

National Aeronautics and Space Administration



NASA's Exploration Strategy

April 2014





Why Human Space Exploration?

- **Scientific and human exploration and pioneering mark advancing civilizations and expand human experience**
 - Expands knowledge, fuels innovation, and spurs commerce
 - Requires risk acceptance
- **Exploration and pioneering leverages humanity's powerful motivations:**
 - Ignites our imaginations
 - Leads to discovery and science & technical advances
 - Creates a vision of a better future for the next generations
- **Space exploration is human and robotic explorers in partnership**
 - Robots explore distant and hazardous environments to extend scientific understanding and planning for human missions
 - Human explorers provide greater speed, intuitive ease, and efficiency
- **Human space exploration garners national prestige and unites nations around a common goal**

Building on our investments in technology, robotic missions, ISS, Commercial Crew, SLS, and Orion, America is poised to lead the next wave of partnerships for international science and human space exploration

The Future of Human Space Exploration

NASA's Building Blocks to Mars

U.S. companies provide affordable access to low Earth orbit

Mastering the fundamentals aboard the International Space Station

Pushing the boundaries in cis-lunar space

Developing planetary independence by exploring Mars, its moons, and other deep space destinations

The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion crew capsule

*Missions: 6 to 12 months
Return: hours*

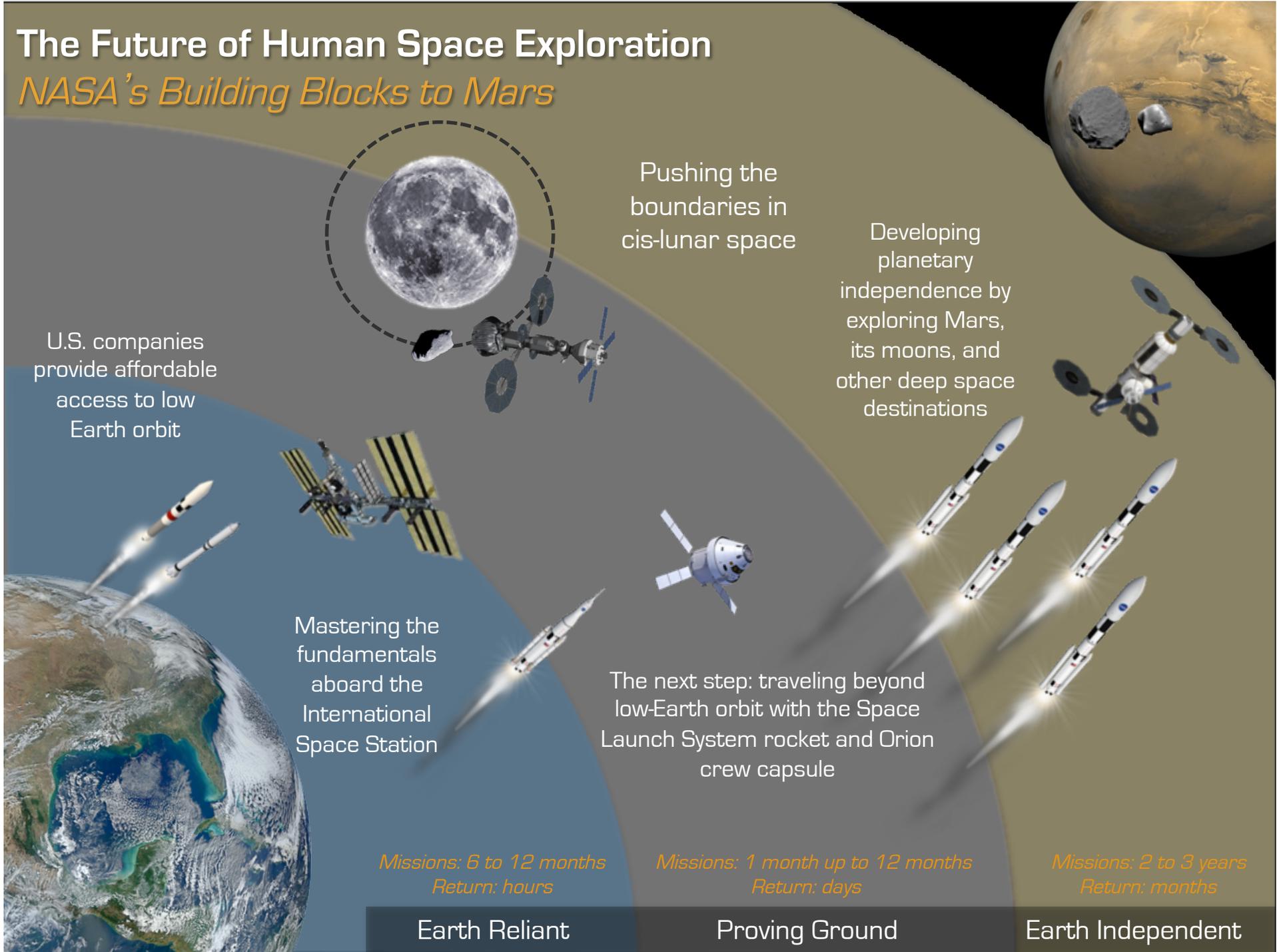
*Missions: 1 month up to 12 months
Return: days*

