (IRTF) is NASA’s infrared-optimized three-meter telescope at an altitude of 13,600 feet on the extinct volcano Mauna Kea on the Big Island of Hawai’i. The NEOO project fully funds IRTF operations, which is a primary NASA planetary defense asset for NEO physical characterization. IRTF continues its mission of strategic support of NASA flight missions and science goals in both planetary science and astrophysics while being on-call for rapid response observations of NEO targets of opportunity and potential threats.

Recent Achievements

The NEOWISE spacecraft orbit has been moving away from the ideal Sun-synchronous orbit alignment since the end of prime operations in 2010. In FY 2023, it completed its tenth year of operations since reactivation and engineers have closely monitored the temperatures and attitude of the spacecraft. Excessive heat would effectively blind the infrared detectors. Also, since NEOWISE has no orbital maintenance thrust capability, the orbital altitude continues to degrade into Earth's upper atmosphere, and it will lose sufficient attitude control to continue effective operations. NEOWISE operations will conclude by the end of July 2024.

The USSF Space Surveillance Telescope in Australia, a collaboration with the Royal Australian Air Force, began operational capability in 2022. The Lincoln Near-Earth Asteroid Research team initiated the data processing pipeline for detecting and retrieving asteroid positions from the data. The team discovered seven previously unknown NEOs in FY 2023 and they continue to work for full data transfer.

MPC continued service modernization efforts to accommodate an increasing volume of observations from current and future surveys. The MPC also increased communications to the worldwide observing community on data requirements and processing improvements through a monthly newsletter and detailed reporting at semi-annual International Asteroid Warning Network meetings.

CNEOS accurately predicted the impact locations of two very small asteroids that disintegrated harmlessly in Earth's atmosphere in FY 2023. Ground-based telescope teams first observed asteroid 2022

OTHER MISSIONS AND DATA ANALYSIS

WJ1 on November 19th, 2022, and 2023 CX1 on February 14th, 2023, only hours before their impacts due to their very small sizes. The CNEOS Scout system calculated and warned of the upcoming impacts using telescope data submitted to MPC. Civilian eyewitnesses and other observations of the harmless fireballs' time and position confirmed NASA's ability to accurately calculate asteroid trajectories and predict impacts.

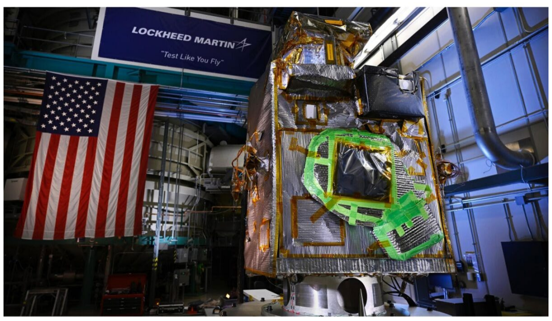
The IRTF held a successful PDR in FY 2023 for the new instrument Spectrograph Express to enhance IRTF's capability to characterize NEOs and enable other NASA science. Such improved NEO characterization capability addresses objectives called out in the national and NASA planetary defense strategies.

LUNAR DISCOVERY AND EXPLORATION

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
VIPER	97.2	69.3	**33.0**	0.0	0.0	0.0	0.0
Other Missions and Data Analysis	389.1	--	**425.3**	456.8	467.8	479.1	488.5
Total Budget	**486.3**	**--**	**458.3**	**456.8**	**467.8**	**479.1**	**488.5**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Shown here, NASA's Lunar Trailblazer sits in a clean room at Lockheed Martin Space in Littleton, Colorado, shortly after being integrated with its second and final science instrument, the Lunar Thermal Mapper. Green tape on the spacecraft will be removed before launch. Credits: Lockheed Martin Space

NASA's exploration strategy will provide an innovative and sustainable approach to scientific and human exploration, with commercial and international collaborators to enable human expansion across the solar system and bring new knowledge and opportunities back to Earth. The agency will achieve these accomplishments with emerging commercial capabilities and innovative approaches to achieving human and science exploration goals, including the return of humans to the Moon.

The Lunar Discovery and Exploration Program (LDEP) in SMD is a key component of the agency's exploration strategy and leads all science strategy, instrumentation development, and training for the human and robotic return to the Moon. LDEP establishes commercial contracts for lunar payload delivery and other related services through the Commercial Lunar Payload Services (CLPS) initiative; continues operations of the Lunar Reconnaissance Orbiter (LRO); and develops SmallSats, instruments, and other payloads that serve lunar science, long-term exploration, and utilization needs. LDEP also develops Artemis Deployed Instrument payloads to be delivered by astronauts on Artemis missions in addition to establishing the integrated lunar science strategy for the agency. LDEP will provide innovative investigations to enhance lunar exploration and science by developing technical capabilities and increased commercialization for an expanded range of lunar services. NASA is prioritizing capabilities that support lunar resource analysis and prospecting to inform future human space flight objectives. For example, LDEP will focus on instrumentation to advance knowledge and technologies for the use of local resources, such as lunar water ice. Working with the science and human exploration communities, our international partners, and U.S. industry, LDEP is defining the goals and objectives for a robust and sustainable lunar science program.

In collaboration with private industry and the scientific community, the program is developing lunar surface payloads (and supporting orbital payloads) along with cost-effective ways to deliver and provide services for these payloads delivered to the lunar surfaces through robotic or crewed lander systems. These payloads and services address the nation's lunar exploration, science, and technology demonstration goals. The recent National Academies of Sciences Decadal Survey (Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032) emphasized the need to

LUNAR DISCOVERY AND EXPLORATION

continue supporting commercial innovation and collaboration initiatives in order to accomplish lunar (and beyond) exploration and science initiatives. The Artemis Deployed Instruments activities will enable greater Artemis science in service of these community goals.

NASA purchases commercial transportation/delivery services to the Moon for NASA instruments and technology demonstration payloads. These transportation or delivery services include needed "utilities" from the commercial systems, such as power, communications, thermal control, launch integration, launch, cruise phase, and in most cases, operations at the lunar destination. In other cases, these services culminate in deployment of a NASA asset such as a rover to fulfill its own mission. In addition, NASA will pursue the purchase of science or engineering data provided by contractor systems, as well as the possibility of returning payloads and/or samples to the Earth. LDEP also makes these commercial lunar services available to other NASA mission directorates.

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA has established two new projects within this program: the Payloads and Research Investigations on the Surface of the Moon-4 (PRISM-4) project and the Artemis III Deployed Instruments (A3DI) project, which includes development of the first suite of Artemis crew-deployed instruments.

ACHIEVEMENTS IN FY 2023

NASA selected the PRISM-3 payload in July 2023. The Dating an Irregular Mare Patch with a Lunar Explorer (DIMPLE) instrument suite will investigate the Ina Irregular Mare Patch, discovered in 1971 in Apollo 15 orbital images. DIMPLE is a first-of-its-kind instrument suite that will date lunar materials in-situ to address outstanding questions about the evolution of the Moon, which in turn can provide clues to the history of the entire solar system. PRISM-2 instruments continue in development with both instruments completing early design reviews in FY 2023. The PRISM-1 Lunar Vertex instrument is now ready for integration and the other two PRISM-1 instruments are on schedule to be complete and ready for integration or storage in FY 2024.

CLPS contractors continue work toward nine existing delivery task orders for five deliveries in FY 2024, two deliveries in FY 2025, and two in FY 2026. NASA competitively selected additional robotic lunar surface science payloads through the PRISM solicitation and continued its two-per year minimum cadence of delivery awards. The next CLPS delivery award will include payloads in partnership with ESA. ESA's Lunar Pathfinder will be the first CLPS delivery into a lunar orbit. ESA and the Korea Astronomy and Space Science Institute (KASI) delivered their instrument flight hardware for CP-11 to IM, a Retroreflector, and the Lunar Space Environment Monitor (LUSEM) respectively.

VIPER entered Phase D, beginning mission system assembly, integration, and testing.

NASA made progress toward delivery and integration of Lunar Trailblazer with its rideshare on an IM delivery, which is now planned for launch in Q1 FY 2025.

NASA completed and delivered 24 of 25 lunar instrument selections from NASA Research Announcements for the Lunar Surface Instrument and Technology Payloads (LSITP) and NASA Provided Lunar Payloads (NPLP) solicitations. The 25th payload is complete and held in vacuum storage awaiting a CLPS contractor request to deliver for integration into their spacecraft.

LUNAR DISCOVERY AND EXPLORATION

NASA released the latest Development and Advancement of Lunar Instrumentation (DALI) solicitation in February 2023 with final proposals submitted in June 2023 and selections in November 2023. NASA released the A3DI solicitation in May 2023.

LRO continued to perform in extended operations and provide support for CLPS landing preparation and providing imaging of domestic and international lunar landing attempts.

WORK IN PROGRESS IN FY 2024

CLPS launched its first set of payloads on Astrobotic's Peregrine lander; however, a propulsion anomaly prevented the lander from attempting a landing on the Moon and it reentered Earth's atmosphere over the Pacific Ocean on January 18, 2024. IM conducted the second contracted CLPS landing utilizing the IM NOVA-C lander in Q2 FY 2024, carrying a total of six NASA payloads to the lunar south polar region. CLPS will deliver the STMD's Polar Resources Ice Mining Experiment-1 to the lunar South Pole region via the IM NOVA-C lander in Q3 FY 2024. Two additional CLPS deliveries to the lunar surface are on track to occur in mid/late-2024 and will include STMD's Electrostatic Dust Shield experiment, and the SOMD's Lunar Global Navigation Satellite System Receiver Experiment. The first PRISM-1 payload, Lunar Vertex, is set to land in April 2024, alongside the STMD Cooperative Autonomous Distributed Robotic Exploration rover and two international payloads, one from South Korea and the other from ESA. The remaining PRISM-1 payloads will also be complete and delivered to the vendor for integration onto the lander.

Lunar Trailblazer will be in its operations phase after delivery to lunar orbit by the second IM lander.

CLPS contractors will continue to work existing lunar instrument deliveries targeting FY 2025 launches. The VIPER team will integrate VIPER with Astrobotic at KSC in preparation for launch in November 2024. NASA will release the PRISM-5, solicitation, and A3DI instruments will begin development.

LRO operations will continue in support of scientific research and future science and exploration mission planning.

SMD has conducted scientific and technical panel reviews on the A3DI proposals leading to a selection in Q2 FY 2024.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

FY 2025 will see the largest CLPS delivery to date with the delivery and deployment of the VIPER mission at the lunar south polar region. CLPS also expects to be in later stages of preparation for the first dual-destination delivery of payloads to both the surface and orbit of the Moon in early FY 2026.

LDEP plans to make awards for PRISM-5 instrument suites, A4DI, and a CLPS task order for the delivery of two international partner payloads.

LUNAR DISCOVERY AND EXPLORATION

Program Schedule

Date	Significant Event
Q1 FY 2024	PRISM 4 (SALSA) Solicitation release
Q2 FY 2024	Scheduled delivery of payloads to the Moon by IM through CLPS*
Q2 FY 2024	A3DI Award
Q2 FY 2024	Lunar Terrain Vehicle Instrument Solicitation release
Q3 FY 2024	Scheduled delivery of PRIME-1 drill and mass spectrometer to southern lunar pole region by IM*
Q3 FY 2024	Artemis Handheld Instrument Solicitation release
Q3 FY 2024	Rideshare launch of Lunar Trail Blazer to lunar orbit coincident with an IM CLPS delivery*
Q3 FY 2024	Deliver VIPER to Astrobotic for integration onto the lander
Q4 FY 2024	Scheduled delivery of payloads to Reiner Gamma by IM through CLPS*
Q4 FY 2024	Scheduled delivery of payloads to Crisium Basin by Firefly Aerospace through CLPS*
Q1 FY 2025	Scheduled delivery of VIPER to lunar South Pole by Astrobotic through CLPS*

**NASA does not manage the launch vehicle portion of the CLPS effort and does not ultimately control final launch schedules of the selected providers that will deliver NASA and other provider-provided payloads. NASA will work with the CLPS vendors to ensure timely and successful launch and delivery of all science and technology payloads.*

Program Management & Commitments

SMD's Planetary Science Division and ARC manage the VIPER mission. The Planetary Science Division and JSC manage the CLPS initiative.

The Planetary Mission Program Office located at MSFC is responsible for managing the LRO and Lunar Trailblazer missions, as well as LSITP and PRISM instruments.

Program Element	Provider
LRO	Provider: GSFC Lead Center: MSFC, GSFC Performing Center(s): GSFC, JPL Cost Share Partner(s): N/A
Lunar Instruments	Provider: Various Lead Center: HQ Performing Center(s): N/A Cost Share Partner(s): N/A

LUNAR DISCOVERY AND EXPLORATION

Program Element	Provider
CLPS	Provider: Various Lead Center: JSC Performing Center(s): N/A Cost Share Partner(s): N/A
VIPER	Provider: ARC Lead Center: ARC Performing Center(s): ARC, JSC, KSC Cost Share Partner(s): N/A
DALI	Provider: Various Lead Center: HQ Performing Center(s): ARC, GRC, GSFC Cost Share Partner(s): N/A
PRISM-1	Provider: JPL, Applied Physics Laboratory (APL), Southwest Research Institute (SwRI) Lead Center: MSFC Performing Center(s): JPL Cost Share Partner(s): N/A
Lunar Trailblazer	Provider: California Institute of Technology Lead Center: HQ, MSFC Performing Center(s): JPL Cost Share Partner(s): N/A
Lunar Management	Provider: HQ, MSFC Lead Center: HQ, MSFC Performing Center(s): MSFC Cost Share Partner(s): N/A
PRISM-2	Provider: ARC, University of Central Florida (UCF) Lead Center: MSFC Performing Center(s): ARC Cost Share Partner(s): N/A
PRISM-3	Provider: Southwest Research Institute (SwRI) Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A

LUNAR DISCOVERY AND EXPLORATION

Acquisition Strategy

LDEP uses flexible contract mechanisms, such as indefinite-delivery-infinite-quantity (IDIQ) contracts, to enable the flexible and rapid procurement of commercial transportation services to deliver NASA scientific, exploration, and technology development payloads to the surface of the Moon, and to lunar orbit. NASA may expand lunar service requirements to include more capabilities, such as mobility or sample return.

In parallel, NASA uses its established solicitation mechanisms, such as the Research Opportunities in Space and Earth Science (ROSES), NASA Research Announcements (NRA) and the Stand-Alone Missions of Opportunity Notice (SALMON) Announcement of Opportunity processes, to select and develop exploration, scientific, and technology development payloads for delivery to the Moon. This is how NASA established the PRISM and Artemis Deployed Instrument payloads, which are solicited through the ROSES call. In some cases, NASA may direct a NASA center to develop a lunar capability or surface payload when it is in the government's best interest, such as when that capability supports multiple NASA applications or when a commercial entity or international stakeholder identifies a near-term opportunity for a lunar surface mission on a timeframe that does not support competitive selection. However, to the maximum extent possible, NASA will leverage competitive solicitations for science instrument procurement and commercial services.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Commercial Lunar Payload Services (2)*	Astrobotic Technology	Pittsburgh, PA
Commercial Lunar Payload Services (3)*	Intuitive Machines	Houston, TX
Commercial Lunar Payload Services (3)*	Firefly Aerospace	Cedar Park, TX
Lunar Trailblazer	California Institute of Technology	Pasadena, CA
Commercial Lunar Payload Services	Draper Laboratory	Boston, MA

** (#) denotes number of contract awards for landing services made to that vendor.*

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

FY 2025 Budget

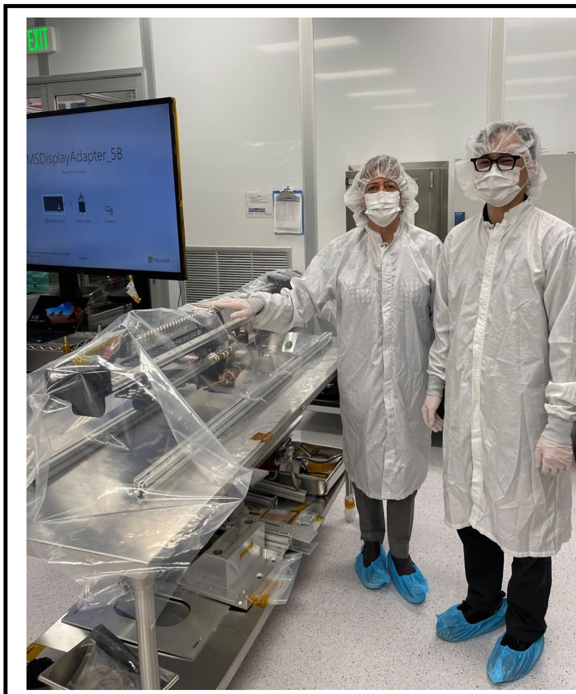
Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	80.1	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	80.1
Development/Implementation	225.8	97.2	69.3	**12.9**	0.0	0.0	0.0	0.0	0.0	405.1
Operations/Close-out	0.0	0.0	0.0	**20.1**	0.0	0.0	0.0	0.0	0.0	20.1
2024 MPAR LCC Estimate	**305.9**	**97.2**	**69.3**	**33.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**505.4**
Total Budget	**305.9**	**97.2**	**69.3**	**33.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**505.4**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

PROJECT PURPOSE

The Volatiles Investigating Polar Exploration Rover (VIPER) is a robotic lunar rover that will explore the relatively nearby, but extreme environment of the Moon, in search of water ice and other potential volatile resources. The suite of instruments will also address high priority science questions by providing information about the origin and distribution of water on the Moon and across the solar system. NASA will use the data the rover collects to determine where the Moon's water ice is most likely to be found and easiest to access, making VIPER the first-ever resource mapping mission on another celestial body. NASA can then use these maps to aid in the decision process for future lunar human space exploration, and beyond. The first water maps of the Moon will mark a critical step forward in NASA's Artemis program to establish a sustainable human presence on the surface of the Moon.



Pictured above is the actual Honeybee Robotics, The Regolith and Ice Drill for Exploring New Terrain (TRIDENT), drill that will fly on VIPER.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

PROJECT PARAMETERS

VIPER will operate for approximately 100 Earth-days to cover three cycles of lunar day/night near the western edge of Nobile Crater in the lunar South Pole region, with a scheduled FY 2025 arrival. VIPER is a remotely commanded, golf-cart sized rover delivered onto the Moon's surface via Commercial Lunar Payload Services (CLPS)-provided services. The CLPS delivery task order awardee will provide all services required to deliver NASA equipment to the Moon's surface, such as the launch, lander system, and lander operations. The CLPS initiative funds all costs associated with the delivery task order.

VIPER will explore Mons Mouton near Nobile Crater and will venture into some of the semi-permanent and permanently shadowed regions of the lunar South Pole to survey different ice-stability regions to detect and assess volatiles distributions and concentrations. To achieve its scientific goals, the rover will carry four instruments including a one-meter drill. Collectively, the instrument set will detect and analyze various lunar soil environments at a range of different depths and temperatures.

The VIPER drill, The Regolith and Ice Drill for Exploring New Terrain (TRIDENT), will excavate using an auger/percussion approach, which utilizes a hammering action in conjunction with a rotary motion, to extract down to a depth of one meter and deliver lunar regolith in small (10 centimeter) segments for vertical profiling.

The Neutron Spectrometer System (NSS) instrument will prospect for and map the distribution of hydrogen-rich materials while roving. NSS will be located on the front of the rover to have an unobstructed view of the lunar surface.

The Near InfraRed Volatiles Spectrometer System (NIRVSS) instrument will operate during roving or while drilling. The instrument will look for near real-time changes in the properties of the materials exposed. Using different wavelengths of light to illuminate the surface, the team will use NIRVSS to provide an additional means of surveying the surface and immediate excavation site for water and other volatiles, providing surface and regolith mineral context.

The Mass Spectrometer observing lunar operations (MSolo) instrument will operate during roving or while drilling. MSolo will identify low-molecular weight volatiles on the surface or from subsurface excavations. Working in concert with the NIRVSS instrument, the instruments will analyze volatiles from the materials delivered by the drill bit from a depth of up to one meter.

ACHIEVEMENTS IN FY 2023

The VIPER project successfully completed its System Integration Review in December 2022 and passed its KDP-D in June of 2023, which transitioned the project into the system assembly, integration, and test phase of development. The team completed development and testing of all four science instruments and delivered them to the rover for vehicle integration. ARC completed the Mission Operations Center with approval to begin flight-like engineering and operational simulations. The simulation activities continue into FY 2024.

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2024

VIPER will conduct its Pre-Ship Review (PSR) in the summer of 2024 and then ship the completed rover to the CLPS provider. After integration with the Griffin lander at KSC, the team will prepare the rover and lander for launch on the CLPS-provided launch vehicle.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

VIPER will launch no earlier than November 2024 and begin operations.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2025 PB Request
KDP-C	Feb 2021	Mar 2021
CDR	Nov 2021	Oct 2021
SIR	May 2022	Dec 2022
PSR/Ship to CLPS Provider	Jul 2023	Aug 2024
Launch Readiness	Nov 2023	Nov 2024
Initial Operational Capability	Nov 2023	Nov 2024

Development Cost and Schedule

The confidence level developed for VIPER confirmation is the result of a combination of analysis between an independent cost estimate and an independent schedule estimate.

Base Year	Base Year Develop-ment Cost Estimate ($M)	CL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (mths)
2021	336.2	70	2024	405.1	+24	IOC	Nov 2023	Nov 2024	+12

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

Development Cost Details

The CLPS project funds all costs associated with launch and landing. Launch vehicle costs reported here are for VIPER integration requirements.

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**336.2**	**405.1**	**+69.0**
Rover	92.2	185.8	+93.6
Payloads	22.8	35.0	+12.2
Systems I&T	15.7	65.2	+49.5
Launch Vehicle	1.8	3.6	+1.8
Ground Systems	37.1	61.2	+24.1
Science/Technology	7.2	12.4	+5.2
Other Direct Project Costs	159.4	42.0	-117.4

Project Management & Commitments

ARC manages the VIPER mission and provides systems engineering, project science, real-time rover surface operations, and flight software.

Element	Description	Provider Details	Change from Baseline
Project Office and Mission Management including Science, System Engineering, Safety and Mission Assurance	Overall mission planning and project management functions.	Provider: NASA Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Rover	A mobility and power platform hosting the VIPER instrument set, communication system, navigation, and other vehicular sub-systems for use to traverse the lunar surface.	Provider: NASA Lead Center: ARC Performing Center(s): JSC Cost Share Partner(s): N/A	N/A

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
TRIDENT	A percussion drilling instrument with force, displacement, and thermal sensors.	Provider: Honeybee Robotics Lead Center: ARC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A
NSS	Neutron Spectrometer instrument	Provider: NASA Lead Center: ARC Performing Center(s): ARC Cost Share Partner(s): N/A	N/A
NIRVSS	Near infrared spectrometer instrument	Provider: NASA Lead Center: ARC Performing Center(s): ARC Cost Share Partner(s): N/A	N/A
MSolo	Mass spectrometer instrument	Provider: NASA Lead Center: ARC Performing Center(s): KSC Cost Share Partner(s): N/A	N/A
Lander and Launch Vehicle	CLPS-provided lander and launch vehicle (not included in VIPER baseline)	Provider: Astrobotic Lead Center: JSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: VIPER needs to make unexpected design changes to enable payload accommodation with the CLPS vendor, Then: This could increase its LCC and schedule.	The VIPER project, CLPS office staff, and Astrobotic are in regular contact to develop interface requirements while maximizing system success. The NASA CLPS team augmented its insight approach and continues to assess payload accommodation approaches for VIPER to identify potential disconnects. The VIPER and the Astrobotic Griffin lander designs are more mature and there is significant collaboration on interfaces.

VOLATILES INVESTIGATION POLAR EXPLORATION ROVER

Formulation	Development	Operations

Risk Statement	Mitigation
If: VIPER mass allocation does not increase by 10Kg to bolster its current low mass margin of less than 2 percent for use to address actual flight hardware mass underestimation, Then: VIPER would have to descope a solar array, potentially complicating mission operations and increasing risk to full science mission success as well as causing a delay to the mission and increasing cost.	Project mass lead and rover leads continue to work the issue to identify any other opportunities to reduce mass and continue negotiations with the vendor on obtaining more mass allocation.

Acquisition Strategy

NASA is designing, developing, building, integrating, and testing most of the elements of VIPER at NASA centers. The VIPER rover at JSC, the NSS and NIRVSS instruments at ARC, and MSolo at KSC are all NASA in-house developments. The TRIDENT drill was competed and awarded to Honeybee Robotics.

NASA awarded a CLPS delivery task order contract to Astrobotic Technology Inc. of Pittsburgh, Pennsylvania to deliver VIPER to the Moon in late 2024. The current contract value is $320.4 million. In a CLPS delivery task order, the company provides all services required to deliver NASA equipment to the Moon's surface such as the launch, lander system, and lander operations. The CLPS initiative funds costs associated with the delivery task order, with the exception of a $4.8 million purchase of additional mass made by VIPER, already incorporated into the previously stated contract value.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

The VIPER Review Team (VRT) is an independent review team tasked to complete key lifecycle reviews for VIPER, as well as to engage the project team with more frequent, less formal, and more mentoring interactions.

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	VRT	Aug 2024	Operational Readiness Review	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Commercial Lunar Payload Services	242.3	--	**224.1**	254.4	254.5	259.5	259.5
Lunar Trailblazer	14.5	--	**3.3**	0.8	0.0	0.0	0.0
Lunar Instruments	15.8	--	**30.5**	49.7	72.9	84.3	85.0
Payloads and RI on Surface of Moon-1	29.3	--	**0.0**	0.0	0.0	0.0	0.0
Payloads and RI on Surface of the Moon-2	31.1	--	**6.2**	5.8	0.0	0.0	0.0
Payloads and RI on Surface of the Moon-3	1.5	--	**20.4**	12.4	3.8	1.3	0.0
Payloads and RI on Surface of the Moon-4	0.0	--	**12.5**	12.5	5.0	0.0	0.0
Artemis Instruments	2.1	--	**38.8**	40.5	31.0	33.0	33.0
Artemis III Deployed Instruments	0.0	--	**13.0**	2.5	0.0	0.0	0.0
Lunar Intl Mission Collaborations	0.2	--	**0.5**	0.5	0.5	0.5	0.5
Development and Advancement of Lunar Instrumentation (DALI)	14.5	--	**15.0**	15.0	15.0	15.3	15.3
Lunar Science	6.7	--	**21.6**	23.1	24.0	23.6	26.3
Lunar Management	4.6	--	**5.8**	5.9	6.0	6.1	6.7
Lunar Future	4.4	--	**11.4**	11.6	32.9	33.4	40.1
Lunar Reconnaissance Orbiter (LRO)	22.1	--	**22.1**	22.1	22.1	22.2	22.0
Total Budget	**389.1**	**--**	**425.3**	**456.8**	**467.8**	**479.1**	**488.5**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Shown here, teams with Astrobotic installed the NASA meatball decal on Astrobotic's Peregrine lunar lander on Tuesday, Nov. 14, 2023, at the Astrotech Space Operations Facility near KSC in Florida. Credit: NASA/Isaac Watson

Mission Planning and Other Projects

Other Missions and Data Analysis includes mission planning, small missions in development, instrument and technology development, operating missions, international collaborations, management activities, and funding for future instrument and mission selections.

COMMERCIAL LUNAR PAYLOAD SERVICES (CLPS)

CLPS is opening competition to U.S. commercial providers of space transportation services, with the strategic goal of supporting affordable commercial operations on and near the Moon, consistent with the National Space Transportation Policy and Commercial Space Act. CLPS consists of a multi-vendor catalog and a 10-year indefinite delivery, indefinite quantity contract. NASA manages this effort through task order competitions for specific lunar surface transportation services of payloads with NASA being one of several customers. NASA also collaborates with international partners on CLPS by manifesting international payloads on CLPS landers and receiving rights to the data and placement of U.S. scientists on the international science teams.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

CLPS now has nine commercial deliveries actively in work that will occur between FY 2023 and FY 2026. These commercial missions are also delivering payloads provided by customers other than NASA. See the list of commercial service company awardees in the Major Contract/Awards table of the Lunar Discovery and Exploration Program section of this document.

Firefly Aerospace won a second CLPS task order to deliver two agency payloads, as well as a communication and data relay satellite for lunar orbit, which is an ESA collaboration with NASA, called Lunar Pathfinder.

Astrobotic completed their Peregrine Mission 1 lunar lander as one of the first CLPS deliveries in March 2023, shipped to the United Launch Alliance (ULA) for integration onto the launch vehicle in October 2023, and launched in January 2023. A propulsion anomaly prevented the lander from attempting a landing on the Moon and it reentered Earth's atmosphere over the Pacific Ocean on January 18, 2024.

The first Intuitive Machines NOVA-C lander, designated IM-1, was completed in October 2023 and launched in Q2 FY 2024.

The Korea Astronomy and Space Science Institute delivered Lunar Space Environment Monitor (LUSEM) flight hardware to Intuitive Machines in September 2022, marking the first international payload delivered to NASA.

The Lunar Surface Electromagnetics Experiment (LuSEE)-Night teams completed preliminary designs of the instrument and are moving towards the critical design phase.

NASA selected the Lunar Advanced Filter Observing Radiometer for Geologic Exploration (LAFORGE) instrument in November 2022. LAFORGE is a collaboration with CSA to help develop interface requirements to use on their CLPS delivery. LAFORGE and CSA are collaborating on maturing systems developments across the payloads as they develop through the life cycle.

LUNAR TRAILBLAZER

NASA selected a SmallSat called Lunar Trailblazer from a Small Innovative Missions for Planetary Exploration (SIMPLEx) call in 2019. Lunar Trailblazer will spend one year orbiting the Moon at an altitude of 100 kilometers to generate a high-resolution map, at 100 meters per pixel, of the form, abundance, and distribution of water while collecting information about the environments where that water exists. Lunar Trailblazer will carry two instruments: a shortwave imaging spectrometer to search for signatures of water; and a multispectral thermal imager to map the temperature, physical properties, and composition of regions where the spectrometer detects water. These data will fill in gaps of our understanding of the distribution and composition of lunar volatiles and contribute to mission planning for future human exploration.

Recent Achievements

Lunar Trailblazer continued system assembly, test, launch and operations activities throughout 2023 and the spacecraft went into pre-ship storage in October 2023. Lunar Trailblazer is a rideshare on the launch of a lunar lander mission, Intuitive Machines IM-2, which will launch in Q1 FY 2025.

OTHER MISSIONS AND DATA ANALYSIS

LUNAR INSTRUMENTS

NASA is developing instruments and technology payloads to manifest on CLPS deliveries and international lunar lander missions. These instruments come from U.S. academia, industry, and from NASA centers. NASA has manifested NASA Provided Lunar Payloads (NPLP), Lunar Surface Instrument and Technology Payloads (LSITP), and Payloads and Research Investigations on the Surface of the Moon (PRISM) payloads on CLPS deliveries with launch and deliveries starting in December 2023 and continuing through FY 2026.

The LuSEE Night instrument builds on the smaller LuSEE instrument originally selected as an LSITP payload. The pathfinder measurements enabled by LuSEE-Night will be extremely valuable for understanding the lunar far side environment and the Dark Ages phase of the universe. LuSEE Night is a partnership between NASA and U.S. DoE. LuSEE-Night is manifested on a CLPS delivery scheduled to launch in late 2025.

LAFORGE is a U.S. lunar instrument development that will be on a CSA rover and serve as an imaging infrared radiometer to better create temperature maps in cold, permanently shadowed regions of the Moon. The Applied Physics Laboratory is leading the development.

Recent Achievements

NASA is nearing completion of development and delivery of payloads awarded in February and May of 2019. The 12 internally developed NPLP payloads are complete, and some delivered to CLPS providers for integration into their delivery systems while the others are in storage at a NASA center. The 12 academic- and industry- developed LSITP payloads are mostly complete and either delivered in place or delivered to vendors for their planned CLPS deliveries to the surface of the Moon. The remaining LSITPs have had their acceptance reviews and two potential payloads on a future Artemis mission. The remaining LSITPs are LuSEE Lite and MoonRanger. LuSEE Lite will have their acceptance review at the beginning of 2024. The team is assessing if MoonRanger is feasible to be manifest on an Artemis mission as opposed to a CLPS delivery. MoonRanger has completed its first pass on the feasibility requirements for deployment by crew on the lunar surface. One of the LSITP Next Gen Laser Retroreflectors may also deploy via Artemis III and has also passed the initial feasibility assessment.

PAYLOADS AND RESEARCH INVESTIGATIONS ON THE SURFACE OF THE MOON (PRISM) - 1

The PRISM instrument selections will continue to help NASA develop science-driven payloads for manifesting on future CLPS deliveries. NASA made the PRISM-1 selections in June of 2021 and will deliver these payloads to high science-value locations on the lunar surface as early as April 2024: the Reiner Gamma albedo swirl on the lunar nearside, and the Schrödinger Basin on the lunar far side. This innovative approach for soliciting science investigations and technology demonstration payloads for future deliveries by CLPS providers will enable decadal-caliber science at the Moon and support the Artemis campaign. The three PRISM-1 selections were: Lunar Vertex (LVx) which is a combination of stationary lander payloads and a rover that will make detailed measurements of the magnetic field, plasma environment, and regolith properties; Farside Seismic Suite (FSS) which will return NASA’s first lunar seismic data from the far side of the Moon; and Lunar Interior Temperature and Materials Suite (LITMS), a suite of two instruments which aims to investigate the heat flow and subsurface electrical conductivity structure of the lunar interior in Schrödinger Basin. LVx is on the CLPS manifest awarded to Intuitive Machines with lunar surface delivery of these payloads no earlier than April 2024. FSS and LITMS are both manifested on a CLPS delivery awarded to Draper Laboratory. Draper will deliver these PRISM science investigations to the far side of the Moon in 2025.

Recent Achievements

The LVx instruments on the static lander are complete and ready for integration onto the Intuitive Machines IM-3 NOVA-C lander. The LVx Rover team prepared for thermal vacuum testing at the Applied Physics Laboratory. FSS started final testing protocols to be complete by February 2024. Similarly, LITMS is also on track to be complete by February 2024. Both FSS and LITMS will go into storage awaiting integration onto the CLPS Task Order CP-12 vendor Draper in late 2025.

PAYLOADS AND RESEARCH INVESTIGATIONS ON THE SURFACE OF THE MOON (PRISM) - 2

CLPS will deliver the PRISM-2 selections to the lunar South Pole and the Gruithuisen Domes. The solicitation focused on environmental monitoring at the south polar region, which will support Artemis crewed missions. The Gruithuisen Domes delivery is to a region of silicic late-stage volcanism and will help us understand the volcanic history of the Moon. NASA selected the PRISM-2 science instrument suites in July 2022. The Lunar Vulkan Imaging and Spectroscopy Explorer (Lunar-VISE) investigation consists of a suite of five instruments, two mounted on a stationary lander and three on a mobile rover provided as a service by the CLPS vendor. The Lunar Explorer Instrument for space biology Applications (LEIA) science suite is a small CubeSat-based device. LEIA will provide biological research on the Moon by delivering yeast to the lunar surface and studying its response to radiation and lunar gravity.

Recent Achievements

On July 10th through July 11th, 2023, the Lunar-VISE team conducted a Technical Interchange Meeting similar to a PDR and determined that the early design is at an acceptable level of risk. The team subsequently also conducted the CDR in December 2023, confirming maturity of the design for mission implementation.

LEIA conducted the CDR in August 2023 and matured the design that fed into the lander requirements for the CLPS CP-22 Task Order Request for Proposals, awarded in December 2023.

PAYLOADS AND RESEARCH INVESTIGATIONS ON THE SURFACE OF THE MOON (PRISM) - 3

The PRISM-3 solicitation allowed proposers to select their own landing sites, justified by the proposed science investigation and associated instrument suites at a landing site within plus or minus 75 degrees of the lunar equator. Delivery to the lunar surface will be by a CLPS provider in 2027.

Recent Achievements

NASA selected the PRISM-3 payload in July 2023. The Dating an Irregular Mare Patch with a Lunar Explorer (DIMPLE) instrument suite will investigate the Ina Irregular Mare Patch. DIMPLE will date lunar materials in-situ to address questions about the Moon's evolution, which can provide clues to the history of the entire solar system. DIMPLE held their kick-off meeting on August 8th, 2023.

OTHER MISSIONS AND DATA ANALYSIS

PAYLOADS AND RESEARCH INVESTIGATIONS ON THE SURFACE OF THE MOON (PRISM) - 4

NASA release the PRISM-4 solicitation in February 2024 which solicits for individual instruments that are destination agnostic across the lunar surface. These instruments will fly on CLPS deliveries in conjunction with other science investigations and/or contributions from other NASA mission directorates or international partners. NASA expects to select up to four instruments for delivery to the lunar surface by a CLPS provider in the 2027-2028 timeframe.

Recent Achievements

NASA will release the PRISM-4 solicitation with ROSES 2024 in February 2024 with selections expected in the fourth quarter of FY 2024.

ARTEMIS INSTRUMENTS

Artemis Instruments will specifically support science on the upcoming Artemis missions, beginning with Artemis III, currently scheduled for launch in FY 2025. These instruments will consist of surface-deployed instruments coupled to a central power/communications station (analogous to Apollo lunar surface experiment) or designed as a stand-alone instrument suite independent of lander/vehicle support. Some of these planned instruments are extra-vehicular activity astronaut-handheld instruments to enhance geological fieldwork/operations. This project includes funding for all future Artemis mission deployed instrument selections.

ARTEMIS III DEPLOYED INSTRUMENTS

NASA released the Artemis III Deployed Instruments solicitation in May of 2023 with selections planned to occur in February 2024. These instrument selections are based on their ability to be scientifically relevant at any of the current 13 lunar surface destinations identified for Artemis III and their ability to be ready for the Artemis III launch timeframe of late 2025.

LUNAR INTERNATIONAL MISSION COLLABORATION

In developing collaborations with our international partners, NASA funds U.S. participating science investigators and provides international collaborators with lunar landing site characterization data, as well as navigation and data relay services, in exchange for U.S. participation. Participation includes establishing U.S. scientists on the international instrument team, access to data returned from the mission, and assurance that participating scientists will publicly archive returned data in a manner consistent with NASA policies. NASA is also providing science instruments to fly on international missions. NASA contributed a Laser Retroreflector Array (LRA) to the ISRO's Chandrayaan-3 mission and an LRA to the JAXA's smart landing technology demonstration mission, expected to land in 2024. NASA is planning to contribute a Neutron Spectrometer to the JAXA Lunar Polar Exploration Mission (LUPEX) rover, which is a partnership between JAXA and ISRO. NASA is also supporting extended operations for the NASA ShadowCam instrument on the Korean Lunar Pathfinder (KPLO).

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

ISRO's Chandrayaan-3 mission successfully landed on the lunar South Pole in August 2023 carrying the NASA LRA which is now set for future laser ranging requirements. NASA's ESDMD built ShadowCam and funded prime operations, and beginning in January 2024, management and extended operations were transferred to and funded by this project.

The NSS build for LUPEX started and NASA will deliver it to JAXA in time for their 2026 mission.

Exploration Science Strategy and Integration Office (ESSIO) has taken over operations for the KPLO ShadowCam instrument in January 2024 and will support Artemis and CLPS mission planning with new maps of the permanently shadowed regions on the South Pole of the Moon.

DEVELOPMENT AND ADVANCEMENT OF LUNAR INSTRUMENTATION (DALI)

DALI focuses on advancing the development of spacecraft-based instruments that show promise for use in future lunar missions, including expected commercial ventures. DALI activities develop and demonstrate lunar science instruments to the point where principal investigators may propose their use in response to future announcements of flight opportunity without additional extensive technology development. DALI focuses on instruments with technology readiness levels (TRLs) four through six and may solicit for new technologies related to specific science gaps such as astronaut handheld instrument technologies.

Recent Achievements

NASA released the DALI 2023 NASA Research Announcement (NRA) in February 2023 and made five selections. NASA will release the DALI 2024 solicitation in February 2024 and make up to five more selections. To date, NASA has awarded 30 technology development efforts.

LUNAR SCIENCE

NASA is maximizing the lunar science achieved in this era of lunar exploration through science planning support for Artemis architecture formulation, including support for tool development and astronaut geology training. This project also supports Artemis-specific curation activities to prepare for the return of new lunar samples, such as those containing volatiles or requiring cold curation. It supports surface operations development, including analog activities to help NASA develop a real-time science support room structure and science team integration. In addition, targeted research and analysis funding will prepare the lunar community to take maximum advantage of data and samples from Artemis and CLPS.

Recent Achievements

In March 2023, NASA announced the selection of project scientists for Artemis III and IV. In August NASA selected an external geology-focused science team for Artemis III. They will work with the NASA Artemis Internal Science Team to define the geologic science objectives and sampling strategy and to provide real-time science support to the Artemis III crew during Extravehicular Activity's (EVA) on the lunar surface. In preparation for Artemis II, the Geology Training Team provided lunar fundamentals classroom training to the Artemis II crew.

OTHER MISSIONS AND DATA ANALYSIS

LUNAR MANAGEMENT

The Planetary Missions Program Office (PMPO) at MSFC manages Planetary Science flight projects that are not part of the Mars Exploration Program, including elements of the LDEP portfolio, such as the LSITP and PRISM payloads selected for lunar delivery by CLPS landers as well as Artemis Instruments awards. PMPO provides programmatic, technical, and business management of these LDEP activities. Lunar Management also includes support for review boards and external technical support as needed and future mission studies.

LUNAR FUTURE

Lunar Future supports future activities, studies, instruments, and missions to help NASA achieve human and science exploration goals, including the return of humans to the Moon. In 2022, the Planetary Science and Astrobiology Decadal Survey identified potential new strategic missions to accomplish on the Moon. NASA will perform studies to address these potential strategic missions as defined in the Decadal alongside other strategic goals for science near and on the Moon.

Recent Achievements

NASA funded two studies in FY 2023. The Endurance A lunar rover mission studies support the Decadal recommendation to address the highest priority lunar science. NASA also supported studies for a potential next generation LRO follow-on mission as well as kicked off a National Academies of Science, Engineering, and Medicine study for science to complete from the Mars' surface with crew.

Operating Missions

LUNAR RECONNAISSANCE ORBITER (LRO)

The LRO mission continues to conduct priority science investigations and acquire valuable data sets that provide support for commercial lunar deliveries under the CLPS project and for human exploration. LRO has contributed to a new understanding of the Moon and its evolution, which provides a foundation for understanding all other objects in our solar system, as well as solar systems beyond our own. LRO's investigations include a focus on lunar volatiles like ice and water and can help scientists answer questions about the nature of these volatiles. LRO has also been characterizing the thermal history of the Moon by identifying unusual volcanic features that may be geologically young, as well as tectonic features that reflect the continued gravitational pull from the Earth. Scientists use the instrument suite on LRO to characterize the rate at which volatiles move across the surface, the development of the regolith on different terrains, and the location and composition of unusual rock types on the surface.

LRO's ongoing characterization of the lunar surface ultimately enables and reduces risk associated with commercial and human exploration initiatives. Through 2024, LRO will characterize areas that may contain volatiles at or near the surface as well as landing sites for upcoming U.S. commercial lunar lander missions. LRO is also providing data products to support current and future Artemis missions.

Recent Achievements

LRO, now in its 14th year of operation, has provided over 1.6 petabytes of lunar data to the Planetary Data System, which comprises about half of all planetary data ever acquired. LRO acquired data to support upcoming CLPS missions and has supported STMD and industry communications, as well as

OTHER MISSIONS AND DATA ANALYSIS

navigation experiments in support of Artemis and commercial lunar infrastructure. LRO components are past their original designed lifespan, but the LRO team continues to develop operational workarounds to accommodate the aging systems and the fuel, which are estimated to last into 2027.

LRO continues to provide relevant data to the science and exploration communities to science campaign planning and surface characterization, enhancing safety for crewed and robotic missions.

LRO imaged the failed landing of Russia's Luna 25 lander and the successful Indian Vikram lander with its LRO Camera (LROC) imaging system.

DISCOVERY

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
DAVINCI	20.2	--	**40.1**	116.4	209.0	295.9	321.9
VERITAS	9.5	--	**36.1**	104.9	177.7	232.1	267.2
Other Missions and Data Analysis	187.7	--	**185.3**	197.0	201.3	262.7	323.3
Total Budget	**217.5**	**--**	**261.5**	**418.3**	**588.0**	**790.8**	**912.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Shown here, a SpaceX Falcon Heavy rocket with the Psyche spacecraft onboard is launched from Launch Complex 39A, Friday, October 13, 2023, at NASA's KSC in Florida. NASA's Psyche spacecraft will travel to a metal-rich asteroid by the same name orbiting the Sun between Mars and Jupiter to study its composition. Credit: NASA/Aubrey Gemignani

NASA's Discovery program supports competitively selected, investigator-led Planetary Science missions to explore the planets, their moons, and small bodies such as comets and asteroids. With a lower mission cost cap than most of NASA's other planetary missions, Discovery provides scientists the opportunity to propose innovative ways to unlock the mysteries of the solar system.

Discovery missions Lucy and Psyche are in prime operations and the Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) and Venus Emissivity, Radio Science, InSAR, Topography and Spectroscopy (VERITAS) missions are in formulation.

The Discovery program also supports the development of instruments that NASA contributes to foreign-led missions, such as the STart from a ROtating FIeld mass spectrOmeter (STROFIO) instrument on the BepiColombo mission. NASA has a partnership with JAXA for two contributions to its Martian Moons eXploration (MMX) mission, including the Mars-moon Exploration with Gamma rays and Neutrons (MEGANE) instrument and a pneumatic sampler (P-Sampler). NASA is contributing the Venus Synthetic Aperture Radar (VenSAR) instrument to the ESA's EnVision mission.

The Discovery 2019 Announcement of Opportunity (AO) had a cost-cap of $500 million in FY 2019, excluding launch vehicle and mission operation costs. Launches have been separated by an average of 43 months since the launch of the Gravity Recovery and Interior Laboratory mission in 2011 through the latest planned launch of DAVINCI in the 2031-2032 timeframe. The Discovery Program also supports research based on completed Discovery missions, develops technology for potential missions to investigate planetary science priorities including Venus, and solicits SmallSat missions through the Small Innovative Missions for Planetary Exploration (SIMPLEx) effort.

DISCOVERY

EXPLANATION OF MAJOR CHANGES IN FY 2025

This budget supports the VERITAS mission to launch during an available Venus opportunity in 2031-2032. NASA reduced the future Discovery and Planetary SmallSat budgets which will delay the release of the next Discovery and SIMPLEx AOs to no earlier than FY 2026. This budget also delays the DAVINCI mission launch from 2029 to an available Venus opportunity in the 2031-2032 timeframe.

ACHIEVEMENTS IN FY 2023

Psyche continued work on the guidance, navigation, and control flight software and in other project areas, such as operational readiness, in preparation for its successful launch in October 2023.

MEGANE completed the flight unit for shipment to JAXA in FY 2024.

Scientists are continually optimizing the STROFIO instrument on the JAXA BepiColombo spacecraft, currently enroute to Mercury, before its planned orbit insertion in 2025.

The DAVINCI mission successfully completed its Mission Requirements Review and System Requirements Review (SRR) for the Venus Mass Spectrometer.

VERITAS science team members conducted an analog field campaign in Iceland to characterize radar and spectroscopy properties of volcanic and tectonic features in conjunction with DLR S/X-band airborne measurements, collecting samples for further laboratory studies. The measurements will help interpret images that will be collected by VERITAS during its science mission.

The VenSAR project developed its unique science requirements, the basis for NASA's Level 1 requirements, based on the EnVision science mission objectives. The NASA team also negotiated its interface requirements with the ESA EnVision mission team. The VenSAR project updated its project plan in key areas such as mission assurance, risk management, acquisitions, technology development, and cybersecurity. These efforts led to the successful completion of the ESA VenSAR Instrument SRR in June 2023 and the NASA VenSAR SRR / Instrument Definition Review in July 2023.

During Q1 FY 2023, the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) Mars lander managed to continue operations with extremely reduced energy production, enabling the recording of the last marsquake of the mission on Sol 1415. Unfortunately, telemetry from December 15, 2022, indicated significant battery voltage problems, and the lander did not respond on the next communications attempt on December 18. After the next missed communications attempt on December 20, 2022, NASA declared the end of InSight surface operations.

WORK IN PROGRESS IN FY 2024

Psyche, launched on October 13, 2023, successfully completed on-orbit checkout, and entered operations at the start of its cruise phase in November 2023.

On November 1, 2023, Lucy executed its first fly-by encounter observation of the small main belt asteroid Dinkinesh. This encounter completed an engineering risk reduction test of the Terminal Tracking System to fully exercise Lucy's instrument suite. The experience from the Dinkinesh observation also helped prepare the team for the upcoming Donaldjohanson fly-by encounter planned for the spring of 2025.

The MEGANE instrument shipped to JAXA in Q1 FY 2024 and began spacecraft integration and testing in preparation for a 2026 launch to Mars on the JAXA H3 launch vehicle.

DISCOVERY

The joint NASA and ESA EnVision Science Study Team (SST) developed the mission profile for ESA's Mission Adoption Review in December 2023, and ESA's formal mission adoption in January 2024. The VenSAR science team continues to help guide the radar instrument development. VenSAR will transition to preliminary design and technology completion activities at a KDP-B in Spring 2024.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

Psyche will begin the second phase of testing of the Deep Space Optical Communication technology demonstration on board the spacecraft. Lucy will perform a flyby of the asteroid Donaldjohanson and use the encounter to further test the spacecraft's instruments. Science operations will begin with the MEGANE instrument.

VERITAS will resume project activities in FY 2025 after the stand-down of FY 2024. The project will reengage with international partners with status reviews and restart the contract with the spacecraft contractor Lockheed Martin, in preparation for the Mission System Review in December 2026.

The VenSAR project will hold the PDR with a NASA Standing Review Board (SRB) at the end of FY 2025.

Program Schedule

Date	Significant Event
Oct 2023	Psyche Launch
FY 2024	MEGANE shipped to JAXA for integration with the spacecraft EnVision Mission Adoption and VenSAR Transition to Phase B (KDP-B)
FY 2025	Lucy fly-by encounter of mid-sized asteroid (Donaldjohanson) in the main asteroid belt EnVision Mission SRR and VenSAR PDR
FY 2026	NET Release of Discovery and SIMPLEx AOs VERITAS Mission System Review

Program Management & Commitments

The Discovery Program is a multiple-project program, with responsibility for implementation assigned to the Planetary Missions Program Office, located at MSFC.

The present launch cadence, calculated from 2011 through 2030, is about 43 months, with variations in the average time between launches from nine to 80 months.

Acquisition Strategy

NASA competitively selects new Discovery missions, releasing AOs when available funding allows.

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**20.2**	**--**	**40.1**	**116.4**	**209.0**	**295.9**	**321.9**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

PROJECT PURPOSE

Shown here is an artist's rendition of the DAVINCI probe descent to Venus.

The DAVINCI mission will provide a new understanding of Venus to help reveal the extent of potential habitability in our inner solar system. The DAVINCI mission addresses three overall goals:

- Understand the origin and evolution of the Venus atmosphere;
- Understand the atmospheric composition and its interaction with the surface; and
- Provide insights into the properties of the unique, highly deformed, high elevation geological surface features which are some of the oldest materials on Venus.

DAVINCI will help scientists answer comparative planetology questions within our solar system such as: How and why are Venus, Mars, and Earth different? And how does Venus compare to Earth-sized exoplanets? DAVINCI will help scientists address questions about the interactions of Venus's atmosphere and surface features. Four instruments in the Descent Sphere "probe" will address the mission's first two goals, making measurements of the current composition of Venus's atmosphere while the probe moves through the atmosphere to the surface of the planet. Lastly, DAVINCI will help scientists address questions about tesserae, some of the oldest geological features on the planet, such as how they formed. Two imagers, one on the probe and another on the spacecraft, will help answer these questions.

EXPLANATION OF MAJOR CHANGES IN FY 2025

Given budget constraints in FY 2025, this budget request reduces DAVINCI funding and delays the mission launch from 2029 until an available Venus opportunity in the 2031-2032 timeframe. Further mission planning in the coming year will determine a more definitive mission schedule.

PROJECT PRELIMINARY PARAMETERS

The mission consists of a spacecraft and a probe. The spacecraft will track motions of the clouds and map surface composition by measuring heat emission from Venus's surface that escapes to space through the massive atmosphere. The probe will descend through the atmosphere, sampling its chemistry as well as

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

the temperature, pressure, and winds. The probe will also take the first high-resolution images of Alpha Regio, an ancient highland twice the size of Texas with rugged mountains, looking for evidence that past crustal water influenced surface materials.

The instruments on the spacecraft include the Venus Imagining System for Observational Reconnaissance (VISOR) and the Compact Ultraviolet to Visible Imaging Spectrometer (CUVIS), a technology demonstration opportunity. VISOR will sense heat from Venus's surface emerging from beneath the clouds, provide insights to better understand the composition of the diverse geological highlands region and, study clouds in the ultraviolet. CUVIS will test new technologies to help identify a mysterious atmospheric compound (colloquially, the "unknown absorber") that soaks up half the incoming sunlight.

The probe will carry a suite of instruments into the Venus atmosphere to characterize the atmosphere and surface. These instruments include: the Venus Mass Spectrometer (VMS), to study the atmosphere; the Venus Tunable Laser Spectrometer (VTLS), to measure atmospheric isotopes to find clues to Venus's past; the Venus Atmospheric Structure Investigation (VASI), to measure pressure, temperature, and wind speed during the probe's descent; the Venus Descent Imager (VenDI), to take ultraviolet images of cloud motion and capture near-infrared images of the Venus surface that will help scientists determine its composition; and a student collaboration experiment called Venus Oxygen Fugacity Experiment (VfOx), to measure oxygen in the lowest part of the atmosphere.

Launch is notionally planned for 2031-2032, with two flybys of Venus prior to the probe’s descent. The flybys are the initial phase of the remote-sensing mission to study the atmospheric circulation and map the surface composition. Approximately two years later, the spacecraft will release the probe to conduct its investigation of the atmosphere during a descent that will last about an hour before landing at Alpha Regio. The planned mission data return is about 65 gigabits, with up to 500 descent images, hundreds of trace gas spectra, millions of Ultraviolet (UV) spectra, and thousands of near-infrared nightside images. The total mission duration after arrival at Venus is two years and one month.

ACHIEVEMENTS IN FY 2023

The DAVINCI project successfully completed their Mission Requirements Review in May 2023, evaluating the requirements for the mission. In June 2023, the project successfully completed the VMS System Requirements Review. Additionally, during FY 2023 the project completed several engineering trade studies.

WORK IN PROGRESS IN FY 2024

The DAVINCI project will continue to place emphasis on completion of System Requirements Reviews to evaluate the requirements for the instruments and flight system. Additionally, the instruments will focus on PDRs to demonstrate that their designs meet requirements with acceptable risk and within the cost and schedule constraints.

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The DAVINCI project will continue activities to mature the mission's preliminary design.

ESTIMATED PROJECT SCHEDULE

The DAVINCI schedule is currently under evaluation. The dates shown below are notional and subject to change.

Milestone	Formulation Authorization Document	FY 2025 PB Request
Formulation Authorization	N/A	Jun 2021
PDR	N/A	NLT 2028
KDP-C	N/A	NLT 2028
CDR	N/A	NLT 2030
SIR	N/A	NLT 2031
KDP-D	N/A	NLT 2031
KDP-E	N/A	NLT 2032
Launch	N/A	NLT 2032

Formulation Estimated LCC Range and Schedule Range Summary

LCC estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or PDR. The information in the table below represents estimates for Phase B; mission cost and schedule are now under review to align with the budget.

KDP-B Date	Estimated LCC Range ($B)	Key Milestone	Key Milestone Estimated Date Range
Jun 2021	1.2 - 1.6	LRD	Jun 2029

Project Management & Commitments

The Principal Investigator for DAVINCI is from GSFC. GSFC also manages the mission and will provide systems engineering, safety and mission assurance, project scientists, flight dynamics, payload management, and mission system management.

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

Element	Description	Provider Details
DAVINCI Spacecraft	Spacecraft delivers the descent sphere and hosts two instruments. Spacecraft's most important role is to deliver the descent sphere and then relay its data back to Earth.	Provider: Lockheed Martin Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A
Descent Sphere	One-meter diameter probe that falls through Venus' atmosphere making continuous measurements to the planet's surface.	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
VASI Instrument	Descent sphere instrument to characterize the structure and dynamics of Venus atmosphere (approximately every 15 minutes from 67 km to surface)	Provider: Johns Hopkins University (JHU) /Applied Physics Laboratory (APL) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A
VMS	Descent sphere instrument to survey the planet’s noble gases and their isotopes, as well as trace gases	Provider: GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A
VenDI	Descent sphere instrument (broadband and narrowband NIR) to image Venus from approximately 38 km down to the surface to define topography and composition	Provider: Malin Space Science Systems Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A
VTLS	Descent sphere instrument to discriminate chemical processes in upper clouds and near surface environment (10 ingests), including the deuterium/hydrogen ratio	Provider: JPL Lead Center: GSFC Performing Center(s): JPL Cost Share Partner(s): N/A
VISOR	Spacecraft instrument to image full disk upper atmosphere in UV (movies) and one µm nightside emissivity (highlands)	Provider: Malin Space Science Systems Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A
VfOx	Descent sphere instrument (solid-state sensor) to measure O2 partial pressure in lower atmosphere, student collaboration	Provider: JHU/APL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

Element	Description	Provider Details
CUVIS	Spacecraft technology demonstration instrument (UV spectrometer) to determine chemistry of upper clouds and mystery absorber	Provider: GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A
Launch Vehicle	Launch vehicle and all launch services	Provider: TBD Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A

Project Risks

Risk Statement	Mitigation
If: Supply chain issues throughout the industry cause increases to total cost and lead times for items such as Electrical, Electronic and Electromechanical parts, Then: There could be impacts to overall mission cost and schedule.	The project will continue to assess priorities between acquisitions and design maturation to accommodate impacts from supply chain disruption.

Acquisition Strategy

NASA competitively selected the DAVINCI mission through a Discovery 2019 Announcement of Opportunity (AO). The major elements of the mission and spacecraft are as proposed for the AO, including the prime contract with Lockheed Martin. NASA will competitively select the launch vehicle through the NASA Launch Services Program.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft	Lockheed Martin	Denver, CO
Navigation analysis	KinetX	Tempe, AZ
VMS instrument electronics	University of Michigan	Ann Arbor, MI
Venus Test Chamber development	National Technical Systems, Inc	Huntsville, AL
VASI instrument development	JHU/APL	Laurel, MD

DEEP ATMOSPHERIC VENUS INVESTIGATION OF NOBLE GASES, CHEMISTRY & IMAGING

Formulation	Development	Operations

INDEPENDENT REVIEWS

The DAVINCI schedule is currently under evaluation. The dates shown below are notional and subject to change.

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	SRB	NLT 2028	PDR	TBD
Performance	SRB	NLT 2030	CDR	TBD
Performance	SRB	NLT 2031	SIR	TBD
Performance	SRB	NLT 2032	ORR	TBD

VENUS EMISSIVITY, RADIO SCIENCE, INSAR, TOPOGRAPHY, AND SPECTROSCOPY

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**9.5**	**--**	**36.1**	**104.9**	**177.7**	**232.1**	**267.2**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

PROJECT PURPOSE

The Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) mission will map Venus's surface to determine the planet's geologic history and why it developed so differently than Earth. Orbiting Venus with a synthetic aperture radar, VERITAS will chart surface elevations over most of the planet to create 3D reconstructions of topography and confirm whether processes such as plate tectonics and volcanism are still active on Venus.

Shown here is an artist's conception of the VERITAS spacecraft design.

VERITAS will also map infrared emissions from Venus's surface to map its rock type, which is largely unknown, and determine whether active volcanoes are releasing water vapor into the atmosphere.

Understanding planetary habitability requires identifying the factors that govern the surface environment over time. Venus very likely had characteristics essential to life, such as surface oceans and a protective magnetic field. And it may still have tectonism and volcanism, which are key to sustaining the atmospheric and surface chemical disequilibria needed to fuel life. What caused Venus, which has so many similarities to Earth, to diverge down such a different evolutionary path? To answer this question, the VERITAS mission will create high resolution data sets of topography, imagery, spectroscopy, and gravity. The combined observations will provide a new view of Venus as a control case for planetary evolution relevant not only to understanding how the Earth developed and maintained conditions suited for life, but also constraining habitability studies of exoplanets.

NASA selected VERITAS as a Discovery mission in June 2021 from the 2019 Discovery Announcement of Opportunity (AO). The mission has significant contributions from ASI, National Center for Space Studies (CNES-France), and DLR.

VENUS EMISSIVITY, RADIO SCIENCE, INSAR, TOPOGRAPHY, AND SPECTROSCOPY

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2025

VERITAS will resume project activities in FY 2025 after NASA directed the project to stand down in FY 2024.

PROJECT PRELIMINARY PARAMETERS

VERITAS will target a launch during an available Venus opportunity in 2031-2032 and conduct a three-year science mission operating from a polar orbit around Venus. The Venus Interferometric Synthetic Aperture Radar (VISAR) on VERITAS will deliver a long-awaited digital elevation model at 250-meter horizontal postings by six-meter height accuracy, image the planet at 30-meter and 15-meter resolution, and provide the first interferometric deformation maps of activity on another planet. The Venus Emissivity Mapper (VEM), an instrument from DLR, will deliver near-global, high signal-to-noise ratio (SNR) maps of Venus emissivity using six surface spectral bands to provide detailed information on surface rock type and current and recent volcanism. The mission also includes a gravity science investigation using the spacecraft telecommunication system that will provide the first estimate of core size and state, as well as crustal elastic thickness and heat flow.

ACHIEVEMENTS IN FY 2023

In FY 2023 NASA directed VERITAS to stand down in FY 2024 and delay the launch date by at least three years from the original December 2027 Launch Readiness Date (LRD). The project conducted mission design studies to determine future feasible launch opportunities and delivered to NASA comprehensive re-plan options, including plans for the stand-down period. In addition, VERITAS worked diligently with the international partners (ASI, CNES, DLR) to determine their continuation options and proposed re-phased development plans to enable a successful resumption of VERITAS activities.

ASI completed their Phase B work, including the completion of three PDRs for the High Gain Antenna (GHA), Integrated Deep Space Transponder, and Radio frequency (RF) Low Power Amplifier. Working with DLR, the VERITAS project also completed the Venus Emissivity mapper (VEM) Filter PDR and the VEM detector radiation testing.

VERITAS science team members conducted an analog field campaign in Iceland to characterize radar and spectroscopy properties of volcanic and tectonic features in conjunction with DLR S/X-band airborne measurements, collecting samples for further laboratory studies. The measurements will help interpret similar images that will be collected by VERITAS during its science mission. The team made progress on a Venus emissivity spectral library development in support of VEM Instrument data interpretation. VERITAS Science team members conducted a workshop in May 2023, which included DAVINCI and ESA EnVision mission participants.

WORK IN PROGRESS IN FY 2024

Because of the stand-down in FY 2024, the VERITAS science team focused on science and the start of the Student Opportunities in Academics and Research (SOAR) collaboration. The science team members

VENUS EMISSIVITY, RADIO SCIENCE, INSAR, TOPOGRAPHY, AND SPECTROSCOPY

Formulation	Development	Operations

continue to analyze the results of the successful Iceland field campaign carried out at the end of FY 2023. The science team has formed working groups to analyze the data sets in the areas of permittivity, thermal spectra, lidar topography, radar, and geology.

The SOAR effort provides hands-on research opportunities across the life cycle of the VERITAS mission. SOAR offers approximately 10 hands-on summer internships at JPL and other co-investigator institutions for undergraduate students from a minority-serving institution (MSI) over six-plus summers. VERITAS science team members will also partner with Pasadena City College (PCC) faculty to support pre-existing classes featuring Venus and the VERITAS mission.

In addition, the VERITAS mission will continue monitoring the progress of the international partners ASI, CNES, and DLR for their readiness to continue in FY 2025 and support the Mission System Review in early FY 2026.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

VERITAS will resume project activities in FY 2025 after the stand down of FY 2024. The project will reengage with international partners (ASI, CNES, DLR) with status reviews and restart the contract with the spacecraft contractor Lockheed Martin, in preparation for the Mission System Review in December 2026. The project will continue the science efforts carried out in FY 2024 and also participate in the Venus Science Coordination Group (VesCoor) for cooperation with the DAVINCI and ESA EnVision missions.

ESTIMATED PROJECT SCHEDULE

The VERITAS schedule is currently under evaluation. The dates shown below are preliminary and subject to change.

Milestone	Formulation Authorization Document	FY 2025 PB Request
Mission System Review	N/A	NLT 2027
PDR	N/A	NLT 2028
KDP-C	N/A	NLT 2028
CDR	N/A	NLT 2030
System Integration Review (SIR)	N/A	NLT 2031
KDP-D	N/A	NLT 2031
KDP-E	N/A	NLT 2032
Launch	N/A	NLT 2032

VENUS EMISSIVITY, RADIO SCIENCE, INSAR, TOPOGRAPHY, AND SPECTROSCOPY

Formulation	Development	Operations

Formulation Estimated LCC Range and Schedule Range Summary

LCC estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or PDR. The following cost and schedule estimates were established at the time of VERITAS mission selection in 2021 and will be updated during the next budget cycle.

KDP-B Date	Estimated LCC Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Jun 2021	1.2 - 1.6	LRD	2027-2028

Project Management & Commitments

The Principal Investigator is from JPL and JPL also serves as the implementing center for the VERITAS mission. JPL provides systems engineering, mission assurance, payload management, mission and science operations, navigation, and ground data systems.

Element	Description	Provider Details	Change from Formulation Agreement
Spacecraft	Venus orbiter that carries the science (VISAR, VEM) payloads during cruise and will conduct the Venus Orbit Insertion (VOI), aerobraking, and science operations.	Provider(s): Lockheed Martin Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
VEM	Provides near-global maps of mafic to felsic rock type and will search for active and recent volcanism.	Provider: DLR Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): DLR	N/A
VISAR	Designed to acquire high resolution imagery and topography of Venus as well as to make repeat pass interferometric measurements of surface deformation	Provider(s): JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): DLR and ASI	N/A
Gravity Science	Enables estimation of elastic thickness (a proxy for thermal gradient) and density differences due to subsurface structures, as well as constraining interior structure, including core size and state	Provider(s): GSFC Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): ASI - University of Roma	N/A

VENUS EMISSIVITY, RADIO SCIENCE, INSAR, TOPOGRAPHY, AND SPECTROSCOPY

Formulation	Development	Operations

Element	Description	Provider Details	Change from Formulation Agreement
Launch Vehicle	Launch vehicle and launch services	Provider: TBD Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Integrated Deep Space Transponder and HGA	Receives commands and transmits data/telemetry to Earth via the HGA	Provider: ASI Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): ASI	N/A
Ka-band Traveling Wave Tube Amplifier	Amplifies the Ka-band downlink signal prior to transmission to Earth via the HGA.	Provider: CNES Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): CNES	N/A

Project Risks

Risk Statement	Mitigation
If: The VISAR Digital Electronics Subsystem is delivered late, Then: VERITAS will incur additional costs to accommodate late delivery to and integration with the spacecraft.	The project assigned additional resources and management/engineering support to mitigate schedule risk.

Acquisition Strategy

NASA competitively selected the VERITAS mission through a Discovery 2019 AO and a down-select in 2021. The major elements of the mission and spacecraft are as proposed for the AO. NASA will competitively select the launch vehicle through the NASA Launch Services Program.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Spacecraft, System Integration and Test, Launch Operations, Mission Operations	Lockheed Martin	Denver, CO

VENUS EMISSIVITY, RADIO SCIENCE, INSAR, TOPOGRAPHY, AND SPECTROSCOPY

Formulation	Development	Operations

INDEPENDENT REVIEWS

All dates shown below are preliminary.

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	NASA Standing Review Board (SRB)	NLT 2028	PDR	TBD
Performance	SRB	NLT 2030	CDR	TBD
Performance	SRB	NLT 2031	SIR	TBD
Performance	SRB	NLT 2032	ORR	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
EnVision	10.9	--	**60.0**	65.6	54.7	37.8	20.2
Psyche	109.3	--	**32.6**	30.8	32.6	33.6	38.1
Janus	1.2	--	**0.0**	0.0	0.0	0.0	0.0
Venus Technology	6.0	--	**3.2**	6.7	6.0	6.0	6.5
InSight	0.3	--	**0.0**	0.0	0.0	0.0	0.0
Lucy	18.9	--	**25.9**	23.8	34.8	34.0	25.7
Strofio	0.9	--	**1.8**	1.2	2.3	2.4	1.0
International Mission Contributions (IMC)	4.8	--	**11.9**	13.8	12.1	11.6	8.0
Planetary Management	23.1	--	**25.6**	28.2	30.0	30.3	31.0
Discovery Future	2.8	--	**12.7**	11.1	15.0	82.8	135.4
Discovery Research	3.8	--	**7.9**	11.7	12.3	12.6	12.9
Planetary SmallSats	0.3	--	**0.0**	0.0	0.0	10.0	44.0
Mars-moon Exploration with GAmma rays and NEutrons (MEGANE)	5.3	--	**3.8**	4.2	1.6	1.7	0.6
Total Budget	**187.7**	**--**	**185.3**	**197.0**	**201.3**	**262.7**	**323.3**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

This image shows the "moonrise" of the satellite as it emerges from behind asteroid Dinkinesh as seen by the Lucy Long-Range Reconnaissance Imager (L'LORRI), one of the most detailed images returned by NASA's Lucy spacecraft during its flyby of the asteroid binary.

Discovery Other Missions and Data Analysis funds research and analysis; management activities; operations of active missions; small projects and international collaborations; and future mission selections.

Mission Planning and Other Projects

ENVISION

EnVision is an ESA-led mission to Venus for which NASA is providing a mission-enabling radar instrument. EnVision will launch in 2031 and provide a holistic view of the planet from its inner core to its upper atmosphere to determine how and why Venus evolved so differently from Earth.

NASA is contributing the Venus Synthetic Aperture Radar (VenSAR), which builds on decades of experience in planetary radar development at NASA, including the Magellan radar mapping mission that launched to Venus in 1989. VenSAR will provide regional and targeted surface imaging, topography from altimetry stereo imaging, surface properties from polarimetry, and radiometry and change detection from repeat imaging and comparison to Magellan. NASA will also support EnVision through contributions of time on its Deep Space Network to support critical events, a ground system for VenSAR radar processing, and expertise to assist in planning for spacecraft aerobraking.

Recent Achievements

The VenSAR activity continued its planned Extended Phase A activities in FY 2023 and the work is aligned with the latest ESA launch date in November 2031.

The VenSAR activity developed its unique science requirements, the basis for NASA's Level 1 requirements, based on the EnVision science mission objectives. The NASA team also negotiated its interface requirements with the ESA EnVision mission team. The VenSAR activity updated its project plan in key areas such as mission assurance, acquisitions, technology development, and cybersecurity. These efforts led to the successful completion of the ESA VenSAR Instrument System Requirements Review (SRR) in June 2023 and the NASA VenSAR SRR / Instrument Definition Review in July 2023.

NASA and ESA also established the Venus Science coordination (VesCoor) group to support coordinating with other Venus missions to identify new, unanticipated scientific approaches and outcomes based on synergies among the missions and suggest studies to enhance overall scientific return.

Technical accomplishments included the early breadboarding of key technologies, the closeout of key trades for the radar system architecture, and the establishment of technical working groups with ESA. The project also completed its National Environmental Policy Act (NEPA) review.

VENUS TECHNOLOGY

High temperatures and pressures on the surface of Venus, as well as an acidic atmosphere, present unique challenges to robotic missions. The Venus Technology Project focuses on developing and advancing technologies that future missions will use to explore Venus and other worlds. Venus Technology includes the Hot Operating Temperature Technology (HOTTech) activity, which supports development of technologies for the robotic exploration of high-temperature environments; and the Glenn Extreme Environment Rig (GEER), a pressure vessel capable of simulating the temperature, pressure and atmospheric gas mix of Venus and other extreme environments in the solar system and beyond.

Recent Achievements

Technologies, developed in HOTTech and tested in GEER, simulated operation in Venus's surface conditions for over 10 days. This test demonstrated the operation of wide bandgap semiconductors electronic components (diodes, transistors, and a 16-bit memory chip).

The Venus Technology Project continued to partner with NASA's Established Program to Stimulate Competitive Research (EPSCoR) to produce prototype concepts for electronic components that can operate in the ambient Venus surface.

INTERNATIONAL MISSION CONTRIBUTIONS (IMC)

NASA works closely with other space agencies to find opportunities to participate in each other's missions. These opportunities complement NASA-led planetary missions and expand the opportunities for the U.S. planetary science community to address scientific priorities identified in the Decadal Survey. Under the International Mission Contributions, NASA funds instruments and scientific investigators and provides navigation and data relay services in exchange for participation in mission science. International missions currently supported include: the JAXA's Hayabusa2, Akatsuki (Venus Climate Orbiter), and

OTHER MISSIONS AND DATA ANALYSIS

Martian Moons eXploration (MMX) missions; and the Korea Pathfinder Lunar Orbiter (KPLO), renamed Danuri.

The Pneumatic Sampler (P-Sampler) is also an element in IMC and is a technology demonstration instrument in development by Honeybee Robotics as a second NASA contribution to JAXA's MMX mission. The P-Sampler will complement the JAXA-developed primary surface sampler system by demonstrating the collection of surface and near-surface material on the Martian moon (Phobos) using compressed gas jets. The MMX mission will fly on a JAXA H3 rocket in 2026.

Recent Achievements

Danuri has been in lunar orbit since December 17, 2022, and completed its one-year nominal science mission. The Korean Aerospace Research Institute extended the mission for at least one additional year. Nine NASA-funded Danuri participating scientists are working with the Danuri Science Team on the orbital mission and data returned from the five scientific instruments. The first publications of science results occurred in late 2023, and mission data was publicly available as of January 2024.

NASA solicited proposals and made selections for the MMX Participating Scientist Program in FY 2023.

PLANETARY MANAGEMENT

The Planetary Missions Program Office (PMPO) at MSFC manages nearly all Planetary Science flight projects outside the Mars Exploration Program, including, Discovery, New Frontiers, and Planetary Defense Coordination Office flight missions. The PMPO includes support for the day-to-day efforts of the mission managers and business office, as well as independent review boards and external technical support for the missions. This project also funds the Science Office for Mission Assessments at LaRC to support the proposal evaluation process for all competed missions, and the formation and operation of independent review panels to evaluate mission proposals.

DISCOVERY FUTURE

Discovery Future funds mission concept development during step one of the AO down-select process and provides funding for future Discovery mission selections. The next Discovery AO is no earlier than 2026.

DISCOVERY RESEARCH

Discovery Research funds analysis of archived data from Discovery missions and supports participating scientists. Discovery Research gives the broad research community an opportunity to access samples and data and allows research to continue for many years after mission completion. NASA solicits planetary research proposals from the U.S. planetary science community and evaluates them for selection through competitive peer review. Discovery Research also funds the analysis of samples returned to the Earth by the Stardust and Genesis missions, as well as the development of new analysis techniques for samples returned by future missions.

The Discovery Data Analysis Program element (DDAP) has provided support for continued analysis of spacecraft data from missions such as the Near-Earth Asteroid Rendezvous (NEAR)-Shoemaker; Stardust; Stardust-New Exploration of Tempel (NExT); Genesis, Deep Impact, Mercury Surface, Space Environment, Geochemistry and Ranging (MESSENGER); Dawn; and Kepler missions. The supported projects conduct new scientific inquiries and regularly obtain new scientific results. The Rosetta Data Analysis Program element (RDAP) has provided additional support targeted for analysis of data from

OTHER MISSIONS AND DATA ANALYSIS

Rosetta, an ESA-led mission with NASA participation, to explore and land on Comet 67P/Churyumov-Gerasimenko.

Recent Achievements

The program awarded nine new research projects in 2023. These included data from different Discovery missions; MESSENGER data from Mercury, Dawn data from Vesta, NEAR data from asteroid 433 Eros, and comet data from the Stardust, Rosetta, Deep Impact and Stardust-NExT missions.

Observations made by Earth-based radar telescopes and the MESSENGER spacecraft provided compelling evidence that water ice exists in Mercury’s polar craters. For example, Arecibo radar measurements of Mercury’s south pole show many high-reflectance regions consistent with ice deposits. DDAP researchers leveraged previously existing terrain elevation maps of Mercury's surface created from the MESSENGER spacecraft’s Mercury Dual Imaging System Narrow Angle Camera images to provide the first high-resolution topographic maps of the south pole. The increased resolution and level of detail provided by their new elevation model allows for a more realistic recovery of illumination conditions in Mercury's south polar region, opening the way for future thermal analyses and for the characterization of potential ice and volatile deposits.

A second study using MESSENGER data focused on the largest northernmost craters on Mercury. The study focused on the thermal environment of the craters, seeking to identify permanently shadowed regions and to predict regions where ice and volatile organic compounds could be stable on the surface. With Mercury so close to the Sun, only permanently shadowed regions can contain stable water ice on or near the surface. The study team compared their predictions against data from the Arecibo radar and two MESSENGER instruments: the Mercury Laser Altimeter (MLA) and Mercury Dual Imaging System (MDIS). The radar analysis showed that high radar backscatter was correlated with areas predicted to host surface ice and that mixed radar backscatter responses could be associated with variations in ice purity or abundance. The MESSENGER data analysis was less conclusive; results from the MLA instrument supported the presence of water ice at the surface, but the MDIS results did not provide conclusive evidence. BepiColombo's upcoming orbital mission at Mercury presents an opportunity to get new measurements of these high latitude craters and test predictions for the distribution of surface volatiles in them.

PLANETARY SMALLSATS

NASA established the Small Innovative Missions for Planetary Exploration (SIMPLEx) program element to develop and operate targeted science investigations that exploit the unique attributes of small spacecraft to conduct compelling science. These small satellite missions take advantage of available launch capacity on larger missions to reduce the overall costs of launching multiple missions, provide a means to mature technologies for future missions, and serve as additional opportunities to provide flight experience to the workforce. NASA selected three missions from the prior SIMPLEx AO: Escape and Plasma Acceleration and Dynamics Explorers (EscaPADE) (in development within the Heliophysics division), Lunar Trailblazer (in development within the Lunar Discovery and Exploration Program) and Janus, which was de-manifested from the Psyche launch. The project plans to release the next SIMPLEx draft AO no earlier than 2026.

MEGANE

The Mars-moon Exploration with Gamma rays and Neutrons (MEGANE, also Japanese for "eyeglasses") instrument is a gamma-ray and neutron spectrometer currently in development by the Johns Hopkins

OTHER MISSIONS AND DATA ANALYSIS

University Applied Physics Laboratory, as a contribution to the JAXA MMX mission. Planned for launch in 2026, MMX will operate near the Martian moons Phobos and Deimos for approximately four years and return a sample from Phobos to Earth in 2031. MEGANE will measure the bulk composition of the near-surface materials on Phobos to constrain theories for the origin of the moons. It will also map the near-surface materials on Phobos to enable the study of surface processes and support MMX sample site selection.

Recent Achievements

MEGANE entered Phase D and began the phase of system assembly, integration and test, launch and checkout at the end of FY 2023. The team delivered the flight unit to JAXA in early FY 2024.

Operating Missions

LUCY

NASA's Lucy mission launched in October 2021 to explore a diverse population of small bodies known as the Jupiter Trojan asteroids. The Trojans are remnants of our early solar system, now trapped on stable orbits associated with Jupiter. The two "swarms" lead and follow Jupiter in its orbit around the Sun and are almost as numerous as the objects in the Main Asteroid Belt. Over its 12-year primary mission, Lucy will explore a record-breaking number of asteroids, flying by two main-belt asteroids and seven Trojan asteroids on a tour that sets another first by being the first mission to traverse from the inner to outer solar system and back as it moves from the leading to trailing swarm.

Solar system formation models suggest that the Trojans are remnants of the same primordial material that formed the outer planets, serving as time capsules from the birth of our solar system. These bodies hold vital clues to deciphering the history of our solar system and may even tell us about the kinds of organic materials supplied to the early Earth. Lucy's objectives are to determine the properties and history of the Trojan asteroids by mapping their surface geology, measuring their color and composition, and determining their mass and density, as well as searching for satellites and/or rings that might exist.

Recent Achievements

Since launch in October 2021 and discovery of the solar array anomaly, the team continued work to fully characterize and monitor the behavior of the spacecraft to ensure that planned operations can continue with acceptable risk. The operations team conducted a series of activities to further deploy one of the two solar arrays that had not properly unfurled and latched shortly after launch. As a result, that solar array is now estimated to be 98 percent deployed and continues to produce the expected level of power and is expected to be able to perform the baseline mission with margin.

Science instruments are all commissioned and performing within specifications. The Lucy team used the high-resolution panoramic camera, L'LORRI, to observe the binary asteroid Didymos at the time of the DART mission's impact on September 26, 2022, and published science results from those observations. The first Earth gravity assist, on October 16, 2022, put the spacecraft into an approximately two-year orbit around the Sun in preparation for the second Earth gravity assist in 2024, which will propel Lucy out to its first encounters in the Trojan asteroid swarms.

The Lucy team took advantage of a newly recognized opportunity and conducted a flyby of the main-belt asteroid (152830) Dinkinesh on November 1, 2023. The flyby allowed the team to test the onboard terminal tracking system, as well as exercise the science instruments and their data processing pipelines.

OTHER MISSIONS AND DATA ANALYSIS

The terminal tracking system ensures that Lucy's instruments point correctly during each asteroid encounter, and conducting this test allowed for some significant risk reduction.

PSYCHE

The Psyche mission will explore one of the most intriguing targets in the main asteroid belt: a giant metal asteroid known as 16 Psyche. This asteroid measures approximately 140 miles in diameter and, unlike most other asteroids that are rocky or icy bodies, is likely comprised mostly of metallic iron and nickel, similar to Earth’s core. The mission will help scientists understand how planets and other bodies separated into their layers, including cores, mantles, and crusts, early in their histories. Psyche will arrive at 16 Psyche in 2029, where the spacecraft will spend more than two years in four different orbits. Each orbit will be at different distances from the asteroid, allowing the team to study its shape and magnetic field, topography and spectral characteristics, gravitational field, and elemental compositions. Each orbit will provide knowledge needed to guide future orbits, enabling operators to update the models, plans, and sequences.

Recent Achievements

NASA successfully launched Psyche on October 13, 2023, and began on-orbit checkout activities. The operations team powered on and calibrated various spacecraft systems to establish a safe orientation and high-rate data downlink. The team vented and primed the electric propulsion (EP) system, which will provide the energy needed for the journey to the Psyche asteroid. In early November 2023, the team subsequently fired two of the four EP thrusters, marking the first use of Hall thrusters in deep space. The mission team completed the initial checkouts for the Gamma Ray and Neutron Spectrometer and magnetometer instruments.

STROFIO

STart from a ROtating FIeld mass spectrOmeter (STROFIO) is a unique mass spectrometer that is part of the suite of instruments flown onboard the joint ESA and JAXA BepiColombo spacecraft, launched on October 20, 2018, and planned to enter Mercury orbit and begin observations in 2025. STROFIO will study and characterize the chemical composition and dynamics of Mercury’s thin atmosphere (exosphere). Eight NASA-funded scientists serve as interdisciplinary scientists, guest investigators, or instrument co-investigators on the BepiColombo Science Team. These investigators collaborate with the BepiColombo team on a variety of projects that will improve understanding of both Mercury and Venus, as well their surrounding space environments.

Recent Achievements

BepiColombo is currently in its cruise phase. It has now completed three of six Mercury flyby maneuvers before its planned Mercury orbit insertion in December 2025. The optimization of the STROFIO instrument continues while the spacecraft travels to Mercury. A NASA-funded guest investigator is leading an effort that will bring together data from multiple BepiColombo instruments, including STROFIO, the development of mathematical methods, and the use of existing datasets from NASA's prior MESSENGER mission to study, in three dimensions, the distribution of sodium in Mercury's thin atmosphere.

NEW FRONTIERS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Dragonfly	400.1	--	**434.6**	496.8	434.2	317.6	32.5
Other Missions and Data Analysis	88.1	--	**65.9**	36.3	50.0	154.0	265.8
Total Budget	**488.2**	**--**	**500.5**	**533.0**	**484.2**	**471.6**	**298.3**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The New Frontiers program is focused on planetary science investigations using innovative and efficient management approaches. The program's prime objective is to answer unique science questions in the exploration of the solar system. Initiated in 2003, the New Frontiers Program solicits medium-class planetary science missions led by principal investigators with high scientific priority and value. The program emphasizes competed and peer-reviewed missions accomplished under the leadership of the scientific research community and aligned with the scientific goals of the Planetary Science Decadal Survey.

Shown here is a view of the outside of the OSIRIS-REx sample collector. Sample material from asteroid Bennu can be seen on the middle right of the image. Scientists have found evidence of both carbon and water in initial analysis of this material. The bulk of the sample is located inside.

Since its inception, the program has successfully launched three missions, one to study Pluto (New Horizons), a second to study Jupiter (Juno), and a third to return samples from the Bennu asteroid (Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer [OSIRIS-REx]). A fourth mission to study the surface of Saturn's moon, Titan, is currently in formulation (Dragonfly).

The program also supports continued research and data analysis from its missions. NASA issues annual calls for proposals and awards research grants based primarily upon their scientific merit. These grants not only broaden participation in the missions, but also deepen our understanding of the science objectives of each mission, produce new discoveries, and train the next generation of scientists.

EXPLANATION OF MAJOR CHANGES IN FY 2025

As part of rebalancing the planetary portfolio, NASA has increased the Dragonfly budget request, consistent with the updated mission cost estimate expected to be reviewed at the upcoming mission confirmation, and consistent with a launch readiness date of July 2028. Given the need to increase the Dragonfly budget, NASA has delayed the New Frontiers 5 AO from November 2023 to no earlier than (NET) 2026.

This budget request also extends the New Horizons mission until the spacecraft exits the Kuiper Belt in the 2028 to 2029 timeframe. This extension takes advantage of the spacecraft's unique position in our solar system to answer important questions about our heliosphere and provides an opportunity to fly by another Kuiper Belt Object if one is discovered.

NEW FRONTIERS

Following the return of the Bennu sample collected by OSIRIS-REx, the spacecraft maneuvered to enter an extended mission phase under a new project entitled OSIRIS-Apophis Explorer (OSIRIS-APEX). It will explore Apophis, an asteroid roughly 1,200 feet (370 meters) in diameter that will come within 20,000 miles (32,000 kilometers) of Earth. OSIRIS-APEX will enter orbit around Apophis soon after the asteroid's Earth flyby in 2029. The project will provide an unprecedented look at a stony S-type asteroid.

ACHIEVEMENTS IN FY 2023

The New Horizons mission continued to downlink data and characterize the environment around the Kuiper belt in the distant outer solar system.

In addition to continued Jupiter encounters, the Juno mission began its observation campaign of Io, the most volcanically active body in the solar system. The spacecraft completed a series of flybys of Io with increasingly closer passes throughout the year, making its closest approach to date at approximately 22,200 kilometers on July 31, 2023.

OSIRIS-REx returned to Earth with samples of the asteroid Bennu on September 24, 2023. The mission team led a successful sample recovery and transported the samples and hardware to a clean room at JSC. Initial assessment confirmed the mission collected and returned more material than planned, which will have long lasting benefits to our efforts to analyze and understand asteroids. Initial analysis shows the asteroid is rich in carbon and water.

Dragonfly completed its PDR in March 2023.

WORK IN PROGRESS IN FY 2024

New Horizons is currently in its second extended mission phase until the end of FY 2024. NASA recently announced plans to extend the mission beyond FY 2024 until the spacecraft exits the Kuiper Belt in the approximate 2028 to 2029 timeframe. During this third extended mission, New Horizons will help fill key knowledge gaps into superthermal ions in the outer heliosphere and interstellar medium. If a suitable Kuiper Belt Object is discovered the team will attempt to conduct a close flyby.

The Juno mission continues its approved extended mission, which continues to study Jupiter and its moons. The spacecraft performed a close approach of Io at approximately 1,500 kilometers altitude in December 2023 and will perform another one in February 2024, providing new insight into this volcanically active body.

NASA will prepare the sample material from the asteroid Bennu returned by OSIRIS-Rex for distribution and analysis, beginning a new phase of scientific research into these primitive bodies. An international consortium of approximately 200 scientists will spend the next two years executing a detailed analysis campaign on a portion of the Bennu sample returned by OSIRIS-Rex. Due to the richness of the sample and the power of laboratory instruments, NASA expects these studies to continue for decades, just as they have for the lunar samples returned by Apollo astronauts.

OSIRIS-APEX executed its first perihelion on January 2, 2024. NASA reconfigured the spacecraft to withstand higher temperatures and prevent overheating.

NASA will conduct a mission confirmation review for the Dragonfly mission. If approved to proceed, Dragonfly will then enter the development phase.

NEW FRONTIERS

Key Achievements Planned for FY 2025

NASA will release a draft of the next AO in FY 2025 to gather feedback and help proposers prepare to respond to the final AO release NET FY 2026. Dragonfly will complete its mission-level CDR, expected to occur NET Spring 2025.

The Juno mission will continue with its goal of understanding the formation, evolution, and structure of Jupiter with its northward perijove progression to explore Jupiter's northern latitudes.

The New Horizons mission will continue its extended journey in the outer reaches of the Kuiper Belt and provide heliophysics science data and flyby data from a possible Kuiper Belt Object, if an opportunity arises.

PROGRAM SCHEDULE

Date	Significant Event
Q2 2024	New Frontiers Data Analysis Program solicitation
Q2 2025	New Frontiers Data Analysis Program solicitation
Q2 2026	New Frontiers Data Analysis Program solicitation
NET 2026	Release of New Frontiers 5 AO solicitation
NET FY 2028	Select fifth New Frontiers mission

PROGRAM MANAGEMENT & PLANNED CADENCE

The New Frontiers Program is a multi-project program, with responsibility for implementation assigned to the Planetary Missions Program Office, located at MSFC.

The first four New Frontiers AOs have been released on an average cadence of five years. Delaying the fifth AO extends the average AO release cadence to six years.

ACQUISITION STRATEGY

NASA competitively selects New Frontiers missions, releasing AOs when available funding allows.

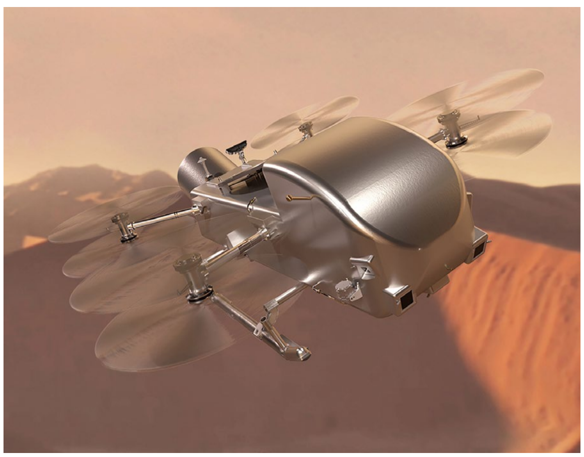
DRAGONFLY

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	400.1	--	434.6	496.8	434.2	317.6	32.5

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Shown here is an artist's impression of Dragonfly soaring over the dunes of Saturn's moon, Titan. (Credit: Johns Hopkins Applied Physics Laboratory [APL]/Steve Gribben)

PROJECT PURPOSE

Dragonfly is a mission to study Titan, the largest moon of Saturn, using a rotorcraft carrying an advanced set of instruments to characterize the surface, atmosphere, and interior from different locations. Titan is a unique world that potentially harbors an interior ocean. Its surface, layered with organic snow on an icy crust possibly shaped by wind and fluvial processes, may be like early Earth, where carbon and nitrogen interacted with water and energy to form life. Through measurements made at diverse locations across Titan, Dragonfly will characterize the habitability of Titan's environment, investigate how far pre-biotic chemistry has progressed, and search for chemical signatures indicative of water-based and/or hydrocarbon-based life.

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA has increased the Dragonfly budget request, consistent with the updated mission cost estimate expected to be reviewed at the upcoming mission confirmation, and consistent with a launch readiness date of July 2028.

PROJECT PRELIMINARY PARAMETERS

Dragonfly will target a launch in July 2028. After a 6.5-year cruise, which includes one Earth gravity assist, Dragonfly will perform an entry, descent, and landing onto Titan's surface. Upon landing, Dragonfly will fly to dozens of locations looking for prebiotic chemical processes on Titan, analogous to processes on early Earth. Dragonfly, which has eight rotors and flies like a large drone, marks the first time NASA will fly a multi-rotor vehicle designed to collect science data on another planetary body. It will take advantage of Titan's dense atmosphere (four times denser than Earth's) and low-gravity (one-seventh that on Earth) to become the first vehicle ever to fly its entire science payload to multiple

Formulation	Development	Operations

sites for repeatable and targeted access to surface materials. It is a scientifically diverse mission that includes an assortment of instruments: the Dragonfly Camera Suite (DragonCam), which is a set of microscopic and panoramic cameras to image Titan's terrain and scout for scientifically interesting landing sites; the Dragonfly Gamma-Ray and Neutron Spectrometer (DraGNS), which consists of a deuterium-tritium Pulsed Neutron Generator and a set of a gamma-ray and neutron spectrometers to identify the surface composition under the lander; the Dragonfly Mass Spectrometer (DraMS), which is an advanced mass spectrometer to identify chemical components in surface and atmospheric samples, especially those relevant to biological processes; and the Dragonfly Geophysics and Meteorology Package (DraGMet), which is a suite of meteorological sensors including a seismometer.

Titan is an analog to the very early Earth and can provide clues to how life may have begun on our planet. During its nearly three-year baseline mission, Dragonfly will explore diverse environments from organic dunes to the floor of an impact crater where liquid water and complex organic materials, key to life, once existed together, possibly for tens of thousands of years. Its instruments will study how far prebiotic chemistry has progressed. They also will investigate the moon’s atmospheric and surface properties and its potential subsurface ocean and liquid reservoirs. Instruments will search for chemical signatures suggestive of past or extant life. A multi-mission radioisotope thermoelectric generator will power the Dragonfly rotorcraft.

ACHIEVEMENTS IN FY 2023

Dragonfly completed its mission-level PDR and began preparations for the KDP-C milestone, which initiates final design and fabrication activities.

WORK IN PROGRESS IN FY 2024

In FY 2024, Dragonfly will proceed to Phase C and mature its system design in preparation for the mission-level CDR.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

In FY 2025, Dragonfly will complete its mission-level CDR, expected to occur no earlier than Spring 2025.

ESTIMATED PROJECT SCHEDULE

Dragonfly's project schedule is based on a notional July 2028 launch readiness date.

Milestone	Formulation Authorization Document	FY 2025 PB Request
KDP-C	N/A	Spring 2024
CDR	N/A	Spring 2025
KDP-D	N/A	Spring 2027
KDP-E	N/A	Spring 2028

DRAGONFLY

Formulation	Development	Operations

Milestone	Formulation Authorization Document	FY 2025 PB Request
Launch	N/A	Jul 2028

Formulation Estimated LCC Range and Schedule Range Summary

LCC estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or PDR.

The information in the table below represents estimates made at the time of KDP-B, with an update to the launch readiness date. Mission cost and schedule are now under review pending formal confirmation.

KDP-B Date	Estimated LCC Range ($B)	Key Milestone	Key Milestone Estimated Date Range
Jun 2019	2.1 - 2.5	Launch	Jul 2028

Project Management & Commitments

The Principal Investigator is from the Johns Hopkins University APL. APL has project management responsibility for Dragonfly.

Element	Description	Provider Details
DraMS	Provides detailed analysis of organic chemistry	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A
DraGNS	Determines bulk near-surface composition and layering	Provider: APL Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A
DraGMet	Measures atmospheric conditions, seismicity, and surface/subsurface properties	Provider: APL Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A
DragonCam	Documents landforms and processes; provides context for samples; and performs aerial imaging to scout landing sites	Provider: Malin Space Science Systems Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A

DRAGONFLY

Formulation	Development	Operations

Element	Description	Provider Details
Drill for Acquisition of Complex Organics Sampling System	Provides pneumatic transfer system and sample acquisition drill	Provider: Honeybee Robotics Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A
Multi-Mission Radioisotope Thermoelectric Generator	Provides power to the Dragonfly lander	Provider: DoE Lead Center: GRC Performing Center(s): N/A Cost Share Partner(s): N/A
Cruise Stage	Propulsion stage to get Dragonfly to Titan	Provider: Lockheed Martin Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A
Entry, Descent, and Landing (EDL) Assembly	Includes aeroshell, parachutes, and support equipment	Provider: Lockheed Martin Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A
Dragonfly Lander	Flight system to carry and support the science instruments	Provider: APL Lead Center: MSFC Performing Center(s): N/A Cost Share Partner(s): N/A

Project Risks

Risk Statement	Mitigation
If: The electrical power system flight hardware fabrication and assembly activities are too numerous for the APL in-house electronics fabrication capability, Then: Schedule delays will result due to capacity constraints.	The project stood up a working group to investigate external vendors to mitigate this risk. The team has found vendors to help identify which boards can be fabricated outside of APL.
If: The lander has leakage in the top and bottom of the inner fuselage, Then: A chimney effect will cause the lander to get too cold on Titan and would cause loss of the lander.	The project will continue analysis and testing to determine the best approach and methods of sealing.

DRAGONFLY

Formulation	Development	Operations

Risk Statement	Mitigation
If: The aerodynamics loads during preparation for powered flight are underestimated in the model, Then: The lander might not achieve a successful release and transition to powered flight.	The team plans to incorporate additional testing and analyses to increase fidelity to the existing models. Improved models will provide confidence in the estimates and ability to transition to powered flight.

Acquisition Strategy

NASA competitively selected the mission through the New Frontiers 4 Announcement of Opportunity (AO); the final down selection occurred in June 2019. The major elements of the mission and spacecraft are as proposed in the AO.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Principal Investigator; Science Co-Is; Mission Management; Lander Development; DraGMet; DraGNS; System I&T; Science Operations; and Mission Operations	APL	Laurel, MD
Cruise Stage; EDL Assembly; and I&T Support	Lockheed Martin	Denver, CO

INDEPENDENT REVIEWS

All dates are preliminary and subject to change.

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Standing Review Board (SRB)	Feb 2023	PDR	Passed
Performance	SRB	Spring 2025	CDR	TBD
Performance	SRB	Apr 2027	SIR	TBD
Performance	SRB	Apr 2028	ORR	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
OSIRIS-Apophis Explorer	5.0	--	**16.0**	19.9	22.1	31.0	36.5
New Frontiers Future Missions	0.9	--	**0.0**	0.0	9.7	106.0	212.3
New Frontiers Research	10.5	--	**8.3**	5.3	10.4	10.5	10.5
Origins Spectral Interpretation Resource	30.7	--	**5.4**	0.0	0.0	0.0	0.0
New Horizons	10.4	--	**10.0**	3.0	7.8	6.5	6.5
Juno	30.5	--	**26.2**	8.1	0.0	0.0	0.0
Total Budget	**88.1**	**--**	**65.9**	**36.3**	**50.0**	**154.0**	**265.8**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

New Frontiers Other Missions and Data Analysis includes support for three operating missions: New Horizons; Juno; and Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx), analysis of data from these missions, and preparation for future missions.

Just hours before NASA's Juno mission completed its 53rd close flyby of Jupiter on July 31, 2023, the spacecraft sped past the planet's volcanic moon Io and captured this dramatic view of both bodies in the same frame. (Credit: JPL-Caltech/SwRI/MSSS)

Mission Planning and Other Projects

NEW FRONTIERS FUTURE MISSIONS

New Frontiers Future Missions provides the funding required for the next Announcement of Opportunity (AO). NASA will release the next AO no earlier than 2026.

Recent Achievements

The Hypervelocity OSIRIS-REx Reentry Imaging & Spectroscopy (HORIS) project, an international collaboration led by the Scientifically Calibrated In-Flight Imaging group, performed airborne and ground-based observations of the OSIRIS-REx Sample Return Capsule (SRC) reentry on September 24, 2023. The multispectral aerothermal data captured is being used to assess the performance of the SRC's heatshield to improve heatshields on future missions. The HORIS project also provided the live video feed of the OSIRIS-REx reentry event and SRC recovery.

NEW FRONTIERS RESEARCH

New Frontiers Research funds analysis of archived data from New Frontiers missions, as well as participating scientists and selected members of the research community who augment and enhance the science teams of New Frontiers missions. New Frontiers Research provides the research community access to data and samples, enabling research to continue for many years after mission completion. Participating scientists bring new ideas to mission teams and frequently provide a pathway for early career investigators to gain experience with planetary missions. This program supports efforts to maximize science return from each of the missions. NASA solicits planetary research proposals from the U.S. planetary science community and evaluates them for selection through competitive peer review.

Recent Achievements

The New Frontiers Data Analysis program element competitively selected and awarded 11 new science investigations. These included studies to explore the origin of tectonic activity (i.e., Plutoquakes) on Pluto, as inferred from images taken by NASA's New Horizons mission, to study the energetics of the aurora at Jupiter as observed by NASA’s Juno mission, and to make a map of the surface properties of rocks and boulders on the surface of asteroid Bennu, as observed by NASA's OSIRIS-REx mission.

New results published from the Juno mission include the first comprehensive analysis of volcanic activity at Io, identifying more than 200 volcanic hot spots across its surface, as observed by the first five years of Juno's operations at Jupiter. These results support a hypothesis that there is global magma ocean on Io, driven by tidal forces from Jupiter.

New studies of the Kuiper belt object Arrokoth show that it was likely formed by the gentle merger of more than a dozen smaller bodies, soon after the formation of the solar system; the uniformity of the size and shape of its components gives never-before seen insight into the nature of the very early solar system.

A recent study of orbital data from NASA's OSIRIS-REx mission measured the quantities of water and organic molecules on individual rocks and boulders on the surface of Bennu. These results will help scientists analyze and put in context the samples recently returned from Bennu.

Operating Missions

NEW HORIZONS

New Horizons is the first scientific investigation to obtain close observations of Pluto and its moons, Charon, Nix, Hydra, Kerberos, and Styx. Scientists discovered the last four moons after the spacecraft launch in January 2006. It successfully encountered Pluto on July 14, 2015, and completed downloading of the primary science observations of the plutonian system in October 2016. The mission is currently in extended operations through the 2028 and 2029 timeframe.

In FY 2025, NASA will place the spacecraft into hibernation mode with scheduled health and safety checks to allow the spacecraft to be safely preserved for future scientific opportunities, while minimizing cost, complexity, and risk. Starting in FY 2026, New Horizons will leave hibernation once per year and will perform a two-week, three-axis distant Kuiper Belt Object (KBO) science observation period. In FY 2027, New Horizons will send and checkout an updated autonomy algorithm and implement a ground system refresh to transition to a new telemetry-processing pipeline and underlying operating system.

Recent Achievements

New Horizons is approximately 57 astronomical units from the Sun, which is more than five billion miles, making it one of few missions with such a large suite of instruments to reach this enormous distance from our home planet. The spacecraft exited a multi-month hibernation period in March 2023 and recently completed a two-month long science operations period as it continues its journey through the

Kuiper Belt. In September 2023, NASA announced plans to extend the mission until the spacecraft exits the Kuiper Belt, in the 2028-2029 timeframe. Beginning in FY 2025, New Horizons will focus on gathering unique heliophysics data and perform flybys of detected KBOs should such opportunities arise.

JUNO

Juno has transformed our view of Jupiter, the most massive planet in the solar system, through significant discoveries about its atmospheric dynamics and composition, interior structure, origin, and evolution. Juno launched on August 5, 2011, and entered Jupiter's orbit on July 4, 2016. The project recently celebrated its 12th launch anniversary, and the spacecraft is in its eighth year of operations in the Jovian system. Juno’s state-of-the-art instruments gather information from deep in Jupiter’s atmosphere, enabling scientists to unveil the planet's properties beneath its top cloud layer. Juno began its extended mission phase in August 2021 and continues investigations through September 2025, including close passes of Jupiter’s north polar cyclones; flybys of the moons Ganymede, Europa, and Io; and the first examination of the faint rings encircling the planet.

Recent Achievements

Juno has completed 55 of 76 planned orbits around Jupiter; following a close flyby of Jupiter's moon, Io. In December 2023, the spacecraft transitioned to its final 33-day orbit configuration.

During FY 2023 science operations, Juno continued sampling Jupiter’s full range of latitudes and longitudes during polar orbits and captured details no other mission has captured before and also focused on flybys of Jupiter's moon, Io. In December 2023 Juno conducted its closest approach of Io at approximately 1,500 km altitude and it accomplished several key objectives: characterize the global magma ocean, monitor volcanic activity, and characterize magnetospheric interaction. The mission team has continued to engage with highly engaged citizen scientists who have provided high-resolution images of Io using data provided by JunoCam.

OSIRIS-REx

OSIRIS-REx is the first U.S. mission to bring a sample from an asteroid back to Earth. The OSIRIS-REx spacecraft traveled to Bennu (asteroid 101955), a near-Earth carbonaceous asteroid (formerly designated 1999 RQ36), studied the asteroid in detail, and brought a sample (at least 60 grams or 2.1 ounces) back to Earth. Analysis of this sample by current and future generations of scientists will yield insight into planet formation, as well as how the delivery of organic material and water from asteroids to Earth played a role in the origin of life. The data collected at Bennu will aid in further understanding asteroids that could collide with Earth.

OSIRIS-REx launched on September 8, 2016, and arrived at Bennu on December 3, 2018. The spacecraft cameras and instruments photographed the asteroid and measured its surface topography, composition, and thermal emissions. Radio science provided mass and gravity field maps. This information helped the mission team select the most promising locations to collect a sample of pristine asteroid material. On October 20, 2020, the OSIRIS-REx spacecraft successfully descended to the surface of Bennu, contacted the surface, collected a sample, and backed away. Following analysis of the sampling head, NASA determined that the spacecraft had likely collected an adequate amount of material and then stowed the sample for secure return to Earth. The spacecraft then conducted a post sampling reconnaissance pass over the sample site and successfully executed the Asteroid Departure Maneuver, placing the spacecraft on an Earth return trajectory. To deliver the sample to Earth, OSIRIS-REx utilizes a capsule similar to the one that returned the sample of Comet 81P/Wild on the Stardust spacecraft.

Recent Achievements

On September 24, 2023, the capsule containing pieces of Bennu separated from the OSIRIS-REx spacecraft and entered Earth's atmosphere, where it parachuted safely to the Utah Test and Training Range in Utah's west desert. The team placed the sample in a secure mobile cleanroom and flew it on a military aircraft to Houston, where it was maintained under nitrogen purge. Delivery to the newly outfitted JSC curation facility occurred September 25, 2023, and disassembly of the sample-return canister began in the closing days of FY 2023.

A small amount of asteroid dust was found on the avionics deck of the SRC, outside the part of the hardware expected to contain the main volume of returned sample, so a tiger team immediately began the process of sample characterization. During further disassembly of the Touch-and-Go Sample Acquisition Mechanism (TAGSAM), which contains the bulk of the sample, the team discovered that two of the 35 fasteners on the TAGSAM head could not be removed using the current set of tools approved for use in the glovebox.

As a first step, the team successfully accessed some of the material by holding down the head's mylar flap and removing the sample inside with tweezers or a scoop, depending on material size. The collection and containment of material through this method, combined with the earlier collection of material located outside the head, yielded a total mass exceeding the 60 grams required. The team worked to develop a new tool to remove the remaining two fasteners and, in January 2024, succeeded in extracting the material from inside the head, while continuing to keep the sample safe and pristine. The OSIRIS-REx science team is proceeding with their multi-year plan to characterize the extracted material and begin analysis of the bulk sample obtained.

OSIRIS-APOPHIS EXPLORER (OSIRIS-APEX)

OSIRIS-APEX is a follow-on to OSIRIS-REx. Using the OSIRIS-REx spacecraft, the OSIRIS-APEX mission will explore Apophis, an asteroid roughly 1,200 feet (370 meters) in diameter that will come within 20,000 miles (32,000 kilometers) of Earth. OSIRIS-APEX will enter orbit around Apophis soon after the asteroid's Earth flyby in 2029. The new project will provide an unprecedented close-up look at a stony S-type asteroid. During 15 months of orbital operations, OSIRIS-APEX will study changes in the asteroid caused by its close flyby of Earth, determine the mass and structure of Apophis, and perform high-resolution global spectral mapping to determine the composition of the asteroid and identify any volatiles on its surface. The mission will also search for signatures of mass shedding, whether due to the tidal encounter with Earth or an episodic process like that observed by OSIRIS-REx at Bennu. At the end of orbital operations, the spacecraft will fire its gas thrusters to dislodge and study the dust and small rocks on and below the surface of Apophis.

Recent Achievements

OSIRIS-APEX completed its first operation with a successful divert burn after OSIRIS-REx jettisoned its sample capsule to Earth on September 24, 2023. OSIRIS-APEX prepared for its first perihelion on January 2, 2024. NASA reconfigured the spacecraft to withstand higher temperatures and prevent overheating.

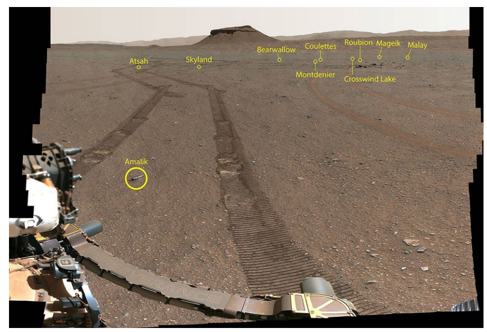
MARS EXPLORATION

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Other Missions and Data Analysis	248.1	--	**324.5**	298.6	305.8	353.3	390.7
Total Budget	**248.1**	**--**	**324.5**	**298.6**	**305.8**	**353.3**	**390.7**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Mars Exploration program seeks to understand when Mars may have had habitable conditions for microbial life, whether Mars has supported microbial life in the past or today, and the extent to which Mars could be a habitable world for humans in the future. As the most Earth-like planet in the solar system, Mars has a landmass approximately equivalent to the Earth's, as well as ancient remnants of many of the same geological features (e.g., riverbeds, river deltas, and volcanoes). Mars also has many of the same "systems" that characterize Earth (e.g., air, water, ice, and geology), that interact to produce the Martian environment. Mars also has fundamental differences from Earth, including the lack of a global magnetic field and chaotic changes in the orientation of its spin axis over tens of millions of years, which have affected its environment.



This image is from the Mars Perseverance rover, showing the 10 samples on the surface of Mars at the Three Forks depot. Based on the measurements of the nearby surface where each sample was taken, these samples represent two major geological units in Jezero crater and have the potential to address all seven objectives envisioned for samples brought from Mars. "Report of the Science Community Workshop on the proposed First Sample Depot for the Mars Sample Return Campaign", Meteoritics & Planetary Science (Credit: https://doi.org/10.1111/maps.13981)

Individual orbital and landed robotic missions have progressively built on the discoveries of past missions, all collectively guided by four broad, overarching goals for Mars Exploration:

- Determine if life ever arose on Mars;
- Characterize the climate of Mars;
- Characterize the geology of Mars; and
- Prepare for human exploration.

Today, our robotic scientific missions are paving the way for a future in which humans and robots will explore Mars and the solar system together.

EXPLANATION OF MAJOR CHANGES IN FY 2025

This budget assumes the Mars Atmospheric and Volatile EvolutioN will complete mission operations in FY 2026. NASA will reassess the mission status in future years. Funding within Mars Future Missions for the formulation and development of the Mars Sample Receiving Facility has been reduced and will be reassessed pending NASA's determination regarding a potential path forward for a Mars Sample Return

MARS EXPLORATION

mission within a balanced Science portfolio, following review of the findings of the MSR IRB Response Team (MIRT).

NASA has significantly expanded support for the ESA Rosalind Franklin ExoMars Rover mission, which was formerly a partnership between ESA and Russia. In addition to the Mars Organic Molecule Analyzer (MOMA) contribution, NASA will contribute radioisotope heater units, a launch service, and landing descent engines. All MOMA operations costs will be accommodated within the new Rosalind Franklin project.

Looking to the future, additional funding within the Mars Technology project will be utilized to initiate studies and technology development activities that will enable the next Mars mission, consistent with the draft "Exploring Mars Together: Mars Exploration Program Future Plan, 2023-2043." These exciting new technologies will enable lower-cost missions and, possibly, more rapid development timelines.

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Mars Organic Molecule Analyzer (MOMA)	3.4	--	**0.0**	0.0	0.0	0.0	0.0
Mars Rover 2020	91.1	--	**85.5**	82.0	82.5	83.0	83.0
Trace Gas Orbiter - ExoMars	2.0	--	**2.0**	2.0	2.0	2.0	2.1
Mars Program Management	12.0	--	**11.4**	13.3	13.3	13.5	14.0
Mars Future Missions	12.9	--	**0.5**	0.0	20.0	40.4	141.0
Mars Mission Operations	5.1	--	**5.5**	5.6	5.4	5.4	5.7
Mars Research and Analysis	14.7	--	**13.7**	13.7	13.7	13.7	13.7
Mars Technology	5.4	--	**43.0**	6.2	9.0	18.1	20.2
2011 Mars Science Lab	42.1	--	**53.0**	40.0	40.0	40.0	40.0
Mars Reconnaissance Orbiter 2005 (MRO)	25.5	--	**25.4**	26.6	26.3	26.0	26.0
Mars Odyssey 2001	11.2	--	**11.0**	11.0	11.0	11.0	11.0
Mars Express	0.3	--	**0.3**	0.3	0.3	0.3	0.3
Mars Atmosphere & Volatile EvolutioN	22.5	--	**24.0**	24.0	0.0	0.0	0.0
Rosalind Franklin Mission	0.0	--	**49.2**	73.9	82.3	99.9	33.7
Total Budget	**248.1**	**--**	**324.5**	**298.6**	**305.8**	**353.3**	**390.7**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Other Missions and Data Analysis includes mission planning and management, small missions in development, research and technology activities, funding for future Mars missions, and Mars operating missions. The operating projects include Mars Science Laboratory (MSL), Mars Reconnaissance Orbiter 2005 (MRO), Mars Odyssey 2001, Mars Express, Mars Atmosphere and Volatile EvolutioNn (MAVEN), and Mars Rover 2020.

This image shows Curiosity's shadow of the rover mast, and the perfectly drilled 'Sequoia' target in the background. In August 2023, Curiosity reached Gediz Vallis Ridge where it has sampled boulders toppled from Mt. Sharp.

Mission Planning and Other Projects

ROSALIND FRANKLIN MISSION (RFM)

NASA has expanded its contribution to the ESA Rosalind Franklin Mission beyond the Mars Organic Molecule Analyzer - Mass Spectrometer (MOMA-MS) instrument and operations. RFM is the second ESA ExoMars mission and will carry a European-built rover to the surface of Mars. RFM was scheduled to launch in 2022 on a launch vehicle provided by Russia; however, the project was reconfigured. ESA moved the launch to 2028 and requested that, in addition to the MOMA-MS, NASA provide the launch vehicle, throttleable descent engines for the lander module, radioisotope heater units (RHUs), and systems engineering support for the mission.

Recent Achievements

To support this effort, NASA has begun procurement activities for the descent engines. In partnership with the Radioisotope Power Systems program, NASA is coordinating with the DoE to provide the RHUs for the mission from their production capability. NASA delivered MOMA-MS to ESA and integrated it into the RFM rover. The NASA team is refining the MOMA-MS Secondary Electronics Box to reduce mission risk and will install it back into MOMA-MS by 2025. The launch vehicle for RFM will be acquired through the existing NASA Launch Services Program contract. The acquisition process for the launch vehicle will begin in FY 2025.

MARS PROGRAM MANAGEMENT

Mars Program Management provides for the broad-based implementation and programmatic management of the Mars Exploration Program. Mars Program Management also supports independent review panels, planetary protection studies, advanced mission and program architecture studies, program science, and coordination and integration of telecommunications between the Earth and Mars (including the Mars Relay Network).

MARS FUTURE MISSIONS

Mars Future Missions supported pre-formulation efforts for the Sample Receiving Project (SRP), chartered to recover, contain, transport, assess safety of, curate, and scientifically investigate the samples returned to Earth by a possible MSR mission. A MSR mission is a Planetary Protection Category V classification (restricted), and SRP is responsible for developing a high-containment sample receiving facility to house the samples for initial curation and safety assessment. SRP is coordinating with ESA as a strategic international partner to develop and operate the sample receiving facility.

Funding within Mars Future Missions for the formulation and development of the Mars Sample Receiving Facility has been reduced and will be reassessed pending NASA's determination regarding a path forward for a MSR mission within a balanced Science portfolio, following review of the findings of the MSR IRB Response Team (MIRT).

Recent Achievements

The SRP team completed a study to assess different high-containment facility types and consider utility of existing Biosafety Laboratories.

MARS MISSION OPERATIONS

Mars Mission Operations provides management and leadership for the development and operation of Mars multi-mission systems for operations. Mars Mission Operations supports and provides common operational systems and capabilities at a lower cost and risk than having each Mars project produce systems individually.

OTHER MISSIONS AND DATA ANALYSIS

MARS RESEARCH AND ANALYSIS (R&A)

Mars R&A provides funding for research and analysis of Mars mission data to understand how geologic, climatic, and other processes have worked to shape Mars and its environment over time, as well as how they interact today. The project has invested in Mars data analysis capabilities to analyze archived data collected from Mars missions, as well as critical products that provide data and analyses for the safe arrival, aero-maneuver, entry, descent, and landing on Mars.

Data analysis through Mars R&A allows research to continue for many years after mission completion. These research projects increase our scientific understanding of Mars' past and present environments and disseminate the results through the scientific publications. By using data collected by spacecraft, researchers can make scientific discoveries and test hypotheses about the Martian environment.

Recent Achievements

Researchers have shown that temperature variations occur in the Martian atmosphere on a daily scale. Some of this variation is due to a phenomenon called migrating thermal tides. Using a sample of satellite observations from different local times on Mars, researchers were able to determine the local time when thermal tides peak. A specific sampling of Martian observations from the 2018 Global Dust Event enabled the correlation of daily temperature variations, reaching 65 degrees kelvin at high southern latitudes near 25-kilometer altitudes, with increased dust distribution, demonstrating that dust is an important factor in heating the Martian atmosphere.

Researchers developed a Martian cloud catalog by utilizing the "Cloudspotting on Mars" project and Zooniverse citizen science data. The researchers created a method to aggregate the crowdsourced data using a novel clustering algorithm and then produced a catalog to aid scientists in understanding the circulation of the Martian atmosphere and overall Martian climate.

Scientists believe that several large and deep craters in western Arabia Terra may be explosive calderas, a type of volcano capable of producing super eruptions. If these craters are calderas, vast layers of volcanic ash should be common in Arabia Terra. Researchers previously observed layered deposits in Arabia Terra but have not associated the layered deposits with the calderas. New research and analysis of mineral signatures revealed that volcanic ash deposit thickness around the calderas decreases with distance from the center. The observations support the idea that explosive calderas exist in western Arabia Terra and have produced thousands of super eruptions spread out over 500 million years of Mars history.

MARS TECHNOLOGY

Mars Technology focuses on technological investments that lay the groundwork for successful future Mars missions, such as miniaturized electronics that enable lower cost science missions, enhanced wind tunnel facilities that allow testing for future Mars aerial vehicles in high-speed forward flight that was not possible before, and technologies that allow safe handling and distribution of samples planned to be returned from Mars.

In FY 2025, NASA will initiate studies and technology development in support of the draft "Exploring Mars Together: Mars Exploration Program Future Plan, 2023-2043." Specific areas of near-term interest include new techniques for Mars entry, descent, and landing; aerial and surface mobility and autonomy; revolutionary subsurface access (i.e., drilling more than 100 meters below the surface); sample handling; communications relay; and transportation to and from Mars. Investments in these areas are considered the initial steps of a "roadmap" for future mission and infrastructure investments. As part of these efforts,

OTHER MISSIONS AND DATA ANALYSIS

NASA will focus on engagement with the commercial sector to leverage growing capabilities in space transportation, communications, and robotics.

Recent Achievements

In FY 2023, technologists developed a highly dependable avionics architecture for future Mars science helicopters. This architecture excels in both performance and radiation tolerance while maintaining a compact footprint, low weight, and minimal power consumption.

Pursuing a deeper understanding of the possibility of past life on Mars demands advancements in drilling technology. Recent efforts in this field yielded effective techniques for compressing gas from the Martian atmosphere and utilizing it to clear drill cuttings from the borehole. This innovation enables faster and more reliable drilling operations than previously feasible.

The technology team also made progress in preparing to handle samples returned from Mars by prototyping key steps in the process of opening sample tubes from Mars and extracting both the Martian atmosphere and solid samples. The team executed these procedures in a manner that meticulously safeguards against contamination of the Martian samples by terrestrial materials and minimizes the risk of inadvertent release of any potentially hazardous substances contained within the Martian samples upon their return to Earth.

Prior investments in Mars technology resulted in the hugely successful Ingenuity Mars helicopter technology demonstration. The Ingenuity helicopter completed its original technology demonstration goal of five flights in 30 Martian days during FY 2022. Since then, Ingenuity's activities transitioned into an operations demonstration, conducting extended operations with the Perseverance rover as a paired aerial-rover exploration system. As a result, the helicopter surpassed the original flight, distance, and lifetime objectives many times over, with a total of 72 successful flights. Ingenuity performed scouting missions for Perseverance to demonstrate the potential capability for aerial platforms to optimize surface exploration operations. The helicopter was also able to observe targets that were inaccessible to the rover and conducted dust-lifting and sound speed experiments. While serving in its operations role, the helicopter completed further capability demonstrations, including higher ascents, longer flights, and more challenging routes. The Ingenuity mission’s flight operations ended on January 18, 2024 when the rotor blades sustained damage during landing, leaving it no longer capable of flight.

Operating Missions

MARS ROVER 2020

NASA's Mars 2020 Perseverance rover advanced one of the top scientific priorities detailed in the Planetary Science and Astrobiology Decadal Survey 2023-2032, initiating the first leg of a round trip to Mars to return samples to Earth for further study. Perseverance is characterizing the planet's geology and past climate, searching for signs of ancient microbial life on Mars, collecting and storing carefully selected rock and sediment samples, and testing new technologies to benefit future robotic missions and paving the way for human exploration of Mars. Subsequent NASA missions would retrieve the sealed samples collected by Perseverance from the surface of Mars and return them to Earth for in-depth analysis.

The Perseverance rover is carrying a competitively selected science and technology payload of seven instruments. Five of the instruments provide the clearest possible measurements for seeking possible signs of ancient life (potential “biosignatures”) on Mars over its 4.6-billion-year history. The remaining two instruments assess environmental hazards and resources for future human exploration. Perseverance also ferried a helicopter named Ingenuity, the first aircraft to achieve powered, controlled flight on another planet. The Mars Rover 2020 mission incorporates new capabilities developed through investments by NASA's STMD and ESDMD and payload contributions from international partners.

Recent Achievements

The Mars 2020 Perseverance rover successfully completed its primary mission of one Mars Year on January 6, 2023. It is now operating in an extended prime mission mode, continuing to collect Martian samples for potential future return by the NASA/ESA MSR program.

After the conclusion of the delta front science campaign, the Perseverance rover team, in coordination with MSR, successfully deposited ten Martian sample tubes (containing seven rock, one regolith, and one atmosphere samples, plus one terrestrial contamination witness tube), forming a cache on the surface at the "Three Forks" location in Jezero Crater for potential retrieval by the future MSR mission. Perseverance collected rock core and regolith samples in pairs so that this initial cache consists of one of each of the paired samples, with the remaining sample-pair left on board the rover for later caching with future samples. This cache serves as a scientifically return-worthy backup in case of any unforeseen event that may preclude retrieving the primary cache of samples onboard Perseverance.

Perseverance completed its next two science campaigns, the Upper Fan campaign and the Marginal Deposit campaign. During these campaigns, the rover acquired an additional five rock core samples. The science team investigated rocks created by multiple events of channel deposition from ancient rivers that fed into the crater lake. The rover took samples of these materials, along with rocks from the margin unit. The rocks contain carbonate and other minerals that indicate the prior presence of large amounts of liquid. During the Marginal Deposit campaign, Perseverance found evidence of carbonates, which confirmed indications from orbital imagery that this is a favorable area for sampling.

The technology investigation payload, Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE), completed its mission on Mars, generating oxygen for the 16th and final time in August 2023. Developing technologies use resources on the Moon and Mars is critical to build a long-term lunar presence, create a robust lunar economy, and allow us to support an initial human exploration campaign to Mars. During its mission, MOXIE generated a total of 122 grams of oxygen, which is approximately what a small dog breathes in 10 hours. At its most efficient, MOXIE was able to produce 12 grams of oxygen per hour at 98 percent purity or better, twice as much as NASA’s original goals for the instrument. MOXIE completed all its technical requirements and operated in a variety of conditions throughout a full Mars year.

Additionally, the Ingenuity helicopter continued in its extended operations demonstration phase, providing scouting support to the Perseverance mission.

TRACE GAS ORBITER - EXOMARS

The first mission in the ESA ExoMars program is the 2016 ExoMars Trace Gas Orbiter, which launched in March 2016 and began its science and relay operations phase in March 2018 with the observations of a global dust storm. For this mission, NASA contributed two Electra ultra-high frequency telecommunication radios, identical to those used successfully on NASA’s MRO and MAVEN. The Electra radio acts as a communications relay and navigation aid for surface assets and supports navigation, command, and data-return needs for Martian landers and rovers. Furthermore, two instruments, the Colour and Stereo Surface Imaging Systems (CaSSIS) and the Nadir and Occultation for MArs Discovery (NOMAD) included significant contributions from U.S. co-investigators.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The NOMAD high-resolution spectrometer allowed researchers to search for organics in the atmosphere, and they are now expanding the searches to key tracers, such as hydrochloric acid and isotopes that probe ancient and current processes on Mars. Scientists recently discovered a new species of organics and designed a three-dimensional view of the water cycle and its deuterium and hydrogen/H isotopes on Mars using NOMAD. Scientists are now exploring carbon isotopes on Mars with NOMAD, obtaining the first vertically resolved measurements of the carbon isotopic composition of CO_2 in the Martian atmosphere. This three-dimensional view is critical to determining present and past habitability on Mars. The CaSSIS camera, with significant participation from U.S. co-investigators, continues its imaging of the surface and has now made more than 40,000 images, including more than 4,200 stereo observations. The stereo observations synthesize three-dimensional landscape models of the surface of Mars, while CaSSIS color distinguishes surface materials at high-resolution.

The ExoMars Trace Gas Orbiter, using the NASA-contributed Electra radio, continues relaying over 55 percent of the science data and images from NASA's Curiosity rover and Perseverance rover. This highly successful international collaboration has proven key to achieving the mission objectives of Perseverance by:

- helping enable the collection of rock samples on the surface of Mars as part of the MSR campaign;
- aiding command and telemetry data transfers with the Ingenuity helicopter; and
- returning a vast number of images to engage with and excite the public.

2011 MARS SCIENCE LABORATORY (MSL)

The Curiosity rover is collecting Martian soil and rock samples and analyzing them for organic compounds and environmental conditions favorable for microbial life, using its cameras, spectrometers, and the Sample Analysis at Mars (SAM) instrument suite. To look for signs of water that may lie below the rover, a radiation detector pointed downward measures hydrogen up to three feet below the surface. The team expects the Curiosity radioisotope thermal generator to produce enough power through 2032 to enable the continued exploration and assessment of Martian regions with potential as past habitats for life.

The Curiosity rover is also providing regular measurements of the Martian atmosphere and weather, one of few stations recording temperature, atmospheric pressure, humidity, and wind on the Martian surface. A radiation detector also regularly monitors high-energy radiation at the Martian surface.

Recent Achievements

In 12 years on the surface of Mars, the Curiosity rover has traveled over 19.3 miles (31 kilometers) and climbed over 2,000 feet (620 meters) in elevation exploring the lower reaches of Mount Sharp, the prime science target of the mission. Over the course of its fourth extended mission, the rover is closely investigating the "sulfate-bearing unit" and increasingly younger geological layers as it continues its ascent through the Marker Band Valley and Gediz Vallis Channel of Mount Sharp. Each unit represents a distinct ancient environment, or change in environment, and each has the potential for groundbreaking advances in understanding Mars' ancient climate.

Curiosity found that the Marker Band, a thin distinct layer of Mount Sharp visible from orbit, has centimeter-scale wave ripples that formed in a shallow lake. The band is rich in iron, manganese, and zinc, and the mineral siderite, an iron carbonate. These findings suggest an abrupt, transient change to a wet environment, with unique geochemical conditions relative to the surrounding sulfate unit.

OTHER MISSIONS AND DATA ANALYSIS

Curiosity recently reached Gediz Valley Ridge and drilled its 39th core in the sulfate-bearing unit there. Sampling along the Gediz Vallis Ridge gives the MSL team access to rocks that were likely carried down Mount Sharp by powerful debris flows three billion years ago.

Overall, the rover is healthy and operating nominally during this phase of the mission. The rover team is closely monitoring the condition of the wheels, which have driven well beyond their original design distance. Given the current distance driven and wheel condition, the estimated life expectancy for the wheels is 26 miles (42 kilometers) and sufficient for the full extended mission.

MARS RECONNAISSANCE ORBITER 2005 (MRO)

MRO, currently in its sixth extended operations phase, carries the highest resolution camera orbiting another planet, the High-Resolution Imaging Science Experiment (HiRISE). This capability yields a more detailed view of the geology and structure of Mars and is critical in identifying obstacles that could jeopardize the safety of future landers and rovers. A second camera, the Context Camera, acquires medium-resolution images that provide a broader geological context for the more detailed observations from higher-resolution instruments. MRO also carries a radar sounder to find subsurface water ice, which is an important consideration in selecting scientifically worthy landing sites for future exploration.

MRO carries a high-resolution imaging spectrometer, the Compact Reconnaissance Imaging Spectrometer for Mars, which ceased operations in FY 2022 as its cryocoolers could no longer maintain the low temperatures required by its detectors. A wide-angle camera, the Mars Color Imager, continues to provide daily global weather maps, and the Mars Climate Sounder maps the vertical distribution of temperature, dust, and water vapor ice around the globe. MRO will extend HiRISE operations and reveal new images of mineral deposits and the three-dimensional structure and content of the polar ice and subsurface ice; characterize the episodic nature of great dust storms; and expand coverage and quantification of active surface change on Mars today.

MRO characterized the landing sites for the Mars 2020 Rover and the ESA ExoMars Rover, planned for launch in 2028.

As it explores Mars, MRO also serves as a major element of an “interplanetary Internet,” as a communications orbiter that relays commands to and data from the MSL Curiosity and Mars 2020 Perseverance rovers to Earth.

Recent Achievements

During the past year, MRO contributed to a better understanding of Mars in multiple areas. Using MRO data, scientists observed regional dust storm activity that ended the InSight mission in December 2022; detected and recorded surface changes of approximately 85 percent of the Martian surface at a 6 m/pixel resolution; conducted targeted imaging surveys to correlate climatological processes with dark streaks observed on slopes near impact craters; and improved estimates of subsurface ice volumes in mid-latitudes through new imaging and radar data.

MRO continued to provide network relay services, as well as dust reports, to the NASA Mars surface assets, Curiosity and Perseverance rovers, and the Mars Ingenuity helicopter, to support their effective operations. MRO acquired stereo images that future enhanced visual landing systems could use. MRO also re-activated its Optical Navigation Camera to determine if it could detect a MSR Orbiting Sample Cache, which, in the current MSR configuration, will be in orbit for at least two weeks before a spacecraft retrieves it. Finally, over 200 peer-reviewed journal articles published this past year used MRO data.

OTHER MISSIONS AND DATA ANALYSIS

MARS ODYSSEY 2001

Mars Odyssey, currently in the 2nd year of a three-year 9th extended mission phase, continues to explore Mars from orbit with its powerful set of instruments, and provides a key element of the communications infrastructure for landed assets. From its unique morning orbit, Odyssey's Thermal Emission Imaging System (THEMIS) is observing frost, clouds, and fogs that no other orbiter can see. It sends information to Earth about Martian geology, climate, and mineralogy. Measurements by Odyssey enable scientists to create maps of minerals and identify regions with near-surface water associated with hydrated minerals or ice. Odyssey continues critical, long-term studies of the Martian climate and has served as an essential link in the communications relay network between Earth and NASA's surface assets on Mars for two decades. Its late-afternoon orbit allows rover planners to assess a full day of data before preparing new commands. Odyssey provided crucial relay support for the InSight lander during its entire mission and continues daily contacts with NASA’s active rovers.

Recent Achievements

Odyssey team scientists are studying the details of Martian weather and climate, revealing the current cycles of water and dust, and mapping terrains that once were potentially hospitable to life. Over the past year, Odyssey team members have published eight peer-reviewed journal articles, and the broader science community have published 22 peer-reviewed journal articles that feature Odyssey data. Odyssey conducted special maneuvers to observe the surface at an angle. At moderate angles, Odyssey’s THEMIS instrument can detect rocks that are usually hidden by thin dust layers. At the extreme, the spacecraft turned all the way to look at the horizon, allowing THEMIS to see the structures of clouds at the limb, including distinguishing water clouds from dust clouds.

Newly processed data from Odyssey’s Gamma Ray Spectrometer (GRS) instrument was used to hunt for the traces of ancient super-volcanoes on the Martian surface, and to understand how such volcanoes have changed over the course of time. Odyssey is performing ongoing coordinated atmospheric observations with instruments on the United Arab Emirates Hope orbiter. Odyssey's neutron spectrometers continue to make significant contributions in tracking solar coronal mass ejections (part of the Mars Space Weather Alert Network) and to triangulate gamma-ray bursts across our galaxy and beyond (an integral part of the Gamma Ray Burst Interplanetary Network). Odyssey’s neutron spectrometers also help prepare for future human exploration of Mars by measuring damaging radiation at a variety of energies. The types of radiation measured by Odyssey complement data taken by other missions (e.g., the European Trace Gas Orbiter, NASA’s MAVEN orbiter, and the Curiosity rover) to form a more complete picture of the radiation environment both in orbit and on the surface. Providing reliable relay support since 2004, Odyssey continues to support NASA’s surface missions, offering essential early morning and late evening contacts for surface operations.

MARS EXPRESS

Mars Express is currently in its eighth extended mission operations phase. Mars Express is an ESA mission that provides an understanding of Mars as a “coupled” system: from the ionosphere and atmosphere down to the surface and sub-surface. This mission addresses the climatic and geological evolution of Mars, as well as the potential for life on the planet. NASA contributed components for the Mars Advanced Radar for Subsurface and Ionospheric Sounding and Analyzer of Space Plasmas and Energetic Atoms instruments aboard Mars Express and participates in the scientific analysis of mission data.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Due to the prioritization of other Mars science investigations, NASA directed that the science collaboration with the Mars Express mission conclude at the end of FY 2021. The current budget supports the Deep Space Network costs to continue communications support for the ESA-operated instruments.

MARS ATMOSPHERE AND VOLATILE EVOLUTION (MAVEN)

MAVEN, now in its fifth extended mission, launched in 2013 and successfully completed its primary mission in November 2015. MAVEN is the first mission devoted to studying Mars' upper atmosphere, with the most comprehensive measurements ever taken to address key scientific questions regarding the loss of the Mars atmosphere, liquid water, and habitability. The instrumentation suite allows scientists to observe the upper atmosphere, ionosphere, solar energetic drivers, and magnetic fields, to determine how Mars' atmosphere evolved through time. These measurements of how the Martian atmosphere responds to the Sun's radiation and intense solar storms are critical for understanding the history of water on Mars. While geological and geomorphic evidence shows that oceans of water once existed on Mars, we now know through MAVEN that much of that water slowly evaporated as the atmosphere eroded over time. Thus, the mission is answering long-standing questions regarding the loss of the Mars atmosphere, liquid water, and habitability. Scientists are also using MAVEN data to determine the role that loss of volatile compounds (e.g., carbon dioxide, water) from the Mars atmosphere to space has played through time, and the importance of this loss in changing the Mars atmosphere and climate through time.

As with all Mars Exploration Program orbiters, MAVEN carries an Electra radio for communications with rovers and landers on the Martian surface. MAVEN has carried out relay activities and began transmitting much higher volumes since 2019 after the spacecraft adjusted its orbit to serve as a more efficient relay. Given anticipated budget constraints and other Planetary Science Division priorities, this budget assumes this mission will complete mission operations in FY 2026. NASA will reassess the mission status in future years.

Recent Achievements

MAVEN recently completed nine years in orbit around Mars. The steep rise in solar activity over the past year, as we approach solar maximum in 2025, has allowed MAVEN scientists to gain unprecedented insights into how the Martian atmosphere responds to extreme conditions. In particular, MAVEN scientists send real time alerts when a "solar storm" is expected to hit Mars. MAVEN works directly with NASA's Heliophysics division and the Moon2Mars program to monitor the Sun, model any major storms, and alert critical points of contact for operational readiness. MAVEN is the only NASA asset that can robustly observe solar activity at 1.5 Astronomical Units and has enabled publication of definitive studies on how solar activity has eroded the Martian atmosphere over time.

MAVEN has also discovered and observed three types of aurorae at Mars and for the first time and has been able to observe different types of aurorae simultaneously. Researchers believe that some of these aurorae are unique to Mars and do not occur on Earth because Mars does not have a global magnetic field. These aurorae would be visible to astronauts with the naked eye if they were on the surface of Mars.

Scientists used MAVEN data in over 60 peer-reviewed articles in FY 2023, covering a wide range of topics, ranging from the structure of the atmosphere and ionosphere, the effects of dust and solar flares, atmospheric escape, and the unique dynamics of Mars' magnetosphere. MAVEN also continues to collaborate with spacecraft and rovers at Mars to enable multi-vantage point scientific discoveries on subjects such as dust storms and water.

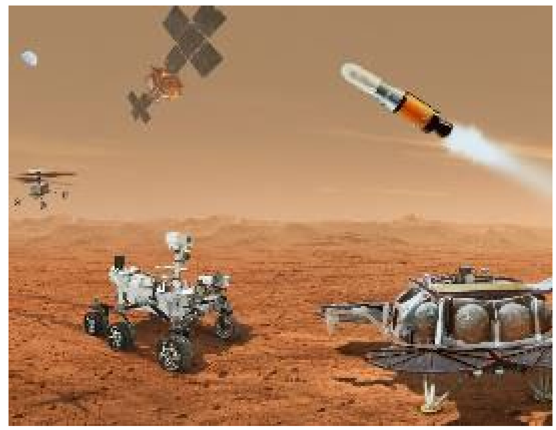
MARS SAMPLE RETURN

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**818.8**	**--**	**200.0**	**100.0**	**100.0**	**100.0**	**100.0**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Mars Sample Return (MSR) program has been a priority of the planetary science community since the 1980s and has been included in the last three Planetary Decadal Surveys. The scientific driver of this campaign is to return samples of early Mars to reveal the first billion years of history of the solar system, informing our understanding of planetary evolution, including the emergence of life. The samples will be available for analysis by the most advanced instrumentation on Earth, including technologies yet to be developed.



Shown above is an artist rendition of the current MSR Campaign elements, which are designed to retrieve the rock and soil samples Perseverance has collected and stored in sealed tubes. The samples will be available to the world's best laboratories for analysis to pursue answers to important science questions about planetary evolution, including the potential for extraterrestrial life.

In FY 2023, NASA conducted a second independent review of the MSR Program (IRB-2), which assessed original cost and schedule estimates as well as overall program management. The review concluded that MSR is a strategically and scientifically important mission. It also concluded that the mission is likely to cost significantly more than currently budgeted, and that the mission faced schedule and management challenges. In response to the findings of this review, and to manage cost growth while maintaining funding for other important Science missions, NASA established an MSR IRB Review Team (MIRT) to review and respond to the IRB-2's findings and recommendations in detail, and to make a recommendation regarding a path forward for MSR, including evaluating other MSR architectures.

On April 15, 2024, the MIRT released its response to the IRB-2. The MIRT recommended to NASA Science Mission Directorate leadership a revised MSR mission design with reduced overall complexity, descoped content, and improved lines of accountability, authority and coordination. However, the revised design would delay the return of samples to 2040, and— consistent with the IRB-2's findings—would likely have a total cost as high as $10 billion.

Given these findings, NASA issued a competitive solicitation for funded industry studies to explore out-of-the-box architecture and mission element options that could offer lower life cycle cost, lower annual cost, provide earlier sample return, and/or lower mission complexity and risk. In parallel, NASA engaged

MARS SAMPLE RETURN

NASA centers and JPL to provide their unique expertise and technology capabilities to also explore out-of-the-box options.

KEY PLANS FOR FY 2025

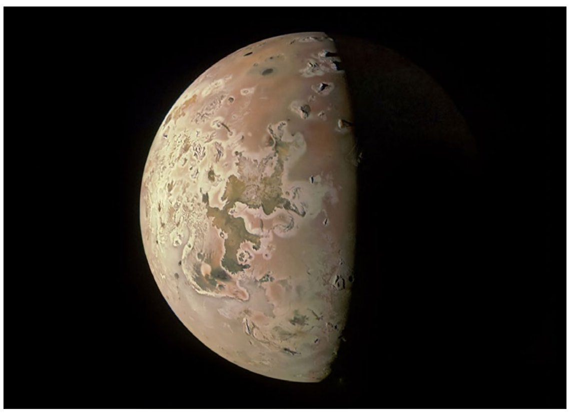
The FY 2025 request will allow the project to advance formulation of mission components and capabilities that have a high likelihood of being used in any future sample return architecture, and to evaluate and appropriately incorporate relevant findings from funded industry and center architecture studies.

OUTER PLANETS AND OCEAN WORLDS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Europa Clipper	345.0	303.3	**101.2**	80.6	77.7	84.0	127.0
Other Missions and Data Analysis	11.8	--	**17.8**	16.8	19.5	42.3	77.3
Total Budget	**356.8**	**--**	**119.0**	**97.4**	**97.1**	**126.3**	**204.3**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



This image revealing the north polar region of the Jovian moon Io was taken on October 15, 2023, by NASA's Juno. Three of the mountain peaks visible in the upper part of image, near the day-night dividing line, were observed here for the first time by the spacecraft's JunoCam. (Credit: JPL-Caltech/SwRI/MSSS, image processing by Ted Stryk)

The Outer Planets and Ocean Worlds Program enables the exploration of worlds possessing vast expanses of liquid water in our solar system. These liquid reservoirs provide insight into some of the most fundamental questions about life and the evolution of the solar system.

NASA missions have revealed a surprising number of ocean worlds in our solar system, while at the same time providing enticing, but limited, details about these oceans. Underneath its icy crust, Jupiter's moon (Europa) contains a global liquid water ocean holding twice as much water as all of Earth's oceans. Scientists detected a similar, though smaller, global ocean on Enceladus, a small moon orbiting Saturn. Other moons (e.g., Ganymede, Titan, and perhaps Callisto) and possibly even Pluto possess oceans deep beneath their surfaces. Titan also possesses huge lakes of liquid methane on its surface, the only place beyond Earth known to have lakes exposed to an atmosphere.

Research and spacecraft measurements have increased our confidence that these ocean worlds possess at least some of the conditions needed for life: long-lived oceans, providing liquid water and a stable habitat; hydrothermal activity and other chemical sources, providing energy; and the basic elements along with organics, providing necessary materials. Thus, ocean worlds, like Europa, are the most likely places to search for currently habitable environments in the solar system and any life forms that could exist in them.

The Outer Planets and Ocean Worlds Program enables science investigations spanning the diversity of worlds hosting large liquid bodies in the outer solar system. These missions enable investigation of more focused scientific questions than smaller and less complex missions in the New Frontiers and Discovery programs can pursue.

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA will delay the initiation of formulation studies of the Decadal Survey-recommended Uranus Orbiter and Probe mission until FY 2027.

EUROPA CLIPPER

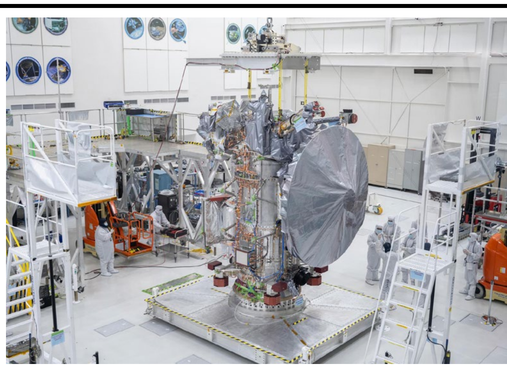
Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	1,219.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	1,219.0
Development/Implementation	1,848.8	345.0	303.3	**11.9**	0.0	0.0	0.0	0.0	0.0	2,509.0
Operations/Close-out	0.0	0.0	0.0	**89.3**	80.6	77.7	84.0	127.0	813.4	1,272.0
2024 MPAR LCC Estimate	**3,067.8**	**345.0**	**303.3**	**101.2**	**80.6**	**77.7**	**84.0**	**127.0**	**813.4**	**5,000.0**
Total Budget	**3,067.8**	**345.0**	**303.3**	**101.2**	**80.6**	**77.7**	**84.0**	**127.0**	**813.4**	**5,000.0**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



NASA's Europa Clipper spacecraft boasts its new 10-foot (three-meter) high-gain antenna (shown here), after its August 14, 2023, installation in High Bay 1 of the Spacecraft Assembly Facility at JPL.

PROJECT PURPOSE

Jupiter's moon, Europa, has the largest known ocean in the solar system and is one of the most likely places to find life beyond our Earth. NASA developed concepts to explore Europa and determine if it is habitable based on characteristics of its vast oceans (twice the size of all the Earth's oceans combined); the ice surface-ocean interface; the chemical compositions of the intriguing, irregular brown surface areas; and the current geologic activity providing energy to the system.

NASA formulated the Europa Clipper mission in response to the Planetary Science Decadal Survey (Vision and Voyages for Planetary Science in the Decade 2013-2022), which identified a strategic mission to Europa as the second-highest priority for planetary science flagship missions.

NASA's Europa Clipper spacecraft will conduct a detailed survey of Europa to determine whether the icy moon harbors conditions suitable for life. The spacecraft, in orbit around Jupiter, will make 45 to 50 close passes over Europa, shifting its flight path for each flyby to soar over a different location so that it eventually scans nearly the entire moon. After each flyby, the spacecraft will send data back to Earth.

Because radiation trapped in Jupiter's magnetic field bathes Europa, a thick-walled vault will enclose Europa Clipper's electronics, a technique successfully used for the first time by NASA's Juno spacecraft. The vault walls, made up of titanium and aluminum, will act as a radiation shield against most of the

EUROPA CLIPPER

Formulation	Development	Operations

high-energy atomic particles, dramatically slowing down the damaging effect that radiation has on the spacecraft's electronics.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

PROJECT PARAMETERS

This mission will leverage the competitively selected payload of investigations to characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of the surface-ice ocean exchange. It will also seek to understand the habitability of Europa’s ocean through composition and chemistry of the surface and exosphere; understand the formation of surface features, including sites of recent or current activity; and identify and characterize high science interest locations. This will be the first NASA mission explicitly designed to explore an ocean world.

Europa Clipper’s science payload consists of ten instruments, grouped as follows:

- Cameras and spectrometers will create high-resolution images and composition maps of the moon's surface and thin atmosphere;
- An ice-penetrating radar, a magnetometer, plasma sensors, and a gravity investigation will reveal the moon’s ocean and deep interior;
- The spacecraft's thermal camera will pinpoint warmer ice and might reveal recent eruptions of water or bodies of liquid water buried near the surface; and
- A dust analyzer and a mass spectrometer will study the chemistry of particles and gases ejected from the surface and subsurface of the moon.

Europa Clipper will launch on a SpaceX Falcon Heavy launch vehicle, utilizing a Mars-Earth Gravity Assist trajectory in October 2024. The Europa Clipper mission will spend four years in orbit around Jupiter, conducting its scientific observations by completing approximately 50 close fly-bys of Europa.

ACHIEVEMENTS IN FY 2023

The Europa Clipper team delivered the four remaining instruments and integrated them onto the spacecraft, completing the science payload for the mission. They stacked the structural components of the Europa Clipper spacecraft, putting all the major spacecraft elements in full flight configuration for the first time. The solar arrays are complete and await final shipment to KSC in April 2024 for final integration with the spacecraft. The team also successfully conducted System Test-1, the first end-to-end system test of the spacecraft, including the payload. This test was a significant milestone for the year, which exercised all subsystems of the spacecraft and in-flight configuration through all phases of the complete mission profile.

EUROPA CLIPPER

Formulation	Development	Operations

WORK IN PROGRESS IN FY 2024

The project will continue operational testing and initiate environmental testing for the entire spacecraft (except for the solar arrays) in preparation for launch in October 2024. The team delivered and installed the final version of the flight software for the spacecraft in January 2024. The spacecraft will ship from the JPL to KSC in April 2024 to begin final testing and processing. The Operational Readiness Review (ORR) will occur in July 2024, leading to the final launch preparations.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The project will complete integration and test of the flight hardware. Europa Clipper will launch in October 2024 and begin its five and a half-year cruise to Jupiter. The spacecraft will conduct its first gravity assist trajectory maneuver when Europa Clipper flies by Mars on May 25, 2025.

SCHEDULE COMMITMENTS/KEY MILESTONES

At confirmation, the project established a Launch Readiness Date (LRD) of September 2025 to fully accommodate all possible launch vehicles available to the mission. NASA selected the SpaceX Falcon Heavy launch vehicle for Europa Clipper in FY 2021 and established a target LRD of October 2024.

Milestone	Confirmation Baseline Date	FY 2025 PB Request
KDP-C	Aug 2019	Aug 2019
CDR	May 2020	Dec 2020
SIR	Mar 2021	Nov 2021
KDP-D	Apr 2021	Feb 2022
ORR	May 2023	Jul 2024
LRD	Sep 2025	Oct 2024
Phase E Start	Nov 2025	Nov 2024

EUROPA CLIPPER

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2020	2,412.8	69	2024	2,509.0	+4	LRD	Sep 2025	Oct 2024	-11

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**2,412.8**	**2,509.0**	**+96.2**
Aircraft/Spacecraft	818.7	1,224.5	+405.8
Payloads	168.7	514.2	+345.5
Systems I&T	63.2	68.5	+5.3
Launch Vehicle	432.0	202.0	-230.0
Ground Systems	104.8	177.6	+72.8
Science/Technology	24.8	33.9	+9.1
Other Direct Project Costs	800.6	288.3	-512.3

EUROPA CLIPPER

Formulation	Development	Operations

Project Management & Commitments

JPL is responsible for project management.

Element	Description	Provider Details	Change from Baseline
Spacecraft	Spacecraft Bus with all flight subsystem capabilities	Provider: JPL Lead Center: JPL Performing Center(s): JPL, Applied Physics Laboratory (APL), GSFC, MSFC, JSC, KSC Cost Share Partner(s): N/A	N/A
Launch Vehicle	Falcon Heavy rocket	Provider: SpaceX Lead Center: KSC Performing Center(s): KSC Cost Share Partner(s): N/A	Previously Space Launch System
Europa Ultraviolet Spectrograph (UVS) Instrument	Ultraviolet Spectrograph	Provider: SwRI Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
MAss SPectrometer for Planetary EXploration/Europa (MASPEX)	Time-of-Flight Mass Spectrometer	Provider: SwRI Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Europa Imaging System	Narrow angle and wide-angle cameras	Provider: APL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
SUrface Dust Analyzer (SUDA)	Dust Analyzer; Mass Spectrometer	Provider: LASP - CU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Europa Thermal Emission Imaging System (E-THEMIS)	Thermal Imager	Provider: ASU Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

EUROPA CLIPPER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Interior Characterization of Europa Using Magnetometry (ICEMAG)	Magnetometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	Terminated
Europa Clipper Magnetometer	Magnetometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	Facility instrument to replace ICEMAG functionality
Plasma Instrument for Magnetic Sounding (PIMS)	Plasma Instrument - Faraday Cups	Provider: APL Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mapping Imaging Spectrometer for Europa (MISE)	Infrared Spectrometer	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)	Sounding Radar	Provider: University of Texas Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: A subsystem, instrument, software, or Ground Support Equipment is late, or if a significant problem occurs during spacecraft Assembly, Test, and Launch Operations (ATLO) integration, or tests take longer than planned, Then: It could consume all the remaining flight project practices margin and impact the ATLO schedule.	Consume margin (as needed); descope some remaining system tests; book weekends and double shift as needed; and execute only incompressible test list items as a minimum to gain back schedule.

EUROPA CLIPPER

Formulation	Development	Operations

Risk Statement	Mitigation
If: Any of the remaining open items (e.g., waivers, Research Focus Areas, Problem Failure Reporting [PFR] procedures, reliability analyses) do not close on schedule, or result in the late discovery of a design deficiency during the remaining ATLO window, Then: This could delay integration and test during the ATLO rework window and/or result in a cost or schedule impact to correct the deficiency.	All systems and subsystems are providing monthly updates to ensure status knowledge. The project is prioritizing all open requirements, Engineering Change Requests, and Functional Design Document updates. Separate owners are assigned to each issue, including Electromagnetic Interference/Compatibility, Internal Electrostatic Discharge, Materials Identification and Usage List, Design/Analysis Discrepancies, PFRs, and waivers.

Acquisition Strategy

The Europa Clipper spacecraft is a JPL "in-house" build with each subsystem completing an internal make/buy assessment, with competed industry contracts where appropriate. JPL is collaborating with APL for development and leveraging each other's strengths, as well as those of other NASA centers. As a result, APL is responsible for the propulsion module and the telecom subsystem and GSFC will provide the propulsion subsystem. The Europa Clipper payload is comprised of nine investigations, each competitively selected via an SMD Announcement of Opportunity.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Telecom and Propulsion Subsystems	APL	Laurel, MD
Europa Imaging System instrument	APL	Laurel, MD
PIMS instrument	APL	Laurel, MD
REASON instrument	University of Texas University of Iowa	Austin, TX Iowa City, IA
MISE instrument	APL	Laurel, MD
SUDA instrument	LASP - University of Colorado	Boulder, CO
MASPEX instrument	SWRI	San Antonio, TX
UVS instrument	SWRI	San Antonio, TX
E-THEMIS instrument	ASU Ball Aerospace Raytheon Vision Systems	Tempe, AZ Boulder, CO Goleta, CA

EUROPA CLIPPER

Formulation	Development	Operations

Element	Vendor	Location (of work performance)
Solar arrays	Airbus Defence and Space	Leiden, The Netherlands Ottobrun, Germany
Launch vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	SRB	Apr 2024	PSR	TBD
Performance	SRB	Jul 2024	ORR	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
JUICE - Jupiter Icy Moons Explorer	4.5	--	**3.5**	2.5	2.6	2.4	2.9
Outer Planets Research	7.3	--	**14.3**	14.3	14.3	14.5	14.6
Planetary Decadal Future	0.0	--	**0.0**	0.0	2.6	25.4	59.8
Total Budget	**11.8**	**--**	**17.8**	**16.8**	**19.5**	**42.3**	**77.3**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Other Missions and Data Analysis includes NASA's contribution to the ESA JUpiter ICy Moons Explorer (JUICE) mission and Outer Planets Research.

Mission Planning and Other Projects

JUPITER ICY MOONS EXPLORER (JUICE)

NASA is collaborating on this ESA-led mission to Ganymede and the Jupiter system. Together, the Europa Clipper and JUICE missions provide an opportunity for comparative investigation of three of the ocean worlds in the Jupiter system: Europa, Ganymede, and Callisto. Researchers believe all three worlds possess liquid water oceans at varying depths beneath their surfaces. The NASA contribution consists of three separate pieces of hardware: one full instrument, the Ultraviolet Spectrograph; two sensors for the Swedish National Space Agency Particle Environment Package suite of instruments; and the transmitter and receiver hardware for the Radar for Icy Moons Exploration instrument.

Recent Achievements

The team integrated all instruments into the spacecraft, which launched on April 14, 2023 from Kourou, French Guiana. The spacecraft is in an eight-year cruise phase and will arrive at Jupiter in July 2031.

OUTER PLANETS RESEARCH

Outer Planets Research increases the scientific return of current and past outer planets missions and paves the way for future missions (e.g., refining landing sites on Titan, characterizing ice shells on Europa).

Recent Achievements

Scientists have recently put together a fundamentally new history of the Saturn system based on NASA data. This new history demonstrates that Saturn's rings have likely been in place for only a short fraction of time in our solar system and, for the first 90 percent or more of its existence, Saturn may have had no rings. Within the last 100 million years Saturn's moon, Titan, may have destabilized a moon named Chrysalis, moving it inward until Saturn's gravity ripped it apart, creating a swarm of debris which gave way to the ring system. Researchers based the new model on a synthesis of a diverse set of data from the instrument suite onboard NASA's Cassini spacecraft, which explored Saturn from 2004-2017.

OTHER MISSIONS AND DATA ANALYSIS

PLANETARY DECADAL FUTURE

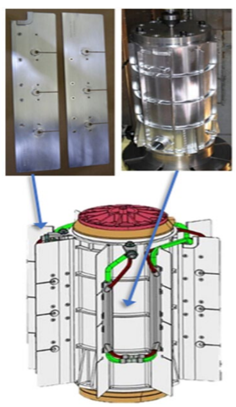
The most recent Planetary Science Decadal Survey recommended a Uranus Orbiter and Probe as the highest priority flagship mission to begin this decade. NASA intends to begin formulation studies in FY 2027 to define the science objectives and explore potential mission architectures. NASA will use the results of these studies to inform future decisions and planning.

RADIOISOTOPE POWER

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**154.9**	**--**	**201.1**	**190.7**	**176.6**	**169.4**	**162.5**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



The image above shows two completed significant flight elements of the Dragonfly Multi-Mission Radioisotope Thermoelectric Generator (MMRTG).

Planetary Science missions demand advances in technology to enable successful trips to distant solar system destinations with harsh environments, and to enable missions with highly challenging trajectories and operations. To meet these needs, Planetary Science supports the development of advanced multi-mission capabilities through technology investments in key spacecraft systems, such as radioisotope power. Exploring the solar system requires radioisotope power when solar power is impractical or unavailable. The Radioisotope Power Systems (RPS) program includes technology maturation and system development to improve efficiency and performance and works in partnership with the DoE to ensure continuing plutonium-238 (Pu-238) production and operations infrastructure. The program also supports nuclear launch approval activities and the implementation of RPS on NASA missions.

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA has increased the budget beginning in FY 2026 to support the Next Gen Radioisotope Thermoelectric Generator (RTG) Mod 1 build, which reconstitutes the capability to produce deep space optimized RTG's for future NASA missions.

ACHIEVEMENTS IN FY 2023

The RPS program concluded that the initial unit of the Next-Gen RTG (Mod 0), based on the General-Purpose Heat Source (GPHS)-RTG existing hardware, will be flight ready for a future mission and continued to develop the capability to manufacture new units of the same design (Mod 1). NASA also continued work to develop the Vulcan multi-mission databook and the Programmatic Environmental Assessment (PEA) for the GPHS. Development of a GPHS PEA will streamline the process to obtain environmental assessments for individual missions, which will simplify the National Environmental Policy Act (NEPA) compliance process and can shorten the schedule to obtain NEPA compliance on future missions utilizing RPS power systems. The RPS program supported the response to the Planetary Decadal Survey in 2023, which emphasized use of RPS, management of the Pu-238 supply, and the importance of developing advanced, high-efficiency RPS systems. NASA evaluated RPS requirements for the Uranus Orbiter and Probe mission, prioritized by the Decadal Survey, and provided data to support a future New Frontiers Announcement of Opportunity, offering up to two MMRTGs and up to 20 Light Weight Radioisotope Heating Units (LWRHU).

RADIOISOTOPE POWER

The RPS program has made significant progress in support of the Dragonfly mission. The team completed their contribution to the mission PDR, MMRTG fins fabrication, machining two out of three housings (one flight, two spares), and 16 flight certified thermoelectric modules. NASA continues to coordinate with ESA in support of the Rosalind Franklin Mission to provide LWRHU's and U.S. launch approval support.

NASA started evaluating emerging commercial development and use of RPS capabilities for heat and power, including evaluating possible international contributions to source material, and supporting development of interagency standards and processes for commercial development and use of RPS.

WORK IN PROGRESS IN FY 2024

The RPS program will continue support to the Dragonfly mission, including the mission CDR milestone and completing detailed MMRTG fueling and testing procedures. NASA will support DoE Pu-238 constant rate production (CRP) efforts, as well as production of LWRHUs to enable the Rosalind Franklin mission.

The Next Gen RTG team will complete an unfueled Mod 0 unit and conduct a formal acceptance review to make the unit ready for a future NASA mission. The Next Gen Mod 1 system will proceed to its PDR.

Skutterudite Technology Maturation and other higher efficiency power conversion technology development will continue in FY 2024 as potentially enabling technologies for emerging public-private partnership opportunities.

NASA will continue work to develop the Vulcan multi-mission databook and the PEA for the GPHS. The development of a GPHS PEA will streamline the process to obtain environmental assessments for individual missions, which will simplify the NEPA compliance process and can shorten the schedule to obtain NEPA compliance on future missions utilizing RPS power systems. The RPS program will continue to evaluate the need to restructure and adapt to emerging opportunities for RPS development and use.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

NASA plans to complete the Dynamic and Thermal Simulators for the Dragonfly MMRTG. RPS, in concert with Dragonfly and DoE partners, will also perform a significant pathfinder readiness and review exercise to dry run the complex integration steps for the MMRTG.

The RPS program will continue to support LWRHU development for the Rosalind Franklin mission and work to evaluate the possible integration of a U.K.-supplied americium-241 RHU.

Program Elements

RADIOISOTOPE POWER SYSTEM (RPS)

The RPS project will continue to ensure the availability of RPS for the exploration of the solar system in environments where conventional solar or chemical power generation is impractical or impossible. NASA will achieve this goal by working with DoE to provide fueled RPS to missions and to support mission design and integration activities. The Next Gen Mod 1 build will demonstrate a revitalization of the

RADIOISOTOPE POWER

General Purpose Heat Source RTG (GPHS-RTG). This system will provide more than twice the power of an MMRTG with significantly lower degradation over time, enabling missions to the icy worlds and more long duration missions to the edges of the solar system. RPS will continue energy conversion research and development to advance state-of-the-art performance in heat to electrical energy conversion.

DOE OPERATIONS AND ANALYSIS

NASA funds the DoE national laboratory personnel and infrastructure required to maintain the capability to develop and fuel radioisotope power systems for deep space missions. DoE resumed domestic production of Pu-238 for the first time since the 1980s. They are now using a CRP approach. NASA provides funds and the DoE Oak Ridge National Laboratory leads the effort and irradiates targets at its High Flux Isotope Reactor. The DoE Idaho National Laboratory (INL) supplies Neptunium-237 and irradiates targets at the Advanced Test Reactor, required to meet Pu-238 production rates. DoE continues to increase annual production, producing approximately 700 grams per year. Over the next several years, refining and automating the process will help ramp production up to a full operational capability of 1.5 kilograms per year by 2026. DoE Los Alamos National Laboratory (LANL) manages the existing Pu-238 inventories and manufactures fuel, resulting in continual annual fueled clad manufacturing by LANL and delivery to INL at a CRP rate of 10 to 15 clads per year. INL integrates the fueled clads with generator systems and manages the transportation and launch operations activities in support of NASA missions.

Program Management & Commitments

Program Element	Provider
RPS	Provider: GRC Lead Center: GRC Performing Center(s): GRC, JPL, GSFC, KSC, DoE Cost Share Partner(s): N/A
DoE Operations and Analysis	Provider: DOE Lead Center: GRC Performing Center(s): GRC Cost Share Partner(s): N/A

Acquisition Strategy

DoE provides radioisotope power systems and production operations on a reimbursable basis. Maturity of the technologies determines the timeline for the acquisition of technologies and new systems. NASA or DoE laboratory-competed acquisitions help mature technology before system development begins. NASA-led DoE laboratory acquisitions procure unfueled designs and flight-qualified hardware when initiating a system development.

The program acquires content via existing agency contracts with JPL and APL. The program will use in-house or competitive procurements, as needed.

ASTROPHYSICS

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Astrophysics Research	284.8	--	**300.5**	378.7	390.5	390.3	377.1
Cosmic Origins	314.8	--	**319.0**	312.8	307.7	300.4	282.1
Physics of the Cosmos	180.7	--	**210.8**	184.3	168.6	176.1	133.7
Exoplanet Exploration	502.9	--	**478.5**	459.0	366.1	323.8	339.9
Astrophysics Explorer	226.8	--	**269.3**	252.2	380.6	456.4	540.6
Total Budget	**1,510.0**	**--**	**1,578.1**	**1,587.0**	**1,613.6**	**1,647.1**	**1,673.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Astrophysics

ASTROPHYSICS RESEARCH

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Astrophysics Research and Analysis	112.2	--	**118.8**	127.2	134.2	138.2	132.3
Balloon Project	52.6	--	**56.1**	61.0	63.0	59.0	58.2
Science Activation	52.0	--	**52.0**	52.0	52.0	52.0	52.0
Other Missions and Data Analysis	68.0	--	**73.6**	138.5	141.3	141.1	134.6
Total Budget	**284.8**	**--**	**300.5**	**378.7**	**390.5**	**390.3**	**377.1**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Long durAtion evalUation solaR hand LAunch (LAURA), shown here, hand-launched on December 11, 2023. LAURA is a NASA Balloon Program Office payload, intended to test instrumentation and power for a long-duration hand launch, to extend range and duration of hand launch missions.

The Astrophysics Research program studies a wide range of astronomical observations from the births of the first stars, black holes, and distant galaxies in the cosmic history, to the nature of planets orbiting other stars in our Milky Way galaxy. High-altitude balloon and sounding rocket flights are used to test new types of instruments, which study the nature of and characterize objects in the universe at wavelengths of lights that are not accessible from ground-based instruments.

The program provides basic research awards for scientists to test their theories and to understand how they can best use data from NASA missions to gain new knowledge from the universe. Awardees analyze the data from Astrophysics missions to understand astronomical objects or events, such as exoplanets; the explosions of stars that lead the creation of compact objects such a White Dwarfs, Neutron Stars, and Black Holes; or the fingerprints of early cosmic history in the microwave background radiation. Competitively awarded science investigations in Astrophysics research can also include funding for data analysis and techniques, theory and computation, laboratory astrophysics, and capital equipment purchases. The program also develops innovative technologies for future missions, including detectors and electronics, optics, gratings, and coatings.

EXPLANATION OF MAJOR CHANGES IN FY 2025

Additional funds are requested within the Balloon Project to cover the establishment of a new North American launch site, as well as additional foreign campaigns. The request augments Astrophysics Research and Analysis in FY 2025 to help improve selection rates and to support increased costs associated with building and launching CubeSats. The Science Activation budget will remain flat at the FY 2023 level. Astrophysics Senior Review Project is decreased in FY 2025 without impact, given that funding has already been allocated for approved mission extensions in 2025.

ASTROPHYSICS RESEARCH

ACHIEVEMENTS IN FY 2023

Researchers have discovered the most distant active supermassive black hole to date with the James Webb Space Telescope (Webb). The galaxy, Cosmic Evolution Early Release Science (CEERS) 1019, existed just over 570 million years after the Big Bang, and its black hole is less massive than any other identified in the early universe. Webb also identified 11 galaxies that existed when the universe was 470 to 675 million years old. The evidence was provided by Webb's CEERS Survey. The program combines Webb's highly detailed near- and mid-infrared images and data, known as spectra, all of which were used to make these discoveries. These are only the first groundbreaking findings from the CEERS survey. Until now, research about objects in the early universe was largely theoretical. With Webb, not only can researchers see black holes and galaxies at extreme distances, but they can also start to accurately measure them.

NASA's Imaging X-ray Polarimetry Explorer (IXPE) has helped astronomers get closer to an answer to the question of how high-speed particles in a blazar's powerful jets get accelerated to high energies. The 2023 study used IXPE to point at Markarian 501, a blazar in the constellation Hercules. This active black hole system sits at the center of a large elliptical galaxy. IXPE watched Markarian 501 for three days in early March 2022, and then again two weeks later. During these observations, astronomers used other telescopes in space and on the ground to gather information about the blazar in a wide range of wavelengths of light including radio, optical, and X-ray. Scientists found that X-ray light is more polarized than optical, which is more polarized than radio. But the direction of the polarized light was the same for all the wavelengths of light observed and was also aligned with the jet's direction.

NASA launched the Cosmic Infrared Background ExpeRiment (CIBER) on April 16, 2023, from White Sands Missile Range.

NASA conducted four balloon campaigns in FY 2023 in McMurdo, Antarctica; Wanaka, New Zealand; Palestine, Texas; and Ft. Sumner, New Mexico. During these campaigns, nine stratospheric balloon payloads were launched, SPIDER, Super Pressure Balloon Imaging Telescope (SuperBIT), Extreme Universe Space Observatory-Super-Pressure Balloon (EUSO-SPB2), WhatsUP-2, Salter Test Flight, Gamma Ray Polarimeter Experiment (GRAPE), The High Altitude Student Platform (HASP), Faint Intergalactic-medium Redshifted Emission Balloon (FIREBALL-2), and REMOTE, with a range of scientific experiments spanning the entire electromagnetic spectrum from the infrared to gamma-ray wavelengths.

Science Activation continues to support competitively selected teams that broaden participation for learners in new and augmented collaborations. NASA will continue to ensure cohesion across the collective set of 45 awards and stronger linkage between objectives and measures of success with the efforts of the portfolio evaluation team. In addition, the citizen science initiative includes 28 projects. The citizen science efforts have scaled to include over 460 citizen scientists that have co-authored peer-reviewed publications through 2023.

WORK IN PROGRESS IN FY 2024

Six additional CubeSats are currently in development: Supernova remnants Proxies for Reionization and Integrated Testbed Experiment (SPRITE), the first Astrophysics 12U CubeSat, will measure UV spectra of ionizing radiation from star forming galaxies; BlackCat will obtain wide field-of-view localization of X-ray transients, with real-time "cell phone" downlink of data; Star-Planet Activity Research CubeSat (SPARCS) will monitor M-star flares in two ultraviolet bands to investigate planetary habitability effects;

ASTROPHYSICS RESEARCH

CANDLE, an engineering demonstration unit with 0.1 percent absolute calibration of 0.4-2.5 micron flux scale for astronomy; BurstCube will detect and monitor gamma-ray bursts; and Monitoring Activity of Nearby sTars with uv Imaging and Spectroscopy (MANTIS) will measure extreme- to near-ultraviolet stellar fluxes on exoplanet habitability. NASA has tentatively scheduled BurstCube, SPRITE, and SPARCS launches for 2024.

NASA scheduled three Astrophysics sounding rockets for launch in FY 2024 from the White Sands Missile Range: The INtegral-Field Ultraviolet Spectroscopic Experiment launched on October 29, 2023; CIBER is scheduled to launch on February 15, 2024; and the Off-Axis Far-UV Off Rowland-circle Telescope for Imaging and Spectroscopy is scheduled to launch on May 8, 2024.

NASA is planning four balloon campaigns in FY 2024 in Antarctica; Sweden; Palestine, Texas; and Ft. Sumner, New Mexico.

In FY 2024, Science Activation will lead the public engagement for learners of all ages of the last solar total eclipse to occur in the United States until 2044. Science Activation will support events leading up to the April 8, 2024, historical event by optimizing six eclipse-focused teams with the rest of the Science Activation community and other Nation-wide events led by NASA’s Heliophysics organizations. Coordination through internal and external eclipse working groups is ongoing and will build on lessons learned from the 2023 annular eclipse to have even greater impact for 2024. Science Activation continues to support competitively selected teams that broaden participation for learners in new and augmented collaborations for community college, differently-abled, immigrant, indigenous, multilingual, neurodiverse, rural, and other disadvantaged, underserved, and underrepresented communities, and plans to use lessons learned from past celestial and other milestone events to engage these communities.

In FY 2024, the National Academies will conduct a second program assessment on Science Activation, which will help shape the direction of Science Activation for the next 10 years. Science Activation leadership will continue to ensure cohesion across the collective set of 50 awards and stronger linkage between objectives and measures of success with the efforts of the portfolio evaluation team. In addition, the citizen science initiative includes 40 projects, up 30 percent from a year ago. New this year is citizen science funding and observing time through the Webb program.

SMD facilitated a community planning workshop to collaboratively create the Bridge Program element with all stakeholders. In FY 2024, SMD anticipates at least two opportunities for Bridge teams to propose for funding.

In FY 2024, NASA will announce opportunities in the Astrophysics Research program solicited through SMD's Research Opportunities in Space and Earth Science (ROSES) 2024. NASA will evaluate proposals using subject-matter experts as peer reviewers, and make diverse selections for investigators, institution types, and geography over a broad range of science investigations. In addition, NASA will evaluate proposals submitted to the General Observer and General Investigator programs of NASA's nine currently operating Astrophysics missions and provide funding to the broad scientific community for new observations, archival, theory, and computational investigations. NASA will also facilitate community planning workshops for the implementation of the Bridge Program element.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

NASA will continue a competed Astrophysics Research program with emphasis on detector, instrument, optics, and key supporting technologies for use as payloads in future missions. Theoretical work, often conducted in networks of scientists at multiple institutions, will provide the foundation to develop science

ASTROPHYSICS RESEARCH

requirements for new missions. Data analysis will multiply the science yield from NASA's astrophysics missions.

Bridge Program seed funding awards are two-year awards, and the bulk of those activities will take place in FY 2024 and FY 2025. NASA also anticipates soliciting proposals for full Bridge teams as part of ROSES-2024. Those will be partnerships funded up to five years, most beginning at the start of FY 2025 and continuing through FY 2029.

NASA is planning four balloon campaigns in McMurdo, Antarctica; Wanaka, New Zealand; Palestine, Texas; and Ft. Sumner, New Mexico. Additionally, NASA plans to launch one CubeSat in FY 2025, BlackCat, to discover transient X-ray sources. Work also begins on the new North American launch site in Burns, Oregon.

In FY 2025, for the Science Activation program, a competitive solicitation process will be finalized and implemented to move into the SciAct 3.0 phase (CY 2026 and beyond) based on findings and recommendations from the National Academies assessment and other SMD requirements. NASA plans selection announcements by the end of FY 2025.

Program Elements

RESEARCH AND ANALYSIS

This project supports basic research, solicited through NASA's annual ROSES announcements. NASA solicits investigations relevant to Astrophysics over the entire range of photon energies, gravitational waves, and particles of cosmic origin. Scientists and technologists from a mix of disciplines review proposals and provide findings that underlie NASA's merit-based selections.

This project also solicits technology development for detectors and instruments for potential use on future space flight missions and science and technology investigations using sounding rockets, high-altitude balloons, and similar platforms. A new type of scientific instrument often flies first on a stratospheric balloon mission or on a sounding rocket flight, which takes it briefly outside Earth's atmosphere. Instruments for balloons and sounding rockets are less expensive than orbital missions and experimenters can build them quickly to respond to unexpected opportunities, such as a newly discovered supernova. The experimenter usually retrieves the equipment after the flight so that they can test, improve, and fly the new instruments again. Suborbital flights are important for training the next generation of scientists and engineers to maintain U.S. leadership in Science, Technology, Engineering, and Mathematics (STEM). The project also supports small experiments flown on the ISS, laboratory astrophysics, and limited ground-based observations.

The Astrophysics Theory element solicits basic theory investigations needed to interpret data from NASA's space astrophysics missions and develops the scientific basis for future missions. Astrophysics Theory topics include the formation of stars and planets, supernova explosions and gamma-ray bursts, the birth of galaxies, dark matter, dark energy, and the cosmic microwave background.

The Exoplanet Research element solicits basic research proposals to conduct scientific investigations that significantly improve our understanding of exoplanets and exoplanet formation.

The Nancy Grace Roman Technology Fellowship develops early career researchers who could lead future flight instruments and missions. Initially, NASA identifies promising early career researchers and

ASTROPHYSICS RESEARCH

supports their investigations. NASA then selects a subset of fellows for additional funding to start a laboratory or develop a research group at the fellow's institution.

Through Future Investigators in NASA Earth and Space Science and Technology, NASA solicits proposals from accredited U.S. universities and other eligible organizations for graduate student-designed and performed research projects that contribute to NASA's science, technology, and exploration goals.

Citizen science is a form of open collaboration in which individuals or organizations participate voluntarily in the scientific process. The Citizen Science Seed Funding Program supports scientists and other experts to develop citizen science projects and to expand the pool of scientists who use citizen science techniques in their science investigations.

Through Topical Workshops, Symposia, and Conferences, SMD solicits proposals from eligible organizations for their events that contribute to NASA's science, technology, and exploration research goals.

The SMD Bridge Program element is designed to boost diversity, equity, inclusion, and accessibility within the NASA workforce and within the U.S. science and engineering community. The SMD Bridge Program element will increase engagement and partnering between Minority-Serving Institutions, such as Historically Black Colleges and Universities; Tribal Colleges and Universities; Primarily Undergraduate Institutions; Primarily Black Institutions; Hispanic Serving Institutions; and Community Colleges, highly research-intensive universities, and NASA centers or facilities. The focus of the program will be on paid research and engineering studentships at participating institutions to transition science and engineering students from undergraduate studies into graduate schools and employment at NASA or related STEM careers. Anticipated funding is approximately $5 million per year to be distributed to Bridge teams in several cost categories (Small, Medium, Large or Key program), with Small proposal budgets requesting less than $70 thousand per year; Medium requesting less than $150 thousand per year; and Large requesting less than $500 thousand per year. "Key Program" proposals must propose to build a consortium of partner institutions whose goals include increasing the research capacity across multiple participating institutions, with a higher funding level (less than $2 million per year). For all cost categories, funding duration can range from one to five years.

BALLOON PROJECT

The Balloon Project offers inexpensive, high-altitude flight opportunities for scientists to conduct research and test new technologies before space flight application. Balloon experiments cover a wide range of disciplines in astrophysics, solar physics, heliospheric physics, and Earth upper-atmosphere chemistry, as well as selected planetary science, such as comet observations. Observations from balloons have detected echoes of the Big Bang and probed the earliest galaxies. The Balloon Project continues to increase balloon size and enhance capabilities, including an accurate pointing system to allow high-quality astronomical imaging and a super-pressure balloon that maintains the balloon's integrity at a high altitude to allow much longer flights at mid-latitudes that include nighttime viewing of astronomical objects. NASA currently has launch sites at Fort Sumner, New Mexico and Palestine, Texas. NASA has chosen Burns, Oregon for the location of the new North American launch site.

ASTROPHYSICS RESEARCH

SCIENCE ACTIVATION

The Science Activation Program delivers SMD's unique science content and expertise into the learning environment for learners of all ages. Through CY 2025, a cooperative network of 50 competitively selected teams from across the Nation will connect NASA science experts, real content, and authentic experiences with community leaders to conduct science in ways that activate minds and promote deeper understanding of our world and beyond. Awardees of cooperative agreements work collaboratively with each other, with internal NASA organizations, and with local and national partners to achieve a multiplier effect utilizing NASA investments. All awards include independent evaluators that assess the individual project's measures of success as well as a portfolio-level independent evaluator. Researchers have published more than 120 papers through 2023.

Science Activation improves connections between subject matter experts (SMEs) and community-based networks in all 50 states and U.S. territories. SMEs working on missions and the latest discoveries can now receive targeted funding to work with awardees and audiences.

Broadening participation, including underserved audiences, continues to be a priority objective. In fact, the entire Science Activation portfolio now focuses on broadening participation among community college, differently-abled, immigrant, multilingual, neurodiverse, rural, and other disadvantaged, underserved, and underrepresented communities. Funding also provides opportunities for indigenous learners in the Southwest, Appalachia, upper Northwest, and Alaska.

Program Schedule

The program issues solicitations every year. A Senior Review process assesses all missions in the extended operations phase every three years and all data archives every three or four years.

Date	Significant Event
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Feb 2024	ROSES-2024 NRA solicitation release
Mar 2024	Astrophysics Archives Programmatic Review
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Feb 2025	ROSES-2025 NRA solicitation release
Mar 2025	Senior Review of Operating Missions
Q1 FY 2026	ROSES-2025 selection within six to nine months of receipt of proposals
Feb 2026	ROSES-2026 NRA solicitation release
Mar 2026	Senior Review of Operating Missions
Q1 FY 2027	ROSES-2026 selection within six to nine months of receipt of proposals
Feb 2027	ROSES-2026 NRA solicitation release

ASTROPHYSICS RESEARCH

Program Management & Commitments

Program Element	Provider
Research and Analysis Project	Provider: All NASA centers Lead Center: HQ Performing Center(s): All Cost Share Partner(s): None
Balloon Project	Provider: Wallops Flight Facility (WFF) Lead Center: WFF Performing Center(s): WFF Cost Share Partner(s): None
Science Activation	Provider: All NASA centers Lead Center: HQ Performing Center(s): All Cost Share Partner(s): Office of STEM Engagement

Acquisition Strategy

NASA issues solicitations for competed research awards each February through ROSES. Panels of SME scientists conduct peer reviews on all proposals. A Senior Review panel reviews all missions in the extended operations phase every three years, and all data archives every three or four years.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Operation of the Columbia Scientific Balloon Facility	Peraton	Antarctica; Fort Sumner, NM; New Zealand; Sweden; Palestine, TX

INDEPENDENT REVIEWS

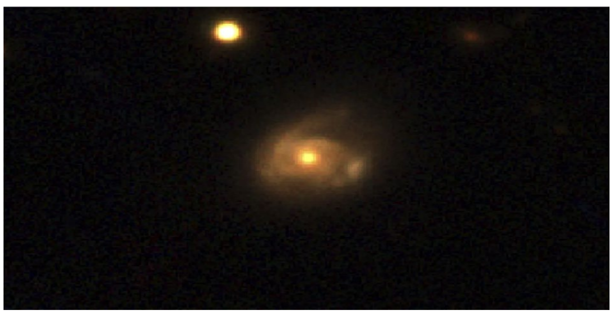
Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Astrophysics Advisory Committee	2023	Review to assess program against strategic objectives of Astrophysics science	Successful
Quality	Astrophysics Archives Programmatic Review	May 2024	Review of Astrophysics data archives	TBD
Quality	Senior Review of Operating Missions	2025	Review of Astrophysics operating missions	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Contract Administration, Audit & QA Svcs	16.0	--	**14.6**	14.6	14.6	14.6	14.6
Astrophysics Senior Review	0.0	--	**0.0**	55.4	55.4	55.4	55.2
Astrophysics Data Program	23.6	--	**25.8**	28.3	30.5	31.5	24.5
Astrophysics Data Curation and Archival	28.4	--	**31.2**	38.2	38.8	37.6	38.2
Astrophysics Directed R&T	0.0	--	**2.0**	2.0	2.0	2.0	2.0
Total Budget	**68.0**	**--**	**73.6**	**138.5**	**141.3**	**141.1**	**134.6**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Using the Neil Gehrels Swift Observatory, scientists have discovered a black hole in a distant galaxy repeatedly nibbling on a Sun-like star, a system referred to as "Swift J0230," shown here. Every time the orbiting star passes close to the black hole, the star bulges outward and sheds material, but survives. The process will repeat until the star loses too much gas and finally breaks apart.

Astrophysics Research Other Missions and Data Analysis includes the Astrophysics Senior Review Project; the data program, including data curation and archival, support for contract audits, and contract quality assurance for SMD, and Astrophysics directed research and technology.

Mission Planning and Other Projects

CONTRACT ADMINISTRATION, AUDIT, AND QUALITY ASSURANCE SERVICES

This project provides critical safety and mission product inspections, as well as contract audit services from the Defense Contract Management Agency and Defense Contract Audit Agency, respectively. It also provides for contract assurance audits, assessments, and surveillance by the NASA Contract Assurance Services Program.

ASTROPHYSICS SENIOR REVIEW

Every three years, the Astrophysics division conducts a senior review to perform evaluations of missions that have successfully completed, or are about to complete, their prime mission operation phase. The Senior Review findings help NASA prioritize which missions will receive funding for extended operations. The 2022 Senior Review found that NASA's fleet of operating astrophysics missions constitute a "portfolio of extraordinary power" and recommended that NASA continue their operations. The next Senior Review will take place in spring 2025. Funding in this line will be allocated to mission extensions recommended by the next Senior Review.

OTHER MISSIONS AND DATA ANALYSIS

ASTROPHYSICS DATA ANALYSIS PROGRAM (ADAP)

ADAP solicits research that emphasizes the analysis of NASA space astrophysics data archived in the public domain at one of NASA's Astrophysics data centers. NASA's archival astronomical data holdings continue to grow with the ongoing successful operation of the agency's portfolio of Astrophysics flight missions. Those missions range from modest Explorer-class like the Nuclear Spectroscopic Telescope Array and the Transiting Exoplanet Survey, to the great observatories of Hubble and Chandra. Investigations funded under the ADAP ensure that the agency's Astrophysics data holdings continue to be the subject of vigorous scientific research, thereby maximizing the scientific return on NASA mission investments.

The ADAP portfolio includes focused investigations that involve the analysis of archival data from a single mission, as well as broader investigations that combine data from multiple missions and span a wide wavelength range. Such multi-mission, multi-wavelength studies are a unique and exciting aspect of the program. The combinations of data collected by different missions operating in different regions of the spectrum often yield scientific insights that are unobtainable through analysis of the individual data sets alone.

Recent Achievements

During FY 2023, ADAP supported more than 150 science investigations at academic institutions, NASA centers, and other federal laboratories across the country. Much of that funding goes to support early-career scientists—undergraduate and graduate student researchers as well as postdoctoral associates—that represent the next generation of astronomers and astrophysicists.

The scientists funded under ADAP are studying the universe at all scales—from its largest structures and earliest moments to the here-and-now. In just the past year, ADAP-funded scientists have unveiled the physics in the interiors of cool, red dwarf stars. Others have used NASA observations to elucidate the effects of magnetic fields within the giant molecular clouds that drive star formation. Some are using past observations from NASA telescopes to search for the signatures of gravitational waves from the collisions of merging supermassive black holes. Scientists using a large set of NASA mission data have measured the cosmic history of the formation of elements, measuring how the atoms in our own bodies were formed over the course of billions of years in the explosions of stars. Reaching back to the dawn of time, researchers have used ADAP funding to resolve a better picture of the universe shortly after the Big Bang.

ASTROPHYSICS DATA CURATION AND ARCHIVAL RESEARCH (ADCAR)

Astrophysics Data Centers constitute an ensemble of archives receiving processed data from individual missions and making them accessible to the scientific community. After the completion of a mission, the relevant, active, and multi-mission archive takes over all data archiving activities. ADCAR covers the activities of the Astrophysics Data Centers and the NASA Astronomical Virtual Observatories (NAVO).

Recent Achievements

In FY 2023, the Astrophysics Data System (ADS), one of the Astrophysics Data Centers, started developing the NASA Science Explorer (SciX), a new interdisciplinary literature portal covering all the NASA science disciplines. SciX will have additional content relevant to the NASA science portfolio and additional features important to the new communities served. As a result, ADS data holdings have increased to 18.3 million records and 175 million citations, an increase of 10 percent and 13 percent, year-over-year, respectively.

OTHER MISSIONS AND DATA ANALYSIS

The Barbara A. Mikulski Archive for Space Telescopes (MAST) developed tools to efficiently archive data from the many small Astrophysics research missions and make those data accessible to increase their scientific impact. MAST used these tools to archive data from the NASA/Korean ultraviolet survey from Korea's first astronomy satellite. MAST hosted and taught workshops for the astronomical community to demonstrate how to use cloud-based science platforms to easily find, retrieve, and analyze the 5-million-plus observations MAST makes available in the cloud.

The High Energy Astrophysics Science Archive Research Center (HEASARC) served 1.1 billion data files, totaling 640 terabytes (TB) (29 percent increase over FY 2022), and roughly 9 million catalog queries. The archive size is now 172 TB (increase of 7.5 percent). HEASARC released cosmic microwave background data from the SPIDER and CLASS projects, as well as the high energy data from the HaloSat final archive, the Monitor of All-sky X-ray Image (MAXI) experiment on the ISS and the Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) Gamma-ray Observatory. Almost all the HEASARC data are now available in SMD's cloud-based Open Data Repository and data from active missions are regularly updated.

The Infrared Science Archive (IRSA) released new data from NASA's Near-Earth Object Wide-field Infrared Survey Explorer and NASA's Infrared Telescope Facility, as well as a variety of highly processed datasets contributed by the community, and simulated data which model what NASA's Nancy Grace Roman Space Telescope will observe after launch. IRSA completed the transfer of the Stratospheric Observatory for Infrared Astronomy (SOFIA) website as part of that mission's closeout process. IRSA significantly improved its data discovery and exploration tools, made many of its data holdings available via the commercial cloud, and collaborated with HEASARC and MAST to develop the capabilities of the cloud-based Astrophysics Science Platform. IRSA responded to an average of 3.8 million data queries per month.

The NASA/Infrared Processing and Analysis Center Extragalactic Database (NED) serves published data from over 132,000 journal articles and catalogs, with more than 1.5 billion cross-identifications among 1.1 billion distinct objects. In FY 2023, NED responded to more than 90.5 million data queries and 540 peer-reviewed articles referenced NED. The mean daily query rate in the two months leading up to the James Webb Space Telescope (Webb) Cycle 2 proposal submission deadline was almost twice the normal rate. NED published its Local Volume Sample, with additional information on galaxies close enough to detect gravitational wave events.

In FY 2023, the NAVO archives improved their protocols for making data accessible from the commercial cloud and enhanced their systems to ease cross-archive data discovery, following Virtual Observatory standards. NAVO members have continued in their leadership roles in the International Astronomical Union and the International Virtual Observatory Alliance to promote interoperability across astronomy and astrophysics archives.

DIRECTED RESEARCH AND TECHNOLOGY

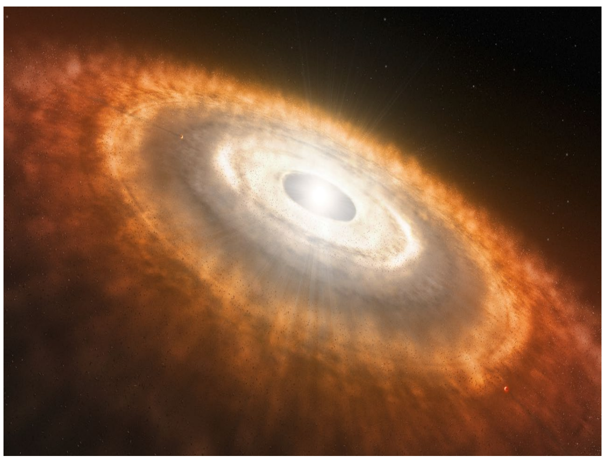
This project funds the civil service staff that will work on emerging Astrophysics projects, instruments, and research.

COSMIC ORIGINS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Hubble Space Telescope (HST)	93.3	--	**88.9**	87.5	87.8	83.0	64.7
James Webb Space Telescope	162.5	--	**187.0**	187.0	187.0	187.0	187.0
Other Missions and Data Analysis	59.0	--	**43.1**	38.2	33.0	30.4	30.4
Total Budget	**314.8**	**--**	**319.0**	**312.8**	**307.7**	**300.4**	**282.1**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



An international team of astronomers has used NASA's James Webb Space Telescope to provide the first observation of water and other molecules in the highly-irradiated inner, rocky-planet-forming regions of a disk in one of the most extreme environments in our galaxy. These results suggest that the conditions for terrestrial planet formation can occur in a broader range of environments than previously thought.

"How did we get here?" This simple but fundamental question drives the broad science objectives of NASA's Cosmic Origins program. The search for answers raises underlying questions and topic areas, such as: How and when did the first stars and galaxies form? When did the universe first create the elements critical for life? How did galaxies evolve from the very first systems to the types we observe "in the here and now," such as the Milky Way in which we live? How do stars and planetary systems form and change over time?

Observatories collect data at different wavelengths to fully address these questions. Currently operating facilities in the Cosmic Origins program are the James Webb Space Telescope and the Hubble Space Telescope.

EXPLANATION OF MAJOR CHANGES IN FY 2025

The request reduces Hubble Space Telescope operations by slightly reducing grant funding and maximizing efficiency through joint operation with other operating missions. The request also reduces the closeout budget for the SOFIA mission due to an accelerated closeout schedule and lower than expected costs. Additionally, NASA transferred funds from the Cosmic Origins (COR) Strategic Research and Technology (SR&T) budget to the new Habitable Worlds Observatory Technology Maturation project beginning in FY 2025.

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	93.3	--	88.9	87.5	87.8	83.0	64.7

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

This striking Hubble Space Telescope image shows the densely packed globular cluster known as New General Catalogue (NGC) 2210, which is situated in the Large Magellanic Cloud (LMC). The LMC lies about 157,000 light-years from Earth and is a so-called satellite galaxy of the Milky Way, meaning that the two galaxies are gravitationally bound. Globular clusters are very stable, tightly bound clusters of thousands or even millions of stars. Their stability means that they can last a long time, and therefore globular clusters are often studied to investigate potentially very old stellar populations.

One of NASA's most successful and long-lasting science missions, the Hubble Space Telescope (Hubble) has beamed over 1 million images back to Earth, helping resolve many of the great mysteries of astronomy. The telescope helped scientists determine the age of the universe, the identity of quasars, and the existence of dark energy. Hubble launched in 1990 and is currently in an extended operations phase. The fifth servicing mission in 2009, the last visit by a Space Shuttle crew, added new batteries, gyroscopes, and instruments to extend Hubble's life even further into the future. April 24, 2023, marked the start of Hubble's 33rd year in orbit. The Hubble Space Telescope Operations budget covers mission operations, software maintenance, guest-observer science grants, and fellowships.

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA proposes to reduce the Hubble budget by approximately 5 percent compared to the FY 2023 operating plan level. Savings will be achieved through efficiencies in the joint operations of Hubble and the James Webb Space Telescope (Webb), which are managed by the same contractor in the same location. NASA also expects to award fewer grants and fellowships through the Hubble program in FY 2025 and beyond. Scientists can continue to apply for funding to conduct research using Hubble data through the Research & Analysis program.

ACHIEVEMENTS IN FY 2023

The Hubble science instruments and three functioning gyros enable Hubble to continue its high level of scientific productivity, including complementary overlap observations with the Webb telescope. The

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

operations team maintains readiness to transition to single gyro science operations should the need arise. The project has completed operations concept, system requirements, and PDR for implementing an operational mode to resume science data collection on the B-side should the A-side become inoperable.

NASA announced the Cycle 31 selections in July 2023. NASA continues to use a dual-anonymous peer review process which has been shown to increase the percentage of investigations led by first-time PIs and has reduced the disparity between male and female PI selection rates.

NASA's Hubble Space Telescope plays a key role in understanding the nature of asteroids and the possibility of redirecting dangerous ones by observing the aftermath of NASA's Double Asteroid Redirection Test (DART) impact with asteroid Dimorphos. DART is the world's first test of the kinetic impact mitigation technique, using a spacecraft to deflect an asteroid that poses no threat to Earth, and modifying the object's orbit. Hubble, in coordination with the Webb infrared space telescope, first observed the immediate debris from the impact on September 26, 2022. Hubble then watched the ejected debris from the impact fan out over several weeks. After a month Hubble found and reported that some debris had formed a twin-tail; by March 2023 Hubble detected a debris cone; and by July 2023 astronomers reported Hubble detections of 37 free-flung boulders ranging in size from three feet to 22 feet across escaping from the asteroid's surface, based on Hubble photometry. They are drifting away from the asteroid at little more than a half-mile per hour. DART scientists are using Hubble data to determine the composition and character of the asteroid and the efficacy of such an intentional impact for future safe asteroid deflection. Other examples of Hubble's powerful role in studies of the solar system include Hubble's ultraviolet light observations of Jupiter's aurora to complement the JUNO missions in situ measurements of Jupiter's magnetic and gravitational fields, and Hubble's new detection of a correlation of Neptune cloud cycles with the 11-year solar cycle. Such long-term patterns are only possible to detect because of Hubble's longevity, rich data archive, and intentional long-term solar system monitoring.

WORK IN PROGRESS IN FY 2024

NASA is reviewing the results of the feasibility study performed with SpaceX and assessing potential next steps to boost the orbit and possibly enhance Hubble using private funding. The current estimated altitude of Hubble is approximately 535 kilometers. Hubble's orbit is slowly decaying, and if lower than 500 kilometers, without a boost, the Hubble orbit will decay to the point that science operations will not be possible by the mid-2030s.

In FY 2024 and beyond, NASA will support mission operations, systems engineering, software maintenance, ground systems support, guest-observer science grants, and the NASA Hubble Fellowship Program. Hubble continues mission life-extension initiatives, such as optimizing the use of gyroscopes and extending the lifetime of Hubble's instruments. NASA will conduct a CDR for the development of an operational mode to enable the science operations on the B side of the Science Instrument Command and Data Handling. NASA will select observations for Cycle 32 in mid-2024 and continue to make timely contributions to the Time Domain and Multi-Messenger era of astronomy.

HUBBLE SPACE TELESCOPE OPERATIONS

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2025

NASA will support mission operations, systems engineering, software maintenance, ground systems support, guest-observer science grants, and the NASA Hubble Fellowship Program. NASA will release the Cycle 33 call for proposals in early 2025, with announcements expected in mid-2025.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	Enacted FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
James Webb Space Telescope	124.0	--	**127.0**	127.0	127.0	127.0	127.0
Webb Science	38.5	--	**60.0**	60.0	60.0	60.0	60.0
Total Budget	**162.5**	**--**	**187.0**	**187.0**	**187.0**	**187.0**	**187.0**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The James Webb Space Telescope (Webb) is a large, space-based astronomical observatory. Webb observes the highly red-shifted early universe and studies objects like protostars and protoplanetary disks, which strongly emit infrared light where dust obscures shorter wavelengths. With more light-collecting area than Hubble and near- to mid-infrared optimized instruments, Webb observes objects farther away and further back in time.

The James Webb Space Telescope (Webb) has imaged the Rho Ophiuchi cloud complex, the closest star-forming region to Earth. Jets bursting from young stars crisscross the image, impacting the surrounding interstellar gas and lighting up molecular hydrogen, shown in red. Some stars display the telltale shadow of a circumstellar disk, the makings of future planetary systems.

The four main science goals are to:

- Search for the first galaxies or luminous objects formed after the Big Bang;
- Determine how galaxies evolved from their formation until now;
- Observe the formation of stars from the first stages to the formation of planetary systems; and
- Measure the physical and chemical properties of planetary systems and investigate the potential for life in those systems.

While Hubble greatly improved knowledge about distant objects, its infrared coverage is limited. Light from distant galaxies is red-shifted out of the visible part of the spectrum and into the infrared by the expansion of the universe. Webb explores the poorly understood epoch when the first luminous objects in the universe came into being after the Big Bang.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2023

Webb observations have demonstrated the existence of galaxies up to redshift 400 million years (Myrs) after the Big Bang, robust measurements of metallicity and gas properties of galaxies up to 500 Myrs after the Big Bang, and quiescent normal galaxies 700 Myrs after the Big Bang. The detections of these structures, more distant than any seen before, were precisely what Webb was designed to do.

In FY 2023, Webb obtained a transmission spectrum of the candidate Hycean world K2-18b, or a world posited to have hydrogen-rich atmosphere on top of a water ocean, observed in the near infrared. The spectrum reveals strong detections of methane and carbon dioxide. These, along with the failure to detect ammonia are consistent with chemical predictions for a Hycean atmosphere. This implies the world has an ocean under a temperate molecular hydrogen-rich atmosphere. The work also reports on potential signs of dimethyl sulfide (DMS). This molecule has an organic origin on Earth and has been predicted to be an observable biomarker in Hycean worlds. The authors include cautionary remarks on the dimethyl sulfide detection. Future observations are needed to better understand and confirm the DMS possibility.

WORK IN PROGRESS IN FY 2024

In FY 2024, Webb will conduct routine operations for Cycle 2 of the Early Release Observations, Early Release Science, Guaranteed Time Observations, and General Observer science programs. Additionally, Webb will release the call for Cycle 3 proposals.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

In FY 2025, NASA will support mission operations, systems engineering, software maintenance, ground systems support, and general observer science grants. The third Cycle of observing proposals will also be executed. In the most recently completed solicitation, Cycle 2, more proposals were received than any other NASA observatory ever. NASA anticipates this will be the case for Cycle 3 as well. It will be the first time that proposers can utilize nearly all the Cycle 1 data as examples, enabling the best-informed planning, regarding the on-orbit performance capabilities, to date.

Mission Elements

JAMES WEBB SPACE TELESCOPE

Webb is an infrared-optimized observatory that conducts imaging and spectrographic observations in the 0.6 to 28 micrometer wavelength range. Webb is roughly 100 times more capable than Hubble because its mirror is seven times larger. It spends about twice as much time observing targets since the Earth is not in the way. Webb's detectors cover larger regions of the sky and are always on. Its multi-object spectroscopic capabilities greatly expand the number of spectra per field.

The 6.5-meter primary mirror consists of 18 actively controlled segments. A multilayer sunshield the size of a tennis court passively cools the mirror, telescope optics, and instruments to about 40 Kelvin. Webb launched in 2021 from Kourou, French Guiana on an Ariane 5 rocket contributed by the ESA. Webb is currently operating in deep space about 1 million miles from Earth.

JAMES WEBB SPACE TELESCOPE

Formulation	Development	Operations

Webb's instruments include the Near-Infrared Camera (NIRCam), Near-Infrared Spectrograph (NIRSpec), Mid-Infrared Instrument (MIRI), and the Fine Guidance Sensor/Near-Infrared Imager and Slitless Spectrograph.

The operating telescope project supports the telescope operations and science team.

WEBB SCIENCE

The Webb Science project funds research enabled by Webb observations and data. Observation time on Webb is allocated in a competitive process each year in cycles of awards. The Space Telescope Science Institute (STScI) announces annual calls for proposals for Webb. The proposals are peer reviewed and those that are selected are executed by Webb during the next calendar year. In Cycle 2 NASA received 1,601 proposals from astronomers worldwide. NASA accepted 249 for execution and Cycle 2 began on July 1, 2023. For Cycle 3, NASA received 1,931 proposals in October 2023. Cycle 3 observations will begin on July 1, 2024, once the peer review selections are made in the Spring of 2024.

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Stratospheric Observ for Infrared Astron	35.5	--	**3.7**	0.0	0.0	0.0	0.0
Astrophysics Program Management	7.5	--	**9.6**	10.4	10.2	11.1	11.1
Cosmic Origins SR&T	12.9	--	**26.8**	24.8	19.8	16.4	16.4
Cosmic Origins Future Missions	3.0	--	**3.0**	3.0	3.0	3.0	3.0
Total Budget	**59.0**	**--**	**43.1**	**38.2**	**33.0**	**30.4**	**30.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Near-Infrared Camera (NIRCam) instrument on NASA's James Webb Space Telescope reveals a portion of the Milky Way's dense core in a new light. An estimated 500,000 stars shine in this image of the Sagittarius C region, along with some as-yet unidentified features. A large region of ionized hydrogen, shown in cyan, contains intriguing needle-like structures that lack any uniform orientation.

Cosmic Origins Other Missions and Data Analysis funds program management, supporting research and technology, and early studies of potential future Cosmic Origins missions.

Mission Planning and Other Projects

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

The SOFIA mission ended its five-year prime mission phase in October 2019 and ended its extended operations phase in September 2022. SOFIA completed 730 science flights and generated over 13 terabytes of raw science data.

In FY 2023, NASA conducted science and mission closeout activities, including archiving of all science data, flight software, and observatory engineering data. The SOFIA team also began decommissioning more than 100,000 property items. NASA decommissioned the following science instruments and made recommendations for potential future scientific use or appropriate museum display: First Light Infrared Test Experiment CAMera (FLITECAM), Echelon-Cross-Echelle Spectrograph (EXES), High-resolution Airborne Wideband Camera-Plus (HAWC+), the High Resolution Mid-InfrarEd Spectrometer (HIRMES), and Faint Object infraRed CAmera for the SOFIA Telescope (FORCAST). NASA decommissioned the German instruments, Field-Imaging Far-Infrared Line Spectrometer (FIFI-LS), German Receiver for Astronomy at Terahertz Frequencies (GREAT) spectrometer, and the Shack-Hartmann Test Instrument, according to direction provided by the German partner. Additionally, NASA decommissioned Information Technology (IT) equipment after the completion of data archiving, as well as the telescope assembly and spares, and disposed of ground support equipment that was at the end of service life.

OTHER MISSIONS AND DATA ANALYSIS

In FY 2024 and FY 2025, NASA will complete closeout work, including continuing the disposition of the fleet of 747 parts, decommissioning of the Flight Simulator and Mirror Coating Facility, disposition of aircraft parts and property at ARC, and returning the Building 703 hangar according to the conditions outlined in the property lease agreement. Additionally, NASA will complete administrative tasks, with the closeout of SOFIA Guest Observer grants that have reached the end of their period of performance.

ASTROPHYSICS PROGRAM MANAGEMENT

Astrophysics Program Management provides streamlined agency oversight for all of NASA's strategic astrophysics missions, consistently applying management best practices to increase the likelihood of mission success. The Astrophysics Strategic Mission Program Office (ASMPO) provides programmatic, technical, business management, and program science leadership for all strategic Astrophysics missions. This support continues throughout the definition, design, development, launch, and operations phases, and facilitates science investigations derived from those missions. This project also provides the funding for Astrophysics Division HQ civil servants and other management and operational needs.

COSMIC ORIGINS STRATEGIC RESEARCH AND TECHNOLOGY

COR SR&T supports program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology solicitation. In addition, funding supports the study of future NASA space observatories, including technology development to support recommendations of the Astrophysics Decadal Survey.

This budget request supports the continuation of the Mirror Technology Development industry solicitation initiated in 2019. Two large teams of aerospace companies lead this on-going effort to increase performance, shorten schedule, and reduce risk and cost of future large space optics. The focus is exclusively on technology maturation and elimination of some technology gaps identified during the study of the four large mission concepts submitted to the Astro2020 Decadal Survey Review.

Recent Achievements

During 2023, NASA, academic, and industry technologists worked on and matured strategic COR technologies. These efforts have contributed to the overall NASA Astrophysics technology development, which has led to over 200 technology infusions into space, suborbital, ground missions, and concepts. The COR SR&T project supported oversight of the Segmented Mirror Technology Program Phase 2E (SMTP-2E) to reduce risk and enable the ultra-stable large space telescopes needed for future flagship observatories such as the Habitable Worlds Observatory (HWO), recommended by the 2021 Astronomy and Astrophysics Decadal Survey. SMTP-2E recently completed its work, with COR Program Office technologists supporting the final reviews of both projects within the program.

Activities in FY 2023 also enhanced and expanded a publicly accessible database of astrophysics technology projects with the latest annual reports from 28 projects and sponsored the Strategic Astrophysics Technology (SAT) and Internal Scientist Funding Model (ISFM) principal investigators annual presentation week, showcasing 37 projects. Program Office technologists convened, facilitated, and supported independent Technology Readiness Level (TRL) vetting of 11 technologies, including one for the Athena X-ray observatory and three for the Laser Interferometer Space Antenna (LISA) gravitational-wave observatory.

OTHER MISSIONS AND DATA ANALYSIS

COSMIC ORIGINS FUTURE MISSIONS

Cosmic Origins Future Missions funding supports studies of future mission concepts.

PHYSICS OF THE COSMOS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Other Missions and Data Analysis	180.7	--	**210.8**	184.3	168.6	176.1	133.7
Total Budget	**180.7**	**--**	**210.8**	**184.3**	**168.6**	**176.1**	**133.7**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

A group of dead stars known as "spider pulsars" are obliterating companion stars within their reach. Data from NASA's Chandra X-ray Observatory of the globular cluster Omega Centauri is helping astronomers understand how these spider pulsars prey on their stellar companions.

The Physics of the Cosmos (PhysCOS) program supports investigations at the intersection of physics and astronomy. Scientists explore some of the most fundamental questions regarding the physical forces and laws of the universe: How do matter, energy, space, and time behave under extreme gravity? What is the nature of dark energy and dark matter? How did the universe grow from the Big Bang to its present size? The PhysCOS program incorporates cosmology, high-energy astrophysics, and fundamental physics projects that address central questions about the nature of complex astrophysical phenomena, such as black holes, neutron stars, dark matter and dark energy, cosmic microwave background, and gravitational waves.

The operating missions within the PhysCOS program continue to provide answers to these fundamental questions and more.

PhysCOS includes a vigorous program to develop the technologies necessary for the next generation of space missions to address the science questions of this program.

EXPLANATION OF MAJOR CHANGES IN FY 2025

Due to budget constraints and to balance the need to support future missions and missions in operations, the request reduces the budget for the Chandra X-Ray Observatory. The Chandra spacecraft has been degrading over its mission lifetime to the extent that several systems require active management to keep temperatures within acceptable ranges for spacecraft operations. This makes scheduling and the post processing of data more complex, increasing mission management costs beyond what NASA can currently afford. The reduction to Chandra will start orderly mission drawdown to minimal operations. The request creates two new projects which support international partnerships: the Ultraviolet Transient Astronomy Satellite (ULTRASAT) transferred from Astrophysics Explorer Future Missions and the Laser Interferometer Space Antenna (LISA) transferred from Physics of the Cosmos SR&T.

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Physics of the Cosmos SR&T	73.6	--	**35.7**	28.6	29.5	30.0	30.0
PCOS/COR Technology Office Management	9.1	--	**8.7**	8.9	9.4	9.6	9.6
Physics of the Cosmos Future Missions	2.8	--	**2.7**	2.7	2.7	2.7	2.5
Laser Interferometer Space Antenna	0.0	--	**73.1**	80.5	89.2	96.0	75.4
Ultraviolet Transient Astronomy Satellite	1.1	--	**21.2**	26.9	1.8	1.8	1.8
Euclid	9.9	--	**9.9**	10.0	9.4	9.5	9.2
Fermi Gamma-ray Space Telescope	12.1	--	**14.5**	0.0	0.0	0.0	0.0
Chandra X-Ray Observatory	68.3	--	**41.1**	26.6	26.6	26.6	5.2
XMM	4.0	--	**4.0**	0.0	0.0	0.0	0.0
Total Budget	**180.7**	**--**	**210.8**	**184.3**	**168.6**	**176.1**	**133.7**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

One of the first images captured by Euclid shows the Perseus cluster, a group of thousands of galaxies located 240 million light-years from Earth. The closest galaxies appear as swirling structures while hundreds of thousands of background galaxies are visible only as points of light. Credit: ESA/Euclid/Euclid Consortium/NASA

Other Missions and Data Analysis supports Physics of the Cosmos (PhysCOS) Supporting Research and Technology; the PhysCOS/Cosmic Origins (COR) Technology Management Office; missions in formulation or development including Ultraviolet Transient Astronomy Satellite (ULTRASAT) and Laster Interferometer Space Antenna (LISA); PhysCOS Future Missions; and operating missions including Euclid, Fermi, Chandra, and X-ray Multi-Mirror Mission (XMM).

Mission Planning and Other Projects

PHYSICS OF THE COSMOS SUPPORTING RESEARCH AND TECHNOLOGY

Physics of the COSMOS Supporting Research and Technology (PhysCOS SR&T) leads strategic technology development efforts to prepare for the next generation of PhysCOS space missions, including program-specific research and advanced technology development efforts, such as the Strategic Astrophysics Technology (SAT) program element.

This budget supports the NASA contribution to ESA's Advanced Telescope for High Energy Astrophysics (Athena) mission, an X-ray observatory dedicated to high-resolution spectroscopy. NASA is a partner in providing two critical technologies (detectors and a cryocooler) for the X-ray Integral Field

Unit spectrometer. NASA will also be involved in the science data acquisition and research in the field of X-ray astronomy.

This budget also supports research and technology development in response to the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy and Astrophysics for the 2020s" recommendation for a Time Domain Astronomy program.

Recent Achievements

NASA continues to make progress on contributions to the Athena mission. The mission is currently undergoing a reconfiguration study by ESA to examine options in light of increased cost estimates for total mission cost. To date, NASA in-house detector development is at Technology Readiness Level (TRL-5) and NASA is finalizing the cryocooler requirements. NASA is currently in pre-phase A development and plans to be in phase B by 2027.

PHYSICS OF THE COSMOS/COSMIC ORIGINS TECHNOLOGY OFFICE MANAGEMENT

The PhysCOS/COR Technology Office provides programmatic, technical, and business management for all technology development and special studies in support of the PhysCOS and COR programs' activities. The technology office acts as a bridge between the nation's science leadership and the larger science community.

PHYSICS OF THE COSMOS FUTURE MISSIONS

PhysCOS Future Missions funding supports concept studies of future missions.

LASER INTERFEROMETER SPACE ANTENNA

The LISA mission is led by ESA with significant contributions from NASA. LISA will advance our understanding in the field of gravitational science and develop a common astronomical catalog of all types of black holes and their characteristics. LISA consists of three spacecraft that are separated by millions of miles which trail tens of millions of miles behind the Earth. These three spacecraft relay laser beams back and forth between the different spacecraft and the signals are combined to search for gravitational wave signatures that come from distortions of spacetime.

NASA supports both ESA and the LISA consortium as a collaborative partner providing science and engineering expertise, technology development, and interface with the U.S. research community. This includes development of enabling technologies, systems engineering support, prototyping of ground segment and data analysis infrastructure, and research in LISA-related astrophysics. NASA is directly supporting the development of five key technologies for possible contribution to the ESA-led LISA mission. The LISA Telescope and laser systems are being developed at the GSFC; a phase measurement system and precision micropropulsion system are being developed at JPL; and a charge management system is being developed by the University of Florida under an award from NASA. The NASA LISA Study Office is coordinating this suite of development activities and managing interfaces with European partners.