*Missions: 2 to 3 years
Return: months*

Earth Reliant

Proving Ground

Earth Independent

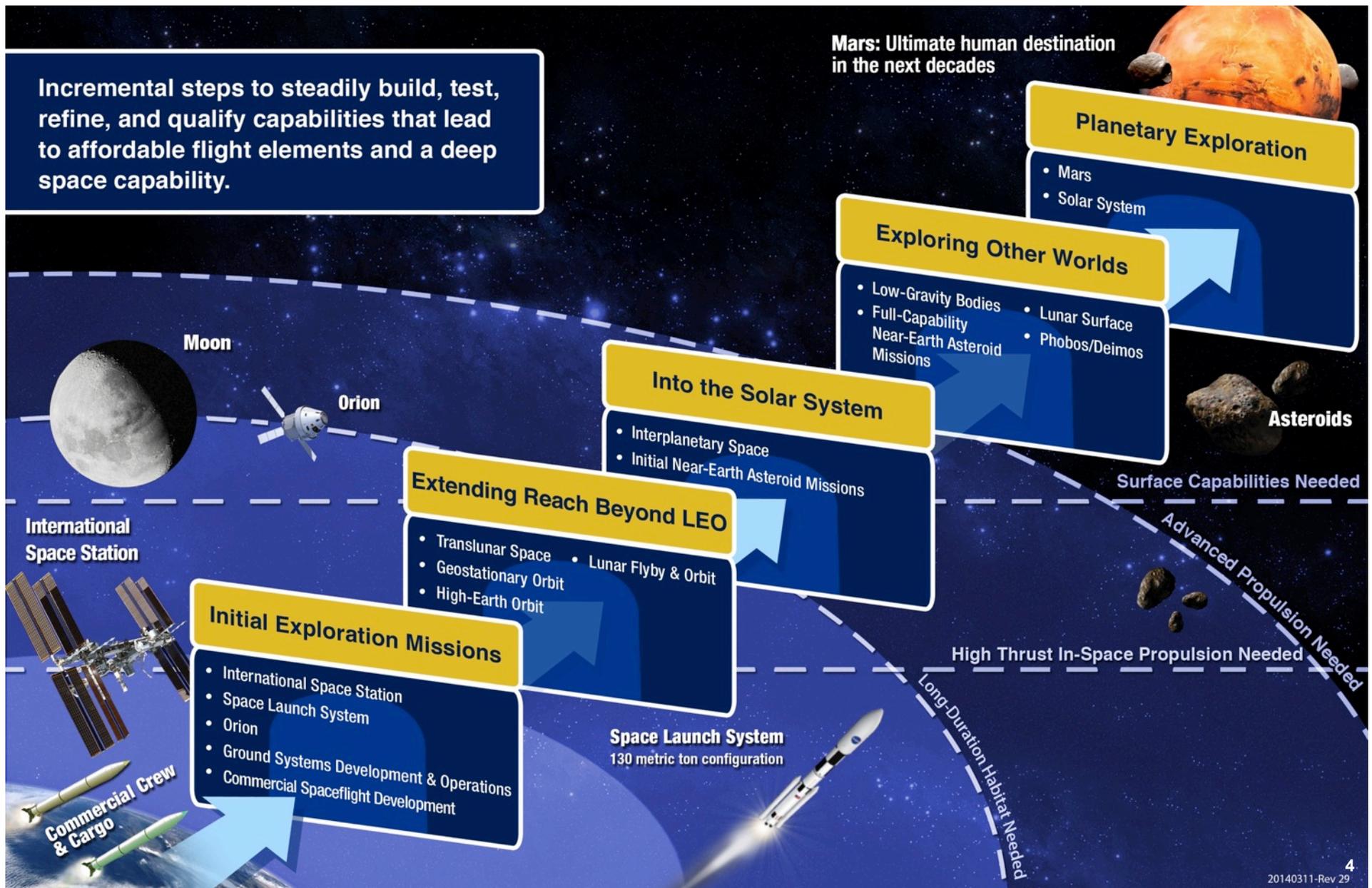


The Capability Driven Framework



Incremental steps to steadily build, test, refine, and qualify capabilities that lead to affordable flight elements and a deep space capability.

Mars: Ultimate human destination in the next decades



Strategic Principles for Exploration Implementation



Six key strategic principles to provide a sustainable program:

1. Executable with current ***budget with modest increases.***
2. Application of ***high Technology Readiness Level*** (TRL) technologies for near term, while focusing research on technologies to address challenges of future missions
3. ***Near-term mission*** opportunities with a defined cadence of compelling missions providing for an incremental buildup of capabilities for more complex missions over time
4. Opportunities for ***US Commercial Business*** to further enhance the experience and business base learned from the ISS logistics and crew market
5. ***Multi-use, evolvable*** Space Infrastructure
6. Significant ***International and Commercial participation,*** leveraging current International Space Station partnerships

Global Exploration Roadmap



2013

2020

2030

International Space Station

General Research and Exploration Preparatory Activities

Note: ISS partner agencies have agreed to use the ISS until at least 2020.

Commercial or Government Low-Earth Orbit Platforms and Missions

Robotic Missions to Discover and Prepare



Human Missions Beyond Low-Earth Orbit



**EARTH
RELIANT**

**PROVING
GROUND**

**EARTH
INDEPENDENT**

International Space Station – The Cornerstone of Exploration





NASA and the ISS



Advance benefits to humanity
through research



Enable a commercial demand driven
market in LEO



Enable long duration human
spaceflight beyond LEO



Basis for international HSF
exploration partnerships



ISS Enables Long Duration Exploration For Mars



- Health and Human Performance
- Crew Habitability and Logistics
- System and Technology Testbed
 - Docking System
 - High Reliability Closed Loop Life Support
 - Long Term System Performance
 - Extravehicular Activity



Human and Health and Performance

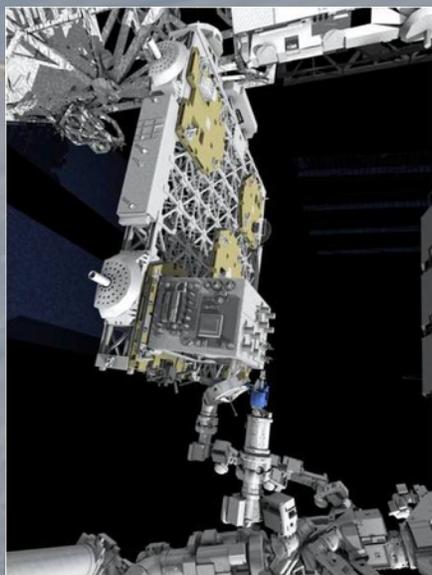


ISS is the platform to understand and develop countermeasures for Human Health & Performance Risks

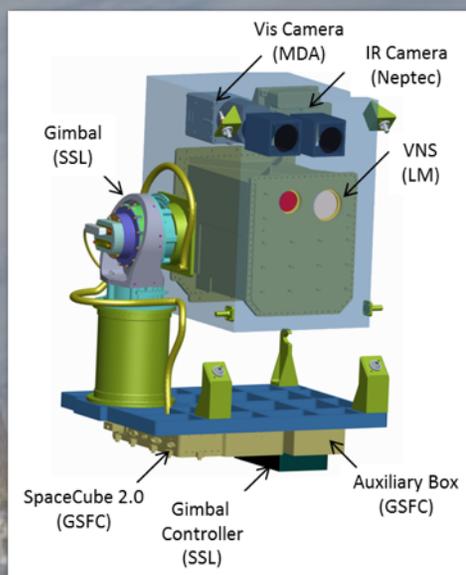
- **Decreased gravity**
(including gravity transitions and launch and landing loads)
bone, muscle, cardiovascular, sensorimotor, nutrition, behavior/performance, immunology, human factors, clinical medicine
- **Isolation/confinement and altered light-dark cycles**
behavior/performance
- **Hostile/closed environment**
(including habitability: atmosphere, microbes, dust, volume/configuration, displays/controls,...)
behavior/performance, nutrition, immunology, toxicology, microbiology
- **Increased radiation**
immunology, carcinogenesis, behavior/performance, tissue degeneration, pharmaceutical stability...
- **Distance from Earth**
behavior/performance, autonomy, food systems, clinical medicine

Note that effect severity generally increases with mission duration.

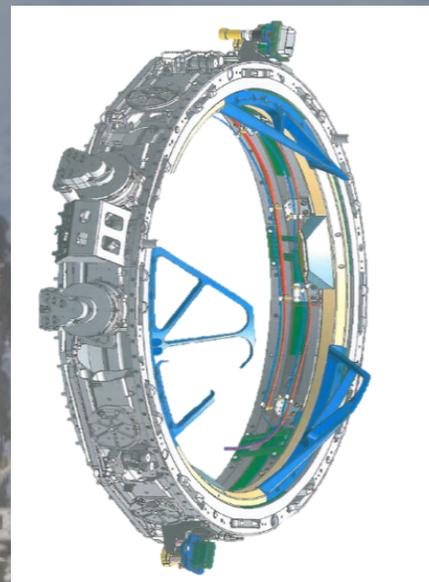
International Space Station: Exploration Platform



In-Space Robotic Servicing



Automated Rendezvous & Docking Sensors



International Docking System



ECLSS/Amine Swingbed



The Next Step Beyond ISS



- **Crew tended habitat in cis-lunar space**
 - **Builds off of the Asteroid redirect mission and ISS**
 - **Allows for further study of gravity assist trajectory operations**
 - **Builds off of ISS life support with less earth support**
 - **Enables international partner and commercial lunar surface activities**
 - **Develops incremental risk management concepts to be developed and accepted**
 - **Exposure to galactic cosmic background radiation**
 - **Allows for Mars operational strategies to be developed**

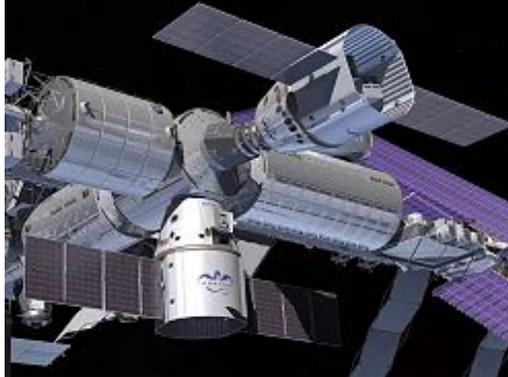
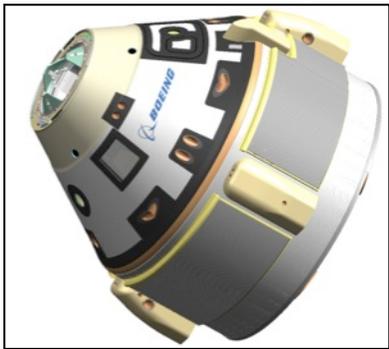
Commercial Cargo & Crew Transportation – Freeing Up NASA to Explore Beyond LEO



Now Acquiring ISS Cargo Services Commercially!