LISA is notionally planned for launch in 2036. NASA will also have a U.S.-based LISA Science Center that will advance understanding in the field of gravitational science and develop a common astronomical catalog of all types of black holes and their characteristics.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

NASA is currently in a detailed study and technology development phase and plans to hold a combined KDP-A/B review in early 2024. NASA completed a demonstration model of the laser system (Master Oscillator Power Amplifier) and shipped to ESA for performance testing. Multiple models of the telescope are in development for design concept, hardware durability, and thermal stability. Additionally, the project's Charge Management Device (CMD) is going through comprehensive testing.

ULTRAVIOLET TRANSIENT ASTRONOMY SATELLITE

The Israel Space Agency and NASA are collaborating on a Ultraviolet (UV) astronomy mission, which will be an important sensor in the study of space transient phenomena contributing to Time Domain and Multi-Messenger Astrophysics. This is one of the science areas recommended by the 2020 Decadal Survey. NASA will launch the spacecraft to the geo-transfer orbit on a U.S. launch vehicle from KSC. In addition to the launch, NASA will participate in the science data and a membership in the ULTRASAT science team and working groups. The ULTRASAT launch is planned for FY 2027.

Recent Achievements

In FY 2023 the project completed the Launch Services Interface Requirements documentation and selected U.S. members for the ULTRASAT science team.

Operating Missions

EUCLID

NASA is collaborating on Euclid, an ESA mission, selected as part of ESA’s Cosmic Visions program. ESA successfully launched the mission on July 1, 2023. The Euclid observatory is in its final orbit L2 and is going through the Performance Verification (PV) phase. The observatory will start science operations in early 2024. Euclid seeks to investigate the accelerated expansion of the universe, the so-called “dark energy,” using a Visible Instrument and a Near Infrared Spectrometer and Photometer instrument, as well as ground-based data. The Euclid Consortium, comprised of over 1,200 scientists and engineers from over 50 institutes in Europe, the United States, and Canada, is responsible for development of the two instruments and the science data centers. NASA has contributed flight detector subsystems for the Near Infrared Spectrometer and Photometer instrument and a NASA Euclid Science Center that forms part of the Euclid Science Ground System. In exchange, NASA receives membership in the Euclid Science Team and Consortium and competed science opportunities for U.S. investigators.

Recent Achievements

The Euclid NASA Science Center at Infrared Processing and Analysis Center (IPAC) is responsible for developing data analysis software, processing data, and supporting U.S. researchers using Euclid data. In preparation for Euclid launch, the center participated in extensive real-time testing of the distributed Euclid Science Ground System to demonstrate the center can process data at the rate needed during on-orbit operations and that the software is capable of meeting science requirements for the mission’s PV phase. The center passed its Operations Readiness Review in May 2023.

OTHER MISSIONS AND DATA ANALYSIS

The NASA Euclid data archive, operated as part of the NASA/IPAC Infrared Science Archive, will focus on the needs of the U.S. research community, complementing ESA's Euclid archive. In FY 2023, work continued the design of features to support U.S. investigators in consultation with the user community.

With the start of the PV phase, the center is receiving on-orbit data from Euclid and analyzing it to generate calibration files applied to survey data. The NASA science team members continued to provide key, critical roles in preparing for the Euclid science survey data, providing a robust method to calibrate Euclid's photometric redshift survey, and identifying optimum observation strategies. These efforts will lead to system performance that exceeds the baseline plan for the spectroscopic survey.

FERMI

The Fermi Gamma-ray Space Telescope (Fermi) explores extreme environments in the universe, from black holes on all scales, to ultra-dense neutron stars spinning hundreds of times per second, to expand knowledge of their high-energy properties. Fermi observations are answering long-standing questions across a broad range of topics, including solar flares, the origin of cosmic rays, and the nature of dark matter. NASA's Fermi mission launched in June 2008, developed in collaboration with the U.S. DoE, along with important contributions from academic institutions and partners in France, Germany, Italy, Japan, Sweden, and the United States. Fermi entered extended mission operations in August 2013. The 2022 Senior Review of Operating Missions recommended continuing Fermi operations through FY 2025.

Recent Achievements

Using 14 years of observations from the Large Area Telescope, the instrument team has found 294 gamma-ray pulsars, rapidly spinning neutron stars. An additional 33 objects are likely to be identified as gamma-ray pulsars in future observations. These pulsars point to locations of some of the fastest spinning and heaviest known neutron stars in the Milky Way. A publication on a subset of pulsars that are eclipsed by a companion star estimated that the masses of some of these neutron stars approach the maximum expected at about twice the mass of the Sun. The steadiest Fermi pulsars serve as tools for seeking the gravitational wave background signal expected from binary supermassive black holes. The Large Area Telescope team publicly released the gamma-ray characteristics for the Fermi pulsars along with the data files used to analyze them.

Fermi detected several astonishingly bright gamma-ray eruptions in the past year. Gamma-ray bursts herald the collapse of a massive star to a black hole, the merger of two neutron stars, or possibly other highly energetic activity. The event that occurred in October 2022 holds the record as the most energetic of more than 3,500 bursts observed by the Fermi Gamma-ray Burst Monitor. The extraordinary brightness and energy of that event allowed the team to perform a unique study of the entire timeline of the eruption from the initial emergence and expansion of the relativistic plasma jet out to the interaction with material surrounding the original star. The millions of gamma rays detected showed that the central energy source continued uninterrupted from the time it started to when it ceased almost five minutes later.

CHANDRA

The Chandra X-ray Observatory, launched in 1999 and one of NASA's Great Observatories, continues to transform our view of the universe with its high-quality X-ray images, providing unique insights into violent cosmic events and extreme conditions — such as star explosions, collisions of galaxies, and matter swirling around black holes. Chandra makes observations of clusters of galaxies that provide direct evidence of the existence of dark matter and that greatly strengthen the case for the existence of dark energy. Observations of the remains of exploded stars – supernovas – have advanced our understanding of the behavior of matter and energy under extreme conditions. Chandra has also discovered and studied thousands of supermassive black holes in the centers of distant galaxies. The Chandra spacecraft has been degrading over the mission lifetime to the extent that several systems require active management to keep temperatures within acceptable ranges for spacecraft operations. This makes scheduling and the post processing of data more complex, increasing mission management costs beyond what NASA can currently afford.. The 2022 Senior Review of Operating Missions recommended continuing Chandra operations through FY 2025 but noted that temperature issues are reducing the ability to provide uninterrupted extended observing time and have greatly increased complexity of mission planning. To accommodate the $28 million reduction in FY 2025, the project will transition to minimal operations mode and will likely reduce total available grant funding.

Recent Achievements

NASA's Chandra X-ray Observatory continues to deliver discoveries addressing a wide range of questions across astrophysics. While conceived and developed prior to the discovery of exoplanets (planets outside our Solar System), Chandra is making headway in understanding these distant worlds and the stars they orbit. For example, a result published in FY 2023 showed that some exoplanets are slowing the apparent aging rate of their host star. Researchers used Chandra, along with ESA's XMM-Newton, to investigate dozens of star–planet systems. They found that giant planets that orbit very closely to their host stars cause the stars to spin more rapidly and produce more X-rays, making them appear younger than they actually are.

In FY 2023, Chandra continued its exploration of black holes, including both ongoing observations of the supermassive black hole at the center of the Milky Way galaxy and studies of supermassive black holes in other galaxies. A notable set of observations of a black hole in a galaxy some 290 million light-years from Earth examined a 'tidal disruption event' in which the black hole had torn apart a star that wandered too close. Researchers used Chandra data to identify elements in the debris of the destroyed star. The X-ray data revealed the relative amounts of nitrogen and oxygen in the stellar debris field, indicating that the star was among the largest ever known to be destroyed by a black hole.

X-RAY MULTI-MIRROR MISSION (XMM)

XMM is an ESA-led mission with substantial NASA contributions. The telescope launched in December 1999. XMM studies everything from conditions of planetary formation to the distribution of dark matter in galaxy clusters, the evolution of chemical elements in galaxy clusters, and the distribution of dark matter in galaxy clusters and elliptical galaxies. The GSFC operations facility provides a clearing house for project-generated technical information and analysis software as well as budget support for U.S. astronomers who apply for XMM-Newton observation time. The 2022 Senior Review of Operating Missions recommended continuing U.S. operations of the Guest Observer Facility (GOF) U.S. science operations through FY 2025.

Recent Achievements

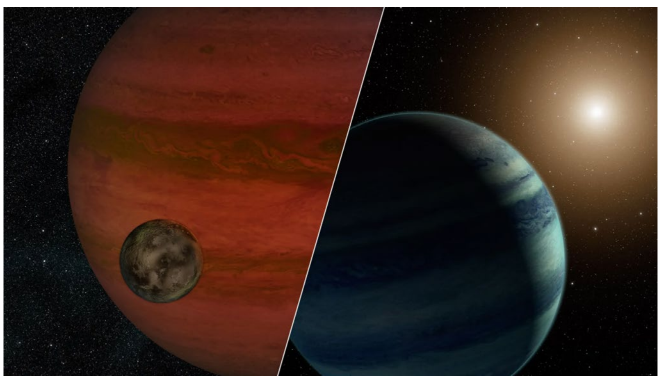
XMM has measured the vertical structure of an accretion disk wind to reveal the wind outflow launching mechanism. The accretion of matter onto black holes and neutron stars often leads to the launching of outflows that can greatly affect the surrounding environments. An important means of studying winds is through their X-ray spectra. Observing Hercules X-1, a nearly edge-on X-ray binary star with a warped accretion disk, scientists watched as the disk rotated and saw a strong decrease in the wind density as their sightlines sampled the wind at greater heights above the accretion disk. The wind became clumpier as it rose upwards and expanded away from the neutron star. Modelling the warped disk shape, XMM data allowed scientists to create a two-dimensional map of wind properties and infer the three-dimensional wind structure for the first time.

EXOPLANET EXPLORATION

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Nancy Grace Roman Space Telescope	447.3	407.3	**384.0**	376.5	216.6	100.5	75.1
Other Missions and Data Analysis	55.6	--	**94.5**	82.5	149.5	223.4	264.8
Total Budget	**502.9**	**--**	**478.5**	**459.0**	**366.1**	**323.8**	**339.9**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Researchers have detected the first "exomoon" candidate — a moon orbiting a planet that lies outside our solar system. Using a technique called "microlensing," they observed what could be either a moon and a planet, or a planet and a star. This artist's conception depicts the two possibilities.

Humankind is gaining insight into timeless questions: Are we alone? Is Earth unique, or are planets like ours common? One of the most exciting fields of research within the NASA Astrophysics portfolio is the search for planets, particularly Earth-like planets, around other stars.

Since the discovery of the first exoplanets in the 1990s, astronomers have confirmed over 5,500 planets orbiting most types of stars in our galaxy. At first, most of the planets discovered were so-called "Hot Jupiters"—gas giants similar in size to the planet Jupiter but orbiting much closer to their parent stars. However, analysis of NASA's Kepler Space Telescope data, in conjunction with data from ground-based telescopes, has revealed that smaller planets, with sizes between those of Earth and Neptune, are much more common than Jupiter-like planets. Rocky planets in the habitable zone of their parent stars also appear to be common. The Transiting Exoplanet Survey Satellite mission is now discovering many more small planets orbiting bright stars.

NASA's Exoplanet Exploration Program is advancing along a path of discovery leading to a point where scientists can directly study the atmospheres and surface features of habitable, rocky planets like Earth around other stars in the solar neighborhood. Following the recommendation of the recent National Academy of Sciences "Decadal Survey on Astronomy and Astrophysics 2020" report, NASA aims to develop systems that will allow scientists to take the pivotal step from identifying an exoplanet as Earth-sized to determining whether it is genuinely Earth-like and possibly even detecting if it bears the spectral fingerprints of life via a program of technology development (funded within a new project entitled Habitable Worlds Observatory Technology Maturation). Such an ambitious goal would require overcoming several technological challenges, and the Exoplanet Exploration effort also provides a robust technology development program to enable a future direct detection and characterization mission.

EXOPLANET EXPLORATION

EXPLANATION OF MAJOR CHANGES IN FY 2025

The budget increases to support the Habitable Worlds Observatory Technology Maturation Project, including work at GSFC, in direct alignment with the Great Observatories Mission and Technology Maturation Program recommendation in the Astro2020 Decadal Survey. The request includes a new project, Exoplanet Exploration Science, which will fund guest observations and competed science once the Roman Space Telescope launches.

NANCY GRACE ROMAN SPACE TELESCOPE

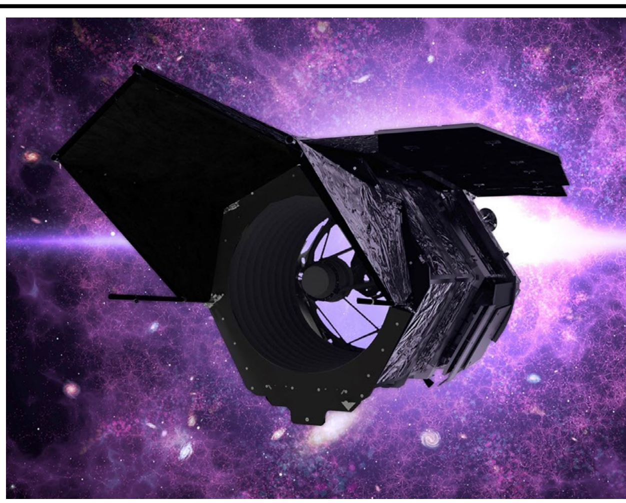
Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	633.8	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	633.8
Development/Implementation	1,534.4	447.3	407.3	**384.0**	367.9	129.1	0.0	0.0	0.0	3,270.0
Operations/Close-out	0.0	0.0	0.0	**0.0**	8.6	87.5	100.5	75.1	140.5	412.2
2024 MPAR LCC Estimate	**2,168.2**	**447.3**	**407.3**	**384.0**	**376.5**	**216.6**	**100.5**	**75.1**	**140.5**	**4,316.0**
Total Budget	**2,168.2**	**447.3**	**407.3**	**384.0**	**376.5**	**216.6**	**100.5**	**75.1**	**140.5**	**4,316.0**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



The Nancy Grace Roman Space Telescope, depicted here, is a NASA observatory designed to tackle essential questions in the areas of dark energy, exoplanets, and infrared astrophysics.

PROJECT PURPOSE

The Nancy Grace Roman Space Telescope (Roman) will investigate long-standing astronomical mysteries, such as the force behind the universe's accelerating expansion and search for distant planets beyond our solar system. Roman will unravel the secrets of dark energy and dark matter, search for and image exoplanets, and explore many topics in infrared astrophysics. This newest NASA observatory addresses the top priority large mission of the 2010 Decadal Survey in Astronomy and Astrophysics.

Roman carries two instruments. The Wide Field Instrument will accomplish the mission's primary science observations over large areas of the sky. The Coronagraph Instrument (CGI) technology demonstration matures components and systems for imaging and spectroscopy of individual nearby exoplanets. NASA has scheduled Roman's launch for May 2027 so that Roman mission's operations overlap with those of the James Webb Space Telescope to provide synergistic science capabilities. Roman ushers in a new era of big data for astrophysics, producing an archive averaging over 10 terabytes of data per day of operations during its first five years of operations.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

PROJECT PARAMETERS

Roman is a NASA observatory designed to investigate essential questions in the areas of dark energy, exoplanets, and infrared astrophysics. To address these questions, the telescope has a large, 7.9-foot (2.4-meter) diameter primary mirror, since a larger surface area gathers more light and produces sharper images. Roman's mirror is the same size as the Hubble Space Telescope's primary mirror, and it is less than one-fourth the weight at only 410 pounds (186 kilograms), thanks to major improvements in technology. To make Roman’s sensitive measurements possible, the telescope observes from a vantage point orbiting about 930,000 miles (1.5 million kilometers) away from Earth in the direction away from the Sun. Near this location, called the second Sun-Earth Lagrange point (L2), the observatory is thermally stable, views more of the sky for longer periods of time, and can prevent stray light from the Sun, Moon, and Earth more easily.

The telescope provides a field of view that is 200 times greater than the Hubble Space Telescope's infrared instrument, allowing it to capture more of the sky with less observing time. The Roman Wide Field Instrument is a 300-megapixel infrared camera and spectrometer built to provide revolutionary surveys of unprecedented size, sharpness, and depth to address key topics in cosmology, exoplanets, and infrared astrophysics. The camera features eight filters for different wavelengths of infrared light suited to studying varied astronomical objects, plus two spectroscopic elements to measure distances and study other physical characteristics of galaxies and supernovae across the universe.

In addition to the Wide Field Instrument, Roman will advance exoplanet observations by carrying the first active coronagraph into space. The CGI, built as a technology demonstration, combines multiple technologies and operation modes to block light from the host star and allow high-contrast imaging of faint exoplanets orbiting it. This capability is critical for next-generation telescopes capable of analyzing the atmospheres of Earth-like planets around other stars.

Roman is planned for a primary mission lifetime of five years, with enough propellant for at least five years of extended mission.

ACHIEVEMENTS IN FY 2023

NASA made substantial progress in the fabrication, testing, and assembly of major flight hardware in FY 2023. All WFI subassemblies have successfully been completed and integrated to the instrument. Widefield has started its first thermal vacuum cycle test. Many subassemblies for the Optical Telescope Assembly have been completed including the Primary Mirror Assembly, Forward Structure Assembly, Tertiary Mirror Assembly, and Tertiary and Collimator Assembly. Chamber readiness is underway for dynamic and environmental testing and the Image Optical Assembly has entered the instrument integration phase. The instrument carrier structure has been successfully completed and shipped to GSFC. The team completed multiple spacecraft bus deliverables, including: all Avionic Panels, Power Distribution Unit Box, Propulsion Tanks, Deployment Propulsion Electronics Boxes, Radio frequency

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

(RF) Transponder, Ka-Band Antenna, and Flight Harness. The spacecraft bus has started integration with the flight hardware. The CGI has completed final assembly and testing of Deformable Mirror Electronics Boxes, Instrument Support Electronics, and Coronagraph Thermal Control Electronics. The coronagraph has started instrument integration and has been fully assembled with the Electronic Heat Transport System Pallet and Optical Bench Structure Assembly. The Coronagraph flight software has made significant progress with the release and installation of version 1.02, which is the first flight candidate software build.

The Committee on Astronomy and Astrophysics released its non-advocate review of Roman observations in October 2022, endorsing the project's community-led approach to setting Roman's observation program. The three core community surveys, defined by the 2010 Decadal Survey, were the subject of a white paper submission round that saw 90 papers proposing ways of improving the baseline survey plans. Groups have been solicited to form the Survey Definition Committees to assess these and other community-wide inputs. During FY 2023, the team reviewed white papers submitted in support of an Early-Definition Survey option. Following the findings of a review committee, the project will proceed to define another core community survey.

NASA released a solicitation for Roman science teams in December 2022 and selected 30 Roman Science teams in July 2023, forming the broad group of experts needed to prepare for and exploit Roman science data. These groups are tasked in part with developing the detailed pipeline algorithms necessary to meet Roman's science objectives for cosmology and exoplanet discoveries and will additionally support a very wide range of other scientific uses.

This year's Roman held its science conference, "Roman Science Inspired by Emerging JWST Results," in Baltimore, Maryland in June 2023. One of NASA's partners on Roman, JAXA, awarded contracts for the Misasa Deep Space Station (MDSS) enhancement that will provide downlinking of Roman data at up to 500 Megabits per second (Mbps). The project completed the MDSS enhancement PDR presentation in February 2023, and the CDR in September 2023. Another NASA partner on Roman, ESA, completed excavation and site preparation for installation of the New Norcia-3 antenna pad foundation in western Australia. The ground system elements achieved the first systemwide development milestone in April 2023, the Ground System Release 1.

WORK IN PROGRESS IN FY 2024

In FY 2024, the project will complete readiness of key milestones in preparation for the Integrated Payload Assembly (IPA) integration: the Optical Telescope Assembly, WFI, CGI, Spacecraft, and Instrument Carrier. The project team will focus on continued assembly, integration, and testing for all aspects of the Roman mission. NASA anticipates completing integration and testing of the WFI. NASA will also complete the Optical Telescope Assembly and its associated electronics, leading to the full Integrated Optics Assembly and its validation and testing. NASA will finish assembly and testing of the Instrument Carrier, readying it for the installation of the WFI and CGI instruments. NASA will receive the Launch Loads Vibration Isolation system. The project team will hold its System Integration Review (SIR) during the Q3 FY 2024.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

KEY ACHIEVEMENTS PLANNED FOR FY 2025

In FY 2025, the elements delivered in FY 2024 will begin assembly and integration, starting with the installation of the two instruments on the Instrument Carrier and the installation of the Integrated Optics Assembly. These elements together will form the IPA. Upon completion of the spacecraft bus and IPA, NASA will then begin integration and test of the larger assembly known as Space Infrared Telescope for Cosmology and Astrophysics.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2025 President's Budget Request
KDP-C	Feb 2020	Feb 2020
CDR	Jul 2021	Sep 2021
SIR	Jul 2023	Jan 2025
Flight Readiness Review	Jun 2026	Jan 2027
Launch	Oct 2026	May 2027
Begin Phase E	Jan 2027	Aug 2027
End Prime Mission	Jan 2032	Aug 2032

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2021	2,898	>70	2024	3,270	+13	LRD	Oct 2026	May 2027	+7

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as Joint Confidence Level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**2,898.1**	**3,270.1**	**+372.0**
Aircraft/Spacecraft	278.1	403.8	+125.7
Payloads	661.6	898.4	+236.8
Systems I&T	183.2	317.3	+134.1
Launch Vehicle	238.6	261.2	+22.6
Ground Systems	217.6	294.1	+76.5
Science/Technology	79.4	110.9	+31.5
Other Direct Project Costs	1,239.6	984.4	-255.2

Project Management & Commitments

NASA HQ is responsible for the overall management of Roman and CGI. GSFC has project management responsibility for Roman. JPL has project management responsibility for CGI.

Element	Description	Provider Details	Change from Baseline
Project Management and Systems Engineering	Management of all technical and programmatic aspects of mission development and system engineering of each element and the integrated system	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Mission Science Management	Management of all project science activities from formulation through development and operations	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC and partners Cost Share Partner(s): N/A	N/A
Wide Field Instrument	Overall instrument management; in-house development of the Focal Plane System, Grism, Prism, and all subsystems other than the Ball Aerospace-managed Wide Field Instrument Opto-Mechanical Assembly (WOMA)	Provider: NASA, Ball Aerospace Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Instrument Carrier	Structural Support for the Optical Telescope Assembly, WFI, and CGI	Provider: NASA, Northrop Grumman Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Spacecraft	Main bus for Roman; providing power, electrical, thermal, and propulsion systems	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
CGI	Management of all technical and programmatic aspects of instrument development and system engineering of the technology demonstration for space-based exoplanet characterization	Provider: NASA Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): N/A	N/A
Star Tracker, Flight Battery	Optical device that measures the positions of stars using photocells or a camera; rechargeable power source	Provider: ESA Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Electron-Multiplying Charge-Coupled Device Detectors	Devices for digital imaging under low-light conditions	Provider: ESA Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): ESA	N/A
Super-polished optics and Off Axis Parabolas	Optical elements to collimate and direct light within the CGI	Provider: French Space Agency (CNES)/LAM Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): CNES	N/A
Precision Alignment Mechanisms	Mechanisms to direct light within the CGI with one to two arcsecond pointing accuracy	Provider: Max Planck Institute for Astronomy (MPIA) Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): MPIA	N/A

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Polarization Optics	Optical elements to select the polarization state of light within the CGI	Provider: JAXA Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): JAXA	N/A
Use of Ground Station	Daily use of a ground station in Japan and data transport to the Science Operations Center	Provider: JAXA Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): JAXA	N/A
Launch Vehicle	Launch services for Roman on required trajectory for L2 operational orbit	Provider: SpaceX Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Mission Operations	Management of on-orbit operations	Provider: NASA Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): N/A	N/A
Ground Control System and Science Operations and Control Center	Science Operations Center responsible for processing, analysis, and archiving of data from the observatory	Provider: Space Telescope Science Institute Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
Coronagraph Ground Control System and Science Operations and Control Center	Science Center responsible for processing and analysis of coronagraph data for infrared astronomy	Provider: Infrared Processing and Analysis Center Lead Center: JPL Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Contractor delivers the Optical Large Aperture Flat System (OLAFS) late, Then: There is a possible delay to the start of IPA Spacecraft Bus + Integrated Payload Assembly (SCIPA) pathfinder and Thermal Vacuum (TVAC) testing, resulting in an impact to the critical path.	The project is in the process of descoping the Optical Large Aperture Flat System bake-out at the contractor in favor of a system level bake-out at GSFC just prior to initiating the SCIPA TVAC Pathfinder testing. This change will accelerate the OLAFS delivery and mitigate any impact to the I&T schedule.
If: The project cannot modify the High-Capacity Centrifuge (HCC) in time to support the Instrument Carrier test need date; and the HCC test does not impart adequate loading to provide full qualification of the Instrument Carrier, spacecraft, primary structure, and the Outer Barrel Assembly, Then: There is a possibility the Instrument Carrier, spacecraft primary structure, and Outer Barrel Assembly will need additional static load test cases, resulting in additional cost/schedule to execute additional testing.	The project completed the HCC platform modification readiness review in September 2023 and received approval to proceed with existing plates. The project has received most of the needed hardware and the installation drawings are in progress. HCC/Motorized Tilt Fixture will be proof tested, which is expected to start mid-November 2023. The HCC/Slew ring proof testing is expected to start late January 2024. Current schedule for modification and testing supports the centrifuge testing of the Instrument Carrier starting in March 2024. This plan mitigates any schedule impact or additional testing.

Acquisition Strategy

The project has awarded all major contracts.

NANCY GRACE ROMAN SPACE TELESCOPE

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Optical Telescope Assembly	L3Harris	Rochester, NY
WOMA	Ball Aerospace	Boulder, CO
Sensor Chip Assemblies	Teledyne	Camarillo, CA
	Hawaii Aerospace	Honolulu, HI
Science Operations Center Support	AURA/Space Telescope Science Institute	Baltimore, MD
Science Center Support	IPAC/Caltech	Pasadena, CA
Launch Vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Standing Review Board (SRB)	Dec 2023	Programmatic Touchpoint number two, recommended by the SRB in the CDR report, between CDR and SIR.	TBD
Performance	SRB	Jun 2024	SIR: Determine Roman readiness to proceed to system integration and test phase.	TBD
Performance	SRB	Jan 2027	FRR: Evaluate the readiness of the project to operate and perform the mission.	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Exoplanet Exploration SR&T	35.7	--	**25.5**	28.3	36.2	36.6	36.8
Exoplanet Exploration Technoloy Off Mgmt	6.7	--	**8.5**	8.5	8.6	8.6	8.6
Exoplanet Exploration Future Missions	5.7	--	**2.8**	2.8	2.6	5.6	4.0
Keck Operations	7.5	--	**7.6**	7.7	7.8	4.9	4.9
Habitable Worlds Observ Tech Maturation	0.0	--	**50.0**	35.2	46.5	119.9	162.8
Exoplanet Exploration Science	0.0	--	**0.0**	0.0	47.8	47.8	47.8
Total Budget	**55.6**	**--**	**94.5**	**82.5**	**149.5**	**223.4**	**264.8**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Mission Planning and Other Projects

Exoplanet Exploration Other Missions and Data Analysis includes funding for Exoplanet Exploration Supporting Research and Technology, Exoplanet Exploration Technology Office Management, Keck Operations, Habitable Worlds Observatory Technology Maturation, Exoplanet Exploration Science, and funding for future mission selections.

EXOPLANET EXPLORATION STRATEGIC RESEARCH AND TECHNOLOGY

Exoplanet Exploration Strategic Research and Technology supports program-specific strategic research and technology development activities that both serve the needs of the U.S. exoplanet science community today and forge a path for ever more ambitious missions of exoplanet discovery in the future. In support of these goals, the project supports the NASA Exoplanet Science Institute (NExScI) and the NASA Exoplanet Archive, which together provide coordination and support for the latest cutting-edge scientific research activities of the U.S. exoplanet community. Similarly, the project maintains and operates an array of highly specialized testbeds and related facilities that are available to the community and support the development of advanced technologies and instrument concepts for exoplanet exploration.

NASA currently supports a portfolio of competitively selected exoplanet science and technology development projects involving researchers from across the nation. The selected projects focus on confirming the exoplanet discoveries of NASA's Kepler/K2 and Transiting Exoplanet Survey Satellite (TESS) missions and vetting potential targets for further observation and characterization with NASA's James Webb Space Telescope (Webb) and Roman Space Telescope. The portfolio of selected technology is also laying the scientific and technological foundation for the top priority large mission recommended by the 2020 Decadal Survey of Astronomy and Astrophysics: a future Great Observatory (or Habitable Worlds Observatory) that will detect and characterize potentially habitable, Earth-sized planets orbiting Sun-like stars in the solar neighborhood and search for signs that they might harbor life.

NASA also supports a range of exoplanet science investigations through its investments in the Keck Observatory in Hawaii and the Wisconsin-Indiana-Yale-National Optical Astronomy Observatory Telescope in Arizona. Those science investigations include ground-based, follow-up observing programs that support NASA's TESS mission and programs that support the operational planning and design of future missions.

Recent Achievements

In August 2023, the field of exoplanet science achieved an amazing milestone when it surpassed 5,500 confirmed exoplanets at the NASA Exoplanet Archive (500 more exoplanets compared to last year's report). This large population of planets, discovered using a variety of detection techniques from the ground and from space, is enabling population studies into planet formation, evolution, and migration processes on an unprecedented scale and providing exciting new targets for Webb to characterize.

As NASA begins preparation for a potential future Habitable Worlds Observatory (HWO), it will leverage the starlight-blocking capability (i.e., a coronagraph) of current technology demonstrations, such as the Coronagraph Instrument for the Roman Space Telescope. Such a mission would need to block starlight at unprecedented levels to detect Earth-like planets (estimated to be about 10 billion times fainter than a Sun-like star). The current concept for a HWO would use a segmented primary mirror (just like Webb) and small optics (i.e., deformable mirrors) to correct imperfections in a space telescope's optics. In 2023, the team developed two key technologies for advancement: a Sub-Nanometer Static Phase Mask for Segmented Pupil Coronagraphy and a Picometer Actuator Motion Control Electronics for Deformable Mirrors. These technologies will help simulate segmented mirrors with a variety of positional offsets, each less than a nanometer (one hundred thousand times smaller than a human hair), and specialized electronics that can move the actuators within the deformable mirrors to better than two picometers (one hundred million times smaller than a human hair).

EXOPLANET EXPLORATION TECHNOLOGY OFFICE MANAGEMENT

Exoplanet Exploration Technology Office Management provides scientific and technical leadership and business management for the program's portfolio of technology development projects. It coordinates, supports, and tracks the progress of the program's numerous technology development tasks. It also manages shared testbed infrastructure for the use of the community of exoplanet technologists, actively engages science community stakeholders, and provides effective public and professional communication of exoplanet science discovery and enabling technologies.

Recent Achievements

The Exoplanet Exploration Technology Office produced the Astrophysics Division's Progress in Technology for Exoplanet Missions (Technology Plan Appendix 2023). The purpose of this document is to guide near-term (one to five year) technology development for future space observatories related to NASA's Exoplanet Exploration Program (ExEP). This document provides an update to ExEP's 2019 Technology Plan Appendix to reflect the recommendations of the National Academies of Science, Engineering, and Medicine 2020 Decadal Survey report Pathways to Discovery in Astronomy and Astrophysics for the 2020s.

EXOPLANET EXPLORATION FUTURE MISSIONS

Exoplanet Exploration Future Missions funding supports the execution of the exoplanet mission science and technology definition teams and, ultimately, the formulation, development, and implementation of a future Exoplanet Exploration flight mission.

OTHER MISSIONS AND DATA ANALYSIS

HABITABLE WORLDS OBSERVATORY TECHNOLOGY MATURATION

This project will support investments in direct support of a potential future Habitable Worlds Observatory (HWO) primarily via the technology maturation program known as Great Observatories Mission and Technology Maturation Program, (GOMAP), as outlined in the Astro2020 Decadal Survey. The budget will support precursor science, mission, and technology maturation efforts for a potential future HWO, a large infrared, optical, and ultraviolet telescope – the first ever space telescope designed specifically to search for signs of habitability or life on planets orbiting other stars. The mission will conduct a survey of stars in the solar neighborhood to search for habitable planets. NASA will follow up on identified habitable planets with a spectroscopic survey to search for biosignatures that would provide evidence for the presence of life. The current concept for the HWO assumes significant collaboration and partnership with industry, academia, and other governments.

The most critical technology challenge is directly imaging and characterizing potentially habitable planets around other stars. The HWO technology will require high precision cancellation of the star's light because host stars are 10 billion times brighter than potentially habitable planets. The current technology in the Roman Coronagraph Instrument will help advance this technology. However, coronagraph technology will need further advancements to increase levels of precision. HWO's coronagraph performance is also coupled with the observatory's ultrastability. While Webb demonstrated nanometer observatory-level stability, HWO requires picometer observatory-level stability per control step – one thousand times higher stability achievement. Such advancements will allow the two technologies to work in concert to the level required to achieve the ambitious goal of searching for signs of life on planets around other stars.

Recent Achievements

NASA has established a community-led Science, Technology, Architecture Review Team to coordinate community activities to mature the HWO concept. These groups will quantify the Astro2020 Decadal science goals for HWO and explore the aerospace landscape opportunities such as heavy lift rockets, robotic servicing, artificial intelligence/machine learning (AI/ML), and quantum technologies, as well as explore the high-level design and architecture trade space.

EXOPLANET EXPLORATION SCIENCE

This project funds competed science under the Exoplanet Exploration Program. Following the scheduled launch in 2027, the project will fund competed research and other related activities from Nancy Grace Roman Space Telescope observations and data.

Operating Missions

KECK OPERATIONS

Keck Operations is the NASA portion of the Keck Observatory partnership. NASA is a partner for one-sixth of the observing nights on the two 10-meter telescopes of the W.M. Keck Observatory, the largest optical telescope pair in the world. NASA uses its share of observing time in support of its Astrophysics and Planetary Science programs. NExScI allocates observing time for NASA astrophysics science goals, as well as for solar system objects and direct space mission support. Supported missions in recent years include Hubble, Chandra, TESS, Spitzer, Euclid, Webb, and the Roman Space Telescope for astrophysics; Parker Solar Probe for heliophysics; and New Horizons, NEOWISE, DART, and Lucy for planetary sciences. All observing time proposal requests are competitive, with peer-review and selection managed by NExScI. The Keck Observatory Archive (KOA), managed by the NASA Exoplanet Science Institute, ingests and curates existing and new data from the Keck Observatory.

Recent Achievements

The large number of proposals submitted continues to demonstrate strong demand for NASA observing nights with a current oversubscription rate for both telescopes around five to one. During the 2024A observing semester that runs from February through July 2024, scientists at institutions around the United States submitted 188 proposals, the highest numbers of proposals ever, requesting 229 observing nights in total for both telescopes.

The second new Keck instrument is the Keck Planet Finder (KPF), which is entering its first semester of normal science operations on the Keck-I telescope. With an instrumental precision less than 20 centimeters (cm/s), KPF will be the premier instrument for Precision Radial Velocity measurements in support of NASA's goals for exoplanet science.

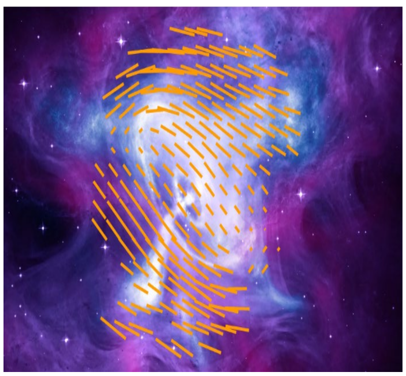
The Data Services Initiative to enhance operational efficiency and easier and open access to fully processed data from Keck instruments continued in 2023. All secured observations plus real time data ingestion are now available for all 12 instruments in KOA, covering nearly 30 years of "Keck Sky." Currently, the astronomical community uses the KOA data with approximately 15 to 20 percent of Keck publications citing the archive as the source of their data. Key strategic mission support programs for operating and future NASA space missions account for about 35 percent of all the NASA competed time to the U.S. community.

ASTROPHYSICS EXPLORER

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
SPHEREx	81.6	65.4	**38.7**	6.0	1.6	0.5	0.0
Compton Spectrometer and Imager (COSI)	36.5	--	**64.4**	68.2	46.9	6.5	3.1
Other Missions and Data Analysis	108.7	--	**166.3**	178.0	332.1	449.4	537.5
Total Budget	**226.8**	**--**	**269.3**	**252.2**	**380.6**	**456.4**	**540.6**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



The Crab Pulsar is a famous astronomical object, about 6,500 light-years from Earth, that originated with the explosion of a massive star. The nebula around the Crab contains a donut-shaped magnetic field, which NASA's Imaging X-ray Polarimetry Explorer (IXPE) observed. The lines highlight the shape of the magnetic field determined by IXPE. It is superimposed on a composite image made with data from the Chandra X-Ray Observatory (blue and white), Hubble Space Telescope (purple), and Spitzer Space Telescope (pink).

The Astrophysics Explorer program provides frequent flight opportunities for world-class astrophysics investigations using innovative and streamlined management approaches for spacecraft development and operations. The program is highly responsive to new knowledge, new technology, and updated scientific priorities by launching smaller missions formulated and executed in a relatively short development cycle. NASA selects new missions based on an open competition of concepts solicited from the scientific community. The program emphasizes the accomplishments of missions under the control of the scientific research community within constrained mission life-cycle costs.

The most recent Astrophysics Medium-Class Explorer (MIDEX) missions cost up to $300 million, excluding launch services. Small Explorer (SMEX) missions cost up to $145 million excluding launch services. Pioneer missions cost up to $20 million, excluding the launch. The most recent Explorer Missions of Opportunity (MO) have a NASA cost of under $80 million.

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA has reduced the Explorer Future missions budget which will preclude the selection of Missions of Opportunity for the 2021 and 2025 Announcements of Opportunity (AOs). The Request includes a new Astrophysics Explorer Science project which funds competed science and related scientific activities conducted with data from Astrophysics Explorer missions. NASA reduced the Pioneers budget which will result in skipping the ROSES-2023 Pioneers solicitation and selections.

ACHIEVEMENTS IN FY 2023

Contribution to ARIEL Spectroscopy of Exoplanets (CASE) mission successfully completed its KDP-C review in February 2023.

ASTROPHYSICS EXPLORER

The X-ray Imaging and Spectroscopy Mission (XRISM) mission launched in September 2023 and began on-orbit checkout activities.

NASA released the Astrophysics Probe AO in July 2023. As recommended by the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy and Astrophysics for the 2020s," the first Astrophysics Probe will be either a far infrared imaging or spectroscopy probe, or an X-ray probe.

The Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory (GUSTO) team successfully reached observatory I&T activities at the Applied Physics Lab starting March 15, 2023, and completed all I&T tasks in June 2023. During August 2023, the GUSTO team completed comprehensive performance testing and Hang-Test activities successfully and on schedule. On October 17, 2023, the GUSTO team successfully passed its KDP-E milestone and was approved for Phase E and launch activities starting in early December 2023.

WORK IN PROGRESS IN FY 2024

GUSTO launched in December 2023 and will complete its prime mission of 75 days.

SPHEREx completed its KDP-D review in January 2024.

COSI will complete its KDP-C review in April 2024 and transition to the development phase.

NASA expects to down-select a MIDEX mission to continue to implementation in early 2024 between the two missions that are currently in Phase A: Ultraviolet Explorer (UVEX) or Survey and Time-domain Astrophysical Research eXplorer (STAR-X). These missions are relevant to the decadal recommendations in Time Domain and Multi Messenger follow up (TDAMM).

NASA received proposals for the Astrophysics Probe on November 16, 2023, and expects to down-select competed missions for a 12-month Phase A study.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The SPHEREx mission will launch in April 2025.

Program Schedule

Date	Significant Event
Dec 2023	GUSTO LRD
Jan 2024	SPHEREx KDP-D
Apr 2024	COSI KDP-C
NET Mar 2024	Down-select one MIDEX mission for implementation
Q2 FY 2025	Select Probe proposals for competitive Phase A studies
Apr 2025	SPHEREx LRD
2025	Down-select one probe mission for implementation

ASTROPHYSICS EXPLORER

Date	Significant Event
Mar 2025	SMEX AO
Mar 2026	Select SMEX proposals for competitive Phase A mission concept studies
Aug 2027	MIDEX AO
2027	COSI LRD
Sep 2028	Down-select one SMEX for implementation

Program Management & Planned Cadence

The Astrophysics and Heliophysics Explorer programs are both coordinated sets of uncoupled missions, where each mission is independent and has unique science. The programs share a common program office at NASA GSFC and a common management structure. The Explorer Program Manager resides at GSFC, reporting functionally to the Center Director and programmatically through the Astrophysics and Heliophysics Division Directors to the Associate Administrator for SMD.

This budget supports approximately a three- to four-year mission cadence, or four AO solicitations every decade.

Acquisition Strategy

NASA selects all Explorer missions through competitive AOs.

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REIONIZATION, AND ICES EXPLORER

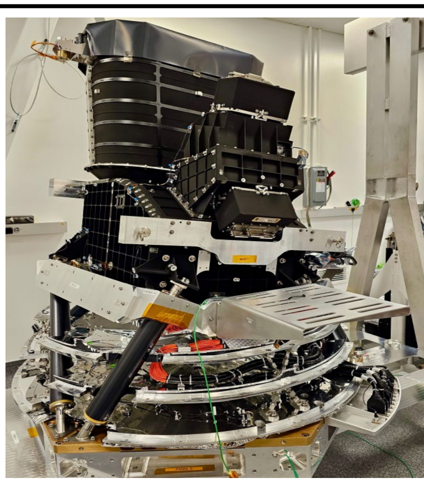
Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	64.2	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	64.2
Development/Implementation	193.5	81.6	65.4	**27.2**	0.0	0.0	0.0	0.0	0.0	367.8
Operations/Close-out	0.0	0.0	0.0	**11.4**	6.0	1.6	0.5	0.0	0.0	19.5
2024 MPAR LCC Estimate	**257.7**	**81.6**	**65.4**	**38.7**	**6.0**	**1.6**	**0.5**	**0.0**	**0.0**	**451.4**
Total Budget	**257.7**	**81.6**	**65.4**	**38.7**	**6.0**	**1.6**	**0.5**	**0.0**	**0.0**	**451.4**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



NASA's SPHEREx infrared astrophysics mission will study the quantum physics of the Big Bang, the subsequent formation of galaxies, and the large-scale interstellar distribution of ices and water. This is an image of the payload component of the observatory showing the telescope assembly on top, and the V-groove thermal radiator system on the bottom. (Credit: JPL-Caltech)

PROJECT PURPOSE

The Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer (SPHEREx) Mission will serve as a powerful tool for understanding how our universe evolved and how common the ingredients for life are in our galaxy's planetary systems. SPHEREx will be NASA's first all-sky spectral astronomy survey mission and will investigate the quantum physics of the Big Bang theory of the origin of the universe. The mission will chart the origin and history of galaxy formation, from light produced by the first galaxies that ended the cosmic dark ages, to the present day. Astronomers will use the mission to gather data on hundreds of millions of galaxies and stars. SPHEREx will also survey water and organic molecules in interstellar ices.

EXPLANATION OF MAJOR CHANGES IN FY 2025

Reduced funding in FY 2025 is offset by increases provided in earlier years, with no impact to LCC.

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REIONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

PROJECT PARAMETERS

SPHEREx is a medium Explorer-class astrophysics mission planned to launch in 2025. It is a three-axis stabilized spacecraft that NASA will launch into a Sun-synchronous Earth orbit with an altitude of approximately 650 kilometers for a baseline two-year science mission. SPHEREx will survey the sky in near-infrared light. SPHEREx will probe the origin of the Universe through a large-volume galaxy redshift survey and provide a rich public spectral archive for diverse investigations. The payload consists of the thermal subsystem, optical subsystem, and instrument control electronics. The Korea Astronomy and Space Science Institute (KASI) will contribute the non-flight cryogenic test chamber. SPHEREx will launch on a SpaceX Falcon 9.

ACHIEVEMENTS IN FY 2023

The SPHEREx project completed payload subsystem integration, including the telescope. Additionally, the project initiated both the payload subsystem environmental testing and spacecraft bus integration.

WORK IN PROGRESS IN FY 2024

SPHEREx held the Systems Integration Review (SIR) in November 2023, and the KDP-D review in January 2024. The project will complete payload subsystem environmental testing and spacecraft bus integration and begin observatory integration and testing.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The project will complete the observatory level integration and testing and prepare for launch operations at Vandenberg AFB.

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2025 PB Request
KDP-C	Dec 2020	Dec 2020
CDR	Sep 2021	Jan 2022
System Integration Review	Mar 2023	Nov 2023
KDP-D	May 2023	Jan 2024
Launch Readiness Date (LRD)	Apr 2025	Apr 2025
Phase E start	May 2025	May 2025

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REIONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milestone Change (months)
2021	367.8	>70	2024	367.8	0	LRD	April 2025	April 2025	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time was developed. Estimates that include combined cost and schedule risks are denoted as joint confidence level (JCL); all other confidence levels (CLs) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**367.8**	**367.8**	**0.0**
Aircraft/Spacecraft	54.9	75.2	+20.3
Payloads	45.8	98.2	+52.4
Systems I&T	11.9	15.5	+3.6
Launch Vehicle	112.4	96.6	-15.8
Ground Systems	12.0	12.9	+0.9
Science/Technology	21.0	25.9	+4.9
Other Direct Project Costs	109.8	43.5	-66.3

Project Management & Commitments

JPL provides project management for the mission. The SPHEREx Principal Investigator resides at the California Institute of Technology (Caltech). JPL manages the overall SPHEREx mission and will provide systems engineering, mission assurance, payload thermal and mechanical mission system, and the operations science team.

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REIONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Payload Thermal Subsystem	The thermal subsystem consists of the photon shields, focal plan radiator, telescope support structure, and V-groove radiators	Provider: JPL Lead Center: JPL Performing Center(s): JPL Cost Share Partner(s): None	N/A
Payload Optical Subsystem	The optical subsystem consists of the baffle and focal plane assemblies	Provider: Caltech Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Payload Electronics Subsystem	The electronics subsystem consists of the payload flight software and instrument control electronics	Provider: Caltech Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Spacecraft	Spacecraft Bus	Provider: Ball Aerospace Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Telescope	20cm wide-field off-axis all-aluminum telescope	Provider: Ball Aerospace Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Focal Plane Assemblies	The two focal plane assemblies are separated by a dichroic filter to deliver full short and long wavelength coverage	Provider: JPL Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A
Detectors	Each of six detector arrays has its own linear variable filters	Provider: Teledyne Lead Center: JPL Performing Center(s): None Cost Share Partner(s): None	N/A

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REIONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Test Chamber	The non-flight cryogenic test chamber will support two test modes: optical mode with an optical window, and dark mode with a cryogenic integrating sphere	Provider: Korea Astronomy and Space Science Institute (KASI) Lead Center: JPL Performing Center(s): None Cost Share Partner(s): KASI	N/A
Launch Vehicle	Launch vehicle and related launch services	Provider: SpaceX Lead Center: KSC Performing Center(s): None Cost Share Partner(s): None	N/A

Project Risks

Risk Statement	Mitigation
If: The spacecraft bus delivery is delayed, Then: The overall observatory level integration schedule and costs will be impacted.	The SPHEREx project will maintain oversight of the spacecraft bus integration, which is now completed and ready to begin observatory integration in March 2024.
If: The photon shield thermal subsystem delivery is delayed, Then: The overall observatory integration schedule will be impacted.	The photon shields have been delivered and are ready to begin observatory integration in March 2024.

Major Contracts/Awards

Element	Vendor	Location (of work performance)
Observatory integration, spacecraft bus	Ball Aerospace	Boulder, CO
Payload detectors	Teledyne	Thousand Oaks, CA
Payload telescope	Ball Aerospace	Boulder, CO
Launch Vehicle	SpaceX	Hawthorne, CA
PI, CO-Is, Mission Payload	Caltech	Pasadena, CA

SPECTRO-PHOTOMETER FOR THE HISTORY OF THE UNIVERSE, EPOCH OF REIONIZATION, AND ICES EXPLORER

Formulation	Development	Operations

Independent Reviews

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	SRB	Nov 2023	SIR	Successful
Performance	SRB	Sep 2024	Operational Readiness Review	TBD

COMPTON SPECTROMETER AND IMAGER

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**36.5**	**--**	**64.4**	**68.2**	**46.9**	**6.5**	**3.1**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

NASA's COSI gamma-ray astrophysics mission will study both the origin and destruction of matter in our Milky Way galaxy, and antimatter electrons (positrons) coming from the center of the Milky Way galaxy.

PROJECT PURPOSE

The Compton Spectrometer and Imager (COSI) mission will revolutionize our understanding of creation and destruction of matter in the Milky Way Galaxy and beyond. COSI will study gamma rays from radioactive atoms produced when massive stars exploded to map where chemical elements were formed in the Milky Way. The mission will also probe the mysterious origin of our galaxy's positrons, also known as antielectrons – subatomic particles that have the same mass as an electron but a positive charge. The COSI mission benefits from years of technology development with scientific balloon flights.

EXPLANATION OF MAJOR CHANGES IN FY 2025

This budget reflects savings due to a reduced launch vehicle estimate from the launch services provider, which resulted in an overall decrease to the LCC.

PROJECT PRELIMINARY PARAMETERS

COSI is a small Explorer-class gamma-ray Astrophysics mission planned to launch in 2027. It is a three-axis-stabilized spacecraft that NASA will launch into LEO with an orbital inclination of less than five degrees for a baseline two-year science mission. COSI is a wide-field survey gamma-ray detector designed to perform imaging, spectroscopy, and polarimetry of astrophysical gamma-ray sources from a single space platform. The science payload consists of a Compton telescope with 16 cryogenically cooled germanium detectors (GeDs). The GeDs are surrounded by bismuth germanate scintillators that shield the GeDs from high-energy photon and particle background.

COSI will obtain coverage of gamma-ray photons from the entire sky in the 0.2-5 MeV energy range. COSI will have polarization sensitivity for the study of gamma-ray bursts (GRBs) and accreting black holes. COSI will localize GRBs and will rapidly report the positions of short GRBs, which are primarily

COMPTON SPECTROMETER AND IMAGER

Formulation	Development	Operations

caused by merging neutron stars. COSI will also obtain coverage of the regions of the sky where high-energy neutrinos originate.

ACHIEVEMENTS IN FY 2023

COSI successfully completed its Systems Requirements Review (SRR) in January 2023.

WORK IN PROGRESS IN FY 2024

COSI will complete its PDR currently planned for February 2024 and the KDP-C review planned for April 2024.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

In FY 2025, the COSI project will hold CDR in December 2024 and will start payload subsystem fabrication.

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2025 PB Request
SRR	Oct 2022	Jan 2023
PDR	Apr 2023	Feb 2024
KDP-C	Jul 2023	Apr 2024
CDR	Apr 2024	Dec 2024
Launch	CY 2026	CY 2027

Formulation Estimated LCC Range and Schedule Range Summary

LCC estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (KDP-C), which follows a non-advocate review and/or PDR.

KDP-B Date	Estimated LCC Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Sep 2022	267- 294	LRD	Q3 FY 2027- Q1 FY 2028

COMPTON SPECTROMETER AND IMAGER

Formulation	Development	Operations

Project Management & Commitments

University of California at Berkeley (UCB) is the location of the COSI Principal Investigator and the COSI Project Office. GSFC is the Technical Authority for the COSI mission and provides overall program management for all Explorers missions.

Element	Description	Provider Details
Payload integration	Integration and test of all payload subsystems	Provider: Space Dynamics Laboratory Lead Center: N/A Performing Center(s): none Cost Share Partner(s): none
Payload	Payload detector readout system, anticoincidence shields	Provider: Naval Research Laboratory Lead Center: N/A Performing Center(s): none Cost Share Partner(s): none
Payload	Payload cryostat, radiators heat removal system	Provider: GSFC Lead Center: N/A Performing Center(s): none Cost Share Partner(s): none
Spacecraft	Spacecraft bus	Provider: Northrop Grumman Space Systems Lead Center: N/A Performing Center(s): none Cost Share Partner(s): none
Observatory integration	Integration of payload and spacecraft bus, testing of combined payload and bus.	Provider: Northrop Grumman Space Systems Lead Center: N/A Performing Center(s): none Cost Share Partner(s): none

Project Risks

Risk Statement	Mitigation
If: The payload germanium detector development schedule is delayed, Then: overall payload integration schedule will be impacted.	Currently the COSI project has multiple parallel path vendors working to develop the 16 flight germanium detectors on schedule. Moreover, a mix of germanium detectors from the different vendors is operationally feasible for the payload.

COMPTON SPECTROMETER AND IMAGER

Formulation	Development	Operations

Acquisition Strategy

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Observatory integration, spacecraft bus	Northrop Grumman Space Systems	Dulles, VA
Payload integration	Space Dynamics Laboratory	North Logan, UT
Payload detector readout system, anticoincidence shields	Naval Research Laboratory	Washington, D.C.

INDEPENDENT REVIEWS

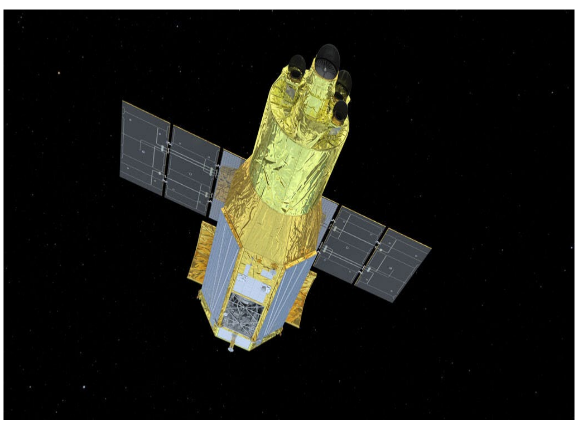
Review Type	Performer	Date of Review	Purpose	Outcome
Performance	SRB	Jan 2023	SRR	Successful
Performance	SRB	Feb 2024	PDR	TBD
Performance	SRB	Dec 2024	CDR	TBD
Performance	SRB	Sep 2026	SIR	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Astrophysics Explorer Science	0.0	--	**2.7**	3.2	4.8	6.3	8.5
Astrophysics Probes Future Missions	0.0	--	**12.5**	22.4	120.0	198.1	298.0
Pioneers	26.5	--	**17.1**	35.0	40.2	40.2	41.9
Contribution to ARIEL Spectroscopy of Ex	6.6	--	**4.0**	2.2	2.9	3.2	3.7
Astrophysics Explorer Future Missions	6.7	--	**51.6**	83.2	144.0	184.2	174.7
Astrophysics Explorer Program Management	13.7	--	**19.2**	14.7	18.2	17.4	10.7
Neutron Star Interior Composition Explor	4.0	--	**4.5**	0.0	0.0	0.0	0.0
Neil Gehrels Swift Observatory	5.6	--	**6.0**	0.0	0.0	0.0	0.0
Nuclear Spectroscopic Telescope Array	6.9	--	**9.6**	0.0	0.0	0.0	0.0
Transiting Exoplanet Survey Satellite	18.7	--	**13.5**	0.0	0.0	0.0	0.0
Galactic/Extragalactic ULDB Spectroscopi	1.7	--	**0.0**	0.0	0.0	0.0	0.0
Imaging X-Ray Polarimetry Explorer	6.8	--	**7.0**	0.0	0.0	0.0	0.0
X-Ray Imaging and Spectroscopy Mission	11.4	--	**18.7**	17.4	2.0	0.0	0.0
Total Budget	**108.7**	**--**	**166.3**	**178.0**	**332.1**	**449.4**	**537.5**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



The X-ray Imaging and Spectroscopy Mission (XRISM) is a JAXA/NASA collaboration, with ESA participation. The objective is to investigate X-ray celestial objects in the universe with high-throughput, high resolution spectroscopy. XRISM launched in Japan on September 7, 2023 from Tanegashima Space Center.

Mission Planning and Other Projects

Astrophysics Explorer Other Missions and Data Analysis includes funding for small missions in formulation and development for the Contribution to ARIEL Spectroscopy of Exoplanets (CASE), Pioneers, operating missions (IXPE, TESS, Neutron Star Interior Composition Explorer [NICER], NuSTAR, Neil Gehrels Swift Observatory, XRISM), and funding for future mission selections and program management functions.

ASTROPHYSICS PROBE FUTURE MISSIONS

NASA released an Announcement of Opportunity (AO) for an Astrophysics Probe mission in July 2023 as recommended by the Astro2020 Decadal Survey "Pathways to Discovery in Astronomy Astrophysics for the 2020s." The first Astrophysics Probe will be one of two mission themes recommended by the Decadal Survey: either a far infrared imaging or spectroscopy probe or an X-ray probe. Principal Investigators (PI) will lead the Astrophysics Probe missions. Proposals were due November 2023, and NASA will make selections using AO acquisition process.

ASTROPHYSICS PIONEERS

Astrophysics Pioneers investigations will provide high-impact science with low cost via the use of new and inexpensive SmallSat and CubeSat technologies, new Ultra-Long Duration stratospheric balloon payloads, and ISS payloads. The Astrophysics Pioneers program element solicits proposals annually for astrophysics suborbital and modest orbital science investigations that are greater in cost and scope than what is possible within the Astrophysics Research and Analysis (APRA) program element, but smaller in cost and scope than those allowed in the Astrophysics Explorer Mission of Opportunity (MO) element. This class of small missions fills the gap between existing ROSES investigations and MO investigations. Each investigation is managed by a PI and is cost capped at $20 million; NASA encourages new and early career researchers to participate. In 2021, NASA announced the selection of the first four Pioneers projects. NASA reduced Pioneers budget because of constraints in the FY 2025 request, which will result in deferred selections for one year. First time PIs lead all five investigations:

- Payload for Ultrahigh Energy Observation (PUEO) is a long duration balloon instrument for particle astrophysics at the highest energies. LRD is scheduled for NET December 2025
- Pandora is a SmallSat for multiwavelength characterization of exoplanets and their host stars. LRD is scheduled for NET March 2025
- Aspera is a SmallSat to measure the intergalactic medium inflow/outflow from galaxies. LRD is scheduled for NET October 2025
- StarBurst is a SmallSat all-sky monitor for high-energy gamma rays from events such as the merger of neutron stars -- events that can be synchronized with the detection of simultaneous gravity waves at facilities such as the ground-based Laser Interferometer Gravitational-wave Observatory (LIGO). LRD is scheduled for NET January 2027
- Trans-Iron Galactic Recorder for the International Space Station (TIGERISS) is designed for deployment from the ISS to measure ultra-heavy galactic cosmic rays. LRD is scheduled for NET September 2026

Recent Achievements

PUEO, Pandora, and Aspera held CDRs in FY 2023. TIGERISS held the Systems Requirements Review (SRR)/Mission Definition Review (MDR) in FY 2023. StarBurst continues to work towards CDR in early calendar year 2024.

CONTRIBUTION TO ARIEL (ATMOSPHERIC REMOTE-SENSING INFRARED EXOPLANET LARGE-SURVEY MISSION) SPECTROSCOPY OF EXOPLANETS (CASE)

ARIEL is a joint ESA/NASA mission planned for launch in late 2029 that will observe hundreds of warm transiting gas giants, Neptune-sized planets, and super-Earths. The mission responds to high-priority science from the Astro2020 Decadal Survey by addressing the question: "What are the characteristics of planetary systems orbiting other stars and do they harbor life?”

OTHER MISSIONS AND DATA ANALYSIS

ARIEL's main science goals include measuring the composition and structure of planetary atmospheres, determining the vertical and horizontal temperature structure, and identifying chemical processes at work. A mission designed and optimized for a large-scale, uniform spectroscopic survey of transiting exoplanet atmosphere will address a key gap in NASA's exoplanet exploration mission portfolio. CASE will fill that gap and ensure the full participation of the U.S. community in ESA's ARIEL mission. The CASE project hardware contribution to ARIEL is a pair of heritage sensor chip assemblies, cold front-end electronics, and cryogenic flex cables together with packaging and thermal management capability. CASE is currently in its development phase and is working with the European ARIEL consortium partners in implementing the NASA/CASE hardware contributions.

Recent Achievements

The mission completed its KDP-C milestone review in February 2023 and is now in phase C of development. All the hardware and detector development are on schedule without any issues. The precursor science analysis begins in the 2024 to 2025 timeframe using mission data simulations and archive datasets. This will prepare the science community when the real data is available post launch.

ASTROPHYSICS EXPLORER FUTURE MISSIONS

Astrophysics Explorer Future Missions funding supports future Astrophysics Explorer missions and MO through concept studies and selections. The goal is to release four AO solicitations within a decade. The next AO is expected in March 2025.

Recent Achievements

NASA expects to down-select a MIDEX mission to continue to implementation in early 2024 between the two missions that are currently in Phase A: Ultraviolet Explorer (UVEX) or Survey and Time-domain Astrophysical Research eXplorer (STAR-X).

ASTROPHYSICS EXPLORER SCIENCE

This project funds competed science and related scientific activities conducted with data from Astrophysics Explorer missions.

ASTROPHYSICS EXPLORER PROGRAM MANAGEMENT

Astrophysics Explorer program management provides programmatic, technical, and business management of ongoing missions in formulation and development. This function provides the independent assessment of astrophysics projects for life cycle reviews and KDPs per NASA Program and Project Management policy. It also provides independent software verification and validation for astrophysics projects in later development. It provides programmatic, technical, and business management assessments and analysis to support projects to ensure they have proper requirements, guidance, and resources. The project also includes support for the Science Office for Mission Assessments (SOMA) at LaRC. SOMA is responsible for the technical and scientific evaluation of Explorer mission proposals.

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

NEUTRON STAR INTERIOR COMPOSITION EXPLORER (NICER)

The NICER instrument launched on June 3, 2017, to an external logistics carrier on ISS for an 18-month prime mission. Its main goal is spectroscopic X-ray observations of neutron stars with high-time resolution, to measure their masses and radii precisely and thus to test models of how matter behaves at extreme densities. NICER's operational flexibility enables it to play the role of X-ray sensor for coordinated campaigns spanning the electromagnetic spectrum with telescopes around the world and in space (including the James Webb Space Telescope [Webb]) targeting a variety of cosmic phenomena. The 2022 Senior Review of Operating Missions approved extended mission operations through FY 2025 to include additional cycles of the NICER Guest Observer (GO) program element. NASA will conduct the next Senior Review in the Spring of 2025.

Recent Achievements

Working with JAXA and the ISS Program, the NICER team developed the Orbiting High-energy Monitor Alert Network (OHMAN), a software payload running on an internal ISS laptop that connects NICER with JAXA's MAXI payload, which scans the x-ray sky for transient phenomena. OHMAN provides an automated mechanism for prompt (within a few minutes) triggering of NICER observations of such transients. The combined capability represents a realization, within Astrophysics,of the ISS-as-laboratory concept, linking distinct instruments to create a new tool that enables novel science.

Among neutron stars, which are the most powerful magnets in the universe, those with exceptionally strong magnetic fields — trillions of times that of the Earth — are known as "magnetars." Through recent multiwavelength observing programs, NICER data have enabled unique demonstrations of correlated behavior across radio and x-ray emissions in two magnetars, revealing that "starquakes" temporarily alter a neutron star's powerful magnetosphere by releasing large quantities of energetic plasma, which comb magnetic field lines and clear a path for particle flows that may be responsible for the still-enigmatic "fast radio burst" phenomenon.

A similar process of energy release through magnetic rearrangement occurs in Sun-like stars, and NICER studies of stellar flares continue to inform our expectations of the habitability of planets around other stars. Most importantly, NICER has measured the radiation content and overall energetics of flares from "young solar analogue" stars, those that resemble our Sun but are much younger, refining our understanding of the radiation environment in which life originated on Earth.

NEIL GEHRELS SWIFT OBSERVATORY

The Neil Gehrels Swift Observatory (Swift) remains NASA's premier mission for prompt and accurate localization of gamma-ray bursts and rapid response x-ray and ultraviolet follow-up observations of transient sources requested by the astronomical community. Swift is a multi-wavelength space-based observatory uniquely equipped to make rapid-response observations to fast-breaking events. The observatory measures the position, brightness, and physical properties of gamma-ray bursts, and is revolutionary in allowing scientists to solve the mystery of their origin in the formation of stellar-mass black holes. The observatory continues to target gamma-ray burst science, while also using its capabilities to increase our understanding of the entire transient universe, ranging in distance from the solar system to high-redshift quasars, and in time from the present to the epoch of reionization. Swift is a MIDEX class mission that launched in 2004 and is currently in extended mission operations. The 2022 Senior Review of Operating Missions approved extended mission operations through FY 2025. NASA will conduct the next Senior Review in the Spring of 2025.

Recent Achievements

The 2022 Senior Review panel deemed Swift as the top ranked satellite among the operating missions, other than Hubble and Chandra. The 2020 Decadal Survey in Astronomy strongly endorsed continued operations of Swift. Science highlights from the last year include the discovery of a star torn apart on repeated orbits around a distant supermassive black hole (a repeating tidal disruption event). Swift is conducting sensitive searches for x-ray and UV counterparts to gravitational-wave detections, continuing its history of breakthrough discoveries in multi-messenger astronomy.

NUCLEAR SPECTROSCOPIC TELESCOPE ARRAY (NUSTAR)

Launched in June 2012, NuSTAR completed its prime mission in July 2014 and is now in extended mission operations. NuSTAR enables scientists to locate supermassive black holes in other galaxies, study extreme accretion onto neutron stars, locate and examine the remnants of collapsed stars in our galaxy and the nearby universe, and observe any new supernovae in the local group of galaxies. NuSTAR's key science products are sensitive x-ray maps of the celestial sky at a higher energy band than any other focusing x-ray satellite. NuSTAR offers opportunities for a broad range of science investigations, ranging from probing cosmic ray origins and studying the extreme physics around collapsed stars to mapping microflares on the surface of the Sun. NuSTAR performs key follow-up observations of sources found by NASA's Chandra, Spitzer, and Wide-field Infrared Survey Explorer (WISE) satellites. The NuSTAR mission implemented a GO program in 2015. NuSTAR is now conducting the observations selected under Cycle 8 of the GO program. The project coordinates some NuSTAR observations with other missions, including Swift, Chandra, The International Gamma-Ray Astrophysics Laboratory (INTEGRAL), XMM-Newton, and NICER. Such coordinated observations take advantage of NuSTAR's unique access to high-energy x-rays with synergistic lower-energy x-ray capabilities of these other missions, such as NICER's exquisite x-ray timing, Chandra's high spatial resolution imaging, and Swift's agility for rapidly slewing across the sky to monitor variable sources. The 2022 Senior Review of Operating Missions approved extended mission operations through FY 2025. NASA will conduct the next Senior Review in Spring of 2025.

Recent Achievements

NASA’s NuSTAR has been operating for over 11 years. NuSTAR now regularly coordinates observations with multiple observatories with the proportion of NuSTAR observations that are performed simultaneously with one, and often more than one observatory, now over 50 percent. Besides coordination with ground- and space-based telescopes such as the Keck telescopes in Hawaii, NASA’s Chandra X-ray Observatory, and NASA’s Neil Gehrels Swift Observatory, NuSTAR began coordinated observations with the newest astrophysics x-ray observatory in 2023, JAXA/NASA’s X-Ray Imaging and Spectroscopy Mission (XRISM).

The majority of observations performed by NuSTAR are of compact objects, like black hole or neutron star binary systems and active galactic nuclei, but recently NuSTAR observed DS TucA, a nearby, young star that is an analog of the early Sun. Analysis of NASA’s Transiting Exoplanet Survey Satellite (TESS) survey data has confirmed the presence of a Neptune-sized planet orbiting this star and recent observations by ESA’s XMM-Newton and NASA’s NICER have detected bright, soft x-ray flares along with increased UV emission, possibly associated with coronal mass ejections impacting the exoplanet's atmosphere. This system is then an ideal proxy for the infant Solar System, at an epoch where the Earth's atmosphere transitioned from the primary to the secondary nitrogen- and carbon dioxide-rich atmosphere. Understanding the nature of the X-ray flares will provide valuable information about exoplanet environments as well as the role of stellar magnetic activity in the early solar system. This NuSTAR observation was part of the first multi-wavelength measurement of powerful flares in a young Sun-like star, with coordinated observations by NICER, NASA's Hubble Space Telescope, and TESS along with ground-based measurements at the Anglo-Australian Telescope, the Australia Telescope Compact Array, and the Murchison Widefield Array.

TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

The TESS mission launched on April 18, 2018, and completed its prime mission on July 4, 2020. TESS is performing an all-sky survey to search for planets transiting nearby stars. TESS monitors the sky with four wide-field visible-light cameras to detect periodic drops in brightness caused by planets passing in front of their stars. TESS is designed to survey over 85 percent of the sky (an area of sky 400 times larger than covered by Kepler) to search for planets around nearby stars (within approximately 200 parsecs). TESS stars are typically 30 to 100 times brighter than those surveyed by the Kepler satellite. Planets detected around these stars are far easier to characterize with follow-up observations, resulting in refined measurements of planet masses, sizes, densities, and atmospheric properties. By finding planets smaller than Neptune that transit stars bright enough to enable follow-up, TESS provides prime targets to learn about the composition and atmospheric properties of planets beyond the solar system

TESS also obtains full-frame images of the entire field-of-view (24 by 96 degrees), originally at a cadence of 10 minutes and now at a cadence of 200 seconds. For a subset of preselected targets, TESS collects data at a higher time-resolution of one image every 120 seconds or 20 seconds. These data collection modes enable a broader range of science investigations. In FY 2024, TESS will observe for three months along the ecliptic plane, then will begin a third survey of the northern ecliptic hemisphere. In FY 2025, TESS will wrap up its third northern ecliptic survey, and begin a fourth southern ecliptic survey, with another visit to the ecliptic plane as well. By the end of the second extended mission, TESS is projected to have collected data for about 97 percent of the sky (and visited at least 84 percent of the sky twice).

The 2022 Senior Review of Operating Missions approved extended mission operations through FY 2025. NASA will conduct the next Senior Review in the Spring of 2025.

Recent Achievements

TESS began its second extended mission in FY 2023 with a new observing cadence of 200 seconds for its full-frame images to enable a broader range of science investigations than was possible before. During its extended observations, TESS is discovering all types of objects that change in brightness, from exoplanets to asteroids to pulsating stars and distant galaxies containing supernovae.

To date, TESS has discovered 136 small (less than 2.5 times the radius of Earth) exoplanets, with 41 of these confirmed during FY 2023. TESS has now discovered nearly 6,800 planet candidates in total, with 392 planets (of all sizes) confirmed so far. TESS has a direct synergy with Webb that is projected to remain strong through FY 2025 and beyond. In FY 2023, around 25 TESS-discovered exoplanets were observed in the first year of Webb's science observations. In FY 2024, 32 TESS-discovered exoplanets will be observed by Webb, an increase over the previous year. Webb will search for evidence of water, carbon dioxide, methane, and other molecules in these planets' atmospheres. Research publications based on TESS data now exceed 1,500 peer-review publications. The rate of new publications using TESS data is accelerating and is trending to far exceed 2,000 by the end of FY 2024, covering topics ranging from solar system to supernovae science.

THE IMAGING X-RAY POLARIMETRY EXPLORER (IXPE)

NASA selected IXPE, a Small Explorer-class (SMEX) mission, in January 2017 and launched in December 2021. Due to the hundred-fold improvement in the sensitivity of X-ray polarimeters during the past two decades, IXPE will enable astrophysicists to open an important new field of investigation into some of the most extremely unusual objects found in the universe. IXPE is examining polarized x-ray emissions from both galactic and extragalactic x-ray sources, such as active galactic nuclei, blazars, pulsars, pulsar wind nebulae, magnetars, accreting x-ray binaries, supernova remnants, and the Galactic Center. These observations have allowed the investigation of general relativistic and quantum effects in the extreme environment associated with these sources and will significantly improve our understanding of fundamental physics. IXPE completed its two-year prime mission in 2023; NASA has approved continued operations through FY 2025.

Recent Achievements

IXPE successfully completed its Mission Success Performance Review, thereafter NASA HQ approved a 20-month mission extension through the end of September 2025.

In FY 2023, IXPE performed a total of 61 observations of 44 sources. Before IXPE, there had been only one source with a secure x-ray polarization detection---namely, the Crab nebula 45 years ago. IXPE has detected sources such as accreting neutron stars and black holes, magnetars, pulsar wind nebulae, supernova remnants, and active galactic nuclei. The IXPE data and analysis tools are publicly available. A total of 43 papers reporting science observations have been published by the IXPE team and outside groups. In June 2023, NASA released the call for proposals for IXPE General Observer Cycle 1. The team organized a Pre-Proposal Workshop that was well attended. IXPE will continue to perform prime mission observations per its publicly available Long-Term Plan and approved Targets of Opportunity through January 2024. Thereafter, IXPE will transition to observations of targets selected in the General Observer Program proposal review.

IXPE continues to refine its operations. IXPE completed the transition to delivering automated daily ephemeris products to Conjunction Assessment Risk Analysis (CARA) for conjunction assessments. The transition to GPS-based orbit determination, expected to complete in FY 2024, will eliminate reliance on Space Track for ephemeris products. The project has initiated a study, scheduled to complete in early FY 2024, to identify options for maximizing battery life. NASA reduced instrument heater set points and will assess and implement other options in early FY 2024 to reduce battery depth of discharge during eclipses. The IXPE Science Operations Center updated their calibration process using new software tools.

THE X-RAY IMAGING AND SPECTROSCOPY MISSION (XRISM)

The X-ray Imaging and Spectroscopy Mission (XRISM), previously named XARM, is a joint NASA and JAXA mission that will recover the soft x-ray spectroscopic capability lost with the Hitomi mission that ended in March 2016. The key scientific objective of XRISM is to investigate celestial x-ray objects in the universe with unprecedented high-resolution x-ray spectroscopy. XRISM will provide breakthrough science in several areas, including structure and formation of the universe, the evolution of clusters of galaxies, and the transport and circulation of energy in the cosmos. NASA contributed the Resolve Soft X-ray Spectrometer and many of its subsystems and the x-ray mirror assemblies for the observatory.

OTHER MISSIONS AND DATA ANALYSIS

NASA is also responsible for the Science Data Center, which has developed the analysis software for all instruments, the data processing pipeline, as well as support of GO.

Recent Achievements

The XRISM team successfully passed its KDP-E milestone on July 25, 2023, and was approved to move into Phase E. JAXA and NASA launched XRISM on September 7, 2023, from the Tanegashima Space Center, Japan. The XRISM spacecraft began commissioning operations in September 2023 and all operations are proceeding nominally. Commissioning activities are expected to be complete by the end of January 2024 with a transition of operations expected to be complete by February 2024. Performance verification observations will be performed over the following six months followed by the prime mission program which is completely open to the community through the GO program. The AO for those GO observations was issued in late November 2023 with selections expected in summer of 2024.

HELIOPHYSICS

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Heliophysics Research	238.2	--	**252.3**	247.7	255.8	257.8	258.5
Living with a Star	155.2	--	**107.7**	100.1	112.1	106.3	101.4
Solar Terrestrial Probes	198.0	--	**133.2**	82.9	64.9	56.1	38.1
Heliophysics Explorer Program	167.9	--	**236.7**	309.4	325.4	355.4	385.4
Space Weather	25.8	--	**47.5**	42.6	40.0	35.9	34.2
Heliophysics Technology	19.9	--	**9.3**	9.2	8.8	8.8	15.8
Total Budget	**805.0**	**--**	**786.7**	**791.9**	**807.0**	**820.3**	**833.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Heliophysics

HELIOPHYSICS RESEARCH

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Heliophysics Research and Analysis	62.3	--	**65.0**	64.7	65.0	63.5	64.8
Sounding Rockets	60.4	--	**75.3**	69.2	74.2	69.5	69.2
Research Range	32.8	--	**24.5**	27.3	27.3	33.1	27.8
Other Missions and Data Analysis	82.8	--	**87.5**	86.5	89.4	91.8	96.7
Total Budget	**238.2**	**--**	**252.3**	**247.7**	**255.8**	**257.8**	**258.5**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Sun, a typical medium star midway through its life, governs the solar system. The Sun wields its influence through its gravity, radiation, solar wind, and magnetic fields, all of which spread out through the heliosphere, interacting with other planets, the Earth, and its space environments to produce space weather, which can affect human technological infrastructure and activities. Heliophysics seeks to understand the Sun, heliosphere, and planetary space environments as a single connected system to answer these fundamental questions:

- How and why does the Sun vary?
- How do Earth and the heliosphere respond to the Sun's changes?
- How do the Sun and the solar system interact with the interstellar medium?
- How do these processes affect human activities?

Shown here is the successful launch of the Dissipation experiment, launched from Poker Flats, AK in November 2023. The experiment provided, for the first time, comprehensive and concurrent in-situ measurements of the response of the thermosphere to Joule heating in the auroral transition region.

The Heliophysics Research program supports a wide variety of activities in support of these questions including:

- Investigations of the Sun, including processes taking place throughout the solar interior and atmosphere and the evolution and cyclic activity of the Sun.
- Investigations of the origin and behavior of the solar wind, energetic particles, and magnetic fields in the heliosphere and their interaction with Earth and other planets, as well as with the interstellar medium.
- Investigations of the physics of magnetospheres, including fundamental interactions of plasmas and particles with fields and waves, and coupling to the solar wind and ionospheres.
- Investigations of the physics of the terrestrial mesosphere, thermosphere, and ionosphere, including the coupling of these phenomena to the lower atmosphere and magnetosphere.

HELIOPHYSICS RESEARCH

EXPLANATION OF MAJOR CHANGES IN FY 2025

The request includes additional funding for Sounding Rockets in order to cover increased domestic and international campaign requirements. Additional funding within R&A will support additional Space Weather research activities at GSFC. Finally, the cadence and rate of the selection of CubeSats has been set at two new CubeSats per year.

ACHIEVEMENTS IN FY 2023

In FY 2023, NASA selected new awards solicited in Research Opportunities in Space and Earth Science (ROSES) 2021 and 2022, including continued research within solar studies, magnetospheric studies, solar wind studies, and investigations of the uppermost regions of the Earth's atmosphere and how they interact with the space environment. Heliophysics selected and funded 146 research projects through the ROSES 2022 program elements.

Scientists made important contributions to the study of solar jets, bursts of gas escaping from the Sun, through a project to build a database of solar jets using classifications by volunteers using more than a decade of NASA's Solar Dynamics Observatory data. After analyzing almost 10,000 subjects, scientists can use a new catalogue of 881 jets with precise information on their timing, position, and extent. NASA will use this data as a great training set to see if we can use machine learning to detect jets in extreme ultraviolet observations.

Within Magnetospheric studies, researchers have completed a large-scale simulation of how the Sun's magnetic field emerges from its interior that specifically examines two spectral lines of Magnesium II. These two lines are among the best diagnostic tools of the upper solar chromosphere. Their results show models with a much-improved correspondence with observations from the Interface Region Imaging Spectrograph (IRIS) spacecraft, demonstrating the importance of the distribution and amount of mass in the chromosphere, and of capturing the shape and evolution of the magnetic field in simulations. The evolution of the solar magnetic field(s) is a key ingredient in understanding solar activity and its impact on Earth, including flares and Coronal Mass Ejections.

Solar wind research elements focus on the study of high-speed flow of charged particles that starts in the Sun's atmosphere and expand outwards. The Parker Solar Probe spacecraft has now entered and exited slow-moving coronal-like plasma more than 400 times, providing statistics that appear to be consistent with this prediction.

Scientists revealed that dust collected in Earth's atmosphere shows an unexpected 22-year cycle, suggesting it is related to the solar cycle over which the number of sunspots and the amount of solar activity vary. This relationship highlights the complex physics connecting the Sun, Earth, and the interplanetary environment.

The FY 2023 sounding rockets manifest featured eight NASA missions that launched from Wallops Flight Facility (WFF), White Sands Missile Range, Poker Flat Research Range, and Norway. These missions covered five disciplines: Astrophysics, Solar Physics, Geospace Science, Education, and Technology.

Heliophysics supported the formulation and development of nine CubeSats and five instrument activities during FY 2023 which will launch in future years to support low-cost access to space and a test bed for science and future scientific discoveries.

HELIOPHYSICS RESEARCH

WORK IN PROGRESS IN FY 2024

In FY 2024, NASA will select new awards solicited in ROSES 2023, including continued research within solar studies, magnetospheric studies, solar wind studies, and investigations of the uppermost regions of the Earth's atmosphere and how they interact with the space environment. New proposals in all these areas will be solicited through the ROSES 2024 call.

During the upcoming year, NASA's growing portfolio of participatory science projects will invite the public to participate in the "Heliophysics Big Year" of participation around the two solar eclipses crossing the Americas as well as solar maximum science. The Heliophysics Big Year is a global celebration of an extraordinary ordinary star with the science and information accessible to all. Participatory science projects around the eclipse include four different tasks imaging the Sun and rare visible solar corona with different levels of technology ranging from cell phones to telescopes with specialized equipment.

Heliophysics is continuing with the three Heliophysics Diversify, Realize, Integrate, Venture, Educate (DRIVE) initiatives as part of the integrated research program element throughout FY 2024:

- DRIVE Science Center 1: Consequences Of Fields and Flows in the Interior and Exterior of the Sun (COFFIES) establishes a collaborative science community to develop comprehensive models of solar dynamics that will substantially improve the physical understanding of the ways internal plasma flows affect the origin and evolution of magnetic activity cycles of the Sun and stars like it.
- DRIVE Science Center 2: The Center for Geospace Storms's (CGS's) vision is to transform the understanding and predictability of space weather. This center will pursue innovation, empowerment, and discovery to improve space weather modeling and research.
- DRIVE Science Center 3: Solar wind with Hydrogen Ion charge Exchange and Large-Scale Dynamics's (SHIELD's) purpose is to understand the nature and structure of the heliosphere.

The current FY 2024 sounding rockets mission manifest features 16 missions flown on 23 rockets from various locations in the United States and Kwajalein Atoll. Included in this manifest is a successfully completed campaign of three launches from White Sands Missile Range during the annular eclipse in October 2023, an upcoming solar flare campaign comprised of three missions from Poker Flat Research Range in March 2024, and a campaign of three launches from WFF during the total solar eclipse in April 2024.

The Solar Orbiter Guest Investigators (SO-GI) Program element solicits proposals focused on analysis of data from the Solar Orbiter mission. Solar Orbiter is a mission of international cooperation between NASA and ESA. NASA intends to maximize the scientific return from the mission by providing support for research beyond the scope of work of the mission science teams. NASA will name Principal Investigators (PIs) and Co-Investigators (Co-Is) from selected proposals (e.g., Guest Investigators of Solar Orbiter) for the duration of the award and invite them to attend and present progress at Solar Orbiter team meetings. The evaluation of proposals to this program will take place in January of 2025, and NASA will make selections in March of 2025.

Heliophysics, in collaboration with Korea Astronomy and Space Science Institute, is developing a next-generation coronagraph instrument called Coronal Diagnostic Experiment (CODEX), that will be mounted on ISS with a launch scheduled in FY 2024.

NASA plans on launching four CubeSats in FY 2024:

- The Relativistic Electron Atmospheric Loss (REAL);

- CUbesat Radio Interferometry Experiment (CURIE);
- Dione - A pathfinder mission for understanding the ionosphere-thermosphere responses to magnetospheric forcing; and
- Atmosphere Effects of Precipitation through Energetic X-rays CubeSat mission (AEPEX).

KEY ACHIEVEMENTS PLANNED FOR FY 2025

NASA will select new awards solicited in ROSES 2023 and 2024, including continued research within solar studies, magnetospheric studies, solar wind studies, and investigations of the uppermost regions of the Earth's atmosphere.

NASA will conclude its activities in the Heliophysics Big Year with the celebration of the Parker Solar Probe's closest approach to the Sun in December of 2024.

NASA will continue to develop and refine the Artificial Intelligence and Machine Learning (AI/ML) capabilities available to the Heliophysics community for data processing of mission science information. Awards will be made within a new element in the R&A program: the Research and Development of Initiatives of Advanced New Technologies (RADIANT). RADIANT is a cross-cutting initiative whose strategic goals relate to all areas of NASA heliophysics research, including but not limited to the Sun, space weather, magnetosphere, ionosphere, thermosphere, mesosphere, inner and outer heliosphere. RADIANT will address critical aspects of developing the next generation of AI/ML enabled science, technology, and discovery.

The current sounding rockets mission manifest features nine missions flown on 13 rockets in FY 2025 from various locations in the United States and Norway.

The Research Range will begin refurbishment efforts of the existing RADAR 18 at WFF as well as scope the requirements for a mobile C-Band telemetry asset to replace existing equipment in Poker Flats Research Range in future funding years.

Program Elements

RESEARCH RANGE

The Research Range project provides operations support, maintenance, and engineering for the WFF launch range in support of suborbital, orbital, and aircraft missions conducted on behalf of NASA and DoD. The project also supports NASA technology missions, autonomous aerial vehicle flights, and commercial launch and flight projects.

The range instrumentation includes meteorological, telemetry, radar, command, launch and range control centers, and optical systems. Research Range mobile assets provide range services at other ranges and remote locations around the world.

SOUNDING ROCKETS

NASA's Sounding Rockets project provides suborbital launch vehicles, payload development, and field operations support to NASA suborbital missions within SMD. The approximately 20 suborbital missions flown annually by the project provide researchers with opportunities to build, test, and fly new instrument and sensor design concepts while conducting world class scientific research. The project conducts operations from fixed launch sites such as WFF's Test Range in Virginia, Poker Flat Research Range in Alaska, White Sands Missile Range in New Mexico, and foreign sites such as Andoya Rocket Range in Norway and Esrange in Sweden.

With the capability to fly higher than many LEO satellites and the ability to launch on demand, sounding rockets often offer the only means to study specific scientific phenomena of interest to many researchers. Sounding rockets can place instruments directly into regions where and when the science is occurring to enable direct, in-situ measurements. The mobile nature of the project enables researchers to conduct missions from strategic vantage points worldwide. To study solar and astrophysics phenomena, telescopes and spectrometers fly on sounding rockets to collect unique science data and test prototype instruments for future satellite missions.

HELIOPHYSICS RESEARCH AND ANALYSIS

The Heliophysics Research and Analysis project supports basic research, solicited through NASA's annual ROSES announcements. It supports investigations in all research areas of Heliophysics. The investigations emphasize the understanding of fundamental processes and interconnections across the traditional science disciplines, on a broad range of spatial and temporal scales. The project also supports investigations focused on processes that create space weather events, and investigations to enable a capability for predicting future space weather events.

Heliophysics supporting research and theory, modeling, and simulation are essential for mission research data collected between the outer edge of the Earth's atmosphere and the interaction of the Sun and solar wind with the local galactic environment (currently explored by Voyager). The DRIVE science center element supports large principal-investigator proposed team efforts, which require a critical mass of interdisciplinary expertise, to make significant progress in understanding complex physical processes with broad importance.

Program Schedule

NASA implements the Heliophysics Research program via a competitive selection process. NASA releases research solicitations each year through the ROSES NASA Research Announcements (NRA).

Date	Significant Event
Q1 FY 2024	ROSES-2023 selection within six to nine months of receipt of proposals
Q2 FY 2024	ROSES-2024 solicitation
Q1 FY 2025	ROSES-2024 selection within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation
Q1 FY 2026	ROSES-2025 selection within six to nine months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation
Q1 FY 2027	ROSES-2026 selection within six to nine months of receipt of proposals
Q2 FY 2027	ROSES-2027 solicitation

HELIOPHYSICS RESEARCH

Date	Significant Event
Q1 FY 2028	ROSES-2027 selection within six to nine months of receipt of proposals
Q2 FY 2028	ROSES-2028 solicitation
Q1 FY 2029	ROSES-2028 selection within six to nine months of receipt of proposals
Q2 FY 2029	ROSES-2029 solicitation

Program Management & Commitments

Program Element	Provider
Research and Analysis	Provider: HQ Lead Center: HQ Performing Centers: GSFC, MSFC, JPL, LaRC, JSC, ARC Cost Share Partners: None
Sounding Rockets	Provider: GSFC Lead Center: HQ Performing Center: GSFC Cost Share Partners: None
Research Range	Provider: GSFC Lead Center: HQ Performing Center: GSFC/WFF Cost Share Partners: None

Acquisition Strategy

NASA issues solicitations for competed research awards each February in the ROSES NRAs. To the widest extent possible, NASA fully and openly competes all new acquisitions. Proposals are peer-reviewed and selected from the annual ROSES announcement. Universities, government research laboratories, and industry, throughout the United States, participate in research projects.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Sounding Rocket Operations	Peraton	Wallops Island, VA

HELIOPHYSICS RESEARCH

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Relevance	Heliophysics Advisory Committee	2023	To review progress towards Heliophysics objectives in the NASA Strategic Plan	Report is expected to be publicly available in Q2 FY 2024.
Quality	Mission Senior Review Panel	2023	A comparative evaluation of Heliophysics operating missions	Completed in Q4 FY 2023, assessed missions individually and as part of a system observatory
Relevance	Heliophysics Advisory Committee	2024	To review progress towards Heliophysics objectives in the NASA Strategic Plan	TBD
Relevance	Heliophysics Advisory Committee	2025	To review progress towards Heliophysics objectives in the NASA Strategic Plan	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Science Planning and Research Support	7.1	--	**7.1**	7.1	7.1	7.1	7.1
CubeSat	12.9	--	**10.9**	11.5	13.0	15.0	15.0
Solar Data Center	2.6	--	**3.9**	4.6	4.7	4.9	5.0
Data & Modeling Services	5.2	--	**4.0**	4.7	4.9	5.2	5.3
Space Physics Data Archive	3.6	--	**4.0**	4.2	4.4	4.6	5.1
Guest Investigator Program	21.5	--	**25.2**	24.0	24.0	24.0	24.0
Community Coordinated Modeling Center	5.0	--	**4.9**	4.6	4.5	4.5	4.5
Space Science Mission Ops Services	13.7	--	**16.0**	16.3	16.6	16.7	20.7
Voyager	6.5	--	**7.0**	7.2	7.8	7.6	7.6
Solar and Heliospheric Observatory (SOHO)	2.4	--	**2.2**	0.1	0.0	0.0	0.0
Wind	2.3	--	**2.3**	2.3	2.3	2.3	2.3
Geotail	0.1	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**82.8**	**--**	**87.5**	**86.5**	**89.4**	**91.8**	**96.7**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

NASA accumulates, archives, and distributes data collected by the Heliophysics System Observatory, a fleet of operating spacecraft. Combining the measurements from all these observing platforms enables interdisciplinary, connected systems science across the vast spatial scales of our solar system. This collective asset enables the data, expertise, and research results to contribute directly to fundamental research on solar and space plasma physics and to the national goal of real-time space weather prediction. NASA teams support day-to-day mission operations for NASA spacecraft and data analysis to advance the state of space science and space weather modeling. NASA conducts science community-based projects to evaluate research models containing space weather information that is of value to industry and government agencies. Heliophysics data centers archive and distribute the science data from operating missions in the Living With a Star (LWS), Solar Terrestrial Probes (STP) Research, and Explorer programs.

Mission Planning and Other Projects

SCIENCE PLANNING AND RESEARCH SUPPORT

This project supports NASA scientists' participation in proposal peer review panels, Decadal Surveys, and National Academies' studies.

CUBESAT

CubeSats are small spacecraft, built to a standardized form-factor of size and mass, which can launch as secondary or ride-share payloads. With lower development costs per investigation and rapid development cycles, CubeSats can provide frequent science and technology flight opportunities. CubeSats have

OTHER MISSIONS AND DATA ANALYSIS

significant potential to leverage exploratory and systematic science observations at minimal additional cost.

The Heliophysics CubeSat project continues to work on the cross-discipline investigations already underway. In response to the capabilities demonstrated by CubeSat investigations in the initial pathfinder stage, the CubeSat activities expanded in 2019 to take advantage of new science achievable via investigations in the $2 million to $10 million range. The larger investigations will enable the development of remote sensing investigations with more sophisticated CubeSats, as well as small constellations of in-situ CubeSat investigations. Beginning in FY 2025, NASA will select CubeSat activities at the rate of two per year in order to establish a stable and robust cadence of flight opportunities for the proposer community.

Recent Achievements

The CubeSat project successfully launched multiple missions including the following: Scintillation Prediction Observations Research Task (SPORT), Low-Latitude Ionosphere/Thermosphere Enhancements in Density (LLITED), and CubeSat Inner Radiation Belt Experiment (CIRBE).

SPORT deployed from ISS in December 2022 and just recently de-orbited. SPORT measured the state of the ionosphere to study the growth of plasma bubbles and how they influence radio scintillations.

LLITED launched in April 2023 and is measuring small-scale wave fluctuations in the neutral atmosphere and ionosphere to determine the relationship between the neutral wind and the zonal structure.

CIRBE, also launched in April 2023, will provide the first advanced resolution of one of Earth's two Van Allen belts.

The CubeSat project continues to support the formulation and development of the four CubeSats planned for launch in FY 2024.

SOLAR DATA CENTER

The Solar Data Center (SDAC) provides mission and instrument expertise to enable high-quality analysis of solar physics mission data. It provides leadership for community-based, distributed development efforts to facilitate identification of and access to solar physics data, including ground-based coordinated observations via the Virtual Solar Observatory, a research tool that allows scientists to search for solar and heliospheric physics data. SDAC also provides a repository for software used to analyze these data.

Recent Achievements

SDAC continues to support the ever-growing storage and archival needs of the Virtual Solar Observatory.

DATA AND MODELING SERVICES

The Data and Modeling Services project supports missions in extended operations and missions planned for decommissioning, by preparing their data holdings for long-term archival curation. This project also provides for the creation of higher-level data products, which are of significant use to the science community and not funded during the prime mission. Higher-level data products are data that combine results of multiple missions and/or instruments.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

The Heliophysics Data and Modeling project continues strengthening data usability and accessibility through development of the HelioCloud. HelioCloud makes high-value Heliophysics data available in a publicly accessible cloud environment. The project Data and Modeling Services will continue to support the growing dataset and increase user load as well as machine learning activities to support the growth in artificial intelligence.

SPACE PHYSICS DATA ARCHIVE

The Space Physics Data Archive (SPDA) ensures long-term data preservation and online access to non-solar heliophysics science data. It operates key infrastructure components for the Heliophysics Data Environment, including inventory and web service interfaces to systems and data. It also provides unique enabling science data services.

The Heliophysics data archives are growing at an exponential rate. All science disciplines have seen a surge of data holdings over the last decade. As such, conventional storage and retrieval has become impractical. This era of Big Data requires the effective curation and preservation of critical data products. NASA will move beyond a traditional repository and toward a functional, collaborative data library. Over the next several years, NASA will transform the Heliophysics archives, consisting of SPDA and SDAC, into a digital resource library.

Recent Achievements

SPDA continues to add data sets from current and historic missions, along with sounding rocket, balloon, and ground instrument datasets. To support these missions, Space Physics Data Facility (SPDF) maintains an automated data ingest pipeline for more than 75 missions. In addition to data ingest, the project must reprocess legacy mission datasets and often place them into the proper formats. SPDA develops the Common Data Format (CDF) to ensure data usability and accessibility to the science and research community.

GUEST INVESTIGATOR PROGRAM

The Guest Investigator Program maximizes the output of currently operating Heliophysics missions by supporting competitive research investigations, which use data from multiple spacecraft. The Heliophysics division strongly encourages investigations that address global system science since Heliophysics, by nature, is the investigation of a large-scale and complex connected system.

Recent Achievements

The plasma in the outermost layer of the Sun's atmosphere has chemical abundances different from the photosphere due to the physical processes in the lower solar atmosphere (chemical fractionation), so examining these abundances provides insight into the mechanisms regulating the heating and mass supply to the corona. Researchers have used a time series of coordinated observations of a solar active region with the Hinode/ Extreme Ultraviolet (EUV) Imaging Spectrometer and the IRIS spectrographs, observing respectively the corona and the lower solar atmosphere to gain insight into the chemical fractionation processes. Their investigation shows a previously unobserved correlation between observed coronal abundance differences, as derived from Hinode/EUV Imaging Spectrometer coronal spectra, and turbulence in the chromosphere, as derived from IRIS Magnesium II spectra. These observational findings provide new crucial constraints to test models that simulate the physical processes leading to the chemical fractionation in the solar corona.

COMMUNITY COORDINATED MODELING CENTER

The Community Coordinated Modeling Center (CCMC) is a multi-agency partnership that enables and performs the research and development for next generation heliophysics and space weather models. The project provides the United States and international research community access to simulations that enable "runs on demand," using models to study space weather events in near-real time. This allows the comparison of observational data and model parameters during or shortly after solar activity, thereby improving accuracy of the models.

Recent Achievements

CCMC continues to develop and expand forecasting methods by procuring new technologies. It provides a highly skilled team of subject matter experts to support the needs within Heliophysics.

SPACE SCIENCE MISSION OPERATIONS SERVICES

Space Science Mission Operations (SSMO) Services manages the on-orbit operations of GSFC Space Science missions. Services include consistent processes and infrastructure for missions operated at various institutions. SSMO currently manages the following Heliophysics missions: Advanced Composition Explorer (ACE), Aeronomy of Ice in Mesosphere (AIM), Geotail, Interstellar Boundary Explorer (IBEX), Ionospheric Connection Explorer (ICON), IRIS, Magnetospheric Multiscale Mission (MMS), Parker Solar Probe, Solar Dynamics Observatory (SDO), Solar and Heliospheric Observatory (SOHO), Solar Terrestrial Relations Observatory (STEREO), Time History of Events and Macroscale Interactions during Substorms (THEMIS), Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED), and Wind. SSMO Services also sustains an operational multi-mission infrastructure for current and future missions.

Operating Missions

VOYAGER

The Voyager Interstellar Mission is exploring the interaction of the heliosphere and the local interstellar medium. Voyager 1, launched in 1977, is making the first in-situ observations of the region outside the heliosphere from about 158 astronomical units (AU), or 158 times Earth's distance from the Sun, and is traveling at a speed of 3.6 AU per year, or 38,000 miles per hour. Voyager 2 is about 132 AU from the Sun and traveling at a speed of about 34,000 miles per hour, or 3.2 AU per year. Voyager 2 crossed the heliopause, the theoretical boundary where the Sun's solar wind is stopped by the interstellar medium, on November 5, 2018. Its twin, Voyager 1, crossed the heliopause on August 25, 2012, and continues to sail outward through the local interstellar medium. Both spacecraft have sufficient power to operate all instruments until the late 2020s; after this time, the project will turn off the instrument heaters and then the instruments one at a time to extend the useful life of the spacecraft to about 2030. Voyager is currently in extended operations. NASA approved Voyager for continued operations in 2023, and the mission will submit a proposal to the 2026 Senior Review cycle.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

Long-awaited in-situ observations made by the two Voyager spacecraft continue to reveal surprising new insights about the nature of the Very Local Interstellar Medium (VLISM). Since crossing the Heliopause, the Voyagers continue to observe transient disturbances caused by solar activity which propagate through the heliosphere, survive out to the heliopause, and transmit waves into the surrounding interstellar medium. These manifest as abrupt jumps in magnetic field strength, changes in electron plasma density, and variations in cosmic ray intensity – three fundamental properties of the VLISM. Scientists hypothesized the existence of such events in the mid 1980's to early 1990's based upon remotely detected radio emissions observed by the spacecraft from inside the heliosphere. However, juxtaposed to the steady-state ambient processes of VLISM, the extent and nature of these events show that the Sun and its heliosphere interact with and modify the surrounding interstellar medium in unexpected ways.

A recent discovery made by Voyager 1 was the detection of a large pressure front that began around 2020. Unlike prior disturbances, the magnetic field and plasma density increased for over a year, achieving a peak before beginning a gradual decline. However, the latest data from the Plasma Wave Subsystem indicates that the field and plasma have likely not returned to their steady-state conditions; rather, the plasma density remains enhanced at a sustained new level. The nature of the ongoing event is highly unusual and completely unanticipated. The origins of the event and therefore the fundamental causes of the above-described phenomena are a topic of avid investigation but are not yet fully understood.

SOLAR AND HELIOSPHERIC OBSERVATORY (SOHO)

SOHO, launched in 1995, is a joint mission of ESA and NASA, and it has been a dependable solar watchdog, providing the only Earth-Sun line coronagraph images of solar storms. Coronal mass ejections (CME) drive most of the space weather effects in the inner heliosphere. SOHO continues to provide essential early alert space weather observations used as inputs to models that further our understanding of the Sun's effect on the Earth. During its extended mission phase, NASA declared SOHO a national space weather asset. SOHO is currently in extended operations. NASA approved SOHO for continued operations in 2023, and the mission will submit a proposal to the 2026 Senior Review cycle.

Recent Achievements

SOHO continues to monitor incoming conditions that have an impact on life and technology on Earth. SOHO's data continue to be invaluable in space weather studies, playing a vital role in the prediction of potentially dangerous solar storms.

WIND

Wind, launched in 1994, studies the solar wind and its impact on the near-Earth environment. It provides comprehensive measurements of thermal to solar energetic particles, quasi-static fields to high-frequency radio waves, and gamma rays. In particular, the Wind instrument suite provides comprehensive and unique high-time resolution in-situ solar wind measurements that enable the investigation of wave-particle interactions. Wind provides critical measurements of the solar wind and space weather events. Correlating those critical measurements with measurements from the Parker Solar Probe and Solar Orbiter Collaboration (SOC) missions will improve our understanding of these events as they move out from the Sun. These multi-spacecraft measurements constrain models of space weather events and improve their predictive capabilities. Wind is also the only near-Earth spacecraft equipped with radio

OTHER MISSIONS AND DATA ANALYSIS

waves instrumentation. The Radio and Plasma Wave (WAVES) experiment measures electric and magnetic fields to reveal wave phenomena in the solar wind. WAVES is also the only instrument on Wind that can unambiguously measure the total electron density in the solar wind. No other L1 spacecraft has this capacity, which allows Wind to calibrate all of its thermal particle instruments more accurately. Wind is currently in extended operations. NASA approved Wind for continued operations in 2023, and the mission will submit a proposal to the 2026 Senior Review cycle.

Recent Achievements

The Wind/Gamma Ray Burst Investigation aided in characterizing a gamma-ray burst (GRB). This discovery of one of the strongest/brightest GRBs ever observed was witnessed by NASA's Fermi, Swift, and Wind spacecraft. Researchers used the data to determine the onset time and total energy output, and to help refine the distance to the event. The total energy output was estimated at approximately 1054 ergs (or approximately 1047 J) among the ten strongest events ever observed. These observations spawned a series of papers speculating on how the energy of the photons could be so high, and prompted individuals to inquire on the existence of axions (i.e., a theoretical particle proposed to explain some charge-parity violations in quantum mechanics).

GEOTAIL

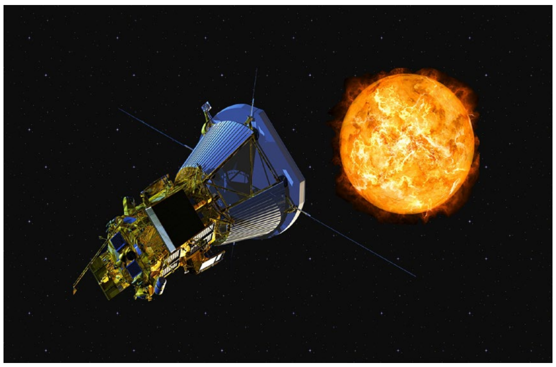
Geotail, launched in 1992, enables scientists to assess data on the interaction of the solar wind and magnetosphere. Its instruments continue to function, sending back crucial information about how auroras form, how energy from the Sun funnels through near-Earth space, and the ways in which magnetic field lines move and rebound, creating explosive bursts that rearrange the very shape of our magnetic environment. The Geotail mission is a collaborative project undertaken by the Japanese Institute of Space and Astronautical Science and NASA. NASA held the KDP-F closeout milestone for the Geotail mission in October 2023, moving the mission into its closeout activities, and bringing its 31-year history of scientific discovery to a close. NASA maintains the mission data in the Heliophysics Archive system for use by the scientific community.

LIVING WITH A STAR

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Other Missions and Data Analysis	155.2	--	**107.7**	100.1	112.1	106.3	101.4
Total Budget	**155.2**	**--**	**107.7**	**100.1**	**112.1**	**106.3**	**101.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Shown here is an artist's impression of Parker Solar Probe near the Sun. Launched in 2018, the mission has now reached a 90-day orbit that sends the spacecraft into close encounters with our star four times per year to investigate sources of the solar wind. The mission is named after Eugene Parker, who predicted the existence of a solar wind in 1958.

The Living With a Star (LWS) program targets specific aspects of the Sun-Earth system that affect life and society. LWS provides a predictive understanding of the Sun-Earth system, linkages among the interconnected systems, and space weather conditions at Earth and the interplanetary medium. Measurements and research from LWS missions may contribute to advances in operational space weather forecasting that help prevent damage to spacecraft, communications and navigation systems, and power grids. LWS products improve our understanding of ionizing radiation, which has human health implications on ISS and high-altitude aircraft flight, as well as operations of future space exploration with and without human presence. LWS products improve the characterization of solar radiation for global climate change, surface warming, and ozone depletion and recovery.

EXPLANATION OF MAJOR CHANGES IN FY 2025

This budget proposes the cancellation of Geospace Dynamics Constellation (GDC) given other priorities in this request. Funding for the Parker Solar Probe mission is increased over the five-year budget horizon to reflect support for its extended mission. The request supports new activities within Living with a Star Program Management such as Europa Clipper cruise observations and the Canadian Ground-based network. (See next section for details.)

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Geospace Dynamics Constellation	73.0	--	**0.0**	0.0	0.0	0.0	0.0
Living With a Star Future Missions	5.0	--	**0.0**	0.0	7.5	7.5	7.5
LWS Science	24.6	--	**30.2**	29.8	29.8	29.8	29.8
LWS Program Management	19.7	--	**26.0**	24.8	26.9	25.1	25.1
Solar Orbiter Collaboration	6.6	--	**11.2**	9.8	8.4	4.2	0.0
Solar Dynamics Observatory (SDO)	13.2	--	**13.6**	14.0	14.5	14.7	15.0
Parker Solar Probe (PSP)	13.1	--	**26.6**	21.7	25.0	25.0	24.0
Total Budget	**155.2**	**--**	**107.7**	**100.1**	**112.1**	**106.3**	**101.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Living With a Star (LWS) Other Missions and Data Analysis budget includes operating LWS missions, scientific research, program management, and funding for missions to launch in the next decade.

Mission Planning and Other Projects

LWS FUTURE MISSIONS

The Future Missions budget supports pre-formulation activities related to the identification of LWS science and mission objectives and priorities.

LWS SCIENCE

NASA solicits proposals leading to a physics-based understanding of the integral system linking the Sun to the Earth, both directly and via the heliosphere, magnetosphere, and ionosphere. Scientists can achieve LWS Science objectives by data analysis, theory and modeling, and the development of tools and methods (e.g., software). The goal of the project is to develop the scientific understanding needed for the United States to address those aspects of heliophysics that may affect life and society. The targeted research element solicits large-scale problems that cross discipline and technique boundaries.