Commercial Crew Partners



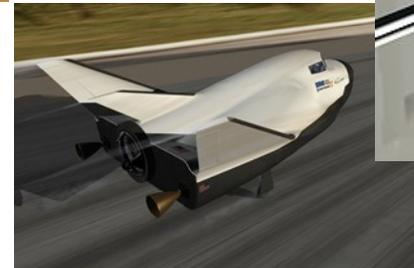
Boeing



Sierra Nevada

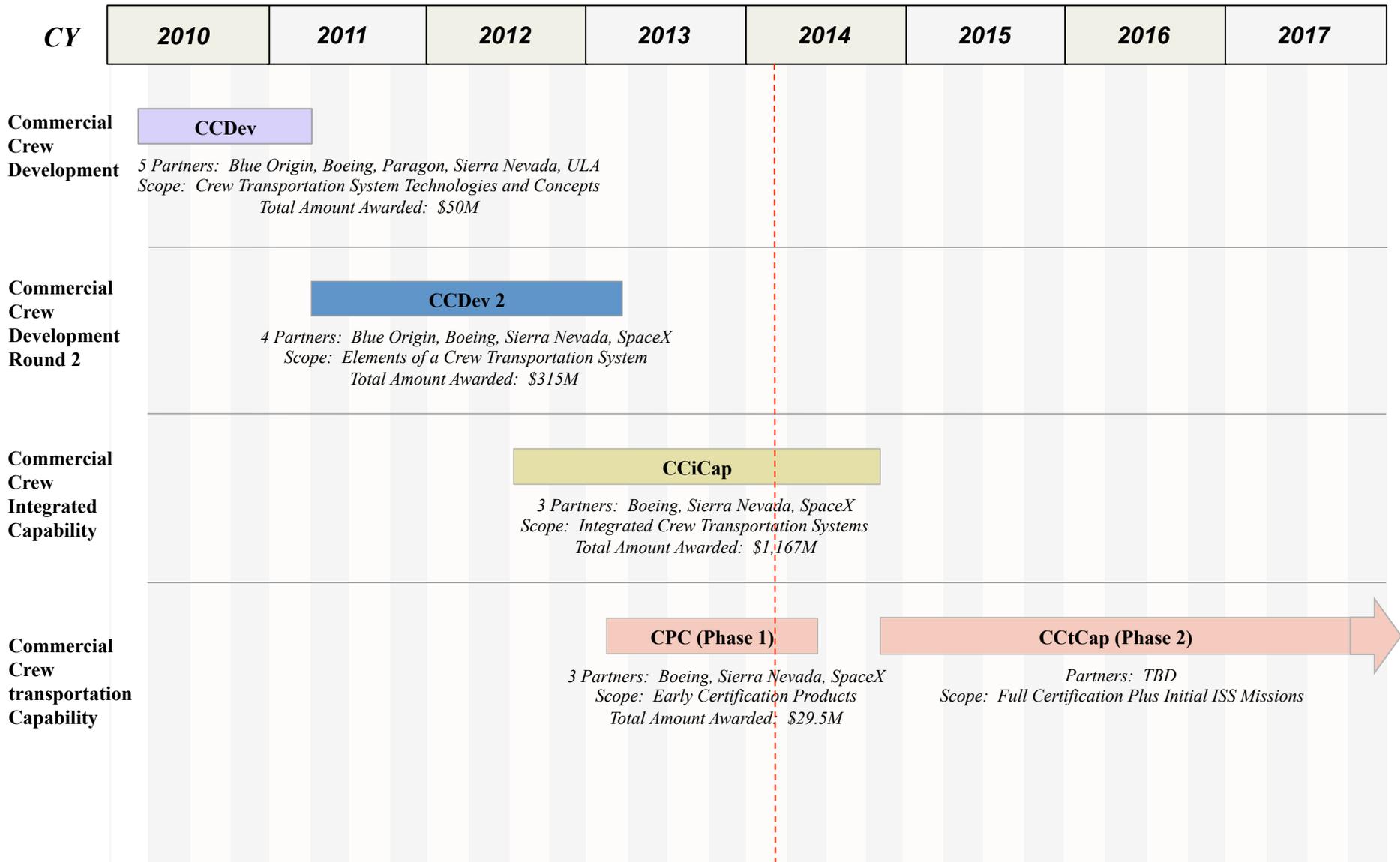


SpaceX



Human Exploration and Operations

Commercial Crew Program: Acquisition



Space Launch System & Orion

– How We'll Get There



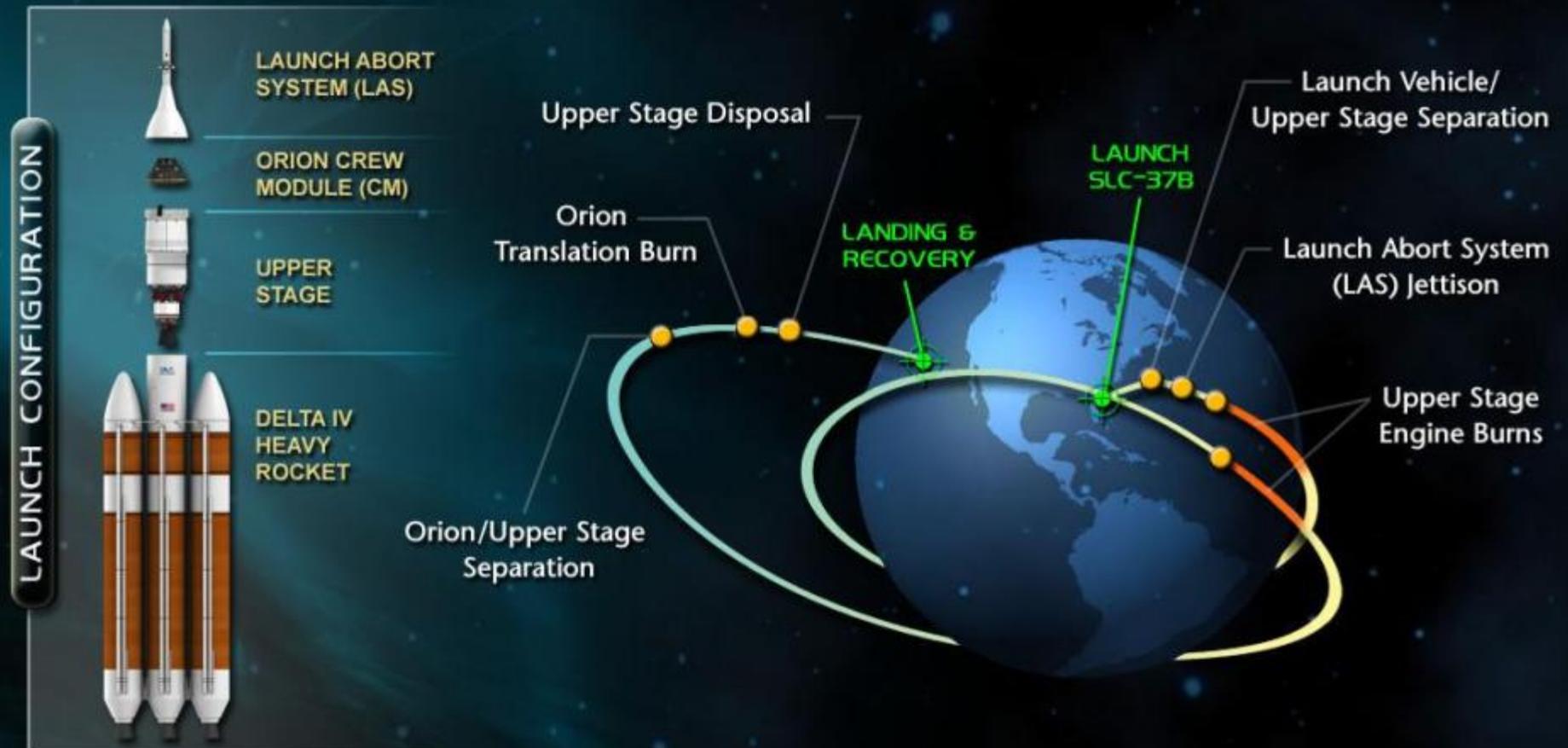
2014 Exploration Flight Test One (EFT-1)



EXPLORATION FLIGHT TEST ONE

OVERVIEW

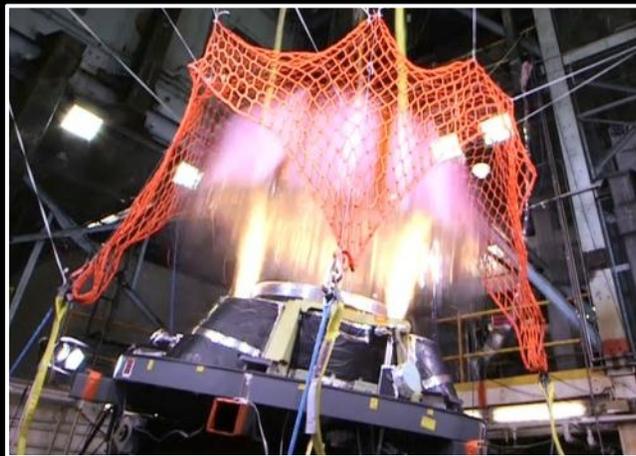
TWO ORBITS • 20,000 MPH ENTRY • 3,671 MILE APOGEE • 28.6 DEGREE INCLINATION



Orion Spacecraft



Orion is the first spacecraft in history capable of taking humans to multiple destinations in deep space.
Long Duration – Adaptable – Life Sustaining



Forward Bay
Cover Jettison
Test Denver, CO



Fairing separation test 2 at Lockheed Martin, Sunnyvale, CA



Heat shield
completed and
delivered to O&C
for final processing

Service Module /
Spacecraft Adaptor
mate complete at O&C



Space Launch System



SLS is the rocket and launch system capable of transporting humans, habitats and support systems directly to deep space.

Powerful – High-Capacity – Flexible

Vertical Assembly Center (VAC)
Status Progress – Tower Install /
Third Upper Half Leg Installed –
NW Leg



Completed
MSA Shell



1:100 scale model of SLS Core
Stage B-2 test stand completed
wind tunnel testing



Center
segment for
QM-1 delivered
to its test bay
at ATK's
facility in Utah



Diaphragm
installed
and tested
on MSA
in support
of EFT-1



F-1B gas generator – tech demo
for advanced booster concept

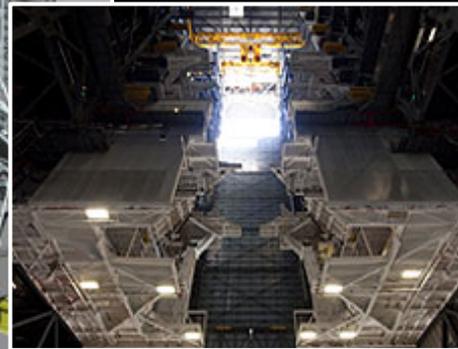
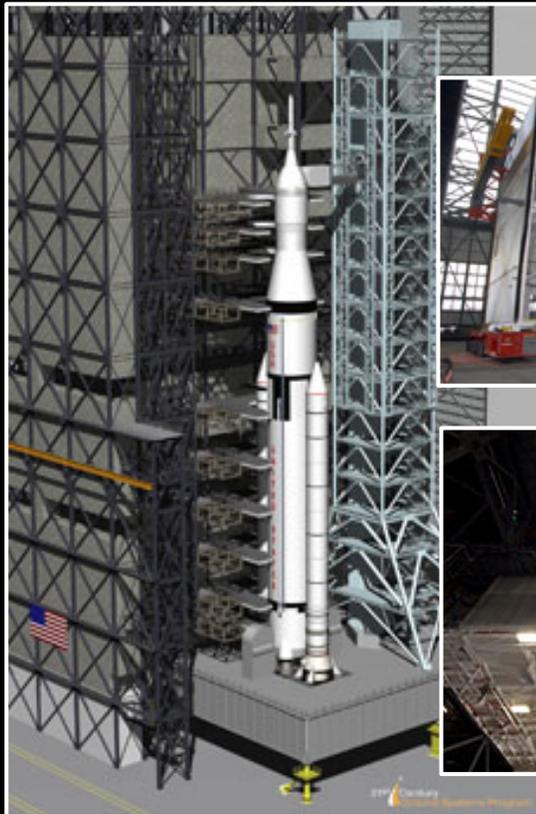
Ground Systems Development and Operations



GSDO is modernizing Kennedy's spaceport with the capabilities to launch spacecraft built and designed by both NASA and private industry.

Adaptable – Partner-Oriented – Versatile

NASA's Vehicle Assembly Building is undergoing major renovations so it can support a new generation of rockets and spacecraft



The 355-foot-tall mobile launcher structure is being modified to support Space Launch System



The Orion ground test vehicle (GTA) is in the Operations and Checkout Facility at KSC



Asteroid Redirect Mission – An Early Use of Exploration Capabilities in the Proving Ground



Asteroid Redirect Mission



Identify



Asteroid Identification:

Ground and space based near Earth asteroid (NEA) target detection, characterization and selection

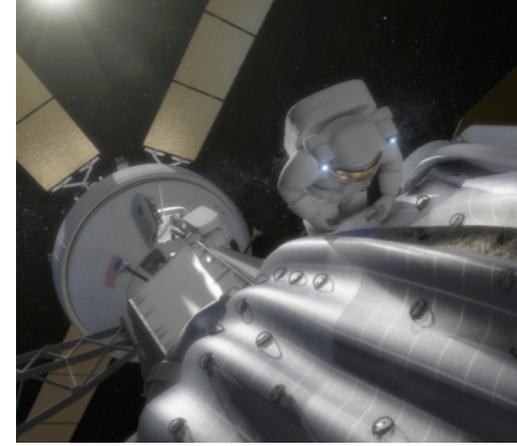
Redirect



Asteroid Redirect Robotic Mission:

High power solar electric propulsion (SEP) based robotic asteroid redirect to lunar distant retrograde orbit

Explore



Asteroid Redirect Crewed Mission:

Orion and Space Launch System based crewed rendezvous and sampling mission to the relocated asteroid

Asteroid Redirect Mission Objectives



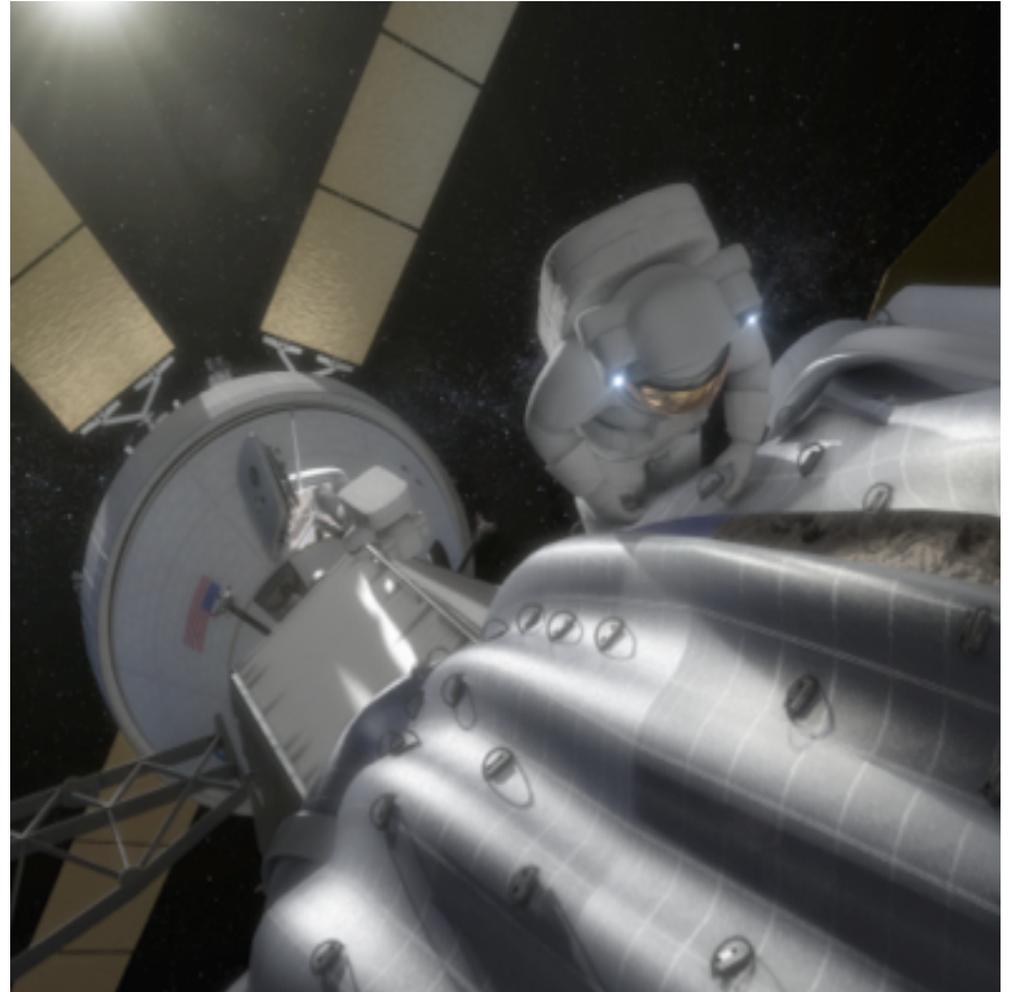
- Conduct a human exploration mission to an asteroid in the mid-2020's, providing systems and operational experience required for human exploration of Mars.
- Demonstrate an advanced solar electric propulsion system, enabling future deep-space human and robotic exploration with applicability to the nation's public and private sector space needs.
- Enhance the detection, tracking and characterization of Near Earth Asteroids, enabling an overall strategy to defend our home planet.
- Demonstrate basic planetary defense techniques that will inform impact threat mitigation strategies required to defend our home planet.
- Pursue a target of opportunity that benefits scientific and partnership interests, expanding our knowledge of small celestial bodies and enabling the mining of asteroidal resources for commercial and exploration needs.

Asteroid Redirect Mission

Builds on Investments Already Being Made by NASA



- **ARM integrates several building blocks of human space exploration to initiate deep space exploration**
 - ISS experience
 - Orion and SLS
 - SEP and other technologies
- **Contributes significantly to the extension of the human exploration of space beyond LEO in an affordable and sustainable way**
 - Operate 1000 times farther than LEO for the first time in 4 decades.
 - Longer duration beyond LEO crewed mission than ever



Near Earth Object Identification – Key Assets



Catalina Sky Survey

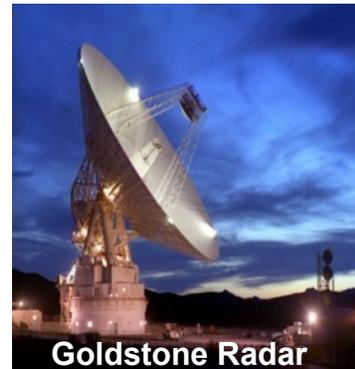


University of Arizona – Tucson

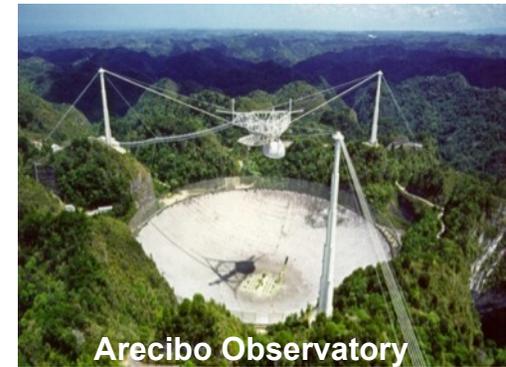


NEOWISE reactivated and dedicated to NEO Search & Characterization

Utilize Radar (Goldstone and Arecibo) increased time for NEO observations.



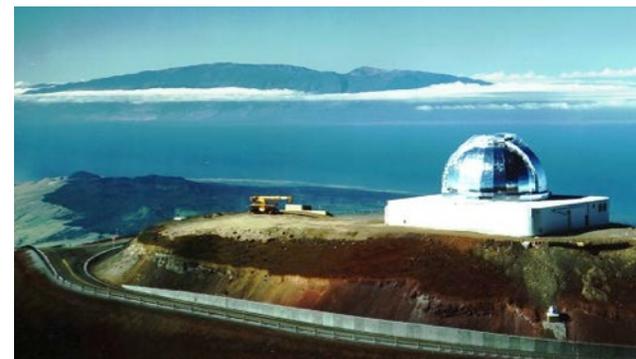
Goldstone Radar



Arecibo Observatory

NASA InfraRed Telescope Facility (IRTF)

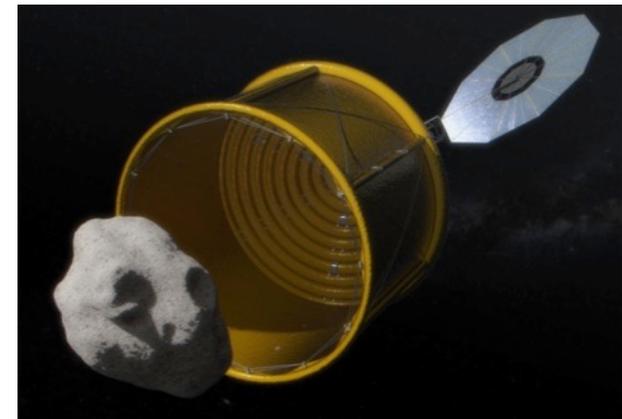
- Increase On-call for Rapid Response.
- Improve Instrumentation for Spectroscopy and Thermal Signatures.