In addition, LWS Science includes funding to train the next generation of heliophysics experts, conduct a heliophysics graduate-level summer school, develop graduate course content, and support a limited number of postdoctoral research positions at universities and government laboratories.

Recent Achievements

In FY 2023, the LWS Science program selected new teams of researchers to perform coordinated scientific investigations addressing two Focused Science Topics. One of these teams is exploring better descriptions of extreme solar ultraviolet radiation impacting the Earth during solar storms using combinations of novel solar observation techniques, numerical modeling, and machine learning tools. This research can improve our ability to predict the atmospheric response to changes in solar activity over time scales from hours to years. Another team is examining how high energy particles and plasma streaming outward from the Sun (i.e., solar wind) can interact with our magnetosphere and be directed into the Earth's upper atmosphere. The results of this research will help determine the solar wind conditions that produce the largest effects on satellite operations and human activity in LEO.

A recent LWS Science Focused Science Topic investigation into the connections between terrestrial and space weather using data from NASA and commercial GPS satellites found remarkable evidence that strong winds associated with a severe winter storm in December 2022 generated waves that travelled up through the entire atmosphere, culminating in disruptions to the plasma-rich region of the Earth's upper atmosphere known as the ionosphere, which extends from approximately 100 to 1,000 kilometer (km) in altitude. Such disruptions can severely disrupt satellite navigation, radio communication, and over-the-horizon radar operation. Understanding these lower atmospheric wave effects is crucial to developing skillful predictive models of the near-space environment that includes LEO.

LWS PROGRAM MANAGEMENT

The Program Management budget supports critical flight project management functions executed by the LWS Program Office at NASA GSFC and provides the resources required to manage the planning, formulation, and implementation of all LWS missions. Included in LWS Program Management is the SMD Rideshare Office. This office implements an SMD-wide rideshare strategy for Evolved Expendable Secondary Payload Adapter-class (ESPA-class) payload opportunities. The office is responsible for coordinating rideshare opportunities and collaborating across SMD, other NASA science directorates, other government agencies, and the greater rideshare community to foster a culture of cross-collaboration and maximize science return through shared launch opportunities and resources.

Heliophysics will partner with the Planetary Science Division to produce valuable solar wind observations during Europa Clipper's cruise to Jupiter. These kinds of observations are challenging to acquire within the Heliophysics portfolio but provide significant insights into the structure and evolution of the solar wind. Another new activity is the Canadian ground-based network. In 2023, Heliophysics Division and CSA transformed a collaboration between a single NASA project and a limited CSA ground-based network into a broader, long-term framework. This new agreement enables the collaborative study of Earth's space environment using all of NASA's missions and an expanding CSA-supported ground-based network. NASA was asked and is currently negotiating to provide a limited contribution to the Canadian refurbishment and expansion of certain sites in this ground-based network.

Operating Missions

SOLAR ORBITER COLLABORATION

The NASA and ESA SOC mission provides measurements that will give NASA better insight on the evolution of sunspots, active regions, coronal holes, and other solar features and phenomena. The instruments explore the near-Sun environment to improve our understanding of the origins of the solar wind streams and the heliospheric magnetic field; the sources, acceleration mechanisms, and transport processes of solar energetic particles; and the evolution of CMEs in the inner heliosphere. To achieve these objectives, SOC makes in-situ measurements of the solar wind plasma, fields, waves, energetic particles, and imaging/spectroscopic observations. SOC adjusts its orbit to the direction of the Sun's rotation to allow the spacecraft to observe one specific area for much longer than is currently possible. The prime mission will continue until May 2027.

OTHER MISSIONS AND DATA ANALYSIS

ESA provided the spacecraft, managed operations, and most of the instruments. NASA provided the launch vehicle and two science investigations/instruments: The Solar Orbiter Heliospheric Imager and the Heavy Ion Sensor.

Recent Achievements

The Solar Orbiter spacecraft has successfully completed seven orbits around the Sun, with its most recent orbit taking it within 27 million miles from the surface of the Sun in October 2023. The prime mission phase will continue until December 2026, when the spacecraft will have completed twelve orbits around the Sun.

Solar Orbiter observed the first close-ups of a source of energetic particles expelled from the Sun, viewing them from just half an astronomical unit (AU), or about 46.5 million miles. In one ion injection, the intensity of the rare isotope Helium-3 exceeded the amount of hydrogen and the levels of iron were similar to the isotope Helium-4. In another injection two days later, the amount of Helium-3 had significantly decreased to an almost negligible amount. The distance of just 0.5 AU has given the scientific team a remarkably detailed view of solar events.

PARKER SOLAR PROBE (PSP)

PSP launched in 2018, is unlocking the mysteries of the Sun's atmosphere. PSP has flown through the solar corona 17 out of an expected 24 times, gradually lowering its orbit closer to the Sun using Venus' gravity during seven flybys over its seven-year mission with the prime mission ending in 2025. After the fifth Venus flyby, the spacecraft flew through the Sun's atmosphere as close as 3.8 million miles to our star's surface—well within the orbit of Mercury. The prime mission will continue until September 2025.

PSP employs a combination of in-situ measurements and imaging to revolutionize our understanding of the corona and expand our knowledge of the origin and evolution of the solar wind. PSP will also make critical contributions to our ability to forecast changes in Earth's space environment.

Recent Achievements

On September 27, 2023, PSP broke its own distance record from the Sun, reaching deep into the solar corona at 11.4 solar radii distance from the Sun's core. This was the 17th successful solar encounter, following on the heels of encounters 14 to 16 and a Venus gravity assist in this performance year alone.

On September 5, 2022, PSP flew safely through a highly violent explosion in the solar corona generating a CME traveling at more than 5.5 million miles per hour. Parker was about 6 million miles from the solar surface, which is approximately 6.5 percent of the Sun-Earth distance.

This event acted as a "vacuum cleaner," sweeping up almost all the solar wind particles in its way, leaving an extremely tenuous medium behind it. The most notable feature is that the CME cleared even dust particles much heavier than the solar wind particles (i.e., electrons and ions). This clearly manifests the role of explosive solar activity in shaping the solar environment and their potential impact as the main space weather drivers. It has implications for the interaction between planetary space environments and their stars.

SOLAR DYNAMICS OBSERVATORY (SDO)

Launched on February 11, 2010, SDO seeks to understand the Sun's influence on Earth and near-Earth space by simultaneously studying the solar atmosphere on small scales of space and time and in many wavelengths. The observatory enables scientists to determine how the Sun's magnetic field is generated and structured and how stored magnetic energy is converted and released in the form of solar wind, energetic particles, and variations in the solar irradiance. SDO collects data to help explain the creation of solar activity, which drives space weather. Measurements of the interior of the Sun, the Sun's magnetic field, the hot plasma of the solar corona, and the irradiance that creates Earth's ionosphere are the primary data products. SDO is currently in extended operations. NASA approved SDO for continued operations in 2023, and the mission will submit a proposal to the 2026 Senior Review cycle.

Recent Achievements

The 2023 Frontier Dynamics Laboratory (FDL) Analysis Ready Data (ARD) effort built the SDO Scientific Computing Platform, a cloud-based system for processing data from SDO. The team designed this tool for flexibility, modularity, and high-performance computing, enabling efficient processing and analysis of solar data. Within the SDO Scientific Computing Platform, ARD enhanced and extended the SDOMLv2 dataset and produced a new version of Virtual- Extreme ultraviolet Variability Experiment (EVE). Virtual-EVE synthesizes all wavelength lines observed by the EVE, one of the three instruments on SDO. Virtual-EVE accomplishes this by ingesting, calibrating, and packaging data from all of SDO's instruments (i.e., Atmospheric Imaging Assembly (AIA), Helioseismic and Magnetic Imager (HMI), and EVE). This platform builds on the results of the 2018 and 2020 FDL tasks and constitutes a steppingstone for future Heliophysics research and discoveries, making the SDO invaluable data accessible to the entire scientific community.

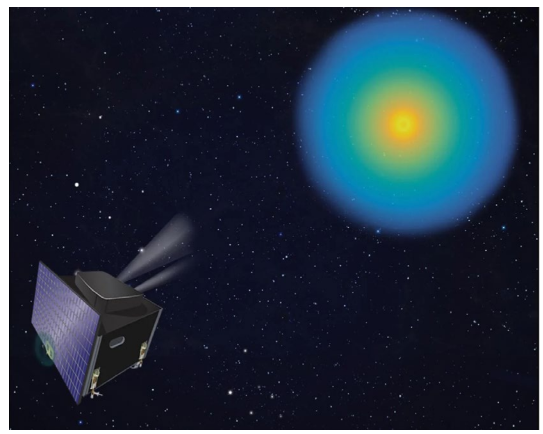
SOLAR TERRESTRIAL PROBES

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Interstellar Mapping and Acceleration Probe (IMAP)	123.3	137.4	**63.9**	39.5	23.9	15.3	0.0
Other Missions and Data Analysis	74.7	--	**69.3**	43.4	41.1	40.8	38.1
Total Budget	**198.0**	**--**	**133.2**	**82.9**	**64.9**	**56.1**	**38.1**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Solar Terrestrial Probes (STP) program focuses on understanding the fundamental physical processes of the space environment from the Sun to the Earth, to other planets, and beyond to the interstellar medium. STP provides insight into the basic processes of plasmas inherent in all astrophysical systems. STP missions focus on processes such as the variability of the Sun, responses of the planets to those variations, and the interaction of the Sun and the solar system. NASA defines specific goals for STP missions and selects investigations for each mission competitively. These missions allow the science community an opportunity to address important research focus areas and make significant progress in understanding fundamental physics.



The illustration above is of Carruthers Geocorona Observatory, which is scheduled to launch in FY 2026. Carruthers will study the structure and processes in the outermost part of Earth's atmosphere.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

The project team completed the Carruthers Geocorona Observatory's primary instrument and delivered it for calibration and environmental testing in September 2023.

Interstellar Mapping and Acceleration Probe (IMAP) completed its CDR and System Integration Review (SIR). Flight instrument development continues with several instruments starting their environmental test campaign in preparation for spacecraft integrations. The team integrated the spacecraft structure and propulsion system and completed the thermal balance testing in preparation for further system integration activities.

SOLAR TERRESTRIAL PROBES

WORK IN PROGRESS IN FY 2024

Consistent with the report language accompanying the FY 2023 appropriations bill and pending FY 2024 appropriations, NASA expects to complete the review of proposals submitted to an Announcement of Opportunity for the Dynamical Neutral Atmosphere-Ionosphere Coupling (DYNAMIC) mission with a goal of completing selections in Q3 FY 2024. The FY 2024 and FY 2025 Budget requests do not include funding to develop the DYNAMIC mission. Carruthers is progressing towards a combined SIR and Pre-Environmental Review (PER) in January 2024.

IMAP will complete system level integration with all instruments completing subsystem testing and integration with the spacecraft. Observatory testing will begin with environmental testing starting prior to the end of the fiscal year.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

Carruthers will continue with project implementation and perform system, assembly, and integration as it continues project development, system assembly, integration and test, launch and checkout (Phase D). Carruthers will then prepare for the Operational Readiness Review (ORR) in December 2024, followed by the operations and sustainment (KDP-E) gate review in January 2025.

IMAP will complete system integration activities and begin preparations for launch vehicle integration. IMAP will complete Pre-Ship review ahead of delivery to the launch site and initiating launch campaign activities.

Program Schedule

Date	Significant Event
Q1 FY 2024	IMAP KDP-D
Q2 FY 2024	Carruthers PER & SIR
Q3 FY 2024	IMAP PER
Q1 FY 2025	IMAP Pre-Ship Review
Q1 FY 2025	IMAP ORR
Q1 FY 2025	Carruthers ORR
Q3 FY 2026	Carruthers KDP-E
Q1 FY 2026	IMAP LRD
Q1 FY 2026	Carruthers LRD

SOLAR TERRESTRIAL PROBES

Program Management and Commitments

GSFC is responsible for the management of the STP program.

Acquisition Strategy

In the acquisition of STP scientific instruments, spacecraft, and science investigations, NASA will use full and open competitions to the greatest extent possible. NASA may acquire certain instruments, missions, or mission systems without competition (e.g., through international partnerships or in-house builds) if there is a clear scientific, technological, or programmatic benefit to NASA.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	SRB	Jan 2024	Carruthers SIR Program Independent Review: Assess performance of program	TBD
Performance	SRB	Dec 2024	Carruthers ORR Program Independent Review: Assess performance of program	TBD
Performance	SRB	Dec 2024	IMAP ORR Program Independent Review: Assess performance of program	TBD

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	117.6	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	117.6
Development/Implementation	261.1	123.3	137.4	**57.8**	10.0	0.0	0.0	0.0	0.0	589.5
Operations/Close-out	0.0	0.0	0.0	**6.1**	29.5	23.9	15.3	0.0	0.0	74.8
2024 MPAR LCC Estimate	**378.6**	**123.3**	**137.4**	**63.9**	**39.5**	**23.9**	**15.3**	**0.0**	**0.0**	**781.8**
Total Budget	**378.6**	**123.3**	**137.4**	**63.9**	**39.5**	**23.9**	**15.3**	**0.0**	**0.0**	**781.8**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

PROJECT PURPOSE

The Interstellar Mapping and Acceleration Probe (IMAP) mission will help researchers better understand the boundary of the heliosphere. This region is where the constant flow of particles from our Sun, called the solar wind, collides with material from the rest of the galaxy. This collision limits the amount of harmful cosmic radiation entering the heliosphere. IMAP will collect and analyze particles that make it through to the heliosphere.

Shown here is an artist's conception of the IMAP spacecraft.

Another objective of the mission is to learn more about the generation of cosmic rays in the heliosphere. Cosmic rays created both locally and from the galaxy and beyond affect human explorers in space and can harm technological systems, and likely play a role in the presence of life itself in the universe.

IMAP is the fifth mission in NASA's Solar Terrestrial Probes (STP) program portfolio. NASA selected IMAP following an extensive and competitive peer review of proposals submitted in 2017. The mission will carry 10 science instruments provided by international and domestic research organizations and universities.

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

PROJECT PARAMETERS

IMAP will study the interaction of the solar wind with the winds from other stars by directly sampling neutral atoms returning from the interstellar boundary and will elucidate how particles are accelerated to high energies in space environments. IMAP will launch on a SpaceX Falcon 9 in 2025 and will conduct operations at the Earth-Sun Lagrange Point 1, upstream of Earth at one percent of the distance to the Sun. IMAP will carry ten instruments, which can be grouped into three categories: energetic neutral atom detectors (i.e., IMAP-Lo, IMAP-Hi, and IMAP-Ultra), charged particle detectors (i.e, Solar Wind and Pickup Ions [SWAPI], SWE, CoDICE, and HIT), and other coordinated measurements (i.e, MAG, IDEX, GLOWS). IMAP will also supply critical real-time space weather data through its IMAP Active Link for Real-Time (I-ALiRT).

Two secondary rideshare payloads will accompany the IMAP mission, taking advantage of the excess performance capability of the launch vehicle. Heliophysics is currently planning to fly an STP mission of opportunity (i.e., Carruthers Geocorona Observatory), along with the NOAA Space Weather Follow-On (SWFO-L1).

ACHIEVEMENTS IN FY 2023

IMAP completed critical design activities including remaining instrument CDRs and the Mission CDR. The team completed spacecraft structure fabrication and integration with the propulsion system. Both elements completed an integrated thermal test to verify system parameters before proceeding with full system integration. IMAP completed its system integration review successfully and in preparation for instrument integrations, subsystem pre-environmental reviews started including IMAP-Ultra and Mag.

WORK IN PROGRESS IN FY 2024

IMAP will conclude subsystem and instrument integration, environmental testing, and calibration activities for all the science instruments. The instruments and spacecraft will then complete integration activities and begin performance and functional system testing. In preparation for the environmental test campaign, IMAP will complete its pre-environmental review.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

In FY 2025, IMAP will complete system and observatory testing including environmental tests, ground tests and operational readiness tests. IMAP will complete a pre-ship review ahead of shipping the integrated space vehicle to the launch site for processing and launch vehicle integration. Launch campaign activities will begin in FY 2025.

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Confirmation Baseline Date	FY 2025 PB Request
KDP-C	Jul 2021	Jul 2021
CDR	Jun 2022	Jan 2023
SIR	Jun 2023	Sep 2023
KDP-D	Jun 2023	Nov 2023
ORR	Dec 2024	Dec 2024
KDP-E	Jan 2025	Jan 2025
Launch (or equivalent)	Dec 2025	Dec 2025

Development Cost and Schedule

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Milestone	Base Year Milestone Data	Current Year Milestone Data	Milesto ne Change (mths)
2021	589.5	70	2024	589.5	0	LRD	Dec 2025	Dec 2025	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time it was developed. Estimates that include combined cost and schedule risks are denoted as JCL (joint confidence level); all other CLs (confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**589.5**	**589.5**	**0**
Spacecraft	67.4	94.2	+26.8
Payloads	124.9	163.3	+38.4
Systems I&T	26.6	27.5	+0.9

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
Launch Vehicle	78.4	80.9	+2.5
Ground Systems	33.7	33.7	0
Science/Technology	21.6	13.3	-8.3
Other Direct Project Costs	236.9	176.6	-60.3

Project Management & Commitments

The mission Principal Investigator is from Princeton University. The Johns Hopkins University/Applied Physics Laboratory (JHU/APL) is responsible for project management and engineering.

Element	Description	Provider Details	Change from Baseline
Spacecraft	Provides a controlled spinning platform at the L1 Lagrange point for an extensive payload of scientific instruments.	Provider: JHU/APL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IMAP-Lo Instrument	Tracks the interstellar flow to precisely determine the species-dependent flow speed, temperature, and direction of the Local Interstellar Medium (LISM) that surrounds, interacts with, and determines the outer boundaries of the global heliosphere.	Provider: University of New Hampshire Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
CoDICE Instrument	Determines the LISM composition and flow properties, to discover the origin of the enigmatic suprathermal tails and advance understanding of the acceleration of particles in the heliosphere.	Provider: Southwest Research Institute Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IDEX Instrument	A high-resolution dust analyzer that provides the elemental composition, speed, and mass distributions of Interstellar Dust (ISD) particles.	Provider: University of Colorado Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
SWAPI Instrument	Delivers the high time and energy resolution required to identify local acceleration processes, fundamental to understanding the solar wind context, sources, and acceleration of particles, PUIs, and the physical processes regulating the global heliosphere.	Provider: Princeton University Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IMAP Ultra Instrument	Images the emission of Energetic Neutral Atoms (ENAs) produced in the heliosheath and beyond.	Provider: JHU/APL Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
HIT Instrument	Delivers full-sky coverage of ion anisotropy measurements, observing the ramps of local shocks, anchoring the high-energy SEP ion spectra, and resolving particle transport in the heliosphere.	Provider: GSFC Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
SWE Instrument	Measures in-situ solar wind electrons at L1 to provide context for the ENA measurements and perform the in-situ solar wind observations necessary to understand the local structures that can affect acceleration and transport.	Provider: Los Alamos National Laboratory Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
IMAP-Hi Instrument	Enables unprecedented, detailed studies of structure and evolution of source plasmas in the heliosphere-LISM interaction region.	Provider: Los Alamos National Laboratory Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A
GLOWS Instrument	Measures the heliospheric resonant backscatter glow of hydrogen and helium.	Provider: Polish Academy of Science, Space Research Center Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): Poland Ministry of Science	N/A

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Element	Description	Provider Details	Change from Baseline
Magnetometer Instrument	Allows new insight into waves and turbulence in the solar wind to frequencies near the electron gyrofrequency and maintains an accurate baseline for space weather applications.	Provider: Imperial College of London Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): UK Space Agency	Yes
Launch Vehicle	The Falcon 9 rocket will deliver the IMAP observatory and up to four rideshare secondary payloads to a proper orbital trajectory.	Provider: SpaceX Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A	N/A

Project Risks

Risk Statement	Mitigation
If: The quantity, complexity, or sensitivity of IMAP instruments causes issues during development or integration and testing, Then: The project could experience the need for additional testing or redesign leading to cost and schedule impacts.	1) Further enhance instrument teams with additional resources including technical and management personnel; 2) Relocating work efforts and transferring scope to other institutions with more bandwidth; 3) Identifying opportunities to schedule six or seven-day work weeks or determining appropriate activities to increase shift work; 4) Evaluate of I&T workflow alternatives to proactively prepare for schedule uncertainty.

Acquisition Strategy

NASA competitively selected the mission through the Solar Terrestrial Program-5 AO and completed final down-selection in 2018. NASA selected the launch vehicle through full and open competition via NASA's Launch Services Program at KSC.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Mission Development, IMAP-Ultra Instrument	JHU/APL	Laurel, MD
SWAPI Instrument and Science	Princeton University	Princeton, NJ
IMAP-Hi and SWE Instruments	Los Alamos National Laboratory	Los Alamos, NM

INTERSTELLAR MAPPING AND ACCELERATION PROBE (IMAP)

Formulation	Development	Operations

Element	Vendor	Location (of work performance)
CoDICE Instrument, Instrument Common Electronics, Payload Systems Engineering	Southwest Research Institute	San Antonio, TX
IMAP-Lo Instrument	University of New Hampshire	Manchester, NH
IDEX Instrument and Science Operations Center	Laboratory for Atmospheric and Space Physics - Colorado University	Boulder, CO
Launch Vehicle	SpaceX	Hawthorne, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Standing Review Board	Dec 2024	ORR ensures that all system and support (i.e., flight and ground) hardware, software, personnel, procedures, supporting capabilities, and user documentation accurately reflect the deployed state of the system and are operationally ready.	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Carruthers Geocorona Observatory	23.3	--	**12.9**	2.9	2.2	2.7	0.0
Solar Terrestrial Probe Future Missions	5.0	--	**0.0**	0.0	0.0	0.0	0.0
STP Program Management	10.0	--	**21.9**	4.9	4.7	4.5	4.5
Magnetospheric Multiscale (MMS)	21.9	--	**20.2**	20.1	18.9	18.4	18.4
Solar Terrestrial Relations Observatory (STEREO)	5.6	--	**6.6**	6.4	6.0	6.0	6.0
Hinode (Solar B)	6.4	--	**4.8**	6.5	6.5	6.5	6.5
TIMED	2.6	--	**2.8**	2.7	2.7	2.7	2.7
Total Budget	**74.7**	**--**	**69.3**	**43.4**	**41.1**	**40.8**	**38.1**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Solar Terrestrial Probes (STP) Other Missions and Data Analysis budget includes operating STP missions, program management, and funding for future missions launching in the next decade.

Mission Planning and Other Projects

CARRUTHERS GEOCORONA OBSERVATORY

In December 2020, NASA selected the Carruthers Geocorona Observatory, formerly known as Global Lyman-alpha Imager of the Dynamic Exosphere (GLIDE), as an STP Mission of Opportunity. Carruthers will study variability in Earth’s exosphere by tracking far ultraviolet light emitted from hydrogen. It will also gather observations at a high rate, with a view of the entire exosphere, ensuring a global and comprehensive set of data, which is currently lacking. Carruthers will help scientists better understand the ways in which Earth’s exosphere changes in response to influences of the Sun. This study will provide us with better ways to forecast and, ultimately, mitigate the ways in which space weather can interfere with radio communications in space. Carruthers will be a rideshare payload on the IMAP mission, launching in FY 2026.

Recent Achievements

The Carruthers Geocorona Observatory's primary instrument is complete and began calibration and environmental testing in September 2023.

STP PROGRAM MANAGEMENT

STP Program Management provides the resources required to manage the planning, formulation, and implementation of all STP missions. The program office ensures successful achievement of STP's program cost and schedule goals, while managing cross-project dependencies, risks, issues, and requirements as projects progress through formal KDPs. STP Program Management received additional funding in FY 2025 to support increased requirements from both the Science Office for Mission Assessments (SOMA), and the Launch Services Program (LSP).

OTHER MISSIONS AND DATA ANALYSIS

Operating Missions

MAGNETOSPHERIC MULTISCALE (MMS)

The MMS mission investigates how the magnetic fields of the Sun and Earth connect and disconnect, explosively transferring energy from one to the other, and throughout interplanetary space. MMS uses Earth's magnetosphere as a natural laboratory to study the microphysics of magnetic reconnection, a fundamental plasma-physical process that converts magnetic energy into heat and charged particle kinetic energy. In addition to solving the mystery of the small-scale physics of the reconnection process, MMS investigates how the energy conversion that occurs in magnetic reconnection accelerates particles to high energies and what role plasma turbulence plays in reconnection events. Magnetic reconnection, particle acceleration, and turbulence occur in all astrophysical plasma systems. Researchers can only study these phenomena in-situ in our solar system, and most efficiently in Earth's magnetosphere, where these processes control the dynamics of the geospace environment and play an important role in the phenomena known as space weather. MMS also helps us understand reconnection elsewhere, such as the atmosphere of the Sun and other stars, near black holes and neutron stars, and at the boundary between the solar system's heliosphere and interstellar space, where it is more difficult to study.

The MMS mission consists of four identically instrumented spacecraft that measure particles, fields, and plasmas. The MMS instrument payload measures electric and magnetic fields and the plasmas found in the regions where magnetic reconnection occurs. Fast, multi-point measurements are enabling dramatically revealing direct observations of these physical processes. A highly elliptical orbit explores how Sun-Earth magnetic fields reconnect in Earth's neighborhood. The four spacecraft fly in a tetrahedron formation that allows them to observe the three-dimensional structure of magnetic reconnection events. The separation between the observatories is adjustable over a range of six to 250 miles during science operations areas of interest. MMS is currently in extended operations.

MMS launched in March 2015 and entered its extended mission phase in September 2017. NASA approved MMS for continued operations in 2023, and the mission will submit a proposal to the 2026 Senior Review cycle.

Recent Achievements

MMS produced the first observations that suggest how the structure of reconnection regions can deviate from the standard geometry that has long underlaid theory, simulations, and data analyses. In two separate crossings through Earth's magnetotail reconnection region, MMS observed plasma flows that were consistent with one axis of the reconnection region (i.e., the X-line) occurring 40 to 60 degrees from the expected orientation. These results show that non-idealized geometries may be common and that current theoretical and modeling capabilities will need updating to fully understand the physics of this universal plasma process.

SOLAR TERRESTRIAL RELATIONS OBSERVATORY (STEREO)

STEREO enables studies of the origin of the Sun's coronal mass ejections (CME) and their consequences for Earth, other planets, and interplanetary space. The mission launched with two spacecraft, one Ahead of Earth (i.e., STEREO-A) and the other Behind Earth (i.e., STEREO-B) in its orbit. STEREO's instrumentation targets the fundamental process of energetic particle acceleration in the low solar corona and in interplanetary space. The mission can image the structure and evolution of solar storms as they leave the Sun and move through space toward Earth. The mission also provides the foundation for understanding space weather events and developing predictive models. The models, in turn, help to identify and mitigate the risks associated with space weather events. In addition, STEREO improves space weather situational awareness not only for Earth and in LEO, but also throughout the solar system.

STEREO launched in October 2006 and entered its extended mission phase in January 2009. NASA has been unable to communicate with STEREO-B since 2016. STEREO-A continues to operate nominally and is still providing significant science data. NASA approved STEREO for continued operations in 2023, and the mission will submit a proposal to the 2026 Senior Review cycle.

Recent Achievements

STEREO provided key data to a cross-disciplinary study that proposed a new stellar phenomenon, called a Surface Mass Ejection (SME), to explain unexpected behavior shown by Betelgeuse, a red giant in the constellation of Orion. In 2020, when Betelgeuse was not observable from Earth, STEREO showed that the star was dimming instead of reaching the expected peak in its brightness cycle. Following that dimming, STEREO and the Earth-based telescopes together showed that a new brightness cycle persisted more than two years later. Scientists inferred these observations were caused by an SME, which would be similar to a solar coronal mass ejection but ejecting a significant part of the star's outer shell and causing a global disturbance in the star's behavior that persists for years. This study shows the value of coordination between federally funded observatories, and how heliophysics missions can contribute to scientific advances well outside their original scientific scope.

HINODE

Hinode is a joint JAXA and NASA mission. The mission consists of a coordinated set of optical, extreme ultraviolet, and X-ray instruments that study the basic heating mechanisms and dynamics of the active solar corona. Hinode explores the magnetic fields of the Sun to improve understanding of what powers the solar atmosphere and drives solar eruptions. Hinode is discovering how the Sun generates magnetic disturbances and the high-energy particle storms that propagate from the Sun to Earth.

Hinode’s solar optical telescope is the first spaceborne instrument to measure the strength and direction of the Sun’s magnetic field on the Sun’s surface, the photosphere. Two other Hinode instruments, the EUV imaging spectrometer and the X-ray/EUV telescope, allow the mission to investigate the causes of eruptions in the solar atmosphere and relate those eruptions to the intense heating of the corona and the mechanisms that drive the constant outflow of solar radiation, the solar wind.

Hinode launched in September 2006 and entered its extended mission phase in November 2009. NASA has approved Hinode for continued operations in 2023, and the mission will submit a proposal to the 2026 Senior Review cycle.

Recent Achievements

Hinode led a coordinated observation program that successfully constrained the temperature from small solar flares, which are challenging to observe but theorized to significantly contribute to solar coronal heating. This program confirmed a very high temperature plasma (i.e., greater than 15 millikelvin (mK) for at least one bright, compact event by combining its own observations with Solar Orbiter's and Solar Dynamics Observatory's. The peak temperature of these flares has direct implications for their impact on coronal heating, but weak emissions at higher temperatures (i.e., greater than 10 mK) have limited the characterization of their full impact. This work has demonstrated a capability to measure small flares' hot plasma and thereby the need for future studies to quantify their contributions to coronal heating.

OTHER MISSIONS AND DATA ANALYSIS

THERMOSPHERE, IONOSPHERE, MESOSPHERE ENERGETICS AND DYNAMICS (TIMED)

The TIMED mission characterizes and studies the physics, dynamics, energetics, thermal structure, and composition of the least explored and understood regions of Earth's atmosphere: the mesosphere, the lower thermosphere, and the ionosphere, collectively known as the ionosphere-thermosphere-mesosphere (ITM) system. This ITM system, located between altitudes of approximately 35 to 100 miles above the surface of Earth, helps protect Earth from harmful solar radiation. It is a gateway between Earth's environment and space, where the Sun's energy first affects Earth's environment. Solar events, as well as temperature changes in the stratosphere can perturb this region, but scientists do not understand the overall structure of and responses to these effects. Advances in remote sensing technology employed by TIMED enable us to explore this region on a global basis from space.

TIMED's data provides scientists an unrivaled perspective on changes in the upper atmosphere. The long lifespan allows scientists to track the upper atmosphere's response to both quick-changing conditions, like individual solar storms, throughout the Sun's 11-year activity cycle, as well as longer-term trends, such as those related to climate change. TIMED's instruments are still producing data, enabling continuing studies of the upper atmosphere.

TIMED launched in December 2001 and entered its extended mission phase in January 2004. NASA approved TIMED for continued operations in 2023, and the mission will submit a proposal to the 2026 Senior Review cycle.

Recent Achievements

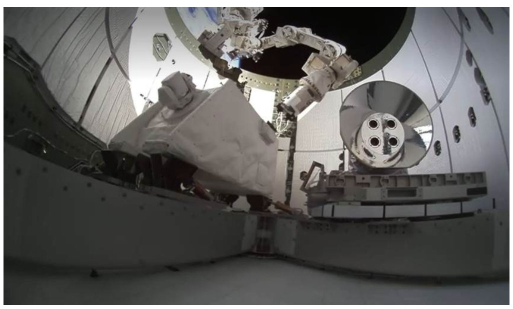
Researchers combined TIMED and Defense Meteorological Satellite Program (DMSP) data to investigate the February 3 to February 5, 2022, geomagnetic storm (in which 40 Starlink satellites were lost) and showed significant underestimation in model predictions. For this storm, a leading atmospheric model used for studies of satellite orbital decay predicted a 5 percent increase in atmospheric density at 210 km. TIMED and DMSP showed increases in the dawn (dusk) sector up to 60 percent (18 percent) at 210 km and about 300 percent (26 percent) at 520 km. This mismatch between prediction and reality was due to the atmosphere's pre-storm state and the storm's geographic bias in auroral heating. This study's results not only constrain some errors in satellite drag predictions, but also identified specific error sources that scientists must target for specific model improvements.

HELIOPHYSICS EXPLORER PROGRAM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
HelioSwarm	10.9	--	**39.3**	126.8	138.2	109.0	86.0
Multi-Slit Solar Explorer	39.5	--	**77.9**	70.5	41.0	14.8	11.1
Other Missions and Data Analysis	117.5	--	**119.5**	112.0	146.2	231.6	288.4
Total Budget	**167.9**	**--**	**236.7**	**309.4**	**325.4**	**355.4**	**385.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Shown here is a view from the cargo bay of the CRS29 DragonX resupply vehicle, which shows the Atmospheric Waves Experiment (AWE) on the right awaiting installation on ISS via the robotic arm.

The Heliophysics Explorer Program provides frequent flight opportunities for world-class scientific investigations on focused and timely science topics. These investigations complement the science of strategic missions of the LWS and STP programs. The program is highly responsive to new knowledge, new technology, and updated scientific priorities by launching smaller missions formulated and executed in a relatively short development cycle. The program features missions competitively selected from the scientific research community with constrained mission LCCs.

The Explorers Program provides two classes (Medium-Class Explorers [MIDEX] and Small Explorers [SMEX]) of flight opportunities to accomplish the goals of the program. MIDEX missions are the most capable Explorers scientific investigations, with a cost cap of $300 million (not including launch services). SMEX missions focus on scientific missions and are limited to a $150 million cost cap (not including launch services). Explorers Missions of Opportunity (MO) are smaller investigations, which may fly as a hosted payload, sub-orbital flight, SmallSat or CubeSat mission, or ISS-attached payloads.

EXPLANATION OF MAJOR CHANGES IN FY 2025

The request includes enhanced project management contributions within the Extreme Ultraviolet High-Throughput Spectroscopic Telescope Epsilon Mission (EVUST) to support NASA's international contribution to the JAXA mission Solar-C. This budget proposes cancellation of the MIDEX 2025 MO. The AIM spacecraft ended operations in 2023 due to loss of battery power after 15 successful years. The ICON mission ended in 2023 while it was in an extended mission due to loss of contact with the spacecraft. Both missions are in closeout.

ACHIEVEMENTS IN FY 2023

NASA made four step-one selections from the 2022 Heliophysics Explorer Program SMEX Announcement of Opportunity (AO) and no MO selections.

Electrojet Zeeman Imaging Explorer (EZIE) successfully passed the CDR in Q2 FY 2023.

HELIOPHYSICS EXPLORER PROGRAM

The Extreme Ultraviolet High-Throughput Spectroscopic Telescope (EUVST), HelioSwarm, and Multi-slit Solar Explorer (MUSE) continued work on preliminary design and technology development activities.

The Sun Radio Interferometer Space Experiment (SunRISE) continued with system assembly and integration and test activities.

Escape and Plasma Acceleration and Dynamics Explorers (ESCAPADE) completed integration of all science instruments in preparation for environmental testing.

Polarimeter to Unify the Corona and Heliosphere (PUNCH) completed instrument testing and instrument pre-ship reviews and spacecraft integration for the first two spacecraft.

Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) continued instrument integration and test activities. TRACERS also completed a replan that shifted the planned Launch Readiness date to November 2025.

The Atmospheric Waves Experiment (AWE) shipped to the launch site and integrated to the launch vehicle. The project passed the Operational Readiness Review.

WORK IN PROGRESS IN FY 2024

The four 2022 SMEX AO selections have begun their Step two concept study reports.

EUVST will conduct the PDR followed by a confirmation review.

MUSE will conduct the mission PDR followed by a confirmation review.

HelioSwarm will continue its preliminary design and technology development activities.

EZIE will complete systems integration and will begin system assembly, integration, and testing activities.

AWE has been launched from Cape Canaveral to ISS. The project team will perform instrument check out and start their prime science mission.

ESCAPADE is working towards delivery and integration of the two spacecraft observatories with a planned launch readiness date of August 2024.

PUNCH will conduct a pre-environmental review, perform their environmental testing, and go into storage until the rideshare opportunity is ready to integrate them to the launch vehicle.

TRACERS will complete instrument integration and test activities, followed by shipment of instruments to support system integration.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

NASA plans on launching the PUNCH and SunRISE missions in FY 2025. EZIE and TRACERS will continue with integration and test activities.

HelioSwarm will proceed to the Systems Requirements Review in Q1 FY 2025 and will complete the PDR in Q4 FY 2025.

MUSE will complete the mission CDR.

EUVST will complete the CDR.

HELIOPHYSICS EXPLORER PROGRAM

NASA plans to establish a Solar-C project office to support NASA's international contribution (EUVST) to the JAXA Solar-C mission.

Program Schedule

Date	Significant Event
Q1 FY 2024	ESCAPADE Pre-Environmental Review
Q1 FY 2024	EZIE System Integration Review
Q1 FY 2024	AWE LRD
Q2 FY 2024	EZIE Pre-Environmental Review
Q2 FY 2024	MUSE PDR
Q3 FY 2024	TRACERS System Integration Review
Q3 FY 2024	ESCAPADE Pre-ship Review
Q3 FY 2024	MUSE KDP C
Q3 FY 2024	ESCAPADE Operational Readiness Review
Q4 FY 2024	EZIE Pre-Ship Review
Q4 FY 2024	PUNCH Pre-Ship Review
Q4 FY 2024	SMEX step 2 CSRs received
Q4 FY 2024	SUNRISE ORR and KDP-E
Q1 FY 2025	ESCAPADE LRD
Q1 FY 2025	SMEX Step 2 down-selection(s)
Q1 FY 2025	TRACERS Operational Readiness Review
Q2 FY 2025	PUNCH Operational Readiness Review
Q2 FY 2025	MUSE CDR
Q3 FY 2025	MIDEX announcement of opportunity
Q3 FY 2025	PUNCH LRD
Q4 FY 2025	SUNRISE LRD
Q1 FY 2026	TRACERS LRD
Q2 FY 2026	EZIE LRD
Q2 FY 2026	MUSE SIR
Q3 FY 2026	MIDEX Step 1 selection(s)

HELIOPHYSICS EXPLORER PROGRAM

Date	Significant Event
Q3 FY 2027	MUSE LRD
Q4 FY 2027	MIDEX Step 2 down-selection(s)

Program Management and Commitments

The Heliophysics and Astrophysics Explorer programs share a common program office at GSFC and a common management structure. The Explorer Program Manager resides at GSFC, reporting functionally to the Center director and programmatically through the Heliophysics and Astrophysics division directors.

The Heliophysics Explorer Program plan accommodates the Decadal Survey's recommendation of a two-to-three-year mission cadence.

Acquisition Strategy

NASA competitively selects new Explorer missions, releasing solicitations when available funding allows, with the expectation of a two-to-three-year cadence. NASA acquires launch vehicles through the Launch Services Program at KSC except when an international partner provides them under an approved agreement or when the Explorer mission is not a primary payload on the launch vehicle.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Program Independent Review	SRB	Jan 2024	Assess performance of program	TBD

HELIOSWARM

Formulation	Development	Operations

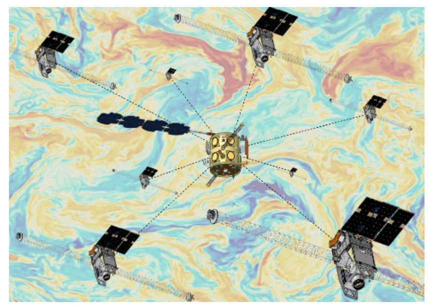
FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**10.9**	**--**	**39.3**	**126.8**	**138.2**	**109.0**	**86.0**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

PROJECT PURPOSE

HelioSwarm plans to observe the solar wind over a wide range of scales to determine the fundamental space physics processes that lead energy from large-scale motion to finer scales of particle movement within the plasma that fills space. Using a swarm of nine spacecraft (i.e., one "Hub" and eight "Nodes"), HelioSwarm will gather multi-point measurements and reveal the three-dimensional mechanisms that control the space plasma turbulence physical processes crucial to understanding the dynamics of the Sun, and the Sun-Earth connection.



Shown above is an artistic rendition of the HelioSwarm Mission which is a constellation of nine spacecraft, one hub spacecraft and eight co-orbiting small satellites, that range in distance from each other and the hub spacecraft.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

PROJECT PRELIMINARY PARAMETERS

HelioSwarm is targeting a launch in FY 2029. HelioSwarm's novel implementation will unlock the mystery of how turbulence heats space plasma. The mission will include the development of nine spacecraft to observe turbulence in the solar wind (i.e., charged particles ejected from the Sun), and interplanetary magnetic field. One large spacecraft, known as the "Hub", and eight smaller spacecraft, called "nodes", will co-orbit to monitor the ever-changing turbulence in space to reveal for the first time how these variations look in three dimensions and how they evolve.

Each spacecraft contains an instrument suite (IS) with Technology Readiness Levels from 6 to 8 providing measurements required to achieve HelioSwarm mission objectives. Nodes consist of three scientific instruments, Fluxgate Magnetometer (FGM), Search Coil Magnetometer (SCM), and a Faraday Cup (FC), as well as an instrument data processing unit (IDPU) and two deployable magnetometer booms. The hub consists of the same elements, as well as an ion Electrostatic Analyzer (iESA). A single flight system with the nodes attached to the hub launches and transfers the instrument suites to the science orbit as a single unit. Each of the node spacecraft then deploy from the hub and the nine-spacecraft co-orbit in a two-week, lunar resonant orbit. HelioSwarm captures measurements in the undisturbed solar wind and interplanetary magnetic field (IMF) as well as in regions containing strongly driven turbulence. Over the course of the 12-month science phase, the instrument suites will rotate through all the regions of scientific interest. During the science phase, each of the nodes send their data to the hub and the data will

HELIOSWARM

Formulation	Development	Operations

be relayed to the ground via the hub downlink antennas at two-week cycles, streamlining mission operations.

ACHIEVEMENTS IN FY 2023

The project continued preliminary design and technology development activities through FY 2023.

WORK IN PROGRESS IN FY 2024

The mission will continue its preliminary design and technology development activities.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The mission will complete the Systems Requirements Review (SRR) in Q1 FY 2025 and the PDR in Q4 FY 2025.

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2025 PB Request
KDP-B	N/A	Feb 2022
SRR	N/A	Oct 2024
PDR	N/A	Oct 2025
KDP-C	N/A	Oct 2025
CDR	N/A	Nov 2026
SIR	N/A	Aug 2027
PER	N/A	Feb 2028
ORR	N/A	Dec 2028
KDP-E	N/A	Mar 2029
Launch	N/A	Jan 2029

Estimated LCC Range and Schedule Range Summary

LCC estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (i.e., KDP-C), which follows a non-advocate review and/or PDR.

KDP-B Date	Estimated LCC Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Feb 2022	500 - 550	Launch	Dec 2028

HELIOSWARM

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details
Hub Spacecraft	The Hub is a heritage based ESPAStar spacecraft platform which will carry and deploy the nodes in space and then act as the central communication device between ground stations and the nodes both for commands and telemetry	Provider: Northrop Grumman Innovation Systems Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A
Node Spacecraft	The nodes are heritage-based commercial spacecraft that will each carry three instruments and communicate with the Hub	Provider: Blue Canyon Technologies Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A
FGM	The FGM is a heritage-based dual core fluxgate magnetometer designed to measure the IMF's lower frequencies	Provider: Imperial College London Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A
iESA	The iESA is a particle sensor designed to measure three-dimensional ion velocity distribution functions (VDFs), which provide the proton and alpha plasma parameters	Provider: Institut de Recherche en Astrophysique et Planétologie Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A
SCM	The SCM is a heritage set of magnetic sensors designed to measure the IMF's higher frequencies	Provider: Laboratoire de Physique des Plasmas Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A
FC	The FC instrument is a heritage-based design that makes measurements of the radial VDF of the Solar Wind ions	Provider: Smithsonian Astrophysical Observatory Lead Center: ARC Performing Center(s): N/A Cost Share Partner(s): N/A
Launch Vehicle	Deliver the spacecraft to operational orbit	Provider: TBD Lead Center: KSC Performing Center(s): N/A Cost Share Partner(s): N/A

HELIOSWARM

Formulation	Development	Operations

Project Risks

Risk Statement	Mitigation
If: Given that the technical maturity of propulsion systems for small satellites has not evolved as needed, if the thrusters cannot meet the baseline performance requirements, Then: There may be a risk to the mission and achieving its science objectives.	Given that continuing to pursue the Enpulsion thrusters would leave the project with a high residual performance and schedule risk, the project requested that Blue Canyon Technologies conduct a propulsion alternatives trade study, as the primary mitigation to the Enpulsion thruster risk.

Acquisition Strategy

NASA competitively selected the mission through the Heliophysics Explorers 2019 Medium-class Explorer (MIDEX) Announcement of Opportunity (AO) and the final down selection occurred in 2022. The major elements of the mission and spacecraft are as proposed in the AO. NASA will competitively select the launch vehicle through the NASA Launch Services Program (LSP).

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Principal Investigator, Instrument Suite Management, Spacecraft Operations Center, and Integrated Data Processing Unit	University of New Hampshire	Durham, New Hampshire

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Standing Review Board (SRB)	Oct 2024	SRR evaluates whether the functional and performance requirements defined for the system.	TBD
Performance	SRB	Oct 2025	PDR demonstrates that the preliminary design meets all system of interest requirements with acceptable risk and within the cost and schedule constraints and establishes the basis for proceeding with detailed design.	TBD
Performance	SRB	Jul 2026	CDR demonstrates that the maturity of the design is appropriate to support proceeding with full-scale fabrication, assembly, integration, and test.	TBD

HELIOSWARM

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	SRB	Jun 2027	SIR ensures segments, components, and subsystems are on schedule to be integrated into the system of interest, and integration facilities, support personnel, and integration plans and procedures are on schedule to support integration.	TBD
Performance	SRB	Oct 2028	ORR ensures that all system and support (flight and ground) hardware, software, personnel, procedures, supporting capabilities, and user documentation accurately reflect the deployed state of the system and are operationally ready.	TBD

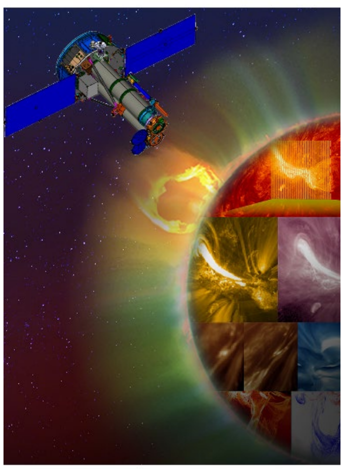
MULTI-SLIT SOLAR EXPLORER

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**39.5**	**--**	**77.9**	**70.5**	**41.0**	**14.8**	**11.1**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



The MUSE observatory is shown here in the upper left, pointing its telescopes towards the Sun.

PROJECT PURPOSE

The Multi-slit Solar Explorer (MUSE) mission will help scientists understand the forces driving the heating of the Sun's corona and the eruptions in that outermost region that are at the foundation of space weather. The mission will offer deeper insight into the physics of the solar atmosphere by using a powerful instrument known as a multi-slit spectrometer to observe the Sun's extreme ultraviolet radiation and obtain the highest resolution images ever captured of the solar transition region and the corona.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

PROJECT PRELIMINARY PARAMETERS

MUSE is targeting a launch no earlier than 2027. The primary goal of the MUSE mission is to investigate the causes of coronal heating and instability, such as flares and coronal mass ejections, and gain insight into the basic plasma properties of the corona. This mission consists of one spacecraft with two Spectrograph and Context Imager instruments. The Multi-slit Spectrograph collects line profiles in bright coronal lines, covering a large temperature range at a 0.4 inch angular and one second slit dwelling time temporal resolution. The Context Imager collects 0.33 inch resolution images over a larger field-of-view, showing transition region and coronal morphology and motions.

Using these instruments, MUSE will obtain high-resolution images of the evolution of solar flare ribbons in a field of view focused on a large, active region on the Sun. The mission will use breakthrough imaging spectroscopy techniques to observe radial motion and heating at 10 times the current resolution, and 100 times faster. This is a key capability when trying to study the phenomena driving heating and eruption processes, which occur on time scales shorter than previous spectrographs could observe.

The MUSE prime mission operations duration will be two years in a low-Earth Sun-synchronous orbit.

MULTI-SLIT SOLAR EXPLORER

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2023

MUSE continued preliminary design and technology completion activities in FY 2023.

WORK IN PROGRESS IN FY 2024

The project will complete the mission PDR in February 2024, followed by a confirmation review in April 2024.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The project will complete the mission CDR in February 2025 and continue with final design and fabrication.

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2025 PB Request
PDR	N/A	Feb 2024
KDP-C	N/A	Apr 2024
CDR	N/A	Feb 2025
SIR	N/A	Feb 2026
KDP-D	N/A	Apr 2026
KDP-E	N/A	May 2027
Launch	N/A	Jun 2027
End of Prime Mission	N/A	Jul 2029

Formulation Estimated LCC Range and Schedule Range Summary

LCC estimates are preliminary. A baseline cost commitment does not occur until the project receives approval for implementation (i.e., KDP-C), which follows a non-advocate review and/or PDR.

KDP-B Date	Estimated LCC Range ($M)	Key Milestone	Key Milestone Estimated Date Range
Feb 2022	300 - 350	Launch	Jun 2027

MULTI-SLIT SOLAR EXPLORER

Formulation	Development	Operations

Project Management & Commitments

The Phase B contract with options for Phases C through F was awarded to the Lockheed Martin Advanced Technology Center for the Principal Investigatorled mission. GSFC is the implementing Center for the MUSE mission.

Element	Description	Provider Details
Instruments	Multi-slit Spectrograph Context Imager	Provider: Lockheed Martin Advanced Technology Center Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A
Spacecraft	Commercial spacecraft	Provider: Lockheed Martin Commercial Civil Space Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A
Ground Systems	Mission Operations Center	Provider: UC Berkeley Space Sciences Laboratory (SSL) Lead Center: GSFC Performing Center(s): N/A Cost Share Partner(s): N/A
Launch Vehicle	Delivery the spacecraft to operational orbit	Provider: TBD Lead Center: GSFC Performing Center(s): KSC Cost Share Partner(s): N/A

Project Risks

Risk Statement	Mitigation
If: Supply chain issues continue and cause delays in key procurements, Then: The program's critical path could be impacted, thereby impacting the project schedule and launch readiness date.	Continue to monitor vendor availability and issue procurements as early as feasible.

Acquisition Strategy

NASA competitively selected the mission through the Heliophysics Explorers 2019 Medium-class Explorer (MIDEX) Announcement of Opportunity (AO) and the final down selection occurred in 2022.

MULTI-SLIT SOLAR EXPLORER

Formulation	Development	Operations

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
Principal Investigator, Project Management, Payload (Spectrograph and Context Imager), Systems Integration & Test, Data Processing, Science Operations and Analysis, Science Operations Center	Lockheed Martin Advanced Technology Center	Palo Alto, CA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Standing Review Board (SRB)	Feb 2024	PDR	TBD
Performance	SRB	Feb 2025	CDR	TBD
Performance	SRB	Feb 2026	SIR	TBD
Performance	SRB	Mar 2027	ORR	TBD

OTHER MISSIONS AND DATA ANALYSIS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Electrojet Zeeman Imaging Explorer	17.9	--	**7.0**	6.3	4.1	3.1	0.0
Escape and Plasma Acceleration and Dynamics Explorers (EscaPADE)	11.2	--	**1.9**	2.8	3.4	2.0	0.0
Extreme Ultraviolet High-Throughput Spectroscopic Telescope (EUVST)	11.2	--	**14.4**	10.4	9.4	7.3	8.3
Ionospheric Connection Explorer	4.3	--	**0.0**	0.0	0.0	0.0	0.0
Global-scale Observations of the Limb and Disk (GOLD)	3.7	--	**2.9**	2.9	3.3	3.2	3.2
Heliophysics Explorer Future Missions	3.1	--	**17.6**	29.8	68.3	161.6	246.9
Heliophysics Explorer Program Management	12.1	--	**21.5**	14.7	22.2	24.3	11.5
Interface Region Imaging Spectrograph (IRIS)	6.4	--	**7.0**	6.6	6.6	6.6	6.6
Interstellar Boundary Explorer (IBEX)	1.9	--	**2.7**	2.2	1.3	1.3	1.3
Aeronomy of Ice in Mesophere (AIM)	2.0	--	**0.4**	0.0	0.0	0.0	0.0
Time History of Events and Macroscale Interactions during Substorms (THEMIS)	5.4	--	**5.8**	6.3	6.3	6.3	6.3
ACE	2.6	--	**2.1**	2.5	2.5	2.5	2.5
Polarimeter to Unify the Corona and Heliosphere (PUNCH)	4.2	--	**10.9**	8.4	4.2	4.2	0.0
Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS)	15.9	--	**9.3**	11.3	6.5	4.0	0.0
Atmospheric Wave Experiment	6.4	--	**5.1**	5.1	5.6	2.5	0.0
Sun Radio Interferometer Space Experiment (SunRISE)	9.4	--	**11.2**	2.8	2.6	2.6	1.8
Total Budget	**117.5**	**--**	**119.5**	**112.0**	**146.2**	**231.6**	**288.4**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Heliophysics Explorer Other Missions and Data Analysis budget includes operating Explorer missions, program management, missions in formulation and development with LCCs less than $250 million, and funding for future mission selections.

Mission Planning and Other Projects

ELECTROJET ZEEMAN IMAGING EXPLORER (EZIE)

In December 2020, NASA selected the EZIE mission (proposed as an Explorer Mission of Opportunity) to study electric currents in Earth's atmosphere linking aurora to the Earth's magnetosphere—one piece of Earth's complicated space weather system, which responds to solar activity and other factors. The Auroral Electrojet (AE) index is a common measure of geomagnetic activity levels, even though scientists do not yet understand all the details of the structure of these currents. EZIE is a trio of SmallSats that will launch together no earlier than November 2024.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

EZIE successfully passed the CDR in March 2023. EZIE completed the systems integration review in November 2023 and entered the next phases of system assembly, integration and test, and launch and checkout.

ESCAPE AND PLASMA ACCELERATION AND DYNAMICS EXPLORERS (ESCAPADE)

ESCAPADE will study the active processes in Mars' magnetosphere and how the solar wind controls them. Using two identical SmallSats, ESCAPADE will be the first mission to characterize the flow of the solar wind and of Mars-produced plasma through the Mars space environment with the ability to distinguish variations in space (e.g., a spacecraft passes through a structure) and in time (e.g., a structure changes size). The mission will focus on the plasma boundaries that define the regions of Mars' magnetosphere, Mars' atmospheric escape, and global changes in the magnetospheric structure under different solar wind conditions. With its thin atmosphere and weak crustal magnetic field in the southern hemisphere, Mars allows the study of fundamental physical processes and their differences across different planetary environments (such as compared to Earth and Venus). Further, characterizing the global system and its variability is a necessary component of understanding the space weather environment ahead of any crewed mission to Mars.

Recent Achievements

ESCAPADE completed the mission systems design review.

The project completed observatory integration and test and all science instruments are integrated into the two spacecraft.

The team completed the spacecraft pre-environmental review on November 9, 2023, and the spacecraft will proceed to environmental testing.

EXTREME ULTRAVIOLET HIGH-THROUGHPUT SPECTROSCOPIC TELESCOPE EPSILON MISSION (EUVST)

In December 2020, NASA selected the EUVST mission (proposed as an Explorer Mission of Opportunity). NASA is a contribution to the JAXA partner-led Epsilon Mission (Solar-C/EUVST Mission) along with other international partners.

Targeted for launch in 2028, EUVST is a solar telescope that will study how the solar atmosphere releases solar wind and drives eruptions of solar material. These phenomena propagate out from the Sun and influence the space radiation environment throughout the solar system. NASA's hardware contributions to the mission include an intensified ultraviolet (UV) detector and support electronics, spectrograph components, a guide telescope, software, and a slit-jaw imaging system to provide context for the spectrographic measurement. NASA has adjusted the EUVST budget profile to accommodate partner delays. NASA will also provide enhanced project management and systems engineering functions as part of NASA's contribution.

Recent Achievements

EUVST continued preliminary design and technology development activities.

OTHER MISSIONS AND DATA ANALYSIS

HELIOPHYSICS EXPLORER FUTURE MISSIONS

Explorer Future Missions funding will support future Explorer missions that have yet to be selected. A typical Explorer mission cadence is an average of two to three years between Announcement of Opportunities (AOs) with alternating Small Explorers (SMEX) and MIDEX selections. NASA released the SMEX AO in 2022 and a MIDEX AO will follow in 2025.

HELIOPHYSICS EXPLORER PROGRAM MANAGEMENT

Explorer Program Management encompasses the program office resources required to manage Explorer projects. The program office is responsible for providing support and guidance to projects in resolving technical and programmatic issues and risks; for monitoring and reporting technical and programmatic progress of the projects; and for achieving Explorer cost, schedule, and technical goals and requirements. The project also includes support for the Science Office for Mission Assessments (SOMA) at LaRC. SOMA is responsible for the technical and scientific evaluation of Explorer mission proposals.

POLARIMETER TO UNIFY THE CORONA AND THE HELIOSPHERE (PUNCH)

The PUNCH mission will focus directly on the Sun's corona and how the corona generates the solar wind. Comprised of four suitcase-size satellites, PUNCH will image and track the solar wind as it leaves the Sun. The spacecraft will also track coronal mass ejections (i.e., large eruptions of solar material that can drive large space weather events near Earth) to better understand their evolution and develop new techniques for predicting such eruptions. These observations will enhance research by other NASA missions, such as Parker Solar Probe and the ESA/NASA Solar Orbiter. PUNCH will be able to image, in real time, the structures in the solar atmosphere that these missions encounter by blocking out the bright light of the Sun and examining the much fainter atmosphere. Together, these missions will investigate how the star we live with drives radiation in space.

NASA selected PUNCH under the 2016 SMEX AO. PUNCH completed preliminary design and technology (i.e., Phase B), and successfully entered the development phase in July 2021. PUNCH is in implementation (i.e., Phase C) with the system integration review held in November 2023 and an expected launch date in April 2025. PUNCH will fly as a rideshare with the Astrophysics mission SPHEREx.

Recent Achievements

The project delivered both the Narrow Field Imager and the Student -contributed X-ray spectrometer to Southwest Research Institute (SwRI) in October 2023. The project delivered the Wide Field Imager #1 in November 2023 to SwRI.

TANDEM RECONNECTION AND CUSP ELECTRODYNAMICS RECONNAISSANCE SATELLITES (TRACERS)

The TRACERS mission will observe particles and fields at the Earth's northern magnetic cusp region (i.e., the region encircling Earth's pole) where our planet's magnetic field lines curve down toward Earth. Here, the field lines guide particles from the boundary between Earth's magnetic field and interplanetary space down into the atmosphere. In the northern magnetic cusp area, with its easy access to our boundary with interplanetary space, TRACERS will study how magnetic fields around Earth interact with those from the Sun. In a process known as magnetic reconnection, the field lines explosively reconfigure, sending particles out at speeds that can approach the speed of light. Earth's magnetic field will guide some of these particles into the region where TRACERS can observe them.

Magnetic reconnection drives energetic events all over the universe, including coronal mass ejections and solar flares on the Sun. It also allows particles from the solar wind to push into near-Earth space, affecting its space weather. TRACERS will be the first space mission to explore this process in the cusp with two spacecraft, providing observations of how processes change over both space and time. The cusp vantage point also permits simultaneous observations of reconnection throughout near-Earth space. Thus, it can provide important context for NASA's Magnetospheric Multiscale mission, which gathers detailed, high-speed observations as it flies through single reconnection events at a time. TRACERS's unique measurements will help with NASA's mission to safeguard technology and astronauts in space.

Recent Achievements

TRACERS completed significant flight hardware manufacturing, integration, and test in FY 2023.

ATMOSPHERIC WAVE EXPERIMENT (AWE)

AWE will observe infrared emissions from the atmospheric layer near 85 kilometers (50 miles) altitude to study how atmospheric gravity waves generated in the lower atmosphere transport energy into the transition region between the upper atmosphere and space. Gravity (or buoyancy) waves are generated near the surface by a variety of processes including wind flow over topography, severe storms, and atmospheric turbulence. AWE is attached to the External Logistics Carrier on ISS, where it will provide the first comprehensive observations of wave energy propagating from the lower atmosphere into the upper atmosphere, which will broaden understanding of the relationship between terrestrial weather and space weather. The results from AWE will help develop improved models used to predict environmental conditions in this highly dynamic region of the upper atmosphere that are known to affect satellite-based navigation and communication systems in LEO.

Recent Achievements

AWE completed its operational readiness review in September 2023 and KDP-E in October 2023. AWE successfully launched on November 9th, 2023, on SpaceX crew resupply 29.

SUN RADIO INTERFEROMETER SPACE EXPERIMENT (SUNRISE)

SunRISE will use six solar-powered CubeSats, each about the size of a toaster oven, to simultaneously observe radio images of low-frequency emission from solar activity and share them via NASA’s Deep Space Network. The constellation of CubeSats will fly within six miles of each other above Earth's atmosphere, which otherwise blocks the radio signals SunRISE will observe. Together, the six CubeSats will create 3D maps to pinpoint where giant particle bursts originate on the Sun and how they evolve as they expand outward into space. This will help determine what initiates and accelerates these giant jets of radiation. The six individual spacecraft will also work together to map the pattern of magnetic field lines reaching from the Sun out into interplanetary space. This information will help improve understanding of how our solar system works and, ultimately, can help protect astronauts traveling to the Moon and Mars by providing better information on how the Sun’s radiation affects the space environment through which they must travel. SunRISE will launch in September 2025.

OTHER MISSIONS AND DATA ANALYSIS

Recent Achievements

SunRISE continued with system assembly and integration and test activities during FY 2023.

Operating Missions

IONOSPHERIC CONNECTION EXPLORER (ICON)

ICON, launched in 2019, studies the ionosphere by simultaneously measuring altitude profiles of the thermosphere and ionosphere's neutral winds, composition, density, temperature, and ion density. It also makes in-situ plasma measurements. ICON studies the frontier of space, which is the dynamic zone high in our atmosphere where Earth's weather meets space weather. ICON provides in-situ measurements of this complicated region of near-Earth space, which can be difficult to fly through given the variable drag on spacecraft. Radio communications and GPS signals travel through the ionosphere, and variations in this region can result in distortions, or even complete disruption, of these signals. As spacecraft travel through this region regularly, improved knowledge will increase NASA's situational awareness to protect satellites and astronauts.

ICON has helped determine the physics of our space environment and paved the way for mitigating its effects on technology, communications systems, and society. ICON completed its prime mission in December 2021 and was in extended operations until November 25, 2022. NASA did not approve ICON for continued operations due to spacecraft failure. The mission is in closeout.

Recent Achievements

Recent work showed the appearance of large-scale inertia gravity waves in the ICON Michelson Interferometer for Global High-resolution Thermospheric Imaging (MIGHTI) data. These large-scale waves have sizes of up to approximately 3,000 kilometers (km) for horizontal wavelengths and approximately 35 km for vertical wavelengths. The observation of the signatures of these large-scale waves was not expected with ICON data, and thus ICON provides a new and unique data set to explore this phenomenon.

An important data product from ICON is the ionospheric O+ density profile between 150 and 450 km altitude. Recent improvements to the algorithm to forward model these profiles from the ICON observations of daytime extreme-ultraviolet (EUV) airglow provide better quality data products with faster analysis speeds.

GLOBAL-SCALE OBSERVATIONS OF THE LIMB AND DISK (GOLD)

GOLD, launched in 2018, performs unprecedented imaging of Earth's thermosphere and ionosphere. GOLD is the first mission to study the weather of the thermosphere-ionosphere rather than its climate and is the first NASA mission to fly as a hosted payload on a commercial communications satellite, pioneering cost-effective access to geostationary orbit. Capturing never-before-seen images of Earth's upper atmosphere, GOLD explores our space environment, which is home to astronauts.

For the first time, GOLD will answer fundamental scientific questions about how the thermosphere/ionosphere system responds to geomagnetic storms, solar radiation, and upward propagating waves and tides. Gathering observations from geostationary orbit above the Western Hemisphere, GOLD measures the temperature and composition of neutral gases in Earth's thermosphere.

This part of the atmosphere co-mingles with the ionosphere's charged particles. Both the Sun from above and terrestrial weather from below can change the types, numbers, and characteristics of the particles found here. GOLD helps track those changes.

Activity in this region is responsible for a variety of key space weather events. GOLD scientists are particularly interested in the cause of low-density, unpredictable bubbles of charged gas that appear over the equator and tropics, sometimes causing communication problems. As scientists discover the very nature of the Sun-Earth interaction in this region, the mission could ultimately lead to ways to improve forecasts of such space weather and mitigate its effects. GOLD is currently in extended operations. NASA approved GOLD for extended operations in 2023, and the mission will submit a proposal to the 2026 Senior Review cycle.

Recent Achievements

GOLD observations captured the up to 80 percent increases in atmospheric density, unpredicted by the existing operational models from February 3 to February 4, 2022, which were responsible for the re-entry and loss of 38 of 49 recently launched Starlink satellites.

During a recent geomagnetic storm on April 23, 2023, GOLD imaged equatorial plasma bubbles at unusually high latitudes (approximately 45 degrees south of the magnetic equator in the southern hemisphere) reaching altitudes of 4,000 km. GOLD confirmed that these bubbles (normally an equatorial phenomenon) are also responsible for GPS and communication losses at midlatitudes during strong magnetic storms.

GOLD provided a global-scale view of wave-like, thermospheric temperature perturbations induced by the Tongan volcanic eruption, providing unambiguous, direct evidence of the dynamic coupling between the lower and upper atmosphere.

INTERFACE REGION IMAGING SPECTROGRAPH (IRIS)

IRIS, launched in 2013, joined a network of solar spacecraft and ground-based observatories to provide unprecedented insight into a little understood region of the Sun called the interface region. IRIS makes use of high-resolution observations and state-of-the-art computer models to unravel how matter, light, and energy move through the dense region of solar material at the bottom of the Sun's atmosphere. Understanding the interface between the Sun's surface and its atmosphere, the corona, is crucial to understanding what drives heat and energy into the corona, as well as what powers solar flares and coronal mass ejections.

IRIS provides key insights into all these processes, and thereby advances our understanding of the solar drivers of space weather from the corona to the far heliosphere by combining high-resolution imaging and spectroscopy for the entire chromosphere and adjacent regions. IRIS is currently in extended operations. NASA approved IRIS for continued operations in 2023, and the mission will submit a proposal to the 2026 Senior Review cycle.

Recent Achievements

Flares are complex phenomena that impact both the chromosphere/photosphere and the corona/transition region. IRIS can observe both regions using a variety of different spectral lines and continues to inform models seeking to explain the complex phenomena resulting in more accurate derived thermodynamic parameters.

OTHER MISSIONS AND DATA ANALYSIS

Recent IRIS results utilized machine learning techniques and inversions of multiple spectral lines formed in the chromosphere to provide unique new diagnostics of the temperature, velocity, turbulence, and density. IRIS observations have also led to exciting discoveries including the first solar observations of the parametric decay instability, a process thought to play a key role in the development of turbulence in the solar wind. IRIS has also revealed coronal nanojets, a new phenomenon thought to play a role in heating the multi-million degree corona, driven by the reconnection of magnetic field lines as they are braided by motions on the Sun’s surface. Researchers have also discovered new observables in the IRIS data that can help predict flares and have exploited IRIS data to provide novel input to modeling of the Sun’s irradiance and its impact on the Earth’s upper atmosphere.

INTERSTELLAR BOUNDARY EXPLORER (IBEX)

IBEX, launched in 2008, is the first mission designed to image the edge of the solar system. As the solar wind from the Sun flows out beyond Neptune, it collides with the material between the stars, forming several boundaries. These interactions create energetic neutral atoms (i.e., particles with no charge that move very quickly). This region emits no light that conventional telescopes can see, therefore IBEX measures particles that happen to be traveling inward from the boundary instead. IBEX contains two detectors designed to collect and measure energetic neutral atoms, providing data about the mass, direction of origin, and energy of these particles. From these data, researchers create maps of the boundary every six months.

The mission’s focused science objective is to discover the nature of the interactions between the solar wind and the interstellar medium at the edge of the solar system. This region is important because it shields a large percentage of harmful galactic cosmic rays from Earth and the inner solar system. IBEX is currently in extended operations. NASA approved IBEX for continued operations in 2023, and the mission will submit a proposal to the 2026 Senior Review cycle.

Recent Achievements

One significant achievement of the IBEX mission is the determination of the magnitude and direction of the interstellar magnetic field far from the Sun (i.e., approximately 1,000 astronomical units [au]), beyond the influence of the heliosphere. This information was extracted through a self-consistent model fit to IBEX ribbon data. IBEX observations provided a unified picture of the behavior of the local interstellar magnetic field, from its draping around the heliopause to its unfolding into the pristine interstellar medium. This aids us in understanding fundamental questions about the large-scale structure of the interstellar magnetic field And how far out a future mission would need to travel to sample the pristine interstellar field.

AERONOMY OF ICE IN MESOSPHERE (AIM)

AIM, launched in 2007, is a mission to determine why polar mesospheric clouds (PMCs) form and why they vary. PMCs, Earth’s highest-altitude clouds, form each summer in the coldest part of the atmosphere about 50 miles above the polar regions. When ice crystals form over tiny microparticles produced when meteors burn up in Earth's atmosphere, they create PMCs. These clouds have been steadily increasing over the past decade. PMCs are of particular interest, as the number of clouds in the middle atmosphere, or mesosphere, over Earth’s poles has been increasing over recent years, possibly related to climate change. The spacecraft completed its prime mission in FY 2009 and was in extended operations until March 13, 2023, when the AIM spacecraft lost voltage, which browned out the onboard-computer (OBC) and put the spacecraft into safehold mode. When the OBC powered off, the flight software patches made over the course of the mission to allow for Morse code commanding were erased and the spacecraft lost command and telemetry capability. NASA did not approve AIM for continued operations due to spacecraft failure and the low likelihood of recovery. The mission is working towards closeout.

Recent Achievements

The Cloud Imaging and Particle Size (CIPS) instrument on the AIM spacecraft has made gravity wave observations at the edge of the polar vortices and investigated gravity wave coupling to the Ionosphere. Gravity wave data measured by the CIPS instrument focus on 50 to 55 km altitude region in the winter polar vortices. Key findings include: During the 2020 to 2021 Arctic winter, the longitude of maximum gravity wave activity, maximum horizontal wind speed, and the polar vortex are co-located; and reduced gravity wave activity during the January 2021 Sudden Stratospheric Warming leads to simultaneous reductions in daytime traveling ionospheric disturbances.

TIME HISTORY OF EVENTS AND MACROSCALE INTERACTIONS DURING SUBSTORMS (THEMIS)

THEMIS is a MIDEX mission that launched in February 2007. Starting as a five-spacecraft mission, the three inner probes of THEMIS now focus on collecting data related to the onset and evolution of magnetospheric substorms, while the two outer probes (now referred to as Artemis) have been repositioned into lunar orbits. Magnetospheric substorms are the explosive release of stored energy within the near-Earth space environment that can lead to space weather effects. The two Artemis probes orbit the Moon’s surface at approximately 100 miles in altitude and provide new information about the Moon’s internal structure and its atmosphere. Artemis provides two-point observations essential to characterizing the Moon’s plasma environment and hazardous lunar radiation. THEMIS and Artemis, among others in the Heliophysics portfolio, are examples of missions offering important dynamics knowledge useful for future human space flight. THEMIS is currently in extended operations. NASA approved THEMIS for continued operations in 2023, and the mission will submit a proposal to the 2026 Senior Review cycle.

Recent Achievements

Using 11 years of observations, THEMIS isolated diurnal and seasonal variations in large-scale waves on the surface of Earth's magnetosphere (the magnetopause) that are a source for energy that can drive space weather effects. These large-scale waves are driven by the solar wind flowing over the magnetopause, similar to how winds drive waves on the ocean’s surface. Averaging over these 11 years, THEMIS found up to a 200 percent variation in wave occurrence across the day and up to a 50 percent variation between the seasons. These results advance our understanding of the underlying physics of energy input into Earth's magnetosphere and provide the next step towards the quantification and prediction of these potential space weather drivers.

ADVANCED COMPOSITION EXPLORER (ACE)

ACE launched in 1997 and observes particles of solar, interplanetary, interstellar, and galactic origins as they pass by its location near the L1 Lagrange point, located about one million miles from Earth toward the Sun. Changing conditions over the solar cycle are presenting new opportunities, including providing new insights relevant to space weather events.

OTHER MISSIONS AND DATA ANALYSIS

Understanding the origin of the solar wind is a fundamental area of research in Heliophysics. Using solar wind data from ACE and Wind, researchers study structures during Carrington Rotation 2002 (April 15 to May 13, 2003). They found that the slow-to-moderate speed solar wind intervals at one au can be mapped to large-scale coronal features such as helmet streamers around active regions. These are precisely the locations predicted by topological analysis to be sites favorable for interactions during the dynamic evolution of the magnetically open and closed regions of the solar corona. This work helps further the understanding of the origin of the slow-to-moderate-speed solar wind.

Recent Achievements

In late 2019, NOAA requested, with support from NASA, that NASA designate ACE as a permanent operational asset. It will continue to provide essential and continuous space weather observations from its location at the Earth's L1 point. The spacecraft has sufficient fuel and electric power remaining to operate and maintain an orbit at L1. ACE is currently in extended operations.

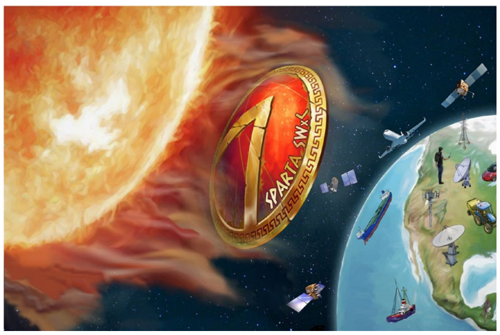
NASA approved ACE for continued operations in 2023, and the mission will submit a proposal to the 2026 Senior Review cycle.

SPACE WEATHER

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	25.8	--	47.5	42.6	40.0	35.9	34.2

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Pictured above is a shield protecting Earth from the Sun's rays. The shield is an illustration of how the Space Weather Research and Technology Applications (SPARTA) operate.

Space weather phenomena pose a significant threat to ground-based and space-based critical infrastructure, modern technological systems, and humans working in space. The NASA Space Weather program plays a vital role in the national space weather enterprise by providing unique and impactful observations and data streams for theory, modeling, and data-driven analysis. This program also supports enabling research and facilitates the transition of this research into solutions for the nation's operational space weather needs. NASA's contributions to observing and understanding space weather will enable the nation to better protect technology, national infrastructure, and astronauts from space weather.

The NASA Space Weather program involves a diverse mixture of activities including competed research, directed and competed space flight components and modeling infrastructure, and interagency and international cooperation. This approach allows the program to address gaps in national space weather capabilities wherever they are found and serves to enable the efficient maturation of technologies and subsequent transfer of critical new capabilities to partner agencies (e.g., NOAA and DoD).

EXPLANATION OF MAJOR CHANGES IN FY 2025

Orbital Debris and Space Situational Awareness (OD-SSA) activities moved from the Living With a Star program to the Space Weather program, with which OD-SSA activities are better aligned. This budget increases the Space Weather Futures project budget to incorporate the funds required to support the NASA contribution to the ESA space weather Vigil mission. The request also includes additional funding to support enhanced Space Weather "Research to Operations to Research" activities.

ACHIEVEMENTS IN FY 2023

The Space Weather program's competed research activities in FY 2023 enabled the transition of Heliophysics science results through the Space Weather Research to Operations to Research pipeline. It created opportunities to empower the research community to tackle critical existing and emerging challenges in space weather.

The program selected three Space Weather Centers of Excellence and is partnering with the Department of Commerce on the joint selection of a fourth proposal. This program element supported multi-institution collaboration to address grand challenge goals of space weather that require more than individual investigators or small teams. The program element took advantage of lessons learned from ongoing and past science centers and promotes synergistic, coordinated efforts to transform space weather capabilities and preparedness.

Final integration and testing work began for the four instruments comprising the Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) science payload that will be the first NASA science investigation on Gateway as part of Artemis. The program also received proposals for NASA's science instrument contribution to the ESA space weather mission Vigil that will monitor and study the Sun from the Sun-Earth Lagrange Point 5. The Space Weather program's orbital debris / space situation awareness effort started a new activity in FY 2023 to support the NASA JSC Orbital Debris Detector instrument for a flight opportunity on a JAXA mission. The Laser-sheet Anomaly Resolution and Debris Observation (LARADO) instrument passed its CDR. Selections were made for new ROSES sub-elements in support of orbital debris.

The Space Weather program’s support of human exploration activities enabled key NASA accomplishments in FY 2023 through the program’s Moon to Mars Space Weather Analysis Office. The office supported the 25.5-day Artemis I mission in close collaboration with the NOAA Space Weather Prediction Center (SWPC) and NASA Space Radiation Analysis Group (SRAG) teams. A post-Artemis-I evaluation identified valuable enhancements for the space weather support for Artemis II.

WORK IN PROGRESS IN FY 2024

The Space Weather program’s competed research activities will select new Space Weather Research to Operations to Research awards to support NASA operational partners. In addition, NASA may select a subset of the FY 2021 awards to continue to a new one-year Transition Step. The intent of this step is to focus the efforts of those selected awards to transition the capability to a proving ground for continued evaluation. Such proving ground efforts advance the maturity of results and products for space weather operations and require the participation of an operational partner or other end user to accomplish.

The program will issue a FY 2024 ROSES solicitation for Space Weather Research to Operations to Research and will select a subset of FY 2022 awardees for transition step funding. New in FY 2024, the program will begin exploring opportunities to expand funded research activities into applications-focused efforts that address decision making and societal benefit needs.

The Space Weather Centers of Excellence will conduct initial meetings and develop their strategic and implementation plans. The program will support a space weather tabletop exercise together with NOAA and NSF that will assess the U.S. government's preparedness and response procedures to a hypothetical large-scale space weather event.

The Space Weather program’s flight portfolio will see the completion of all instruments including additional hardware for HERMES. This flight hardware will enter storage in preparation for payload integration and testing prior to shipment for the first Gateway launch. The program will select the NASA science instrument contribution to ESA’s Vigil space weather mission scheduled to launch NET 2029. The first Space Weather payload pipeline instruments will complete integration and test activities and enter storage to be prepared for future opportunities hosted on commercial, space-based platforms.

The Space Weather program's orbital debris / space situation awareness effort will begin a new activity using spacecraft operations data to detect orbital debris strikes and the LARADO instrument will be delivered in preparation for launch. ROSES solicitation activity will continue in support of orbital debris research and instrument development.

SPACE WEATHER

The Space Weather program will select a NASA center to host the Space Weather Program Office in FY 2024. The program office will begin initial activities to provide programmatic support.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The Space Weather program's competed research activities will issue a ROSES solicitation for Space Weather Research to Operations to Research. Previously selected awardees may propose for transition step funding for the FY 2025 augmentation. The program will conduct second-year site visits at the Space Weather Centers of Excellence to evaluate and provide advice on progress, management, transition to operations, and outreach. The Space Weather program will begin to implement activities and opportunities to support space weather application projects aimed at supporting decision making and creating direct societal benefit.

The Space Weather program's flight portfolio will complete payload integration and testing of HERMES. Four space weather CubeSats will complete final preparations for launch in FY 2025.

The Space Weather program's orbital debris / space situation awareness effort will see the launch of the LARADO instrument on the DoD's Space Test Program (STP) mission STP-Sat7 in FY 2025.

The Space Weather program's support of human exploration will see the Moon to Mars Space Weather Analysis Office partnering with NOAA SWPC and NASA SRAG to support the Artemis II mission that will be the first crewed mission to the Moon since Apollo 17 in 1972.

Program Elements

SPACE WEATHER SCIENCE AND APPLICATIONS

The Space Weather Science and Applications project supports NASA missions as well as basic Space Weather Research and the Research to Operations to research pipeline, establishing the ecosystem required to support the effective transition of heliophysics science results, tools, technology, and techniques to applications that enhance the user communities' ability to address impacts caused by the dynamic space environment. To accomplish this, the Space Weather Science and Applications project engages with users and agencies to understand their space weather needs and with user communities to understand how they are impacted. This project is NASA's primary touchpoint for interagency space weather efforts and is consistent with the recommendations of the National Academy 2013 Decadal Survey for Solar and Space Physics, the Office of Science and Technology Policy 2019 National Space Weather Strategy and Action Plan, and the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow Act (PROSWIFT) Act of 2020.

Additional activities within the project include: mission support for the Moon to Mars office and Space Weather Satellite Operations Center; research support to the Community Coordinated Modeling Center (CCMC) and High-End Computing; research to operations to research support through CCMC; the Small Business Innovation Research Program; and support for Orbital Debris and Space Situational Awareness activities.

Orbital debris at all scales is present in the space environment, which affects objects in space, including space-based critical infrastructure and humans working in space. The NASA OD-SSA activity addresses a knowledge gap of this environment by focusing on orbital objects of both natural and anthropogenic sources that researchers cannot directly characterized by ground measurements, typically below three centimeters (cm) in size and all the way to nanometer-sized dust. This information is invaluable in understanding and mitigating the hazard posed by orbital debris. In addition, there is new space environment relevant science in the anthropogenic signatures caused by these objects passing through space plasmas. These interactions are becoming an increasing background signal especially in the more proliferated LEO, which researchers would like to differentiate from natural signals.

The NASA OD-SSA activity involves a diverse mixture of elements including competed research, directed and competed flight components, and interagency and international cooperation. This approach allows the activity to address gaps in orbital object detection and gaps in our scientific understanding of their interactions with the environment and serves to enable the efficient maturation of technologies and subsequent transfer of critical new capabilities to partner agencies such as the U.S. Department of Commerce (DOC), NOAA, and the DoD.

SPACE WEATHER RESEARCH AND ANALYSIS

The Space Weather Research and Analysis project supports competed research solicited under NASA ROSES, including Space Weather Research to Operations to Research efforts, funding HERMES interdisciplinary scientists, and the Space Weather Centers of Excellence. It also supports hardware through a partnership with the Heliophysics Technology program and its ROSES elements (Heliophysics Technology and Instrument Development for Science [HTIDeS] and Heliophysics Flight Opportunities in Research and Technology [HFORT]) and, starting in 2023, solicits proposals for a new pipeline instruments program element. These competed research opportunities serve to empower the research community to tackle critical existing and emerging challenges in space weather.

HELIOPHYSICS ENVIRONMENTAL AND RADIATION MEASUREMENT EXPERIMENT SUITE (HERMES)

HERMES will be a space weather payload on the Gateway (i.e., NASA's outpost in lunar orbit) as part of NASA's Artemis Campaign. The payload will be comprised of a suite of high-maturity instruments that will enable meaningful science in the lunar environment, support crew safety at the Moon, and be a pathfinder for future missions to Mars.

HERMES will launch with the first two elements of the Gateway. HERMES will enable the investigation of fundamental science questions like the acceleration mechanisms of solar energetic particles, variability of solar wind structures and Galactic Cosmic Rays, and magnetotail dynamics. Data collected by HERMES will also provide critical safety information for astronaut operations in the lunar environment. HERMES will support operational forecasting and nowcasting, or prediction of current events, of solar energetic particles that pose a risk to astronauts during extravehicular activities on the lunar surface.

In coordination with the two-spacecraft mission Odyssey's THEMIS and Artemis already in lunar orbit, HERMES will comprise a heliophysics lunar constellation that enables science investigations and space weather observations not possible before now. A second payload installed on the Gateway (European Radiation Sensors Array, provided by ESA) will further amplify the work of HERMES by providing additional data characterizing high-energy particles that are dangerous to crew safety.

SPACE WEATHER

SPACE WEATHER FUTURE MISSIONS

The Space Weather Future Missions project will support future space weather investigations and future NASA participation in international space weather missions which could provide valuable science data to advance understanding of the dynamics of space weather and improve space weather predictions. This project manages the international partnership with ESA on the Vigil mission.

Program Schedule

Date	Significant Event
Q1 FY 2024	HERMES flight instruments and hardware enter storage
Q2 FY 2024	ROSES-2023 Space Weather to Operations to Research (SWR2O2R) selections no earlier than six months after receipt of proposals
Q2 FY 2024	ROSES-2024 SWR2O2R solicitations
Q3 FY 2024	Selection of NASA science instrument contribution to ESA's Vigil mission
Q1 FY 2025	Moon to Mars Space Weather Analysis Office supports Artemis II mission
Q2 FY 2025	ROSES-2024 SWR2O2R selections no earlier than six months after receipt of proposals
Q2 FY 2025	ROSES-2025 SWR2O2R solicitations
Q2 FY 2025	HERMES payload integration and testing is completed
Q1 FY 2026	HERMES launches with first Gateway modules NET Oct 2025
Q2 FY 2026	ROSES-2025 SWR2O2R selections no earlier than six months after receipt of proposals
Q2 FY 2026	ROSES-2026 SWR2O2R solicitations
Q2 FY 2027	ROSES-2026 SWR2O2R selections no earlier than six months after receipt of proposals
Q2 FY 2027	ROSES-2027 SWR2O2R solicitations
Q2 FY 2028	ROSES-2027 SWR2O2R selections no earlier than six months after receipt of proposals
Q2 FY 2028	ROSES-2028 SWR2O2R solicitations
Q2 FY 2029	ROSES-2028 SWR2O2R selections no earlier than six months after receipt of proposals
Q2 FY 2029	ROSES-2029 SWR2O2R solicitations

Program Management & Commitments

Program Element	Provider
Space Weather Science and Applications	Provider: Various Lead Center: GSFC Performing Center(s): ARC, GSFC, HQ, JPL, LaRC, MSFC Cost Share Partner(s): None
Space Weather Research and Analysis	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, HQ, JPL, LaRC, MSFC Cost Share Partner(s): None
HERMES	Provider: GSFC Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): None
Space Weather Future Missions	Provider: Various Lead Center: HQ Performing Center(s): ARC, GSFC, HQ, JPL, LaRC, MSFC Cost Share Partner(s): None

Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA centers, industry, and academia, as well as other government agencies, Federally Funded Research and Development Centers, and nonprofit organizations. NASA may directly fund critical technologies identified through a gap analysis.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	SRB	2025	Review of instrument preliminary design- Vigil Instrument PDR	TBD
Performance	SRB	2025	Review of readiness for final payload integration work - HERMES Integration Readiness Review 2	TBD
Performance	SRB	2025	Review of readiness for final payload testing- HERMES Pre Environmental Review	TBD
Performance	SRB	2025	Review of readiness for shipment of HERMES payload to KSC - HERMES Pre Ship Review	TBD

SPACE WEATHER

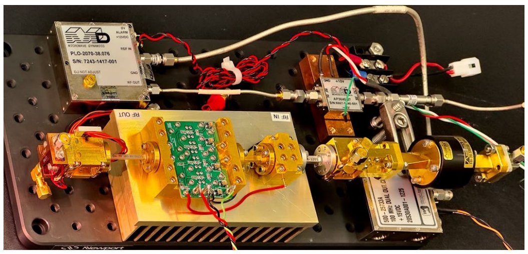
Review Type	Performer	Date of Review	Purpose	Outcome
Performance	SRB	2026	Review of instrument critical design - Vigil Instrument CDR	TBD
Performance	SRB	2028	Review of readiness to delivery instrument -Vigil Instrument Delivery Review	TBD

HELIOPHYSICS TECHNOLOGY

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	19.9	--	9.3	9.2	8.8	8.8	15.8

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Pictured above is a TeraHz Limb Sounder (TLS). TLS development will mature and optimize a low-noise, high-sensitivity Terahertz (THz) receiver to advance Heliophysics science in future space weather missions with reduced cost and schedule risks.

Advancements in Heliophysics depend on the ability to produce novel and transformative technologies, capabilities, and mission concepts. The Heliophysics Technology program makes strategic investments in the development and demonstration of instruments and technologies for infusion into future missions. Investments in new technologies will enable previously infeasible science investigations; improve existing measurement capabilities; reduce the cost, risk, and/or development times for Heliophysics science instruments and advanced space missions of the future; and yield applications that benefit the broader economy in areas of strategic importance such as space weather.

The Heliophysics Technology program supports projects that are competitively selected through the NASA ROSES solicitation, including the HTIDeS and Heliophysics Flight Opportunities Studies (HFOS) program elements. The program also includes the technology demonstration mission: the Magnetometers for Innovation and Capability (MAGIC).

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA has delayed the initiation of the Decadal recommendations for technology development until 2029.

ACHIEVEMENTS IN FY 2023

NASA conducted its inaugural Heliophysics technology symposium and completed the Heliophysics technology Gap and Trend Analysis and shared it with the community.

NASA selected technology proposals from non-heliophysics technologists to expand the heliophysics community and infuse novel technology ideas.

WORK IN PROGRESS IN FY 2024

NASA is developing a heliophysics technology website. The Web site will inform the heliophysics technologists of funded technology projects and create a community to generate novel and transformative ideas and proposals to the NASA solicitations.

NASA is developing the first annual heliophysics technology report, highlighting the progress made during the previous years.

HELIOPHYSICS TECHNOLOGY

KEY ACHIEVEMENTS PLANNED FOR FY 2025

NASA will complete the development of the heliophysics technology website to allow the principal investigators access to the Heliophysics technology portfolio, including highlights of technology development projects.

NASA will continue to publish the annual heliophysics technology report, highlighting the achievements of previous years and will continue to conduct the annual technology symposiums.

Program Elements

TECHNOLOGY ANALYSIS AND MISSION DESIGN

The Technology Analysis and Mission Design project invests in mission concept studies of novel and transformative applications of new technologies in future Heliophysics flight missions. This includes and expands on Heliophysics flight opportunities studies. This project also conducts periodic technology gap analyses and analyses of trends in technology development/advancement to identify gaps in Heliophysics technology. This will enable more focused solicitations in the Advanced Technology Development Project.

ADVANCED TECHNOLOGY DEVELOPMENT (ATD)

The ATD Project invests in the development of critical and innovative new instruments and technologies, and novel and transformative capabilities to achieve significant progress toward addressing the scientific and technical challenges in Heliophysics in the coming years. This includes and expands on HTIDeS. This project will also establish an incubator process for the most promising early Technology Readiness Level (TRL) technologies to proactively nurture and advance these capabilities. This project includes direct funding for critical technologies identified through the gap analysis.

This project also includes the Alternative Initiation of Technology Exploration (AITE) element to grow and diversify the Heliophysics technology development community. As a component of the HTIDeS element, AITE solicits proposals from non-heliophysics technologists to collaborate with heliophysics scientists and apply their technologies in solving key Heliophysics Science questions. The goal is to tap into non-heliophysics technologies to solve Heliophysics Science questions.

MAGNETOMETERS FOR INNOVATION AND CAPABILITY (MAGIC)

MAGIC is a five-year project to develop key fluxgate magnetometer technology and to design, build, test, and fly a next-generation space flight fluxgate. Fluxgate magnetometers are a widely used instrument that provides measurements of the Direct Current (DC) and low-frequency Alternating Current (AC) magnetic field. MAGIC will deliver world-class magnetic measurements without relying on the legacy ring-cores used by other providers and can be scaled and tuned for other applications.

NASA will launch MAGIC as a technology demonstration payload on the Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) mission in FY 2026.

HELIOPHYSICS TECHNOLOGY

Program Schedule

Date	Significant Event
Q1 FY 2024	ROSES-2023 HTIDeS and HFOS selections
Q2 FY 2024	ROSES-2024 HTIDeS and HFOS solicitations released
Q3 FY 2024	MAGIC 1&2 delivery for TRACERS Instrument Suite integration and test
Q1 FY 2025	ROSES-2024 HTIDeS and HFOS selections
Q2 FY 2025	ROSES-2024 HTIDeS and HFOS solicitations released
Q1 FY 2026	ROSES-2025 HTIDeS and HFOS selections
Q2 FY 2026	ROSES-2025 HTIDeS and HFOS solicitations released
Q1 FY 2027	ROSES-2026 HTIDeS and HFOS selections
Q2 FY 2027	ROSES-2026 HTIDeS and HFOS solicitations released
Q1 FY 2028	ROSES-2027 HTIDeS and HFOS selections
Q2 FY 2028	ROSES-2027 HTIDeS and HFOS solicitations released
Q1 FY 2029	ROSES-2028 HTIDeS and HFOS selections
Q2 FY 2029	ROSES-2028 HTIDeS and HFOS solicitations released

Program Management & Commitments

NASA assigned program management responsibility of the Heliophysics Strategic Technology Office to the WFF.

Program Element	Provider
Technology Analysis & Mission Design (TAMD)	Provider: WFF Lead Center: WFF Performing Center(s): WFF Cost Share Partner(s): None
Technology Development (TD)	Provider: Various Lead Center: HQ Performing Center(s): TBD Cost Share Partner(s): None
MAGIC	Provider: University of Iowa Lead Center: GSFC Performing Center(s): GSFC Cost Share Partner(s): None

HELIOPHYSICS TECHNOLOGY

Acquisition Strategy

NASA primarily procures tasks through full and open competition, such as the ROSES announcements. The solicitation of technology investments is competitive and selected from NASA centers, industry, and academia as well as other government agencies, Federally Funded Research and Development Centers, and nonprofit organizations. NASA may directly fund critical technologies identified through a gap analysis.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Relevance	National Academies of Science, Committee for Solar and Space Physics (CSSP)	2024	Independent assessment of targeted technology development priorities for Heliophysics Technology	TBD

BIOLOGICAL AND PHYSICAL SCIENCES

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**85.0**	**--**	**90.8**	**91.3**	**93.0**	**94.8**	**96.6**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Biological and Physical Sciences

BIOLOGICAL AND PHYSICAL SCIENCES

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**85.0**	**--**	**90.8**	**91.3**	**93.0**	**94.8**	**96.6**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Shown here, Astronaut Serena M. Auñón-Chancellor is conducting cancer research aboard ISS using the Microgravity Sciences Glove Box.

NASA's Biological and Physical Sciences (BPS) division conducts research in space to obtain critical insights into how biological and physical systems function. The unique, extreme conditions found in space, such as altered gravity and deep-space radiation, enable scientists to probe biological and physical systems in ways not possible on Earth. The resulting knowledge can lead to scientific discoveries and technological advancements that both support NASA's deep-space missions and benefit life on Earth.

In September 2023, BPS received the 2023-2032 Decadal Survey on Biological and Physical Sciences Research in Space from the National Academies of Science, Engineering, and Medicine. The report focuses on three scientific themes: 1) Adapting to Space; 2) Living and Traveling in Space; and 3) Probing Phenomena Hidden by Gravity or Terrestrial Limitations. The priorities recommended by the Decadal will help shape BPS's strategic science plan for the decade ahead. The division is also completing research commitments recommended by the 2011 Decadal Survey.

BPS is currently comprised of three programmatic elements: Space Biology, Physical Sciences, and Commercially Enabled RapId Space Science (CERISS). While the division formulates its Decadal response, BPS will continue research in the previously established focus areas:

- Physical Sciences: The Physical Sciences Program includes research in the following disciplines: Fundamental Physics/Quantum Science, Fluid Physics, Combustion, Material Science, Soft Matter, and Biophysics. Prior to the receiving the Decadal Survey, the Physical Sciences Program prioritized a pivot area to study Quantum Science, primarily using the Cold Atom Lab (CAL) on ISS.
- Space Biology: Thriving In DEep Space (TIDES), which pioneers fundamental biological discoveries that enable humans to go farther and stay longer in space, and contributes to biomedical and agricultural advancements on Earth.
- CERISS: Developing transformative research capabilities with commercial space industry to dramatically increase the pace of research through the development and demonstration of in-situ analysis, sample preparation and handling, and specialized equipment for the next generation of microgravity science.

BIOLOGICAL AND PHYSICAL SCIENCES

BPS conducts investigations via competitively awarded research grants to scientists at universities, research institutions across the country, and NASA centers and to the extent practicable, leverages Small Business Innovation Research (SBIR) investments. BPS develops critical equipment and processes to support new experiments and shares research results with academia, commercial industry, and other government agencies.

The division facilitates and oversees collaborations between a wide range of agencies, including the National Institutes of Health (NIH), National Center for Advancing Translational Sciences, NIH's National Institute of Allergy and Infectious Diseases, NIH's National Cancer Institute Division of Cancer Treatment and Diagnosis, Biomedical Advanced Research and Development Authority, U.S. Department of Agriculture, U.S. DoD, National Research Office, and the Food and Drug Administration.

EXPLANATION OF MAJOR CHANGES IN FY 2025

BPS funding is reduced compared to the FY 2024 President's Budget level due to constraints in the FY 2025 Request and other NASA priorities. This reduction will delay implementation of Decadal Survey recommendations. Within the BPS budget, NASA is prioritizing funding for the CERISS project, which, while reduced in scope compared to the FY 2024 Request, will expand suborbital or orbital demonstrations compared to what was funded in the FY 2023 enacted level. Space Biology will implement reductions to animal and cellular and molecular science studies.

ACHIEVEMENTS IN FY 2023

2023-2032 Decadal Survey: BPS received the Academies' Decadal Survey in September 2023 and began reviewing the priority recommendations.

CERISS: BPS received responses from two Requests for Information (RFIs): one for commercial space companies to identify current and future capabilities, and the second to the scientific community at large to identify which areas of research would most benefit from in-situ analysis and sample preparation. Additionally, BPS established a collaborative solicitation with the Flight Opportunities program which presently has full proposals under review.

Quantum Science: Research using the CAL facility on ISS demonstrated the first simultaneous production of a dual species Bose Einstein Condensates (BECs) in space resulting in a publication in Nature. In FY 2023, CAL launched a replacement science module (i.e., SM-3B) to ISS on the Northrop Grumman commercial resupply flight 19 (NG-19) to provide needed upgrades. These upgrades will contribute to fundamental science—the foundation for many technological advancements—by enabling researchers to explore interacting quantum matter to gain insight into analogous systems from subatomic particles to cosmological phenomena, precision tests of gravity, and the nature of dark matter and dark energy.

TIDES: BPS successfully flew four Artemis I experiments aboard the Orion capsule in the early part of the fiscal year. These experiments focused on robust single-cell model organisms (e.g., algae, fungi, yeast) and plant seeds. Analysis began in FY 2023 and continues into FY 2024. The Plant Habitat-03 experiment, a generational study that examines the transmission of environmentally induced genetic changes in seeds grown in space flight to subsequent generations, successfully grew two generations of plants aboard the space station to analyze whether those changes stabilize or continue to accumulate over time. Analysis will continue into FY 2024. The VEG-05 experiment, a joint effort with NASA's Human Research Program (HRP), grew Red Robin tomatoes on the space station. This investigation will test different light color ratios for fruit production, microbial food safety, nutritional value, and overall crew behavioral health benefits. The joint NASA-JAXA Mouse Habitat Unit 8 (MHU-8) flew the first vertebrate investigation utilizing centrifugation aboard the space station to simulate partial gravity as well as 1g (Earth's gravity) to increase the fundamental understanding of the effects of gravity as a continuum. This fundamental understanding will inform future crewed missions of possible oxidative stress and inflammatory responses that may be exhibited when adapting to altered gravity environments as will be encountered on planetary and other future exploration missions.

Combustion Safety for Exploration: Given that scientists do not understand the full range of ignition and extinction conditions for solid fuels in microgravity, NASA began utilizing the Solid Fuel Ignition and Extinction (SoFIE) facility to conduct the Growth and Extinction Limit (GEL) investigation to study thermally thick, non-flat fuels where interior sample heating causes unsteady flame propagation. Flow fields around such samples are also different than for flat samples, causing different burning and extinction characteristics. This research can contribute to safer conditions for crew in space during long-duration missions.

Cryogenic Fluid Management: The Physical Sciences Program is working on a series of experiments on ISS called Zero Boil-Off Tank experiment (ZBOT) using simulant fluids to study fundamental fluid phenomena for propulsion system applications resulting in models to improve understanding. The current experiment, ZBOT- non-condensable gas (NC), is studying the effects of non-condensables on pressurizing propellant tanks analogous to helium pressurization. The ZBOT-NC project is currently developing the flight hardware assembly currently scheduled to launch in early 2025. The third experiment under consideration pending review of Decadal priorities, ZBOT-DP, is intended to study active cooling applications using droplet phase physics to control pressure. The key output from these experiments is the development of validated models to help better predict propellant tanks directly applicable to in-space and lander propellant systems.

Thermal Management: BPS launched the Flow Boiling Condensation Experiment (FBCE) facility to ISS on NG-16 in August 2021 as a multi-user facility with multiple module inserts planned. The first module, Flow Boiling Module (FBM), completed research in 2023 studying two-phase flow and heat transfer models in microgravity. The second FBCE module, Condensation Module-Heat Transfer (CM-HT), launched in August 2023 and will investigate condensation of a flowing saturated or superheated vapor.

WORK IN PROGRESS IN FY 2024

Decadal Survey: BPS will formulate the division's strategic response plan, develop roadmaps, and map current research to the Decadal's Key Science Questions. BPS will also meet with colleagues across NASA, other government agencies, international partners, commercial industry, and academia to discuss areas of mutual interest and collaboration. NASA will issue an initial written response in 2024.

Artemis II: BPS plans to prepare tissue chip research to fly aboard the Orion capsule on Artemis II. This research could provide valuable insights into the effects of deep-space stressors, such as ionizing radiation, on human tissues. This research could pave the way for developing preventative measures to ensure crew safety on long-duration missions, as well as enable other health organizations to advance treatments for cancer, disease, and aging on Earth.

CERISS: BPS plans to award contract(s) to the commercial space industry to develop capabilities needed to conduct research in LEO. BPS will take steps towards addressing CERISS capability needs by partnering with NASA's Flight Opportunities program to solicit for suborbital or orbital flights. Flight studies to develop in-situ analysis and sample preparation capabilities will support science in LEO.

Quantum Science: CAL will enable new experiments with improved atom numbers of rubidium and potassium gases cooled to within a billionth of a degree of absolute zero. These experiments will investigate the fundamental nature of matter, as well as mature sensors to enable new studies of Earth and planetary sciences, navigation, and quantum materials.

TIDES: In FY 2024, BPS will continue its focus on understanding the fundamental mechanisms to adapting and thriving in space by continuing to fly research on the space station and conducting space- and relevant ground-based investigations: 1) Rodent Research-20, which will aid in our understanding of space flight impacts on female astronaut health; 2) microbial research, studying antibiotic resistance in the bacteria found on ISS, which could provide insights for ensuring crew health and on pathogens in environments such as hospitals; and, 3) plant research on microbes, metabolism, genetics, and responses to space flight stressors, to understand what's needed to sustainably grow crops for long-duration missions and benefitting agriculture in austere environments on Earth.

Enabling Exploration Engineering: BPS will continue fundamental investigations into physical sciences phenomena that will support deep-space missions: 1) Fluids - To combat potential propellant losses using a combination of techniques, BPS will deliver the second experiment in the ZBOT investigation series (i.e., ZBOT-NC) to the space station; 2) Materials Sciences - To enable the development of new materials and alloys for novel applications, BPS investigators will participate in an ESA-led team to collect, share, and analyze thermophysical property data collected in ESA's Electromagnetic Levitator facility; 3) Fabrication - To develop improved fabrication techniques that can mimic complex, efficient natural materials, NASA will conduct two investigations in micro- and partial gravity environments that will provide a better fundamental understanding of both solidification behavior and complex structure formation; 4) Flammability studies - Given that the conditions of the Moon's atmosphere and gravity could pose a greater fire hazard than on Earth or in microgravity, NASA will use the SoFIE facility to conduct the Residence Time Driven Flame Spread (RTDFS) investigation that will study flame propagation over solid fuels of varying thickness in microgravity; and 5) Thermal management - NASA will allow the ISS National Laboratory to utilize FBCE hardware for NSF investigators to perform additional studies, enabling both organizations to advance their investigations and more fully optimize the hardware investment. In addition, NASA will begin development on a third module, Transfer Line (TL), to investigate the microgravity effects online chilldown of fluid transfer systems.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

Artemis II: BPS will analyze tissue chip samples returned from the Artemis II mission and share insights across NASA, including HRP, and with other government agencies.

CERISS: BPS plans to award contract(s) to the commercial space industry to develop capabilities needed to conduct rapid research in LEO that aligns with Decadal survey recommendations. BPS will leverage its partnership with the NASA Flight Opportunities program to solicit for suborbital or orbital flights in order to evaluate and demonstrate new CERISS capabilities prior to implementation. BPS will also seek the utilization of launches on suborbital and orbital platforms from commercial entities, which offer innovative solutions to the limited access and high cost of space science research.

TIDES: BPS will continue to focus primarily on currently awarded investigations in LEO that examine fundamental mechanistic impacts across multiple biological systems. These investigations will focus on advancing understanding of how different biological systems adapt to space flight and how these systems may impact crew health. BPS will also continue space-based plant experiments to further understand how fundamental mechanisms associated with plant growth are impacted by the space flight environment. BPS plans to fly Arabidopsis inside the Biological Research in Canisters- Light Emitting Diode (BRIC-LED) payload to understand the role of Reactive Oxygen Species (ROS) in signaling when plants are under attack from a pathogen. This is significant since understanding the basic signaling mechanisms plants employ against bacterial pathogens will aid in future space-based crop production, as well as potential plant infection identification techniques on Earth. BPS also plans to continue FY 2024 studies that seek to understand how certain strains of bacteria develop antibiotic resistance aboard ISS. Results from this study may help advance our understanding of how bacteria develop antibiotic resistance in other built environments like hospitals.

Quantum Sciences: NASA will continue research using CAL, including bringing on new research awards. In collaboration with ESA and JPL, NASA will launch the ACES atomic clock mission. NASA will collaborate with the National Reconnaissance Office (NRO) to launch the Satellite Entanglement and Annealing QUantum Experiment (SEAQUE) mission to the space station to study quantum entanglement.

Physical Sciences: NASA will launch, commission, and begin operations on the ZBOT-NC experiment and continue hardware design and development for the FBCE-TL experiment. NASA will continue operations of the SoFIE investigation series. In collaboration with ESA, NASA will continue materials sciences research using the Material Science Lab and in collaboration with JAXA, NASA will continue materials sciences research using the Electrostatic Levitator Facility (ELF) on station.

Research Solicitations: BPS will issue research solicitations focused on advancing the division's Decadal implementation strategy.

Program Elements

BPS Program Management

This project funds BPS's institutional and crosscutting activities including: National Academies studies, proposal peer review processes, printing and graphics, information technology, the NASA Postdoctoral Fellowship Program, NASA Research and Educational Support Services (NRESS), working group support, independent assessment studies, communications, and other administrative tasks.

Space Biology

The main objective of the Space Biology Project is to build a better understanding of how space flight affects living systems in spacecraft (e.g., ISS) or in ground-based experiments that mimic aspects of space flight, and to prepare for future human exploration missions far from Earth. The experiments researchers conduct on these platforms examine how plants, microbes, and animals adjust or adapt to living in space. Researchers study the processes of metabolism, growth, stress response, physiology, and development. The program studies how organisms repair cellular damage and protect themselves from infection and disease in conditions of microgravity, while being exposed to space radiation—and across the spectrum of biological organization, from molecules to cells, from tissues to organs, and from systems to whole organisms, to communities of microorganisms. These studies often reveal new insights into biological functions that would be difficult or impossible to obtain only through Earth-based experiments.

In addition to providing useful information on how living organisms adapt to space flight, the discoveries NASA researchers make in space have significant implications for life on Earth. Space Biology's research into the virulence of pathogens in space, loss of bone density, and the changes in the growth of plants can

BIOLOGICAL AND PHYSICAL SCIENCES

impact the development of drugs that promote wound healing or tissue regeneration. This research will also inform treatments designed to counter osteoporosis on Earth, and high-tech fertilizers that increase crop yield.

BPS is committed to open science via comprehensive space-related omics databases where users can upload, download, share, store, and analyze space flight and space flight-relevant data from experiments using model organisms. Omics refers to a collection of biological classes of study, such as genomics, transcriptomics, and others that focuses on the collective characterization and quantification of pools of biological molecules that translate into the structure, function, and dynamics of an organism or organisms. BPS's databases include: GeneLab, the Life Sciences Data Archive, and Ames Life Sciences Data Archive.

PHYSICAL SCIENCES

Physical Sciences research makes contributions in two distinct ways. The first, basic research investigates physical phenomena in the absence of gravity, fundamental laws of the universe, and provides transformative understanding of the underlying mechanisms governing physics. Quantum Science is the primary focus area for basic research, which takes advantage of the ability to "float" assemblies of ultra-cold atoms in microgravity for long times with extremely gentle forces—something that researchers cannot do on Earth.

The second type of contribution is applied research, which contributes to the basic understanding of underlying space exploration technologies (e.g., power generation and storage, space propulsion, life support systems, and environmental monitoring and control) and leads to transformational capabilities for exploration. The Combustion Science, Fluid Physics, and Materials Science research is in this category. In these applied areas, microgravity is both a scientific tool but also a major challenge for engineering systems that must operate in space. The scientific advances in these areas can enable transformative advances in spacecraft systems. BPS stores the data acquired from these investigations in NASA's Physical Sciences Informatics system (PSI) and makes it available to the public.

COMMERCIALLY ENABLED RAPID SPACE SCIENCE (CERISS)

CERISS will develop transformative research capabilities with commercial space industry partners to dramatically increase the pace of research. Long-range goals include developing automated hardware for experiments both in LEO and beyond, including the lunar surface. The benefits will include a dramatically faster pace of research for a wide range of research sponsored by BPS, the NASA HRP, other government agencies, and industry. A potential additional benefit could be a signal of possible future increases in demand for research and development (R&D) in LEO, facilitating growth of the commercial space industry.

Program Schedule

The BPS program solicits proposals as part of the SMD's annual Research Opportunities in Space and Earth Sciences (ROSES) research calls. The program issues solicitations every year.

BIOLOGICAL AND PHYSICAL SCIENCES

Date	Significant Event
Q1-Q2 FY 2024	Decadal Survey response workshops
Q3 FY 2024	ROSES-2024 NASA Research Announcements (NRA) selection within six to nine months of receipt of proposals
Q4 FY 2024	ROSES-2024 selection within six to nine months of receipt of proposals
Q2 FY 2025	ROSES-2025 solicitation release
Q2 FY 2025	ROSES-2025 NRA selections within six to nine months of receipt of proposals
Q4 FY 2025	ROSES-2025 selections within six to nine months of receipt of proposals
Q2 FY 2026	ROSES-2026 solicitation release
Q2 FY 2026	ROSES-2026 selections within six to nine months of receipt of proposals
Q4 FY 2026	ROSES-2026 selections within six to nine months of receipt of proposals

Program Management & Commitments

SOMD, through the ISS Program Vehicle Office, will retain responsibility for the sustainment, maintenance, and operation of multi-user hardware that supports the BPS research portfolio. Additionally, SOMD, through the ISS Program Research Integration Office, will retain responsibility to fund the Mission Integration and Operations (M&IO) work for BPS investigations through at least FY 2024. NASA will reassess this support as commercial LEO capabilities evolve.

Program Element	Provider
Space Biology (animal biology, microbiology, and open science)	Provider: Various Lead Center: ARC Performing Center(s): ARC, KSC Cost Share Partner(s): N/A
Space Biology (plant biology, cell biology, molecular biology, and plant microbiology)	Provider: Various Lead Center: KSC Performing Center(s): ARC, KSC Cost Share Partner(s): N/A
Physical Sciences (soft matter, fluids, combustion, Fluids Integrated Rack, Combustion Integrated Rack)	Provider: Various Lead Center: GRC Cost Share Partner(s): N/A
Physical Sciences (materials and Materials Science Research Rack)	Provider: Various Lead Center: MSFC Cost Share Partner(s): N/A

BIOLOGICAL AND PHYSICAL SCIENCES

Program Element	Provider
Physical Sciences (quantum research, fundamental physics, CAL)	Provider: Various Lead Center: JPL Cost Share Partner(s): N/A

Acquisition Strategy

BPS competitively selects its research via NRAs. Once selected, the principal investigator is paired with a NASA field center and a commercial partner to facilitate the implementation of the project.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Independent Review Board (IRB)	Mar 2023	SoFIE GEL: Operational Readiness Review (ORR)	Successful
Performance	IRB	Aug 2023	FBCE Condensation Module Heat Transfer (CMHT): ORR	Successful
Relevance	National Academies of Sciences	Sep 2023	Decadal survey review of BPS research priorities	A report outlining the Academies' recommendations for physical and biological sciences research in the decade ahead. BPS is reviewing the report, preparing roadmaps, meeting with partners (within NASA, other government agencies, international partners, academia, et al), and preparing an initial response.
Performance	IRB	Oct 2023	PFMI MEFC-FC2	Successful
Performance	IRB	Jan 2024	CAL SM-3B: ORR	TBD
Performance	IRB	Jan 2024	SoFIE MIST: ORR	TBD
Performance	IRB	May 2024	SoFIE RTDFS: ORR	TBD
Performance	IRB	Sep 2024	ZBOT: Non-Condensables System Acceptance Review	TBD
Performance	IRB	Nov 2024	ZBOT: Non-Condensables ORR	TBD

AERONAUTICS

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Airspace Operations and Safety Program	151.6	--	**151.2**	164.3	174.1	177.7	180.9
Advanced Air Vehicles Program	258.0	--	**278.8**	269.6	262.4	248.8	218.7
Integrated Aviation Systems Program	261.1	--	**264.4**	277.0	277.6	300.9	342.0
Transformative Aeronautics Concepts Program	147.1	--	**155.3**	157.6	171.1	175.2	179.0
Aerosciences Evaluation and Test Capabilities	117.3	--	**116.2**	116.5	119.5	122.3	124.7
Total Budget	**935.0**	**935.0**	**965.8**	**985.1**	**1,004.8**	**1,024.9**	**1,045.4**

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

AERONAUTICS

FY 2025 Budget

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NASA's X-59 supersonic aircraft sits on the apron outside Lockheed Martin's Skunk Works. The X-59 seeks to make sonic booms quieter.

Credit: Lockheed Martin Skunk Works

NASA Aeronautics leads the nation's aviation community in research to maintain and advance American leadership in aviation. ARMD is working to improve efficiency and reduce the noise and emissions of commercial aircraft; advance the safety, capacity, and efficiency of air transportation; and enhance aviation as an economic engine. The Aviation sector is critical to the U.S. economy providing a positive manufacturing trade balance of $51 million in 2021 and 2.1 million aerospace/defense jobs.

ARMD is working to enable transformation of future air travel in at least four major areas.

- <u>Ultra-Efficient Airliners</u>: NASA is committed to supporting the U.S. climate goal of achieving net-zero greenhouse gas emissions from the aviation sector by 2050. Under the Sustainable Flight National Partnership (SFNP), NASA is leading federal agencies and industry to accelerate the development of sustainable technologies. The Advanced Air Vehicles Program (AAVP), Integrated Aviation Systems Program (IASP), and Airspace Operations and Safety Program (AOSP) execute the SFNP activities.

- <u>High-Speed Commercial Flight</u>: NASA's Quesst mission will demonstrate that supersonic aircraft (X-59) can fly without generating loud sonic booms and survey what people hear when it flies overhead. Reaction to the quieter sonic "thumps" will be shared with regulators who will then consider writing new rules to lift the ban on faster-than-sound flight over land. AAVP and IASP execute the Quesst mission.

- <u>Future Airspace and Safety</u>: NASA is working with the Federal Aviation Administration (FAA), industry, and academia to transform air traffic management systems to safely accommodate the growing demand of new air vehicles entering the airspace, enabling them to perform a variety of missions no matter what airspace that mission may require. AOSP executes the future airspace activities.

- Advanced Air Mobility (AAM): NASA's AAM mission will help emerging aviation markets safely grow and integrate into the air transportation system, moving people and cargo between places previously not served or underserved by aviation, using revolutionary new aircraft and operational concepts that are only just now becoming possible thanks to converging technologies. AAM management technologies will be leveraged to improve responses to wildfires. AOSP and AAVP execute the AAM mission.

In addition to research that directly aligns with the four major transformation areas, ARMD conducts foundational research on crosscutting ideas and technologies. This research enables a broad range of aeronautics and aerospace applications and explores opportunities for technology convergence from disparate technology areas. Flight and ground capabilities for experimentation and feasibility demonstrations are additional elements that support the entire ARMD portfolio.

ARMD guides these transformation efforts through a strategic implementation plan. The plan lays out NASA’s approach to addressing the three key drivers of aviation transformation: the growing demand for global air mobility; energy efficiency and environmental sustainability; and the opportunity for convergence between traditional aeronautical disciplines and technology advances in information technology, communications, energy, and other rapidly evolving technologies. The strategic implementation plan identifies six research thrusts to comprehensively address the three key drivers.

For more information on the Aeronautics strategic plan, go to: https://www.nasa.gov/aeronautics/nasa-releases-newest-vision-for-flight-research/

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA adjusted funding for elements of the SFNP. The Sustainable Flight Demonstrator project is being allocated increased funding as the X-66 aircraft moves into the design/build phase. Funding for the Electrified Powertrain Flight Demonstrations project is being decreased as it completes the build phase. Additionally, funding for the Hi-Rate Composite Aircraft Manufacturing (HiCAM) project is being increased by more than previously planned to enable the completion of major ground tests of both a wing and fuselage component.

NASA increased funding for the Low Boom Flight Demonstrator (LBFD) to cover rebaselined commitments for cost and schedule. The project was rebaselined due to poor contractor performance and COVID impacts from 2020 through 2022 that caused delays to X-59 aircraft delivery.

NASA increased funding for non-CO_2 greenhouse gas emissions research and studies in AAVP. With increased scientific and engineering focus, this research could lead to completely eliminating a major aviation greenhouse gas effect in the relatively near-term.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The budget request supports five programs within the agency’s aeronautics portfolio:

AOSP advances mobility through modernizing and transforming the national air traffic management system, in partnership with the FAA and the aviation community. The program develops and explores advanced technologies for more efficient gate-to-gate flight trajectories, leads research on increasingly autonomous aviation, and provides tools for the integration and analysis of data to support in-time system-wide safety assurance. The program has focused efforts to advance the safe integration of new advanced air mobility vehicles into the airspace. The program is also addressing the need for improved responses to wildfires by leveraging its UAS traffic management capabilities. In FY 2025, AOSP will:

- Evaluate operating standards and performance requirements for the safe operation of small drones in beyond visual line-of-sight missions to assist FAA rulemaking;
- Initiate development of the airspace management technology and mission capabilities needed to improve aerial responses to wildfires based on an interagency concept of operations;
- Deliver tools and methods to the FAA and industry that support safety certification of advanced aerospace technologies and systems; and
- Working with the FAA, mature the vision for future airspace operations in 2045 and establish critical research and development goals to meet desired outcomes.

AAVP develops the tools, technologies, and concepts that enable new generations of civil aircraft that are safer, faster, more energy-efficient, and have a smaller environmental footprint. The program pioneers fundamental aeronautics research and matures the most promising concepts for transition to the community. Key focus areas include: enabling major leaps in the safety, efficiency, and environmental performance of subsonic fixed and rotary wing aircraft; overcoming noise and other technology challenges to high-speed flight, including demonstration of quiet supersonic flight with the X-59 aircraft via community response testing; and understanding and tackling critical challenges of hypersonic flight. In FY 2025, AAVP will:

- Evaluate and select high-rate composite aircraft manufacturing technologies for two major aircraft component demonstrations;
- Continue development of integrated small core aircraft engine technologies for demonstration in FY 2027;
- Conduct fundamental and applied research to enable a broad spectrum of hypersonic systems and missions; and
- Complete preparation for the initial X-59 supersonic aircraft community-response flight test, planned for FY 2026.

IASP explores, assesses, and demonstrates the benefits of the most promising technologies at an integrated system level, including in flight. The program has three major flight projects: Sustainable Flight Demonstrator, Electrified Powertrain Flight Demonstrations, and Low Boom Flight Demonstrator. Also, the program funds flight support capabilities and other aeronautics research related to flight tests. In FY 2025, IASP will:

- Conduct acoustic validation flight testing of the X-59 Low Boom Flight Demonstrator to prove that acoustic characteristics match design targets for quiet supersonic flight;
- Complete final stages of development of electrified powertrain flight demonstrators with GE Aerospace and magniX; and
- Continue working with Boeing on the Sustainable Flight Demonstrator which has a planned first flight date in FY 2028.

The Transformative Aeronautics Concepts Program (TACP) demonstrates initial feasibility of concepts supporting the discovery and development of new transformative solutions supporting the NASA Aeronautics strategy, including exploring opportunities to create a net zero-emissions aviation future. The program encourages revolutionary concepts, creates the environment for researchers to become immersed in new ideas, performs ground and small-scale flight tests, allows failures and learns from them, and drives rapid turnover of new concept development. In FY 2025, TACP will:

- Advance state-of-the-art computational and experimental tools and technologies that are vital to aviation applications;
- Explore new concepts such as data and decision support tools and weather capabilities for advanced air mobility flight within the Convergent Aeronautics Solutions activity; and
- Fund up to three new University Leadership Initiative awards and will evaluate the results of five ongoing awards.

Aerosciences Evaluation and Test Capabilities Portfolio (AETC) manages NASA's portfolio of 12 large wind tunnels used for ground testing of advanced technologies and configurations across all speed regimes: subsonic, transonic, supersonic, and hypersonic. These test facilities also serve the needs of other NASA mission directorates, as well as non-NASA users. In FY 2025, AETC will:

- Conduct wind tunnel experiments for NASA and external customers to assess technology in simulated ground-test environments;
- Assess the condition and health of testing capabilities at ARC, GRC, and LaRC to identify and address equipment with a high-risk of failure due to age or maintenance issues; and
- Develop robust testing methodologies to reduce flight certification time in low-speed, high-lift flight envelope using the LaRC National Transonic Facility.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**151.6**	**--**	**151.2**	**164.3**	**174.1**	**177.7**	**180.9**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Advanced Capabilities for Emergency Response Operations project will develop an interagency Concept of Operations (ConOps) and demonstrate airspace management and emerging aviation technologies to improve emergency response to wildland fires.

The U.S. air transportation system is one of the most efficient and safest systems in the world. NASA has substantially contributed to the Federal Aviation Administration (FAA)-led NextGen modernization effort that will meet growing air traffic demand by enabling efficient passage through the increasingly crowded skies. However, there are additional opportunities for reducing fuel burn, aircraft emissions, weather- and operations-related flight delays, and environmental impacts through increased operational efficiency.

With the FAA, industry, and academic partners, the Airspace Operations and Safety Program (AOSP) conceives, develops, and demonstrates technologies to safely improve aircraft systems that will operate in the National Airspace System (NAS). The program develops advanced technologies for a service-oriented and federated NAS architecture to enable seamless integration of emergent vehicles (e.g., unmanned aircraft systems [UAS] and advanced air mobility [AAM] vehicles) with present-day aircraft. AOSP also works with other ARMD programs to define safe NAS operational requirements for the next generation of vehicles, mature new transformative concepts, and demonstrate integrated systems.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

- NASA worked with industry partners to demonstrate a computer cloud-based trajectory management service that enables flight operators to identify efficient departure routes and improve the environmental sustainability of air transportation. (Air Traffic Management eXploration [ATM-X])
- NASA engaged with industry to develop and evaluate novel air traffic management capabilities for AAM vehicles in flight. These capabilities were rigorously validated in a controlled environment and were transitioned for use in field demonstrations. Version 2.0 of the Urban Air Mobility (UAM) Airspace Research Roadmap was published. (ATM-X)

AIRSPACE OPERATIONS AND SAFETY PROGRAM

- NASA conducted a series of simulations and flight tests with industry partners as part of the National Campaign-1 flight demonstrations to test ecosystem-wide system-level safety and integration scenarios and scalable system concepts. (AAM)
- Through simulation and flight testing, NASA demonstrated automated aircraft vertiport operations involving automated small UAS flying nominal and off-nominal approach and landing operational scenarios that aligned with the UAM Concept of Operations. (AAM)
- NASA delivered draft evidence and recommendations to industry standards committees and safety and regulatory partners on the use of run-time monitoring for automated components and the robustness of remote operators as a backup in case of automation failure. (System-Wide Safety [SWS])
- NASA began a new project, the Advanced Capabilities for Emergency Response Operations (ACERO). This project aims to improve aerial responses to wildland fires. The project will leverage NASA-developed UAS traffic management capabilities and begin to develop an interagency concept of operations with other federal, state, and local agencies. (ACERO)

WORK IN PROGRESS IN FY 2024

- NASA will evaluate Cooperative Operating Practices for interactions of diverse aircraft in Upper Class E airspace. (ATM-X)
- NASA will establish new collaboration efforts with the FAA and UTM industry to facilitate new FAA regulatory standards enabling beyond visual line-of-sight operations commercial applications (ATM-X)
- NASA will integrate and demonstrate multiple UAM mission-types, integrated into multiple high-fidelity air traffic service environments associated with midterm operations as defined in UAM ConOps version 2.0 (Air Mobility Pathfinders [AMP])
- NASA will conduct Integration of Automated Systems (IAS) Flight Testing. IAS flights focus on testing new technologies related to AAM. NASA will share lessons learned and identified requirements and standards gaps with the FAA and industry. (AMP)
- NASA will complete final testing and provide summary findings and recommendations on implementation of an in-time system-wide safety assurance data architecture to achieve required assurance levels. (SWS)
- NASA will deliver final evidence and recommendations for the FAA, Unmanned Aircraft Safety Team, and Flight Safety Foundation on a process for certification of machine learning-enabled components in aerospace systems. (SWS)
- NASA's ACERO project will publish ConOps version 1.0. (ACERO)

KEY ACHIEVEMENTS PLANNED FOR FY 2025

- NASA will conduct an operational demonstration that shows the ability of machine learning to efficiently scale a cloud-based sustainable aviation service to a new airport. (ATM-X)

AIRSPACE OPERATIONS AND SAFETY PROGRAM

- NASA will identify performance metrics and conduct a simulation evaluation of trajectory management automation to improve integration of remotely piloted aircraft with conventional aircraft. (ATM-X)
- NASA will complete an evaluation of In-Time Aviation Safety Management System (IASMS) architecture characteristics and requisite services, functions and capabilities to enable emergency response operations. (SWS)
- NASA will perform an evaluation of assurance methodologies necessary to assure machine-learning enabled IASMS services, functions and capabilities that enable emergency response operations. (SWS)
- NASA's ACERO project will conduct an initial demonstration of local information sharing, airspace management, and aircraft deconfliction to enable shared situation awareness necessary for emergency wildland fire operations (ACERO)

Program Elements

AIR TRAFFIC MANAGEMENT – EXPLORATION (ATM-X)

The ATM-X project will transform the air traffic management system to accommodate the growing demand of new entrants with new mission requirements, while also allowing established, large commercial aircraft operators to fly more user-preferred routes with improved predictability. The ATM-X project focuses on demonstrating, through an open architecture approach, that integration of air traffic technologies, system-wide data use, advances in human-machine teaming, and increasingly autonomous decision-making will provide comprehensive situational awareness and enable coordinated decision-making and improved disruption management. This approach will incorporate advanced machine learning and artificial intelligence capabilities for air traffic management and contingency management that will enable flexible, user-preferred, predictable, and robust airspace operations. ATM-X is developing extensible airspace requirements and capabilities for integrating new missions and vehicles such as UAS and AAM into the NAS. ATM-X is exploring advanced trajectory management services and advanced flight deck capabilities to enable efficient, environmentally sustainable operations as part of the Sustainable Flight National Partnership. ATM-X is also working with the FAA and industry partners to operationalize UAS traffic management beyond visual line-of-sight operations at a FAA key site. The project will validate and transfer key concepts and technologies to FAA and industry stakeholders to enable transformation of the NAS.

AIR MOBILITY PATHFINDERS (AMP)

In FY 2024, the Advanced Air Mobility project was renamed as the Air Mobility Pathfinders (AMP) project. The AMP project focuses on enabling emerging aviation markets for transformational local and intra-regional missions that will provide substantial benefit to the U.S. public and industry. The project closely coordinates with ARMD's other projects on airspace, safety, and vehicle technologies to prioritize and deliver solutions to key enabling technical challenges. The AMP project will conduct focused research in key areas, such as architecture, airspace, and autonomy, required to achieve NASA's vision for AAM. One of the primary functions of the project is to execute a series of integrated evaluations that will promote public confidence in AAM safety, facilitate aviation community-wide learning, and help identify the focus of future research. The AMP project works closely with other government and commercial entities to achieve this objective.

SYSTEM-WIDE SAFETY (SWS)

The SWS project develops tools, methods, and technologies to enable capabilities envisioned by ARMD's strategies. The SWS project performs research to explore and understand the impact on safety of the complexity introduced by technology advances, particularly those aimed at improving the efficiency of flight, broadening access to airspace, and expanding the types of service provided by air vehicles. The project also develops and demonstrates innovative solutions that enable the aviation transformation envisioned by ARMD through proactive mitigation of risks in accordance with target levels of safety, increased access to relevant data, integrated analysis capabilities, improved in-time detection and alerting of hazards at the domain level, and decision support for mitigation. In some cases, automated mitigation strategies will help achieve expanded system safety awareness. The SWS project also addresses the need for safety-related advances in methods used for the verification and validation of machine learning-enabled components and advanced, increasingly autonomous systems.

ADVANCED CAPABILITIES FOR EMERGENCY RESPONSE OPERATIONS (ACERO)

The ACERO project leverages NASA-developed tools and technologies to improve aerial response for wildland fire fighting. The ACERO project works with other government agencies and regional fire response organizations to develop and demonstrate capabilities for the coordination of aerial assets and real-time data exchange to increase the duration and density of aerial firefighting operations. The project will initially focus on establishing a common, multi-agency concept of operations to enable more streamlined coordination of wildland fire aerial response efforts. The project will demonstrate a common interoperable platform for situational awareness of all aerial assets and data. Longer term objectives include the development of advanced aircraft technologies and airspace management capabilities to enable diverse simultaneous crewed and uncrewed operations for persistent (up to 24 hours per day) observation and suppression operations.

Program Schedule

Date	Significant Event
Jun 2024	SWS – Delivery of final evidence and recommendations for a process for certification of machine learning-enabled components in aerospace systems.
Sep 2024	ACERO – Publish interagency concept of operations (ConOps version 1.0) with other federal, state, and local agencies for wildfire response operations that will inform future NASA research under the ACERO project. ATM-X – Develop a prototype aviation service that leverages machine learning and data from cloud-based digital information platform to demonstrate improvements to the sustainability of aviation operations.

AIRSPACE OPERATIONS AND SAFETY PROGRAM

Date	Significant Event
Aug 2025	AMP - Conduct a flight test in partnership with an electric Vertical Takeoff and Landing vehicle manufacturer and the FAA to establish baseline performance and to identify and capture key data. ATM-X – Conduct an operational assessment of an aviation service in complex airspace that leverages machine learning and data from cloud-based digital information platforms to demonstrate improvements to the sustainability of aviation operations. SWS – Deliver final evidence and recommendations to the FAA, Unmanned Aircraft Safety Team, and the Flight Safety Foundation on a process for certification of machine learning-enabled components in aerospace systems. ACERO – Publish an updated interagency concept of operations (ConOps version 2.0) with other federal, state, and local agencies for wildfire response operations that will inform future NASA research under the ACERO project.

Program Management & Commitments

Program Element	Provider
Air Traffic Management - eXploration (ATM-X)	Provider(s): ARC, LaRC, GRC Lead Center: ARC Performing Center(s): ARC, LaRC, GRC, AFRC Cost Share Partner(s): FAA, DLR, JAXA, American Airlines, Southwest, Dallas Fort Worth Airport (DFW), AURA, ANRA Technologies, ARINC Inc., Avision Inc., Metron Aviation Inc., OneSky Systems Inc., SkyGrid, Unmanned Experts Inc.
System-Wide Safety (SWS)	Provider(s): ARC, LaRC, GRC Lead Center: LaRC Performing Center(s): ARC, LaRC, GRC, AFRC Cost Share Partner(s): FAA, DoD Air Force Research Laboratory, Defense Advanced Research Projects Agency, MITRE, Boeing Research & Technology, GE Global Research, American Airlines, Delta Air Lines, Swiss International Airlines, Commercial Aviation Safety Team, Drone Safety Team, Association for Unmanned Vehicle Systems International, RTCA, Society of Automotive Engineers, Flight Safety Foundation, Texas A&M Lone Star UAS Center of Excellence, Federal Bureau of Investigation
Advanced Capabilities for Emergency Response Operations (ACERO)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: ARC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): To be determined

AIRSPACE OPERATIONS AND SAFETY PROGRAM

Program Element	Provider
Air Mobility Pathfinders (AMP)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: HQ Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): Not applicable

Acquisition Strategy

AOSP research and technology spans from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a wide array of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages teaming among large companies, small businesses, and universities.

MAJOR CONTRACTS/AWARDS

AOSP awards multiple smaller contracts, which are generally less than $5 million and widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Expert Review	Oct 2023	The 12-month review is a formal independent peer review. Experts from other government agencies report on their assessment of technical and programmatic risk and/or program weaknesses.	Determined that the projects made satisfactory progress in meeting technical challenges and all annual performance indicators.

ADVANCED AIR VEHICLES PROGRAM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	258.0	--	278.8	269.6	262.4	248.8	218.7

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Pictured above, NASA's Mobile Laboratory (lower left) samples emissions from sustainable aviation fuels burned by Boeing's ecoDemonstrator 777-200. Credit: Boeing / Paul Weatherman

The Advanced Air Vehicles Program (AAVP) develops knowledge, technologies, tools, and innovative concepts to enable safe new aircraft that will fly faster, cleaner, and quieter and use fuel far more efficiently than in the past. All large modern U.S. aircraft incorporate NASA research and technology. AAVP's research will prime the technology pipeline, enabling continued U.S. leadership, competitiveness, and high-quality jobs in the future. Fuel efficiency and environmental factors will play an increasingly significant role as the aviation market grows in capacity and as airlines, manufacturers, and regulators commit to new environmental targets and explore new markets.

AAVP develops a broad range of technologies that help ensure continued U.S. industrial leadership that will benefit both the economy and the environment. Specifically, with respect to subsonic transport aircraft and as part of NASA's leadership of the Sustainable Flight National Partnership, AAVP accelerates development of key subsonic transport technologies to ensure they will be ready by the mid- to-late 2020s to transition into U.S. industry's next generation single-aisle transport aircraft. Across the program, NASA will continue to engage partners from industry, academia, and other government agencies to maintain a broad perspective on technology solutions to these challenges, to pursue mutually beneficial collaborations, and to leverage opportunities for effective technology transition.

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA increased funding for the Hi-Rate Composite Aircraft Manufacturing (HiCAM) project by more than previously planned to enable the completion of major ground tests of both a wing and fuselage components.

NASA increased funding for non-CO_2 greenhouse gas emissions research and studies. With increased scientific and engineering focus, this research could lead to completely eliminating a major aviation greenhouse gas effect in the relatively near-term.

ACHIEVEMENTS IN FY 2023

- NASA crash tested an all-composite fuselage representing a six-passenger AAM configuration. The crash test provided data to the FAA and standards organizations about the loads experienced in the cabin during impact, which support the development of new crash safety requirements for AAM. (Revolutionary Vertical Lift Technology [RVLT])

ADVANCED AIR VEHICLES PROGRAM

- In collaboration with industry, NASA demonstrated megawatt (MW)-class electric motors at simulated altitude conditions and integrated electrified systems for transport-class aircraft. These demonstrations included the flight-weight and flight-like components required to bring the technology to flight. Further, the system also met safety requirements for fault management, redundancy, and power quality needed for use on commercial transports. In taking this approach, future transports will be able to use hybrid propulsion technologies for aircraft efficiency benefits. (Advanced Air Transport Technology [AATT])
- NASA designed, built, tested, and evaluated an aircraft fuselage segment fabricated with a suite of novel manufacturing technologies in a relevant environment that can improve high-rate, lightweight metallic fuselage manufacturing. The demonstration validated improvements to fasteners such as reduced weight, assembly time, and less crack initiation. New metallic manufacturing processes enhanced sustainability while reducing weight and cost and improving manufacturing rates. (AATT)
- NASA completed development tests at NASA and partner facilities for a suite of small-core engine materials technologies. Testing at NASA successfully matured advanced barrier coatings for high temperature engine core components to a level sufficient for potential inclusion on the Hybrid Thermally Efficient Core (HyTEC) Phase 2 core demonstration. These new coatings have increased temperature capability to improve engine fuel efficiency and durability. (HyTEC)
- The HiCAM supply chain team collaborated to create custom material systems required to meet the production rate and weight goals of HiCAM. The team invented a new thermoset resin that can be infused and cured at the same temperature in a closed mold and tailored existing thermoset systems to reduce autoclave cure time by 80 percent. Rapid cure materials increase production efficiency, which can reduce the number of manufacturing lines, making factories smaller and lowering cost and energy consumed during manufacturing. (HiCAM)
- NASA completed work on computational tool improvements for predicting ground acoustic sound levels of the X-59 in preparation for application during its validation flights. (Commercial Supersonic Technology [CST])
- NASA experimented with real-time automatic transitions between a turbojet engine simulator and a dual-mode ramjet simulator in a combined cycle engine system. These experiments established the control theory and methods for such transition. To ensure operability while maximizing system performance requires automated control for successful operation of a combined cycle system. (Hypersonic Technology [HT])

WORK IN PROGRESS IN FY 2024

- NASA will complete work in powertrain systems for electric propulsion and provide data to standards committees and industry to improve the safety and reliability of AAM powertrains. NASA will focus on designs that increase motor reliability, methods to detect or reduce the effect of electrical faults, and modeling methods for assessing powertrains. Improving powertrain reliability and fault detection will increase the safety of future AAM vehicles. (RVLT)
- NASA will develop, test, and apply a model-based systems analysis and engineering framework for integrated vehicle concept design optimization and technology assessments. A new modeling and analysis framework will facilitate the digital integration of the considerable data, learnings, and models generated throughout the Sustainable Flight National Partnership to measure the partnership's success. NASA will also make the new framework available for industry use. (AATT)

- NASA will test for ice accretion on the wing/truss junction of an efficient Transonic Truss-Braced Wing (TTBW) configuration. Experimental icing data on TTBW models will determine the potential for ice buildup, validate computational icing tools, and improve understanding of ice protection requirements. (AATT)
- NASA will award a Phase 2 contract to demonstrate integrated core engine technologies in an environment that simulates flight conditions. An integrated demonstration will show sufficient technical maturity that the demonstrated technologies may be considered for inclusion on next-generation aircraft engines. These technologies will enable future aircraft engines to consume less fuel, produce fewer emissions, integrate hybrid electrification, and be more durable than the current state of the art. (HyTEC)
- NASA will demonstrate new joining methods for assembling aircraft structures made from thermoplastic composites. Parts will be heated and fused together, rather than assembled with metallic fasteners, reducing component assembly cost and weight. (HiCAM)
- NASA will reduce the uncertainty of landing and takeoff noise predictions. NASA will provide the aeronautics community with tools and data on relevant supersonic propulsion systems, reducing risk to manufacturers in certification of future aircraft. (CST)
- NASA will complete preparations to validate the acoustic performance of the X-59 aircraft. Preparations include test equipment and final risk reduction testing and will expedite beginning the X-59’s acoustic validation after first flight. (CST)
- NASA will experiment with automatic transitions between a live turbojet engine and a dual mode ramjet simulator in a combined cycle engine system. These experiments will validate the control theory and methods for such transition. Ensuring operability while maximizing system performance requires automated control for successful operation of a combined cycle system. (HT)

KEY ACHIEVEMENTS PLANNED FOR FY 2025

- NASA will research crash safety for AAM vehicles by identifying materials for energy absorbers, conducting artificial bird strike tests on sharp surfaces, and testing battery packs under impact conditions. NASA will provide test data to the FAA and standards development organizations developing AAM crash safety standards as the first publicly available data for this application. (RVLT)
- NASA will test a revolutionary unducted propulsor through a partnership to collect experimental data that are expected to show a significant improvement in fuel efficiency. This effort supports the noise and fuel burn reduction goals for the Sustainable Flight National Partnership and FAA's Continuous Lower Energy, Emissions, and Noise Program. The testing will reduce risk and uncertainty inherent in the design of a new class of revolutionary propulsor, enable initial flight tests, and maintain schedule for a new 2030s aircraft. (AATT)
- NASA will identify the biggest noise sources for the new TTBW configuration using simulations of the TTBW with high-lift devices deployed in the landing phase of flight. To guide the TTBW to meet noise standards, NASA must adapt model-scale data to full scale and refine noise prediction tools used for systems analysis. (AATT)
- NASA will test dual-spool power extraction at simulated altitude conditions in partnership with industry in the Propulsion Systems Laboratory. This test will demonstrate modern aircraft engine

hybridization with 20 percent of the engine's power extracted in the form of electricity without compromising operability or performance. After this test, power extraction may carry forward into an advanced engine core demonstration and, potentially, the next generation of aircraft engines. (HyTEC)

- NASA will demonstrate high-rate composite aircraft manufacturing technologies that have been scaled up and integrated to produce structural panels with required quality and performance. Demonstrated technologies will include next generation thermosets, resin-infused composites, and thermoplastic composites. (HiCAM)
- NASA will collect data on the X-59 to understand the acoustic characteristics of the aircraft. Acoustic characterization will determine whether the aircraft's low boom features perform as expected and whether future testing plans need to be adjusted. (CST)
- In support of high-Mach turbine engine configurations, NASA will fabricate a high-Mach inlet model. Subsequent testing of the high-Mach inlet model will provide unique performance and operability data that will be used to improve system modeling and analysis tools. Validated tools for advanced high-Mach turbine propulsion systems will streamline the design process for the hypersonics community. (HT)

Program Elements

REVOLUTIONARY VERTICAL LIFT TECHNOLOGY (RVLT)

The RVLT project develops, demonstrates, and validates tools, technologies, and flight operations methods that reduce vertical take-off and landing (VTOL) aircraft noise and improve safety, enabling expanded use of VTOL aircraft in an integrated airspace environment. The unique ability of vertical lift vehicles to hover has significant applications in the civil market for human and cargo transportation and delivery systems as evidenced by the emerging urban air mobility (UAM) industry within the broader AAM industry. Additionally, advanced vertical lift technologies and capabilities are directly relevant to vehicles for public good missions, such as disaster relief, emergency services, and many more critical operations. RVLT research advances technologies that will increase safety and reduce noise and annoyance to improve future vehicles operating in the new UAM and AAM market. To accomplish this research, NASA uses advanced computer-based, multi-fidelity prediction methods, unique NASA facilities, and state-of-the-art experimental techniques. RVLT considers current and future vertical lift vehicles of many classes and sizes, focusing on configurations that are viable as inter-city and intra-city transportation.

ADVANCED AIR TRANSPORT TECHNOLOGY (AATT)

The AATT project seeks to enable revolutionary advancements in future aircraft performance. As part of the NASA-led Sustainable Flight National Partnership, research explores solutions to advance knowledge, technologies, and concepts, enabling major steps in energy efficiency and reducing environmental impacts by reducing fuel burn, harmful emissions, and noise around airports. The research also benefits U.S. industrial competitiveness in the subsonic transport aircraft market, as well as potentially opening new markets for U.S. entrants in the regional jet and smaller size classes. The knowledge gained from this research in the form of experiments, data, system studies, and analyses is critical for conceiving and designing more efficient and quieter aircraft. Advanced air transport research focuses on developing advanced technologies and tools for future generations of commercial transport – including the emerging area of electrified aircraft propulsion and the complementary gas turbine engine research needed to develop new engines that will ultimately power the new vehicles. Although this project focuses on the long-term technology timeframe, it also contributes to both near-term and mid-term development by demonstrating interim technology advancements.

HYBRID THERMALLY EFFICIENT CORE (HYTEC)

The HyTEC project will develop small core turbofan engine technologies aimed at achieving a five to 10 percent fuel burn reduction compared to 2020 best-in-class turbofan engines and up to 20 percent power extraction at altitude, culminating in an advanced core demonstration in the 2027 timeframe. As part of this effort, HyTEC will advance design capabilities for effective and efficient, Sustainable Aviation Fuel (SAF)-compatible small core combustors. Within the Sustainable Flight National Partnership, NASA will collaborate with industry in a cost-sharing arrangement on key technologies and will accelerate these key technologies to strengthen the U.S. industry position on small core-enabling technology and integrated systems for a future single aisle aircraft.

HI-RATE COMPOSITE AIRCRAFT MANUFACTURING (HICAM)

The HiCAM project will demonstrate manufacturing approaches and associated technologies for large, composite primary airframe structures that enable high-rate production (up to 80 aircraft per month) with reduced cost and no weight penalty versus 2020 technology for composite structures. The project focus will be airframe structural components for single-aisle transport aircraft expected to enter service in the early to mid-2030s. HiCAM will develop model-based engineering tools to rapidly mature, optimize, and transition high-rate composite manufacturing and assembly methods. NASA will team with partners to share expertise, facilities, and resources to accelerate technology maturation efforts. As part of the Sustainable Flight National Partnership, the HiCAM project technologies will enable advanced vehicle concepts that require composite structures and will introduce manufacturing considerations into future vehicle designs. However, the findings and techniques developed will generally advance manufacturing technology applicable to a variety of composite structures, including aircraft engine applications, urban air mobility vehicles, and space launch vehicle applications. The findings and techniques may also contribute to future in-space construction and assembly of composite structures.

COMMERCIAL SUPERSONIC TECHNOLOGY (CST)

Supersonic vehicle research includes tools, technologies, and knowledge that will help eliminate today's technical barriers to practical commercial supersonic flight. These barriers include sonic boom noise, supersonic aircraft fuel efficiency, airport community noise, high-altitude emissions, vehicle aeroservoelastic design, supersonic operations, and the ability to design vehicles in an integrated, multidisciplinary manner. CST will leverage the X-59 quiet supersonic technologies vehicle to gather data on the human responses to low-level sonic booms. This human community response data will inform national and international regulatory organizations' efforts to define certification standards that commercial aircraft manufacturers can follow to create new high-speed aircraft markets. In preparation for the use of the X-59 vehicle, CST research will establish the necessary approaches and techniques for objectively measuring the level of supersonic overflight noise acceptable to communities living near future commercial high-speed flight paths. These approaches, techniques, and resulting data will be the foundation for establishing the sonic boom acoustic limits as part of the international certification standards. CST is also working to reduce the uncertainty in landing and takeoff noise prediction.

HYPERSONIC TECHNOLOGY (HT)

NASA focuses on fundamental and applied research that explores key challenges in hypersonic flight and maintains unique, specialized facilities and experts. The HT project focuses on hypersonic propulsion systems, reusable vehicle technologies, high-temperature materials, and systems analysis. NASA applies its expertise to support and evaluate the potential for future commercial hypersonic vehicles, including commercial point-to-point and reusable access to space missions. In addition, this project coordinates closely with the DoD, so NASA can leverage DoD investment in ground and flight activities to develop and validate advanced physics-based computational models. At the same time, DoD benefits from NASA expertise, analyses, testing capabilities, and computational models. NASA also supports U.S. industry's emerging interest in commercial high-speed/hypersonic vehicles.

Program Schedule

Date	Significant Event
Feb 2024	HyTEC – Award of Phase 2 Core Demonstration contracts for core technology development and integration.
Apr 2024	AATT – Partnership contracts in place with industry and academia for Advanced Aircraft Concepts for Environmental Sustainability (AACES) 2050.
Jun 2024	RVLT – Demonstrate the ability to model AAM fleet noise in urban areas near vertiports and propose a method of modeling annoyance caused by AAM vehicle noise and operations.
Jun 2024	RVLT – Complete work in electric propulsion powertrain systems that provides data to standards committees and industry to improve the safety and reliability of AAM powertrains.
Sep 2024	CST – Completion of white paper on the state-of-the-art for predicting landing and takeoff noise for supersonic aircraft and identifying future validation testing needs.
Sep 2024	AATT –Tests of two megawatt-class motors at altitude and demonstration of integrated fault and thermal management system.
Oct 2024	AATT – Begin Open Fan isolated configuration test campaign at GRC.
Nov 2024	HiCAM – Select capstone manufacturing technologies based on manufacturing demonstrations, test results, and development risk for high-rate, low-cost, lightweight large composite aircraft structures.
Mar 2025	CST – Completion of all preparations and ready to execute the acoustic validation testing phase of the Quesst mission.
Mar 2025	HT – Development of technology for mode transition in a turbine-based combined cycle.
Jul 2025	HyTEC – Complete assessment of Phase 1 Technology Development performance against project metrics.
Sep 2025	AATT – TTBW High-Reynolds number high-lift test complete.
Sep 2025	HyTEC – Complete Dual Spool Power Extraction Test at simulated altitude at GRC to demonstrate engine hybridization in a modern aircraft engine.

ADVANCED AIR VEHICLES PROGRAM

Date	Significant Event
Oct 2025	AATT – NASA Electric Aircraft Testbed relocation complete and facility capability available to outside customers.

Program Management & Commitments

Program Element	Provider
Advanced Air Transport Technology (AATT)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: GRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): Boeing, Pratt & Whitney, General Electric Aerospace, Raytheon Technologies Corporation, FAA, United States Navy, Department of Energy, ARPA-e, magniX, Wright Electric
Revolutionary Vertical Lift Technology (RVLT)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: LaRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): FAA, United States Army, United States Air Force, United States Navy, Moog Surefly, A&P Technologies, DLR, ONERA, Ohio State University – Gearlab and Smart Vehicle Concept Center, Pennsylvania State University – Applied Research Laboratory, University of Illinois – Power Optimization of Electro-thermal Systems, University of Maryland, Georgia Institute of Technology, Sikorsky Aircraft, Textron Aviation, University of Akron, University de Sherbrooke
Commercial Supersonic Technology (CST)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: LaRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): FAA
Hypersonic Technology (HT)	Provider(s): AFRC, GRC, LaRC Lead Center: LaRC Performing Center(s): AFRC, GRC, and LaRC Cost Share Partners: DoD, John Hopkins University/Applied Physics Laboratory, Boeing
Hi-Rate Composite Aircraft Manufacturing (HiCAM)	Provider(s): GRC, LaRC Lead Center: LaRC Performing Center(s): GRC, LaRC Cost Share Partners: FAA, Advanced Thermoplastic Composites, Aurora Flight Sciences, Boeing, Collins Aerospace, CGTech, Collier Aerospace, Convergent Manufacturing Technologies - US, Electroimpact, General Electric Aviation, Hexcel, Lockheed Martin, Northrop Grumman, Solvay, Spirit AeroSystems, Toray Advanced Composites, University of South Carolina, Wichita State University, Mississippi State University

ADVANCED AIR VEHICLES PROGRAM

Program Element	Provider
Hybrid Thermally Efficient Core (HyTEC)	Provider(s): GRC, LaRC Lead Center: GRC Performing Center(s): GRC, LaRC Cost Share Partners: GE Aviation, Raytheon Pratt & Whitney

Acquisition Strategy

AAVP research and technology spans from foundational research to integrated system capabilities. This broad spectrum necessitates the use of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages collaboration among large companies, small businesses, and universities.

MAJOR CONTRACTS/AWARDS

AAVP awards multiple smaller contracts, which are generally less than $5 million, with a few exceptions, and are widely distributed across academia and industry. AAVP anticipates awarding larger contracts to support the HyTEC and HiCAM projects' large technology development and demonstrations.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Expert Review	Oct 2023	The 12-month review is a formal independent peer review. Experts from other NASA programs and government agencies report on their assessment of technical and programmatic risk and/or program weaknesses.	The Panel provided favorable reviews to the projects. The Panel also gave constructive comments and recommendations.

INTEGRATED AVIATION SYSTEMS PROGRAM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Low Boom Flight Demonstrator	51.3	42.6	**70.9**	44.5	5.7	0.0	0.0
Electrified Powertrain Flight Demonstration	91.6	--	**61.6**	65.0	75.5	50.0	0.0
Other Projects	118.2	--	**131.9**	167.6	196.4	250.9	342.0
Total Budget	**261.1**	**--**	**264.4**	**277.0**	**277.6**	**300.9**	**342.0**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

NASA and Boeing unveiled the livery for the X-66 aircraft being built through the Sustainable Flight Demonstrator project. Credit: Boeing

The Integrated Aviation Systems Program (IASP) conducts research on promising concepts and technologies at an integrated system level, with a focus on flight research and demonstrations to establish a level of maturity that enables these technologies to transition to the aviation community for the benefit of the nation and U.S. flying public.

IASP supports two critical cross-program mission efforts: Sustainable Flight National Partnership (SFNP) and the Quesst mission. In support of SFNP, IASP leads the Sustainable Flight Demonstrator (SFD) and Electrified Powertrain Flight Demonstrations (EPFD) projects. For the Quesst mission, IASP leads the Low Boom Flight Demonstrator (LBFD) project to build, assemble, and conduct flight validation tests for the X-59 supersonic aircraft.

IASP's Flight Demonstrations and Capabilities (FDC) project conducts integrated research demonstrations that support a variety of ARMD initiatives as well as the development of supersonic flight-testing techniques that will validate the acoustic signature of X-59 and support X-59 community response testing. Furthermore, FDC operates, sustains, and enhances flight capabilities essential for enabling flight research, such as a flight test range and laboratory infrastructure required to test complex flight demonstrations.

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA increased funding for the SFD project as it moves into the design/build phase.

NASA decreased funding for the EPFD project as the build phase nears completion.

NASA increased funding for the LBFD project to cover rebaselined commitments for cost and schedule. The project was rebaselined due to poor contractor performance and COVID impacts from 2020 through 2022 that caused delays to X-59 aircraft delivery.

INTEGRATED AVIATION SYSTEMS PROGRAM

ACHIEVEMENTS IN FY 2023

- NASA selected Boeing for the SFD Funded Space Act Agreement in January 2023. This kicked off the start of engagement with industry, academia, and other government organizations to identify, select, and mature a transonic truss-braced wing concept and other key airframe technologies that have a high probability of transition to a next generation single-aisle seat class airliner. (SFD)
- NASA completed F-15B retrofit and flight checkout of the aircraft's life support system for future X-59 high altitude research flights in support of the Quesst mission. (FDC)
- NASA completed the development and delivery of the Mobile Operations Facility to Lockheed in Palmdale, CA in support of X-59's flight line run stall power-on checks. (FDC)

WORK IN PROGRESS IN FY 2024

- The SFD project will complete the Systems Requirement Review to align preliminary plans and requirements with the project's objectives and requirements. This achievement will position the project to prove the benefits of new aircraft technologies for use in the next generation airliner expected in the 2030s. (SFD)
- In preparation for the X-59 first flight and envelope expansion, NASA will deliver a validated F-15-based test capability that enables precise, near-field probing and airborne imaging of the X-59 shockwave structure. This capability will ensure that the shockwave structure produced in flight is comparable with current simulations during the flight test campaign. (FDC)

KEY ACHIEVEMENTS PLANNED FOR FY 2025

- The SFD project will complete the system-level PDR of the X-66 aircraft thereby demonstrating the design meets system requirements with acceptable risk and establishing the basis for proceeding with detailed design. (SFD)
- The SFD project will complete KDP-C demonstrating that the project is sufficiently mature to begin the implementation phase and establishing the project's baseline commitment to develop and flight test the X-66 aircraft. (SFD)
- NASA will complete precise, near-field probing and airborne imaging of the X-59 shockwave structure using the F-15-based test capability which will enable the acoustic validation of X-59 required prior to community response testing. (FDC)
- NASA will complete key community response planning milestones in support of the Quesst mission to include required Mobile Operations Facility modifications needed for deployment and community response testing site selections. (FDC)

Program Elements

The EPFD and LBFD projects within IASP are reported in separate sections since they are major projects of greater than $250 million and have completed KDP-B.

INTEGRATED AVIATION SYSTEMS PROGRAM

FLIGHT DEMONSTRATIONS AND CAPABILITIES (FDC)

NASA's FDC project validates the benefits of various technologies and demonstrates the feasibility and maturity of new technologies by conducting complex and integrated small-scale flight research demonstrations. By modifying an existing asset of FDC's support aircraft fleet, aggressive, success-oriented flight campaign schedules of flight experiments are enabled. While many such technologies are at mid-levels of technology readiness, the FDC project supports all phases of technology maturation. FDC's support aircraft fleet also enables safety chase and in-flight experimental measurements in support of a variety of NASA missions. Collaborative opportunities for flight testing are leveraged as appropriate from across academia, industry, and government organizations. The FDC project also engages with NASA researchers and university students in flight research to bring low Technology Readiness Level innovation concepts that aim to address key barriers to new markets through flight.

The FDC project operates, sustains, and enhances other national flight research capabilities that enable complex and/or high-risk flight research and test missions for NASA Aeronautics as well as to meet broader NASA and national needs. These assets, located at NASA's AFRC, include the Aeronautics Test Data Portal, Flight Loads Laboratory, the Dryden Aeronautical Test Range, and a suite of flight simulators. Collaborative opportunities for flight testing are leveraged as appropriate from across the aeronautical industry.

SUSTAINABLE FLIGHT DEMONSTRATOR (SFD)

One of the key components of the Sustainable Flight National Partnership is the SFD project. The purpose of the project is to mature key airframe technologies that have a high probability of transition to the next generation single-aisle seat-class airliner by the 2030s while reducing fuel burn, carbon emissions, and noise. The centerpiece of the project is the X-66 aircraft which seeks to inform a potential new generation of more sustainable single-aisle aircraft – the workhorses of passenger airlines around the world which account for greater than 50 percent of worldwide aviation emissions. Working with NASA, Boeing will build, test, and fly a full-scale demonstrator aircraft with extra-long, thin wings stabilized by diagonal struts, known as a Transonic Truss-Braced Wing concept.

Program Schedule

Date	Significant Event
Mar 2024	FDC - Deliver a validated F-15-based test capability for Quesst mission.
Nov 2024	SFD - Complete KDP-C for transition into the project implementation phase.
Sep 2025	FDC - Complete community response planning milestones in support of the Quesst mission.

INTEGRATED AVIATION SYSTEMS PROGRAM

Program Management & Commitments

Program Element	Provider
Flight Demonstrations and Capabilities (FDC)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: AFRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): DoD, Air Force Research Laboratory, Lockheed Martin, ESAero
Sustainable Flight Demonstrator (SFD)	Provider(s): ARC, AFRC, GRC, LaRC Lead Center: HQ Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): The Boeing Company

Acquisition Strategy

IASP research and technology development focuses on integrated aircraft system capabilities. The program uses a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition.

MAJOR CONTRACTS/AWARDS

IASP awards multiple smaller contracts, which are generally less than $7 million and widely distributed across academia and industry for efforts supporting small-scale flight demonstrations. IASP awards substantially larger awards for the design and build of large-scale flight demonstrations (e.g., LBFD, EPFD, SFD).

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Expert Review	Oct 2023	The 12-month review is a formal independent peer review. Experts from other government agencies report on their assessment of technical and programmatic risk and/or program weaknesses.	Given FY 2023 performance and alignment with NASA ARMD Strategic Goals, the Review Panels recommended continuation of IASP projects (FDC, SFD, LBFD, EPFD).

LOW BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Prior	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029	BTC	Total
Formulation	100.5	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	0.0	100.5
Development/Implementation	523.2	51.3	42.6	**69.4**	19.0	3.7	0.0	0.0	0.0	709.2
Operations/Close-out	0.0	0.0	0.0	**1.5**	25.5	2.0	0.0	0.0	0.0	28.9
2024 MPAR LCC Estimate	**623.7**	**51.3**	**42.6**	**70.9**	**44.5**	**5.7**	**0.0**	**0.0**	**0.0**	**838.6**
Total Budget	**623.7**	**51.3**	**42.6**	**70.9**	**44.5**	**5.7**	**0.0**	**0.0**	**0.0**	**838.6**

The 2024 MPAR LCC Estimate reflects the Fiscal Year 2024 Quarter 1 Financial Report, which is current as of January 2024. The requested budget authority is the project's current budget requirements.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

NASA's X-59 quiet supersonic research aircraft is seen fully assembled and painted on the ramp at Lockheed Martin's Skunk Works facility in Palmdale, CA where the airplane was constructed.

Credit: Lockheed Martin Skunk Works

PROJECT PURPOSE

New environmental standards related to aircraft noise are required to open the market to supersonic flight over land. Over the past decade, fundamental research and experimentation has demonstrated the possibility of supersonic flight with greatly reduced sonic boom noise. The Low Boom Flight Demonstrator (LBFD) project will demonstrate these advancements in flight by utilizing a purpose-built experimental aircraft designated the X-59.

The LBFD project encompasses the design, fabrication, ground tests, and checkout flights of NASA’s X-59 aircraft and is one of several projects supporting NASA's Quesst mission, a three-phase effort. The LBFD project leads Phase 1 of the Quesst mission, which includes the X-59 aircraft development activities. These activities started with the detailed design, continue through fabrication, and will conclude with functional checkouts and supersonic envelope expansion. In Phase 2, a NASA-led team will perform low-boom acoustic validation flights of the X-59 aircraft. These flights will characterize and evaluate the near-field, mid-field, far-field, and ground sonic boom signatures from the X-59 aircraft. Following the completion of acoustic validation at the end of Phase 2, the LBFD project will conclude, and the X-59 aircraft will transfer to IASP's Flight Demonstrations and Capabilities (FDC) project to conduct Phase 3 flight operations. For Phase 3, FDC, with contributions from other ARMD projects, will operate the X-59 aircraft in support of reduced sonic boom community response flight campaigns over varied locations to understand what sound level the public will find acceptable. In FY 2029, NASA will provide the finalized data to the Federal Aviation Administration and the International Civil Aviation Organization which could lead to the development of new standards that

LOW BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

enable a new generation of environment-friendly, over-land supersonic civil transport aircraft. If a new standard is established, the U.S. aviation industry will position itself to lead the commercial supersonic market, and passengers will benefit from significantly shorter travel times.

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA increased funding for the LBFD project to cover rebaselined commitments for cost and schedule. The project was rebaselined due to poor contractor performance and COVID impacts from 2020 through 2022 that caused delays to X-59 aircraft delivery. NASA informed Congress by letter dated December 20, 2023, that LBFD project experienced a significant cost overrun and schedule delay. NASA performed an assessment of the remaining work to inform the rebaseline cost and schedule. NASA has transmitted the final LBFD Project Cost and Schedule Analysis Report pursuant to Section 103(d) of the NASA Authorization Act of 2005 (P.L. 109-155).

Pursuant to Section 103(e) of P.L. 109-155, this budget request establishes a new baseline for LBFD. The detailed discussion of LBFD included in this budget request constitutes NASA’s response to the requirements of Section 103(e) of P.L. 109-155 for a New Baseline Report for LBFD. This new baseline is consistent with NASA’s prior notifications and reflects a revised LCC estimate of $838.6 million and development cost of $709.2 million. The new baseline plan also includes a revised development schedule, with first flight in October 2024. Previous baseline established in 2018 included a first flight in January 2022 with development cost of $467.7 million.

In FY 2025, the LBFD project will complete aircraft envelope expansion (Phase 1) and begin acoustic validation flights (Phase 2), which causes the budget increase compared to the FY 2024 President's Budget Request.

PROJECT PARAMETERS

The LBFD project is responsible for building and flight validation of the X-59 aircraft through Phase 2. The X-59 aircraft is NASA’s newest experimental supersonic aircraft designed to reduce the sonic boom noise levels to a level acceptable to the public. The vehicle will enable reduced sonic boom community response overflight studies with multiple test campaigns over varied U.S. locations as part of the Quesst mission. The Quesst mission ends in FY 2029 with the delivery of the final set of community response data to the International Civil Aviation Organization and the FAA.

ACHIEVEMENTS IN FY 2023

- NASA’s X-59 underwent final installation of its lower empennage, better known as the tail assembly. The installation allowed the team to continue final wiring and the completion of unpowered system checkouts on the aircraft. (LBFD)
- NASA’s X-59 research aircraft moved from its fabrication site in the hangar to the flight line run stall which enabled the team to complete ground vibration and surface freeplay tests at Lockheed Martin Skunk Works in Palmdale, CA. (LBFD)

LOW BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

WORK IN PROGRESS FOR FY 2024

- The X-59 aircraft will complete power-on system checkouts and ground tests including the engine runs and taxi tests. (LBFD)
- NASA will complete the Flight Readiness Review for the X-59 aircraft. (LBFD)

KEY ACHIEVEMENTS PLANNED FOR FY 2025

- NASA will complete First Flight of the X-59 aircraft and start envelope expansion flights to validate the full envelope needed for the Phase 3 community response testing. (LBFD)

SCHEDULE COMMITMENTS/KEY MILESTONES

Milestone	Baseline Date	FY 2025 PB Request
Flight Readiness Review	Mar 2024	Mar 2024
First Flight Complete	Oct 2024	Oct 2024
System Acceptance Review (Phase 1) Flight Testing Complete	Feb 2026	Feb 2026
Acoustic Validation (Phase 2) Complete	Oct 2026	Oct 2026
LBFD project Close-Out Complete	Dec 2026	Dec 2026

Development Cost and Schedule

The LBFD project life cycle includes aircraft concept refinement studies, aircraft preliminary design, aircraft final design and build, and acoustic validation flight testing. These activities span from FY 2014 to FY 2027 (Phase 1 and Phase 2 of the Quesst mission). Given continued challenges with contractor performance and, to a lesser extent, persistent COVID-19 impacts from 2020 through 2022, a rebaseline of the remaining work was recommended to and agreed to by NASA leadership in early 2023. Since then, plans were made to conduct a thorough assessment of cost and schedule risks associated with remaining work in anticipation of a Rebaseline Review, which was completed on December 12, 2023. The table below reflects the results of the Rebaseline Review which reset the project baseline and established a new Agency Baseline Commitment (ABC) for remaining project milestones. Pursuant to Section 103(e) of P.L. 109-155, this budget request establishes a new baseline for LBFD.

LOW BOOM FLIGHT DEMONSTRATOR

Formulation	**Development**	Operations

Base Year	Base Year Develop-ment Cost Estimate ($M)	JCL (%)	Current Year	Current Year Develop-ment Cost Estimate ($M)	Cost Change (%)	Key Mile-stone	Base Year Milestone Data	Current Year Mile-stone Data	Mile-stone Change (months)
2024	709.2	-	2024	709.2	0	First Flight	Oct 2024	Oct 2024	0

Note: The confidence level estimates reported reflect an evolving process as NASA improves its probabilistic estimation techniques and processes. Estimate reflects the practices and policies at the time of development. Estimates that include combined cost and schedule risks denoted as JCL (joint confidence level); all other CLs(confidence levels) reflect cost confidence without necessarily factoring the potential impacts of schedule changes on cost. An updated JCL was not conducted for this rebaseline due to the level-of-effort nature of remaining work.

Development Cost Details

Element	Base Year Development Cost Estimate ($M)	Current Year Development Cost Estimate ($M)	Change from Base Year Estimate ($M)
TOTAL:	**$709.2**	**$709.2**	**0**
Flight Sciences	39.7	39.7	0
Flight Systems	37.5	37.5	0
Aircraft	476.7	476.7	0
Aircraft Operations	70.8	70.8	0
Other Direct Project Costs	84.5	84.5	0

Project Management & Commitments

Element	Description	Provider Details
Flight Sciences	Vehicle sonic boom, aerodynamics, propulsion, structures, and mission performance NASA in-house flight simulation tools, and analysis of vehicle handling qualities and control laws	Provider: ARC, AFRC, GRC, LaRC Lead Center: LaRC Performing Center(s): ARC, AFRC, GRC, LaRC Cost Share Partner(s): N/A

LOW BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Element	Description	Provider Details
Flight Systems	Design, development, and test of Power Distribution System, Flight Test Instrumentation System, and eXternal Vision System	Provider: AFRC, LaRC Lead Center: AFRC Performing Center(s): AFRC, LaRC Cost Share Partner(s): N/A
Aircraft	Design, build, and initial test of a single-piloted X-plane	Provider: Lockheed Martin Lead Center: AFRC Performing Center(s): N/A Cost Share Partner(s): N/A
Aircraft Operations	Demonstrate airworthiness of aircraft, flight operations, and develop key aircraft subsystems - including life support and crew escape systems Provide Government Furnished Equipment to construct the research aircraft, support and maintain F414 engine, and perform insight/oversight of Ops-related tasks that the vehicle Contractor performs	Provider: AFRC, LaRC Lead Center: AFRC Performing Center(s): AFRC, LaRC Cost Share Partner(s)/subcontractors: GE, Northrop, Honeywell, and Lockheed Martin

Project Risks

Risk Statement	Mitigation
Sonic Boom Level is Not Acceptable for Community Overflight Research Given that achieving a fully shaped sonic boom ground signature in the 70-75 perceived decibel level range requires a complex and integrated design solution that is sensitive to outer mold line changes, there is a possibility that the mission requirements related to ground signature loudness may not be achievable - resulting in an aircraft that may not be fully acceptable for community response studies.	NASA will ensure that all configuration assessments use the latest and most mature aircraft configuration and periodically assess any updates to the aircraft configuration, such as the outer mold line or performance characteristics.
Reduced Aircraft Performance Could Impact Mission Effectiveness Given the aircraft and propulsion system selection and integration complexity, there is a possibility of reduced aircraft performance resulting in loss of mission effectiveness and leading to longer duration time to meet flight parameter(s), increased costs, and limitations of flight test points to standard-day conditions.	NASA will ensure that the contractor has sufficient margin for aircraft weight growth with propulsion configuration; assess contractor aircraft performance and thrust predictions (both computationally and experimentally) over the aircraft flight envelope; and perform a trade study on engine performance during demanding conditions.

LOW BOOM FLIGHT DEMONSTRATOR

Formulation	Development	Operations

Acquisition Strategy

The acquisition strategy for LBFD is to award to industry a contract for the detailed design/build/test of the experimental X-59 aircraft. NASA will provide in-house support that will include in-flight and ground systems, instrumentation and operations, simulation, wind tunnel testing, and safety and mission assurance. NASA supplies aircraft components and systems as Government Furnished Equipment whenever feasible and considered to add value to the development of the X-59 aircraft.

MAJOR CONTRACTS/AWARDS

Element	Vendor	Location (of work performance)
X-59 Aircraft - Design, Build, and Initial Testing	Lockheed Martin	Palmdale, CA
F414-GE-100 Engine	General Electric Aviation	Lynn, MA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Flight Readiness Review Board	NET Q2 FY 2024	Flight Readiness Review	TBD

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATIONS

Formulation	Development	Operations

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	91.6	--	61.6	65.0	75.5	50.0	0.0

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

GE Aerospace and magniX are preparing to test megawatt-class electrified powertrain systems to accelerate the transition of aircraft to hybrid propulsion systems.

PROJECT PURPOSE

The purpose of the Electrified Powertrain Flight Demonstrations (EPFD) project is to mature integrated megawatt (MW)-class electrified powertrain systems and components, thereby accelerating the introduction of these systems to the U.S. commercial transport fleet. NASA is collaborating with two industry partners to demonstrate these technologies by using existing aircraft that will be modified and flown with MW-class electrified powertrain systems and components to reduce fuel consumption by up to five percent and reduce harmful emissions.

The EPFD project's goal is to accelerate the transition of electrified powertrain systems with MW power levels to short-haul turboprop aircraft and single-aisle commercial airliners. EPFD will reduce risks for critical electrified powertrain systems and address specific gaps in regulations and standards associated with introducing electrified propulsion systems into commercial aircraft. Addressing these gaps will inform the development of new standards for next-generation hybrid-electric aircraft. EPFD is a critical component of the Sustainable Flight National Partnership.

EXPLANATION OF MAJOR CHANGES IN FY 2025

NASA decreased funding for the EPFD project as the design/build phase nears completion.

PROJECT PRELIMINARY PARAMETERS

NASA will complete two flight demonstrations within the next five years to help introduce electrified powertrain systems to the U.S. commercial fleet within the 2030-2035 timeframe. GE Aerospace is developing a MW-class hybrid electric powertrain for ground and flight tests in the middle of this decade. GE Aerospace is partnering with Boeing and its subsidiary, Aurora Flight Sciences, to support the flight tests using a modified Saab 340B aircraft. The flight test campaigns will be based out of Aurora Flight Sciences' facilities in Manassas, Virginia. magniX is partnering with AeroTEC to test its hybrid powertrain installed on a modified De Havilland "Dash 7" aircraft. The flight test campaigns will be based out of the AeroTEC Flight Test Center in Moses Lake, Washington.

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATIONS

Formulation	Development	Operations

ACHIEVEMENTS IN FY 2023

- magniX completed trade studies to inform its aircraft integration plans for the hybrid powertrain system and also completed the instrumented build-up of their magni650 electric propulsion unit in preparation for high-power, high-voltage simulated altitude testing. (EPFD)
- GE completed baseline characterization flights of the unmodified Saab 340B aircraft which determined the aircraft performance baseline for future comparison of performance with the electrified powertrain. GE also completed high voltage testing at their Electrical Power Integrated Systems Center in Dayton, Ohio. (EPFD)
- Following the completion of the magniX Systems Requirements Review, EPFD completed a Delta System Requirements Review verifying system architecture is credible and responsive to project requirements and represent achievable capabilities. (EPFD)

WORK IN PROGRESS IN FY 2024

- magniX will complete high-power, high voltage simulated altitude testing of its magni650 electric propulsion unit at NASA's Electric Aircraft Testbed facility. In parallel, magniX will work with their aircraft integrator, AeroTEC, to complete baseline characterization flights of the unmodified Dash-7 aircraft to determine the aircraft performance baseline for future comparison of performance with the electric powertrain. magniX will complete its PDR ensuring the preliminary design complies with project requirements. (EPFD)
- GE will complete its CDR ensuring the design is mature to continue with final design and fabrication. (EPFD)
- EPFD project will complete KDP-C demonstrating that the project is mature to begin the implementation phase and establishing the project's baseline commitment for the full project life cycle. (EPFD)

KEY ACHIEVEMENTS PLANNED FOR FY 2025

- magniX will complete its CDR and Flight Readiness Review for the first flight of the modified Dash-7 with one of two magni650 electric power units installed (known as Spiral 1). (EPFD)
- GE will complete the integration of the hybrid powertrain on the right-side of the Saab 340B and start flight testing this configuration while operating in the turbine mode (known as Spiral 1) as a build-up approach to subsequent testing in the hybrid-electric mode (known as Spiral 2). (EPFD)
- EPFD project will complete KDP-D demonstrating that the project is mature to begin the assembly, integration, and test phase. (EPFD)

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATIONS

Formulation	Development	Operations

ESTIMATED PROJECT SCHEDULE

Milestone	Formulation Authorization Document	FY 2025 PB Request
Project Level Delta System Requirements Review (SRR) GE SRR magniX SRR	TBD TBD TBD	Jun 2023 May 2022 Feb 2023
Project Level Integrated Baseline Review (IBR) GE IBR magniX IBR	TBD TBD TBD	Q2 FY 2024 Q2 FY 2024 Q2 FY 2024
GE PDR magniX PDR	Feb 2022 - Aug 2022 Feb 2022 - Aug 2022	Aug 2022 Q2 FY 2024
KDP-C	Mar 2022	Q3 FY 2024
GE CDR magniX CDR	Feb 2023 - Aug 2023 Feb 2023 - Aug 2023	Q2 FY 2024 Q1 FY 2025

Formulation Estimated LCC Range and Schedule Range Summary

The formulation agreement documents project costs at approximately $340.3 million during the design and build phase. The LCC of $412 million includes pre-Formulation and Formulation costs and related technology maturation activities conducted by the Advanced Air Transport Technology project, which occurred between FY 2017 and FY 2020.

LCC estimates are preliminary. A baseline cost commitment does not occur until the project reaches KDP-C planned for 2024, which follows a non-advocate review and/or PDR.

KDP-B Date	Estimated LCC Range ($M)	Key Milestone	Key Milestone Estimated Date Range
October 7, 2020	312 - 470	First Flight	Q3 FY 2025 - Q4 FY 2026

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATIONS

Formulation	Development	Operations

Project Management & Commitments

Element	Description	Provider Details
MW-class electric powertrain, power distribution, and energy storage systems.	Flight demonstration and evaluation of the performance of MW-class hybrid-electric propulsion system technologies for commercial aircraft.	Provider: ARC, AFRC, GRC, LARC Lead Center: HQ Performing Center(s): ARC, AFRC, GRC, LARC Cost Share Partner(s): General Electric and magniX

Project Risks

During Phase A, EPFD's risk management process identified and matured specific risks related to the MW-class powertrain flight demonstrations. During Phase B, the development of risk identification and mitigations remains ongoing. The EPFD project has a risk registry containing all active risks stored in a document management system. Mitigation plans are being developed and funded (where necessary) to mitigate technical, cost, schedule, and safety risks based on the likelihood and potential consequences.

The following tables shows the top risks and current mitigation steps:

Risk Statement	Mitigation
Contractor(s) May Not be Able to Provide Sufficient Test Data to Demonstrate Technology Maturation Given that NASA will execute ground and flight tests with Industry Partners through a contract, there is a possibility that the industry partner test plan will fulfill the contract requirements but not all the data requirements for project success, resulting in a lack of data to validate Electrified Aircraft Propulsion technologies, mature those technologies, and make the project successful.	Define Data needed to measure performance against Key Performance Parameters (Vision Vehicle) and Technical Performance Measures (TPMs) (Flight Demonstrations); measure advancement of TRL levels of MW-class powertrains; measure progress against Barrier Technical Risk (Vision Vehicle) based on progress against related Specific Technical Risks (Flight Demonstrations) Define data needed to support regulations and standards. Define data needed to provide validation data for NASA and industry tools and research. The use of validation data will reduce uncertainty in model estimation of EAP system performance in configurations not previously developed, tested, and evaluated. The following programs/projects will help support this effort: Advanced Air Vehicles Program's Advanced Air Transport Technology and Hybrid Thermally Efficient Core projects, and Transformative Aeronautics Concepts Program's Transformational Tools and Technologies project and the EPFD team. Create a Data Management Plan (preliminary) to address the data identified in the previous steps. Be sure this coincides with the Technology Development Plan and requirements for a Master Measurement List. Communicate data needs to industrial partners through Data Requirements Descriptions.

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATIONS

Formulation	Development	Operations

Risk Statement	Mitigation
Integrated MW-Class Powertrain System Fails to Meet Technical Performance Metrics Under Flight Environments Given that Integrated MW-Class Powertrain Systems are under development, there is a possibility that they will not meet the required Technical Performance Metrics under flight environments resulting in the need for additional development with associated schedule and cost impacts.	At each lifecycle review, industry partners provide estimated technical performance as part of proposal in response to the Technical Data Requirements and Reporting and expected environments as part of their Systems Requirements Document. Industry Partners provide final assessment of overall activity in response to the Technology Maturation Report.

Acquisition Strategy

EPFD project awarded two contracts using full and open competition. EPFD project will conduct integrated ground and flight demonstrations of MW-class electrified powertrain technologies and systems with two industry partners to identify and address electrified powertrain certification gaps.

MAJOR CONTRACTS/AWARDS

The release of the Request for Proposal, proposal selection, and contract awards occurred during FY 2021.

Element	Vendor	Location (of work performance)
Electrified Powertrain	General Electric Aviation (GE)	Cincinnati, OH
Electrified Powertrain	magniX USA Inc.	Everett, WA
Aircraft Mod and Integration	General Electric Aviation (GE)	Manassas, VA
Aircraft Mod and Integration	magniX USA Inc.	Moses Lake, WA
Flight Test	General Electric Aviation (GE)	Victorville, CA
Flight Test	magniX USA Inc.	Moses Lake, WA

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	EPFD Independent Review Board (IRB)	Q3 FY 2023	Delta Systems Requirement Review (dSRR)	Successfully completed

ELECTRIFIED POWERTRAIN FLIGHT DEMONSTRATIONS

Formulation	Development	Operations

Review Type	Performer	Date of Review	Purpose	Outcome
Performance GE Performance magniX	EPFD IRB	Aug 2022 Q2 FY 2024	PDR	Successfully completed TBD
Performance GE Performance magniX	EPFD IRB	Q2 FY 2024 Q1 FY 2025	CDR	TBD

TRANSFORMATIVE AERONAUTICS CONCEPTS PROGRAM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**147.1**	**--**	**155.3**	**157.6**	**171.1**	**175.2**	**179.0**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

NASA's Convergent Aeronautics Solutions project tests the 10-foot wingspan Dryden Remotely Operated Integrated Drone (DROID 2) taking off during a wind study to collect data to improve NASA's ability to replicate low-altitude wind conditions that could impact air taxi takeoffs and landings.

The Transformative Aeronautics Concepts Program (TACP) cultivates multi-disciplinary, revolutionary concepts to enable aviation transformation. TACP fosters innovative solutions to aviation challenges by capitalizing on advancements in the aeronautics and non-aeronautics sectors to create new opportunities in aviation. One major goal of the program is to reduce or eliminate technical barriers and infuse ground-breaking concepts into the aviation community.

TACP creates advanced and improved computational tools, technologies, and experimental capabilities for use by other aeronautics programs, industry partners, and government collaborators.

TACP's activities offer flexibility for innovators to explore technology feasibility and provide the knowledge for radical transformation. The program creates an environment for researchers to incubate and test new ideas, and leverage the knowledge gained from their discoveries. Therefore, the program's investments are in brand-new areas that can provide paradigm-shifting analysis and experimental capabilities.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

- NASA completed the first flights of the Shape Memory Alloy Reconfigurable Technology Vortex Generators on the Boeing eco-Demonstrator 777-200ER, which seeks to make aviation more sustainable and fuel-efficient by decreasing drag in flight and thereby reduce aviation's environmental impact. The completed test results displayed favorable performance at a range of operational conditions, confirming a computational fluid dynamic drag analysis that predicted reduced overall drag on the airplane, in turn allowing engines to work more efficiently, saving fuel and releasing fewer emissions. (Transformational Tools and Technologies [TTT])
- NASA developed a new alloy, GRX-810, which endures higher temperatures, is more malleable, and significantly increases durability than existing state-of-the-art alloys. The NASA STMD projects used GRX-810 on combustor domes for rocket injectors. The GRX-810 had no significant damage after

39 hours of testing, allowing for future sustainable flight engines with less harmful environmental impacts. (TTT)

- NASA completed the Data and Reasoning Fabric (DRF) activity, which enables the creation of a data and reasoning services marketplace providing an open framework software architecture within the aviation community to solicit, discover, and use these services to inform the design, operation, and oversight of our future air-mobility operations. Urban Air Mobility (UAM) aircraft operations require decisions based on diverse and dynamic data (e.g., vehicle, airspace, weather, infrastructure, payload, and customer data). These decisions (or reasonings) can be vast, and the density of these operational decision processes continues to move from human decision-making to software-intelligence-based decisions. DRF's essential features, including data and reasoning services, will transition to the Airspace Operations and Safety Program for further development. (Convergent Aeronautics Solutions [CAS])
- NASA selected four new University Leadership Initiative (ULI) awards across 19 universities and seven industry partners. These awards will address technical barriers to achieving ARMD's strategic outcomes: (University Innovation [UI])
    - The team led by Boston University will study the critical knowledge and prediction methods in designing low-noise multirotor UAM vehicles and control strategies for operating in urban settings where wind conditions can vary.
    - The team led by the University of Notre Dame will develop an automated decision-making capability that ensures small drones are safe for flying using the NASA-developed Unmanned Aircraft Systems Traffic Management (UTM) system.
    - The team led by the New Mexico State University will develop a mobility-energy-coordinated platform for infrastructure planning to support advanced air mobility (AAM) aircraft operations. NASA will collect flight and battery test data for model validation and calibration, review flight energy consumption, battery dynamics and trip requests, and assess energy cost, emissions, and reliability from an electric grid perspective.
    - The team led by Tennessee Technological University will deliver a preliminary design for an electrified 150-passenger aircraft that uses an ammonia-based integrated propulsion, power, and thermal management system.

WORK IN PROGRESS IN FY 2024

- NASA will continue research in support of the AAM vision under the Revolutionary Aviation Mobility sub-project for the universal operations of UAM in dense environment research focusing on human-autonomy teaming and autonomous vehicle technology, including distributed sensing and intelligent contingency management for these vehicles. Two human-in-the-loop studies will focus on utilization for passenger carrying UAM applications and foundational human-autonomy providing the research studies to Advanced Mobility Pathfinder project informing safe design of multi-vehicle human-autonomy teaming systems. (TTT)
- NASA will complete feasibility/transition assessments on two CAS activities: Solid-State Architecture Batteries for Enhanced Rechargeability and Safety (SABERS) and Advanced Exploration of Reliable Operation at low Altitudes: meteorology, Simulation, and Technology (AEROcAST). The SABERS activity focuses on developing a non-flammable aviation battery technology that can produce two times the energy to transform future electrified flight vehicles—a potential transition to the TTT project, DoD, and the aviation industry. The AEROcAST activity will

develop technology that benefits AAM vehicles to predict and navigate through complex low-altitude weather conditions, specifically wind effects on Unmanned Aircraft Systems-based weather sensors around building structures. The resulting technology is planned to transition to the Advanced Capabilities for Emergency Response Operations (ACERO) project, TTT, System-Wide Safety (SWS) project, and the NASA Artemis program, with possible external partnership transitions. (CAS)

- NASA will extend research efforts on 21 existing ULI awards as the project's portfolio has grown to address the public need for considering all potential energy sources in producing zero aviation emissions, new fuel cell technology, hybrid electric propulsion systems, developing safe air transportation systems and autonomous aircraft knowledge working with many universities, industry partners, other government agencies and ARMD programs. NASA will also make additional ULI award solicitations to include zero-emission and AAM topics. (UI)

KEY ACHIEVEMENTS PLANNED FOR FY 2025

- NASA combustion research will improve combustor performance and minimize the impact of aircraft emissions on the environment and human health. This research will focus on developing new tools for modeling the evolution of soot formation and oxidation in combustors, improving quantifying aviation's impact on the environment. New models are needed to predict the concentration usage of conventional petroleum jet fuel and sustainable aviation fuel to meet future emission standards. Research activities will further develop fuel-sensitive soot evolution models utilizing experiments conducted under the Advanced Air Transport Technology project. (TTT)
- NASA will complete feasibility/transition assessments on three CAS activities: Beaming Energy for Air Mobility (BEAM), Airports as Energy Nodes (AENode), and Attritable Flight Research. The BEAM activity plans to build a backup system to power AAM vehicles in harsh or remote areas during emergencies and natural disasters, a potential transition collaboration with the Defense Advanced Research Projects Agency. The AENode activity proposes to create airport energy infrastructure energy nodes to support AAM battery-electric or hydrogen-powered aircraft, benefiting the aviation community by creating alternative aviation energy. The Attritable Flight Research activity plans to build cost-effective flight research, allowing for safe, rapid, and efficient deployment of new concept designs of recyclable/reconfigurable aviation across NASA and other government agencies with potential transition to Flight Demonstrations and Capabilities project. (CAS)
- NASA will award new ULI proposals and will close out and evaluate the results of several current ULI awards (UI):
    - Georgia Institute of Technology: researching ways to implement new structural materials, manufacturing techniques, and maintenance processes for new vertical lift vehicles as part of the AAM mission;
    - Purdue University: Refining techniques and hardware associated with optical and laser sensors that can be used examining the surfaces of a hypersonic vehicle helping the aircraft maintain control in flight;
    - University of California, San Diego: Creating computational tools, part of an AAM environment, that will enable U.S. industry to develop electronic vertical takeoff/landing vehicles;
    - Pennsylvania State University: Identifying the design of a gas turbine engine for future use in single-aisle, medium- and short-haul aircrafts using hybrid-electric propulsion; and

- University of Texas, Austin: Developing theory and concept of operations used by AAM community verifying concept of autonomous cargo operations will work and, if deployable, on a large scale.

Program Elements

CONVERGENT AERONAUTICS SOLUTIONS (CAS)

The CAS project performs rapid feasibility assessments of early-stage innovations that challenge existing technical approaches, create alternate paths to solutions, and enable new strategic outcomes. The project focuses on merging traditional aeronautics disciplines with advancements driven by the non-aeronautics world to overcome barriers and enable new capabilities in commercial aviation. Internal research teams conduct initial feasibility studies, perform experiments, test new ideas, and identify and learn from failures. When a review determines that the developed solutions have met their goals and identified potential for future aviation impact, ARMD considers the most promising capabilities for continued development by other programs or by direct transfer to the aviation community.

TRANSFORMATIONAL TOOLS AND TECHNOLOGIES (TTT)

The TTT project advances state-of-the-art computational and experimental tools and technologies that are vital to aviation applications. These new computer-based tools, models, and associated scientific knowledge provide novel capabilities to analyze, understand, and predict performance for a variety of aviation concepts. Applying these tools will enable and accelerate NASA's research and enable the aviation community to introduce advanced concepts and designs. An example is the development and validation of new computational tools to predict complex turbulent airflow around vehicles and within propulsion systems, ultimately leading to an improved ability to predict future vehicle performance in flight. The project also explores technologies that are critical to advancing ARMD strategic outcomes, such as understanding new types of strong and lightweight materials, innovative aircraft control techniques, and experimental methods. The TTT project explores new capabilities to enable improved performance and safety of innovative autonomous aircraft and their operational controls. Such technologies will support and enable concept development and benefit assessment across multiple ARMD programs and disciplines.

UNIVERSITY INNOVATION (UI)

The UI project contains a portfolio of disruptive technologies and other new concepts to meet the goals established by the ARMD strategic thrusts and support education of the next generation of engineers. The project uses NASA Research Announcement solicitations where university-led teams assess solving the most critical technical challenges to achieve Aeronautics strategic outcomes and propose independent, innovative research projects to find those solutions. Universities develop their own success criteria, progress indicators, and technical approaches. Universities pursue multi-disciplinary approaches and incorporate opportunities with other universities, industry, and U.S. entities.

TRANSFORMATIVE AERONAUTICS CONCEPTS PROGRAM

Program Schedule

Date	Significant Event
Mar 2024	UI - Release ULI Round 8 Solicitation
Sep 2024	TTT - Complete development of tools and methods for electric and hybrid-electric vehicles capturing effect of engine operability on conceptual designs
Sep 2024	TTT - Perform studies focusing on passenger-carrying UAM applications and human-autonomy models under AMP project
Sep 2024	CAS - Close-out/transition of Solid-State Architecture Batteries for Enhanced Rechargeability and Safety, and Advanced Exploration of Reliable Operation at low Altitudes: Meteorology, Simulation, and Technology activities
Sep 2024	UI - Award ULI Round 7 Selections
Sep 2024	UI - Final Annual Reviews of ULI Round 2 Selection for University of Illinois; ULI Round 3 Selections for North Carolina A&T State University, Stanford University, University of Delaware, Oklahoma State University, and University of South Carolina; ULI Round 4 Selections for Purdue University and University of California, San Diego; ULI Round 5 Selection for Georgia Institute of Technology
Mar 2025	UI - Release ULI Round 9 Solicitation
Sep 2025	TTT - Develop fuel-sensitive soot formation and oxidation experiments improving combustor performance under AATT project
Sep 2025	TTT - Perform first tethered hover flight of RAVEN applying aerodynamic modeling and electric Vertical Takeoff and Landing learning configuration controls
Sep 2025	CAS - Close-out/transition of BEAM, AENode, and Attritable Flight Research activities
Sep 2025	UI - Award ULI Round 8 Selections
Sep 2025	UI - Final annual reviews of ULI Round 4 Selections for Pennsylvania State University, University of Texas, Austin and University of Texas, Austin (Air Force Office of Science Research funded)

Program Management & Commitments

Program Element	Provider
Convergent Aeronautics Solutions (CAS)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: HQ Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): N/A
Transformational Tools and Technologies (TTT)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: GRC Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): Boeing, FAA, Blue Origin, LLC, Rolls Royce - North American Technologies, Inc. (LibertyWorks), DoE Golden Field Office, DoD, ASM International, UTC Aerospace Systems, Naval Air Systems Command, U.S. small businesses

TRANSFORMATIVE AERONAUTICS CONCEPTS PROGRAM

Program Element	Provider
University Innovation (UI)	Provider(s): ARC, GRC, LaRC, AFRC Lead Center: HQ Performing Center(s): ARC, GRC, LaRC, AFRC Cost Share Partner(s): N/A

Acquisition Strategy

TACP research and technology development focuses on foundational research capabilities. The program uses of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition. For all procurement actions, NASA strongly encourages teaming among large companies, small businesses, and universities.

MAJOR CONTRACTS/AWARDS

TACP awards multiple smaller contracts, which are generally less than $5 million and are widely distributed across academia and industry.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Expert Review	Oct 2023	The 12-month review is a formal independent peer review. Experts from other government agencies report on their assessment of technical and programmatic risk and/or project weaknesses.	Received expert feedback on project improvement. Determined that the projects made satisfactory progress in meeting objectives.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	117.3	--	116.2	116.5	119.5	122.3	124.7

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Shown above, researchers inspect the ice formation on the spinner of an Advanced Air Mobility proprotor model tested in the Icing Research Tunnel.

Credit: NASA/Jordan Salkin

The Aerosciences Evaluation and Test Capabilities (AETC) Portfolio sets the strategic direction and funds operations, maintenance, and upgrades of NASA's versatile and comprehensive portfolio of aerosciences ground-test capabilities and assets. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels, propulsion test facilities, and specialty tunnels at ARC, GRC, and LaRC.

Through broad alliances outside of NASA, AETC optimizes the use of these capabilities across the government. NASA participates in the National Partnership for Aeronautical Testing and collaborative working groups that include NASA, the DoD, and other partners. Members of these working groups: (1) gain awareness of capabilities across the government, academia, and industry; (2) share best practices; (3) provide technical support; and (4) refer test programs to facilities best suited to meet test requirements. Within NASA, AETC directly supports the testing needs of five mission directorates: ARMD, ESDMD, SOMD, SMD, and STMD.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

AETC wind tunnels were fully operational or in planned maintenance mode. Tunnel utilizations supported various NASA mission testing needs, including those related to advanced aircraft concepts, future space exploration mission vehicle developments, planetary entry system modeling, external customer tests, and multiple classified tests in support of national security efforts. Specifically, some AETC key testing supported include:

- ARMD:
  - Advanced Air Transport Technologies Boundary Layer Ingesting Tailcone System/Tailcone Thruster Test (LaRC National Transonic Facility);
  - Advanced Air Transport Technologies Swept Wing Flow Test (LaRC National Transonic Facility);
  - Common Research Model-High Lift Test (LaRC 14- by 22-Foot Subsonic Wind Tunnel);

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

    - Advanced Ducted Propulsor Fan Commissioning Test (GRC 9- by 15-Foot Low Speed Wind Tunnel);
    - Subscale Advanced Air Mobility Rotor Icing (GRC Icing Research Tunnel);
    - Combined Cycle Experiment – Large Inlet Mode Transition Simulation Test (GRC 10- by 10-Foot Supersonic Wind Tunnel); and
    - Advanced Air Transport Technologies Panel Flutter Test (ARC Unitary Plan Wind Tunnel).
- SMD:
    - Dragonfly Coaxial Rotor Performance and Aeroshell Test (LaRC Transonic Dynamics Tunnel);
    - Dragonfly Transition Performance Test (LaRC 14- by 22-Foot Subsonic Wind Tunnel); and
    - Mars Sample Return Earth Entry System Test (LaRC Transonic Dynamics Tunnel, Vertical Spin Tunnel, and Aerothermodynamics Laboratory).
- ESDMD:
    - Space Launch System Block 2 with Mobile Launcher Test (LaRC 14- by 22-Foot Subsonic Wind Tunnel); and
    - Artemis Heat Shield Test (LaRC Aerothermodynamics Laboratory).

AETC completed assembly and checkout of a new Mach 6 nozzle in the LaRC 8-Foot High Temperature Tunnel. The upgraded wind tunnel will provide high-fidelity, true enthalpy, and true pressure Mach 6 test environments for durations of up to five minutes required to meet future NASA and DoD hypersonic vehicle ground test requirements.

WORK IN PROGRESS IN FY 2024

- AETC will continue to digitally transform wind tunnel operations and management by establishment of real-time tunnel performance and value metrics that will drive more effective decision-making and business outcomes and align with the Federal Data Strategy.
- AETC will demonstrate with a customer the new state-of-the-art system to measure, assess, and visualize unsteady aerodynamics for advanced and complex aerospace vehicles at high-resolution and unprecedented data turn-around times at the ARC Unitary Plan Wind Tunnel and continue development for future applications at other tunnels.
- AETC will complete assessments of the accuracy and efficiency of computational analysis compared to the multiple AETC wind tunnel's experimental data across multiple Computational Fluid Dynamics models having a wide spectrum of aerodynamic prediction challenges. NASA will continue to use methods learned from these assessments in future wind tunnel assessments.
- AETC will complete the deployment of a new propulsion simulation calibration and testing capability for aircraft and spacecraft models at the NASA LaRC National Transonic Facility. This new capability enables acquisition of next generation aerodynamic test data from aircraft and spacecraft models that integrate with propulsion simulators (e.g., air ejection nozzle or air-powered turbine propulsion simulators).
- AETC will begin a multi-year project to replace the current, failing drive system at the ARC Unitary Plan Wind Tunnel with a state-of-the-art variable frequency drive control system which will increase water and energy efficiency as well as reliability.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

KEY ACHIEVEMENTS PLANNED FOR FY 2025

- AETC will employ new ways to assess the condition and health of testing capabilities at ARC, GRC, and LaRC and new tools to assess and draw insights for more strategically planned investments.
- AETC will deploy a new propulsion simulation calibration and testing capability for aircraft and spacecraft models at the NASA ARC Unitary Plan Wind Tunnel. This new capability enables acquisition of next generation aerodynamic test data from aircraft and spacecraft models that integrate with propulsion simulators (e.g., air ejection nozzle or air-powered turbine propulsion simulators).
- AETC will continue development of Aerosciences Data Platform(s)/Portal(s) for all AETC tunnels to house test facility data assets that will be findable, accessible, interoperable, and reusable, understandable, secure, and trustworthy and develop collaboration platforms for seamless partner sharing of data in a secure and trustworthy manner. In parallel, AETC will maintain viable data systems, instrumentation, and front-end hardware that are adaptable to customer needs as well as invest in development activities to replace aging operational technology and make strides toward improving cyber security posture per federal mandates.
- AETC will develop robust testing methodologies to reduce flight certification time in low speed, high lift flight envelope using the LaRC National Transonic Facility.
- The new LaRC Flight Dynamics Research Facility will become operational replacing the 83-year-old Vertical Spin Tunnel having enhanced capability serving the future needs of NASA.

Program Element

AEROSCIENCES EVALUATION AND TEST CAPABILITIES (AETC)

Aerosciences ground-test capabilities (e.g., facilities, systems, workforce, and tools) that support future aircraft, space vehicles, and operations require efficient and effective investment, operations, and management. Efforts in this area preserve and enhance ground test capabilities necessary to achieve the agency’s multi-Mission requirements. Among these assets are subsonic, transonic, supersonic, and hypersonic wind tunnels and propulsion test facilities at ARC in Mountain View, CA, GRC in Cleveland, OH, and LaRC in Hampton, VA. These test facilities and capabilities also serve the needs of non-NASA users and are listed below:

- ARC Unitary Plan 11- by 11-Foot Transonic and 9- by 7-Foot Supersonic Wind Tunnels
- GRC 9- by 15-Foot Low Speed and 8- by 6-Foot Supersonic Wind Tunnels
- GRC 10- by 10-Foot Supersonic Wind Tunnel
- GRC Icing Research Tunnel
- GRC Propulsion Systems Laboratory
- LaRC 14- by 22-Foot Subsonic Wind Tunnel
- LaRC National Transonic Facility
- LaRC Transonic Dynamics Tunnel
- LaRC Aerothermodynamics Laboratory

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

- LaRC 8-Foot High Temperature Tunnel
- LaRC 20-Foot Vertical Spin Tunnel
- LaRC Unitary Plan Wind Tunnel

NASA's integrated approach to test capability planning, use, and management will consider the complementary computational tools, software, and related systems to effectively acquire and process research data. NASA offers research customers high-quality data that accurately reflects the simulated test environment and the interactions of test articles in those test environments. Furthermore, NASA expertise helps ensure safe and successful use of the assets and the high quality of research outcomes. The AETC Portfolio is cross-cutting and supports the ARMD's Strategic Thrusts, as well as other agency efforts and those of key industry partners.

Program Schedule

Date	Significant Event
May 2024	AETC – Demonstrate with a customer the new state-of-the-art system to measure, assess, and visualize unsteady aerodynamics
Sep 2024	AETC – Completion of report on the evaluation of CFD for testing at high supersonic speeds at LaRC Unitary Wind Tunnel
Sep 2024	AETC – Aerosciences Data Platform(s)/Portal(s) operational
Sep 2024	AETC – Completion of LaRC Propulsion Simulator Calibration Facility
May 2025	AETC – Completion of ARC Propulsion Simulator Calibration Facility
Sep 2025	AETC – Develop robust testing and CFD methodologies to reduce flight certification in low speed, high lift flight envelope using the LaRC National Transonic Facility
Sep 2025	AETC – Operations of new LaRC Flight Dynamics Research Facility
Sep 2025	AETC – Aerosciences Data Platform(s)/Portal(s) operational

Program Management & Commitments

Program Element	Provider
Aerosciences Evaluation and Test Capabilities (AETC)	Provider: ARC, LaRC, GRC Lead Center: HQ Performing Center(s): ARC, LaRC, GRC Cost Share Partner(s): Multiple

Acquisition Strategy

AETC uses of a variety of acquisition tools relevant to the appropriate work awarded externally through full and open competition.

AEROSCIENCES EVALUATION AND TEST CAPABILITIES

MAJOR CONTRACTS/AWARDS

AETC awards multiple smaller contracts, which are generally less than $5 million, and are typically with industry, which provide systems applicable to the sustainment and operations for large-scale wind tunnel assets.

INDEPENDENT REVIEWS

Review Type	Performer	Date of Review	Purpose	Outcome
Performance	Expert Review	Dec 2023	This 12-month review is a formal independent peer review. Experts from other NASA missions report on their assessment of technical and programmatic risk and/or program weaknesses.	This was a very favorable review. The expert reviewers encouraged the team to continue improving its processes including those that support operational efficiency gains and improved investment and divestment decision making.

STEM ENGAGEMENT

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
NASA Space Grant	58.0	--	**57.0**	58.2	59.3	60.5	61.6
Established Program to Stimulate Competitive Research	26.0	--	**24.8**	25.3	25.8	26.3	26.8
Minority University Research and Education Project	45.5	--	**46.3**	47.2	48.2	49.2	50.1
Next Gen STEM	14.0	--	**15.4**	15.7	16.0	16.3	16.7
Total Budget	**143.5**	**143.5**	**143.5**	**146.4**	**149.3**	**152.3**	**155.3**

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

STEM ENGAGEMENT

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
NASA Space Grant	58.0	--	**57.0**	58.2	59.3	60.5	61.6
Established Program to Stimulate Competitive Research	26.0	--	**24.8**	25.3	25.8	26.3	26.8
Minority University Research and Education Project	45.5	--	**46.3**	47.2	48.2	49.2	50.1
Next Gen STEM	14.0	--	**15.4**	15.7	16.0	16.3	16.7
Total Budget	**143.5**	**143.5**	**143.5**	**146.4**	**149.3**	**152.3**	**155.3**

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

These photos illustrate a wide variety of NASA STEM student opportunities, including the Artemis Student Challenges, Students to Launch partnership, and Minority University Research and Education Project (MUREP) Innovation and Tech Transfer Idea Competition (MITTIC).

NASA makes investments in Science, Technology, Engineering, and Mathematics (STEM) engagement, in direct alignment with NASA's Strategic Plan, Goal 4.3 to "build the next generation of explorers," as well as the Administration’s priority of building a future diverse STEM workforce. The Office of STEM Engagement (OSTEM) leads the agency's STEM engagement function, providing strategic guidance and direction in partnership with the mission directorates.

The scope of NASA STEM Engagement comprises all endeavors to attract, engage, and educate students and to support educators and educational institutions. STEM Engagement encompasses a broad and diverse set of programs, projects, activities, and products. This includes student internships and fellowships; student learning opportunities (e.g., challenges and competitions, camps, and other hands-on and virtual experiences); informal education and out-of-school learning activities; educational products, tools, and platforms; educator and faculty support; competitive grants and cooperative agreements to educational institutions for research and development and institutional support; and strategic partnerships with organizations to expand reach and impact.

NASA will continue to support federal STEM education priorities and drive strategic alignment of the agency's STEM engagement efforts through the NASA Strategy for STEM Engagement via three strategic goals:

1. Create unique opportunities for a diverse set of students to contribute to NASA’s work in exploration and discovery.
2. Build a diverse future STEM workforce by engaging students in authentic learning experiences with NASA's people, content, and facilities.

3. Attract diverse groups of students to STEM through learning opportunities that spark interest and provide connections to NASA's mission and work.

These goals, along with their corresponding objectives and strategies, guide the agency's STEM engagement efforts and are complemented by five design principles -- (1) mission-driven authentic STEM experiences, (2) evidence-based practices, (3) scalability, (4) outcome-driven, and (5) diversity and inclusion -- that guide the planning and execution of work in direct support of achieving the strategic goals.

OSTEM is accountable for the management of NASA's STEM Engagement Program, which is composed of four projects: National Space Grant College and Fellowship Project (Space Grant); Established Program to Stimulate Competitive Research (EPSCoR); Minority University Research and Education Project (MUREP); and Next Generation STEM project (Next Gen STEM). These projects are outlined in detail in subsequent sections.

NASA will continue work begun in FY 2024 to advance its work around three priority focus areas:

- First, NASA will implement strategies to broaden student participation to increase diversity, equity, and inclusion in STEM through NASA opportunities and activities. NASA will continue to foster a culture and commitment across the STEM engagement community, including its grantees, partners, and collaborators, to broaden student participation through implementation of an action plan that was developed in FY 2021.
- Second, NASA will continue to build productive strategic partnerships and networks, expanding NASA's STEM ecosystem to magnify reach and impact. This will be accomplished through establishing formal partnerships with organizations through Space Act Agreements, in order to scale activities and expand results and impact, capitalizing on existing networks and distribution systems to deploy products and opportunities.
- Third, NASA will expand contributions in engaging K-12 students in STEM pathways, with an approach toward a continuum of experiences. This will include efforts to increase the accessibility and navigability of NASA opportunities and products for students and educators.

EXPLANATION OF MAJOR CHANGES IN FY 2025

Within a constrained budget, the request prioritizes funding for MUREP and Next Gen STEM to expand the reach and impact of NASA's STEM efforts, including expanding NASA programming targeting partnerships with external organizations.

WORK IN PROGRESS IN FY 2024

In FY 2024, OSTEM continues agency-wide coordination in support of agency and federal government priorities to attract, engage, and educate students toward building a future STEM workforce. OSTEM continues to implement enterprise initiatives to improve efficiency and strengthen standards and rigor in program management, fiscal accountability, and performance measurement. In FY 2024, NASA will continue to implement a mission-driven STEM Engagement Program through its four projects. Details regarding project plans and activities are provided in dedicated subsequent sections.

In FY 2024, NASA's STEM Engagement enterprise remains committed to continuing the implementation of the following:

- Drive strategic alignment and a mission-driven programmatic model. This includes conducting a comprehensive analysis of the portfolio and building on programmatic efforts established in partnership with the mission directorates.
- Implement cross-cutting strategies to more effectively reach and serve students, educators, and educational institutions, and to improve operations.
  - NASA will continue to drive the continued use of STEM Gateway, a database to provide oversight and transparency to the agency's STEM activities.
  - NASA will continue to further its work in significantly enhancing its digital footprint to better reach students, including improved products at https://stem.nasa.gov.
  - NASA will continue to drive progress on the agency internships program, with objectives for growth and enhanced student experiences.
  - NASA will continue the implementation of a partnership strategy, cultivating new partnerships to increase reach and impact.
  - NASA will continue progress and evolution of the performance assessment and evaluation approach and Learning Agenda with continued cadence of focused evaluation studies to inform evidence-based program changes.
  - NASA will continue the implementation of an integrated action plan toward broadening student participation in STEM engagement programs and activities.
- Further an enterprise operating model and focus on building skills and capabilities of the NASA STEM Engagement workforce.
- Continue its annual planning process and program management practices in defining and implementing a portfolio of projects, activities, and products directed toward achieving the agency's Strategy for STEM Engagement goals and objectives. Ultimately, the work dedicated to this strategy will contribute to achieving NASA's STEM Engagement vision to immerse students in NASA's work, attract students to STEM, and inspire the next generation to explore.

KEY ACHIEVEMENTS PLANNED IN FY 2025

NASA will enable student opportunities aligned with NASA STEM Strategy and objectives and continue to provide mission-driven competitive opportunities via Space Grant, EPSCoR, and MUREP in partnership with mission directorates.

NASA will continue to enhance and evolve the STEM Gateway, enable performance measurement and analytics, and implement the next stage of the STEM engagement learning agenda, with completion of targeted studies to drive design and evolution of products and activities.

Specific achievements planned for the Space Grant, MUREP, EPSCoR, and Next Gen STEM projects are summarized in subsequent sections.

NASA SPACE GRANT

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	58.0	--	57.0	58.2	59.3	60.5	61.6

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Students pictured were supported by the New Jersey Space Grant to build, travel, and compete in the yearly student rocket launch competition held in Huntsville, AL.

Space Grant is a competitive grant opportunity that actively involves 52 consortia in 50 states, the District of Columbia, and Puerto Rico. Space Grant supports science, technology, engineering, mathematics, education, and research efforts for educators and students by leveraging the resource capabilities of over 1,000 affiliates from universities, colleges, industry, museums, science centers, and state and local agencies. Cooperative agreements with each consortium align their work with the nation's Science, Technology, Engineering, and Mathematics (STEM) education priorities, NASA's missions, and the annual agency performance goals.

Space Grant utilizes key NASA resources to provide students access to research and hands-on STEM learning experiences. To maximize impact for these STEM investments, Space Grant leverages agency resources in STEM education through strategic collaborations with NASA centers, subject matter experts, and mission directorates.

The activities conducted by the 52 consortia are in alignment with agency goals, the Office of STEM Engagement (OSTEM) priorities, and the National Science and Technology Council's (NSTC) Committee on Science, Technology, Engineering, and Math Education (CoSTEM) priority areas. Direct student support is provided by Space Grant awards at the state level consisting of scholarships, fellowships, and/or internships. In addition to the individual efforts of each consortium, the consortia collectively support a broad array of projects nationwide, including the Artemis Student Challenges.

EXPLANATION OF MAJOR CHANGES IN FY 2025

The budget reduces support compared to the FY 2024 Budget request for a new collaboration with ARMD in support of the University Student Research Challenge. In addition, Space Grant consortia award augmentations (currently $110,000) will be reduced. These adjustments enabled NASA to prioritize funding for MUREP and Next Gen STEM efforts to expand partnerships.

ACHIEVEMENTS IN FY 2023

In FY 2023, Space Grant Consortia each received $800,000, and received the opportunity to propose for an additional $110,000 in augmented funds to Year 4 of the current multi-year base award, which was

NASA SPACE GRANT

extended to a five-year award (active into FY 2025). The consortia proposed activities directly aligning with mission directorate needs and priorities and were required to apply at least 32 percent of their NASA funds toward direct student awards (e.g., fellowships, internships).

Space Grant executed the fifth-year option and extended the on-going four-year cooperative agreement by one year. This solicitation supports funding to the 52 consortia for an additional year while a new multi-year solicitation is released.

FY 2023 saw the first of a two-year award for the independent program-level evaluation effort, which was awarded to the Alaska Space Grant at the University of Alaska, Fairbanks. The award is specifically evaluating the overall efficacy of Space Grant and how the entire Space Grant Consortia retains students in STEM.

Space Grant developed a new partnership with ARMD for the release of a solicitation toward the development of student, faculty, and community involvement during the upcoming X-59 Quiet Supersonic Transport (QueSST) flights.

Space Grant also provided additional opportunities for the consortia to directly participate in other mission directorate or other OSTEM projects. Space Grant continued a partnership with STMD to provide the Breakthrough, Innovative, and Game-changing (BIG) Idea Challenge. The challenge provided the opportunity for consortia student teams to design, develop, and demonstrate technologies that will enable the production of lunar infrastructure from In-Situ Resource Utilization derived metals found on the Moon.

Space Grant awarded $1.4 million for the second of the three-year Space Grant K-12 Inclusiveness and Diversity in STEM (SG KIDS) award, which helps advance racial equity and support hands-on activities in historically underrepresented student populations. For this award, four lead space grant consortia are collaborating with many others across the nation to help increase the reach and impact from SG KIDS.

Space Grant Awards in FY 2023		
Award Type	**Number of Awards**	**Funding Total**
Base Awards	52	$47,020,000
Space Grant K-12 Inclusiveness and Diversity (KIDS) Award	4	$1,400,000
Space Grant Collaborations & Special Topics	4	$2,167,000
Total	**60**	**$50,587,000**

WORK IN PROGRESS IN FY 2024

Space Grant consortia will be completing the year-four activities outlined in their accepted proposals and will be initiating the fifth year of the five-year award. In FY 2024, the Space Grant project will award a funding augmentation to each eligible consortium, which provides the opportunity for the consortia to propose raising their total award funding levels to $910,000. Additionally, in FY 2024, Space Grant will release a new four-year solicitation to support Space Grant consortia from 2025 to 2028.

Space Grant will provide oversight of the four SG KIDS projects to help ensure the targeted student populations are truly impacted.

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Space Grant will continue to monitor the final year of the two-year award for the independent program-level evaluation activities. The results of the evaluation program will be reviewed by the OSTEM Performance and Evaluation Team and reported in FY 2025.