Asteroid Redirect Robotic Mission Concept Option A



- **Rendezvous with small less than 10 meter mean diameter Near Earth Asteroid (NEA)**
 - Capture <1000 metric ton rotating NEA
 - Demonstrate planetary defense techniques
 - Maneuver to stable, crew accessible lunar Distant Retrograde Orbit (DRO)
- **Candidate target is 2009 BD**
 - 5 meter mean diameter and < 145 metric tons
 - Launch mid-2019*; Crew accessible after 2/2024
- **Additional candidate targets expected to be discovered and characterized at the rate of approximately 5 per year**
- **Other candidates under evaluation**
 - Recent Spitzer observation of 2011 MD which is crew accessible in August 2025
 - 2014 BA3 crew accessible in early 2025
 - 2013 EC 20 crew accessible in late 2025

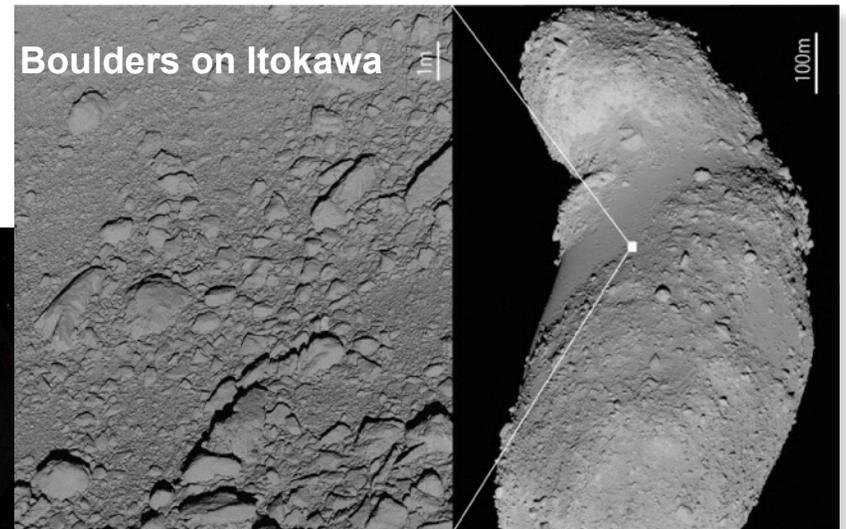


* Launch vehicle dependent

Asteroid Redirect Robotic Mission Concept (Option B)



- Rendezvous with a larger (~100+meter diameter) NEA
 - Collect ~2-4 meter diameter boulder (~10-70 metric tons)
 - Perform deflection demonstration(s) and track to determine effect
 - Return boulder to same lunar orbit
- Candidate asteroid Itokawa
 - 2-3 meter, 18 ton boulder to DRO in 2025 (2019 robotic mission launch)*
- Other targets to be characterized by in situ observation and crew accessible in DRO in 2025
 - Bennu by OSIRIS-Rex
 - JU3 by Hayabusa 2
 - 2008 EV5 by radar or other means



* Launch vehicle dependent

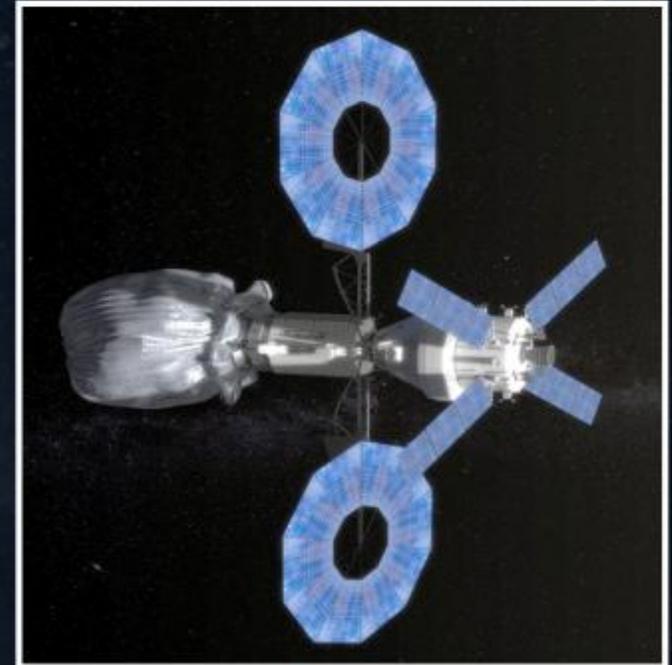
Asteroid Redirect Crewed Mission Overview



Deliver crew on SLS/Orion



Orion Docks to Robotic Spacecraft



Return crew safely to Earth with asteroid samples in Orion

EVA from Orion to retrieve asteroid samples



Crewed Mission Trajectory: Earliest Mission for 2009BD

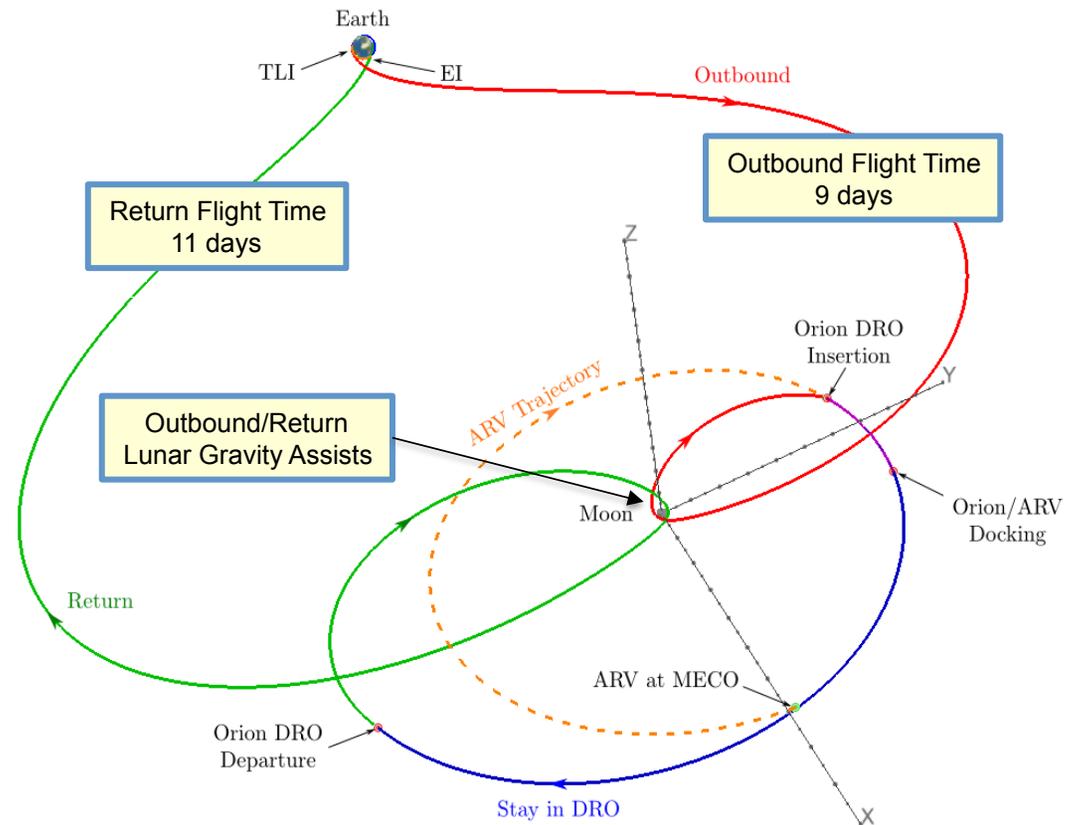


- MECO Epoch: 2024-May-16 14:36:08 TDB
- Entry velocity: 10.99 km/s

- Total iCPS Δv : 2820 m/s (All iCPS capacity)
- Total Orion Δv : 1010 m/s
- Total Mission Duration: 25.65 days