Space Grant will also continue productive partnerships with the mission directorates to engage Space Grant Consortia more effectively in mission priorities. Space Grant continues the successful partnership with STMD in the execution of the BIG Idea. It will leverage that experience to expand the partnership formed in FY 2023 with ARMD toward supporting the upcoming X-59 test flights.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

The budget supports base awards for the 52 consortia to do the following:

- Provide hands-on learning experiences for U.S. graduate and undergraduate students to prepare them for the future workforce and/or academic careers;
- Continue support for student internships across all consortia;
- Conduct programs and projects that align with the NASA STEM engagement and mission directorate priorities, the National Science and Technology Council's Committee on STEM priority areas, and state-specific needs to build STEM pathways in higher education, research infrastructure, pre-college, and informal education; and
- Continue progress of the SG KIDS awardees in expanding access to NASA-aligned activities in historically underrepresented student populations.

PROJECT SCHEDULE

Date	Significant Event
Q1 FY 2024	Selection of X-59 QueSST Awardees
Q2 FY 2024	Fund X-59 QueSST Awards
Q2 FY 2024	Release of next Multi-Year Space Grant Notice of Funding Opportunity (NOFO)
Q2 and Q3 FY 2024	Release of Year 5 Base Award Funding
Q3 FY 2024	Fund Breakthrough, Innovative, and Game-changing (BIG) Idea Challenge
Q3 and Q4 FY 2024	Consortia Site Visits
Q4 FY 2024	Year 2 Progress Review with SG KIDS awardees
Q4 FY 2024	Release Award Funding for SMD Science Activation Collaboration
Q4 FY 2024	Release 3rd and Final Year Award Funding for SG KIDS awardees
Q4 FY 2024	Review Consortia Proposals for Multi-Year Space Grant NOFO

NASA SPACE GRANT

PROJECT MANAGEMENT & COMMITMENTS

The Space Grant Project Manager at NASA HQ provides management responsibility for day-to-day Space Grant operations. Civil servants at NASA centers actively engage with regional Space Grant Consortia, providing direction, oversight, and integration with center and mission directorate activities.

ACQUISITION STRATEGY

NASA solicits through competitive proposals from the 52 Space Grant consortia in 50 states, the District of Columbia, and Puerto Rico. Each consortium program or project must align with the Administration priorities, NASA's Strategic Plan, and the NASA Strategy for STEM Engagement. All award selections undergo rigorous peer reviews by internal and external panels that evaluate technical merit and assess content, feasibility, and alignment to agency STEM engagement, research, and technology goals. Awards are typically multi-year.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

NASA continues to use performance assessment and evaluation-driven processes to enhance the effectiveness of STEM engagement investments, executing the refined OSTEM Learning Agenda to understand the outcomes of its investments. Space Grant has continuously assessed its content and activities in pursuit of continuous improvement, in the context of the OSTEM Learning Agenda.

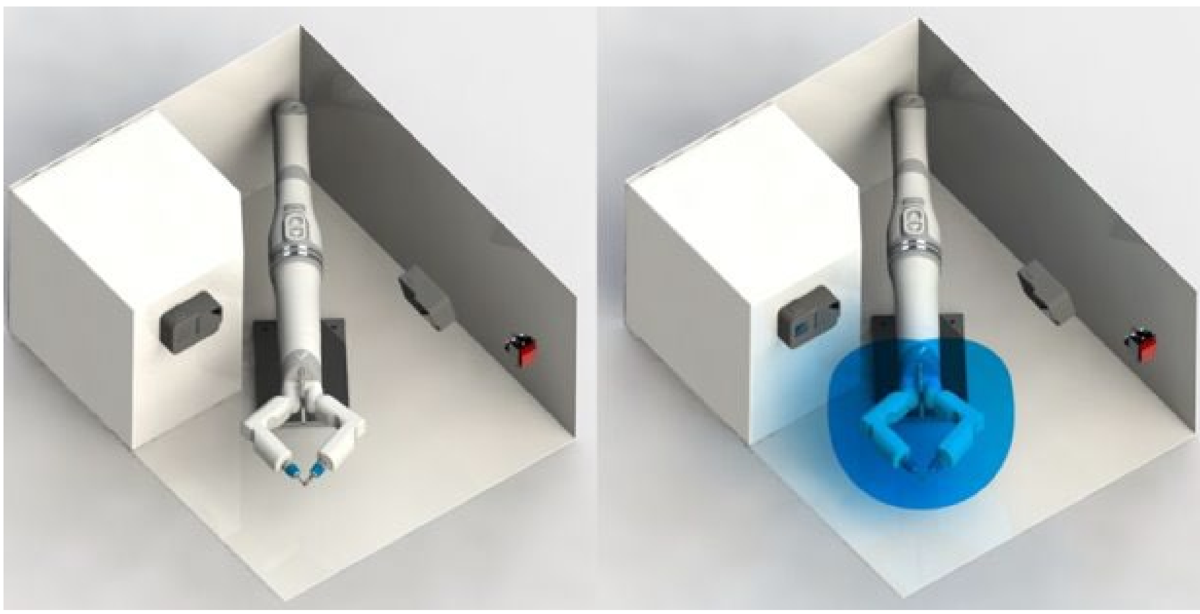
In FY 2022, two competitively selected Space Grant Consortia (i.e., New Mexico State University and University of Alaska, Fairbanks) completed a two-year, independent program-level evaluation pilot of Space Grant. These pilot evaluations were representative of Space Grant offerings across multiple states with the purpose to (1) determine how and to what extent the Space Grant Program is designed and executed in alignment with federal law and NASA's STEM engagement goals and priorities; and (2) assess the impact and degree to which the Space Grant Program is achieving its intended outputs and outcomes on a national level. These efforts provided robust evidence that can be used to drive future scaled evaluation strategy, program policy, data collection plans, and appropriated competitive awards. Overall results from the awardees' evaluation reports provide preliminary evidence that student participation in Space Grant programming has a positive effect on both short-to-medium-term and long-term student outcomes and revealed several potential faculty-level outcomes. The University of Alaska, Fairbanks was selected to scale up evaluation efforts for an additional two-years beyond the initial two-year pilot award to evaluate the entire Space Grant Consortia.

ESTABLISHED PROGRAM TO STIMULATE COMPETITIVE RESEARCH

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	26.0	--	24.8	25.3	25.8	26.3	26.8

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



Shown here is the University of Nebraska's experimental design of miniature robotic surgery technology set to be tested in microgravity on the ISS to verify remote operation in a relevant environment.

NASA's Established Program to Stimulate Competitive Research (EPSCoR) project provides competitive cooperative agreements (CA) designed to establish partnerships between government, higher education, and industry to build stronger research and development capabilities in 28 eligible EPSCoR jurisdictions (states or regions). The primary goal of the project is to enhance a jurisdiction's research infrastructure, empowering its research and development programs to significantly contribute to its overall economic development. EPSCoR has established a series of individual components to facilitate this work.

- EPSCoR Research Infrastructure Development (RID) CA has a five-year base period of performance with awards up to $200,000 per year, for a total of $1 million.
- EPSCoR Research Notice of Funding Opportunity (NOFO) awards are up to $750,000 for a three-year performance.
- EPSCoR ISS Flight Opportunity NOFO utilizes the ISS as a microgravity platform for space flight research.

ESTABLISHED PROGRAM TO STIMULATE COMPETITIVE RESEARCH

- EPSCoR Rapid Response Research (R3) NOFO is a collaborative effort between EPSCoR and NASA SMD, STMD, and ESDMD, NASA centers, commercial partners, and others to provide a streamlined method to address high priority research issues such as advancing equity, climate change, and IT Modernization and Cybersecurity.
- The NSF Research Infrastructure Improvement (RII) Track 4: @NASA is a joint EPSCoR project with the NSF on a Minority Serving Institution (MSI)/Primarily Undergraduate Institution (PUI)-focused program to fund research teams to conduct research in NASA facilities with a NASA researcher.

EXPLANATION OF MAJOR CHANGES IN FY 2025

The budget reduces funding for EPSCoR by five percent relative to the 2023 level. Funding for the Research Infrastructure Development cooperative agreements and the joint NASA-NSF Research Infrastructure Improvement project will be prioritized and maintained at the FY 2023 level, which means other funding opportunities will be reduced by more than five percent.

ACHIEVEMENTS IN FY 2023

The EPSCoR RII Track-4: EPSCoR Research Fellows program dovetails with the NSF EPSCoR's strategic objective of establishing sustainable pathways for professional development in STEM. This initiative provides awards aimed at bolstering research capacity within institutions, reshaping investigators' career paths, and fostering collaborative ventures with leading private, governmental, and academic research centers.

NASA EPSCoR has significantly contributed to pairing faculty members from underrepresented universities and colleges with research opportunities crucial to the NASA space program. Leveraging all allotted awards, the collaboration between NASA and NSF witnessed substantial interest, with 97 faculty members expressing interest in the RII Track-4 initiative. Notably, the NASA EPSCoR office successfully matched 100 percent of these faculties with NASA scientists and engineers.

The program facilitates robust collaborations through extended or periodic visits to selected NASA sites, enabling fellows to acquire new skills, forge fresh partnerships, and access specialized facilities. These collaborations can potentially steer research toward transformative new directions. The intent is for these fellowship experiences to have enduring impacts, shaping the research trajectories of the fellows well beyond the award period. Moreover, the anticipated benefits to the fellows are expected to contribute to the broader enhancement of research capacity within their institutions and jurisdictions.

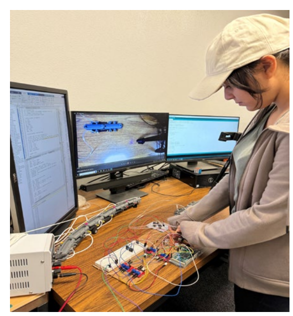
Established Program to Stimulate Competitive Research

In FY 2023, NASA EPSCoR invested a total of $22,321,092 through awards via the components. Below are the amounts allocated to each element.

EPSCoR Awards in FY 2023 (Component Award Values)		
Element	**Awards**	**Total Amount**
EPSCoR Research Infrastructure Development (RID) continuation	28	$5,600,000
Research	16	$11,627,438
ISS Flight Opportunity	5	$500,000
Rapid Response Research (R3)	40	$3,993,654
FY 2023 RII Track-4 investment ($600K; NSF is $2,747,321)	10	$600,000
TOTAL	**99**	**$22,321,092**

The EPSCoR website document highlights EPSCoR-funded research accomplishments within the eligible jurisdictions and is available at: https://www.nasa.gov/stem/epscor/home/index.html

The impact of this initiative is evident across various domains:



Ayla Valles, a graduate student at the University of New Mexico, is shown here working on the electro-pneumatic controller of the artificial muscle-driven snake robot for agile and energy-efficient limbless locomotion during planetary exploration.

Research Output:

- Published Papers: 157
- Conference Presentations: 421
- New/Revised Courses: 147

Engagement and Collaboration:

- Students/Researchers Involved: 1,665

Collaborations:

- NASA Collaborators: 475
- Industry Collaborators: 392
- Grants (Non-EPSCoR Grants): 65

Economic Value and Technological Advancement:

- Total value: $29,653,059.00
- Technology/Technique: 95
- Patent Issued: 5
- Reported Invention: 15

Dissemination and Outreach:

- URLs: 185
- List of talks, presentations, events, and outreach activities: 309
- Explanations in various formats (APA, Book, Newspaper Op-Ed, etc.): 45

ESTABLISHED PROGRAM TO STIMULATE COMPETITIVE RESEARCH

Recognized Achievements:

- Reported Accomplishments: 103
- Sub-Awards: 123

WORK IN PROGRESS IN FY 2024

EPSCoR will make new research, R3, ISS, and NSF RII Track 4: @NASA awards. Each funded proposal will establish research activities with the potential to make significant contributions to NASA's strategic research and technology development priorities, while also contributing to the overall research infrastructure, science, and technology capabilities of higher education, and economic development within the EPSCoR jurisdiction.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

NASA EPSCoR will continue to issue calls for five to 10 ISS Flight Opportunity awards, four to six Suborbital Flight Awards, 30 to 35 R3 awards, and 15 to 18 Research NOFO awards.

Project Plan

Date	Significant Event
Q1 and Q2 FY 2024	Release of Solicitations Research NOFO Research Infrastructure Development (RID) EPSCoR Rapid Response Research (R3) NSF Research Infrastructure Improvement (RII) Track 4: @NASA
Q2 and Q3	Proposals Due and Review Process

Project Management & Commitments

The NASA EPSCoR project manager is responsible for overall administrative duties of this national project. The project manager is supported by a team consisting of an integration manager, grants manager, budget analyst, and contractor staff. The EPSCoR project office works closely with representatives from each OSTEM project, NASA center, mission directorate, and scientific team to ensure that current and future research requirements are in EPSCoR solicitations. The mission directorate and NASA center representatives serve as the proposal selection committee, further ensuring that the selected work contributes to NASA priorities. Subject matter experts from NASA centers and HQ monitor and assess the progress of each award. They provide scientific guidance and technical advice as required throughout the year regarding the overall progress of the proposed effort and review all progress reports.

NASA is a member of the federal EPSCoR Interagency Coordinating Committee (EICC), chaired by the NSF. The committee works to improve the leveraging of federal EPSCoR investments. This committee is dedicated to enhancing the effective use of federal EPSCoR investments.

ESTABLISHED PROGRAM TO STIMULATE COMPETITIVE RESEARCH

Acquisition Strategy

NASA solicits and awards EPSCoR cooperative agreements through a competition among institutions from designated EPSCoR states called jurisdictions. Each jurisdiction's proposal must align with the Administration's priorities and NASA's Strategic Plan. All award selections undergo rigorous peer reviews by internal and external panels that assess technical merit, content, feasibility, and alignment to agency research and technology goals. Awards are typically multi-year.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

NASA continues to use performance assessment and evaluation-driven processes to enhance the effectiveness of STEM engagement investments, executing a refined OSTEM Learning Agenda to understand the outcomes of its investments. EPSCoR has continuously assessed its activities in pursuit of continuous improvement within the context of the OSTEM learning. In FY 2023, OSTEM piloted an Institutional Research Capacity (IRC) study to examine how institutional research capacity is conceptualized by awardees of the EPSCoR project, identify metrics to measure IRC across programs, and assess the outcomes of the NASA EPSCoR awardees' institutional research capacity building efforts.

MINORITY UNIVERSITY RESEARCH AND EDUCATION PROJECT

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**45.5**	**--**	**46.3**	**47.2**	**48.2**	**49.2**	**50.1**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Tuskegee Scholars (shown here) perform serial dilutions of soil samples taken from campus and city sites before attempting to grow bacteria on culture plates as part of the 2023 NASA MUREP Tuskegee University Pre-College Summer Institute. Tuskegee, Alabama.

The Minority University Research and Education Project (MUREP) provides grants and cooperative agreements to the nation's Historically Black Colleges and Universities (HBCUs), Hispanic Serving Institutions (HSIs), Asian American and Native American Pacific Islander-Serving Institutions (AANAPISI), Tribal Colleges Universities (TCUs), Alaska Native and Native Hawaiian Institutions (ANNHs), Predominantly Black Institutions (PBIs), and eligible community colleges. These minority-serving institutions (MSIs) play a vital role in educating students who may be underrepresented and underserved in Science, Technology, Engineering, and Mathematics (STEM), including women and girls, veterans, and persons with disabilities. MUREP's investments in these MSIs are part of a comprehensive approach toward advancing equity for all, including people of color and others who have been historically underserved, marginalized, and underrepresented in STEM fields.

Participation in NASA projects and research has the potential benefit of both increasing numbers of students in STEM and encouraging them to earn degrees in STEM fields that are critical to NASA and the nation.

NASA's MUREP investments enhance the research, academic, and technology capabilities of MSIs through competitive, multi-year awards. Awards assist faculty and students in research and provide authentic STEM engagement related to NASA missions. These funded opportunities provide NASA-specific knowledge and skills to historically underrepresented and underserved students in STEM. MUREP investments also assist NASA in meeting the goal of a diverse future workforce through student participation in internships and fellowships at NASA centers.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

In FY 2023, MUREP finalized its approach for creating the NASA MSI Data Report. This new agency-wide report will introduce MUREP's new reporting capability developed through the MSI Data Team's work with the NASA Office of Chief Information Officer's Information, Data, & Analytics

MINORITY UNIVERSITY RESEARCH AND EDUCATION PROJECT

Services (IDAS) team. These enhancements improve the ability agency-wide to collect and provide broader awardee information holistically while tailoring the data to suit its various user communities. Until the Performance and Evaluation Team has completed its verification and validation process, all performance data reported should be considered preliminary.

Strengthening Minority Serving Institutions (MSI)

In FY 2023, MUREP provided engagement and oversight of 161 active awards made up of grants, cooperative agreements, and prizes at 89 MSIs across 33 states and territories.

Addressing the Gender Gap in STEM

MUREP supported advancement opportunities, access, and representation for underserved communities through the NASA MUREP Women's Colleges and University (WCU) initiative. NASA MUREP WCU Activity is a new initiative seeking to address the significant gender gap and disparate experiences of women in STEM in the United States, both in higher education and the workforce. The MUREP WCU funding opportunity, in response to Executive Order 14035, "Diversity, Equity, Inclusion, and Accessibility in the Federal Workforce", calls on WCUs, as identified by Department of Education data, to leverage their women-centered expertise and experience to address barriers to women seeking, retaining, and remaining in STEM degrees and employment. NASA awarded more than $5 million in funding to seven WCUs to research and develop strategies that increase retention of women in STEM degree programs and careers. These programs factor in gender, race, sexual orientation, socio-economic status, and other identities that can play a role in students' career trajectories. Each awardee also will provide a guidebook of data, instructions, and best practices to serve as a blueprint for other MSIs and Women's Colleges seeking to create similar programs.

Investing in Historically Black Colleges and Universities

MUREP awarded $11.7 million to eight institutions creating its first cohort of grantees under the Data Science Equity, Access, and Priority (DEAP) Artificial Intelligence & Machine Learning (AI/ML) activity, in collaboration with SMD. The awards will enable HBCU students and faculty to conduct innovative data science research that contributes to NASA's missions.

This particular effort has two key elements:

- By focusing exclusively on HBCUs/PBIs, there is intentionality around increasing the research capacity in these burgeoning fields at MSIs. Targeted solicitations also assist the agency in meeting its White House Initiative for HBCUs goals, objectives, and metrics; and
- Reinforce SMD's Open Science Data initiatives wherein barriers to accessing scientific data are reduced/eliminated and MSIs are encouraged to utilize NASA's rich repository of data sets to foster research and discovery.

The awarded projects have up to three years to establish institutes and partnerships to increase the number and research capacity of STEM students at HBCUs, accelerate innovation in a wide range of NASA STEM research areas, and prepare the future workforce for data-intensive space-based Earth sciences.

Additionally, new awards were made under the MUREP Precollege Summer Institute (PSI). MUREP PSI increases participation and retention of historically underserved and underrepresented high school students in STEM areas and prepares them for success in college STEM degree programs and STEM careers. Seven HBCUs and one PBI were awarded more than $3 million in funding to strengthen their support for students in those communities in precollege summer programs around the nation. PSI uses evidence-based strategies to enhance high school students' precollege performance, prepare them for college entrance, and ultimately help them achieve success in their higher education pursuits and in STEM careers. This project gave students an opportunity to experience what it's like to live on a college campus, attend classes, and build relationships with professors and peers. Students participated in engineering design challenges and research related to NASA missions with support from NASA subject matter experts.

Building Capacity at MSIs

The MUREP Partnership Annual Notification (MPLAN) awarded nearly $900,000 to 15 MSIs to develop new technologies for use in space exploration as well as in the commercial marketplace. Through this award, MSIs will contribute to research in preparation for larger funding programs. These include NASA's annual Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) solicitation within STMD, ARMD's University Leadership Initiative, and human performance research within SOMD.

WORK IN PROGRESS IN FY 2024

FY 2024 will see the next iteration of one of MUREP's most robust and financially impactful awards, the MUREP Institutional Research Opportunities (MIRO) activity. This fiscal year will highlight a significant change in MIRO's philosophy on creating a more diverse portfolio that values MSI category, size of institution, and other Diversity, Equity, Inclusion, and Accessibility (DEIA) elements, while remaining true to the tenants of increasing overall research competitiveness and sustainability at the universities. As more agencies move into the MSI arena and provide funding opportunities, MIRO is set to usher in the next wave of institutional changing opportunities that can shift the STEM research trajectory at MSIs.

MUREP will continue to make investments through its American Indian and Alaska Native STEM Engagement to increase engagement in STEM through authentic and unique NASA experiences. Partnership efforts with the American Indian Science and Engineering Society (AISES) as well as the American Indian Higher Education Consortium (AIHEC) will help to ensure greater reach into the academic institutions and STEM communities. Funding opportunities will again be provided to promote STEM identity for students and strengthen institutional capacity efforts.

In support of the NSF Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (INCLUDES) initiative, NASA is committed to broadening participation in STEM by establishing coalitions of organizations led by MSIs in the United States that can support broadening participation initiatives in engineering-related disciplines and fields. INCLUDES seeks to (1) build strong foundations for STEM literacy; (2) increase diversity, equity, and inclusion in STEM; and (3) prepare a highly qualified future STEM workforce that reflects the diversity of the nation. MUREP will fund a second cohort of MSIs in FY 2024.

The MUREP Space Technology Artemis Research (MSTAR) opportunity supports STMD by fostering and increasing MSI participation in research and technology development concepts that align with the agency's needs for upcoming Artemis missions to the Moon. The agency chose nine institutions, awarding a total of more than $8 million to carry out their projects. MSTAR focuses on connecting MSI administrators and university STEM leaders to cutting-edge initiatives at NASA that can increase interest in securing research and contracting opportunities, while supporting NASA's policy to achieve an agency-wide goal of providing one percent of total contract value for prime and subcontracting awards to MSIs.

MINORITY UNIVERSITY RESEARCH AND EDUCATION PROJECT

KEY ACHIEVEMENTS PLANNED FOR FY 2025

MUREP will feature its next climate-focused collaboration with SMD's Earth Sciences division as a follow up to the OCEANS activity. NASA's strategic objective for Earth Science is to advance knowledge of Earth as a system in order to meet the challenges of environmental change and to improve life on our planet. The new solicitation will engage MSIs in understanding the complex, changing planet on which we live, how it supports life, and how human activities affect its ability to do so.

MUREP will feature its next Aeronautics focused collaboration with ARMD as a follow on to the MUREP High Volume activity. The new solicitation will seek to engage MSIs in NASA's Aeronautics programs in research, development, and testing of aviation technology advancements that will benefit humankind and retain U.S. leadership in a vital manufacturing and transportation sector.

MUREP will pilot an effort for community colleges and other two-year institutions in order to create deeper engagement with these institutions and the students that they serve. This pilot will address the critical need for technology development and apprenticeship programs to meet the ever-growing demands of the aerospace industry.

MUREP will continue to support the agency's one percent Procurement/Small Business goal by creating forums for HBCUs/MSIs to leverage their strengths in the contracting arena. Jointly coordinated road tour events at strategically located MSIs with the Office of Procurement and the Office of Small Business Programs will offer new and novel ways for Higher Education Institutions (HEIs) to engage in the work of NASA outside of traditional grants and cooperative agreements.

PROJECT SCHEDULE

Engagement Opportunities in NASA STEM (EONS) is an omnibus announcement that includes a range of NASA STEM Engagement opportunities for basic and applied science and technology research and education. In FY 2023 to 2024, the OSTEM Program (inclusive of Space Grant, Next Gen STEM, MUREP, and EPSCoR) incorporated their various funding opportunities under the renamed EONS. The consolidated approached was derived for the purpose of: (1) establishing best practices for the projects; (2) eliminating redundancies and duplicative efforts; and (3) generating more consistent solicitation approaches for the broader community of proposers for OSTEM opportunities.

The table below includes significant FY 2024 MUREP milestones.

Date	Significant Event
Q1 FY 2024	Open EONS Omnibus Solicitation; MUREP Institutional Research Opportunity (MIRO) appendix
Q2 FY 2024	MUREP/ARMD appendix
Q3 FY 2024	MUREP INCLUDES Cohort 2 appendix
Q4 FY 2024	Student Engagement Team Competitions/Challenges kickoff(s)

PROJECT MANAGEMENT & COMMITMENTS

The MUREP project manager is located at NASA HQ and provides management and oversight for overall activity operations. NASA centers manage significant investments in project activity elements. MUREP

MINORITY UNIVERSITY RESEARCH AND EDUCATION PROJECT

activities map strategically to three investment pillars: Research Infrastructure and Capacity Building, Student Engagement, and Partnerships & Sustainability.

ACQUISITION STRATEGY

NASA MUREP awards cooperative agreements, grants, and contracts (if applicable) through full and open competition.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS OR EVALUATION

All MUREP activities document performance through either external evaluations or internal reviews. MUREP continues to utilize performance assessment and program evaluation to inform continuous improvement processes and evidence-based decision making. In FY 2023, NASA utilized the MUREP Outcome Evaluation Framework/Plan to conduct an outcome assessment of MUREP investments. The MUREP Outcome Assessment implemented a validated data collection instrument to measure student outcomes (e.g., student identity, student sense of belonging, student academic self-efficacy, etc.) at the program-level and included National Student Clearinghouse (NSC) data to assess persistence, retention, and graduation rates. Evaluation findings highlight the importance of personal networks to recruit students into MUREP-funded activities. Creating meaningful relationships and welcoming environments encourages student participation across multiple semesters, strengthens psycho-social outcomes, and strengthens relationships with potential STEM employers. MUREP students persist to second semester studies and have higher six-year graduation success than national comparisons. MUREP-funded activities help students pursue STEM education and increase confidence about continuing to the STEM workforce. Partnerships with professionals in the STEM ecosystem support student opportunities to join the STEM workforce and impact NASA missions.

NEXT GEN STEM

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**14.0**	**--**	**15.4**	**15.7**	**16.0**	**16.3**	**16.7**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

NASA SPARX (Sparking Participation and Real-world eXperiences in STEM) challenges and competitions aim to broaden student participation in agency STEM opportunities.

Next Gen STEM (NGS) contributes to building a strong, diverse future STEM workforce by providing learning opportunities for students in grades K-12 that infuse the excitement of NASA missions and programs into an integrated portfolio of educational products, experiences, challenges, and competitive awards. NGS reaches students in school, in after school programs, in informal education institutions, and at home. NGS employs evidence-based practices to broaden student participation in STEM, ensuring the greatest accessibility to NASA STEM opportunities while providing educator support.

NGS includes a competitive awards program for Informal Education Institutions (IEIs), Teams Engaging Affiliated Museums, and Informal Institutions (TEAM II). The TEAM II program is supported by the Museum and Informal Education Alliance, a vibrant community of practice for all IEIs that is administered within the NASA CONNECTS (Connecting Our NASA Network of Educators for Collaborating Together in STEM) online community of practice platform.

EXPLANATION OF MAJOR CHANGES IN FY 2025

The 10 percent budget increase (relative to the FY 2023 level) in FY 2025 affords NGS the opportunity to implement a pilot effort for partnerships jointly funded by NASA and external organizations. Leveraging partnerships has potential in advancing K-12 objectives. This pilot promotes further developing networks and driving systemic change to continue to grow our reach and impact, including broadening student participation resulting in increased NASA contributions for diversity and equity in STEM.

NGS will evaluate the effectiveness of two long-standing engineering design challenges in FY 2024 and may eliminate one of them in favor of increasing support to other projects that have the potential to impact larger numbers of students and educators.

NEXT GEN STEM

ACHIEVEMENTS IN FY 2023

The project created new standards-aligned educational content, expanded support to educators, redesigned and launched a new program for engaging students with NASA content and people, and created a new software tool for use by the whole agency to collect and fulfill engagement needs in communities across the nations. Specific accomplishments in FY 2023 included:

- Created over 15 new educational products in partnership with NASA mission directorates featuring the Artemis program, Earth science, solar eclipses, aeronautics, and more. These products were designed for cultural relevance to highlight career connections and are deeply aligned to national standards.
- Grew the NASA CONNECTS educator community of practice membership by approximately 200 percent and significantly increased the value to educators through monthly virtual classroom connections with NASA experts with career exploration, monthly educator discussion sessions on topics of interest, two in-person engagement days at KSC, and a virtual career day attended by tens of thousands of students and teachers.
- Redesigned the NASA SPARX student engagement program following a formal evaluation of its initial pilot year and relaunched the program for the 2023-2024 school year with over 150,000 students registered to date. NASA SPARX provided STEM learning and challenges that lower the barrier to entry for educators and students to build STEM identity and efficacy; provided tailorable execution, educator training and support throughout; and supported access to NASA role models for student career exploration.
- Completed initial development of NASA Engages, a modern software tool and training and support program that enabled the entire agency to strategically and effectively meet public demand for STEM engagement at a larger scale than previously possible. This tool formally launched in the first quarter of FY 2024.
- Initiated the Artemis Moon Trees Initiative, a partnership with the USDA Forest Service, which put saplings grown from seeds that flew to the Moon on Artemis I into communities across the nation to increase scientific engagement and learning. The seeds were returned from the Moon on the Orion capsule flown and germination and growth are being overseen by the Forest Service. The first round of recipients will be chosen in FY 2024.

Almost $4 million in TEAM II awards were made to 21 informal education institutions, including 17 Community Anchors and four larger awards. These 17 Community Anchors joined the first 21-member cohort from 2022 to share best practices and perspectives to make all awarded institutions even more effective STEM ambassadors in their respective communities.

WORK IN PROGRESS IN FY 2024

In FY 2024, NGS is continuing to create new NASA mission-inspired educational content for formal and informal education settings, but with significantly fewer products being developed than in FY 2023. Also, virtual and in-person engagements with students will continue, but fewer events are planned due to reduced personnel and travel funds. The NASA SPARX student challenges are successfully ongoing with over 150,000 participants, and the NASA Engages online platform and support program is complete and is being used to enable the NASA workforce to effectively connect to needs in communities across the nation at scale.

NEXT GEN STEM

The TEAM II competitive awards program is continuing and plans to award informal education institutions in FY 2024 at the level supported by the FY 2024 enacted budget.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

Key initiatives begun in FY 2023-2024 will come to fruition or will be enhanced and extended. These initiatives provide critical infrastructure and resources that will enable the agency in FY 2025, to reach larger and more diverse K-12 audiences more effectively:

- Implementation of a pilot for partnerships, jointly funded by NASA and external organizations. This pilot will support the development and deployment of high-impact national learning opportunities to engage students in NASA STEM.
- Adoption of agency-wide use of NASA Engages.
- Implementation of the re-designed NASA SPARX program.

NGS will also continue its practice of funding formal evaluations of its key components. For FY 2025, that will include the first evaluation of the NASA Engages online platform and support program.

PROJECT SCHEDULE

As described in previous sections, FY 2024 and FY 2025 will be pivotal years for NGS, with many new and improved products and offerings for K-12 students, informal and formal educators, and IEIs.

Date	Significant Event
Q1 FY 2024	2023-2024 SPARX student challenge and traditional student design competitions launched
Q2 FY 2024	Selection of new TEAM II full and Community Anchor Awardees
Q2 FY 2024	Formal public launch of NASA Engages
Q3 FY 2024	Culminating Events for school year 2023-2024 traditional and SPARX challenges and competitions
Q4 FY 2024	New education products available for back-to-school campaign
Q4 FY 2024	New TEAM II award solicitation released
Q1 FY 2025	NASA SPARX and traditional student competitions begun for 2024-2025 school year
Q2 FY 2025	Selection of TEAM II Full and Community Anchor Awardees
Q2 FY 2025	Begin formal evaluation of NASA Engages
Q3 FY 2025	Conclusion of 2023-2024 School Year challenges and culminating events
Q4 FY 2025	Final report available for formal evaluation of NASA Engages

NEXT GEN STEM

PROJECT MANAGEMENT & COMMITMENTS

The NGS project leadership team reports to NASA HQ but are each located near a NASA field center. The remainder of the NGS activity leads, and all supporting personnel for project efforts, are located at various NASA field centers. The current NGS elements are as follows:

- Earth (Includes a focus on Earth and Climate Science, as well as activities ongoing on the ISS);
- Moon (Focused on exploration of the Moon through the Artemis program);
- Aeronaut-X (Focuses on NASA's endeavors in aeronautics research and development);
- Solar System and Beyond (Brings the excitement of space science and exploration of the solar system to classrooms);
- Competitive Awards - TEAM II; and
- Educator Support and Development (Includes CONNECTS Community of Practice with Formal and Informal [MIE Alliance] Subgroups and opportunities for educator learning).

ACQUISITION STRATEGY

Consistent with existing NASA practices, NASA uses cooperative agreements, grants, and contracts through full and open competitions. All NGS award selections undergo rigorous peer reviews by internal and external experts, usually including panel reviews, that evaluate proposals technical merit, feasibility, and alignment to agency STEM Engagement goals and objectives. In-house initiatives are executed through civil servant leadership and contractor support through the newly awarded Office of STEM Engagement unified contract.

MAJOR CONTRACTS/AWARDS

None.

INDEPENDENT REVIEWS

Since its inception, NGS has used program evaluation to inform its continuous improvement process. In FY 2022, NGS evaluation centered around an evaluation of the NASA SPARX challenge and competition pilot. The overall purpose of the evaluation was to build knowledge about NGS activities by understanding feasibility, appropriateness, and usability of NASA SPARX. Findings from the study focused on streamlining the requirements for participation, engaging students from underrepresented communities, and recommendations for program improvement. These findings were used to inform FY 2023 evidence-building plans.

Building on the FY 2022 findings, FY 2023 evaluation activities focused on evaluating NASA CONNECTS and building an evidence-based program design framework (EBPD) for four NGS efforts: NASA SPARX, NASA CONNECTS, NASA Engages, and Educator Professional Development (EPD). The NASA CONNECTS evaluation provided evidence about how NASA CONNECTS supports teachers in creating compelling educational activities that support NASA STEM Engagement and confirmed that NASA CONNECTS community members find the platform useful for efficiently locating relevant NASA materials. Study participants also highlighted potential areas for improvement and identified collaboration as a key area for potential growth. The overall outcome of these evaluation activities laid the groundwork for the execution of evaluation activities in FY 2024.

NEXT GEN STEM

In FY 2024, a TEAM II Innovation in Informal Education (IE) evaluation will be conducted collecting data about innovative granting practices and supports for IE institutions. This study will also examine the ways in which TEAM II competitive opportunities are positioned to the IE community and make recommendations to support the broader goals of the TEAM II project. Additionally, educator guides developed under the SPARX activity will be reviewed to assess alignment with Next Generation Science Standards and participant focus groups will be conducted to generate continuous improvement feedback to project management.

SAFETY, SECURITY, AND MISSION SERVICES

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Mission Services & Capabilities	2,067.4	--	**2,058.1**	2,099.2	2,141.3	2,184.1	2,227.6
Engineering, Safety, & Operations	1,069.1	--	**986.3**	1,006.1	1,026.1	1,046.6	1,067.7
Total Budget	**3,136.5**	**3,129.5**	**3,044.4**	**3,105.3**	**3,167.4**	**3,230.7**	**3,295.3**

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023. Amounts include $8 million that was transferred to NASA's Information Technology Modernization Working Capital Fund.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

SAFETY, SECURITY, AND MISSION SERVICES

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Mission Services & Capabilities	2,067.4	--	**2,058.1**	2,099.2	2,141.3	2,184.1	2,227.6
Engineering, Safety, & Operations	1,069.1	--	**986.3**	1,006.1	1,026.1	1,046.6	1,067.7
Total Budget	**3,136.5**	**3,129.5**	**3,044.4**	**3,105.3**	**3,167.4**	**3,230.7**	**3,295.3**

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023. Amounts include $8 million that was transferred to NASA's Information Technology Modernization Working Capital Fund.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

The Safety, Security, and Mission Services (SSMS) account enables NASA's missions by providing foundational support capabilities responsive to evolving mission needs. SSMS also funds independent oversight over NASA's missions and programs to ensure the health, safety, and security of NASA people and property as well as the public. SSMS programs provide the services and capabilities that ensure NASA has the technical skills, physical assets, financial resources, and top talent to be successful. The SSMS FY 2025 budget is comprised of two themes: Mission Services and Capabilities (MSaC) and Engineering, Safety, and Operations (ESO).

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

MISSION SERVICES AND CAPABILITIES

MSaC provides enterprise solutions under three programs: Information Technology (IT), Mission Enabling Services (MES), and Infrastructure and Technical Capabilities (I&TC). Strategically, these programs meet workforce, infrastructure, information technology, and business operations requirements necessary to enable NASA's mission. MSaC ensures critical agency operations are effective, efficient, safe, and meet statutory, regulatory, and fiduciary responsibilities. These mission enabling services and capabilities provide efficient and effective administration across all NASA centers and HQ.

- **Information Technology (IT)** provides the information services needed to fulfill NASA's multifaceted missions and operations, including cybersecurity, IT asset planning and management, and technical support. NASA's IT program helps improve agency outcomes by accelerating results through tools that increase productivity, sharing NASA's data and discoveries, enabling access to transformational Artificial Intelligence (AI) capabilities, and increasing the quality, resiliency, and cost-effectiveness of its information systems. Reliable, adaptable, and secure authorized cloud-based IT, data and AI services are increasingly important to NASA's mission portfolio because they are key enablers for advances in science, technology, aeronautics, and space exploration. In FY 2025, the Information Technology program will:
  - Strengthen the agency's cybersecurity posture through the deployment of new tools and implementation of a strategy aimed to modernize and improve NASA's overall network security.

  - Transform IT business services through utilization of AI, cloud adoption, and robotic process automation.
  - Continue to invest in the high-tech tools needed to improve authorized collaboration capabilities across the agency, including transitioning to hybrid workspaces that will increase productivity through remote and virtual collaborative work.
  - Appoint a Chief AI Officer and establish AI governance to maximize NASA's benefit from AI in a safe, secure, ethical, responsible, and respectful manner, in accordance with Executive Order 14110 on the Safe, Secure, and Trustworthy Development and Use of Artificial Intelligence and other federal directives.
  - Lead innovative adoption of AI use cases in direct support of advanced mission outcomes, improved cybersecurity detection and response, accelerated cybersecurity assessments, and to gain efficiencies across all mission support functions.
- **Mission-Enabling Services (MES)** provides an enterprise approach to managing NASA business operations and mission support activities. Missions rely on these institutional services to provide the business services and skilled staff required to accomplish their objectives. Enterprise management of these areas ensures that critical agency operations are effective, efficient, and meet statutory, regulatory, and fiduciary responsibilities. Business services include financial management, human capital management, procurement, small business, legislative affairs, equal opportunity and diversity management, legal, communications, international and interagency relations, and protective services. In FY 2025, the MES program will:
  - Continue to partner with all NASA organizations in execution of their Diversity, Equity, Inclusion, and Accessibility (DEIA) implementation plans in accordance with the DEIA and Equity Strategic Plans.
  - Enhance NASA's workforce by strengthening the professional development framework to build the current and future talent pool.
- **Infrastructure and Technical Capabilities (I&TC)** provides sustainment, operations, and maintenance for facilities and technical capabilities. The program also provides effective oversight and management of real property, environmental program activities, aircraft operations, and logistics functions. These capabilities enable NASA to meet statutory and regulatory responsibilities and ensures that the necessary infrastructure is available to meet mission requirements. This mission is accomplished through effective management of assets and capabilities, proactive coordination with NASA mission directorates, institutional planning, proactive deployment of sustainable practices, ongoing regulatory compliance, and reduction of current and future infrastructure-related risks. In FY 2025, the I&TC program will:
  - Maintain the agency's most critical infrastructure capabilities and assets using condition-based maintenance to prevent failures and increase operational readiness while maintaining compliance with environmental and mandatory standards.
  - Optimize the agency's infrastructure portfolio through implementation of the Agency Master Plan (AMP) processes, including divestment of facilities no longer needed to execute NASA's mission thereby reducing future facilities maintenance costs.
  - Continue agency efforts to transition to 100 percent Zero Emission Vehicle acquisitions by 2035, including 100 percent light-duty acquisitions by 2027.

SAFETY, SECURITY, AND MISSION SERVICES

ENGINEERING SAFETY AND OPERATIONS

ESO provides for the management and operations of NASA HQ, nine centers, and component facilities under two programs: (1) Agency Technical Authority (ATA); and (2) Center Engineering, Safety, and Operations (CESO). Both programs support scientific and engineering activities. They contribute to the reduction of program risks by ensuring that: technical skills and assets are ready and available to meet program and project milestones; mission and research endeavors are technically and scientifically sound; and center practices are safe and reliable, including the highly skilled staff and specialized infrastructure at the centers that facilitate NASA missions.

- **Agency Technical Authority (ATA)** provides the foundation for NASA's system of checks and balances, defined in NASA's Strategic Management and Governance Handbook, by providing independent technical authority over health, safety, and engineering requirements for the missions. Through independent analysis and deep subject matter expertise, ATA develops policy, designs procedural requirements, and provides recommendations to NASA's Administrator, mission directorates, center directors, and program managers, who are ultimately responsible for the safety and mission success of all NASA activities. In FY 2025, the ATA program will:
    - Work to improve orbital debris environment models, tools, and algorithms to improve orbit predictions, understand spacecraft anomalies, and better interpret sensor data.
    - Continue providing key guidance, testing, and oversight over NASA missions and programs to ensure health, safety, and stewardship of resources.
- **Center Engineering, Safety, and Operations (CESO)** ensures NASA's unique, technical, and innovative capabilities are mission-ready by supporting center-level institutional and technical capabilities through independent research, development projects, and maintenance of facilities, laboratories, and other mission-critical assets. CESO fulfills a key component of NASA's overall approach to risk management by providing center-level independent technical authority. Center-level oversight and reporting activities uphold the strategy and guidance from ATAs, putting checks on safety, engineering, and mission assurance that are separate from mission directorates. CESO funds NASA HQ operations and center management activities across the agency. Institutional administration and operational safety programs allow centers the flexibility to address and manage conditions unique and specialized to their facilities. CESO also ensures that agency policies and guidance are operationalized across centers with consistency and efficiency. In FY 2025, the CESO program will:
    - Continue to maintain critical strategic investments in laboratories, technical equipment, and facilities as aligned with agency goals and objectives in support of all NASA missions.

BALANCING SSMS AND CECR

NASA's mission support portfolio is divided between two accounts: SSMS and Construction and Environmental Compliance and Restoration (CECR). The Mission Support Directorate (MSD) utilizes both accounts to maintain NASA's critical infrastructure. SSMS and CECR programs are dependent upon each other and there is a balance between maintenance of assets and infrastructure, repairs and renewal of failing assets, and the replacement and demolition of obsolete assets. Required maintenance activities drive SSMS spending decisions, while repairs, renewals (including new construction), and associated demolition drive CECR spending.

SAFETY, SECURITY, AND MISSION SERVICES

Much of NASA's infrastructure dates back to Apollo-era space exploration. Maintenance activities funded by SSMS are necessary to prevent costly delays to missions and risks to health and safety. Meanwhile, failures require immediate repairs and account for an increasing share of the SSMS facilities maintenance budget. These activities are vital to support evolving mission requirements. SSMS also funds proactive maintenance initiatives such as Condition Based Maintenance to identify issues and provide lower cost, scheduled maintenance. Without a sufficient facilities maintenance budget, assets and facilities worsen to a state requiring CECR funding for more expensive solutions. The increasing deep space exploration development and testing requirements place an additional strain on NASA's infrastructure and mission-unique facilities. Both SSMS and CECR activities are vital to support mission infrastructure requirements. MSD takes an agency-wide approach to make difficult trade-off decisions that ensure critical capabilities and assets are mission-ready, while also investing in the long-term asset health, sustainability, and footprint reductions that ensure NASA's future mission success. This approach allows NASA the ability to prioritize investments in support of long-term asset health, sustainability, and footprint reductions that ensure NASA's future mission success.

MISSION SUPPORT PRIORITIES

NASA Strategic Plan 2022, Goal 4, directs NASA's mission support functions to enhance capabilities and operations to catalyze current and future mission success through three key objectives: 1) attract and develop a talented and diverse workforce; 2) transform mission support capabilities for the next era of aerospace; and 3) build the next generation of explorers. Functions and capabilities that align to these three priorities comprise the foundational business that supports NASA activities, including the agency’s mission goals.

Mission Support’s strategic approach ensures that critical services are mission-ready as requirements evolve and foundational services are keeping pace with cybersecurity, industry standards, and agency needs. NASA Mission Support will continue to support the critical capabilities needed for mission success by staying focused on mission needs, center conditions, and transformational opportunities. Mission support content is prioritized to achieve the Administration, NASA, and mission support goals and objectives, to include:

- Workforce, Essential Services, and Partners:
  - Support mission-critical services that enable NASA's activities and address workforce needs, including procurement of essential goods and "best-in-class" contracts.
- Critical Infrastructure:
  - Conduct vital construction, repairs, and demolition to reduce risk in NASA's infrastructure portfolio and ensure the right capabilities are mission-ready at the right time.
- Business Transformation:
  - Introduce technologies and new processes to create strategic cohesion, service resilience, new efficiencies, and cutting-edge capabilities to enhance how people work and reduce costs.
- Cybersecurity:
  - Strengthen NASA's IT infrastructure, monitoring, detection systems, encryption, cloud security, and authentication to enhance protection for data and telecommunications.

MISSION SERVICES & CAPABILITIES

Budget Authority (in $ millions)	FY 2023	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Information Technology (IT)	628.6	--	**628.6**	641.1	654.0	667.1	680.4
Mission Enabling Services	754.3	--	**732.7**	747.4	762.3	777.5	793.0
Infrastructure & Technical Capabilities	684.5	--	**696.8**	710.7	725.0	739.5	754.2
Total Budget	**2,067.4**	**--**	**2,058.1**	**2,099.2**	**2,141.3**	**2,184.1**	**2,227.6**

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023. Amounts include $8 million that was transferred to NASA's Information Technology Modernization Working Capital Fund.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Mission Services and Capabilities (MSaC) provides foundational business service and enterprise solutions to all of NASA. While mission requirements evolve with agency priorities and external conditions, MSaC is focused on the permanent and critical essentials that enable all NASA activity.

MSaC offers a range of foundational services, including, but not limited to, human capital, financial management, physical asset management, software and hardware services, communications, diversity and inclusion programs, legal services, small business program, procurement services, and safety/protective services. MSaC is comprised of three programs: Information Technology (IT), Mission Enabling Services (MES), and Infrastructure and Technical Capabilities (I&TC).

Representatives from Bulgaria are shown here signing the Artemis Accords to demonstrate their commitment to Safe and Sustainable Space Exploration.

Program Elements

INFORMATION TECHNOLOGY

The IT program provides the information services needed to fulfill NASA's multifaceted missions and operations, including cybersecurity, IT asset planning and management, and technical support. NASA's Information Technology program helps improve agency outcomes by accelerating results through tools that increase productivity; sharing NASA's data and discoveries; and increasing the quality, resiliency, and cost-effectiveness of its information systems. Reliable, adaptable, and secure cloud-based IT is increasingly important to NASA's mission portfolio because it is a key enabler for advances in science, technology, aeronautics, and space exploration.

MISSION SERVICES & CAPABILITIES

MISSION ENABLING SERVICES

The MES program provides an enterprise approach to managing NASA's business operations and mission support activities. Missions rely on these institutional services to provide the business services and skilled staff required to accomplish their objectives. Enterprise management of these areas ensures that critical agency operations are effective, efficient, and meet statutory, regulatory, and fiduciary responsibilities. Business services include financial management, human capital management, procurement, small business, legislative affairs, equal opportunity and diversity management, legal, communications, international and interagency relations, and protective services.

INFRASTRUCTURE AND TECHNICAL CAPABILITIES

The I&TC program provides sustainment, operations, and maintenance for facilities and technical capabilities. The program also provides effective oversight and management of real property, environmental program activities, aircraft operations, and logistics functions. These capabilities enable NASA to meet its statutory and regulatory responsibilities and ensures that the right infrastructure is available to meet mission requirements. Utilization of the Agency Master Plan will provide the guidance to accomplish this mission through effective management of assets and capabilities, proactive coordination with NASA mission directorates, institutional planning, proactive deployment of sustainable practices, ongoing regulatory compliance, and reducing current and future infrastructure-related risks.

INFORMATION TECHNOLOGY (IT)

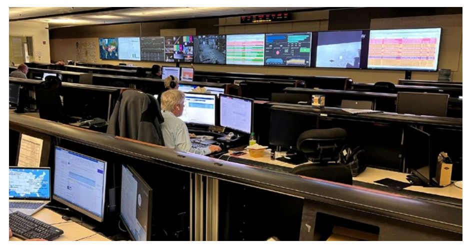
FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**628.6**	**--**	**628.6**	**641.1**	**654.0**	**667.1**	**680.4**

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023. Amounts include $8 million that was transferred to NASA's Information Technology Modernization Working Capital Fund.

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

NASA's Information Technology (IT) program provides cross-cutting corporate IT products and services, such as applications, data platforms and analytics, devices, networks, and cybersecurity, to support achievement of all NASA objectives. It continues to improve NASA's cybersecurity posture as a shared responsibility through implementation of a Zero Trust Reference Architecture and Plan enhancing Security Orchestration, Automation, and Response (SOAR) capabilities, allowing operational visibility across all NASA Centers, identification of potentially illicit patterns of activity as well as transitioning to a single Endpoint Detection and Response (EDR) capability, ensuring equitable and consistent monitoring and response, and network segmentation-based Software-Defined Access (SDA) which minimizes lateral movement and reduces the impact of security breaches. IT also provides tailored services to support specific mission support requirements such as data management, networks, cloud computing, and artificial intelligence.



NASA Integrated Operations Center (NIOC) analysts are the first line of defense of enterprise network disruptions, service degradations, and infrastructure and network device failures. The NIOC is the centralized location for 24/7/365 monitoring of health and performance for all NASA corporate enterprise services.

NASA's IT ecosystem supports the successful execution of NASA's missions which:

- Enables the operation of the ISS;
- Prepares for human exploration beyond LEO;
- Enables better understanding of the solar system and the universe; and
- Enables safer, faster, and more efficient air transportation systems.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

INFORMATION TECHNOLOGY (IT)

ACHIEVEMENTS IN FY 2023

Cybersecurity

- Increased NASA's implementation of Multi Factor Authentication by 48 percent, Data-at-Rest encryption by 46 percent, and Data-in-Transit encryption by 36 percent strengthening the cybersecurity postures of IT systems, defense, and protection against attacks and increasing mission safety and resilience.
- Launched the Cybersecurity Improvement Portfolio (CIP) to centrally facilitate and manage federally mandated cybersecurity improvements to protect and enable NASA's missions, including NASA's transition to a Zero Trust Architecture. Since its inception, the CIP has identified over 230 unique requirements and has established an order of events for implementation.
- As part of the effort to improve agency-wide communications, devised methods to segment communications to ensure critical mass communication capabilities in the event of a catastrophic information technology failure (e.g., SMS text message delivery across NASA in the event of a complete loss of email).

Business Transformation

- Increased cloud storage by 74 percent from May 2022 to May 2023, which allowed NASA to modernize and decommission physical data centers while taking advantage of the benefits of cloud storage, including reduced costs, improved performance, and enhanced security.
- Launched NASA's Enterprise Data Platform (EDP) to facilitate a culture of data transparency, fair and equal access, and collaboration across organizations; and integrate with other agency data initiatives to provide users the enterprise ability to store, manage, analyze, and visualize data for improved visualization and decision making.
- Established the IT Modernization Working Capital Fund (WCF) to enable the formulation and execution of cost effective, strategic modernization projects that appropriately consider risks, merits, and alternatives for IT modernization investments.

WORK IN PROGRESS IN FY 2024

Cybersecurity

- Migrate corporate network services to Cisco Software-Defined Access (SDA) segments, each having specific access policies based on segment functions (e.g., printers, endpoint, phones), with plans to be approximately 60 percent migrated to the SDA fabric by the end of FY 2024.
- Redesign and upgrade the agency cybersecurity logging solution increasing visibility, data retention requirements, and response to potential incidents, including enabling monitoring, logging, and analysis of NASA's cloud platforms as part of implementation of specific Microsoft 365 capabilities.

Business Transformation

- Support NASA missions including Crew 5, Crew 6, and SLS/Orion, and consolidate three OCIO image management systems into one, streamlining mission research.

INFORMATION TECHNOLOGY (IT)

- Expand real-time secure collaboration capabilities with external federal, university, and commercial partners to provide improved user productivity and experiences, while decommissioning legacy platforms.
- Complete enterprise range of technical and data-oriented skills and technology capabilities to mine enterprise platforms for data insights and information, and a data platform to advance intelligent search and analytics.

PLANNED ACHIEVEMENTS AND KEY INITIATIVES FOR FY 2025

IT Program

- Improve public access and discoverability of NASA-funded research publications by implementing persistent identifiers that create associations between publications, supporting data, authors, and funding per agency and federal Open Science policy.
- Improve the experience of employees with disabilities by increasing the accessibility of the Office of the Chief Information Officer (OCIO) IT products and services, workforce training and awareness on Section 508 of the Rehabilitation Act of 1973, and tracking and remediating IT accessibility issues.
- Reduce NASA’s data center hardware costs and improve performance by harvesting appropriate on-premise data center applications to migrate to cloud services.
- Enable insights from NASA’s mission and administrative data through a data platform that offers data science tools and services to effectively manage, analyze, visualize, and share data resources at scale and speed.

Cybersecurity

- Centralize access and visibility to data before, during, and after a potential cybersecurity incident through the implementation of Security Orchestration and Automated Response, behavioral analytics, and event management on the NASA network.
- Provide quicker reaction times and consolidation of tools and appliance by integrating the Enterprise Network Operations Center (ENOC), Security Operations Center (SOC), and NASA Ground Communications System (NASCOM) Operations Management Center (NOMC).
- With enhanced Endpoint Detections and Response implemented solutions, protect mission organizations from cyber threats, including malware, ransomware, and phishing attacks.
- Implement cybersecurity improvements that secure NASA's data, achieve compliance with federal mandates, and deliver a Zero Trust Architecture.
- Authorize a Federal Information Security Modernization Act (FISMA) high cloud environment to support NASA's return to the Moon and future exploration of Mars.

Business Transformation

- Expand the Digital Academy platform for agency-wide training on Data and Artificial Intelligence (AI) and continue to develop engaging training to increase data acumen and literacy and educate on ways to best leverage data using AI.

INFORMATION TECHNOLOGY (IT)

- Evolve the NASCOM Mission Alternate Operating Facility from a warm site back up (available for use if needed) to a distributed active operations center that will provide concurrent support to customers in support of Artemis II and beyond.
- Accelerate digitally enabled transformation at NASA, utilizing the Agency Roadmap Manager tool to synchronize and refine an Organization's Digital Transformation Plans, identifying gaps and opportunities to streamline enterprise and OCIO services.
- Establish a Portfolio Optimization process to analyze 25 percent of Class F (i.e., business enabling) Applications annually to identify consolidation opportunities and plans for efficiencies and resource savings.
- Expand the reach of the rapid response team digital service. This service deploys small teams across the agency to provide User Experience (UX) methodologies for solving key priority agency challenges quickly and effectively.

Program Elements

ENTERPRISE IT

The Enterprise IT program is multifaceted and includes the following six project elements, each with unique functions and work focus:

- Applications and Platforms Services: anticipates and aligns customer requirements with solutions that best meet agency needs by delivering secure, sustainable applications quickly and cost effectively, establishing a platform-centric architecture that empowers mission support, enhanced software management to reduce software license costs, and continuous portfolio rationalization.
- Network and Telecommunications Services: provides fully managed network and communications services supporting institutions, programs, and projects located at the NASA centers. Communications is also responsible for maintaining, operating, and continually evolving services to improve delivery capabilities, strengthen NASA's cybersecurity posture, and reduce costs.
- Cloud and Computing Services: brokers commercial cloud computing services for the NASA community, providing oversight of NASA's compliance with the Federal Data Center Optimization Initiative (DCOI). Cloud Computing Services extends to all NASA missions, mission support, and external collaborators.
- Workplace and Collaboration Services: provides high-quality, reliable, cost-effective service desk, end-user computing services, collaboration, content management systems, and identity, credential, and access services in support of all NASA federal and contractor employees, including support for laptops, desktops, mobile devices, printing, email, messaging, help desk services, software patching, distribution, and more.
- Information, Data, and Analytics Services: provides NASA with framework, guidelines, and services to ensure secure and efficient access, use, analysis, and preservation of the agency's information resources. The program ensures NASA's compliance with federal statutes relating to data access and integrity.

INFORMATION TECHNOLOGY (IT)

- Transformation and Data Services: guides NASA's data strategy, technology infusion, strategic investment decisions, and identification of emerging information technologies to support NASA's needs most effectively in a rapidly changing world.

SAFEGUARDING DATA AND IT ASSETS

NASA OCIO is responsible for agency cybersecurity policy and the implementation and management of enterprise cybersecurity and privacy services. The IT program budget is aligned to the National Institute of Standards and Technology (NIST) Cybersecurity Framework to evaluate cybersecurity gaps and investments against the NIST cybersecurity functions: Identify, Detect, Protect, Respond, and Recover. This alignment allows the agency to make strategic investments to develop, modernize, and enhance agency cybersecurity capabilities to address the greatest areas of risk to the agency, missions, and supporting functions.

IT GOVERNANCE AND OVERSIGHT

NASA OCIO provides agency-level capabilities for managing IT and meeting agency and federal requirements. IT Governance and Oversight efforts involve collaborating with stakeholders across the agency to formulate plans and manage budgetary data to meet legal mandates, OMB guidance, Executive Orders, and regulations. These efforts also include the E-Government activities and Federal Chief Information Officer (CIO) Council Committees in which NASA participates.

MISSION ENABLING SERVICES

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	754.3	--	732.7	747.4	762.3	777.5	793.0

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Artemis II Astronauts from NASA and CSA participate in an event at the Canadian Embassy in Washington, DC (shown above). The astronauts, who will fly around the Moon on Artemis II, visited Washington to discuss their upcoming mission with members of Congress and others.

Mission Enabling Services (MES) ensure NASA mission success with foundational support services using enterprise service delivery, while promoting diversity, inclusion, and engagement to enhance problem solving and agile responses to evolving requirements. Using an enterprise approach, the MES program eliminates duplicative capabilities, provides opportunities for employees to collaborate across geographic boundaries, and remains agile to shifting demands and surge requirements, while ensuring the health, safety, and security of NASA people, property, and the public. Missions rely on MES's institutional capabilities to accomplish their objectives. Enterprise management ensures that critical agency operations are strategic, mission-focused, agile, and streamlined.

Recruiting, hiring, and maintaining the right mix of high-performing talent remains a critical focus for the MES program, in alignment with the workforce goal in the NASA Strategic Plan.

MES provides NASA with a bedrock of business functionality in human capital and financial management; procurement and protective services; small business, diversity and equal opportunity programs; legislative affairs; communications; and international and interagency operations. It also provides the agency's outreach and engagement with the public, industry, and federal and international partners, to ensure the world partners and shares in NASA's incredible work of exploration, innovation, inspiration, and discovery.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

- Supported the transformation of NASA's primary website (https://www.nasa.gov) and NASA's Science website (https://www.Science.NASA.gov) to share matching user interfaces and site searches, providing high-quality, user-friendly, modern, and consistent experience to visitors, while still ensuring the agency's content is authoritative, up to date, and builds support for NASA priorities.
- Supported SMD by providing the infrastructure, facility modifications, and security in developing the Earth Information Center located at NASA HQ raising awareness of NASA's Earth science, while

MISSION ENABLING SERVICES

informing visitors about Earth's environment and climate through easily accessible, readily usable, and scalable information.

- Released a new NASA+/NASA app, transitioning the agency from traditional, linear 24/7 NASA Television channels distributed over satellite to a robust, on-demand, non-linear streaming service distributed via terrestrial networks to multiple internal and external platforms, totaling more than 536,000 people around the world in the Virtual Guest Program, representing all 50 U.S. states and 173 countries.

Business Transformation

- Transitioned more than 40 communications and digital services contracts from across the agency into two contracts, one agency-wide strategic communications contract, and one digital services contract, providing deeper insight into costs, and enabling more capability trades and greater efficiencies.
- Reduced time to hire from 134 days to 75 days by centralizing agency recruitment activities, which garnered recognition in OPM's Human Capital Reviews report.
- Standardized and improved planning, communications, and operations for protective services by eliminating cumbersome interfaces and costly systems across the agency, through selection of a single secure Web application for communications, command, control, planning, and other actions, including inter-agency and multi-agency, multi-location coordination.
- Reduced prime contracts for regionalized security and agency fire protection from twenty-five to three, decreasing duplication of effort and acquisition lead times, ensuring consistency/standardization, and facilitating cross-agency support. These consolidation efforts are estimated to save the agency nearly $6 million annually and nearly $12 million in cost avoidance associated with acquisition activities.

Strengthening Interns/Empowering the Workforce/Talent Pipelines

- Increased NASA's Spanish-language social media accounts reach by 30 percent to 3.4 million followers, helping to develop and sustain interest in Science, Technology, Engineering and Mathematics careers among individuals with limited English proficiency, and bolstering outreach and engagement to build the current and future talent pool.
- Launched a new interactive e-learning platform to provide developmental opportunities and training for employees, managers, and leaders through industry standard courses, mandated training, books, resources, learning labs, live courses, bootcamps, and more, capturing 4,254 unique users viewing more than 160,000 pages of content, and totaling more than 15,000 session hours.
- Released a 12-month Aspiring Executive Program that provides extensive leadership development for a diverse, agency-wide group of employees selected for their high potential for assuming executive-level roles and responsibilities. There were 91 nominees and 40 selected participants. The program included targeted learning sessions on psychological safety, inclusion, and building trusting environments; access to a BetterUp Coach and the additional Diversity, Equity, Inclusion, and Accessibility (DEIA) specific content through the BetterUp coaching platform; and intentional exposure through mentoring, shadowing, and panel sessions with a diverse set of leaders both internal and external to NASA.

MISSION ENABLING SERVICES

- Launched the Women's Executive Leadership Lab, an in-person cohort-learning opportunity to equip women leaders with self-awareness and skills to achieve a greater level of influence and excel at higher levels of leadership.
- Launched NASA's agency-wide Recruitment Ambassador's Initiative, which provides employee guidance for digital recruiting best practices, in-person events, and external resources for recruitment.
- Launched the Employee Resource Group Stellar Program, a proof of concept for MentorcliQ, an enterprise wide and easy-to-use platform that facilitates workplace mentorships and great tool for fostering workplace inclusion, belonging, employee development and advancement, retention, and engagement. The program is designed to supercharge the leadership development and career advancement goals for Employee Resource Group chairs, officers, and members.

Diversity, Equity, Inclusion, and Accessibility (DEIA) and Advancing Equity

- Developed and submitted to the Domestic Policy Council (DPC) as part of the White House's Gender Equity Report, and internally implemented, NASA's Gender Equity Plan, an agency-wide, cross-organizational approach to advance gender equity and equality across the nation and beyond.
- Produced 12 dashboards to improve DEIA data analytics, including NASA workforce demographics, analysis of USAJOBs data, and center workforce portfolio.
- Conducted NASA's first DEIA organizational climate survey to assess equity, inclusion, anti-harassment climate, accessibility, discrimination, psychological safety, and comfort of NASA civil servants identifying DEIA areas to further explore and address.
- Implemented an IT solution to track and report progress on all DEIA implementation plans and developed contract mechanisms for the deployment of NASA's Pay Equity Assessment, with the completion of a Phase 1 report of pay equity action analysis results.
- Increased awareness of contracts and grants policies through more than 20 active engagements in conferences and outreach efforts targeting businesses from underserved communities, including six training sessions and 13 outreach events.
- Developed NASA's agency-level Language Access Plan, which was submitted to the Department of Justice and implemented at all NASA centers to establish a more equitable communication strategy for reaching limited English proficient populations.
- Launched the SERVIR Gender Analysis Tool to enable gender integration into geospatial services. This innovative activity will apply the Gender Analysis Tool to deepen the understanding of gender impacts in carbon monitoring services for women, girls, men, and boys across various socioeconomic groups, racial, and Indigenous identities in the Amazon. Additionally, four SERVIR hubs in Asia, Africa, and Latin America will build capacity to develop gender-integrated geospatial services. The activity will enable hubs to conduct a gender analysis, integrate findings into service design, and engage more diverse groups of stakeholders.
- Won multiple recruitment awards: #1 Internships (Vault Magazine), Top 20 Government Employers (STEM Workforce Diversity Magazine), (Woman Engineer Magazine and Equal Opportunity Magazine); and America's Best Employers for Women (Forbes Magazine). NASA's digitization and modernization recruitment activities were also featured in the Advancing DEIA Promising Practices for Federal Agencies, a publication by the United States Office of Personnel Management and the Executive Office of the President.

MISSION ENABLING SERVICES

Acquisition Improvement

- Awarded the NASA Transformational Shared Services Contract (NTSS), which provides consolidated select business and technical services for NASA. The seven-year contract has a total value not to exceed $400 million.
- Developed and launched an external facing Made in America (MIA) Web page (https://www.nasa.gov/eo14005/) to inform the public of NASA's successes, launched the MIA Success Story Repository for the NASA workforce, and developed an MIA dashboard to assess and improve the quality of data entry and simplify bi-annual reporting.
- Designed and developed custom solutions (e.g., interactive dashboards) to optimize available contract and acquisition resources and provide an automated method to present near real-time data to all levels of users and leadership to inform mission critical decisions, alleviate issues with data integrity, deliver concise and consistent answers, and communicate a cohesive message agency-wide.
- Accomplished several major milestones for the NASA Contract Management System Replacement project, including completion of the discovery phase, future state process mapping, development of use cases, and demos of vendor capabilities, resulting in the determination to leverage an existing Government off-the-shelf (GOTS) solution to serve as the basis for the next NASA Contract Management System.
    - A Small Business Innovation Research (SBIR) Phase III contract was also awarded to a service-disabled veteran-owned small business to utilize an SBIR phase III technology for configuration, implementation and sustainment of the future solution.

WORK IN PROGRESS IN FY 2024

Business Transformation and IT Modernization

- Launch the Human Resources Services Center and NASA Office of the Chief Human Capital Officer Virtual Agent tools that will help enable a shift to a tiered service delivery model.

Strengthening Interns/Empowering the Workforce/Talent Pipelines

- Fully implement NASA's Aspiring Executive Cohort (ASPIRE), providing a comprehensive suite of targeted learning and development experiences (e.g., inclusion, mentoring, shadowing with a diverse set of leaders) to prepare aspiring executives for potential future entry into the executive cadre.
- Hire approximately 275 interns in FY 2024 (an increase from 266 in FY 2023), which will comprise approximately 22 percent of all hires made by NASA.

DEIA and Advancing Equity

- Implement a second NASA-wide Anti-Harassment Campaign, with strategic communication from senior leadership to include education and awareness opportunities for the entire workforce. Issue first-ever NASA Procedural Requirement on religious accommodation to ensure that all religious faiths and practices at NASA are treated inclusively.

MISSION ENABLING SERVICES

- Complete barrier analysis of NASA grants, cooperative agreements, and study lessons learned from implementation of Dual Anonymous Peer Review in the Research Opportunities in Space and Earth Science program.
- Utilize the Intercultural Development Inventory on intercultural competency in support of the agency's DEIA strategy. The inventory offers the participant an opportunity to create an intercultural competency development plan. Participants in NASA Next take the inventory at the start of the cohort program and at the conclusion which allows for the collection of empirical data on their progress along the intercultural competence continuum.

Acquisition Improvement

- Continue to strengthen NASA's acquisition strategy and analyze non-domestically procured products. NASA will meet with the requirements owners for NASA products purchased from foreign suppliers in recent years to: (1) educate them on domestic preference laws and the actions taken by NASA to ensure compliance therewith; and (2) develop a forecast of anticipated future foreign purchases. NASA will then use this information to partner with National Institute of Standards and Technology's Manufacturing Extension Partnership to identify domestic suppliers capable of fulfilling NASA's unique product requirements to fortify the domestic supply chain for American goods.
- Award the NASA Enterprise Services Contract (ESC) supporting a broad range of functional activities to include but not limited to Document Imaging, Customer Contact Center, Enterprise Service Desk, and Mailroom Services for the NASA Shared Services Center. ESC will leverage process improvement and transformational activities (e.g., bots, intelligent automation, and ServiceNow) to improve efficiencies in delivering Enterprise Services to NASA customers. The five-year contract has a total value not to exceed $35 million.
- Award the Agency Wide Acquisition Support Services Contract (AWASS 2.0) providing a wide-range of non-inherently governmental agency-wide acquisition support services. These services include requirements document development support, procurement administrative services, acquisition policy support, procurement operations support, procurement source selection support, cost/pricing support, and contract closeout. Services under AWASS 2.0 offers services to all NASA centers, including HQ. The five-year contract has a total value not to exceed $77.5 million.

PLANNED ACHIEVEMENTS AND KEY INITIATIVES FOR FY 2025

- Implement "Trusted Workforce 2.0," an aligned policy framework regarding background. Investigations for the entire federal and contractor workforce to improve the vetting process as mandated in the Performance Management Implementation Guidance jointly issued by the Director of National Intelligence and Office of Personnel Management Director in October 2023.

Business Transformation and IT Modernization

- Continue support of the NASA Contract Management System Replacement Project to include finalizing configuration of the federal GOTS solution for use at NASA, training, deployment, and stabilization at an initial NASA center, followed by full training and deployment rollout for the rest of agency.

MISSION ENABLING SERVICES

- Update SAP ECC 6.0, the Core Financial System used to manage and execute NASA’s budget, to SAP S/4HANA and begin a comprehensive business modeling and business process reengineering effort to define requirements for a follow-on business transformation implementation. The version update and business modeling activities are expected to take two years to complete, and the follow-on transformation will take an additional two to three years to complete.
- Continue standardization of internal processes and templates to streamline the procurement process and identify efficiencies. Additional efforts also continue in the implementation of an Enterprise Product Service Line delivery model for institutional contracts. Further develop and advance NASA's diversity, equity, inclusion and access (DEIA) analytics capability using the enterprise data platform in support of the agency's DEIA Strategic Plan to ensure equitable opportunities and remove barriers for underrepresented audiences and are committed to engaging, inspiring, and promoting diverse student populations in science, technology, engineering, and math.
- Create a centrally managed fund to accelerate and strengthen NASA's evidence-based, data-driven evaluation activities that are responsive to learning agenda questions or already included in NASA’s Annual Evaluation Plan.

Strengthening Interns/Empowering the Workforce/Talent Pipelines

- Conduct and support the Historically Black Colleges and Universities /Minority Serving Institutions Technology Infusion Road Tour Initiative to help diversify NASA's talent pipeline.
- Ensure recruitment plans focus on under-represented individuals and members of underserved communities and individuals with disabilities, utilizing the full potential of Special Emphasis Programs and Human Capital Strategic Planning.
- Maintain and offer multiple internship opportunities to grow a diverse STEM workforce.
- Increase awareness of NASA opportunities to attract targeted candidates, promoting NASA as an employer of choice and increasing the diversity and quality of the candidate pools for critical positions, from entry-level to senior-level, across NASA.
- Develop content across digital channels (e.g., social media, website), to cultivate talent communities for candidates with needed skills.

DEIA and Advancing Equity

- Conduct agency-level barrier analyses and deploy data analytics bootcamp activities at center-level to increase center-level barrier analysis activities at least annually.
- Provide mandatory training for subject matter experts and the NASA workforce on the anti-harassment program, to raise awareness and reinforce aspects that support employee trust, safety, and confidentiality. This involves moving from a process-oriented approach to one that incorporates a victim-centered, trauma approach.
- Increase growth of Spanish language communications by 10 percent to expand accessibility for limited English Proficient populations.

MISSION ENABLING SERVICES

Program Elements

OFFICE OF THE CHIEF FINANCIAL OFFICER

The Office of the Chief Financial Officer (OCFO) provides leadership for the performance reporting, budget analysis, justification, control, and reporting of all agency fiscal resources; provides co-leadership for the strategic planning of all agency fiscal resources; directly supports the development of the agency's overarching strategic plan and associated annual performance reports; leads the agency's planning, programming, budgeting, and execution process; oversees all financial management activities relating to the programs and operations of the agency; and monitors and reports the financial execution of the agency budget. Through supporting and fostering an agile workforce and enhancing robotic process automation, the OCFO continuously develops and matures modern toolsets, services, and processes for tracking, analyzing, and reporting mission and agency financial information. The OCFO manages the agency's budget and financial operations, directs the preparation and submission of annual financial and budgetary reports, and coordinates agency financial management activities with other federal agencies.

OFFICE OF CHIEF HUMAN CAPITAL OFFICER

The Office of the Chief Human Capital Officer (OCHCO) provides the full spectrum of human capital services to NASA's employees and supervisors. OCHCO focuses on innovative solutions to ensure NASA's most valuable resource, its people, can meet the needs of NASA's mission today and into the future. From creating a learning culture to implementing technology that supports work/life balance, OCHCO supports and strengthens the human foundation of NASA. OCHCO focuses on helping agency leaders understand workforce investments, anticipate workforce needs, and easily acquire talent for the task. Recent priorities have included implementing a new service delivery model where self-service puts HR information at employees' fingertips; and enhancing our Strategic Workforce planning capability to ensure NASA has the talent needed to accomplish tomorrow's missions. Future areas of focus include performance management and ensuring NASA has a modern employee recognition program that recognizes the amazing accomplishments of our team. NASA's human capital needs are always evolving with mission activities that test the limits of human capability. Leaning forward to be a global leader in human capital excellence, OCHCO enables the people of NASA to push the boundaries of achievement by supporting NASA's mission first and its people always.

OFFICE OF LEGISLATIVE AND INTERGOVERNMENTAL AFFAIRS

The Office of Legislative and Intergovernmental Affairs (OLIA) provides executive leadership, direction, and coordination of all communications and relationships, both legislative and non-legislative, between NASA and the United States Congress as well as state and local governments.

OFFICE OF PROCUREMENT

The Office of Procurement (OP) explores and executes innovative, effective, and efficient acquisition business solutions to optimize capabilities and operations that enable NASA's mission. NASA spends approximately 85 percent of its budget on acquiring goods and services through approximately 800 procurement and small business professionals across the agency. In FY 2023, total agency procurement spending was $22.3 billion via approximately 34,700 procurement actions (e.g., awards, modifications),

MISSION ENABLING SERVICES

while managing nearly 25,000 instruments (e.g., contracts, grants, purchase orders, task orders, and delivery orders). OP transformed workforce, optimized capabilities, and continuous training opportunities keep it poised to deliver effective and efficient procurement services that ensure mission agility, resilience, and success.

OFFICE OF SMALL BUSINESS PROGRAMS

The Office of Small Business Programs (OSBP) promotes and integrates small businesses into NASA's industry base of competitive contractors that pioneer the future of space exploration, scientific discovery, and aeronautics research. OSBP provides integration, policy, initiatives, and oversight needed to ensure compliance with law and regulation to increase the agency's small business industry base while offering the best technical solutions and value to support the agency's mission. OSBP conducts, sponsors, and participates in small business outreach activities which assist small businesses, including small disadvantaged businesses (SDBs), women-owned small businesses (WOSBs), historically underutilized business zones (HUBZones), service-disabled veteran-owned small businesses (SDVOSBs), and historically black colleges and universities (HBCUs) / minority serving institutions (MSIs) in supporting the NASA mission.

OFFICE OF PROTECTIVE SERVICES

The Office of Protective Services (OPS) provides security services at all NASA facilities to ensure the protection of life, information, and property across the agency. OPS resources include a large contractor workforce in addition to its civil servant workforce. OPS provides secure access to intelligence and information essential to mission success, fire services, and emergency management at all NASA facilities and is the focal point for policy formulation, oversight, coordination, and management of agency physical security, intelligence, counterintelligence, counterterrorism, emergency management, continuity of operations, fire services, national security, communications security (COMSEC), classified information security, personnel security, identity and credential management, electronic physical access management, insider threat, Operations Security (OPSEC), and protective services training programs. OPS provides services to ensure the safety and security of people, property, and information at 20 locations across the country.

OFFICE OF DIVERSITY AND EQUAL OPPORTUNITY

The Office of Diversity and Equal Opportunity (ODEO) leads NASA's civil rights programs to include Equal Employment Opportunity (EEO), Equal Opportunity (EO) and Diversity, Inclusion and Accessibility to ensure a workplace and assisted and conducted programs that are free of unlawful discrimination. ODEO provides leadership to ensure a diverse, inclusive, and talented workforce through the analysis of data to identify barriers to equal employment access, whether during recruitment, to retain the best and brightest, and other employment activities or through programs that support religious or medical accommodation and a workplace free of unlawful harassment. ODEO also touches external grantees and schools who receive financial assistance to promote NASA's mission. ODEO ensures that these entities follow anti-discrimination laws through compliance and complaint processing efforts.

MISSION ENABLING SERVICES

OFFICE OF COMMUNICATIONS

The Office of Communications (OCOMM) delivers NASA's incredible work to billions of people around the world with transparent release of information, as well as inspiring storytelling through a variety of methods. OCOMM supports NASA's founding function from the 1958 Space Act to "provide for the widest practicable and appropriate dissemination of information" with intentionality and efficiency. It facilitates media engagement and connects directly to the public via digital platforms such as a streaming service, websites, and social media. OCOMM empowers employees as ambassadors of NASA, providing accessible agency information and direct engagement between NASA people and the public through domestic and international strategic outreach. OCOMM's collaborations reach underserved audiences, share U.S. innovation across the planet. As NASA makes history, OCOMM captures and preserves that history and agency historical archives and provides additional services managing technical libraries and Freedom of Information Act (FOIA) inquiries. OCOMM's work is critical to ensure that the public goes together with NASA to explore the unknown in air and space, innovate for the benefit of humanity, and inspire the world through discovery.

OFFICE OF INTERNATIONAL AND INTERAGENCY RELATIONS

The Office of International and Interagency Relations (OIIR) provides executive leadership and coordination for all NASA international and interagency activities, and for policy interactions between NASA and other U.S. Executive Branch offices and agencies. OIIR manages the agency's Export Control Program, including compliance with federally mandated requirements and all NASA and U.S. export and import laws, policies, and regulations, to maximize the benefits of the agency's international efforts. OIIR leads international engagement for the agency, including management of the more than 650 active international agreements in over 134 countries (and counting). OIIR provides management oversight and staff support of NASA's advisory committees, commissions, and panels.

OFFICE OF THE GENERAL COUNSEL

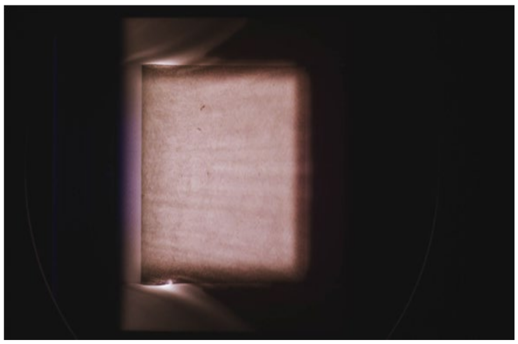
The Office of the General Counsel (OGC) provides legal services agency-wide, including establishing and disseminating legal policy and interpreting new statutes and cases to enable diverse and cutting-edge agency activities, thus ensuring NASA remains in compliance with all statutory and regulatory requirements. Additionally, OGC is responsible for developing the ethics and patent program requirements, establishing metrics, and developing quality standards. As a functional office, OGC serves in an advisory capacity to the Administrator, Enterprise Associate Administrators, and Center Directors across nearly 20 core legal disciplines. OGC provides litigation expertise to the agency and acts as the agency representative before the United States Patent and Trademark Office and other administrative forums. NASA attorneys also function as leaders and trusted advisors on matters of policy and legal risk, upholding NASA values and enabling the NASA mission. OGC enables commercial partnerships on non-reimbursable, reimbursable, and funded terms to accomplish NASA objectives including fostering new U.S. industry in areas such as LEO, Near Earth Communications, and Green Aviation.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**684.5**	**--**	**696.8**	**710.7**	**725.0**	**739.5**	**754.2**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



The ORION heat shield sample is shown here undergoing Arc-Jet testing in the Laser Enhanced Arc Jet Facility to investigate the Artemis I heat shield anomaly.

The NASA Infrastructure and Technical Capabilities (I&TC) program addresses agency-wide operating requirements for physical assets considered institutional and not fully funded by a single NASA mission directorate. Most of NASA's physical assets date back to the Apollo era, with approximately 83 percent of facilities beyond their design life. The agency's aging infrastructure has resulted in increased deferred maintenance (DM) costs, currently at approximately $3 billion and growing, due to increases in unplanned maintenance. The program operates and maintains facilities, utilities, structures, and technical capabilities supporting all of NASA's diverse missions. It also provides oversight and management of real property assets, environmental program activities, and logistics functions. Critical to supporting NASA's missions, the underlying infrastructure and skilled workforce keeps the centers and facilities operating effectively and efficiently. Funding is allocated between failure prevention, in the form of reliability centered maintenance activities comprised of predictive, preventative, condition based, and routine preventative maintenance programs; and other forward-looking investments in capabilities to support NASA's future missions and reinforce strategic goals of strengthening infrastructure readiness and resilience and driving affordability. The agency's first mission-driven Agency Master Plan (AMP) catalogs NASA's facilities and infrastructure and aligns them to meet current and future mission needs. The AMP also determines areas of investment and divestment and ensures comprehensive environmental compliance and stewardship while maintaining effective logistics support.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

Environmental Compliance, Planning, and Stewardship

- Developed the NASA Zero Emission Vehicle (ZEV) infrastructure installation support, validated center charging practices and mechanisms for collecting fees, and inventoried 164 charging ports, which cumulatively is 29 percent of the agency goal.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

- Improved sustainability across the agency by reducing Scope 1 (direct greenhouse gas emissions from NASA) and Scope 2 (indirect greenhouse gas emissions from purchased energy such as electricity, steam, and heat) emissions 47 percent from the FY 2008 baseline, maintained carbon pollution-free electricity acquisitions at 41 percent of the agency total, reduced facility energy use intensity 40 percent from the FY 2003 baseline, and reduced water use intensity 33 percent from the FY 2007 baseline.
- Invested a combined $36.6 million in projects and initiatives that decrease energy and water consumption, which resulted in decreased operational costs and increased resiliency.
- Increased sustainable building gross square footage (GSF) to 32 percent of total building GSF and increased renewable electricity use to 10 percent of total electricity.

Agency Master Plan (AMP)

- Continued AMP development to drive toward a mission-driven and affordable facility portfolio by executing tiered maintenance across all of NASA's real property, prioritizing investment in mission critical degraded facilities, and prioritizing divestment of facilities no longer needed by the agency.
- Reached consensus on over 30 divestment opportunities and identified other affordability strategies to explore, and revised and published the NASA Interim Directive (NID) 8831.124 to formally align agency tiered maintenance implementation policy and procedures to AMP methodology.

Facility Management

- Completed Reliability Centered Maintenance assessments at three centers in support of transforming the Agency Maintenance programs and Facilities Operations & Maintenance (O&M) contracts into more proactive, reliability-centered maintenance requirements and practices, like Conditioned Based Maintenance (CBM).
- Conducted Reliability Centered Maintenance and CBM training for managers, engineers, and technicians who support the Space Environments Testing infrastructure, which led to the formulation of Strategic Maintenance five-year plans for critical assets.
- Completed Phase 1 equipment asset criticality assessments at several locations and initiated Phase 2 assessments at multiple sites to continue the agency tiered maintenance policy and implementation plan. Plans will address routine and backlogged maintenance through the prioritization of risk to mission-relevant assets based on available funding and mission priorities.

Space Environments Testing Management Office (SETMO)

- Advanced commercial space activities by supporting various testing services for SpaceX, Blue Origin, Sierra Nevada, and other commercial space companies.
- Continued modernization of ARC's Arc Jet Complex, a critical agency ground testing capability used for flight qualified thermal protection systems for atmospheric entry, while maintaining operability for critical path testing for Orion/Artemis, by completing a critical repair work-package.
- Provided sustainment support that led to the refurbishment of JSC's Vacuum Chambers A and B with upgrades for safety, data collection, and unique capabilities to support Exploration Extravehicular Mobility Unit Design Verification Test activities and Volatiles Investigating Polar Exploration Rover.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

WORK IN PROGRESS IN FY 2024

Environmental Compliance, Planning, and Stewardship

- Install 58 additional Electric Vehicle Charging Ports, 35 percent of the agency goal, throughout NASA and facilitate the phase out/replacement of fossil fuel government owned vehicles with leased GSA Electric Vehicles.

Agency Master Plan (AMP)

- Establish an annual prioritization process with diverse quantitative and qualitative criteria (Figures of Merit) to generate a prioritized project list for informed decision-making. This process ensures ongoing alignment of capabilities with mission requirements and the optimization of the agency's real property portfolio through the implementation of AMP mission-driven and affordability strategies and initiatives.
- Generate NASA's first agency-wide Capital Investment Program Plan (CIPP) to facilitate planning and design of center projects aligned to the AMP. The CIPP is designed to guide the strategy for funding discreet renewal/recapitalization investments across the agency's facility enterprise. This is the first time the agency is adopting an enterprise approach to renewal funding by utilizing the metrics defined in the Agency Master Plan (AMP) to justify investments.
- Standardize and institutionalize AMP processes into an updated internal regulation (NPD/NPR 8810, "Master Planning for Real Property"). This update ensures sustained linkage between capability, facility, and mission requirements, prioritizing mission-driven investments effectively.

Facility Management

- Mature CBM performance and measures across all centers through continued investments in pressure, vibration, and temperature sensors on critical equipment to enable prediction and mitigation of potential systems and equipment failures, reduce unplanned maintenance and associated spending, and increase facility reliability.
- Complete the agency tiered maintenance policy and implementation plan via on-site Equipment Asset Criticality Analysis (EACA) at one center and two sites, and initiate EACA at two additional centers.

Space Environments Testing Management Office (SETMO)

- Provide 1,950 available operational days of SETMO Tier 1 testing and simulation services to NASA programs and other DoD/Industry Partners.

PLANNED ACHIEVEMENTS AND KEY INITIATIVES FOR FY 2025

Environmental Compliance, Planning, and Stewardship

- Install 130 Electric Vehicle Charging Ports, 41 percent of the agency goal, throughout NASA and facilitate the phase out/replacement of fossil fuel government owned vehicles with leased General Services Administration (GSA) Electric Vehicles.
- Complete Center Resiliency Studies, identifying NASA's susceptibility to climate change and measures to mitigate risk and ensure mission success.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

Agency Master Plan (AMP)

- Establish an AMP/Asset Inventory Assessment (AIA) database and dashboard tied to organizational dashboard.
- Continue Center Master Plan (CMP) updates aligned to the AMP, with a target of completing two CMPs per year.
- Complete update of NASA Procedural Requirements (NPR) and NASA Policy Directive (NPD) 8810 with the agency's new Master Planning strategy.
- Complete Post-AIA Center Consolidation Plans at all 10 centers to identify additional divestment opportunities tied to facility consolidation projects.

Facility Management

- Initiate a data strategy focusing on interoperable enterprise IT, documenting data requirements, and leveraging data as a strategic asset.
- Deploy advanced analytics and continue to implement Tiered Maintenance I across all centers, in line with updated NID 8831.124 requirements, ensuring Maintenance and Operations (M&O) funds are allocated against the highest priority Mission Relevant (MR) assets.
- Institutionalize Tiered Maintenance measurement tool to measure Center M&O expenditures against Work Breakdown Structures (WBS) elements in Tiers 1-4, validating MR equipment assets are the focus of Center M&O programs.
- Mature Centers Predictive Maintenance Program utilization by continued investments in technologies through route-based and remote sensors on prioritized MR equipment assets to enable prediction and mitigation of unplanned failures.
- Complete Post-Asset Inventory Assessment (AIA) Center Consolidation Plans at all 10 centers to identify additional divestment opportunities tied to facility consolidation projects.
- Complete a comprehensive End-to-End Inventory of NASA personal property that focuses on property residing in long-term storage and identify candidates for divestment to reduce long-term warehouse and storage space requirements.
- Evaluate, update, and consolidate (as necessary) personal property accountability requirements in NPD 4200 Equipment Management Program, NPD 4100 Supply Support and Material Management Policy, and NPD 4500 Administration of Property in the Custody of Award Recipients.

Space Environments Testing Management Office (SETMO)

- Provide 1,950 available operational days of SETMO Tier 1testing and simulation services for NASA programs and other DoD/Industry Partners, and advance space commercialization initiatives by sustaining NASA's unique ground-based testing and simulation capabilities for use by industry partners.

INFRASTRUCTURE & TECHNICAL CAPABILITIES

Enterprise Transformation

- Fully implement an Enterprise Freight System to eliminate redundant software applications and integrate the new freight system with a Customer Service Portal using the Enterprise application software ServiceNow to streamline access to logistics services.
- Integrate Baseline Performance Measures for Logistics Services with Dashboard and automate data from the Logistics IT enterprise systems to the dashboard to support accurate and timely performance reporting.
- Implement enterprise IT infrastructure/support in a phased approach to reduce redundant application usage while also improving data accessibility, quality, security, and interoperability.

Program Elements

ENVIRONMENTAL MANAGEMENT

The Environmental Management program enables compliance with applicable federal, state, and local environmental laws and regulations, as well as NASA policy in day-to-day operations and mission support. Specifically, Environmental Management covers NASA's programs for local environmental policy development, Environmental Management System (EMS) implementation, environmental permitting and compliance, recycling, sustainable acquisition, hazardous materials and waste management, pollution prevention, energy and water management systems and reporting, renewable energy, natural resources, historic properties, and National Environmental Policy Act (NEPA) program support.

FACILITIES SERVICES

The Facilities Services program encompasses the institutional facilities support activities throughout the agency. The I&TC program budget supports utility services, operations and maintenance services, infrastructure and facility repair projects, facilities management, real estate, and facilities engineering to include civil construction designers, engineers, and project managers. I&TC funds the civil servants and procurements that operate, maintain, and manage NASA’s institutional infrastructure. NASA recently deployed a cost model that forecasts the funding requirements to sustain its inventory of facilities at the current condition. NASA manages a portfolio of assets with over $3 billion in deferred maintenance. The I&TC budget pursues a strategy to reinforce infrastructure readiness and drive affordability by stemming growth of backlogged maintenance and systematically improving the reliability of NASA's critical institutional infrastructure (from transformers and substations to buildings, horizontal infrastructure, and test capabilities) while effectively managing risk and reliability for the remainder of the portfolio.

LOGISTICS MANAGEMENT

The Logistics Management program encompasses the development, implementation, and management of agency-wide logistics policies, processes, services, system innovation, and facilitates the implementation of government and industry best practices for NASA's centers and facilities. Logistics Management provides functional management, oversight, and coordination over the agency's personal property equipment, supply and material, warehouse and receiving operations, property disposal, and artifact

INFRASTRUCTURE & TECHNICAL CAPABILITIES

property disposition. The program also provides oversight for contractor-held property management, mail and freight management, transportation management, life cycle logistics and supply chain management, policy compliance and logistics contracts. Logistics Management ensures the readiness of material and equipment for NASA's scientific, aeronautics, and space exploration mission requirements at 10 NASA centers and three component facilities. The program includes receiving and inspecting supplies/materials as well as issuing and moving those materials so that products critical to NASA's mission arrive at the desired locations in an efficient manner.

TECHNICAL CAPABILITIES MANAGEMENT

The Space Environments Testing Management Office provides centralized and strategic management of a portfolio of specific ground-based capabilities to enable NASA's missions in science, technology, aeronautics, and space exploration. To meet requirements in support of other national interests, these capabilities are also offered to other federal agencies and industry partners. Examples of these capabilities are provided below:

- The high-enthalpy test capability at ARC's Arc Jet Complex provides simulated high-temperature, high-velocity environments and supports the design, development, test, and evaluation of Thermal Protection Surface materials, vehicle structures, aerothermodynamics, and hypersonic aerodynamics experienced by a vehicle during planetary atmospheric entry.
- Flight simulators are of critical importance to NASA's research in fundamental aeronautics and aviation safety. These capabilities provide scientists and engineers with tools to explore, define, and resolve issues in vehicle design and mission operations. The capabilities include the motion simulators and development laboratories used in the research and development of flight and crewed operations at the ARC Vertical Motion Simulator and the LaRC Flight Simulation Facility.
- Space environments testing capabilities and facilities whose primary use is related to spacecraft and instrument development and qualification, space technology development, human-rated space environments, and launch environments. Capability components include vacuum, thermal/vacuum, and thermal chambers; vibration tables; acoustic labs; cleanrooms; and electromagnetic interference and electromagnetic compatibility, magnetic, optical, X-ray, solar spectrum, and ionizing radiation facilities. Located at most NASA centers, testing performed with these capabilities ensures the equipment, sub-systems, and assembled spacecraft will survive the harsh noise and vibrations experienced during launch and the ultra-low pressure and ultra-low or ultra-high temperatures experienced in space environments.
- The external radiation testing capability procures the necessary time and facility support at non-NASA facilities to meet the requirements of agency programs and projects. The test facilities provide controlled sources of electrons, heavy ions, neutrons, protons, and other relevant types of high-energy radiation that NASA uses to simulate the impact of the natural space radiation environment on a wide range of electronic and material systems. National laboratories, private companies, and universities at both domestic and foreign locations operate these highly specialized facilities. Test activities support a wide range of assessment, development, and flight activities.

ENGINEERING, SAFETY, & OPERATIONS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Agency Technical Authority	190.1	--	**180.3**	183.9	187.6	191.3	195.2
Center Engineering, Safety, & Operations	879.0	--	**806.0**	822.2	838.5	855.3	872.5
Total Budget	**1,069.1**	**--**	**986.3**	**1,006.1**	**1,026.1**	**1,046.6**	**1,067.7**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

Shown here is the Multifunction Process Calibrator at the Launch Equipment Test Facility (LETF), used to troubleshoot an issue on the load cell of the Mobile Launcher 2 (ML-2) Vehicle Support Post Test Fixture being assessed at KSC.

Engineering, Safety, and Operations (ESO) supports NASA's high standard of safety and mission assurance, while maintaining center flexibilities that promote innovation and mission success. ESO is divided between two distinct programs: Agency Technical Authority (ATA) and Center Engineering, Safety, and Operations (CESO).

ATA protects the overall health and safety of NASA's workforce and programs by providing technical oversight for safety, health, quality, and engineering. The independence of ATA offices is a vital part of NASA's safeguards to ensure safety, quality, and engineering concerns are always vetted, analyzed, and mitigated. ATA offices develop policies, guidance, and conduct reviews at a corporate-level, which are implemented at the center-level through CESO programs and evaluate risks to mission, including the potential loss of life, engineering failures, health impacts, and mission failure.

CESO provides funding for the operations and management at nine centers and component facilities, corporate leadership at NASA HQ, the execution of delegated technical authority, and center investments. CESO funding allows centers the ability to address mission-critical requirements, such as acquiring specialized scientific and engineering equipment, providing critical capabilities and skilled workforce in analytical support, test services, lab services, and fabrication capabilities. CESO funds center-level implementation of ATA policies and guidelines at each center to ensure the highest standards of health, safety, and mission assurance. It also supports NASA's Internal Research and Development (IRAD) program, which is designed to develop strategic technical capabilities and transformational advances in science and technology needed for future agency missions. CESO encompasses a diverse set of ongoing activities and unique projects in support of center operations and infrastructure, while enabling safe and effective mission support as well as agency-level operations at NASA HQ to ensure the development and implementation of agency-wide policies, standards, and processes are effective and efficient.

ENGINEERING, SAFETY, & OPERATIONS

Programs

AGENCY TECHNICAL AUTHORITY (ATA)

ATA work is managed by the Offices of the Chief Health and Medical Officer (OCHMO), Safety and Mission Assurance (OSMA), and the Chief Engineer (OCE) and includes vital programs like the NASA Safety Center (NSC), the Independent Verification and Validation (IV&V), and the NASA Engineering and Safety Center (NESC). These activities provide the foundation for NASA's system of checks and balances, defined in NASA's Strategic Management and Governance Handbook, by providing for the technical authority over health, safety, and engineering, independent of the missions. Through independent analysis and deep subject matter expertise, ATA develops policy, designs procedural requirements, and provides recommendations to NASA's Administrator, mission directorates, center directors, and program managers, who are ultimately responsible for the safety and mission success of all NASA activities.

ATA provides training and maintains a competent technical workforce with expertise in system engineering, system safety, reliability, quality, and space medicine. Subject matter experts analyze risks and risk acceptability through an established process of independent reviews and assessments. The information and advice from these experts provide critical data required to develop authoritative decisions related to the application of requirements on programs and projects.

CENTER ENGINEERING, SAFETY, AND OPERATIONS (CESO)

NASA's Center Engineering, Safety, and Operations (CESO) is a multifaceted program that ensures agency leadership is implemented at the center-level, while centers have the flexibility and support to ensure mission success and uphold NASA's high standard of safety and engineering excellence.

CESO ensures NASA's unique, technical, and innovative capabilities are mission-ready by supporting center-level institutional and technical capabilities through independent research, development projects, and maintenance of facilities, laboratories, and other mission-critical assets. The technical skill and specialized assets or services that support analyses, design, research, testing, laboratories, and fabrication enable the efficient and effective implementation of mission work at the centers, now and in the future. CESO funds are used by centers to ensure the technical skills and capabilities are available and mission-ready based on mission requirements and timelines.

CESO is a key component of NASA's overall approach to risk management by providing center-level independent technical authority. By funding center-level oversight and reporting activities that uphold the strategy and guidance from ATAs, checks on safety, engineering, and mission assurance remain separate from the mission directorates.

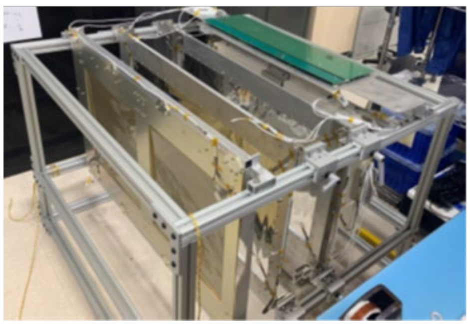
CESO funds NASA HQ operations and center management across the agency. Support for institutional administration and operational safety are vital to allow centers the flexibility to address and manage conditions unique and specialized to their center. CESO also ensures that agency policies and guidance are operationalized across centers with consistency and efficiency.

AGENCY TECHNICAL AUTHORITY

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	190.1	--	180.3	183.9	187.6	191.3	195.2

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."



The prototype Multi-layer Acoustics & Conductive-grid Sensor (MACS) unit is shown here being assembled in the laboratory. MACS is designed for in-situ measurements of millimeter-sized orbital debris in LEO.

Agency Technical Authority (ATA) program protects the health and safety of NASA's workforce by evaluating programs, projects, and operations to ensure safe and successful completion. ATA capabilities provide expert technical excellence, mission assurance, and technical authority agency wide.

ATA is managed by the Offices of the Chief Health and Medical Officer (OCHMO), Safety and Mission Assurance (OSMA), and the Chief Engineer (OCE). It includes vital programs such as the NASA Safety Center (NSC), Independent Verification and Validation (IV&V), and NASA Engineering and Safety Center (NESC). These programs provide the foundation for NASA's system of checks and balances defined in NASA's Strategic Management and Governance Handbook. Through independent analysis and deep subject matter expertise, ATA develops policy, designs procedural requirements, and provides recommendations to NASA's Administrator, mission directorates, center directors, and program managers, who are ultimately responsible for the safety and mission success of all NASA activities.

ATA provides training and maintains a competent technical workforce with expertise in system engineering, system safety, reliability, quality, and space medicine. Subject matter experts analyze risks and risk acceptability through an established process of independent reviews and assessments. The information and advice from these program experts provide critical data required to develop authoritative decisions related to the application of requirements.

Orbital Debris

A primary focus for NASA is to take steps to preserve the near-Earth space environment, in accordance with the National Space Policy, the National Orbital Debris Implementation Plan issued July 2022 by the National Science and Technology Council, and the U.S. government Orbital Debris Mitigation Standard Practices to mitigate risks from orbital debris to human spaceflight and robotic missions. As more commercial and international entities become spacefaring, and with the proliferation of small satellites and large constellations, the amount of debris in orbit grows and the need to understand the debris environment and mitigate the orbital debris hazard increases. NASA's efforts will characterize the orbital debris environment, support the protection of NASA, other government, and commercial assets, while laying the groundwork for addressing this growing environmental problem.

AGENCY TECHNICAL AUTHORITY

Independent Verification and Validation (IV&V)

Activities conducted through the IV&V program are funded through a combination of ATA and mission directorate resources. The following table shows the funds provided by the SSMS, Science, Deep Space Exploration, and Space Operations accounts:

	Estimated IV&V Funding ($M)		
Mission Account	**FY 2023**	**FY 2024***	**FY 2025***
Safety, Security, and Mission Services (SSMS)	39.2	39.2	37.8
Science	1.0	--	2.2
Deep Space Exploration	1.8	3.3	2.8
Space Operations	0.9	0.8	--
Total	**42.9**	**43.3**	**42.8**

**Note: FY 2024 and FY 2025 estimates are subject to change depending on mission schedules and agency risk analysis.*

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

Health and medical expertise to support NASA's priority missions

- Provided health and medical expertise to the agency's portfolio of development and operations, including involvement with the White House Cancer Moonshot initiative to reduce cancer deaths by 50 percent in the next 25 years.
- Developed and posted 42 Human Standard Technical Briefs to offer technical data, background, and application notes to aid with the development of hardware, systems, and vehicles, as well as human needs and limitations. This unique human spaceflight knowledge is benefitting commercial industry for Artemis and LEO missions, as well as the international community.
- Maintained the health and safety of the NASA workplace, NASA employees, space crews, and members of the public, through the review and update of NASA-STD-3001 Spaceflight Human-System Standard; Volume 1 Crew Health; and Volume 2 Human Factors, Habitability, and Environmental Health. NASA-STD-3001 Spaceflight Human-System Standard is a two-volume set of NASA agency-level technical requirements established by OCHMO, directed at minimizing health and performance risks for flight crews in human spaceflight programs.

Safety and mission assurance independent evaluations and technical expertise

- Organized and hosted the Second International Orbital Debris Conference to promote orbital debris research in the United States, foster collaborations with the international community, and encourage adoption of orbital debris mitigation best practices to support space sustainability. This event

AGENCY TECHNICAL AUTHORITY

produced more than 150 technical paper presentations and drew several hundred domestic and international participants.

- Provided custom meteoroid forecasts to help the James Webb Space Telescope (Webb) protect itself against meteoroid impacts and take protective action when sporadic showers are observed thereby extending the telescope's lifetime.

Technical review and engineering expertise, guidance, and oversight

- Ensured independent technical insight and assessment of agency programs at key programmatic milestones by supporting engineering and safety for Artemis, Commercial Crew, Orion, Space Launch System, ISS, X-57, and others.
- Reduced risks by conducting over 80 independent assessments of NASA's highest risk and priority mission work, such as: micrometeoroid orbital debris, propellant storage and handling, aerospace valve reliability, and parachute reliability.
- Implemented corrections to NASGRO® a popular finite element modeling code used to predict crack growth, and recommended update to industry standards, following the investigation of the complex behavior of composite overwrapped pressure vessels used extensively in spaceflight, which identified that tests could lead to microscopic cracks not accounted for in modeling and lifetime predictions.

WORK IN PROGRESS IN FY 2024

Health and medical expertise to support NASA's priority missions

- Provide health and medical requirements and standards in the lunar and Mars architectures.

Safety and mission assurance independent evaluations and technical expertise

- Continue support for the upcoming Artemis II crewed mission, ISS, and five high-priority science missions through independent verification and validation.

Orbital Debris

- Conduct radar and optical measurements to monitor the ever-changing orbital debris environment and update models to better assess risks from orbital debris.
- Partner with SMD to develop a Multi-layer Acoustics & Conductive-grid Sensor (MACS) flight unit for a technology demonstration mission in 2026, in preparation for a potential future mission opportunity to collect direct measurement data on the millimeter-sized orbital debris at 600-1,000 km altitude.

Technical review and engineering expertise, guidance, and oversight

- Provide Engineering Technical Authority support to NASA's programs (e.g., X-57 Maxwell aircraft, X-59 Low Boom Flight Demonstrator, ISS, CPP, Artemis, and Gateway) ensuring independent technical insight and assessment at key programmatic milestones.

AGENCY TECHNICAL AUTHORITY

- Conduct independent assessments of NASA's highest risk challenges to ensure a logical decision-making process for flight readiness, specifically enabling eventual Human Lunar Lander, Deep Space Gateway, certification of a second commercial provider for ISS access, and commercial science payloads to the surface of the Moon.

PLANNED ACHIEVEMENTS AND KEY INITIATIVES FOR FY 2025

Health and medical expertise to support NASA's priority missions

- Continue technical, development, and human systems expertise to enable lunar and Mars architecture in support of the NASA missions, as set forth by the Administrator's priorities memo.
- Provide health and medical support for NASA crewed flight programs and projects (e.g., ISS Commercial Crew, Private Missions, Commercial LEO, Artemis) to include insight, oversight, joint activities with commercial providers, and readiness assessments.
- Update NASA human spaceflight standards, including NASA Standard 3001 Volume 1-2, and requirements to enable the lunar exploration architecture with an eye toward Mars as set forth by the Administrator's priorities memo.
- Develop training material, such as technical briefs for NASA Standard 3001, HMTA History and Implementation, and implement training for NASA, commercial industry, and other government entities related to human health and performance across all phases of flight and including mishap planning.

Safety and mission assurance independent evaluations and technical expertise

- Conduct software validation and verification activities for 14 of NASA's highest profile science and human-rated missions, including Artemis, Nancy Grace Roman Space Telescope, and Europa Clipper.
- Produce a documented assessment of the state of NASA's safety program in an annual report to the Occupational Safety and Health Administration.
- Continue to evolve the NASA Supply Chain Insight Central for a robust supply chain and implement a proactive strategy for programmatic and technical resilience against threats to the industrial base and the supply chain.
- Continue support of the Program Mishap Preparedness and Contingency Plan and investigations to enable an effective mishap prevention and readiness program.
- Produce technical standards for nuclear launch authorization and safe in-space operation that bridge the gap in agency policy and community best practices, such that requirements can be effectively retained or applied depending on the specifics of the program.
- Upgrade the Orbital Debris Engineering Model (ORDEM) (used by hundreds of mission operators around the world) to include new data and a debris shape factor to significantly improve the fidelity of debris impact risk assessments.

AGENCY TECHNICAL AUTHORITY

- Complete the MACS flight unit for the HTV-X3 technology demonstration mission, the success of which will address a critical orbital debris data gap in LEO to better characterize risks from orbital debris in the future.
- Provide technical guidance and assurance of planetary protection of NASA and NASA-partnered missions to support compliance with the Outer Space Treaty.

Technical review and engineering expertise, guidance, and oversight

- Conduct over 70 independent assessments of NASA's highest risk challenges to ensure a logical decision-making process for flight readiness, specifically enabling the eventual Human Lunar Lander, Deep Space Gateway, certification of a second commercial provider for ISS access, and commercial science payloads to the surface of the Moon.
- Provide Engineering Technical Authority support to NASA's programs, ensuring independent technical insight and assessment of programs at key programmatic milestones, such as: X-59 Low Boom Flight Demonstrator, ISS, CCP, Artemis, and Gateway.