- Outbound
 - Flight Day 1 – Launch/TLI
 - Flight Day 1-7 – Outbound Trans-Lunar Cruise
 - Flight Day 7 – Lunar Gravity Assist
 - Flight Day 7-9 – Lunar to DRO Cruise
- Joint Operations
 - Flight Day 9-10 – Rendezvous
 - Flight Day 11 – EVA #1
 - Flight Day 12 – Suit Refurbishment, EVA #2 Prep
 - Flight Day 13 – EVA #2
 - Flight Day 14 – Contingency/Departure Prep
 - Flight Day 15 – Departure
- Inbound
 - Flight Day 15 – 20 – DRO to Lunar Cruise
 - Flight Day 20 – Lunar Gravity Assist
 - Flight Day 20-26 – Inbound Trans-Lunar Cruise
 - Flight Day 26 – Earth Entry and Recovery

Mission Duration and timing of specific events will vary slightly based on launch date and trajectory strategy



Outbound Flight Time: 8 days, 9 hrs
 Return Flight Time: 11 days, 6 hrs
 Rendezvous Time: 1 day
 DRO Stay Time: 5 days

Asteroid Redirect Mission Provides Capabilities For Deep Space/Mars Missions



In-space Power and Propulsion :

- High Efficiency Solar Arrays and SEP advance state of art toward capability required for Mars
- Robotic ARM mission 40kW vehicle components prepare for Mars cargo delivery architectures
- Power enhancements feed forward to Deep Space Habitats and Transit Vehicles

High Efficiency
Large Solar Arrays

Solar
Electric
Propulsion
(SEP)

Exploration
EVA
Capabilities

EVA:

- Build capability for future exploration through Primary Life Support System Design which accommodates Mars
- Test sample collection and containment techniques including planetary protection
- Follow-on missions in DRO can provide more capable exploration suit and tools

Crew Transportation and Operations:

- Rendezvous Sensors and Docking Systems provide a multi-mission capability needed for Deep Space and Mars
- Asteroid Initiative in cis-lunar space is a proving ground for Deep Space operations, trajectory, and navigation.

Deep Space
Rendezvous
Sensors & Docking
Capabilities

Next Steps – Pathways into the Proving Ground of Cis-Lunar Space and On to Mars



Human Exploration Pathways

Mastering the Fundamentals

- Extended Habitation Capability (ISS)
 - High Reliability Life Support
- Deep-space Transportation (SLS and Orion)
- Exploration EVA
- Automated Rendezvous & Docking
- Docking System

Pushing the Boundaries

- Deep Space Operations
 - Deep Space Trajectories
 - Deep Space Radiation Environment
 - Integrated Human/Robotic Vehicle
- Advanced In-Space Propulsion (SEP)
 - Moving Large Objects
- Exploration of Solar System Bodies

On to Mars

Towards Earth Independent
Crewed Orbit of Mars or Phobos/Deimos

Land on Mars

To Moon And Beyond
(International and/or Industry Partners)

To Mars

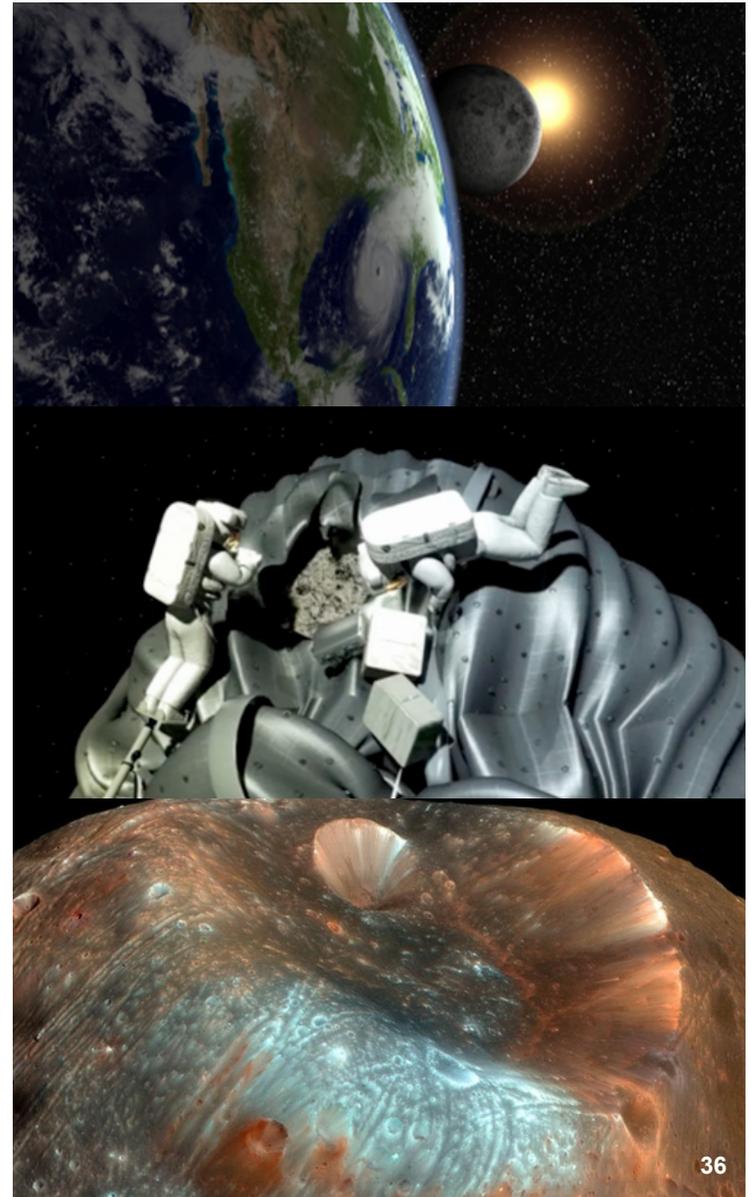
Bringing the moon within
Earth's economic sphere.