Program Elements

OFFICE OF THE CHIEF HEALTH AND MEDICAL OFFICER (OCHMO)

OCHMO promulgates agency health and medical policies and standards to support the medical technical capabilities of NASA. As a functional area, OCHMO provides independent oversight and advances expert health and medical capabilities from development through de-commissioning. It assures the physical and mental health and well-being of the NASA workforce.

OCHMO also ensures that bioethics principles and NASA's policies and practices related to the use of human and animal subjects in research are in accordance with all relevant federal regulations and guidelines. The program oversees NASA's processes for reviewing the use of human and animal subjects in research.

OCHMO administers the Human Medical Technical Authority (HMTA), which engages in all crewed programs. The HMTA provides guidance, insight, and oversight, while translating health and medical standards into tailored technical requirements for all Human-Rated programs across the agency. HMTA ensures that integrated spaceflight systems reflect the most current knowledge on health and medical impacts related to flight, life support, and environmental systems.

OFFICE OF SAFETY AND MISSION ASSURANCE (OSMA)

OSMA provides policy direction, functional oversight, and assessment for all agency safety, reliability, maintainability, quality engineering and assurance, software assurance, risk management, orbital debris mitigation, nuclear flight safety, aviation safety, and planetary protection activities and serves as a principal advisory resource for the Administrator and other senior officials on matters pertaining to safety and mission success. The program develops technical excellence in these areas and assesses and communicates cross-cutting and significant risks to appropriate decision makers.

AGENCY TECHNICAL AUTHORITY

OSMA conducts a schedule of reviews and assessments that focuses on the lifecycle-decision milestones for crucial NASA programs and projects, safety, reliability, and quality processes. Embodied in this program is a structured development of methodology and investigation into system attributes that improve the probability of mission success.

OSMA includes the Mission Programs and Assessments Division, Institutional Safety Management Division, Mission Assurance Standards and Capabilities Division, and NSC, as well as the IV&V.

The NSC, an OSMA component, consolidates safety and mission assurance activities for affordable and consistent service across the agency. It supports general technical excellence, knowledge management, audits and assessments, and mishap investigation support. NSC helps protect the safety of people, equipment, and property by verifying compliance with OSMA policies and works proactively to prevent mishaps and failures.

INDEPENDENT VERIFICATION AND VALIDATION (IV&V)

IV&V, a component of OSMA, ensures that mission critical systems and software will operate reliably, safely, and securely. It provides independent oversight and technical knowledge across NASA missions. IV&V is funded through the SSMS account with additional support from mission directorates.

Software, as an asset on NASA missions, is extremely critical. IV&V provides a proven means of identifying software problems early and helps to minimize the cost of software development and potential rework.

In support of independent evaluations of software related approaches and processes, IV&V provides resources and software expertise to other S&MA elements. It supports the sustainment of software technical excellence within the S&MA community, sustainment of software domain knowledge within the S&MA organization, and formulation of software development improvement recommendations to the agency.

IV&V’s independent test capability enables advanced testing and simulations of NASA’s mission and safety critical software; testing and evaluation of robotics and intelligent systems; capability development within the systems engineering disciplines; and training and education for workforce and students.

OFFICE OF THE CHIEF ENGINEER (OCE)

OCE ensures that NASA's development efforts and mission operations are planned and conducted with sound engineering practices, proper controls, and management of technical risks. The program provides independent engineering oversight and guidance to ensure that decisions have the benefit of different points of view and are not made in isolation.

OCE creates the foundation for excellence of program/project management and engineering workforce, system-engineering methodology, and system of engineering standards throughout the agency. OCE establishes and maintains engineering policy and technical standards; and through its Mission Resilience and Protection Program, supports spaceflight missions by integrating the consideration of potential threats (including cybersecurity) into systems engineering processes and improving the resilience and protection of systems from the effects of threat actors.

OCE also sponsors the Academy of Program/Project and Engineering Leadership Knowledge Services (APPEL KS) to develop program and project management and systems engineering skills and support critical knowledge sharing across the agency’s technical workforce. APPEL provides a formal professional development curriculum designed to address four career levels spanning from recent college graduate to executive.

OCE manages the NESC, which enables rapid, cross-agency responses to mission critical engineering and safety issues at NASA and improves the state of practice in critical engineering disciplines. Established in FY 2003 in response to the recommendations of the Space Shuttle Columbia Accident Investigation Board, the NESC performs independent testing, analysis, and assessments of NASA's high-risk projects to ensure safety and mission success. As an agency-wide resource with a reporting path that is independent of the mission directorates and directly funded from OCE, the NESC helps the agency ensure mission safety and obtain objective technical results.

CENTER ENGINEERING, SAFETY, & OPERATIONS

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**879.0**	**--**	**806.0**	**822.2**	**838.5**	**855.3**	**872.5**

For background information on FY 2023 and FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

The Berkeley Space Center (above), a proposed innovation hub and satellite campus of the University of California, Berkeley, is to be housed in the NASA Research Park at ARC. The project was announced in October 2023.

NASA's Center Engineering, Safety, and Operations (CESO) Program provides strategic management and crucial policy direction at the agency- and center-level in addition to center-level technical authority and capabilities that ensure mission success.

CESO maintains test capabilities, laboratories, and other mission-critical assets so they are available and mission-ready based on mission requirements and timelines. The technical skill and specialized assets or services that support analyses, design, research, testing, laboratories, and fabrication enable the efficient and effective implementation of mission work at the centers.

CESO programs contribute to NASA's overall approach to risk management by providing center-level, independent technical authority. By funding center-level oversight and reporting activities that uphold the strategy and guidance from Agency Technical Authorities (ATAs), checks on safety, engineering, and mission assurance remain independent from the mission directorates.

CESO funds HQ and agency-level operations, as well as center management across the agency. This institutional support for center operations and infrastructure allows the centers to focus on managing conditions unique to their center. CESO also ensures that agency-wide developed and implemented policies, guidance, standards, and processes are operationalized across the centers with consistency and efficiency.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

Capabilities, Facilities, Labs, and Test Equipment

- Invested in refurbishment of facilities and related components, such as new hardware for the KSC Material Analysis Lab, to maintain capabilities for mission success. The new hardware enables increased resolution, inspection size, and utilization, and improves effectiveness and range, which prevented an Artemis launch delay by helping to diagnose the cause of a 13,000 volt arc flash and averted a SpaceX launch scrub.
- Completed a $10 million refurbishment project for the miter gates as part of the lock access from the Pearl River to the SSC canal system, which provides a required connection for SSC to move large

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space hardware into the test complex. The gates maintain a constant water level for the canal system that connects all large test stands on site.

Operational Safety

- Utilized small unmanned airborne systems with beyond visual line-of-sight operations to support perimeter security and building inspections and ensure the safety of people, buildings, and missions, which avoided significant cost, time, and risk compared to current methods.
- Performed 7,500 propellants and life support tasks, received nearly 600 tankers of various propellant commodities from off-site sources, delivered 3.6 million gallons of propellants and 1 billion standard cubic feet of helium and nitrogen to seven launch complexes in support of 66 launches at KSC.
- Completed an upgrade to the Range Mission Network at Wallops Flight Facility, while deconflicting implementation with the heavy launch schedule. Upgrades provided improved network performance, increased the ability to accommodate future growth, improved security, increased reliability, simplified and centralized tools for managing the network, and enabled potential long-term support cost savings.

Engineering and Safety and Mission Assurance Technical Authorities

- Reviewed data from all GSFC launched missions since 2000 and drafted new guidance and requirements.

Institutional Management and Administration

- Implemented data-fused smart center integration with real-time data monitoring at LaRC, through piloting of Artificial Intelligence/Machine Learning analysis tools for real-time autonomous off-nominal condition detection and mission-critical facility system health assessments.
- Completed the consolidation and relocation of SSC's Administration facility to a joint location with the NASA Shared Services Center, moving approximately 2,000 employees and enabling demolition of over 250 thousand square feet of real property.

WORK IN PROGRESS IN FY 2024

Operational Safety

- Recertify Pressure Systems as vessels become available and continue deployment of Nondestructive Evaluation (NDE) personnel to other centers for inspection of layered vessels.

Engineering and Safety and Mission Assurance Technical Authorities

- Plan, conduct, and monitor results from audits supporting the center's compliance with AS9100/ISO9000, ISO14000, and Occupational Safety and Health Administration (OSHA) / Voluntary Protection Program (VPP). Maintain an audited vendors list to support program purchasing in accordance with NPR 8735.2C (Hardware Quality Assurance Program Requirements for Programs and Projects).

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- Perform biennial self-assessment and declaration of compliance of the Quality Management System with ISO9001/AS9100 standards through collection and review of relevant data to demonstrate compliance.

Institutional Management and Administration

- Award the Glenn Langley Administrative Support Services (GLASS) contract to streamline and centralize the delivery of administrative services ensuring the most efficient service delivery model, eliminating unnecessary work, optimizing critical work, and automating wherever possible. This model allows for a more agile and flexible workforce management to account for future admin scope requirements, with significant efficiencies and cost savings.

PLANNED ACHIEVEMENTS AND KEY INITIATIVES FOR FY 2025

- Provide technology, policy, and economic analyses on space safety and sustainability, norms of behavior in space, and emerging technologies - which includes participation in chartered interagency working groups and funding external research opportunities.
- Award research grants and complete internal studies of active debris remediation technologies and the policy implications on space safety and sustainability.
- Coordinate and participate on national and international engagements to advance climate and other science.

Capabilities, Facilities, Labs, and Test Equipment

- Modernize aircraft assets for critical capabilities to enhance our understanding of Earth's climate changes and enable safe return of humans from space to support the next generation of NASA missions.

Operational Safety

- Complete an electrical infrastructure project replacing 2,400 failure prone splices across KSC’s expansive power distribution system to reduce launch delay risk, help meet mission timelines, and keep pace with growing spaceport demand.

Engineering and Safety and Mission Assurance Technical Authorities

- Provide independent Safety and Mission Assurance Technical Authority and Safety, Reliability/Quality support in existing and planned projects, such as Artemis II, Artemis III, subsequent manufacturing, and Space Launch System hardware delivery for the Integrated Core Stage.
- Complete inspection and certification of pressure systems and vessels prior to lapse in certification.
- Complete research in intelligent flight systems and recommend policy changes to improve the safety of the national airspace.

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- Test and develop entry, descent, and landing technology to enable the safe return of humans to the Moon.
- Lead the Volatiles Investigating Polar Exploration Rover (VIPER) Mission Safety and Mission Assurance Team through a successful launch and operation of the rover on the lunar surface.

Institutional Management and Administration

- Improve Information System Security Officer (ISSO) compliance by finding overall efficiencies through digital advancements.
- Modernize digital architectures and capabilities, including Smart Center operation and maintenance automation technologies, and digital engineering capabilities to enable NASA's future complex missions.
- Perform load testing and associated nondestructive testing (NDT) on all lifting devices and equipment in Attachment J-10, “Lifting Devices,” of the FOMSS contract in accordance with NASA-STD-8719.9.
- Continue rocket propulsion testing to support the Artemis Program and expand the application of Autonomous Systems and Unmanned Aircraft Systems (UAS).

Center Investments

- Continue consolidation of Energy Conversion Laboratory and Administration Building to reduce GRC's footprint by 76,000 square feet and eliminate $700,000 of constructive maintenance backlog.
- Continue risk mitigation of high-voltage systems and subsystems through purchase and installation of additional high-voltage and large motor controllers as outdated ones fail.

Program Elements

AGENCY SUPPORT AND HEADQUARTERS MANAGEMENT

CESO supports agency-level strategic leadership and planning by funding corporate activities conducted at NASA HQ. Strategic planning, budget activities, workforce management, and other foundation business functions require strategic planning, policy development, monitoring, audits, and ongoing management. These activities dovetail with center operations through mission support functional offices and senior management. CESO funds also ensure there is enterprise-enabling support for centers and missions in functional areas not aligned to a mission support enterprise office (which would then be funded through Mission Services and Capabilities).

INSTITUTIONAL ADMINISTRATION

CESO supports certain foundation business functions at the center-level by funding center management, center reserves, and certain unique functions that were not transitioned to enterprise management due to their unique value or specification at the center. Activities deemed center-centric remained under center management to ensure location-specific conditions and decisions are considered when supporting mission

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requirements. These center-level activities include occupational health, local IT support, and local management personnel.

INSTITUTIONAL OPERATIONAL SAFETY

CESO funds safety and mission success requirements based upon federal regulations and NASA standards, ensuring these requirements are properly implemented throughout NASA's programs and projects. Examples of such efforts include: safety audits and assessments, safety surveillance, inspections, testing and observations, mishap investigation and reporting, hazard identification, and safety outreach.

SAFETY AND MISSION ASSURANCE (S&MA) TECHNICAL AUTHORITY

The Office of Safety and Mission Assurance (OSMA) issues policies, guidance, and corporately managed communications that ensure the consistent application of safety and quality standards. At each center, Safety and Mission Assurance (S&MA) personnel are responsible for the application and implementation of policies and instructions provided by OSMA and related governing organizations. This is accomplished through S&MA Technical Authority (TA) member participation on program/project control boards, change boards, and internal review boards. S&MA personnel also formulate and communicate the S&MA TA position on significant technical issues, disposition changes, waivers, deviations, and exceptions to respective program/project S&MA requirements. S&MA TA independently assess program/project-owned risks and execute, implement, and otherwise maintain the checks and balances of safety and quality standards. It is critical that this money is independent of mission funding to ensure there is an independent process for identifying and managing safety and quality concerns.

SCIENCE AND ENGINEERING

Centers maintain highly technical laboratories, critical capabilities, and associated specialized skills and equipment thereby ensuring mission readiness. These capabilities support center mission work ensuring required technical capabilities are mission ready. Such functions include providing for the on-site capability to fabricate, test articles, test fixtures, prototype, proto-flight, and flight articles necessary to support the design, development, and testing of research models, instruments, flight and related ground support hardware, technical components, and laboratory test apparatus. Centers also provide for the on-site capability to support research, development testing, and sustaining engineering for science and technologies necessary to support their program activities. These funds are specific to the centers because of the variety and distribution of highly technical work that is spread across the agency's 10 distinct centers and other installations.

CENTER INVESTMENTS

Ensuring the right talent and technical capabilities are mission-ready for NASA priority projects and missions, centers utilize investment funding to maintain their technical skills and capabilities in support of local mission work. Investments fund institutional research that aligns with assigned center roles, development projects, and business innovation. Centers use a competitive approach to achieve this mission work and support NASA's commitment to innovation and creativity. Centers have the flexibility to support Internal Research and Development (IRAD) pursuing collaboration with academia and private

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industry so that NASA has the leading-edge capabilities needed to support NASA's missions, today and in the future.

ENGINEERING TECHNICAL AUTHORITY

The Office of the Chief Engineer (OCE) develops and distributes standards, policies, and guidance related to engineering safety, quality, and process. At each center, personnel are dedicated to providing independent oversight of programs and projects in support of safety and mission success as prescribed in the NASA technical authority model, thus ensuring requisite policies and processes are successfully implemented, thereby upholding NASA's high standard of engineering excellence. Key technical authority positions, including managers in research and engineering, testing, and fabrication, use these funds to conduct reviews, oversight, and management of quality and safety standards independent of mission directorates. These activities are a crucial part of NASA's checks and balances, which ensure the highest standard of engineering excellence and reporting.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Construction of Facilities	346.2	--	**344.7**	298.3	304.3	310.4	316.6
Environmental Compliance and Restoration	76.2	--	**79.4**	81.0	82.6	84.2	85.9
Total Budget	**422.4**	**414.3**	**424.1**	**379.3**	**386.9**	**394.6**	**402.5**

FY 2023 reflects Division B funding amount of $47.3 million and Division N funding amount of $367 million, as specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

FY 2025 reflects Division N funding amount of $296 million, designated for an emergency requirement pursuant to section 251(b)(2)(A)(i) of the Balanced Budget and Emergency Deficit Control Act of 1985.

Construction and Environmental Compliance and Restoration

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Construction of Facilities	346.2	--	**344.7**	298.3	304.3	310.4	316.6
Environmental Compliance and Restoration	76.2	--	**79.4**	81.0	82.6	84.2	85.9
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FY 2025 reflects Division N funding amount of $296 million, designated for an emergency requirement pursuant to section 251(b)(2)(A)(i) of the Balanced Budget and Emergency Deficit Control Act of 1985.

The Aerospace Communications Facility at the NASA GRC, completed in 2023, is a state-of-the-art research facility consisting of efficient, flexible laboratories, anechoic test chambers, an RF-shielded high-bay space, collaboration spaces, information technology support areas, and both a rooftop and ground-based platforms for communication antennas. The new facility consolidates more than 80 researchers in over 50 labs located in seven separate buildings across Glenn’s main campus into one cutting-edge 55,000 square-foot building. Inside the new building, researchers and scientists will develop advanced communication methods for use on Earth as well as supporting the agency’s Artemis and Advanced Air Mobility missions.

Through the Construction and Environmental Compliance and Restoration (CECR) account, NASA manages two themes related to the agency's asset portfolio: capital repairs and improvements to NASA's infrastructure, and environmental compliance and restoration activities. Activities related to the design, construction, and demolition of infrastructure, including utility systems and facilities, are funded through Construction of Facilities (CoF). Environmental compliance, cleanup, and restoration activities are funded through Environmental Compliance and Restoration (ECR).

CECR funding enables NASA to address challenging infrastructure needs. More than 83 percent of NASA's infrastructure is beyond its design life, posing significant risk of failure, inefficiency, and potential impacts to health and wellness. Apollo-era infrastructure is inefficient and costly to maintain, as well as insufficient to accomplish NASA's future missions that require facilities with leading-edge capabilities. The agency currently faces a deferred maintenance backlog of $3 billion, resulting in unscheduled maintenance that can cost up to three times more than scheduled maintenance to repair or replace equipment after it has failed. To address these growing challenges, CECR is focused on modernizing and consolidating NASA's infrastructure into fewer, more efficient, and more sustainable facilities, and on repairing and upgrading infrastructure before it has failed.

CECR funding also enables NASA to address its commitment to environmental stewardship by conducting critical cleanup efforts, maintaining compliance with regulatory requirements, and managing environmental issues. NASA's estimated current environmental liability, excluding asbestos removal that is not funded by the ECR appropriation, is approaching $2.3 billion and is expected to grow as plans to address 173 areas of potential concerns for emerging per- and polyfluoroalkyl substances (PFAS) contaminants are developed.

CECR funding ensures that NASA's assets are ready, available, and appropriately sized to conduct NASA's current and future missions, while remaining compliant with the agency and governmental environmental regulations. This funding is critical to fulfill NASA's 2022 Strategic Plan Objective 4.2 to "Transform mission support capabilities for the next era of aerospace." CECR programs strive to execute construction priorities identified in the Agency Master Plan and reduce the agency's physical footprint and environmental burden.

CECR Priorities

CECR focuses on ensuring the viability and readiness of mission-critical infrastructure, while also supporting NASA's commitment to environmental stewardship and sustainability. The activities below outline how CECR allocations are made:

- Construct new facilities and replace, repair, or upgrade existing infrastructure to support NASA's mission requirements and timeline.
- Design facilities and infrastructure solutions to support construction and repairs, while optimizing sustainability, increasing efficiency, and reducing NASA's footprint.
- Demolish unneeded and degraded facilities to avoid costs and improve sustainability.
- Invest in energy and water savings opportunities to improve NASA's environmental stewardship.
- Comply with mandates, regulations, and best practices to protect the health and wellness of the environment, NASA's workforce, and the general public.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

CECR will continue to enable critical mission work in FY 2025, while maintaining NASA's dedication to environmental stewardship. The following list highlights high-priority FY 2025 projects. A more robust list with project descriptions is available in each program section.

- Construct, repair, or revitalize institutional infrastructure and facilities that have capabilities and impacts that span NASA centers and enable mission directorate priorities:

- Upgrade Mechanical Systems, Component Refurbishment and Chemical Analysis Facility at KSC.
- Repair canal impoundment system - inlet/outlet valves at SSC.
- Replace natural gas system at White Sands.
- Renew the High-Pressure Gas Facility at SSC (Phase 1 of 2), which supports all rocket engine testing programs.
- Repair sanitary sewer at LaRC.
- Relocate electromagnetic interference / compatibility at LaRC.
- Sewage system conveyance and treatment repairs at SSC (Phase 3 of 3).

- Support ESDMD priorities with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Modification to KSC launch infrastructure for the Space Launch System (SLS).
  - Sustainment of Exploration Ground Systems infrastructure for Artemis.

- Support SOMD priorities with the construction, repair, or revitalization of critical facilities and infrastructure:
  - Continue the Deep Space Network Aperture Enhancement Project Beam Wave Guide (DAEP BWG) antenna projects with the construction of DSS-23 at Goldstone, DSS-33 at Canberra, and pedestal replacement of DSS-54 at Madrid.
  - Continue underground tank replacements, replace aging generators, and replace heating, ventilation, and air conditioning (HVAC) and mechanical systems.
  - Replace obsolete BWG antenna drives and cabinets and provide additional BWG redundant power feed Apollo substations at Goldstone Deep Space Communications Complex (GDSCC).

- Demolish unneeded or degraded facilities to support a more sustainable NASA with a smaller footprint, while avoiding repair and operational costs.
- Invest in energy savings projects that reduce operational costs and utility usage across NASA.
- Conduct facility planning and design associated with all construction and revitalization projects to ensure optimal consolidation, energy savings, cost effectiveness, and mission success.
- Maintain NASA's commitment to environmental stewardship by conducting critical cleanup efforts, maintaining agency-wide compliance with regulatory requirements, and managing environmental issues.

Balancing SSMS and CECR

NASA's mission support portfolio is divided between two accounts: Safety, Security, and Mission Services (SSMS) and CECR. MSD utilizes both accounts to maintain NASA's critical infrastructure. SSMS and CECR programs are dependent upon each other and there is a balance between maintenance of assets and infrastructure, repairs and renewal of failing assets, and the replacement and demolition of obsolete assets. Required maintenance activities drive SSMS spending decisions, while repairs, renewals (including new construction), and associated demolition drive CECR spending.

Much of NASA's infrastructure dates back to Apollo-era space exploration. Maintenance activities funded by SSMS are necessary to prevent costly delays to missions and risks to health and safety. Meanwhile, failures require immediate repairs and account for an increasing share of the SSMS facilities maintenance budget. These activities are vital to support evolving mission requirements. SSMS also funds proactive maintenance initiatives (e.g., Condition Based Maintenance) to identify issues and provide lower cost, scheduled maintenance. Without a sufficient facilities maintenance budget, assets and facilities worsen to a state requiring CECR funding for more expensive solutions. The increasing deep space exploration development and testing requirements place an additional strain on NASA's infrastructure and mission-unique facilities. Both SSMS and CECR activities are vital to support mission infrastructure requirements. MSD takes an agency-wide approach to make difficult trade-off decisions that ensure critical capabilities and assets are mission-ready, while also investing in the long-term asset health, sustainability, and footprint reductions that ensure NASA's future mission success. This approach allows NASA the ability to prioritize investments in support of long-term asset health, sustainability, and footprint reductions that ensure NASA's future mission success.

Themes

CONSTRUCTION OF FACILITIES (COF)

CoF funds capital repairs and improvements to NASA's infrastructure to provide NASA programs and projects with the research, development, and testing facilities required to accomplish their missions. CoF repairs the facilities that have suffered degradations, recent failures, or deterioration from inadequate maintenance over time. Due to mission priorities, projects to address immediate needs may displace renewal or new construction projects planned to replace obsolete facilities. These necessary tradeoffs preclude the construction of new, more advanced and energy efficient facilities and infrastructure that would reduce costs and increase sustainability in the long run.

CoF is comprised of two programs: Institutional CoF and Programmatic CoF. Institutional CoF activities are divided across five project definitions: discrete projects costing over $10 million; minor revitalization and construction less than $10 million; facility planning and design; demolition; and investments in energy savings. Programmatic CoF is focused on mission directorate-funded projects for specialized capabilities that align to specific NASA missions, separated between two project definitions of either discrete projects costing over $10 million or minor revitalization and construction costing less than $10 million.

NASA's CoF budget funds the agency's highest priority construction projects and continues to replace obsolete and deteriorating facilities that directly support NASA's mission. Institutional CoF does not fund routine maintenance and repairs projects, or projects with cost estimates of less than $1 million.

ENVIRONMENTAL COMPLIANCE AND RESTORATION (ECR)

ECR mitigates environmental risk at NASA installations and NASA-owned industrial plants supporting NASA activities. ECR supports agency-wide environmental compliance and risk management initiatives. ECR supports remediation at current or former sites where NASA operations have contributed to environmental degradation or where the agency is legally obligated due to past releases of pollutants, including emerging contaminants (e.g., polyfluoroalkyl substances [PFAS]).

At every center, ECR is investigating contaminated sites; remediating contaminated soil, water, and other media; and monitoring for continued compliance with agency objectives and obligations. ECR ensures NASA's compliance with environmental requirements, including the Resource Conservation and Recovery Act (RCRA); Comprehensive Environmental Response, Compensation, Liability Act (CERCLA); state regulatory requirements; consent orders; and legal obligations.

CONSTRUCTION OF FACILITIES

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Institutional CoF	230.6	--	**292.5**	298.3	304.3	310.4	316.6
Exploration CoF	94.3	--	**32.5**	0.0	0.0	0.0	0.0
Space Operations CoF	17.8	--	**19.7**	0.0	0.0	0.0	0.0
Science CoF	3.6	--	**0.0**	0.0	0.0	0.0	0.0
Total Budget	**346.2**	**--**	**344.7**	**298.3**	**304.3**	**310.4**	**316.6**

FY 2023 reflects Division B funding amount of $47.3 million and Division N funding amount of $367 million, as specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

For background information on FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

FY 2025 reflects Division N funding amount of $296 million, designated for an emergency requirement pursuant to section 251(b)(2)(A)(i) of the Balanced Budget and Emergency Deficit Control Act of 1985.

Shown here is the refurbishment of the lock system gate at SSC. The lock system is required for the waterway transportation of Artemis hardware to the SSC Test Complex. The canal impoundment is also the sole water source for SSC Test Complex fire safety deluge water.

NASA's Construction of Facilities (CoF) Program includes both institutional and programmatic construction projects. These projects reduce facility-related risk to mission success, increase sustainability, and improve technical infrastructure capabilities in support of NASA missions. CoF provides for the design and construction of facilities projects that enable NASA's infrastructure to meet mission needs. The CoF Program mitigates risks associated with real property assets, defined by NASA as "risks to infrastructure, information technology, resources, personnel, assets, processes, operations, occupational safety and health, environmental management, security, or programmatic constraints that affect capabilities and resources necessary for mission success, including institutional flexibility to respond to changing mission needs and compliance with internal (e.g., NASA) and external requirements (e.g., Environmental Protection Agency or Occupational Safety and Health Administration regulations)." Outyear plans do not include funding for Programmatic CoF, which is not identified until annual budget formulation.

CoF Priorities

CoF spans two programs: institutional and programmatic (for a full description of these two program areas, see the Program Elements section). All CoF projects are prioritized by agency and center leadership based upon immediate mission requirements and long-term affordability. Project priorities are best defined by a project's ability to address the following desired outcomes (for a full description of these project categories, see the Program Elements in each program section):

CONSTRUCTION OF FACILITIES

- Construct or revitalize facilities and infrastructure with discrete projects (greater than $10 million) and minor projects (less than $10 million) to meet mission and center requirements for NASA priorities.
- Plan and design facilities to ensure optimal outcomes and comply with statutory and mission requirements.
- Demolish unnecessary or degraded buildings following the consolidation or new construction of replacement facilities to reduce costs and NASA's footprint.
- Invest in energy savings projects that significantly change utility usage, including energy and water, for reduced operational costs and increased sustainability.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

Program Elements

INSTITUTIONAL CONSTRUCTION OF FACILITIES (INSTITUTIONAL COF)

Institutional CoF addresses infrastructure and facilities that span all mission areas and enable the effectiveness of NASA centers. Horizontal infrastructure and center-wide systems, such as roads and utilities, support all mission activities and are therefore considered "institutional." Institutional CoF also funds activities that support the overall agency goals of reducing operating costs, maintenance obligations, and utility usage through demolition and energy savings projects.

PROGRAMMATIC CONSTRUCTION OF FACILITIES (PROGRAMMATIC COF)

Programmatic CoF is funded by mission directorates for construction of specialized capabilities that directly support specific NASA missions, with appropriate funding transferred into CoF during the formulation of each budget year. Facilities and infrastructure supporting the execution of specific mission directorate requirements or having a unique capability required specifically for the execution of mission directorate programs and/or projects are funded through Programmatic CoF. Construction, repairs, and revitalization funded by Programmatic CoF do not have center-wide or agency-wide applications. Because projects funded through Programmatic CoF are unique to the missions they support, the description of projects are included below by mission area.

INSTITUTIONAL COF

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	230.6	--	292.5	298.3	304.3	310.4	316.6

FY 2023 reflects Division B funding amount of $47.3 million and Division N funding amount of $367 million, as specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

For background information on FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

FY 2025 reflects Division N funding amount of $296 million, designated for an emergency requirement pursuant to section 251(b)(2)(A)(i) of the Balanced Budget and Emergency Deficit Control Act of 1985.

The new 16,590 square-foot Emergency Operations Center (EOC) provides a secure, hardened, and centralized location for the JSC Incident Commander and staff to operate and to coordinate with key JSC staff and community emergency responders during a disaster or an emergency event. This project consolidated the JSC Protective Services Division assets from four locations into a single facility, and consolidated the Office of Emergency Management, Physical Security, Fire Protection Services, Occupational Health, and the Operations Control Center, which are now centrally located on JSC. The new EOC provides adequate and redundant communications for command and control during a disaster or an emergency incident as well as, to allow for easier command and control of day-to-day operations.

Institutional CoF sustains the readiness of NASA's physical infrastructure required to keep the centers open and operational. Real property assets include horizontal and vertical infrastructure and the associated collateral equipment. Repair and revitalization projects are prioritized using a risk-informed process that evaluates mission risks in terms of safety, schedule, cost, and technical capability. For each major facility replacement project, NASA develops a business case that includes a cost-benefit analysis.

NASA maintains an ongoing effort to identify, quantify, and prioritize institutional risks. Significant risks to a mission attributed to institutional real property are mitigated through the Institutional CoF Program. The criticality of mission risks may be reassessed as the risk posture changes due to mission and/or infrastructure condition. Currently, NASA has identified $5.4 billion worth of repairs and projects to mitigate known risks and optimize mission critical capabilities.

Institutional CoF Priorities

Institutional CoF funding is allocated across different projects depending on facility and infrastructure criticality, long-term sustainability, and mission needs. The goals of the Institutional CoF Program are to reduce risk to NASA missions and to reduce operational costs. Specifically:

INSTITUTIONAL COF

- Reduce Institutional risks, including risks to personal safety and deficiencies, and enable missions with discrete (greater than $10 million) and minor (less than $10 million) projects that address critical mission requirements.
- Demolish unnecessary and degraded buildings to avoid costs, eliminate risks, and reduce NASA's overall footprint for increased sustainability.
- Plan and design facilities to optimize capabilities, enhance sustainability, and comply with all federal and state obligations.
- Invest in energy savings projects that enhance sustainability and support NASA's commitment to environmental stewardship.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

NASA continued projects initiated in FY 2023 and prior years.

Discrete Projects

- Initiated replacement of the Wallops Island Causeway Bridge; funding has been provided to the Federal Highway Administration for construction of the replacement bridge.
- Initiated construction of the Aircraft Logistics and Operations Facility at JSC, with completion of the design and award of construction contract.
- Initiated replacement of the electrical distribution equipment in South Wing of the Operations and Checkout Building at KSC, with completion of the design and award of the construction contract.
- Completed construction of the Bioscience Collaborative Facility at ARC.
- Completed construction of the Aerospace Communications facility at GRC.
- Completed repairs to the steam distribution system at MSFC.

Minor Projects

- Design completed and contract awarded of the repair of Center-wide building envelopes at AFRC.
- Completed lighting upgrades at AFRC.
- Design completed and contract awarded for the replacement of the Ames Power Management System at ARC.
- Design completed and contract awarded for repair of high voltage electrical transformers at GRC Substation J.
- Design completed and contract awarded for the repair of central process systems at GRC.
- Completed Phase 4 of 5 repair of the GRC steam distribution system.
- Completed Phase 3 of 5 repair of the GRC electrical distribution systems.
- Completed repair of the water distribution system and cooling towers 3 and 6 at GRC.
- Design completed and contract awarded for repair of the Greenbelt Parkway Bridge at GSFC.
- Design completed for replacement and upgrade the switchgear in buildings 170 and 158 at JPL.
- Completed repairs of electrical bank 68 in Building 264 at JPL.

INSTITUTIONAL COF

- Completed fortification of the security gates at JPL.
- Design completed for replacement and upgrade of the switchgear in Building 230 at JPL.
- Design completed and contract awarded for repair of the utility tunnels at LaRC.
- Design completed and contract awarded for repair of the central steam plant at LaRC.
- Design completed and contract awarded for utility control system risk reduction at MSFC.
- Completed replacement of the emergency egress lighting system at MSFC.
- Design completed and contract awarded for Mitigating the threat of low-voltage arc flash issues at SSC.
- Completed rehabilitation of the E-Complex deluge system
- Completed replacement of the hazard fire detection system.

Demolition

- Demolished 47 inefficient and aged facilities, totaling over 500,000 square feet; thus, eliminating $44.7 million of deferred maintenance and avoided $1.4 million in maintenance and operations costs.

Energy Savings

- Implemented energy conservation measures and upgrade control systems for improve efficiency at JSC.
- Repaired vacuum jacketed electrical lines at LaRC for improved system efficiency.
- Installed critical water meters across the agency.

WORK IN PROGRESS IN FY 2024

NASA continues projects initiated in FY 2023 and prior years along with six new discrete projects and 16 minor projects, dependent on the enacted FY 2024 budget.

Discrete Projects

- Construct Engineering and Mission Operations Facility at ARC. This building includes a Multi-Mission Operation Center, SpaceShop, Rapid Prototyping system, engineering collaborative spaces, payload/instrument development labs, engineering offices, and support areas.
- Center Wide Fire Alarm System Upgrade (Phase 3) at GSFC. This project replaces obsolete and failing fire alarm systems across the center.
- Construct the Integrated Logistics and Processing Facility at GSFC. All missions require logistics to deliver flight hardware to other facilities.
- Compressor Station Upgrades (Phase 3 of 4) at LaRC. This upgrade replaces an obsolete compressor and associated ancillary systems.
- Repair Crew and Thermal Systems Mechanical Infrastructure at JSC Building 7. This effort replaces 19 fifty-plus-year-old severely deteriorated air handling units and their associated equipment.
- Renew High Pressure Gas Facility (HPGF), Phase 1 at SSC. The HPGF serves as Point-of-Origin for helium, hydrogen, nitrogen, and missile grade air to all test stands and support facilities.

INSTITUTIONAL COF

Minor Projects

- Repair Center-wide electrical systems at AFRC.
- Repair of AFRC Center-wide sewer system.
- Restore ARC reliability of HVAC and Uninterruptible Power Supply systems at Agency Telecom Gateway (N254).
- Reduce ARC electrical arc flash risk to personnel.
- Repair GRC cooling towers 1 and 4.
- Repair of GRC storm sewer system (Phase 3 of 3).
- I&T Complex mechanical repairs at GSFC.
- Wallops main base switchgear modernization at WFF/GSFC.
- Replace 16.5kV oil impregnated, paper insulated, underground distribution cable at JPL.
- JSC upgrade to mission control infrastructure (Phase 2 of 2).
- Install paging area warning system in propellants serving area at KSC.
- KSC electrical safety and reliability upgrades (Phase 5 of 5).
- Sanitary sewer repairs at LaRC.
- Conduct electrical safety repairs at MSFC.
- SSC arc flash repair and mitigation - Area 9.
- SSC sewage system conveyance and treatment repairs (Phase 2 of 2) - lift stations and piping.

Demolition

- Demolish multiple inefficient and aged facilities totaling 292,000 square feet to reduce operational costs and increase environmental sustainability.

Energy Savings

- Convert motors for power factor correction in Building 37 at GRC.
- Improve water treatment system, cooling towers 168 and 182 at GRC.
- Upgrade energy monitoring and control system head end at WFF.
- Implement energy conservation measures in Building 5 at GSFC.
- Implement energy conservation measures and upgrade control system phase 2 at JSC.
- Implement energy and water conservation measures at KSC.
- Replace central chiller plant pumps in Building 4473 at MSFC.

KEY ACHIEVEMENTS PLANNED FOR FY 2025

NASA's Institutional CoF Program includes seven discrete projects, 14 minor projects, four energy savings investment projects, and numerous demolition projects. Depending on final FY 2024 appropriations and because all CoF projects are prioritized based on criticality and mission urgency, NASA may allocate this funding to address some deferred projects before addressing planned FY 2025 activities.

INSTITUTIONAL COF

Discrete Projects

- Natural gas distribution system replacement at JSC/WSTF, $10.5 million:
  - Replace original 1960s carbon steel non-serviceable main and branch lines with new corrosion resistant lines and install cathodic protection.
  - Address critical reliability and safety issues in support of critical systems for Aerospace Fluids Testing and Analysis, Flight Acceptance Standard Test, Oxygen Compatibility Analysis, Calibration and Standards Labs.
- Upgrade mechanical systems, Components Refurbishment and Chemical Analysis (CRCA) Facility at KSC, $22.0 million:
  - Relocate existing shipping and receiving to an adjacent building and build a new 2,400 square-foot ISO Class 5 backup 1318 clean room.
  - The CRCA facility supports component precision cleaning and testing, chemical analysis, and instrument calibration for all flight programs at KSC.
- Electromagnetic interference / compatibility relocation at LaRC, $12.0 million:
  - Relocate test capability from B1220 to B1250 to enable demolition of B1220.
  - This test capability is required for qualification of space hardware per Military Test Standard-461 and for aircraft avionics per the American Radio Technical Commission for Aeronautics (RTCA) Document 160 for electromagnetic interference.
- Sanitary Sewer Repairs, Phase 2 of 2 at LaRC, $18.0 million:
  - Complete the repair of critically deteriorated sanitary sewer system to eliminate inflow and infiltration (I&I) and modernize the utility.
  - The local sanitary sewer treatment services provider issued a regulatory Administrative Order formally requiring LaRC to correct excessive I&I. Failure to comply could result in shutdown of the Center's sanitary connection to the municipal wastewater treatment facilities and/or fines of up to $32,500 per day of violation.
- Repair canal impoundment system –inlet/outlet valves at SSC, $10.0 million:
  - Repair and replace deteriorated critical navigation lock equipment to ensure continued dam functionality for reliable canal impoundment and lock operation supporting marine transportation. Dam functionality enables liquid hydrogen and liquid oxygen transfers for SLS testing operations.
- Sewage system conveyance and treatment repairs, Phase 3 of 3 at SSC, $11.0 million:
  - Repair and replace deteriorated sewage system piping, lift stations, and all associated appurtenances applicable to SSC’s sanitary sewage system.
- Renew High Pressure Gas Facility (HPGF), Phase 1 of 2 at SSC, $16.0 million:
  - Building modifications and relocation of High-Pressure Gas Control Center to B3226 to address aging equipment, code compliance issues, and occupancy requirements.
  - The HPGF serves as Point-of-Origin for helium, hydrogen, nitrogen, and missile grade air to all test stands and support facilities.

INSTITUTIONAL COF

Energy Savings

- Upgrade energy monitoring and control system and meters at GRC's Armstrong Test Facility to reduce energy consumption and expenditures through enhanced HVAC control and enabling reimbursement from test customers.
- Replace Boiler No. 1 at the Michoud Assembly Facility /(MAF) Building 207 to reduce energy consumption through a more efficient unit with an economizer.
- Improve energy efficiency at GSFC Wallops Flight Facility (WFF) Building F-010 by replacing the HVAC system to improve energy consumption and indoor air quality through more efficient and properly sized components.
- Improve Energy Efficiency at GSFC Building 34. This project retrofits, repairs, or replaces the building's laboratory fume hood, HVAC ducts and filters, lighting, and electrical transformers to reduce energy consumption through better sealed and more efficient components.

Minor Projects

- Repair aprons and taxiways Phase 1of 2 at AFRC to repair high-severity distresses and minimize ingestion of spalled concrete into engines of taxiing aircraft.
- Replace computer room air conditioning (CRAC) Units in the Data Analysis Facility at AFRC to ensure adequate cooling for sensitive information technology equipment.
- Restore reliability of domestic water infrastructure Phase 1 of 3 at ARC to replace the corroded and failing underground potable water distribution system.
- Repair N233 data Center HVAC system at ARC to ensure adequate cooling for sensitive information technology equipment in the Center's central computer facility.
- Repair of steam system Phase 5 of 5 at GRC to complete the replacement of the failing underground steam distribution system and ensure sufficient heating for the center.
- Repair electrical distribution system, Phase 5 of 5 at GRC to replace the failing electrical distribution system.
- Dam safety compliance repairs at GSFC to ensure integrity of the water retention pond and meet municipal storm sewer system permit requirements.
- Repair wastewater treatment system at GSFC/WFF to prevent wastewater contamination into the groundwater.
- Sitewide arc flash mitigation at JPL to mitigate the probability of catastrophic arc flash events.
- B180 seismic upgrade Phase 2 of 2 at JPL to ensure compliance with Executive Order 13717.
- Safety and reliability electrical upgrades, Phase 6 of 6 at KSC to replace degraded and obsolete switchgear and substations at various KSC locations.
- Revitalize building electrical systems (4583) at MSFC to replace the failed electrical equipment in Building 4583.
- Revitalize pressure and propellant distribution system, Phase 3 of 4 at MSFC to replace the failing distribution systems and ensure supply of gases to test facilities.

INSTITUTIONAL COF

- Sitewide high-voltage electrical system repairs at SSC to replace the failing electrical distribution system.

Demolition of Facilities

The FY 2025 Budget funds demolition activities of multiple facilities to reduce the agency's footprint, reduce operational costs, and increase environmental sustainability. This footprint reduction will be achieved over several years as the projects are completed.

Facility Planning and Design

Institutional CoF will support facility planning and design. Facility planning and design is a requirement for all CoF projects to ensure optimal outcomes, including consolidation and utility usage:

- Plan all projects, including efforts to consolidate work and leverage work-from-home options which have proven effective during the agency's response to COVID-19.
- Study and assessment of engineering, design and construction management, facility operations and maintenance, condition-based maintenance, and facility utilization.
- Support for engineering in facilities management systems, oversight, and capital leveraging research.
- Assess footprint reduction, consolidation, and environmental stewardship options.

EXPLORATION COF

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**94.3**	**--**	**32.5**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2023 reflects Division B funding amount of $47.3 million and Division N funding amount of $367 million, as specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

For background information on FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

FY 2025 reflects Division N funding amount of $296 million, designated for an emergency requirement pursuant to section 251(b)(2)(A)(i) of the Balanced Budget and Emergency Deficit Control Act of 1985.

Exploration Construction of Facilities (CoF) supports NASA's exploration missions, including the Space Launch System (SLS), Orion, and Exploration Ground Systems (EGS) programs. Exploration CoF is managed in collaboration with institutional projects but funded through ESDMD.

Shown here is the 1.25-million-gallon Liquid Hydrogen Sphere at the KSC's Launch Complex 39B. NASA's SLS is fueled with hydrogen from this sphere prior to launch.

Exploration CoF Priorities

Exploration construction priorities in FY 2025 continue to support facility upgrades and modernization for the Artemis campaign at the KSC and the Michoud Assembly Facility (MAF).

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

Exploration CoF continued infrastructure modifications necessary to support SLS and Orion launch operations, along with other exploration missions.

Discrete Projects

- Design completed and contract awarded for modifications to the launch infrastructure at KSC.
- Design completed and contract awarded for rehabilitation of KSC's LCC HVAC system.
- Design completed and contract awarded for renovation of the interior infrastructure of KSC's Booster Fabrication Facility (Phase 2 of 2).

EXPLORATION COF

Minor Projects

Exploration CoF will conduct critical repairs, modernization, and upgrades for facilities, infrastructure, and assets that support exploration projects:

- Design completed and contract awarded for upgrading the HVAC system at KSC's Booster Fabrication Facility to improve efficiency and lower costs (Phase 1 of 2).
- Design completed and contract awarded for refurbishing the KSC Booster Fabrication Facility complex cranes needed to support the SLS and Artemis Campaign Booster flight hardware operations.
- Design completed and contract awarded for refurbishing the cranes needed to support the SLS and Artemis Campaign Booster flight hardware operations in the MAF.
- Design completed and contract awarded for upgrading the fire suppression system in buildings 110 and 114 at MAF to improve safety and mission assurance.
- Design completed and contract awarded for upgrading the steam system at MAF to improve reliability in the critical manufacturing plant (Phase 3 of 3).

WORK IN PROGRESS IN FY 2024

Exploration CoF will continue infrastructure modifications necessary to support SLS and Orion launch operations, along with other exploration missions.

Discrete Projects

- Modifications to KSC launch infrastructure for SLS. The project will continue fabrication and installation of additional platforms in High Bay 3 for SLS Block 1b and start construction of the payload environmental access room in High Bay 4 to support Exploration Upper Stage processing. Construction will also start on LC-39B infrastructure modifications to support the Liquid Nitrogen skid to support RL-10 engines of the EUS.

Facility Planning and Design

None.

PLANNED ACHIEVEMENTS AND KEY INITIATIVES FOR FY 2025

Exploration CoF will continue infrastructure modifications necessary to support SLS and Orion launch operations, along with other exploration missions.

Discrete Projects

- Modifications to KSC launch infrastructure for SLS, $21.7 million:
  - Continue fabrication and installation of additional VAB platforms in HB-3 for SLS Block 1b and continue construction of the payload environmental access room in HB-4 to support EUS processing. Construction will also continue LC-39B infrastructure modifications to support the liquid nitrogen skid to support RL-10 engines of the EUS.

EXPLORATION COF

- Perform facility modifications at the Converter Compressor Facility to reduce helium loss, revitalize scavenger compressor, relocate desiccant bank, and remove railcar loading stations.

- Sustainment of EGS Infrastructure for Artemis, $10.75 million:
  - Includes projects to sustain the existing launch infrastructure at KSC in support of Artemis, including systems within the VAB; Pad 39B; LCC; Rotation, Processing and Surge Facility; and Multi-Payload Processing Facility.
  - Performing revitalization of various medium- and low-voltage power systems in the VAB Towers B, C, and D.

SPACE OPERATIONS COF

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**17.8**	**--**	**19.7**	**0.0**	**0.0**	**0.0**	**0.0**

FY 2023 reflects Division B funding amount of $47.3 million and Division N funding amount of $367 million, as specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

For background information on FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

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Space Operations CoF provides construction to support Space Communications and Navigation (SCaN), the ISS Program, and the Launch Services Program (LSP). Funds required for the planning and design of out-year programmatic construction remain in the applicable program accounts. Space Operations CoF is managed in collaboration with institutional projects but funded through SOMD.

Shown here is the pedestal metal stud framing for the DSS-23 34-meter Beam Waveguide antenna at the Goldstone Deep Space Communications Complex.

Space Operations CoF Priorities

Space Operations CoF is prioritized based on mission requirements and the criticality of mission assets.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

Space Operations CoF conducted repairs, modernization, and upgrades to ensure the safe and reliable continued operations of vital communication and monitoring systems. Repairs and upgrades addressed crucial systems in current assets, including electrical and fire systems, accessibility and code compliance, and additional necessary refurbishment.

Discrete Projects

- Continued the Deep Space Network Aperture Enhancement Project (DAEP) Beam Waveguide (BWG) antennae projects at the Goldstone and Canberra Deep Space Communication Complexes:
    - Completed the construction and start operations of the Dynamic Spectrum Sharing (DSS)-53 antenna at the Madrid Deep Space Communication Complex, enabling the array of four antennae for an enhanced aperture.

SPACE OPERATIONS COF

- Completed the DSS-23 antenna pedestal at the Goldstone Deep Space Communication Complex, along with other critical infrastructure, including flood controls, water, HVAC systems, electrical, surveillance, and fire detection systems.
- Enabled both radio frequency and optical communications for deep space exploration missions.

Minor Projects

- Modified the DSS-14 Antenna and the Goldstone Solar System Radar facility for improved long-range exploration and scientific missions.
- Built redundant data and signal processing centers to ensure the security and storage of vital mission data gathered during explorational and scientific missions.
- Replaced the fire detection system at Goldstone for improved site operations.

WORK IN PROGRESS IN FY 2024

Discrete Projects

- Continue DAEP BWG antennae projects with the construction of DSS-23 at Goldstone and the pedestal replacement of DSS-45 at Madrid, $5.8 million.

Minor Projects

- Replacement of underground tank at Goldstone Deep Space Communications Complex (JPL/GDSCC).
- Replacement of underground tank at Madrid Deep Space Communications Complex (JPL/MDSCC).
- Replacement of 750 kilowatt (kW) generators (JPL/GDSCC).
- Upgrade of Building 836/840 mechanical systems and controls (KSC/VAFB).
- Replacement of 750 kW generators (JPL/MDSCC).
- Replacement of backup generators (JPL/GDSCC).
- Replacement of the BWG antenna drives and cabinets replacement, subnet project (JPL).
- Install BWG redundant power feed (JPL/GDSCC).

PLANNED ACHIEVEMENTS AND KEY INITIATIVES FOR FY 2025

Discrete Projects

- Continue DAEP BWG antenna projects with the construction of DSS-23 at Goldstone, DSS-33 at Canberra and pedestal replacement of DSS-54 at Madrid, $14.1 million.

Minor Projects

- The BWG #1 Transmitter Facilities Upgrade (MDSCC) project will replace obsolete equipment and upgrade facilities to support the new 20kW transmitter at DSS-55.
- The BWG #2 Transmitter Facilities Upgrade (GDSCC) project will replace obsolete equipment and upgrade facilities to support the new 20kW transmitter at DSS-25.
- The GDSCC sewer upgrade project will replace portions of the sewage system to avoid environmental issues arising and meeting current environmental regulations.
- The replacement of 750 kW or less generators at CDSCC project will enable powerhouse modernization and increase overall reliability and availability of equipment at the complex.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

FY 2025 Budget

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**76.2**	**--**	**79.4**	**81.0**	**82.6**	**84.2**	**85.9**

FY 2023 reflects Division B funding amount of $47.3 million and Division N funding amount of $367 million, as specified in Public Law 117-328, Consolidated Appropriations Act, 2023.

For background information on FY 2024 funding amounts, please see footnotes in the front tables of this chapter or in the section titled "FY 2025 President's Budget Request Summary."

FY 2025 reflects Division N funding amount of $296 million, designated for an emergency requirement pursuant to section 251(b)(2)(A)(i) of the Balanced Budget and Emergency Deficit Control Act of 1985.

NASA's Environmental Compliance and Restoration (ECR) Program cleans up hazardous materials and waste products released to the surface or groundwater at current and former NASA installations or associated facilities. Over the years, NASA activities have contributed to environmental problems. It is the agency's ethical and legal responsibility to address hazardous pollutants and environmental impacts.

Following the excavation of 1,658 cubic yards of Polycyclic Aromatic Hydrocarbons (PAH) and lead-affected soil from a KSC restoration site, the disturbed areas were re-vegetated with approximately 2,000 native plants to restore native scrub-jay foraging habitat.

ECR stewardship, compliance, and restoration activities include:

- Execution of projects, studies, assessments, investigations, sampling, plans, designs, construction, engineering, program support, monitoring, and regulatory oversight.
- Development and execution of policies, guidance, communications, risk analysis, strategy, planning, coordination, and outreach.
- Provision of critical equipment needed for containment, monitoring, treatment, and analysis of harmful substances and contaminants.
- Land acquisitions required to ensure operation of remedial treatment processes and facilities as part of remediation and cleanup measures.
- Addressing tribal concerns for environmental actions through formal consultation.

ECR Priorities

ECR activities are prioritized based on a combination of legal and statutory requirements, assessed risk, and mission requirements. ECR's overarching goal is to ensure public health, conserve and restore natural resources, and reduce NASA's environmental burden. ECR activities are conducted in each of the following high priority areas:

ENVIRONMENTAL COMPLIANCE AND RESTORATION

- Stewardship: Ensure the responsible use and protection of the NASA infrastructure, assets, cultural and natural environment, and resources through the active execution of conservation efforts and sustainable practices that conform with legal requirements and presidential directives.
- Compliance: Ensure the public and the NASA workforce are not exposed to harmful chemicals from current or previous mission activities by identifying, monitoring, measuring, assessing, mitigating, treating, and identifying significant environmental risks; and executing regulatorily required compliance actions and reporting environmental compliance challenges and risks.
- Restoration: Conduct cleanup activities, including contaminant surveys, groundwater and soil investigations, groundwater treatment, soil removal, demolition, and associated regulatorily required activities to eliminate harmful substances or materials and reduce environmental impacts.

EXPLANATION OF MAJOR CHANGES IN FY 2025

None.

ACHIEVEMENTS IN FY 2023

ECR continued cleanup activities at all NASA centers, with priority for protecting health and conforming to environmental regulations and statutory requirements. ECR activities also supported execution of NASA's Climate Action Plan in accordance with Executive Order 14008, Tackling the Climate Crisis at Home and Abroad. In addition to the specific actions below, the ECR Program continued to implement site-wide restoration activities, operated and maintained groundwater treatment systems at sites with contaminated groundwater, investigated soil contamination agency-wide, and provided regulatory risk analysis and communication support.

- Completed demolition of Santa Susana Field Lab (SSFL) Bravo Test Stands and began demolition of Coca Test Stands.
- Implemented groundwater remediation test pilot programs at SSFL that are actively removing contaminants.
- Completed debris removal and initiated remedial design at Disposal Area 2A at GRC.
- Completed remediation of Quiet Engine Test Stand at GRC and submitted closeout report.
- Installed new groundwater treatment systems, removed contaminated soils, and sampled over 700 monitoring wells at KSC.
- Completed the closure activities and received a "No Further Action" notification from the regulator for Area A at SSC.
- Completed the construction of Plume-Front recloser and power meter at White Sands Test Facility (WSTF).
- Completed Vertical Process Facility air sparge system abandonment at KSC.
- Implemented the emulsified zero-valent iron Phase 3 enhanced remediation project at SSC.
- Updated the Agency Climate Action Plan in accordance with Executive Order 14008, Tackling the Climate Crisis at Home and Abroad, to integrate NASA’s climate change adaptation and climate resilience across agency programs.
- Completed development of NASA Tribal Consultation Plan.

ENVIRONMENTAL COMPLIANCE AND RESTORATION

WORK IN PROGRESS AND KEY INITIATIVES IN FY 2024

ECR will continue cleanup activities at all NASA centers, with priority given to protecting health and conforming to environmental regulations and statutory requirements. ECR activities are supporting execution of NASA's Climate Action Plan in accordance with Executive Order 14008, Tackling the Climate Crisis at Home and Abroad. In addition to the specific achievements below, the ECR Program continues to implement agency-wide compliance initiatives and site-wide restoration activities, operate and maintain groundwater treatment systems at sites with contaminated groundwater cleanup, investigate soil contamination agency-wide, and provide regulatory risk analysis and communication support.

- Continue to demolish Coca Test Stands at SSFL.
- Continue interim groundwater remedy operations at SSFL.
- Implement soil removal action at South Wallops Island.
- Continue to investigate and clean up contamination at KSC.
- Continue MSFC site-wide restoration activities including implementing interim actions to address the groundwater plume operable unit source areas.
- Continue to operate and maintain groundwater treatment systems at JPL and continue to operate the Lincoln Avenue and Monk Hill drinking water treatment systems.
- Continue site-wide restoration activities, contaminated groundwater cleanup, and investigate soil contamination at WSTF.
- Conduct remedial investigation/feasibility study at Engine Research Building at GRC.
- Conduct feasibility study and proposed plan at GRC’s Disposal Area 2A and 2B.
- Continue investigation of PFAS release at KSC Repeater Building.
- Implement initiatives to improve operational performance and efficiencies agency wide.
- Continue agency-wide environmental compliance initiatives to comply with federal, state, and local requirements and implement environmental risk management initiatives.

PLANNED ACHIEVEMENTS AND KEY INITIATIVES FOR FY 2025

ECR plans to continue cleanup activities at all NASA centers, with priority given to protecting health and conforming to environmental regulations and statutory requirements. ECR activities will support execution of NASA's Climate Action Plan in accordance with Executive Order 14008, Tackling the Climate Crisis at Home and Abroad. The ECR Program will continue to implement agency-wide compliance initiatives and site-wide restoration activities, operate and maintain groundwater treatment systems at sites with contaminated groundwater cleanup, investigate soil contamination agency-wide, provide regulatory risk analysis and communication support, and continue expanded soil investigations at multiple centers.

- Address legacy soils and groundwater contamination where identified.
- Make measurable progress on launch complex restoration activities across the agency.
- Update agency sustainability and climate action plans and continue performance reporting.
- Initiate final solution contaminated soil excavation and removal at SSFL.
- Continue demolition of Coca Test Stand at SSFL.
- Continue interim groundwater remedy operations at SSFL.

INSPECTOR GENERAL

Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	**47.6**	**47.6**	**50.5**	**51.5**	**52.5**	**53.6**	**54.7**

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

INSPECTOR GENERAL

FY 2025 Budget

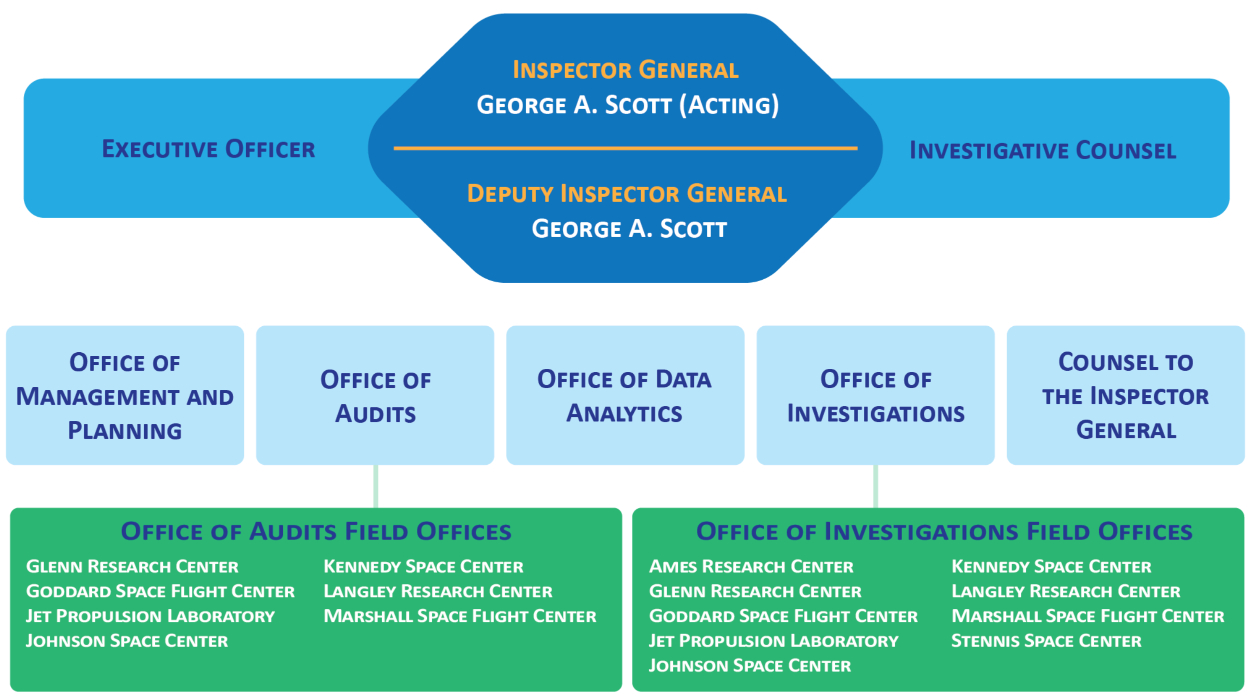
Budget Authority (in $ millions)	Op Plan FY 2023	CR FY 2024	Request FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Total Budget	47.6	47.6	50.5	51.5	52.5	53.6	54.7

FY 2023 reflects the funding amount specified in Public Law 117-328, Consolidated Appropriations Act, 2023, as revised in NASA's FY 2023 final Operating Plan, September 2023.

A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.

The Office of Inspector General (OIG) conducts audits, investigations, and reviews of NASA programs, personnel, and contractors to prevent and detect fraud, waste, abuse, and mismanagement, and assists NASA leaders and Congress in promoting economy, efficiency, and effectiveness through its oversight role. To accomplish this work, OIG employs auditors, investigators, data analysts, attorneys, and support staff at NASA HQ in Washington, D.C. and nine locations throughout the United States. The OIG's operational offices consist of the Office of Audits (OA), Office of Investigations (OI), Counsel to the Inspector General, Office of Management and Planning (OMP), and Office of Data Analytics (ODA).

OIG ORGANIZATIONAL CHART



OA conducts independent and objective audits of NASA programs, projects, operations, and contractor activities, and oversees the work of the independent public accounting firm that conducts the annual audits of the agency's financial statement and information security programs. OA targets high-risk areas and top management challenges to assist NASA's efforts to achieve its space exploration, scientific discovery, space technology, and aeronautics goals. OIG audits provide fact-based analysis with actionable recommendations that help NASA improve its operations.

OI investigates allegations of cybercrime, fraud, waste, abuse, and misconduct related to NASA programs, operations, and resources. OI refers its findings to the U.S. Department of Justice for criminal prosecution and civil litigation or to NASA management for administrative action. OI also develops recommendations for NASA management that aim to reduce the agency's vulnerability to criminal activity, misconduct, and administrative inefficiency. OI's caseload includes investigations of suspected false claims submitted by NASA contractors, product substitution and counterfeit parts, and conflict-of-interest cases that involve NASA employees placing private gain before public service.

The Counsel to the Inspector General (Office of Counsel) provides legal advice and assistance to OIG managers, auditors, and investigators. The Office of Counsel serves as counsel for administrative litigation and assists the Department of Justice when the OIG is part of the prosecution team, or when the OIG is a witness or defendant in legal proceedings. In addition, the Office of Counsel is responsible for educating agency employees about prohibitions on retaliation for protected disclosures, and rights and remedies for protected whistleblower disclosures.

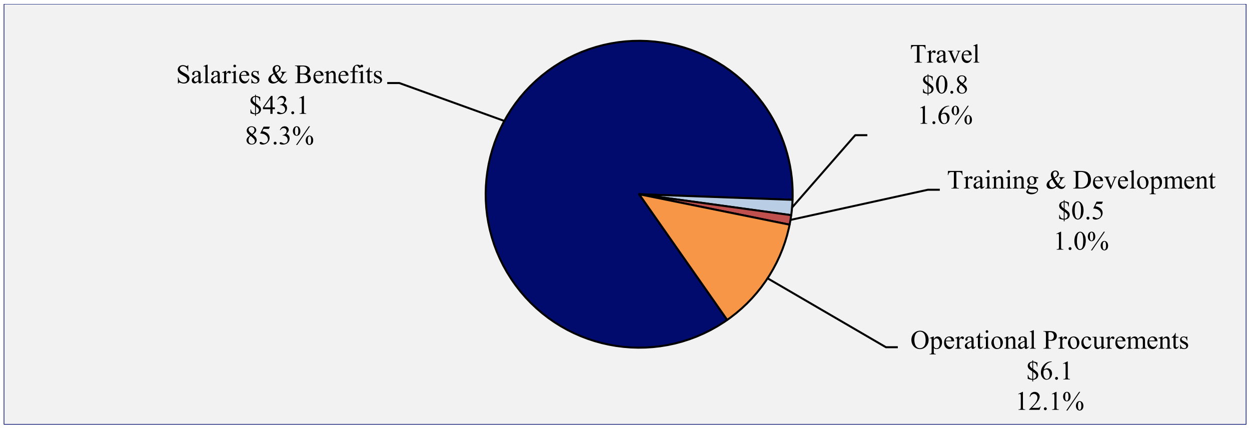
OMP and staff within the front office provide financial, procurement, human resources, administrative, and information technology (IT) services and support to OIG staff. OMP advises the Inspector General and OIG senior management on budget issues and human resources staffing matters, directs OIG internal management and support operations, and oversees development and adherence to management policies and procedures. Additionally, OMP ensures state-of-the-art IT system capabilities for OIG staff.

ODA is responsible for providing analytic consultation, data services, and data products to support audits, investigations, and management and planning functions. OIG develops and maintains a secure data analytic infrastructure that automates processes; secures data in cloud and on-premises environments; and rapidly disseminates critical information to decision makers to detect and deter fraud, waste, and abuse. ODA is comprised of statisticians, data scientists, data engineers, and business intelligence experts with domain experience in audits, investigations, and management and planning functions.

BUDGET REQUEST OVERVIEW

For FY 2025, the NASA OIG requests $50.5 million in direct appropriations to support the OIG's mission to improve NASA's programs and operations through independent and objective oversight. The FY 2025 budget request seeks the funding necessary to enable OIG to maintain its current staffing levels to deliver impactful audits and investigations.

FY 2025 OIG BUDGET REQUEST ILLUSTRATION



- $43.1 million (85.3 percent) for personnel and related costs, including salaries, benefits, monetary awards, and government contributions for Social Security, Medicare, health and life insurance, retirement, and the Thrift Savings Plan, which includes increased rates for retirement contributions;
    - Salaries include an increase for Calendar Year 2025 of 2 percent in base pay for cost-of-living-adjustments for all employees plus and the required additional 25 percent law enforcement availability pay for OIG's approximately 53 criminal investigators.
    - Awards and Recognition: The estimate of salary spending, excluding salary spending for Senior Executive Service (SES), for FY 2024 is $27.2 million and for FY 2025 is $27.8 million. The estimate of awards spending as a percent of non-SES salary spending for FY 2024 and FY 2025 is 2.5 percent.
- $0.8 million (1.6 percent) for employee travel, per diem, and related expenses;
- $0.5 million (1 percent) for training and staff development; and
    - In accordance with the Inspector General Act, 5 U.S.C. 406(g), the Inspector General certifies that the amount requested for required training and staff development would satisfy all the OIG's fiscal year 2025 training requirements.
- $6.1 million (12.1 percent) for operational procurements including vehicles, special equipment for criminal investigators, and information technology equipment unique to the OIG. Specifically, this cost estimate includes:
    - $3 million to procure the statutorily required annual audit of the agency's financial statements; and
    - $0.2 million to provide the resources necessary to support the Council of the Inspectors General on Integrity and Efficiency in accordance with 5 U.S.C. 406(g)6.

FY 2025 BUDGET REQUEST (in millions) WITH OUTYEARS:	FY 2024*	FY 2025	FY 2026	FY 2027	FY 2028	FY 2029
Budget Baseline	$47.6	$47.6	$51.5	$52.5	$53.6	$54.7
Technical Adjustment		$2.9				
Budget Request - Current Services	**$47.6**	**$50.5**	**$51.5**	**$52.5**	**$53.6**	**$54.7**
Breakdown by Built-ins						
Salaries & Benefits		$43.1	$44.0	$44.9	$45.9	$46.8
Travel		$0.8	$0.8	$0.8	$0.8	$0.9
Training and Employee Development		$0.5	$0.5	$0.5	$0.5	$0.5
Operational Procurements		$6.1	$6.2	$6.3	$6.4	$6.5
Budget Request - Current Services	**$47.6**	**$50.5**	**$51.5**	**$52.5**	**$53.6**	**$54.7**
Anticipated Collections	**$0.1**					
FTE - Direct	186	187	186	184	183	181
FTE – Reimbursable	1					
FTE Supportable	**187**	**187**	**186**	**184**	**183**	**181**

** A full-year 2024 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Consolidated Appropriations Act, 2023 (Division B of P.L. 117-328, as amended). The amounts included for 2024 reflect the annualized level provided by the continuing resolution.*

EXPLANATION OF MAJOR CHANGES IN FY 2025

The budget request provides two-year availability for all funds under this account.

PROPOSED CHANGE IN FUNDING AUTHORITY

All other NASA mission funding has at least two-year availability. Aligning the full OIG appropriation with the rest of NASA improves resource planning, especially under continuing resolutions, and provides more certainty in funding and efficiencies in hiring for an organization that is 85.3 percent personnel driven. Importantly, it will allow OIG to align its business processes and other financially related year-end processes within NASA's centralized financial systems and budgetary framework to execute the oversight mission more efficiently.

Appropriations Language for FY 2025

For necessary expenses of the Office of Inspector General in carrying out the Inspector General Act of 1978, $50,500,000, to remain available until September 30, 2026.

ACHIEVEMENTS IN FY 2023

To support the budget request, OIG has included the following select accomplishments and ongoing work performed by OI and OA.

Judicial or Civil Actions	
Indictments or Informations	14
Convictions or Plea Bargains	7
Cases Referred to NASA Management	41

Administrative Actions	
Administrative or Disciplinary Actions	29
Suspensions or Debarments from Government Contracting	13

Investigative Recoveries	
Total Criminal, Civil, and Cost Recoveries	$30.2 Million
Total Related to NASA	$3 Million

In FY 2023, OIG issued 30 audit products (e.g., audits, inspections, examinations, or reviews) containing 137 recommendations for improvement and identifying $84.9 million in questioned costs for NASA with an additional $4 million in potential monetary savings. Audit products included reports examining NASA's management of its:

- Artificial Intelligence capabilities;
- Deep Space Network;
- Efforts to increase diversity in its workforce;
- Electrified aircraft propulsion research and development efforts;
- FY 2022 financial statements;
- FY 2022 Federal Information Security Modernization Act (FISMA);
- FY 2022 Payment Integrity Information Act compliance;
- FY 2022 Geospatial Data Act compliance;
- Partnerships with international space agencies for the Artemis Campaign;
- Radioisotope Power Systems Program;
- Software asset management;
- Earth System Science Pathfinder Program;
- Space Launch System (SLS) booster and engine contracts; and
- STMD portfolio.

In FY 2023, OI Special Agents experienced a 28 percent increase in their caseloads that included a wide variety of criminal and administrative matters involving procurement fraud, theft, counterfeit parts, ethics violations, computer intrusions, and cyber incidents leading to more than $30.2 million in criminal, civil, and administrative penalties and settlements with approximately $3 million of these funds returned directly to NASA. OI's efforts in FY 2023 resulted in 14 indictments, six convictions, seven sentencings, four civil settlements, 29 administrative actions, and 13 suspensions or debarments.

Examples of OI's work over the past year include:

- The former Chief Executive Officer (CEO) of a Titusville, Florida, engineering firm and the firm's parent company agreed to a three-year voluntary exclusion from federal contracting after the CEO and three other employees were convicted of conspiracy, wire fraud, and misprision of felony for engaging in a 22-year fraud scheme against the government. The firm, misrepresenting itself as a woman-owned small business, received more than $84 million in contract payments to complete work at KSC. The former CEO, parent company, and two other employees were previously debarred from federal government contracting.

- As the result of a joint investigation by the NASA OIG and Defense Criminal Investigative Service, a Florida company agreed to a civil settlement of $7,759,694 to resolve allegations that it fraudulently obtained contracts from NASA and other federal agencies by making false claims related to its small and disadvantaged business status.
- The U.S. Attorney's Office for the Northern District of Texas reached a civil settlement with a Texas 3D printing company that agreed to pay the United States up to $4.54 million to resolve allegations that it violated the False Claims Act by improperly transmitting export-controlled NASA and U.S. DoD technical data to a company in China. The potential full settlement amount includes $2.27 million in restitution and an additional $2.27 million in penalties should the company fail to pay the same amount to the U.S. Department of State and U.S. Department of Commerce in connection with a parallel administrative settlement.
- As the result of a joint investigation by the NASA OIG, Air Force Office of Special Investigations, and Defense Criminal Investigative Service, a Colorado laser manufacturer agreed to a civil settlement of $402,621 to settle allegations that it collaborated with foreign entities for research and development consulting services without government approval.
- A Florida company pleaded guilty to major fraud against the United States following the previous arrest and indictment of its director for fraudulently obtaining a DoD aircraft and two NASA X-34 unmanned space planes for personal use through the General Services Administration Federal Excess Property Program.
- As the result of a joint investigation by the NASA OIG, Federal Bureau of Investigation, U.S. Army Criminal Investigation Division, and NSF OIG, an Ohio university agreed to a civil settlement of $875,689 to resolve allegations that it failed to disclose a professor's affiliations with and support from a foreign government in connection with research funding from NASA and other federal agencies.
- A former JSC civil servant pleaded guilty to engaging in a scheme to secure over $150,000 in Paycheck Protection Program funding by claiming to own a fictitious business. As a result, they were sentenced to 60 months of probation and ordered to pay $156,400 in restitution.
- A former KSC civil servant was charged by the Florida State Attorney's Office with felony grand theft for fraudulently securing $20,832 in Paycheck Protection Program funding by inflating costs related to a side business they failed to disclose on their Confidential Financial Disclosure Report.
- A senior GSFC employee received a letter of reprimand for integrity violations after creating the appearance that they attempted to direct NASA funding to a contractor with whom they had a personal business relationship.
- A senior GSFC contractor employee received written counseling for their role in an alleged assault against another employee at the Goddard Child Development Center.
- A GSFC contractor employee was terminated for theft of government property valued at $1,300, which was later recovered.
- As the result of a joint investigation by the NASA OIG, Federal Bureau of Investigation, and Internal Revenue Service–Criminal Investigation, two senior contractor employees were terminated for

receiving government property and gifts from another contractor in exchange for insider information used to obtain NASA contracts.

- A former Florida police officer was sentenced to two years of probation and 100 hours of community service after pleading no contest to felony Unauthorized Computer Access for their role in assisting an ex-wife to frame her ex-husband—a NASA civil servant—for making terroristic threats against her. The investigation found the former police officer misused official computer systems and engaged in other misconduct while on duty. The ex-wife of the civil servant previously pled guilty and was sentenced in federal court to six months of imprisonment for her role in the conspiracy.

WORK IN PROGRESS AND KEY ACHIEVEMENTS PLANNED FOR FY 2024 - FY 2025

OIG will examine the Mars Sample Return Program, ISS operations through 2030, and the Commercial Lunar Payload Services initiative. The OIG will continue to monitor the progress of the Artemis campaign, including readiness for the Artemis II crewed mission to lunar orbit and management of Artemis IV and future missions. The OIG is also reviewing NASA’s High-End Computing Program and its privacy program, as well as the agency’s Science, Technology, Engineering, and Mathematics (STEM) engagement efforts and their effectiveness at attracting a diverse and skilled STEM workforce. Ongoing OI work includes proactive initiatives designed to identify acquisition and procurement fraud schemes. Additionally, representatives from both OI and OA are working together to use OIG’s advanced data analytics capabilities to help identify indicators of potentially fraudulent activity.

In FY 2024, OIG will continue to focus its work on NASA’s top management and performance challenges identified in our November 2023 report. Specifically, OIG plans to undertake work in the following areas:

- Returning humans to the Moon;
- Improving management of major programs and projects;
- Sustaining a human presence in LEO;
- Maturing IT management and security;
- Improving oversight and management of contracts, grants, and cooperative agreements;
- Attracting and retaining a highly skilled and diverse workforce; and
- Addressing NASA's outdated infrastructure and facilities.

OIG will also continue mandated oversight in a variety of financial management and quality control areas to include:

- Payment Integrity Information Act compliance;
- Desk and quality control reviews of selected single audit reporting packages;
- Oversight of financial statement audit;
- Risk assessment of purchase and travel card programs;
- Geospatial Data Act; and
- Federal Information Security Modernization Act.

As NASA continues to work toward landing the first woman and person of color on the Moon, with the eventual goal of landing humans on Mars, additional OIG funding will enable enhanced oversight of major NASA projects.

From an investigative perspective, the FY 2025 request will continue support for investigations of cybercrime, fraud, waste, abuse, and misconduct related to NASA programs, projects, personnel, operations, and resources.

Given the important role of NASA's contracting practices in agency missions, most of OIG's proactive initiatives focus on acquisition activities that are susceptible to procurement fraud schemes. Examples of ongoing, proactive initiatives that will continue include the following:

- An Investigative Analysis Division (IAD) – Financial Accountant & Analysis (FA&A) section project to aggregate, analyze, and monitor cost data related to NASA's Artemis campaign;
- An IAD-FA&A cross collaboration project with OA to conduct incurred cost audits of specific NASA subcontractors;
- A joint IAD project in conjunction with ODA and the Department of Justice Procurement Collusion Strike Force to utilize procurement data to identify potential collusion and/or anti-trust matters;
- A project to monitor and aggregate data related to NASA's Artemis campaign to identify indications of fraud on the part of prime contractors and subcontractors; and
- Multiple initiatives commenced to identify, detect, and deter fraud involving grant and contract recipients who surreptitiously receive significant financial support from foreign governments and/or fail to identify potential foreign-based conflicts of interest in violation of NASA policies and/or federal law.

Supporting Data

FUNDS DISTRIBUTION

DISCRETIONARY BUDGET REQUEST BY MISSION BY NASA CENTER

Budget Authority ($ in millions)	FY 2025*
Deep Space Exploration Systems	44.5
Space Technology	36.5
Space Operations	15.7
Science	255.7
Aeronautics	194.0
STEM Engagement	3.0
Safety, Security, and Mission Services	195.7
Construction and Environmental Compliance and Restoration	19.0
ARC Total	**764.0**
Deep Space Exploration Systems	0.0
Space Technology	24.9
Space Operations	0.3
Science	13.5
Aeronautics	200.5
STEM Engagement	0.4
Safety, Security, and Mission Services	60.0
Construction and Environmental Compliance and Restoration	14.5
AFRC Total	**314.1**
Deep Space Exploration Systems	241.8
Space Technology	73.2
Space Operations	99.6
Science	48.0
Aeronautics	200.7
STEM Engagement	2.6
Safety, Security, and Mission Services	217.1
Construction and Environmental Compliance and Restoration	15.0
GRC Total	**898.0**
Deep Space Exploration Systems	8.3
Space Technology	17.4
Space Operations	212.5
Science	3,007.8
Aeronautics	-
STEM Engagement	7.7
Safety, Security, and Mission Services	352.4
Construction and Environmental Compliance and Restoration	14.7
GSFC Total	**3,620.8**

FUNDS DISTRIBUTION

Budget Authority ($ in millions)	FY 2025*
Deep Space Exploration Systems	18.7
Space Technology	20.7
Space Operations	199.8
Science	1,388.1
Aeronautics	-
STEM Engagement	3.5
Construction and Environmental Compliance and Restoration	32.0
Safety, Security, and Mission Services	8.5
Jet Propulsion Laboratory (JPL/NMO) Total	**1,671.3**
Deep Space Exploration Systems	2,049.3
Space Technology	12.7
Space Operations	2,728.3
Science	280.6
STEM Engagement	1.3
Construction and Environmental Compliance and Restoration	331.0
Safety, Security, and Mission Services	10.5
JSC Total	**5,413.6**
Deep Space Exploration Systems	911.9
Space Technology	7.3
Space Operations	687.7
Science	281.4
Aeronautics	-
STEM Engagement	21.7
Safety, Security, and Mission Services	329.4
Construction and Environmental Compliance and Restoration	59.5
KSC Total	**2,298.8**
Deep Space Exploration Systems	29.0
Space Technology	18.6
Space Operations	9.1
Science	200.3
Aeronautics	284.0
STEM Engagement	25.4
Construction and Environmental Compliance and Restoration	30.0
Safety, Security, and Mission Services	255.1
LaRC Total	**851.4**
Deep Space Exploration Systems	4,045.4
Space Technology	128.2
Space Operations	144.0
Science	211.4
Aeronautics	-
STEM Engagement	3.9
Construction and Environmental Compliance and Restoration	493.8
Safety, Security, and Mission Services	17.9
MSFC Total	**5,044.5**

FUNDS DISTRIBUTION

Budget Authority ($ in millions)	FY 2025*
Deep Space Exploration Systems	222.2
Space Technology	840.2
Space Operations	260.8
Science	1,878.9
Aeronautics	86.6
STEM Engagement	49.8
Safety, Security, and Mission Services	741.0
Construction and Environmental Compliance and Restoration	166.0
Office of Inspector General	50.5
NASA Headquarters (HQ) and Inspector General (IG) Total	**4,295.9**
Deep Space Exploration Systems	47.3
Space Technology	2.1
Space Operations	32.0
Science	0.1
Aeronautics	-
STEM Engagement	24.3
Safety, Security, and Mission Services	60.6
Construction and Environmental Compliance and Restoration	45.0
SSC Total	**211.4**
	25,383.7

**Totals may not add due to rounding*

NOTE: Funds will not be fully distributed to the centers until after final acquisition decisions are made. Thus, FY 2025 allocations by center should not be considered final or directly comparable to prior year allocations

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

NASA's workforce continues to be one of its greatest assets for enabling missions in space and on Earth. The workforce enables NASA to lead or participate in emerging technology opportunities, collaborate and strengthen the capabilities of commercial partners, and communicate the challenges and results of agency programs and activities. The civil service staffing levels funded in the FY 2025 Budget support the work of scientists, engineers, researchers, managers, technicians, and administrative professionals at NASA centers, HQ, and NASA-operated facilities.

NASA continually assesses and adjusts the mix of skills in its workforce to address changing mission priorities, effectively leveraging industry and academic partnerships, and on and near-site support contracts. A knowledgeable and well-trained civil service workforce is critical for conducting mission-essential work in research and technology. Centers will explore cross-mission retraining opportunities for employees whenever possible, offer targeted buyouts in selected surplus skill areas, and continue to identify, recruit, and retain a multi-generational workforce of employees who possess skills critical to the agency.

CIVIL SERVICE FULL-TIME EQUIVALENT (FTE) DISTRIBUTION BY CENTER – DIRECT FUNDED

	Actual	Estimate	Request
	FY 2023	**FY 2024**	**FY 2025**
HQ	1,510	1,601	1,542
ARC	1,269	1,207	1,159
AFRC	523	500	471
GRC	1,466	1,437	1,361
GSFC	3,039	2,929	2,588
JSC	2,956	3,136	3,127
KSC	2,003	2,055	1,940
LaRC	1,813	1,662	1,565
MSFC	2,236	2,290	2,246
SSC	256	261	260
NSSC	-	-	-
NASA Total*	**17,071**	**17,078**	**16,259**
OIG	180	186	187

**Totals may not add due to rounding*

NOTE: Funds will not be fully distributed to centers until after final acquisition decisions are made. Thus, center FY 2024 and FY 2025 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

CIVIL SERVICE FULL-TIME EQUIVALENT (FTE) DISTRIBUTION BY CENTER – REIMBURSABLE FUNDED

	Actual	Estimate	Request
	FY 2023	FY 2024	FY 2025
HQ	18	180	180
ARC	24	22	22
AFRC	27	15	15
GRC	26	3	3
GSFC	180	219	219
JSC	36	-	-
KSC	18	1	1
LaRC	29	15	15
MSFC	37	-	-
SSC	20	25	25
NSSC	171	180	180
NASA Total*	**586**	**660**	**660**
OIG	4	-	-

**Totals may not add due to rounding*

NOTE: Funds will not be fully distributed to centers until after final acquisition decisions are made. Thus, center FY 2024 and FY 2025 allocations should not be considered final or directly comparable to prior year allocations.

CIVIL SERVICE FULL-TIME EQUIVALENT DISTRIBUTION

FY 2025 FTE DISTRIBUTION BY ACCOUNT BY CENTER

	Deep Space Exploration Systems	Space Operations	Space Technology	Science	Aeronautics	STEM Engagement	Safety, Security, and Mission Services	Reimbursable / Working Capital Fund**	Inspector General	NASA-Funded Total	Agency TOTAL
HQ	55	46	51	256	65	18	1,052	180	-	1,542	1,722
ARC	60	32	79	210	305	1	474	22	-	1,159	1,181
AFRC	-	1	22	41	235	1	172	15	-	471	486
GRC	179	115	130	73	399	3	460	3	-	1,361	1,364
GSFC	14	162	44	1,241	-	4	1,123	219	-	2,588	2,807
JSC	1,054	1,225	33	61	-	6	749	-	-	3,127	3,127
KSC	587	499	33	25	-	5	792	1	-	1,940	1,941
LaRC	82	21	94	169	538	3	659	15	-	1,565	1,580
MSFC	940	185	130	249	-	6	735	-	-	2,246	2,246
SSC	51	38	9	-	-	3	160	25	-	260	285
NSSC	-	-	-	-	-	-	-	180	-	-	180
NASA Total*	**3,021**	**2,324**	**624**	**2,325**	**1,542**	**49**	**6,374**	**660**	**-**	**16,259**	**16,919**
OIG	-	-	-	-	-	-	-	-	187	187	187

**Totals may not add due to rounding.*

*****Includes 180 FTE funded by Working Capital Fund.*

NOTE: Funds will not be fully distributed to centers until after final acquisition decisions are made. Thus, center FY 2025 allocations should not be considered final or directly comparable to prior year allocations.

WORKING CAPITAL FUND

NASA established the Working Capital Fund (WCF) to satisfy specific recurring needs for goods and services through use of a business-like buyer and seller approach under which NASA's WCF entities provide goods or services pursuant to contracts and agreements with their customers. The overarching aim of the WCF is to promote economy, efficiency, and accountability with fully reimbursed rates and by focusing on streamlining operations, measuring performance, and improving customer satisfaction.

NASA's WCF is comprised of five entities:

- NASA Shared Services Center (NSSC);
- Solutions for Enterprise-Wide Procurement (SEWP) Government-Wide Acquisition Contract;
- Enterprise IT Services Program [formerly Information Technology Infrastructure Integration Program (I3P)];
- National Center for Critical Information Processing and Storage (NCCIPS); and
- IT Modernization.

WORKING CAPITAL FUNDS BUDGET SUMMARY

Spending Authority from Offsetting Collections	Actual	Estimate	Request
($ in millions)	**FY 2023**	**FY 2024**	**FY 2025**
NSSC	83	87	97
SEWP	49	50	63
I3P	187	235	246
NCCIPS	21	38	52
IT Modernization	8	32	38
Total New Spending Authority	**348**	**442**	**496**
Unobligated Brought Forward, Oct. 1	42	43	17
Recoveries of Prior Yr. Unpaid Obligations	10	6	21
Total Budgetary Resources	**400**	**491**	**534**
NSSC	83	98	97
SEWP	49	42	63
I3P	187	274	246
NCCIPS	30	28	52
IT Modernization	8	32	38
Total Obligations	**357**	**474**	**496**
Unobligated Balance (end-of-year)*	**43**	**17**	**38**

NASA SHARED SERVICES CENTER (NSSC)

NSSC opened in March 2006 to provide centralized administrative processing services and customer contact center operations for support of human resources, procurement, financial management, agency IT, and agency business support services. NASA established NSSC, a function under the NASA HQ MSD, as a public/private partnership. NSSC has awarded its major business management and IT services contract to COLSA Corporation, General Dynamics Information Technology (GDIT), and InspiriTec. Typical expenditures are related to the civil service workforce, support contractor, other direct procurements, and agency training purchases.

NSSC is located on the grounds of SSC and operates in a manner that provides for transparency and accountability of costs and services. NASA has reduced its administrative costs through centralized processing at NSSC. The work performed by NSSC reduces duplicative efforts and increases cost efficiencies.

NSSC's revenue streams include funding from the NASA mission support enterprise offices, mission directorates, and various NASA mission support offices. During FY 2024, NSSC will continue to offer similar services as in FY 2023. During FY 2025, NSSC will continue to offer similar services as in FY 2024 making minor expansions to existing services.

SOLUTIONS FOR ENTERPRISE-WIDE PROCUREMENT (SEWP)

SEWP refers to operations related to the Government-Wide Acquisition Contract that was established under the authority of section 5112 of the Information Technology Management Reform Act (40 U.S.C. 1412[e]), enacted in 1996, under which NASA is designated by the Office of Management and Budget (OMB) as a Federal Government Executive Agent for SEWP contracts.

SEWP was established as a WCF entity to allow all federal agencies use of a best value tool to purchase IT product solutions and services. Under this approach, the buying power of federal agencies is combined to acquire best value for IT products and services more efficiently. Typical acquisitions include a wide range of advanced technologies, such as: UNIX-Linux and Windows-based desktops and servers, peripherals, network equipment, storage devices, security tools, software, and other IT products and product-based solutions.

SEWP promotes aggressive pricing using online tools to obtain multiple, competitive quotes from vendors. On average for FY 2024, SEWP quotes have a 20 percent savings for any federal customer using SEWP contracts. In addition, SEWP offers a low surcharge to recover NASA's costs to operate the program with an average 0.34 percent fee as compared to the government standard of 0.75 percent. SEWP revenue is generated solely from the surcharge fees on all transactions processed. For FY 2024, the federal government saved about $4.2 billion in fees, based on the difference between General Services Administration (GSA) and SEWP surcharge fees.

ENTERPRISE IT SERVICES PROGRAM

WCF operations supporting Enterprise IT Services Program began in early FY 2012. WCF enables Enterprise IT Services Program to improve the efficiency and economy in which contract services and management are provided to support NASA's IT strategic initiatives and to increase visibility into NASA's IT budget and expenditures. Under the Enterprise IT Services Program, NASA has consolidated 19 separately managed contracts into four centrally managed ones described as follows:

- The Enterprise Applications Service Technologies (EAST2) contract supports Agency Applications Office (AAO) applications hosted by MSFC. The AAO operates and maintains a broad spectrum of NASA's enterprise applications, with an emphasis on fully integrating business process expertise with application and technical knowledge. A small team of civil servants and support contractors sustain operations, implement new applications and capabilities, and provide business readiness support to the stakeholders and end-users.

- The Enterprise Applications Service Technologies Web Enterprise Service Technologies (EAST2-WSO) contract provides public website hosting, web content management and integration, and search services. GSFC and ARC host these services.
- The End User Services Contract (NASA End-User Services and Technology [NEST] / End User Services Office [EUSO]) provides program management, provisioning, and support of desktops, laptops, cell phones, personal digital assistants, office automation software, and video conferencing. NSSC hosts these services.
- The Networx Telecommunications Circuits contract provides telecommunication services, which includes tele-conferencing services, core circuit services, mission network services, and regional circuit services hosted at MSFC. The work under the Networx contract slowly started transitioning to the follow-on contract, Enterprise Infrastructure Solutions Contract (EIS) in July 2019 with some services transitioning to other Enterprise Contracts. The transition of work is still ongoing in FY 2024 and should be completely transitioned by the end of FY 2024.

Enterprise IT Services Program consolidated contracting approach benefits NASA by providing cost saving opportunities, such as the reduction in administrative burden involved with the business management of contracts and a significant reduction in procurement request transaction volume. Other Enterprise IT Services Program benefits include: streamlining the budgeting, funding, and costing of Enterprise IT Services Program services; achieving transparency through the provision of detailed customer monthly billings; and providing consolidated, consistent reporting of agency-wide consumption of Enterprise IT Services Program-related goods and services.

Enterprise IT Services Program is unique in that revenue streams and expenditures are limited to contract costs for its four service contracts. Revenue streams include funding from the NASA centers, NASA mission directorates, and various NASA mission support offices. As reflected in the FY 2024 anticipated funding level, the Enterprise IT Services Program WCF will continue to offer similar services as in FY 2023 with one significant change. The follow-on contract for EAST 2 and EAST 2 WSO, the NASA Consolidated Applications and Platform Services (NCAPS) contract, will be managed outside of WCF starting in July 2024. In FY 2025, NSSC will continue to offer similar services as in FY 2024.

NATIONAL CENTER FOR CRITICAL INFO. PROCESSING AND STORAGE (NCCIPS)

NCCIPS is a federal shared services data center designed for sensitive and secure processing and storage. NCCIPS is a 211,000-square-foot secure data center facility on a 64-acre campus within SSC. NCCIPS offers federal customers collocation services from a state-of-the-art data center facility. NCCIPS offers 24x7x365 availability at a Tier III level as defined by the Uptime Institute, with complete redundancy in the cooling system and in the electrical distribution system from the national power grid to the rack-level.

NCCIPS provides the following infrastructure/services:

- Five Layer Security – Buffer Zone/perimeter fencing, armed security at all gates, roving guards, and NCCIPS armed guards, and NCCIPS Access Control System;

- Three separate commercial power generation systems available to NCCIPS;
- Tier III redundant (N + 1) power from commercial power systems down to racks on the datacenter floors with N + 1 diesel generator backup;
- Tier III redundant (N + 1) cooling;
- Expert IT staff with a proven track record of uninterrupted service;
- 24x7 facility operations staff monitoring;
- Robust network infrastructure with multiple, discreet communication paths; and
- FE-25 clean agent fire suppression.

The NASA WCF provides NASA with a mechanism to collect amounts sufficient to finance continuing operations, acquire capital assets, and adjust for prior year results of operations, in addition to normal operating expense recovery at NCCIPS. NCCIPS WCF benefits NASA and its customers by:

- Enabling funds to be collected over time and (once earned) used for new equipment and technology.
- Allowing the NSSC to incorporate a level of equipment replacement, maintenance, and technology refresh costs into customer rates.
- Helping to normalize rates charged to NCCIPS customers from year-to-year, as the need for facility repairs, infrastructure upgrades, and routine equipment maintenance increases; thus, enabling NCCIPS customers to maintain their appropriation funding without incurring potentially large unplanned expenses.
- Facilitating NCCIPS business opportunities for new customers.
- Reducing the probability of hardware failure within the NCCIPS operational environment.

The NCCIPS revenue streams include funding from the NASA Centers, NASA HQ Office of the Chief Human Capital Officer, and external federal agencies, including Department of Homeland Security (DHS), U.S. Army Program Executive Offices - Missiles and Space (ARMY – APEO) and Aviation (ARMY – AAVN), U.S. Navy DoD Supercomputing Resource Center (DSRC), DoD High Performance Computing Modernization program – Engineer Research and Development Center (ERDC), National Reconnaissance Office (NRO), Government Services Administration (GSA), Department of Transportation OCIO (DOT-OCIO), DOT Maritime Administration, Department of Housing and Urban Development (HUD), and Naval Air Systems Command (NAVAIR). During FY 2024 and FY 2025, NCCIPS will continue to offer similar services as in FY 2023 with no significant scope changes anticipated.

IT MODERNIZATION

In FY 2023, NASA's existing authority under 51 U.S.C. 30102 was amended to authorize the WCF for IT Modernization activities on a non-reimbursable basis and included transfer authority from the Safety, Security, and Mission Services account into the WCF to fund such activities. The Administrative Provisions in the FY 2025 Budget include transfer authority for up to $38,500,000 for purposes of IT modernization.

BUDGET BY OBJECT CLASS

FY 2025 Estimated Direct Discretionary Obligations
($ millions)

Code	Object Class	Deep Space Exploration Systems	Space Operations	Space Technology	Science	Aeronautics	STEM Engagement	Safety, Security, and Mission Services	Construction & Environmental Compliance & Restoration	Office of Inspector General	NASA Total
11.1	Full-time permanent	437	361	83	372	224	7	948	-	28	**2,460**
11.3	Other than full-time permanent	5	5	3	9	11	-	21	-	1	**55**
11.5	Other personnel compensation	2	2	-	2	1	-	50	-	1	**58**
11.8	Special Personal Services Payments	-	2	-	-	-	-	1	-	-	**3**
11.9	*Subtotal Personnel Compensation*	*444*	*370*	*86*	*383*	*236*	*7*	*1,020*	-	*30*	***2,576***
12.1	Civilian personnel benefits	183	135	31	161	86	2	365	-	13	**976**
13.0	Benefits to former personnel	-	-	-	-	-	-	-	-	-	-
	Total Personnel Compensation & Benefits	**627**	**505**	**117**	**544**	**322**	**9**	**1,385**	-	**43**	**3,552**
21.0	Travel & transport. of persons	15	15	-	2	-	1	2	-	1	**36**
22.0	Transportation of things	-	1,652	7	8	-	-	2	-	-	**1,669**
23.1	Rental payments to GSA	-	-	-	-	-	-	36	-	-	**36**
23.2	Rental payments to others	5	-	-	20	-	-	2	-	-	**27**
23.3	Communications, utilities & misc.	16	10	-	13	5	-	93	2	-	**139**
24.0	Printing & reproduction	-	-	-	3	-	-	2	-	-	**5**
25.1	Advisory & assistance services	485	180	51	183	27	2	453	17	2	**1,400**
25.2	Other services from non-Federal sources	35	156	28	234	29	21	205	46	3	**757**
25.3	Other purchases of goods & services from Government accounts	33	35	84	286	8	-	49	114	1	**610**
25.4	Operation & maintenance. of facilities	113	26	5	18	59	-	234	54	-	**509**
25.5	Research & development contracts	5,414	1,525	786	5,149	377	3	164	8	-	**13,426**
25.6	Medical care	-	-	-	-	-	-	6	-	-	**6**
25.7	Operation & maintenance of equipment	112	182	7	49	38	2	153	3	-	**546**
26.0	Supplies & materials	84	17	8	32	13	-	11	-	-	**165**
31.0	Equipment	348	27	16	123	37	7	188	1	1	**748**
32.0	Land & structures	315	4	1	5	4	-	22	179	-	**530**
41.0	Grants, subsidies, & contributions	16	56	72	897	47	99	37	-	-	**1,224**
42.0	Insurance claims and indemnities	-	-	-	-	-	-	-	-	-	-
	Other Object Classes	**6,991**	**3,885**	**1,065**	**7,022**	**644**	**135**	**1,659**	**424**	**8**	**21,833**
	NASA Total, Direct	**7,618**	**4,390**	**1,182**	**7,566**	**966**	**144**	**3,044**	**424**	**51**	**25,384**

**Totals may not add due to rounding.*

NOTE: The table only reflects the FY 2025 request and does not include remaining funding from previous direct or supplemental appropriations.

STATUS OF UNOBLIGATED FUNDS

The table below displays actual and estimated unobligated balances of direct and reimbursable budget authority in each NASA account at the end of each fiscal year.

END OF YEAR UNOBLIGATED FUNDS SUMMARY BY APPROPRIATIONS ACCOUNT

Budget Authority ($ millions)	Unobligated Balances Sept. 30, 2023	Estimated Unobligated Balances Sept. 30, 2024	Estimated Unobligated Balances Sept. 30, 2025
Deep Space Exploration Systems	109	515	921
Space Technology	38	68	98
Space Operations	168	544	919
Science	703	856	1,009
Aeronautics	34	58	82
STEM Engagement	5	7	9
Safety, Security, and Mission Services	917	917	917
Construction and Environmental Compliance and Restoration	452	452	452
Working Capital Fund	43	17	-
Total NASA	**2,469**	**3,434**	**4,407**

**Totals may not add due to rounding*

REIMBURSABLE ESTIMATES

Reimbursable agreements are agreements where the NASA costs associated with the undertaking are borne by the non-NASA partner. NASA undertakes reimbursable agreements when it has equipment, facilities, and services that it can make available to others in a manner that does not interfere with NASA mission requirements. Reimbursable agreements are executed under various legal authorities including:

- National Aeronautics and Space Act of 1958, as amended [P.L. 85–568] - Space Act Agreements (SAAs) and Enhanced Use Leasing (EUL) authority [incorporated through P.L. 108-7].
- Commercial Space Launch Act [P.L. 98-575] – authority to outsource the use of its launching facilities and services to private companies.
- National Historic Preservation Act (NHPA) [P.L. 89-665] – leasing authority for historic property.
- Government Employees Training Act [P. L. 85-507] – authority to conduct employee training for other government organizations.
- Economy Act [P.L. 31–15359] – authority for agencies to obtain supplies or services from another agency.

The agreements are transacted in three accounts (Safety, Security, and Mission Services [SSMS]; Construction and Environmental Compliance and Restoration [CECR]; and Office of Inspector General [OIG]). Most of the work is managed by a specific NASA center and performed by the relevant mission directorate or office program at the center (i.e., Aeronautics, Human Exploration and Operations, Exploration Technology, Mission Support, Office of STEM Engagement, and Office of Inspector General). Examples include the use of NASA-operated wind tunnel test facilities and rocket test stand facilities by other government agencies or private sector users. Some larger agreements and those that involve multiple centers or mission directorates are managed by NASA HQ. For example, NASA serves as the acquisition agent for the GOES series of satellites operated by NOAA.

The table below presents the budget authority for NASA's reimbursable work. As most reimbursable requests to NASA do not occur until the year of execution, the FY 2024 and FY 2025 estimates are based on anticipated reimbursable agreements reported by NASA HQ and centers.

REIMBURSABLE BUDGET AUTHORITY BY APPROPRIATIONS ACCOUNT

($ millions)	Actual FY 2023	Estimate FY 2024	Request FY 2025
Safety, Security, and Mission Services (including NHPA)	1,741	3,327	3,279
Construction and Environmental Compliance and Restoration (including EUL)	23	43	44
Office of Inspector General	1	-	-
Total	**1,765**	**3,370**	**3,323**

ENHANCED USE LEASING

In 2003, Congress authorized NASA to enter into leasing arrangements at two centers. In 2007 and 2008, Congress expanded that authority such that NASA may enter into Enhanced Use Leasing (EUL) arrangements at all centers. EUL revenues help NASA maintain critical facilities and address deferred maintenance challenges as well as support centers' revitalization plans. Additionally, NASA's EUL authority enhances important relationships with industry, academia, and non-profit organizations.

NASA's EUL authority expired without an extension on December 31, 2021, pursuant to the "sunset" provision in 51 U.S.C. 20145(g). However, Title III of Division B of the FY 2023 Omnibus Appropriations Act extends the existing EUL authority through December 31, 2032.

After deducting the costs of administering the leases, NASA centers are permitted to retain 65 percent of net receipt revenue. The balances are made available to NASA for use agency wide. These funds are in addition to annual appropriations. The table below depicts the estimated FY 2025 EUL expenses and revenues. The amounts identified under Capital Asset Account Expenditures may be adjusted between projects listed based on actual contract award. There are no civil servants funded from EUL income.

SUMMARY OF PROJECTED FY 2025 EUL ACTIVITY

FY2025 EUL Expenses and Revenues ($ Whole Dollars)	ARC	GRC	GSFC	JPL(NMO)	MSFC	SSC	KSC	JSC	Agency	Total
Base Rent	12,942,927	34,661	1,852,300	113	2,213,424	5,009,955	7,027,769	-	3,745,000	32,826,148
Institutional Support Costs (AAI, ISP, Shared Center Support Costs)	592,953	6,606	268,600	-	2,501,958	697,242	1,605,259	-	-	5,672,618
Lease Management and Administration	-	-	9,500	-	191,007	-	50,000	-	-	250,507
Operations and Maintenance Included in Lease NOT AS a DEMAND SERVICE	849,832	10,900	-	-	126,453	15,000	4,380,577	-	-	5,382,762
Total Estimated Lease Collections (N + E Funds Lease Project Code) - Program Year 2025	**14,385,712**	**52,167**	**2,130,400**	**113**	**5,032,842**	**5,722,197**	**13,063,605**	**-**	**3,745,000**	**44,132,035**
Estimated Lease Costs										
Institutional Support Costs (AAI, ISP, Shared Center Support Costs)	-592,953	-6,606	-286,600	-	-2,501,958	-779,825	-1,605,259	-	-	-5,773,201
Lease Management and Administration	-1,773,200	-	-	-23	-191,007	-	-50,000	-	-	-2,014,229
Operations and Maintenance Included in Lease NOT AS a DEMAND SERVICE	-	-10,900	-	-	-	-15,000	-	-	-	-25,900
	-849,832	-	-	-	-126,453	-15,000	-4,380,577	-	-1,500,000	-6,871,862
Total Estimated Cost Associated with Leases (N Fund) - Program Year 2025	**-3,215,985**	**-17,506**	**-286,600**	**-23**	**-2,819,418**	**-809,825**	**-6,035,836**	**-**	**-1,500,000**	**-14,685,192**
Estimated Net Proceeds from Lease Activity (E Fund) - Program Year 2025	**11,169,727**	**34,661**	**1,843,800**	**90**	**2,213,424**	**4,912,372**	**7,027,769**	**-**	**2,245,000**	**29,446,843**
Projected Balance, Capital Asset Account - Prior Program Years	**7,979,118**	**664,891**	**82**	**161,117**	**842,325**	**1,068,156**	**2,869,981**	**-**	**150,000**	**13,735,669**
Estimated Net Proceeds from Lease Activity Retained at Center - Program Year 2025	**7,260,323**	**22,530**	**1,198,470**	**59**	**1,438,726**	**3,193,042**	**4,568,050**	**-**	**9,305,926**	**26,987,124**
Total Estimated Available, Capital Assest Account - All Program Years	**15,239,440**	**687,420**	**1,198,552**	**161,176**	**2,281,050**	**4,261,198**	**7,438,031**	**-**	**9,455,926**	**40,722,793**
Planned Capital Projects for Net Proceeds for Fiscal Year 2024										
Maintenance and Repair, Various Buildings	-7,260,323	-	-	-	-	-4,000,000	-5,000,000	-	-	-16,260,323
Estimated Capital Asset Account (OSI Project Codes) Expenditures	**-7,260,323**	**-**	**-3,500**	**-**	**-**	**-4,000,000**	**-5,000,000**	**-**	**-**	**-16,263,823**
Estimated Capital Asset Account (OSI Project Codes) Ending Balance	**7,979,118**	**687,420**	**1,195,052**	**161,176**	**2,281,050**	**261,198**	**2,438,031**	**-**	**9,455,926**	**24,458,971**
Estimated In Kind Activity	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

ENHANCED USE LEASING

DEFINITIONS

Base Rent

Revenue collected from the tenant for rent of land or buildings lease.

Institutional Support Costs

Cost for institutional shared services, such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, as well as routine administrative support and management oversight (e.g., environmental).

Total Lease Income

Total gross proceeds from EUL activities including expenses due to renting NASA property.

In-Kind Activity

Consideration accepted in lieu of rent payment (only applies to selected leases signed prior to January 1, 2009).

Reimbursable Demand Services

Services, such as janitorial, communications, and maintenance, that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

NATIONAL HISTORIC PRESERVATION ACT

The National Historic Preservation Act (NHPA) 54 U.S.C. §306121-306122 provides NASA with the following authority.

§306121. Lease or exchange

(a) Authority To Lease or Exchange.-Notwithstanding any other provision of law, any federal agency after consultation with the Council [the Advisory Council on Historic Preservation], shall, to the extent practicable, establish and implement alternatives for historic properties, including adaptive use, that are not needed for current or projected agency purposes, and may lease an historic property owned by the agency to any person or organization, or exchange any property owned by the agency with comparable historic property, if the agency head determines that the lease or exchange will adequately insure the preservation of the historic property.

(b) Proceeds of Lease.-Notwithstanding any other provision of law, the proceeds of any lease under subsection (a) may, notwithstanding any other provision of law, be retained by the agency entering into such lease and used to defray the costs of administration, maintenance, repair, and related expenses incurred by the agency with respect to such property or other properties which are on the National Register which are owned by, or are under the jurisdiction or control of, such agency. Any surplus proceeds from such leases shall be deposited into the Treasury of the United States at the end of the second fiscal year following the fiscal year in which such proceeds were received.

§306122. Contracts for management of historic property

The head of any federal agency having responsibility for the management of any historic property may, after consultation with the Advisory Council on Historic Preservation, enter into contracts for the management of such property. The contract shall contain such terms and conditions as the head of such agency deems necessary or appropriate to protect the interests of the United States and insure adequate preservation of historic property.

In FY 2014, NASA established a program for leasing its historic properties based upon the NHPA authorities. Funds received from historic property leases are expended for the purposes of operating, maintaining, and managing the properties, or for authorized demolition or removal of buildings. Federal workforce costs associated with executing the leasing program are funded from annual appropriations, not leasing revenues.

The table below depicts the estimated amounts of anticipated NHPA expenses and revenues for FY 2025 for the use of several historic properties at ARC Moffett Field, CA and Building 925 and adjacent land at JSC Houston, TX. NASA currently expects total rental income of approximately $20.9 million. Of the $20.9 million in total rental income, approximately $8.6 million represents net revenue from lease activities. The net revenue amount of $8.6 million will be used for historic building maintenance and repairs at ARC and JSC starting in FY 2025.

NATIONAL HISTORIC PRESERVATION ACT

FY2025 NHPA Expenses and Revenues ($ Whole Dollars)	Ames Research Center	Johnson Space Center
Base Rent	4,917,019.0	4,219,988.0
Institutional Support Costs (AAI, ISP, Shared Center Support Costs)	10,832,981.0	270,079.0
Lease Management and Administration		40,000.0
Operations and Maintenance Included in Lease NOT AS a DEMAND SERVICE	-	710,810.0
Total Estimated Lease Collections (N Fund and E Fund Lease Project Code)	**15,750,000.0**	**5,240,877.0**
Institutional Support Costs (AAI, ISP, Shared Center Support Costs)	(10,832,981.0)	(270,079.0)
Lease Management and Administration	(530,500.0)	(40,000.0)
Operations and Maintenance Included in Lease NOT AS a DEMAND SERVICE	-	(710,810.0)
Total Estimated Cost Associated with Leases (N Fund)	**(11,363,481.0)**	**(1,020,889.0)**
Estimated Net Proceeds from Lease Activity (E Fund Lease Project Code)	**4,386,519.0**	**4,219,988.0**
Planned Capital Projects for Net Proceeds for Fiscal Year 2025		
Unobligated Proceeds Prior Years (as of 9/30/2025)	-	-
Deferred Maintenance for Buildings 2, 10, 15, 16, 17, 19, 20, 25, 26, N200, N226, N227, N234, N238 & N243		
Repair Replacement Water Mains and Sewer Lines Supporting Historic Facilities		
Renovate Building 25 to Conference Spaces, Phase 2 of 4		
Section 106 Consultation with SHPO		
Estimated Capital Asset Account Expenditures (E Fund OSI Projects)	-	-
Estimated Capital Asset Account Ending Balance (E Fund OSI Projects)	**4,386,519.0**	**4,219,988.0**
Estimated In Kind Activity	-	

DEFINITIONS

Base Rent

Revenue collected from the tenant for rent of land or buildings.

Institutional Support Costs

Cost for institutional shared services such as fire, security, first responder, communications, common grounds, road, and infrastructure maintenance, as well as routine administrative support and management oversight (e.g., environmental).

Reimbursable Demand Services

Services, such as janitorial, communications, and maintenance, that solely benefit the tenant and are provided for their convenience. There is no net income received by NASA, as these payments may only cover the costs of NASA and its vendors providing these services.

Total Rental Income

Total gross proceeds from NHPA activities including expenses due to renting NASA property.

BUDGET FOR SAFETY OVERSIGHT

The following table provides the safety oversight budget request. This includes the agency-wide surveillance functions as well as the project specific safety, reliability, maintainability, and quality assurance elements embedded within individual projects. NASA does not have a single safety oversight budget line item, but instead amounts are embedded in program, project, and mission support budgets.

BUDGET SUMMARY FOR SAFETY OVERSIGHT

Budget Authority ($ millions)	Actual FY 2023	Estimate FY 2024	Request FY 2025
Safety and Mission Assurance	51.9	49.8	48.1
Institutional Operational Safety	37.8	39.4	38.9
SMA Technical Authority	52.2	54.8	54.2
Agency-Wide Safety Oversight	**141.9**	**144.0**	**141.2**
Program Specific*	**300.0**	**300.0**	**300.0**
NASA Total, Safety**	**441.9**	**444.0**	**441.2**

* *Estimated values*

***Totals may not add due to rounding*

Agency-Wide Safety Oversight – Agency-level programs and activities that support the overarching NASA Safety and Mission Success program.

Safety and Mission Assurance – The Safety and Mission Assurance (S&MA) program administers and refines the pertinent policies, procedural requirements, and technical safety standards. The program participates in forums that provide advice to the administrator, mission directorates, program managers, and center directors who are ultimately accountable for the safety and mission success of all NASA programs, projects, and operations. The program's policy focuses on protecting the public, workforce, high-value property, and the terrestrial, orbital, and planetary environments from potential harm; assuring crew safety and mission success; and cultivating a robust Safety Culture that values and pursues technical and organizational excellence to understand and reduce risk. Notable S&MA managed programs include, but are not limited to, NASA's Orbital Debris program (measurements and modeling of orbital debris; characterizing the debris environment; mitigation standards development and review), the NASA Safety Center's S&MA Technical Excellence Program, and NASA's Electronic Parts Program. The budget for the Safety and Mission Assurance is part of the Agency Technical Authority (ATA) program under the Safety, Security, and Mission Services (SSMS) mission account.

Institutional Safety – NASA's Institutional Operational Safety program is driven by 29 CFR 1960, Basic Program Elements for Federal Employee Occupational Safety and Health Programs and Related Matters, NASA Procedural Requirement (NPR) 8715.1A, NASA Occupational Safety and Health Programs, and NPR 7900.3, Aircraft Operations Management Manual. The program includes: risk management, safety training, safety awareness, construction safety, the voluntary protection program, safety metrics and trend analysis, contractor insight/oversight, support to safety boards and committees, support to the emergency preparedness and fire safety programs, aviation safety, explosives and propellants safety, nuclear safety, radiation safety, confined space entry, fall protection, lifting devices, pressure vessel safety, hazard

BUDGET FOR SAFETY OVERSIGHT

reporting and abatement systems, cryogenic safety, electrical safety requirements (lock out/tag out), facility systems safety, institutional safety policy development, visitor and public safety, institutional safety engineering, and a mishap prevention program (including a reporting system and investigations). The Institutional Operational Safety program requires significant federal, state, and local coordination. The budget for Institutional Operational Safety is part of the Center Engineering, Safety, and Operations (CESO) program under the SSMS mission account.

S&MA Technical Authority – S&MA Technical Authority provides independent oversight of programs and projects in support of safety and mission success and is a key part of NASA's overall system of checks and balances. The S&MA Technical Authority program includes travel and labor only for all S&MA supervisors, branch chiefs, or above and designated deputies. In addition, where the principal job function of a non-supervisory S&MA person consists of rendering authoritative decisions on S&MA matters relating to the design or operation of a program or project, that person's salary is included. Often, these positions are the lead S&MA managers for large programs where the decision-making process is nearly a full-time demand. This category does not include salaries for individuals who only occasionally work on an authority task; however, the program budget does include travel funds in direct support of these tasks when needed. The budget for S&MA Technical Authority is part of the CESO program under the SSMS mission account.

Program Specific – Program specific S&MA costs are included in individual project budgets and are reflected in the table above using a rough order of magnitude estimate. These costs include the technical and management efforts of directing and controlling the safety and mission assurance elements of the project. This incorporates the design, development, review, and verification of practices and procedures and mission success criteria intended to assure that the delivered spacecraft, ground system, mission operation, or payload meets performance requirements and function for their intended lifetimes.

BUDGET FOR PUBLIC RELATIONS

The NASA budget for Communications is funded within the Safety, Security, and Mission Services account under Mission Services & Capabilities, Mission Enabling Services. These program activities include release of information and strategic communications through a variety of methods. They facilitate media engagement and connect NASA content directly to the public via digital platforms such as a streaming service, websites, and social media. Communications activities enable employees to be informed ambassadors of NASA. They provide accessible agency information and promote engagement between NASA staff and the public through domestic and international strategic outreach. Activities also include capture and preservation of agency history and historical archives and provision of services to manage technical libraries and Freedom of Information Act (FOIA) inquiries.

NASA COMMUNICATIONS BUDGET SUMMARY, BY CENTER

Budget Authority (in $ millions)	Actual	Estimate	Request
	FY 2023	FY 2024	FY 2025
ARC	3.4	3.4	3.4
AFRC	1.3	1.4	1.4
GRC	4.2	3.7	3.7
GSFC	5.8	5.9	5.9
HQ	19.0	36.1	33.8
JSC	9.9	4.2	4.2
KSC	9.3	7.8	7.8
LaRC	2.4	2.5	2.5
MSFC	5.0	5.9	5.9
SSC	1.9	1.4	1.4
NASA Total	**62.4**	**72.4**	**70.1**

The Office of Communications per baseline service level definition as part of the Safety, Security, and Mission Services Budget. Consolidation of enterprise managed services is disbursed to center locations based on annual requirements. Library services were added to the communications roles beginning in FY 2024.

**Totals may not add due to rounding*

CONSULTING SERVICES

NASA uses paid experts and consultants to provide advice and expertise beyond that which is available from its in-house civil service workforce. Management controls ensure that there is ample justification for consulting services before these services are obtained. Much of the agency's expert and consultant support is for the NASA Advisory Council and the Aerospace Safety Advisory Panel. NASA uses experts and consultants to provide expertise on the selection of experiments for future space missions. The use of these experts and consultants provides the agency with an independent view that promotes the selection of experiments likely to have the greatest scientific merit. Other individuals provide independent views of technical and functional problems to offer senior management a wide range of information to support decision-making. Historically, each mission directorate engages a few consultants to primarily support programmatic and Aerospace Safety Advisory Panel issues.

NASA CONSULTING SERVICES BUDGET SUMMARY

	Actual	Estimate	Request
(Cost in $ millions)	**FY 2023**	**FY 2024**	**FY 2025**
Number of Paid Experts and Consultants	38	38	38
Salaries	1.1	1.1	1.1
Benefits Costs	0.1	0.1	0.1
Travel Costs	0.2	0.2	0.2
Total Costs	**1.4**	**1.4**	**1.4**

FY 2023 are actual obligations. FY 2024 and FY 2025 are estimated Budget Authority.

A broader definition of consulting services could include the total of the Advisory and Assistance Services object class as shown in the Supporting Data - Budget by Object Class section of this volume. Advisory and Assistance Services includes: (1) Quality Control, Testing, & Inspection Services; (2) Management and Professional Support Services; (3) Studies, Analysis, & Evaluations; (4) Engineering and Technical Services; and (5) IT Services.

	Actual	Estimate	Request
(Cost in $ millions)	**FY 2023**	**FY 2024**	**FY 2025**
Quality Control, Testing & Inspection Services	62.7	61.2	61.1
Management and Professional Support Services	919.8	898.0	897.3
Studies, Analysis, & Evaluations	55.4	54.1	54.1
Engineering and Technical Services	11.5	11.2	11.2
IT Services	385.6	376.5	376.2
Total Costs, Advisory & Assistance Services	**1,435.0**	**1,400.9**	**1,399.9**

DEFINITIONS

Consultant - A person who can provide valuable and pertinent advice generally drawn from a high degree of broad administrative, professional, or technical knowledge or experience. When an agency requires public advisory participation, a consultant also may be a person who is affected by a particular program and can provide useful views from personal experience.

CONSULTING SERVICES

Expert - A person who is specially qualified by education and experience to perform difficult and challenging tasks in a particular field beyond the usual range of achievement of competent persons in that field. An expert is regarded by other persons in the field as an authority or practitioner of unusual competence and skill in a professional, scientific, technical, or other activity.

These definitions are located under 5 CFR 304.102. The appointments are made under 5 U.S.C. 3109, and the use of this authority is reported to Office of Personnel Management (OPM).

E-Gov Initiatives and Benefits

E-Government Funding Contributions and Service Fees by Initiative

NASA will provide funding contributions in FY 2025 for each of the following E-Government initiatives:

Initiative	2025 Contributions (Includes In-Kind) ($ in Dollars)	2025 Service Fees* ($ in Dollars)
E-Rulemaking	-	14,487
Grants.gov	144,000	-
E-Training	-	1,583,625
Recruitment One-Stop	-	129,375
Enterprise HR Integration	-	357,500
E-Payroll	-	5,359,290
E-Travel	-	89,520
Integrated Award Environment (IAE)	-	519,508
Financial Management LoB	124,236	-
Human Resources Management LoB	68,478	-
Geospatial LoB	225,000	-
Budget Formulation and Execution LoB	130,000	-
Federal Audit Clearinghouse LoB	42,251	
Federal PKI Bridge	-	183,349
Performance Management LoB	100,000	-
Consolidated Appropriations Act of 2023	484,292	-
Lead Agency Coordination Request System	6,516	
NASA Total	**1,324,773**	**8,236,654**

**Service fees are estimates as provided by the E-Government initiative Managing Partners*

After submission of the budget, NASA will post FY 2025 Exhibit 300 IT business cases on the IT Dashboard located at: https://www.itdashboard.gov

The E-Government initiatives serve citizens, businesses, and federal employees by delivering high-quality services more efficiently at a lower price. Instead of expensive "stove-piped" operations, agencies work together to develop common solutions that achieve mission requirements at a reduced cost, which makes resources available for higher priority needs. Benefits realized by NASA through these initiatives in FY 2025 are described below:

e-Rulemaking (Managing Partner EPA) FY 2025 Benefits

NASA has benefited from the e-Rulemaking initiative by being able to better provide the public with one-stop access to the agency's information on rulemakings and non-rulemaking activities via the Regulations.gov website (see: https://www.regulations.gov/).

NASA uses the Federal Docket Management System (FDMS) to post its rulemakings so that the public can gain access to review and comment on these rulemakings. NASA relies on Regulations.gov to retrieve public comments on its rulemakings. NASA's use of the FDMS and Regulations.gov substantially improves the transparency of its rulemaking actions and increases public participation in the regulatory process. Direct budget cost savings and cost avoidance has resulted from the FDMS and Regulations.gov.

E-GOV INITIATIVES AND BENEFITS

Grants.gov (Managing Partner HHS) FY 2025 Benefits

In addition to the federal requirement for all grant-issuing agencies to, at a minimum, post a synopsis of all new grant and cooperative agreement funding opportunities to Grants.gov (see: https://www.grants.gov/), the Grants.gov initiative benefits NASA and its grant programs by providing a single location with broader exposure to publish grant and cooperative agreement funding opportunities and application packages. Posting internally, NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES), as well as externally (e.g., Grants.gov), makes the process easier for applicants to apply for funding with multiple agencies. All 26 major federal grant-making agencies post 100 percent of their synopses for discretionary funding opportunity announcements on Grants.gov.

In addition, Grants.gov provides a single site for the grantee community to apply for grants using a standard set of forms, processes, and systems. This gives grantees greater access and ability to apply for federal funding. Through the continued use of Grants.gov, NASA can reduce operating costs associated with online grant posting and application evaluation. Additionally, the agency is able to improve operational effectiveness through the use of Grants.gov by increasing data accuracy and reducing processing cycle times.

e-Training (Managing Partner OPM) FY 2025 Benefits

The e-Training initiative provides access to premier electronic training systems and tools that support the training and development of the federal workforce. The initiative supports agency missions through efficient one-stop access to e-Training products and services. The availability of an electronic training environment enhances the ability of the federal government and NASA to attract, retain, manage, and develop highly skilled professionals needed for a flexible and high-performing government workforce.

The e-Training initiative benefits NASA by reducing redundancies and achieving economies of scale in the purchase, development, and deployment of e-learning content and in the management of learning technology infrastructure. This initiative allows NASA to remain in a positive security posture by allowing access to applications based upon completed required trainings and real-time integrations with our identity and credential access management systems. The System for Administration, Training, and Educational Resources at NASA (SATERN) is a Web-based talent management tool that serves as NASA's training system of record for over 100,000 active civil servants and contractor accounts tracked within the system. This centralized approach allows NASA to reduce and leverage training costs by eliminating unique systems, standardizing training processes, and maintaining valid data across the agency. In 2018, NASA migrated SATERN to a software as a service (SaaS) cloud hosted solution.

Through SATERN, employees can view required training, launch online content, view training history, and self-register for approved courses and conferences. In addition, the system allows NASA officials to identify groups and individuals who have not met basic training requirements and ensure accountability for mission-critical and federally-mandated training and development. SATERN also offers employees access to career planning tools, individual development plans, and competency management assistance. Currently, SATERN offers learners access to almost 3,000 online courses and more than 10,000 online courses, books, and training videos via our partnership with SkillSoft and/or Percipio. We are also working with other entity partnerships to enhance the overall learning experience and provide more learning opportunities. SATERN is available at all times and can be accessed from work, home, or via approved mobile devices.

E-GOV INITIATIVES AND BENEFITS

Recruitment One-Stop (Managing Partner OPM) FY 2025 Benefits

USAJOBS simplifies the federal job search process for job seekers and agencies. The USAJOBS.gov website (see: https://www.usajobs.gov/) provides a place where citizens can search for employment opportunities throughout the federal government. Through USAJOBS.gov, users have access to:

- A centralized repository for all competitive service job vacancies;
- Job vacancies;
- A resume repository used by agencies to identify critical skills;
- A standardized online recruitment tool and services;
- A standard application process; and
- Intuitive job searches including e-mail notifications for jobs of interest.

Integration with Recruitment One-Stop allows NASA to better attract individuals who can accomplish the agency's mission. The USAJOBS interface allows job-seekers to view and apply for all NASA employment opportunities, as well as those from other federal agencies.

In 2005, NASA adopted the USAJOBS resume as the basic application document for all NASA positions, except for astronaut positions. To date NASA has not identified any specific savings, either in terms of budgeted savings or cost avoidance. Although the agency believes that implementation of Recruitment One-Stop has resulted in significant intangible benefits in terms of providing better vacancy information to applicants, it has not resulted in any specific cost savings to NASA. The numerous intangible benefits Recruitment One-Stop provides to NASA and other agencies include:

- Decreasing hiring time for managers;
- Providing an integrated solution to agency applicant assessment systems;
- Providing a cost-effective marketing and recruitment tool;
- Realizing cost savings over commercial job posting boards;
- Reducing the delay associated with filling critical agency vacancies; and
- Enhancing competition with the private sector for the best and brightest talent for federal service.

Enterprise HR Integration (Managing Partner OPM) FY 2025 Benefits

The Enterprise HR Integration (EHRI) Program supports the strategic management of human capital by providing agency customers access to timely and accurate federal workforce data. In support of this objective, EHRI has the following goals: 1) streamline and automate the exchange of federal employee human resources (HR) information government wide; 2) provide comprehensive knowledge management and workforce analysis, forecasting, and reporting across the Executive Branch; 3) maximize cost savings captured through automation; and 4) enhance retirement processing throughout Executive Branch.

A key initiative of EHRI is the electronic Official Personnel Folder (eOPF), a Web-based application capable of storing, processing, and displaying the OPFs of all current, separated, and retired federal employees. Specific EHRI/eOPF benefits to NASA include: improved convenience in searching for information, better security and safety for electronic files, decreased costs, streamlined business processes, and the ability to have a central repository of OPF records for the agency. NASA deployed the eOPF capability of electronic transfer of eOPFs between agencies in FY 2010. Specific NASA employee benefits include secure online access to OPFs, automatic notification when documents are added, exchange of retirement and HR data across agencies and systems, and the elimination of duplicate and repetitive personnel data in personnel folders. NASA completed its implementation to eOPF in March 2008, and transitioned personnel actions processing to the NASA Shared Service Center (NSSC).

E-GOV INITIATIVES AND BENEFITS

E-Payroll FY 2025 Benefits

The E-Payroll Initiative standardizes and consolidates government-wide federal civilian payroll services and processes by simplifying and standardizing HR/payroll policies and procedures and better integrating payroll, HR, and finance functions. Since 2004, the Department of Interior (DOI) has served as NASA's payroll provider. DOI's system (i.e., Federal Personnel and Payroll System [FPPS]) processes NASA's HR and Payroll transactions and supplies all key delivery aspects of its payroll operation functions. The E-Payroll Initiative benefits NASA by permitting the agency to focus on its mission-related activities rather than on administrative payroll functions. Payroll processing costs are reduced through economies of scale and avoid the cost of duplicative capital system modernization activities. The initiative also promotes standardization of business processes and practices and unified service delivery. NASA continues to work closely with DOI to pilot innovative solutions such as Robotic Process Automation to realize cost savings and more modern data connections to more reliably exchange our HR data.

E-Travel (Managing Partner GSA) FY 2025 Benefits

NASA completed migration of its travel services to Electronic Government Travel System 2 (ETS2) - Concur Government Edition (CGE) (formerly HP Enterprise Services [FedTraveler]). Completed in 2014, this migration has allowed NASA to provide more efficient and effective travel management services. ETS2 is a streamlined, adaptable, world-class travel management service that continually applies commercial best practices to realize travel efficiencies and deliver a transparent, accountable, and sustainable service that yields exceptional customer satisfaction.

Integrated Award Environment (Managing Partner GSA) FY 2025 Benefits

The Integrated Award Environment (IAE) initiative is designed to support a common, secure business environment which facilitates and supports the cost-effective acquisition of and payment for goods and services; resulting in effective management of federal acquisition and assistance awards, and consistent transparency into federal awards. The IAE services enable NASA to do business with industry, whether it is through contracts, grants, or loans, in a smart, streamlined, and shared services platform. Services range from entity management, pre-award, post award, and common services (e.g., data governance, security, hosting, help desk, single sign-on, and search). Use of the IAE common services allows agencies to focus on specific needs (e.g., strategy, operations, and management), while leveraging shared services for common functions. Furthermore, use of a government-wide business-focused service environment reduces funding and resources for technical services and support for acquisition systems originally housed by individual agencies.

Through adoption of the tools and services provided by IAE, NASA improves its ability to make informed and efficient purchasing decisions and allows it to replace manual processes. If NASA did not use IAE systems, the Agency would need to build and maintain separate systems to record vendor and contract information and to post procurement opportunities. Agency purchasing officials would not have access to databases of important information from other agencies on vendor performance and could not use systems to replace paper-based and labor-intensive work efforts.

E-GOV INITIATIVES AND BENEFITS

Integrated Award and Environment – Loans & Grants FY 2025 Benefits

All agencies participating in the posting and/or awarding of Contracts and Loans & Grants are required by the Federal Funding Accountability and Transparency Act (FFATA) of 2006 and the Digital Accountability and Transparency Act of 2014 (DATA Act) reporting requirements to disclose award information on a publicly accessible website. On December 14, 2007, the Office of Management and Budget (OMB) launched USASpending.gov (see: http://www.USASpending.gov) to meet the FFATA statutory requirements. NASA analyzes the past and present total funding amounts of each proposing entity, as well as its total number of awards to assist in assessing each grant proposer's risk level and score during the 2 Code of Federal Regulations (CFR) 200 required pre-award risk assessment process. This information is submitted and housed in USASpending.gov by funding agency. Understanding the total dollar amounts managed and the number of awards provides insight on a proposer's experience with managing federal funds.

Federal PKI Bridge - FY 2025 Benefits

The Federal Public Key Infrastructure (FPKI) is the primary, secure mechanism that allows for electronic business transactions across government and between government and industry. It is the backbone and trust anchor for HSPD-12 and PIV cards and is critical to enabling cyber security via identity management. The FPKI enables secure physical and logical access using strong credentials, such as the PIV card, and allows NASA documents to be digitally signed, sent, encrypted, and archived in digital media without fear that they will be compromised, spoofed, or altered. A number of core government-wide documents mandate NASA's use of the FPKI.

LINES OF BUSINESS (LOB)

Financial Management (FM) LoB (Managing Partners DOE and DOL) FY 2025 Benefits

NASA's contribution to the FM LoB supports efforts to transform federal financial management, reduce costs, increase transparency, and improve delivery of agencies' missions by operating at scale, relying on common standards and shared services, and using state-of-the-art technology. NASA benefits from the FM LoB because it provides a forum in which federal agencies can share information and weigh pros and cons of various initiatives (e.g., shared services). A shared services solution may be an alternative considered by NASA as part of its financial system improvements.

Human Resources Management LoB (Managing Partner OPM) FY 2025 Benefits

The HR LoB vision is to create government-wide, modern, cost-effective, standardized, and interoperable HR solutions to provide common core functionality to support the strategic management of Human Resources through the establishment of SSCs.

NASA works in partnership with one of the approved service providers, the Department of Interior's Business Center (IBC). Through this partnership, NASA shares and receives "best-in-class" HR solutions. The IBC delivers NASA-developed solutions to their customer agencies, enabling improved efficiencies and system integrations at a fraction of the cost and delivery time of similar solutions that could have been produced by the Interior Business Center. NASA achieves the benefits of "best- in-class" HR solutions through the implementation and integration of IBC and NASA-developed HR solutions. NASA's participation in the HR LoB provides the agency opportunities to implement modern HR solutions and benefit from government-wide strategic HR management best practices. NASA participates in the ongoing development of a 10-year Federal Human Resources Strategic Plan and government-wide data standards with the HR LoB managing partner (OPM) and member agencies.

Geospatial LoB (Managing Partner DOI) FY 2025 Benefits

The Geospatial LoB was sunset when OMB released the Federal IT Shared Services Strategy in 2012. However, NASA continues to be active in the Federal Geographic Data Committee (FGDC) and supports FGDC standards wherever applicable. NASA also continues to provide support and data to the Geoplatform and supports three National Geospatial Data Assets in partnership with USGS.

Budget Formulation & Execution LoB (Managing Partner Education) FY 2025 Benefits

The Budget Formulation and Execution LoB (BFELoB) provides significant benefits to NASA and other partner agencies by encouraging best practices crossing all aspects of federal budgeting – from budget formulation to execution to performance to human capital needs. To benefit all agencies, BFELoB continues to support the idea of shared service budget systems. As NASA currently has its own budgeting tools, the agency has not chosen to move to a new budget system; however, a shared service budget system is an option in the future.

Performance Management LoB (Managing Partner GSA) FY2025 Benefits

Performance Management develops government-wide performance management capabilities to help meet the requirements of the Government Performance and Results Modernization Act of 2010 (GRPAMA), and support government-wide performance management efforts.

Lead Agency Coordination Request (LACR) system LoB FY 2025 Benefits

The FY 2025 Budget will initiate the collection of funds from agencies to support the launch and maintenance of the LACR system, which will serve as the official workflow management system of the Interagency Suspension and Debarment Committee (ISDC). The LACR will help the ISDC meet its statutory responsibility pursuant to section 873 of P.L. 110-417 to coordinate suspension and debarment actions among agencies when two or more agencies may have an interest in initiating suspension and debarment proceedings pertaining to the same contractor or recipient. The new system will resolve cybersecurity risks associated with the ISDC's current collaboration process and provide added administrative efficiencies.

COMPARABILITY ADJUSTMENT TABLES

FY 2023 Budget Structure Crosswalk to FY 2025 Budget Structure Budget Authority ($ in millions)	FY 2023 Structure	FY 2025 Structure
NASA TOTAL	**$25,383.7**	**$25,383.7**
Deep Space Exploration Systems	**$7,447.6**	**$7,447.6**
Common Exploration Systems Development (renamed Moon to Mars Transportation System)	**$4,716.6**	**$4,716.6**
Artemis Campaign Development (renamed Moon To Mars Lunar Systems Development)	**$2,542.4**	**$2,630.5**
Gateway	$779.2	$779.2
Advanced Exploration Systems		$140.3
Adv Cislunar and Surface Capabilities	$52.2	
xEVA and Human Surface Mobility Program	$324.9	$324.9
Human Landing System	$1,386.1	$1,386.1
Human Exp Requirements & Architecture	**$48.3**	**$100.5**
Moon & Mars Architecture (renamed Strategy and Architecture)	$48.3	$48.3
Future Systems		$52.2
Adv Cislunar and Surface Capabilities		*$52.2*
Mars Campaign Development	**$140.3**	
Exploration Capabilities	$140.3	
Advanced Exploration Systems	*$140.3*	
Space Operations	**$4,266.7**	**$4,266.7**
Space Technology	**$1,193.0**	**$1,193.0**
Space Technology	**$1,193.0**	**$1,193.0**
Early Stage Innovation and Partnerships	$122.0	$122.0
Technology Maturation	$323.9	$323.9
Technology Demonstration	$515.4	$515.4
Restore & SPIDER (OSAM-1)	*$227.0*	*$227.0*
Solar Electric Propulsion (SEP)	*$18.5*	*$18.5*
Nuclear Propulsion		*$91.3*
Nuclear Electric Propulsion		$1.3
Nuclear Thermal Propulsion		$90.0
Small Spacecraft, Flight Opportunities & Other Tech Demo	*$269.9*	*$178.6*
Nuclear Electric Propulsion	$1.3	
Nuclear Thermal Propulsion	$90.0	
SBIR and STTR	$231.7	$231.7
Science	**$7,791.5**	**$7,791.5**
Earth Science	**$2,194.0**	**$2,175.0**
Earth Science Research	$502.0	$502.0
Earth Systematic Missions	$915.0	$915.0
GRACE-Continuity		*$166.8*
GRACE-Continuity		$166.8
Surface Water and Ocean Topography	*$20.1*	
NASA-ISRO SAR	*$93.5*	*$93.5*
Sentinel-6	*$40.3*	*$40.3*
PACE	*$112.8*	*$112.8*
Other Missions and Data Analysis	*$648.3*	*$501.6*
Mass Change	$166.8	
Surface Water and Ocean Topography Missi		$20.1

COMPARABILITY ADJUSTMENT TABLES

FY 2023 Budget Structure Crosswalk to FY 2025 Budget Structure Budget Authority ($ in millions)	FY 2023 Structure	FY 2025 Structure
Earth System Explorers	$2.5	$2.5
Responsive Science Initiatives		$55.0
Other Missions and Data Analysis		*$55.0*
Commercial Satellite Data Acquisition		$55.0
Earth System Science Pathfinder	$232.1	$232.1
MAIA	*$10.6*	
GeoCarb	*$20.0*	
Venture Class Missions	*$150.7*	*$161.2*
Multi-Angle Imager for Aerosols		$10.6
Other Missions and Data Analysis	*$50.9*	*$70.9*
GeoCarb		$20.0
Earth Science Data Systems	$365.1	$291.1
Earth Science Data Systems (ESDS)	*$365.1*	*$291.1*
Commercial SmallSat Data Acquisition	$55.0	
Open Source Science	$19.0	
Earth Science Technology	$102.2	$102.2
Applied Sciences	$75.2	$75.2
Planetary Science	**$3,197.5**	**$3,216.5**
Planetary Science Research	$291.6	$310.6
Planetary Science Research and Analysis	*$205.1*	*$205.1*
Other Missions and Data Analysis	*$86.5*	*$105.5*
Open Source Science		$19.0
Planetary Defense	$135.5	$135.5
Lunar Discovery and Exploration	$486.3	$486.3
Mars Sample Return	$818.8	$818.8
Discovery	$217.5	$217.5
DAVINCI	*$20.2*	*$20.2*
VERITAS	*$9.5*	*$9.5*
Psyche	*$109.3*	
Other Missions and Data Analysis	*$78.4*	*$187.7*
Psyche		$109.3
New Frontiers	$488.2	$488.2
Mars Exploration	$248.1	$248.1
Outer Planets and Ocean Worlds	$356.8	$356.8
Jupiter Europa (renamed Europa Clipper)	*$345.0*	*$345.0*
Other Missions and Data Analysis	*$11.8*	*$11.8*
Radioisotope Power	$154.9	$154.9
Astrophysics	**$1,510.0**	**$1,510.0**
Astrophysics Research	$284.8	$284.8
Cosmic Origins	$314.8	$314.8
Physics of the Cosmos	$180.7	$180.7
Exoplanet Exploration	$502.9	$502.9
Astrophysics Explorer	$226.8	$226.8
SPHEREx	*$81.6*	*$81.6*
Compton Spectrometer and Imager (COSI)		*$36.5*
Other Missions and Data Analysis	*$145.2*	*$108.7*
Compton Spectrometer and Imager	$36.5	

COMPARABILITY ADJUSTMENT TABLES

FY 2023 Budget Structure Crosswalk to FY 2025 Budget Structure Budget Authority ($ in millions)	FY 2023 Structure	FY 2025 Structure
Heliophysics	**$805.0**	**$805.0**
Heliophysics Research	$238.2	$238.2
Living with a Star	$155.2	$155.2
Solar Terrestrial Probes	$198.0	$198.0
Heliophysics Explorer Program	$167.9	$167.9
HelioSwarm		*$10.9*
Multi-Slit Solar Explorer		*$39.5*
Other Missions and Data Analysis	*$167.9*	*$117.5*
HelioSwarm	$10.9	
Multi-slit Solar Explorer	$39.5	
Heliophysics Technology	$19.9	$19.9
Space Weather	$25.8	$25.8
Biological and Physical Sciences	**$85.0**	**$85.0**
Aeronautics	**$935.0**	**$935.0**
STEM Engagement	**$143.5**	**$143.5**
Safety, Security, and Mission Services	**$3,136.5**	**$3,136.5**
Construction & Envrmtl Compl Restoration	**$422.4**	**$422.4**
Inspector General	**$47.6**	**$47.6**
NASA TOTAL	**$25,383.7**	**$25,383.7**

COMPARABILITY ADJUSTMENT TABLES

FY 2024 Budget Structure Crosswalk to FY 2025 Budget Structure Budget Authority ($ in millions)	FY 2024 Structure	FY 2025 Structure
NASA TOTAL	**$27,185.0**	**$27,185.0**
Deep Space Exploration Systems	**$7,971.1**	**$7,971.1**
Common Exploration Systems Development (renamed Moon to Mars Transportation System)	**$4,525.4**	**$4,525.4**
Artemis Campaign Development (renamed Moon To Mars Lunar Systems Development)	**$3,234.8**	**$3,336.3**
Gateway	$914.2	$914.2
Advanced Exploration Systems		$161.8
Adv Cislunar and Surface Capabilities	$60.3	
xEVA and Human Surface Mobility Program	$379.9	$379.9
Human Landing System	$1,880.5	$1,880.5
Human Exp Requirements & Architecture	**$49.1**	**$109.3**
Future Systems		$60.3
Adv Cislunar and Surface Capabilities		*$60.3*
Moon & Mars Architecture	$49.1	$49.1
Mars Campaign Development	**$161.8**	
Exploration Capabilities	$161.8	
Advanced Exploration Systems	*$161.8*	
Space Operations	**$4,534.6**	**$4,534.6**
Space Technology	**$1,391.6**	**$1,391.6**
Science	**$8,260.8**	**$8,260.8**
Earth Science	**$2,472.8**	**$2,442.8**
Earth Science Research	$577.9	$577.9
Earth Systematic Missions	$1,027.1	$1,027.1
GRACE-Continuity		*$35.5*
NASA-ISRO SAR	*$96.4*	*$96.4*
Sentinel-6	*$63.9*	*$63.9*
PACE	*$91.4*	*$91.4*
Other Missions and Data Analysis	*$775.5*	*$740.0*
Mass Change	$35.5	
Earth System Explorers	$27.8	$27.8
Responsive Science Initiatives		$65.0
Other Missions and Data Analysis		*$65.0*
Commercial Satellite Data Acquisition		$65.0
Earth System Science Pathfinder	$235.6	$235.6
Earth Science Data Systems	$411.7	$316.7
Earth Science Data Systems (ESDS)	*$411.7*	*$316.7*
Commercial SmallSat Data Acquisition	$65.0	
Open Source Science	$30.0	
Earth Science Technology	$105.3	$105.3
Applied Sciences	$87.3	$87.3
Planetary Science	**$3,383.2**	**$3,413.2**
Planetary Science Research	$307.4	$337.4
Planetary Science Research and Analysis	*$224.6*	*$224.6*
Other Missions and Data Analysis	*$82.8*	*$112.8*
Open Source Science		$30.0
Planetary Defense	$250.7	$250.7
Lunar Discovery and Exploration	$458.5	$458.5
Mars Sample Return	$949.3	$949.3

COMPARABILITY ADJUSTMENT TABLES

FY 2024 Budget Structure Crosswalk to FY 2025 Budget Structure Budget Authority ($ in millions)	FY 2024 Structure	FY 2025 Structure
Discovery	$247.5	$247.5
DAVINCI	*$55.8*	*$55.8*
VERITAS	*$1.5*	*$1.5*
Psyche	*$57.7*	
Other Missions and Data Analysis	*$132.5*	*$190.2*
Psyche		$57.7
New Frontiers	$407.5	$407.5
Mars Exploration	$268.6	$268.6
Outer Planets and Ocean Worlds	$318.4	$318.4
Radioisotope Power	$175.5	$175.5
Astrophysics	**$1,557.4**	**$1,557.4**
Heliophysics	**$750.9**	**$750.9**
Biological and Physical Sciences	**$96.5**	**$96.5**
Aeronautics	**$995.8**	**$995.8**
STEM Engagement	**$157.8**	**$157.8**
Safety, Security, and Mission Services	**$3,369.4**	**$3,369.4**
Construction & Envrmtl Compl Restoration	**$453.7**	**$453.7**
Inspector General	**$50.2**	**$50.2**
NASA TOTAL	**$27,185.0**	**$27,185.0**

RE-BASELINED PROJECTS

FY 2025 Congressional Justification

Original Agency Baseline Commitments vs. Re-baseline Life Cycle Calculation Section

As part of the NASA Corrective Action Plan related to the Government Accountability Office (GAO) High Risk List, re-baselined projects are reported periodically to Congress, GAO, and the Office of Management and Budget (OMB). For projects that have been re-baselined due to performance (vice scope change), and for transparency purposes, NASA includes original cost and schedule Agency Baseline Commitments (ABCs) in quarterly, semi-annual, and annual external cost and schedule reports alongside the current re-baselined LCCs.

Low Boom Flight Demonstration	Date	Prior	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	BTC	Total
Original Life Cycle Cost	2018	489	75	14	4	-	-	-	-	-	-	**582**
Rebaselined Life Cycle Cost	2024	530	93	51	43	71	44	6	-	-	-	**839**

NISAR	Date	Prior	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	BTC	Total
Original Life Cycle Cost	2016	714	84	25	21	16	-	-	-	-	7	**867**
Rebaselined Life Cycle Cost	2022	825	62	80	93	25	21	12	-	-	-	**1,118**

On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1)	Date	Prior	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	BTC	Total
Original Life Cycle Cost	2020	1,040	227	227	177	83	-	-	-	-	25	**1,780**
Rebaselined Life Cycle Cost	2022	1,040	227	227	227	175	123	29	-	-	-	**2,047**

Orion	Date	Prior	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	BTC	Total
Original Life Cycle Cost	2015	10,869	293	121	-	-	-	-	-	-	-	**11,283**
Rebaselined Life Cycle Cost	2021	12,351	809	404	156	92	-	-	-	-	-	**13,811**

Solar Electric Propulsion (SEP)	Date	Prior	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	BTC	Total
Original Life Cycle Cost	2019	295	25	9	6	-	-	-	-	-	-	**336**
Rebaselined Life Cycle Cost	2021	280	29	21	22	20	11	-	-	-	-	**382**

Dollars in Millions

BTC: Budget To Complete

**Note: The Low Boom Flight Demonstrator (LBFD) has recently been re-baselined and is currently pending reauthorization by Congress.*

*** Re-baselined LCCs don't necessarily align with the budget request contained in this document.*

COST AND SCHEDULE PERFORMANCE SUMMARY

2024 Major Program Annual Report Summary

The 2024 Major Program Annual Report (MPAR) is provided to meet the requirements of Section 103 of the NASA Authorization Act of 2005 (P.L. 109-155). The 2024 MPAR consists of this summary and FY 2025 Congressional Justification pages designated as “Projects in Development” for the projects outlined below. These project pages constitute each project’s annual report or, if this is the first year for which it is reporting, the baseline report. The MPAR summary also includes the confidence level of achieving the commitments as requested in the Conference Report accompanying the FY 2010 Consolidated Appropriations Act (P.L. 111-117).

Changes in MPAR Composition since the FY 2024 NASA Budget Estimates

There are three new projects, Human Landing System (HLS) Initial Capability, Gateway Initial Capability, and Space Launch System (SLS) Block 1B, with an estimated lifecycle cost greater than $250 million that received authority to proceed into development since NASA submitted its 2023 MPAR in the FY 2024 NASA Congressional Justification. There is one project, Psyche, that has completed reporting since the previous report.

1. The Psyche project successfully launched on October 13, 2023.
2. The HLS Initial Capability was approved with a baseline development cost of $2,339 million and a baseline schedule milestone of Lunar Orbit Checkout Review (LOCR) in February 2028 at a joint confidence level of 70 percent. The agency’s Artemis III launch planning date is September 2026; detailed program schedule-level updates for Artemis III dates are in work.
3. Gateway Initial Capability was approved with a baseline development cost of $3,562 million and a baseline schedule milestone of Launch Readiness Date (LRD) in December 2027 at a joint confidence level of 70 percent.
4. The SLS-Block-1B was approved with a baseline development cost of $3,674 million and a baseline schedule milestone of Design Certification Review (DCR) in January 2028 at a joint confidence level of 70 percent. The agency’s Artemis IV launch planning date is September 2028; detailed program schedule-level updates for Artemis IV dates are in work.

Changes in Development Cost and Schedule Estimates from the 2023 MPAR

The Low Boom Flight Demonstrator (LBFD) project has been rebaselined with a revised development cost of $709.2 million and a new milestone date of First Flight in October 2024. A follow-on cost and schedule analysis has been submitted to Congress.

The On-orbit Servicing, Assembly, and Manufacturing-1 (OSAM-1) has undergone a continuation review, and NASA has notified the Congress that the agency has concluded that OSAM-1 will be cancelled, and an orderly closeout will be undertaken.

There are six projects with development cost increases/decreases and schedule changes since last year’s MPAR.

1. NASA-ISRO Syntehtic Aperture Radar (NISAR) development costs decreased two percent with no change in the launch date.

2. Orion development costs increased three percent with a 16-month delay in the Artemis II LRD date.
3. Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) development costs decreased by three percent with no change in the launch date. (Launched February 8, 2024).
4. Sentinel-6 development costs decreased by 10 percent with no change in the spacecraft B launch date.
5. Solar Electric Propulsion (SEP) development costs increased 10 percent with a three-month delay.
6. Volatiles Investigating Polar Exploration Rover (VIPER) development costs increased by one percent with no change in the launch date.

There are five projects that had no changes in their development cost or schedule estimates over the last year: Europa-Clipper, Interstellar Mapping and Acceleration Probe (IMAP), NEO-Surveyor, Roman, and Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx).

MPAR Summary Table

Table 1 provides cost, schedule, and confidence level information for NASA projects currently in development with lifecycle cost estimates of $250 million or more. The Base Year column is the calendar year when project was confirmed at KDP-C, or the year of any subsequent rebaseline. NASA records the estimated development cost and a key schedule milestone and then tracks changes from them. NASA tracks one of several key milestones, listed below, for reporting purposes:

- Initial Operating Capability (IOC);
- Full Operational Capability (FOC);
- Launch Readiness Date (LRD);
- Launch Readiness for Artemis II;
- Design Certification Review (DCR); or
- Lunar Orbit Checkout Review (LOCR).

As a note for clarification, LRD schedule milestones, as reported here, are not typically the launch dates on the NASA launch manifest but are the desired launch dates as determined by the payload mission and approved by the NASA Flight Planning Board (FPB). A launch manifest is a dynamic schedule that is affected by real world operational activities conducted by NASA and multiple other entities. It reflects the results of a complex process that requires the coordination and cooperation by multiple users for the use of launch range and launch contractor assets. The launch dates shown on the NASA FPB launch manifest are a mixture of confirmed range dates for missions launching within approximately six months and contractual/planning dates for the missions beyond six months from launch. The NASA FPB launch manifest date is typically earlier than the reported schedule dates reported here, thereby allowing for the operationally driven fluctuations to the launch schedule that may be outside of the project’s control. The NASA FPB launch manifest is updated on a periodic basis throughout the year.

Additional information on the projects shown in the table below can be found in their individual program and project pages.

COST AND SCHEDULE PERFORMANCE SUMMARY

Table 1: MPAR Summary and Confidence Levels

Project	Base Year [1]	JCL (%)	Development Cost Estimate ($M)		Cost Change (%)	Key Milestone Event	Key Milestone Date		Schedule Change (months)
			Baseline	FY 2024			Baseline	FY 2024	
Europa Clipper	2019	Not Avail [2]	2,412.8	2,509.0	4%	LRD	Sep 2025	Oct 2024	-11
Gateway IC	2023	70	3,562.0	3,562.0	0%	LRD	Dec 2027	Dec 2027	0
HLS IC	2023	70	2,339.0	2,339.0	0%	LOCR	Feb 2028	Feb 2028	0
IMAP	2021	70	589.5	589.5	0%	LRD	Dec 2025	Dec 2025	0
LBFD	2023 (2018)	Not Avail [3]	709.2	709.2	0%	First Flight	Oct 2024	Oct 2024	0
NEO Surveyor	2022	86	1,228.6	1,228.6	0%	LRD	Jun 2028	Jun 2028	0
NISAR	2022 (2016)	70	921.1	901.1	-2%	LRD	Oct 2024	Oct 2024	0
Orion	2021 (2015)	70	9,301.2	9,622.4	3%	Artemis II LRD	May 2024	Sep 2025	16
OSAM-1	2022 (2020)	88	1,244.0	Cancelled	N/A	LRD	Dec 2026	Cancelled	N/A
PACE	2019	70	558.0	605.2	8%	LRD	Jan 2024	Feb 2024	1
Roman	2021	78	2,898.1	3,270.0	13%	LRD	Oct 2026	May 2027	7
SEP[4]	2021 (2019)	70	203.2	223.2	10%	Electric Propulsion Thruster Life Qual Test	Oct 2028	Jan 2029	3
Sentinel-6	2017	70	465.9	363.5	-22%	LRD (B)[5]	Nov 2026	Nov 2026	0
SLS Block 1B	2023	70	3,674.0	3,674.0	0%	DCR	Jan 2028	Jan 2028	0
SPHEREx	2020	70	367.8	367.8	0%	LRD	Apr 2025	Apr 2025	0
VIPER	2021	70	336.2	405.1	20%	IOC	Nov 2023	Nov 2024	12

[1] *Original calendar year of KDP-C approval shown in parenthesis.*

[2] *As stated in the Decision Memo, the LRD of 2025 was outside the timeframe of the JCL results.*

COST AND SCHEDULE PERFORMANCE SUMMARY

[3] *As stated in the Decision Memo, an updated JCL was not conducted for this rebaseline due to the level-of-effort nature of remaining work.*

[4] *Electric Propulsion Thruster Life Qual Test: The test demonstrates continuous long-term operation of the system sufficient to characterize and predict the capability and lifetime of the system.*

[5] *Sentinel-6 Spacecraft (A) successfully launched November 21, 2020.*

FY 2025 PROPOSED APPROPRIATIONS LANGUAGE

DEEP SPACE EXPLORATION SYSTEMS

For necessary expenses, not otherwise provided for, in the conduct and support of exploration research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $7,618,200,000, to remain available until September 30, 2026.

SPACE OPERATIONS

For necessary expenses, not otherwise provided for, in the conduct and support of space operations research and development activities, including research, development, operations, support, and services; space flight, spacecraft control, and communications activities, including operations, production, and services; maintenance and repair, facility planning and design; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $4,389,700,000, to remain available until September 30, 2026.

SPACE TECHNOLOGY

For necessary expenses, not otherwise provided for, in the conduct and support of space technology research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $1,181,800,000, to remain available until September 30, 2026.

SCIENCE

For necessary expenses, not otherwise provided for, in the conduct and support of science research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $7,565,700,000, to remain available until September 30, 2026.

AERONAUTICS

For necessary expenses, not otherwise provided for, in the conduct and support of aeronautics research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $965,800,000, to remain available until September 30, 2026.

FY 2025 PROPOSED APPROPRIATIONS LANGUAGE

SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS ENGAGEMENT

For necessary expenses, not otherwise provided for, in the conduct and support of aerospace and aeronautical education research and development activities, including research, development, operations, support, and services; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $143,500,000, to remain available until September 30, 2026.

SAFETY, SECURITY, AND MISSION SERVICES

For necessary expenses, not otherwise provided for, in the conduct and support of science, aeronautics, space technology, exploration, space operations and education research and development activities, including research, development, operations, support, and services; maintenance and repair, facility planning and design; space flight, spacecraft control, and communications activities; program management; personnel and related costs, including uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; travel expenses; purchase and hire of passenger motor vehicles, including zero emission passenger motor vehicles and supporting charging or fueling infrastructure; not to exceed $63,000 for official reception and representation expenses; and purchase, lease, charter, maintenance, and operation of mission and administrative aircraft, $3,044,440,000, to remain available until September 30, 2026.

CONSTRUCTION AND ENVIRONMENTAL COMPLIANCE AND RESTORATION

For necessary expenses for construction of facilities including repair, rehabilitation, revitalization, and modification of facilities, construction of new facilities and additions to existing facilities, facility planning and design, and restoration, and acquisition or condemnation of real property, as authorized by law, and environmental compliance and restoration, $424,100,000, to remain available until September 30, 2030: Provided, That proceeds from leases deposited into this account shall be available for a period of 5 years to the extent and in amounts as provided in annual appropriations Acts: Provided further, That such proceeds referred to in the preceding proviso shall be available for obligation for fiscal year 2025 in an amount not to exceed $33,000,000: Provided further, That each annual budget request shall include an annual estimate of gross receipts and collections and proposed use of all funds collected pursuant to section 20145 of title 51, United States Code: Provided further, That of the amounts made available under this heading, $296,000,000 is designated by the Congress as being for an emergency requirement pursuant to section 251(b)(2)(A)(i) of the Balanced Budget and Emergency Deficit Control Act of 1985: Provided further, That such amount shall be available only if the President designates such amount as an emergency requirement pursuant to such section 251(b)(2)(A)(i).

OFFICE OF INSPECTOR GENERAL

For necessary expenses of the Office of Inspector General in carrying out the Inspector General Act of 1978, $50,500,000, to remain available until September 30, 2026.

ADMINISTRATIVE PROVISIONS

(INCLUDING CANCELLATION AND TRANSFERS OF FUNDS)

Funds for any announced prize otherwise authorized shall remain available, without fiscal year limitation, until a prize is claimed or the offer is withdrawn.

Not to exceed 10 percent of any appropriation made available for the current fiscal year for the National Aeronautics and Space Administration in this Act may be transferred between such appropriations, but no such appropriation, except as otherwise specifically provided, shall be increased by more than 20 percent by any such transfers. Any funds transferred to "Construction and Environmental Compliance and Restoration" for construction activities shall not increase that account by more than 50 percent. Balances so transferred shall be merged with and available for the same purposes and the same time period as the appropriations to which transferred. Any transfer pursuant to this provision shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

Not to exceed 5 percent of any appropriation provided for the National Aeronautics and Space Administration under previous appropriations Acts that remains available for obligation or expenditure in fiscal year 2025 may be transferred between such appropriations, but no such appropriation, except as otherwise specifically provided, shall be increased by more than 10 percent by any such transfers. Any transfer pursuant to this provision shall retain its original availability and shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

The spending plan required by this Act shall be provided by the National Aeronautics and Space Administration at the theme and program level. The spending plan, as well as any subsequent change of an amount established in that spending plan that meets the notification requirements of section 504 of this Act, shall be treated as a reprogramming under section 504 of this Act and shall not be available for obligation or expenditure except in compliance with the procedures set forth in that section.

Not more than 20 percent or $50,000,000, whichever is less, of the amounts made available in the current-year Construction and Environmental Compliance and Restoration (CECR) appropriation may be applied to CECR projects funded under previous years' CECR appropriations. Use of current-year funds under this provision shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

Of the amounts made available in this Act under the heading "Science, Technology, Engineering, and Mathematics Engagement" ("STEM Engagement"), up to $5,000,000 shall be available to jointly fund, with an additional amount of up to $1,000,000 each from amounts made available in this Act under the headings "Science", "Aeronautics", "Space Technology", "Exploration", and "Space Operations", projects and activities for engaging students in STEM and increasing STEM research capacities of universities, including Minority Serving Institutions.

Not to exceed $38,500,000 made available for the current fiscal year in this Act within "Safety, Security and Mission Services" may be transferred to the Working Capital Fund of the National Aeronautics and Space Administration. Balances so transferred shall be available until expended only for activities described in section 30102(b)(3) of title 51, United States Code, as amended by this Act, and shall remain available until expended. Any transfer pursuant to this provision shall be treated as a reprogramming of funds under section 504 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

Upon enactment of this Act:

> *(1) obligated balances in Treasury Appropriation Fund Symbol 080X0115 pertaining to Space Operations Direct Program shall be transferred to and merged with Treasury Appropriation Fund Symbol 080–25/26–0115, Space Operations, and any upward adjustments pursuant to 31 U.S.C. 1553 to such obligations may be made from Treasury Appropriation Fund Symbol 080–25/26–0115;*

(2) obligated balances in Treasury Appropriation Fund Symbol 080X0115 pertaining to Space Operations Hurricane Recovery shall be transferred to and merged with Treasury Appropriation Fund Symbol 080–25/30–0130, Construction and Environmental Compliance and Restoration, and any upward adjustments pursuant to 31 U.S.C. 1553 to such obligations may be made from Treasury Appropriation Fund Symbol 080–25/30–0130; and

(3) any unobligated balances identified in Treasury Appropriation Fund Symbol 080X0115 are hereby permanently cancelled.

Following the abovementioned transfer of obligated balances and cancellation of unobligated balances pertaining to Treasury Appropriation Fund Symbol 080X0115, such Treasury Appropriation Fund Symbol shall be closed. Any collections authorized or required to be credited to such Treasury Appropriation Fund Symbol that are not received before closing of such Treasury Appropriation Fund Symbol shall be deposited in the Treasury as miscellaneous receipts.

ACRONYMS AND ABBREVIATIONS

AA	Associate Administrator
AACES	Advanced Aircraft Concepts for Environmental Sustainability
AAM	Advanced Air Mobility
AANAPISI	Asian American and Native American Pacific Islander-Serving Institutions
AATT	Advanced Air Transport Technology
AAVP	Advanced Air Vehicles Program
ABC	Agency Baseline Commitment
AC	Alternating Current
ACCESS	Advanced Communications Capabilities for Exploration and Science Systems
ACCP	Aerosol and Cloud, Convection, and Precipitation
ACE	Advanced Composition Explorer
ACERO	Advanced Capabilities for Emergency Response Operations
ACF	Analytic Collaborative Frameworks
ACO	Announcement of Collaboration Opportunity
ACRES	A Climate Resilient Ecosystem Approach
ACS	Altitude Combustion Stand
ACSC	Advanced Cislunar and Surface Capabilities
ACSI	American Customer Satisfaction Index
ACT	Advanced Component Technologies
ACTIVATE	Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment
ADAP	Astrophysics Data Analysis Program
ADCAR	Astrophysics Data Curation and Archival Research
ADS	Astrophysics Data System
AE	Auroral Electrojet
AENode	Airports as Energy Nodes
AEPEX	Atmosphere Effects of Precipitation through Energetic X-rays
AEROcAST	Advanced Exploration of Reliable Operation at low Altitudes: meteorology, Simulation, and Technology
AES	Advanced Exploration Systems
AETC	Aerosciences Evaluation and Test Capabilities
AFRC	Armstrong Flight Research Center
AFSS	Autonomous Flight Safety System
AgMIP	Agricultural Model Intercomparison and Improvement Project
AI	Artificial Intelligence
AI&P	Assembly, Integration & Procession
AI&T	Assembly, Integration, and Test
AIA	Atmospheric Imaging Assembly
AIA	Asset Inventory Assessment
AIHEC	American Indian Higher Education Consortium
AIM	Aeronomy of Ice in Mesophere
AIML	Artificial Intelligence and Machine Learning
AIRS	Atmospheric Infrared Sounder

ACRONYMS AND ABBREVIATIONS

AISES	American Indian Science and Engineering Society
AIST	Advanced Information Systems Technology
AITE	Alternative Initiation of Technology Exploration
AMMOS	Advanced Multi-Mission Operations System
AMP	Air Mobility Pathfinders
AMP	Agency Master Plan
AMSU	Advanced Microwave Sounding Unit
AO	Announcement of Opportunity
AoA	Analyses of Alternatives
AOS	Atmosphere Observing System
AOSP	Airspace Operations and Safety Program
APL	Applied Physics Laboratory
APMC	Agency Program Management Council
APMC	Agency Project Management Council
APRA	Astrophysics Research and Analysis
ARC	Ames Research Center
ARD	Analysis Ready Data
ARIEL	Atmospheric Remote-sensing Infrared Exoplanet Large-Survey mission
ARMD	Aeronautics Research Mission Directorate
ARSET	Applied Remote Sensing Training
ASCAN	Astronaut Candidate
ASEAN	Association of Southeast Asian Nations
ASI	Italian Space Agency
ASM	Acquisition Strategy Meeting
ASMPO	Astrophysics Strategic Mission Program Office
ASPIRE	Aspiring Executive Cohort
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATA	Agency Technical Authority
ATD	Advanced Technology Development
ATF	Armstrong Test Facility
Athena	Advanced Telescope for High Energy Astrophysics
ATI	Advanced Technology Initiatives
ATLAS	Asteroid Terrestrial-impact Last Alert System
ATLO	Assembly, Test, and Launch Operations
ATP	Authority to Proceed
AU	Astronomical Unit
AWE	Atmospheric Wave Experiment
Ax	Axiom Mission
Ax	Axiom Private Astronaut Mission
B1B	Block 1B
B777	Boeing 777

ACRONYMS AND ABBREVIATIONS

BAA	Broad Agency Announcement
BEAM	Beaming Energy for Air Mobility
BFF	BioFabrication Facility
BIG	Breakthrough, Innovative, and Game-changing
BOLE	Booster Obsolescence and Life Extension
BPA	Brine Processor Assembly
BPOC	Booster Production and Operations Contract
BPS	Biological and Physical Sciences
BWG	Beam Waveguide
C3	Command, Control, Communication
CAA	Crew Access Arm
CADRE	Cooperative Autonomous Distributed Robotic Exploration
CAL	Cold Atom Laboratory
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CAPSTONE	Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment
CARA	Conjunction Assessment Risk Analysis
CaRD	Carbothermal Reduction Demonstration
CAS	Convergent Aeronautics Solutions
CASE	Contribution to ARIEL Spectroscopy of Exoplanets
CASI	Climate Adaptation Science Investigators
CASIS	Center for the Advancement of Science in Space, Inc
CaSSIS	Colour and Stero Surface Imaging Systems
CBM	Conditioned Based Maintenance
CCMC	Community Coordinated Modeling Center
CCP	Commercial Crew Program
CCRPP	Civilian Commercialization Readiness Pilot Program
CCRS	Capture, Contain, and Return System
CCSC	Collaborations for Commercial Space Capabilities
CCtCap	Commercial Crew Transportation Capability
CDCS	Core Data and Computing Services
CDCSP	Core Data and Computing Services Component
CDF	Common Data Format
CDFF	Commercial Destinations Free Flyers
CDISS	Commercial Destinations for ISS
CDR	Critical Design Review
CDSCC	Canberra Deep Space Communications Complex
CECR	Construction and Environmental Compliance and Restoration
CEERS	Cosmic Evolution Early Release Science
CEO	Chief Executive Officer
CERCLA	Comprehensive Environmental Response, Compensation, Liability Act
CERES	Clouds and the Earth's Radiant Energy System

ACRONYMS AND ABBREVIATIONS

CERISS	Commercially Enabled RapId Space Science
CESD	Common Exploration Systems Development
CESO	Center Engineering, Safety, and Operations
CFM	Cryogenic Fluid Management
CFT	Crew Flight Test
CGI	Coronagraph Instrument
CHAPEA	Crew Health and Performance Analog
CHS	Crew Health and Safety
CIBER	Cosmic Infrared Background ExpeRiment
CIF	Center Innovation Fund
CIG	Climate Impacts Group
CIMR	Copernicus Imaging Microwave Radiometer
CIO	Chief Information Officer
CIP	Cybersecurity Improvement Portfolio
CIPHER	Complement of Integrated Protocols for Human Exploration Research
CIPP	Capital Investment Program Plan
CIPS	Cloud Imaging and Particle Size
CIR	Critical Integration Review
CIR	Combustion Integrated Rack
CIRBE	CubeSat Inner Radiation Belt Experiment
CIS	Commercialization Innovation and Synergies
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CLDP	Commercial LEO Development Program
CLPS	Commercial Lunar Payload Service
CLV	Commercial Launch Vehicle
CM	Crew Module
CMA	Crew Module Adapter
CMD	Charge Management Device
CME	Coronal Mass Ejections
CMHT	Condensation Module Heat Transfer
CMMS	Computerized Maintenance Management System
CMP	Contamination Monitoring Package
CMP	Center Master Plan
CMR	Common Metadata Repository
CNEOS	Center for Near-Earth Object Studies
CNES	Centre National d'Études Spatiales
CODEX	Coronal Diognostic Experiment
CoECI	Center of Excellence for Collaborative Innovation
CoF	Construction of Facilities
COFFIES	Consequences Of Fields and Flows in the Interior and Exterior of the Sun
COMSEC	Communications Security

ACRONYMS AND ABBREVIATIONS

CONVEI	Collaborative Network for Valuing Earth Information
COR	Cosmic Origins
COSI	Compton Spectrometer and Imager
CoSTEM	Committee on Science, Technology, Engineering, and Math Education
COWVR	Compact Ocean Wind Vector Radiometer
CPF	Climate Absolute Radiance and Refractivity Observatory Pathfinder
CRISTAL	Copernicus Polar Ice and Snow Topography Altimeter
CRP	Constant Rate Production
CRS	Commercial Resupply Services
CS	Core Stage
CSA	Canadian Space Agency
CSDA	Commercial SmallSat Data Acquisition
CSESP	Citizen Science for Earth Systems Program
CSLI	CubeSat Launch Initiative
CSM	Crew and Service Module
CSP	Communications Services Program
CSSP	Committee for Solar and Space Physics
CST	Commercial Supersonic Technology
CTE-TDEA	Composite Technologies for Exploration -- Thermoplastic Development for Exploration Applications
CubeRRT	CubeSat Radio Frequency Interference Technology
CURIE	CUbesat Radio Interferometry Experiment
CUVIS	Compact Ultraviolet to Visible Imaging Spectrometer
CYGNSS	Cyclone Global Navigation Satellite System
DAA	Deputy Associate Administrator
DAAC	Distributed Active Archive Center
DAEP	Deep Space Network Aperture Enhancement Project
DALI	Development and Advancement of Lunar Instrumentation
DAPR	Dual Anonymous Peer Review
DARPA	Defense Advanced Research Projects Agency
DART	Double Asteroid Redirection Test
DAVINCI	Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging
DC	Direct Current
DCC	Dream Chaser Cargo
DCCS	Dream Chaser Cargo System
DCOI	Data Center Optimization Initiative
DCOTSS	Dynamics and Chemistry of the Summer Stratosphere
DCR	Design Certification Review
DDAP	Discovery Data Analysis Program
DDT&E	Orion Design Development, Test and Evaluation
DEAP	Data Science Equity, Access, and Priority
DEIA	Diversity, Equity, Inclusion, and Accessibility

ACRONYMS AND ABBREVIATIONS

DEVELOP	Digital Earth Virtual Environment and Learning Outreach Program
DFW	Dallas Fort Worth Airport
DIMPLE	Dating an Irregular Mare Patch with a Lunar Explorer
DLEU	DSN Lunar Exploration Upgrades
DLP	Data Loss Prevention
DLR	German Aerospace Center
DM	Decision Memo
DMS	Dimethyl Sulfide
DMSP	Defense Meteorological Satellite Program
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DPR	Dual-frequency Precipitation Radar
DRACO	Demonstration Rocket for Agile Cislunar Operations
DRaGMet	Dragonfly Geophysics and Meteorology Package
DRaGNS	Dragonfly Gamma-Ray and Neutron Spectrometer
DragonCam	Dragonfly Camera Suite
DRaMS	Dragonfly Mass Spectrometer
DRCS	Disaster Response Coordination System
DrEAM	Dragonfly Entry Aerosciences Measurements
DRF	Data and Reasoning Fabric
DRIVE	Diversify, Realize, Integrate, Venture, Educate
DSA	Distributed Spacecraft Autonomy
DSCOVR	Deep Space Climate Observatory
DSE	Data System Evolution
DSI	Decadal Survey Incubation
DSL	Deep Space Logistics
DSN	Deep Space Network
DSOC	Deep Space Optical Communications
dSRR	Delta Systems Requirement Review
DSS	Deep Space Station
DTN	Delay Tolerant Networking
DYNAMIC	Dynamical Neutral Atmosphere-Ionosphere Coupling
E4D	Enhanced European Exploration Exercise Device
EACA	Equipment Asset Criticality Analysis
ECF	Early Career Faculty
ECI	Early Career Initiative
ECLSS	Environmental Control and Life Support System
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
ECR	Environmental Compliance and Restoration

ACRONYMS AND ABBREVIATIONS

ECR	Early Career Research
ECS	Environmental Control System
EDL	Entry, Descent, and Landing
EDP	Enterprise Data Platform
EDR	Endpoint Detection and Response
EDS	Electrodynamic Dust Shield
EEO	Equal Employment Opportunity
EES	Emergency Egress System
EGS	Exploration Ground System
EHP	Extravehicular Activity and Human Surface Mobility Program
EIC	Earth Information Center
EICC	EPSCoR Interagency Coordinating Committee
EIO	Earth Independent Operations
EIR	Enterprise Integration Review
EIS	Earth Information System
ELF	Electrostatic Levitator Facility
EM	Exploration Mission
EMD	ElectroMagentic Compatability
EMDT	Electro-Motive Drop Tower
EMI	ElectroMagnetic Interference
EMIT	Earth Surface Mineral Dust Source Investigation
EMS	Environmental Management System
ENOC	Enterprise Network Operations Center
EO	Equal Opportunity
EONS	Engagement Opportunities in NASA STEM
eOPF	electronic Official Personnel Folder
EOS	Earth Observation Systems
EOSDIS	Earth Observing System Data and Information System
EP	Electric Propulsion
EPA	Environmental Protection Agency
EPCAPE	Eastern Pacific Cloud Aerosol Precipitation Experiment
EPD	Educator Professional Development
EPFD	Electrified Powertrain Flight Demonstrations
EPIC	Earth Polychromatic Imaging Camera
EPOCh	Extrasolar Planet Observation and Characterization
EPSCoR	Established Program to Stimulate Competitive Research
ERB	Earth Radiation Budget
ERDC	Earth Radiation Data Continuity
ERG	Employee Resource Group
ERM	ESPRIT Refueling Module
ERP	Expert Review Panel

ACRONYMS AND ABBREVIATIONS

ESA	Electronically Steered Array
ESA	European Space Agency
EscaPADE	Escape and Plasma Acceleration and Dynamics Explorers
ESD	Exploration Systems Development
ESD	Earth Science Division
ESDIS	Earth Science Data and Information System
ESDMD	Exploration Systems Development Mission Directorate
ESDS	Earth Science Data System
ESE	Earth System Explorers
ESI	Early Stage Innovations
ESIC	Early Stage Innovation and Commerce
ESIP	Early Stage Innovation and Partnerships
ESM	European Service Module
ESM	Earth Systematic Missions
ESO	Engineering, Safety, and Operations
ESO	Earth System Observatory
ESP	ERG Stellar Program
ESPRIT	European Systems Providing Refueling, Infrastructure, and Telecommunications
ESSIO	Exploration Science Strategy and Integration Office
ESSP	Earth System Science Pathfinder
ESTP	Earth Science Technology Program
ETA	Environmental Test Article
EUL	Enhanced Use Lease
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EUS	Exploration Upper Stage
EUV	Extreme Ultraviolet
EUVST	Extreme Ultraviolet High-Throughput Spectroscopic Telescope
EV	Earth Venture
EVA	Extravehicular Activity
EVC	Earth Venture Continuity
EVE	Extreme ultraviolet Variability Experiment
EVI	Earth Venture Instruments
EVM	Earth Venture Missions
EVS	Earth Venture Suborbital
EVUST	Extreme Ultraviolet High-Throughput Spectroscopic Telescope
ExEP	Exoplanet Exploration Program
EXES	Echelon-Cross-Echelle Spectrograph
EXPAND	Enhancing eXploration Platforms and Analog Definition
EZIE	Electrojet Zeeman Imaging Explorer
FA&A	Financial Accountant & Analysis
FAA	Federal Aviation Administration

ACRONYMS AND ABBREVIATIONS

FAIR	Findability, Accessibility, Interoperability, and Reusability
FAMLLE	Fully Additively Manufactured Liquid Oxygen/Liquid Hydrogen Engine
FAR	Federal Acquisition Regulation
FBCE	Flow Boiling Condensation Experiment
FBM	Flow Boiling Module
FC	Faraday Cup
FDC	Flight Demonstrations and Capabilities
FDL	Frontier Dynamics Laboratory
FFRDC	Federally-Funded Research and Development Center
FGM	Fluxgate Magnetometer
FIFI-LS	Field-Imaging Far-Infrared Line Spectrometer
FIRST	For the Inspiration and Recognition of Science and Technology
FISMA	Federal Information Security Modernization Act
FLITECAM	First Light Infrared Test Experiment CAMera
FM5	Flight Model 5
FO	Flight Opportunities
FOIA	Freedom of Information Act
FORCAST	Faint Object infraRed CAmera for the SOFIA Telescope
FRR	Flight Readiness Review
FSP	Fission Surface Power
FSR	Formulation Synchronization Review
FSS	Farside Seismic Suite
FTIS	Flight Test Instrumentation System
GAO	General Accounting Office
Gbps	Gigabit per second
GCD	Game Changing Development
GDC	Geospace Dynamics Constellation
GDSCC	Goldstone Deep Space Communications Complex
GE	General Electric Aviation
GEDI	Global Ecosystem Dynamics Investigation
GeDs	Germanium Detectors
GEER	Glenn Extreme Environment Rig
GEL	Growth and Extinction Limit
GEO	Group on Earth Observations
GEO	Geosynchronous Equatorial Orbit
GERS	Gateway External Robotic System
GFE	Government Furnished Equipment
GHA	High Gain Antenna
GHG	Greenhouse Gas
GIBS	Global Imagery Browse Services
GIC	Gateway Initial Capability

ACRONYMS AND ABBREVIATIONS

GIS	Geographic Information System
GISS	Goddard Institute for Space Studies
GLIDE	Global Lyman-alpha Imager of the Dynamic Exosphere
GLIMR	Geosynchronous Littoral Imaging and Monitoring Radiometer
GLOBE	Global Learning and Observation to Benefit the Environment
GLS	Gateway Logistics Services
GMI	GPM Microwave Imager
GNSS	Global Navigation Satellite System
GO	Guest Observer
GOES	Geostationary Operational Environmental Satellites
GOF	Guest Observer Facility
GOLD	Global-scale Observations of the Limb and Disk
GOMAP	Great Observatories Mission and Technology Maturation Program
GOTS	Government Off-the-Shelf
GPHS	General-Purpose Heat Source
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GRAM	Global Reference Atmospheric Model
GRB	Gamma-Ray Bursts
GRC	Glenn Research Center
GREAT	German Receiver for Astronomy at Terahertz Frequencies
GRS	Gamma Ray Spectrometer
GSA	General Services Administration
GSE	Ground Support Equipment
GSF	Gross Square Footage
GSFC	Goddard Space Flight Center
GSI	Ground Systems Implementation
GSLV	Geosynchronous Satellite Launch Vehicle
GSSR	Goldstone Solar System Radar
GUSTO	Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory
HALO	Habitation and Logistics Outpost
HAQAST	Health and Air Quality Science Team
HARP-2	Hyper-angular Rainbow Polarimeter 2
HASP	High Altitude Student Platform
HAWC+	High-resolution Airborne Wideband Camera-Plus
HBY	Heliophysics Big Year
HCC	High-Capacity Centrifuge
HEASARC	High Energy Astrophysics Science Archive Research Center
HEC	High End Computing
HECC	High-End Computing Capability

ACRONYMS AND ABBREVIATIONS

HEOMD	Human Exploration and Operations Mission Directorate
HEPA	High Efficiency Particulate Air
HERA	Human Exploration Requirements & Architecture
HERA	Human Exploration Research Analog
HERMES	Heliophysics Environmental and Radiation Measurement Experiment Suite
HERO	Human Exploration Research Opportunities
HFORT	Heliophysics Flight Opportunities in Research and Technology
HFOS	Heliophysics Flight Opportunities Studies
HIAD	Hypersonic Inflatable Aerodynamic Decelerator
HiCAM	Hi-Rate Composite Aircraft Manufacturing
HiRISE	High-Resolution Imaging Science Experiment
HIRMES	High Resolution Mid-InfrarEd Spectrometer
HITL	Human-In-The Loop
HLS	Human Landing System
HMI	Helioseismic and Magnetic Imager
HMTA	Human Medical Technical Authority
HORIS	Hypervelocity OSIRIS-REx Reentry Imaging & Spectroscopy
HOTTech	Hot Operating Temperature Technology
HPSC	High Performance Spaceflight Computing
HQ	Headquarters
HRP	Human Research Program
HRSC	Human Resources Services Center
HSFO	Human Space Flight Operations
HSIs	Hispanic Serving Institutions
HSM	Human Surface Mobility
HT	Hypersonic Technology
HTIDeS	Heliophsyics Technology and Instrument Development for Science
HTPB	Hydroxyl-Terminated Polybutadiene
HTV	H-II Transfer Vehicle
Hubble	Hubble Space Telescope
HVAC	Heating, Ventilation, and Air Conditioning
HW	Habitable Worlds
HWO	Habitable Worlds Observatory
HyTEC	Hybrid Thermally Efficient Core
I&T	Integration and Test
I&TC	Infrastructure and Technical Capabilities
I3P	Information Technology Infrastructure Integration Program
IA	Independent Assessment
IA	Implementing Arrangement
IAD	Investigative Analysis Division
I-ALiRT	IMAP Active Link for Real-Time
IAS	Integration of Automated Systems

ACRONYMS AND ABBREVIATIONS

IASMS	In-Time Aviation Safety Management System
IASP	Integrated Aviation Systems Program
IBEX	Interstellar Boundary Explorer
IBR	Integrated Baseline Review
ICEMAG	Interior Characterization of Europa Using Magnetometry
ICESat	Ice, Cloud, and Land Elevation Satellite
ICON	Ionospheric Connection Explorer
I-Corps	Innovation-Corps
ICPS	Interim Cryogenic Propulsion Stage
IDAS	Information, Data, & Analytics Services
IDI	Intercultural Development Inventory
IDIQ	Indefinite Delivery Indefinite Quantity
IDPU	Instrument Data Processing Unit
iESA	ion Electrostatic Analyzer
IG	Inspector General
I-Hab	International Habitat
IIP	Instrument Incubator Program
IM	Intuitive Machines
IMAP	Interstellar Mapping and Acceleration Probe
IMC	International Mission Contributions
IMF	Interplanetary Magnetic Field
IMPACT	Interagency Implementation and Advanced Concepts Team
IMPACT	Informing Mission Planning via Analysis of Complex Tradespaces
IMPACTS	Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms
IMPALA	Information Management Platform for Data Analytics and Aggregation
INCLUDES	Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science
INCUS	Investigation of Convective Updrafts
INL	Idaho National Laboratory
InSight	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport
InSPA	In Space Production Applications
INTEGRAL	International Gamma-Ray Astrophysics Laboratory
IPA	Integrated Payload Assembly
IPAC	Infrared Processing and Analysis Center
IPE	ISRU Pilot Excavator
IRAD	Internal Research and Development
IRB	Independent Review Board
IRC	Institutional Research Capacity
IRIS	Interface Region Imaging Spectrograph
iROSA	ISS Roll Out Solar Array
IRSA	Infrared Science Archive

ACRONYMS AND ABBREVIATIONS

IRT	Independent Review Team
IRTF	Infrared Telescope Facility
IS	Instrument Suite
ISAM	In-space Servicing, Assembly, and Manufacturing
ISD	Interstellar Dust
ISFM	Internal Scientist Funding Model
ISON	Interagency Satellite Observation Needs
ISPF	In-Space Propulsion Facility
ISRO	Indian Space Research Organization
ISRU	In-Situ Resource Utilization
ISS	International Space Station
ISSO	Information System Security Officer
IT	Information Technology
IT	Ion Technology
ITL	Integrated Test Lab
ITM	Ionosphere-Thermosphere-Mesosphere
IV&V	Independent Verification and Validation
IXPE	Imaging X-ray Polarimetry Explorer
JAXA	Japanese Aerospace Exploration Agency
JCL	Joint Confidence Level
JHU	Johns Hopkins University
JOINS	Lockheed Martin Joining Demonstrations In-Space
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSC	Johnson Space Center
JTWC	Joint Typhoon Warning Center
JUICE	JUpiter ICy moons Explorer
KARI	Korea Aerospace Research Institute
KASI	Korea Astronomy and Space Science Institute
KBO	Kuiper Belt Object
KDP	Key Decision Point
KGS	Kuiper Government Solutions
KIDS	K-12 Inclusiveness and Diversity
KOA	Keck Observatory Archive
KPF	Keck Planet Finder
KPLO	Korea Pathfinder Lunar Orbiter
KSC	Kennedy Space Center
kW	Kilowatt
LAFORGE	Lunar Advanced Filter Observing Radiometer for Geologic Exploration
LANCE	Land, Atmosphere Near real-time Capability for EOS
LANL	Los Alamos National Laboratory

ACRONYMS AND ABBREVIATIONS

LARADO	Laser-sheet Anomaly Resolution and Debris Observation
LaRC	Langley Research Center
LAS	Launch Abort System
Laser VMX	Laser Vitreous Material Transformation
LASP	Laboratory for Atmospheric and Space Physics
LAURA	Long durAtion evalUation solaR hand Launch
LBFD	Low Boom Flight Demonstrator
LCC	Life Cycle Cost
LCL	Latching Current Limiters
LCOT	Low-Cost Optical Terminal
LCPSO	Land Cover Project Science Office
LCRD	Laser Communications Relay Demonstration
LCRNS	Lunar Communications Relay and Navigation Systems
LCS	Launch Communications Segment
LDEP	Lunar Discovery and Exploration Program
LEDM	Lunar Electrostatic and Dust Mitigation
LEGS	Lunar Exploration Ground System
LEIA	Lunar Explorer Instrument for space biology Applications
LEO	low-Earth orbit
LETF	Launch Equipment Test Facility
LH2	Liquid Hydrogen
Lhe	liquid helium
LiDAR	Light Detection and Ranging
LIFD	Lunar Infrastructure Flight Demonstrations
LIGO	Laser Interferometer Gravitational-wave Observatory
LIS	Land Information System
LISA	Laser Interferometer Space Antenna
LISM	Local Interstellar Medium
LITMS	Lunar Interior Temperature and Materials Suite
LLITED	Low-Latitude Ionosphere/Thermosphere Enhancements in Density
LLM	Large Language Model
LMA	Liquid Oxygen and Methane Assessment
LMC	Large Magellanic Cloud
LOCR	Lunar Orbit Checkout Review
LOFTID	Low-Earth Orbit Flight Test of an Inflatable Decelerator
LRA	Laser Retroreflector Array
LRD	Launch Readiness Date
LRI	Laser Ranging Interferometer
LRO	Lunar Reconnaissance Orbiter
LROC	LRO Camera
LSAH	Lifetime Surveillance of Astronaut Health

ACRONYMS AND ABBREVIATIONS

LSG	Life Sciences Glovebox
LSII	Lunar Surface Innovation Initiative
LSITP	Lunar Surface Instrument and Technology Payloads
LSP	Launch Services Program
LTV	Lunar Terrain Vehicle
LTVS	Lunar Terrain Vehicle Services
LUCI	Lunar Combustion Investigation
LuGRE	Lunar GNSS Receiver Flight Experiment
Lunar-VISE	Lunar Vulkan Imaging and Spectroscopy Explorer
LUPEX	Lunar Polar Exploration Mission
LuSEE	Lunar Surface Electromagnetics Experiment
LUSEM	Lunar Space Environment Monitor
LuSTR	Lunar Surface Technology Research
LVSA	Launch Service Stage Adapter
LWRHU	Light Weight Radioisotope Heating Units
LWS	Living With a Star
M&IO	Mission Integration and Operations
M2M	Moon to Mars
M365	Microsoft 365
MA	Management Agreement
MACS	Multi-layer Acoustics & Conductive-grid Sensor
MAF	Michoud Assembly Facility
MAGIC	Magnetometers for Innovation and Capability
MAIA	Multi-Angle Imager for Aerosols
MANTIS	Monitoring Activity of Nearby sTars with uv Imaging and Spectroscopy
MaROS	Mars Relay Operations Service
MASPEX	MAss SPectrometer for Planetary EXploration/Europa
MAST	Mikulski Archive for Space Telescopes
MAV	Mars Ascent Vehicle
MAVEN	Mars Atmosphere and Volatile Evolution
MAXI	Monitor of All-sky X-ray Image
MBRSC	Mohammed bin Rashid Space Centre
MCC	Mission Control Center
MCL	Metrology and Calibration Laboratory
MCO	Mars Campaign Office
MDIS	Mercury Dual Imaging System
MDR	Mission Definition Review
MDSS	Misasa Deep Space Station
MEaSUREs	Making Earth System Data Records for Use in Research Environments
MEGANE	Mars-moon Exploration with Gamma rays and Neutrons
MES	Mission Enabling Services

ACRONYMS AND ABBREVIATIONS

MEVV	Multi Element Verification and Validation
MIA	Made in America
MIDEX	Medium-Class Explorer
MIGHTI	Michelson Interferometer for Global High-resolution Thermospheric Imaging
MiniTOCA	mini-Total Organic Carbon Analyzer
MIO	Maturation and Integration Office
MIRI	Mid-Infrared Instrument
MIRO	MUREP Institutional Research Opportunity
MIRT	MSR IRB Response Team
MISE	Mapping Imaging Spectrometer for Europa
MISSE	Materials International Space Station Experiment
ML	Machine Learning
MLA	Mercury Laser Altimeter
MLI	Multi-Layer Insulation
MMPACT	Moon-to-Mars Planetary Autonomous Construction Technology
MMS	Magnetospheric Multiscale
MMTC	Multi-Mission Time Correlation
MMX	Martian Moons eXploration
MO	Mission of Opportunity
MO&I	Mission Operations and Integration
MOMA	Mars Organic Molecule Analyzer
MOXIE	Mars Oxygen ISRU Experiment
MPC	Minor Planet Center
MPIA	Max Planck Institute for Astronomy
MPLAN	UREP Partnership Annual Notification
MPP	Mentor Protégé Program
MR	Microwave Radiometer
MR	Mission Relevant
MRO	Mars Reconnaissance Orbiter
MSaC	Mission Services and Capabilities
MSD	Mission Support Directorate
MSFC	Marshall Space Flight Center
MSI	Minority Serving Institution
MSL	Mars Science Laboratory
Msolo	Mass Spectrometer observing lunar operations
MSR	Mars Sample Return
MSTAR	MUREP Space Technology Artemis Research
MUREP	Minority University Research and Education Project
MURI	Multiband Uncooled Radiometer Imager
MUSE	Multi-slit Solar Explorer
MUSS	Multi-User Systems Support

ACRONYMS AND ABBREVIATIONS

MW	Megawatt
Myrs	million years
NAS	National Airspace System
NASCOM	NASA Ground Communications System
NASEM	National Academy of Sciences, Engineering, and Medicine
NAVO	NASA Astronomical Virtual Observatories
NC	Non-Condensable Gas
NCAS	NASA Community College Aerospace Scholars
NCRP	National Council on Radiation Protection and Measurements
NDE	Nondestructive Evaluation
NDS	NASA Docking System
NDT	Nondestructive Testing
NEA	Near Earth Asteroid
NEAR	Near-Earth Asteroid Rendezvous
NED	NASA/Infrared Processing and Analysis Center Extragalactic Database
NEO	Near-Earth Object
NEOO	Near-Earth Object Observations
NEP	Nuclear Electric Propulsion
NEPA	National Environmental Policy Act
NESC	NASA Engineering and Safety Center
NET	No Earlier Than
NEX	NASA Earth eXchange
NExScI	NASA Exoplanet Science Institute
NExT	New Exploration of Tempel
NextSTEP	Next Space Technologies for Exploration Partnerships
NG	Northrop Grumman
NGC	New General Catalogue
NGS	Next Gen STEM
NHC	National Hurricane Center
NIAC	NASA Innovative Advanced Concepts
NICER	Neutron Star Interior Composition Explorer
NID	NASA Interim Directive
NIH	National Institutes of Health
NIKA	Network Initiative for Ka-band Advancement
NIRCam	Near-Infrared Camera
NIRSpec	Near-Infrared Spectrograph
NIRVSS	Near InfraRed Volatiles Spectrometer System
NISAR	NASA-ISRO Synthetic Aperture Radar
NIST	National Institute of Standards and Technology
NISTAR	National Institute of Standards & Technology Advanced Radiometer
NLS	NASA Launch Services

ACRONYMS AND ABBREVIATIONS

NOAA	National Oceanic and Atmospheric Administration
NOFO	Notice of Funding Opportunity
NOJMO	NASA Office of JPL Management and Oversight
NOMAD	Nadir and Occultation for MArs Discovery
NOMC	NASCOM Operations Management Center
NOS	Novel Observing Strategies
NPD	NASA Policy Directive
NPLP	NASA Provided Lunar Payloads
NPR	NASA Procedural Requirements
NPS	National Park Service
NRA	NASA Research Announcement
NRESS	National Research and Educational Support Services
NRHO	Near Rectilinear Halo Orbit
NRO	National Reconnaissance Office
NRPTG	National Rocket Propulsion Test Group
NSC	NASA Safety Center
NSC	National Student Clearinghouse
NSF	National Science Foundation
NSIDS	National Snow and Ice Data Center
NSN	Near Space Network
NSpC	National Space-Based PNT Advisory Board and the National Space Council
NSS	Neutron Spectrometer System
NSTC	National Science and Technology Council's
NSTGRO	NASA Space Technology Graduate Research Opportunities
NTP	Nuclear Thermal Propulsion
NTRE	Nuclear Thermal Rocket Engine
O&M	Operations and Maintenance
O&TM	Operations and Test Management
O2O	Optical-to-Orion
OA	Office of Audits
OBC	Onboard-Computer
OCE	Office of the Chief Engineer
OCFO	Office of the Chief Financial Officer
OCHCO	Office of the Chief Human Capital Officer
OCHMO	Office of the Chief Health and Medical Officer
OCI	Ocean Color Instrument
OCOMM	Office of Communications
OCTL	Optical Communications Telescope Laboratory
ODA	Office of Data Analytics
ODEO	Office of Diversity and Equal Opportunity
OD-SSA	Orbital Debris and Space Situational Awareness

ACRONYMS AND ABBREVIATIONS

OGC	Office of the General Counsel
OHMAN	Orbiting High-energy Monitor Alert Network
OI	Office of Investigations
OIG	Office of Inspector General
OIIR	Office of International and Interagency Relations
OLAFS	Optical Large Aperture Flat System
OLIA	Office of Legislative and Intergovernmental Affairs
OLIF	Orion Life Support Integration Facility
OMB	Office of Management and Budget
OME	Orion Main Engine
OMP	Office of Management and Planning
OMPS	Ozone Mapping and Profiler Suite
ONERA	Office National d'Etudes et Recherches Aérospatiales
OP	Office of Procurement
OPOC	Orion Production and Operations Contract
OPS	Office of Protective Services
OPSEC	Operations Security
ORCA	Optimized and Repeatable Components in Additive Manufacturing
ORDEM	Orbital Debris Engineering Model
ORR	Operational Readiness Review
OSA	Orion Stage Adapter
OSAM	On-orbit Servicing, Assembly, and Manufacturing
OSBP	Office of Small Business Programs
OSHA	Occupational Safety and Health Administration
OSI	Open Science Implementation
OSIRIS-Rex	Origins, Spectral Interpretation, Resources Identification, Security-Regolith Explorer
OSMA	Office of Safety and Mission Assurance
OSS	Open Source Science
OSST	Ocean Salinity Science Team
OSTEM	Office of Science, Technology, Engineering, and Math
OSTST	Ocean Surface Topography Science Team
OTPS	Office of Technology, Policy, and Strategy
OVWST	Ocean Vector Wind Science Team
OWST	Ocean Winds Science Team
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
PAM	Private Astronaut Mission
Pan-STARRS	Panoramic Survey Telescope and Rapid Reporting System
PASS	Precision Assembled Space Structure
PB	Petabyte
PBAN	Polybutadiene Acrylonitrile
PCC	Pasadena City College

ACRONYMS AND ABBREVIATIONS

PCC	Prizes, Challenges, and Crowdsourcing
PCDU	Power Conditioning Distribution Unit
PDCO	Planetary Defense Coordination Office
PDR	Preliminary Design Review
PDS	Power Distribution System
PDS	Planetary Data System
PEA	Programmatic Environmental Assessment
PEAR	Payload Environmental Access Room
PER	Pre-Environmental Review
PESTO	Planetary Exploration Science Technology Office
PFAR	Post-Flight Assessment Review
PFAS	Polyfluoroalkyl Substances
PhysCOS	Physics of the Cosmos
PI	Principal Investigator
PIMS	Plasma Instrument for Magnetic Sounding
PM	Particulate Matter
PME	Program Mission Execution
PMM	Precipitation Measuring Mission
PMPO	Planetary Missions Program Office
PMT	Program Management Team
PNT	Positioning, Navigation, and Timing
PolSIR	Polarized Submillimeter Ice-cloud Radiometer
POWER	Prediction of Worldwide Energy Resources
PPE	Power and Propulsion Element
PR	Pressurized Rover
PREFIRE	Polar Radiant Energy in the Far Infrared Experiment
PRIME	Polar Resources Ice Mining Experiment
PRISM	Payloads and Research Investigations on the Surface of the Moon
PROSWIFT	Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow Act
P-Sampler	Pneumatic Sampler
PSI	Precollege Summer Institute
PSP	Parker Solar Probe
PSR	Pre-Ship Review
PSRR	Pre-Shipment Readiness Review
PTD	Pathfinder Technology Demonstrator
PUEO	Payload for Ultrahigh Energy Observation
PUFFER	Pop Up Flat Folding Exploration Robot
PUI	Primarily Undergraduate Institution
PUNCH	Polarimeter to Unify the Corona and Heliosphere
PV	Performance Verification
QSAR	Qualification System Acceptance Review

ACRONYMS AND ABBREVIATIONS

QueSST	Quiet Supersonic Transport
R&A	Research and Analysis
R&D	Research and Development
R3	Rapid Response Research
RAAMBO	Refractory Alloy Additive Manufacturing Build Optimization
RADIANT	Research and Development of Initiatives of Advanced New Technologies
RadReads	Radiation Assessment During Exposure and Long Duration Spaceflight
RALB	Robotically Assembled Light Bender
RAM	Revolutionary Aviation Mobility
RAP	Robotics Alliance Project
RBI	Radiation Budget Instrument
RCM	Reliability Centered Maintenance
RCRA	Resource Conservation and Recovery Act
RCS	Reaction Control System
RDAP	Rosetta Data Analysis Program
RDRE	Rotating Detonation Rocket Engine
REAL	Relativistic Electron Atmospheric Loss
REASON	Radar for Europa Assessment and Sounding: Ocean to Near-surface
RF	Radio Frequency
RFI	Request for Information
RFM	Rosalind Franklin Mission
RFMG	Radio Frequency Mass Gauge
RFP	Request for Proposal
RID	Research Infrastructure Development
RII	Research Infrastructure Improvement
ROS	Reactive Oxygen Species
ROSES	Research Opportunities in Space and Earth Science
RPS	Radioisotope Power System
RPT	Rocket Propulsion Test
RSI	Responsive Science Initiative
RSR	Responsive Science Research
RTDFS	Residence Time Driven Flame Spread
RTG	Radioisotope Thermoelectric Generator
RVLT	Revolutionary Vertical Lift Technology
S&MA	Safety and Mission Assurance
SaaS	Software as a Service
SABERS	State Architecture Batteries for Enhanced Rechargeability and Safety
SAC	Strategic Analysis Cycle
SAC	Super-lightweight Aerospace Composites
SAF	Sustainable Aviation Fuel
SAGE	Stratospheric Aerosol and Gas Experiment

ACRONYMS AND ABBREVIATIONS

SAM	Spacecraft Atmosphere Monitor
SAM	Sample Analysis at Mars
SANSA	South African National Space Agency
SAO	Strategy & Architecture Office
SAR	Search and Rescue
SAR	Synthetic Aperture Radar
SAT	Strategic Astrophysics Technology
SATCOM	Satellite Communications
SBG	Surface Biology and Geology
SBIR	Small Business Innovation Research
SC	Scientific Computing
SCA	Sensor Chip Assemblies
SCALPSS	Stereo Camera for Lunar Plume-Surface Studies
SCaN	Space Communications and Navigation
SCE	Sensor Chip Electronics
SCIC	Supply Chain Insight Central
SCIFLI	Scientifically Calibrated In-Flight Imagery
SCIPA	Spacecraft Bus + Integrated Payload Assembly
SCLT	Strategic Capabilities Leadership Team
SCM	Search Coil Magnetometer
SDA	Software-Defined Access
SDAC	Solar Data Center
SDC	Surface Deformation and Change
SDL	Space Dynamics Laboratory
SDO	Solar Dynamics Observatory
SDR	System Definition Review
SDS	Survey Data System
SE&I	Systems Engineering and Integration
SEAQUE	Satellite Entanglement and Annealing QUantum Experiment
SEB	Source Evaluation Board
SEDAC	Socio-economic Data and Applications Center
SEP	Solar Electric Propulsion
SES	Senior Executive Service
SETMO	Space Environments Testing Management Office
SFCO	Space Flight Crew Operations
SFD	Sustainable Flight Demonstrator
SFNP	Sustainable Flight National Partnership
SFS	Space and Flight Support
SGP	Space Geodesy Project
SIF	Solar-Induced Chlorophyll Fluorescence
SIM	Spectral Irradiance Monitor

ACRONYMS AND ABBREVIATIONS

SIMPLEx	Small Innovative Missions for Planetary Exploration
SIPS	Science Investigator-led Processing Systems
SIR	System Integration Review
SLA	Service Level Agreement
SLC	Space Launch Complex
SLD	Sustaining Lunar Development
SLI	Sustainable Land Imaging
SLR	Satellite Laser Ranging
SLS	Space Launch System
SM	Service Module
SMAP	Soil Moisture Active and Passive
SMD	Science Mission Directorate
SME	Surface Mass Ejection
SME	Subject Matter Expert
SMEX	Small Explorer
SMODE	Sub-Mesoscale Ocean Dynamics Experiment
SMOS	Soil Moisture and Ocean Salinity
SMTP-2E	Segmented Mirror Technology Program Phase 2E
SNP	Space Nuclear Propulsion
SNR	Signal-to-Noise Ratio
SNWG	Satellite Needs Working Group
SOAR	Student Opportunities in Academics and Research
SOAR	Security Orchestration, Automation, and Response
SOC	Solar Orbiter Collaboration
SOC	Security Operations Center
SOFIA	Stratospheric Observatory for Infrared Astronomy
SoFIE	Solid Fuel Ignition and Extinction
SOHO	Solar and Heliospheric Observatory
SOMA	Science Office for Mission Assessments
SOMD	Space Operations Mission Directorate
SOST	Subcommittee on Ocean Science and Technology
SPARCS	Star-Planet Activity Research CubeSat
SPDA	Space Physics Data Archive
SPDF	Space Physics Data Facility
SPEC	Stages Production and Evolution Contract
SPEXOne	Spectro-Polarimeter for Exploration
SPHEREx	Spectro-Photometer for the History of the Universe and Ices Explorer
SPIDER	SPace Infrastructure DExterous Robot
SPIE	Spacecraft Payload Integration and Evolution
SPLICE	Safe and Precise Landing - Integrated Capabilities Evolution
SPOC	Spacecraft Processing Operations Contract

ACRONYMS AND ABBREVIATIONS

SPORT	Scintillation Prediction Observations Research Task
SPoRT	Short-term Prediction Research and Transition Center
SPRITE	Supernova remnants Proxies for Reionization and Integrated Testbed Experiment
SpX	SpaceX
SR&T	Strategic Research and Technology
SRAG	Space Radiation Analysis Group
SRB	Standing Review Board
SRC	Sample Return Capsule
SRL	Sample Retrieval Lander
SRON	Netherlands Institute for Space Research
SRP	Sample Receiving Project
SRR	System Requirements Review
SSC	Stennis Space Center
SSL	Space Sciences Laboratory
SSMO	Space Science Mission Operations
SSMS	Safety, Security, and Mission Services
SSO	Sun Synchronous Orbit
SST	Science Study Team
SST	Small Spacecraft Technology
STA	Structure Test Article
STEM	Science, Technology, Engineering, and Mathematics
STEREO	Solar Terrestrial Relations Observatory
STMD	Space Technology Mission Directorate
STP	Solar Terrestrial Probes
STP	Space Test Program
STRATO	Strategic Radio and Tactical Overwatch
STRG	Space Technology Research Grants
STRI	Space Technology Research Institutes
STROFIO	Start from a ROtating FIeld mass spectrOmeter
STScI	Space Telescope Science Institute
STTR	Small Business Technology Transfer
SubC	Suborbital Crew
SUDA	SUrface Dust Analyzer
SunRISE	Sun Radio Interferometer Space Experiment
SuperBIT	Super Pressure Balloon Imaging Telescope
SWOT	Surface Water and Ocean Topography
SWPC	Space Weather Prediction Center
SWR2O2R	Space Weather to Operations to Research
SwRI	Southwest Research Institute
SWS	System-Wide Safety
T2X	Technology Transfer Expansion

ACRONYMS AND ABBREVIATIONS

TA	Technical Authority
TACP	Transformative Aeronautics Concepts Program
TAGSAM	Touch-and-Go Sample Acquisition Mechanism
TAMD	Technology Analysis & Mission Design
TB	Terabytes
TBIRD	TeraByte InfraRed Delivery
TD	Technology Development
TDAMM	Time Domain and Multi Messenger
TDM	Technology Demonstration Missions
TDRS	Tracking and Data Relay Satellites
TDU	Technology Demonstration Unit
TEMPEST	Temporal Experiment for Storms and Tropical Systems
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TESS	Transiting Exoplanet Survey Satellite
THEMIS	Thermal Emission Imaging System
THEMIS	Time History of Events and Macroscale Interactions during Substorms
TIDES	Thriving In DEep Space
TIGERISS	Trans-Iron Galactic Recorder for the International Space Station
TIM	Total Irradiance Monitor
TIM	Technical Interchange Meeting
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics
TL	Transfer Line
TM	Tiered Maintenance
TOCA	Total Organic Carbon Analyzer
TOPEX	Topography Experiment
TP	Tipping Point
TRACERS	Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites
TRIDENT	The Regolith and Ice Drill for Exploring New Terrain
TRISH	Translational Research Institute for Space Health
TRL	Technology Readiness Level
TRMM	Tropical Rainfall Measuring Mission
TROPICS	Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats
TSC	Telescience Support Center
TTBW	Transonic Truss-Braced Wing
TTT	Transformational Tools and Technologies
TVAC	Thermal Vacuum
UA	University of Arizona
UAE	United Arab Emirates
UAG	Users' Advisory Group
UAM	Urban Air Mobility

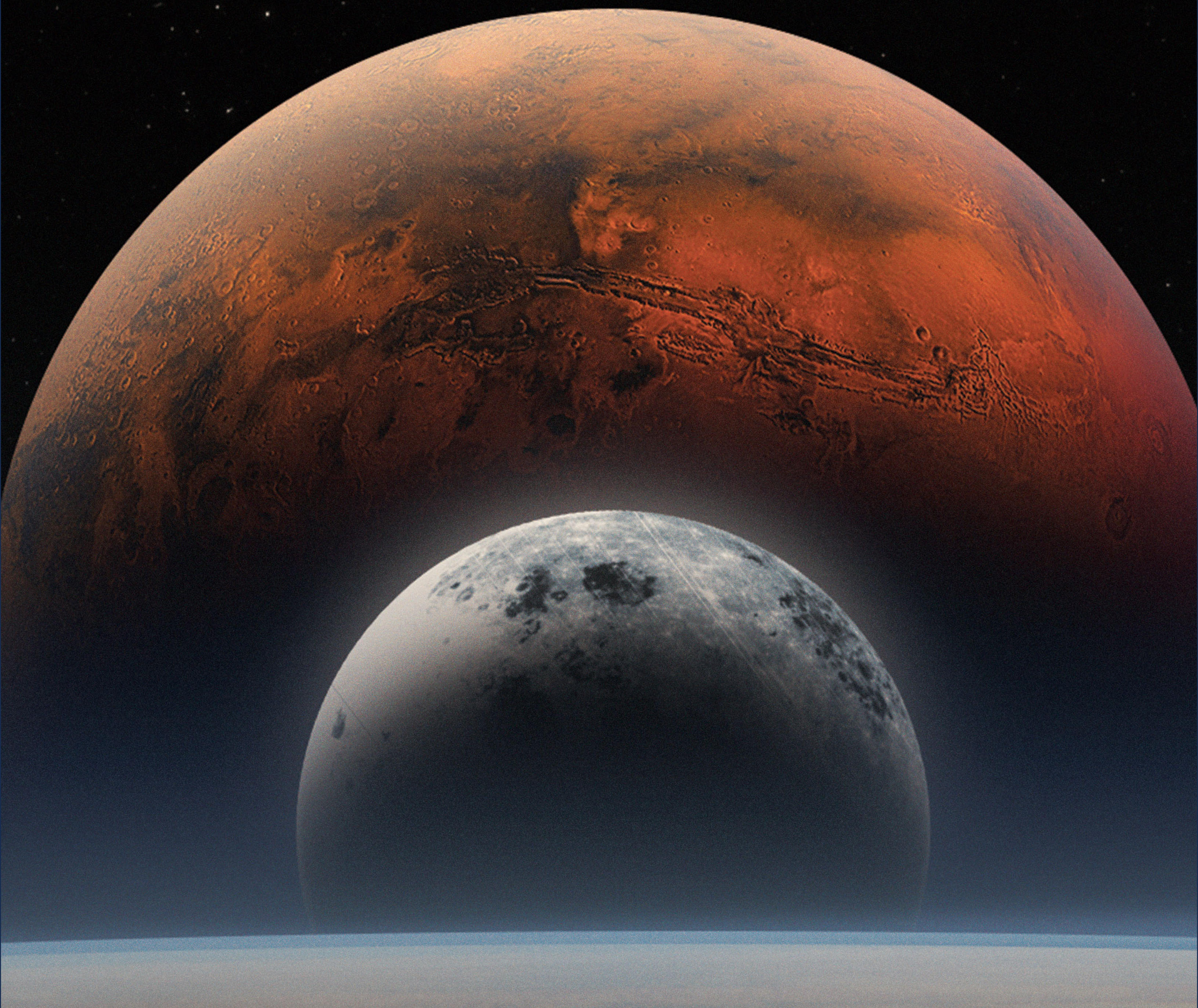
ACRONYMS AND ABBREVIATIONS

UAS	Unmanned Aircraft Systems
UCB	University of California at Berkeley
UCF	University of Central Florida
UFE	Unallocated Future Expenses
UI	University Innovation
UK	United Kingdom
UKSA	United Kingdom Space Agency
ULA	United Launch Alliance
ULI	University Leadership Initiative
ULTRASAT	Ultraviolet Transient Astronomy Satellite
UMBC	University of Maryland Baltimore County
UN	United Nations
UPA	Urine Processor Assembly
UR	Under Review
URT	Underway Recovery Test
USA	Universal Stage Adapter
USAF	United States Air Force
USAID	United States Agency for Internal Deployment
USDV	United States De-orbit Vehicle
USGCRP	United States Global Change Research Program
USGS	United States Geological Survey
USOS	United States Orbital Segment
USSF	United States Space Force
USTP	University SmallSat Technology Partnerships
UTAS	UTC Aerospace Systems
UTM	Unmanned Aircraft Systems Traffic Management
UV	Ultraviolet
UVEX	Ultraviolet Explorer
UVS	Ultraviolet Spectrograph
UX	User Experience
VAB	Vehicle Assembly Building
VADR	Venture-Class Acquisition of Dedicated and Rideshare
VASI	Venus Atmospheric Structure Investigation
VCLS	Venture Class Launch Services
VEDA	Visualization, Exploration, and Data Analysis
VEM	Venus Emissivity Mapper
VenDI	Venus Descent Imager
VenSAR	Venus Synthetic Aperture Radar
VERITAS	Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy
VERS	Vulcan Engine Reuse Scale
VesCoor	Venus Science Coordination Group

ACRONYMS AND ABBREVIATIONS

VfOx	Venus Oxygen Fugacity Experiment
VIIRS	Visible Infrared Imaging Radiometer Suite
VIPER	Volatiles Investigating Polar Exploration Rover
VIPR	Vapor In-Cloud Profile Radar
VISAR	Venus Interferometric Synthetic Aperture Radar
VISE	Vehicle Interfaces to Suit Equipment
VISOR	Venus Imagining System for Observational Reconnaissance
VLBI	Very Long Baseline Interferometry
VLISM	Very Local Interstellar Medium
VMS	Venus Mass Spectrometer
VNIR	Visible and Near-Infrared Reflectance
VOI	Venus Orbit Insertion
VPP	Voluntary Protection Program
VRT	VIPER Review Team
VSAT	Vertical Solar Array Technology
VSFB	Vandenberg Space Force Base
VTLS	Venus Tunable Laser Spectrometer
VTOL	Vertical Take-Off and Landing
WAVES	Radio and Plasma Wave Experiment
WBS	Work Breakdown Structures
WCF	Working Capital Fund
WCU	Women's Colleges and University
Webb	James Webb Space Telescope
WFF	Wallops Flight Facility
WHC	Waste and Hygiene Compartment
WHIHBCU	White House Initiative for HBCUs
WISE	Wide-field Infrared Survey Explorer
WMKO	W.M. Keck Observatory
WOMA	Wide Field Instrument Opto-Mechanical Assembly
WPA	Water Processor Assembly
WSC	White Sands Complex
WSTF	White Sands Test Facility
WWAO	Western Water Applications Office
xEMU	Exploration Extravehicular Mobility Unit
xEVA	Exploration Extravehicular Activity
xEVAS	Exploration Extravehicular Activity Services
XMM	X-ray Multi-Mirror Mission
XRISM	X-Ray Imaging and Spectroscopy Mission
XVS	Xternal Vision System
ZBOT	Zero Boil-Off Tank Experiment
ZEV	Zero Emission Vehicle

National Aeronautics and
Space Administration



National Aeronautics and Space Administration

NASA Headquarters

300 E Street SW
Washington, DC 20546
www.nasa.gov/centers/hq

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NP-2024-02-3108-HQ