Solar System Exploration Research Virtual Institute (SSERVI)

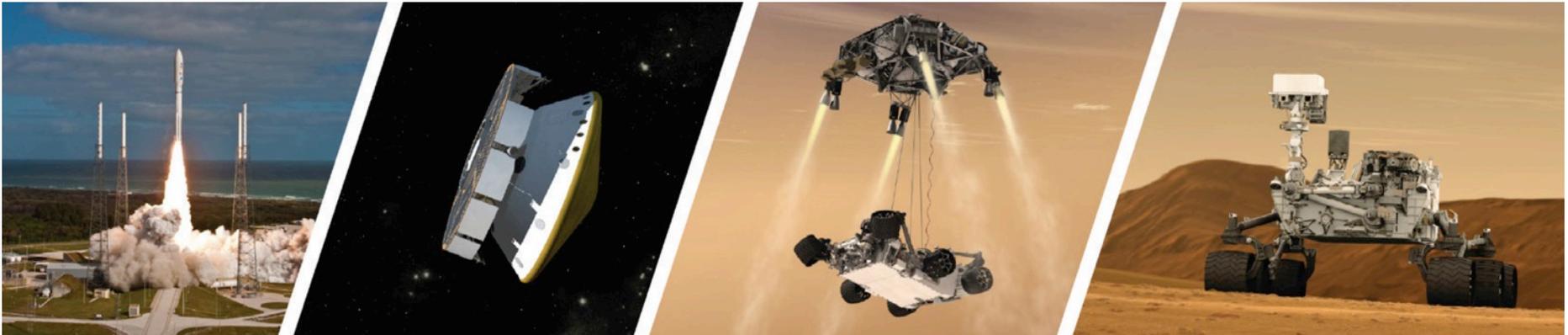


SSERVI provides scientific, technical and mission-defining analyses for relevant NASA programs, planning and space missions, including:

- The role of the Moon, NEAs, Phobos & Deimos in revealing the origin and evolution of the inner Solar System
- Moon, NEA, and Martian moon investigations as windows into planetary differentiation processes
- Near-Earth asteroid characterization (including NEAs that are potential human destinations)
- Lunar structure and composition
- Regolith of Target Body(s)
- Dust and plasma interactions on Target Body(s)
- Volatiles (in its broad sense) and other potential resources on Target Body(s)
- Innovative observations that will advance our understanding of the fundamental physical laws, composition, and origins of the Universe



Mars 2020 Collaboration Among SMD, HEOMD and STMD



Mars 2020 will seek signs of past life on Mars, collect and store a set of soil and rock samples that could be returned to Earth in the future, and test new technology to benefit future robotic and human exploration of Mars.

HEOMD / SMD / STMD are jointly sponsoring investigations to address high priority strategic knowledge gaps and technology development objectives for Human Exploration

- Mars Entry, Descent and Landing Instrumentation (MEDLI) to refine atmospheric entry models to inform future landing system design
- Exploration technology payloads that make significant progress towards filling at least one major Strategic Knowledge Gap.



Lunar CATALYST



Lunar Cargo Transportation And Landing by Soft Touchdown

BRINGING THE MOON INTO EARTH'S ECONOMIC SPHERE

Accelerating private-sector lunar landing capabilities
with NASA expertise using public-private partnerships



STATUS

Currently evaluating
proposals with partner
selections in April and
executed agreements in
May 2014

Evolutionary Capabilities



EARTH RELIANT

Return to Earth: hours



PROVING GROUND

Return to Earth: days



EARTH INDEPENDENT

Return to Earth: many months

Transportation

EARTH-BASED SUPPORT: HIGH
Low-Earth Orbit

EARTH-BASED SUPPORT: LIMITED
Cis-lunar Space

EARTH-BASED SUPPORT: NEGLIGIBLE
Mars and Beyond

Crew Transit

- Routine crew rotations via international and industry partners
- Earth Re-entry: 3,000°F

- 2-4 crew launch aboard evolvable Space Launch System
- Orion Earth Re-entry: 5,300°F

- Up to 6 crew launch aboard Space Launch System
- Orion Earth Re-entry: 5,500°F

Cargo Transit

- Routine cargo deliveries to LEO via industry and international partners

- 105t SLS to lunar vicinity

- 130t SLS to Mars and beyond
- Crew must live and work without resupply from Earth

Propulsion & Energy Storage

- Large scale use of solar panels

- Demonstrate potential resource utilization techniques
- Demonstrating high-power, advanced solar electric propulsion

- Potential to expand resource utilization
- Utilizing large-scale solar electric and other advanced propulsion

Planetary rendezvous & landings

- Planetary rendezvous with strong gravity field

- Deep Space Rendezvous; gravity free
- Lunar surface landers

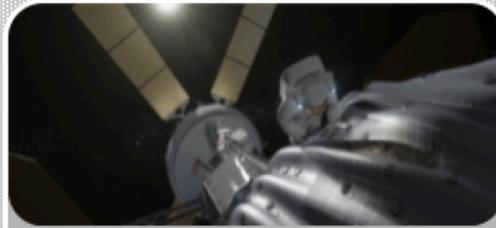
- Phobos/Deimos micro-gravity Rendezvous
- Mars entry, descent, landing on surface

Evolutionary Capabilities



EARTH RELIANT

Return to Earth: hours



PROVING GROUND

Return to Earth: days



EARTH INDEPENDENT

Return to Earth: many months

Working In Space

EARTH-BASED SUPPORT: HIGH
Mastering the Fundamentals

EARTH-BASED SUPPORT: LIMITED
Pushing the Boundaries

EARTH-BASED SUPPORT: NEGLIGIBLE
Exploring Independently

Exploration and Science

- Microgravity science and human physiology research

- Sampling asteroid for return to Earth for analysis

- Mars moons and surface exploration and search for life with in-situ analysis

Communicating with Earth

- Immediate and continuous support from mission control

- Limited delay with minimal crew impact

- Independent and self-reliant crew operates with up to 40 min. delay

Spacewalk and Mobility

- Zero-g outside spacecraft for short distances

- Zero-g systems for short-distance, exploration

- Surface exploration in partial gravity with longer distance and duration

Spacecraft Assembly & Maintenance

- Crew-assisted ISS Assembly
- Frequent deliveries & servicing

- Limited deliveries requires more efficient systems with common, interchangeable parts

- Maintenance with only the parts and tools they carry or produce in-situ

Human-Robotic Interactions

- Testing safety and control methods for efficient human-robotic teams

- Human- robot teams, with periods where robots are left alone

- Pre-deployed equipment depends on robots until humans arrive, then human-robot teams share critical tasks

In-situ Resource Utilization

- Recycle and reuse water and trash

- Learning to recycle destination resources for fuel, water, oxygen, and building materials

- Crew harvests destination resources to create fuel, water, oxygen, and building materials

Evolutionary Capabilities



EARTH RELIANT

Return to Earth: hours

EARTH-BASED SUPPORT: HIGH
Mission Duration:
6-12 months



PROVING GROUND

Return to Earth: days

EARTH-BASED SUPPORT: LIMITED
Mission Duration:
1-12 months



EARTH INDEPENDENT

Return to Earth: many months

EARTH-BASED SUPPORT: NEGLIGIBLE
Mission Duration:
2-3 years

Staying Healthy

Spacecraft Life Support Systems

- Developing onboard life support systems for long-duration missions

- Validating onboard recycling and regenerating life support systems without resupply

- Living and working in spacecraft that must fully support crew for years

Human Health and Performance

- Studying space environment health risks and testing solutions

- Applying health and performance risk mitigation techniques

- Living in space for years while maintaining crew health and performance

Autonomous Medicine

- Developing integrated medical capability and crew-reliant medical care

- Testing semi-autonomous integrated medical capability and crew-reliant medical treatment

- Autonomous medical capability and medical crewmember for diagnosis and treatment

Environmental Monitoring

- Testing on-board environmental monitors with ground validation

- Demonstrating onboard environmental monitoring systems (no sample return)

- Monitoring crew environment for hazards, eliminating environmental emergencies

Advanced Space Suits

- Testing next-generation space suits

- Demonstrating advanced space suits in deep space

- Conducting EVAs in unprecedented planetary environments

EVOLVABLE MARS CAMPAIGN

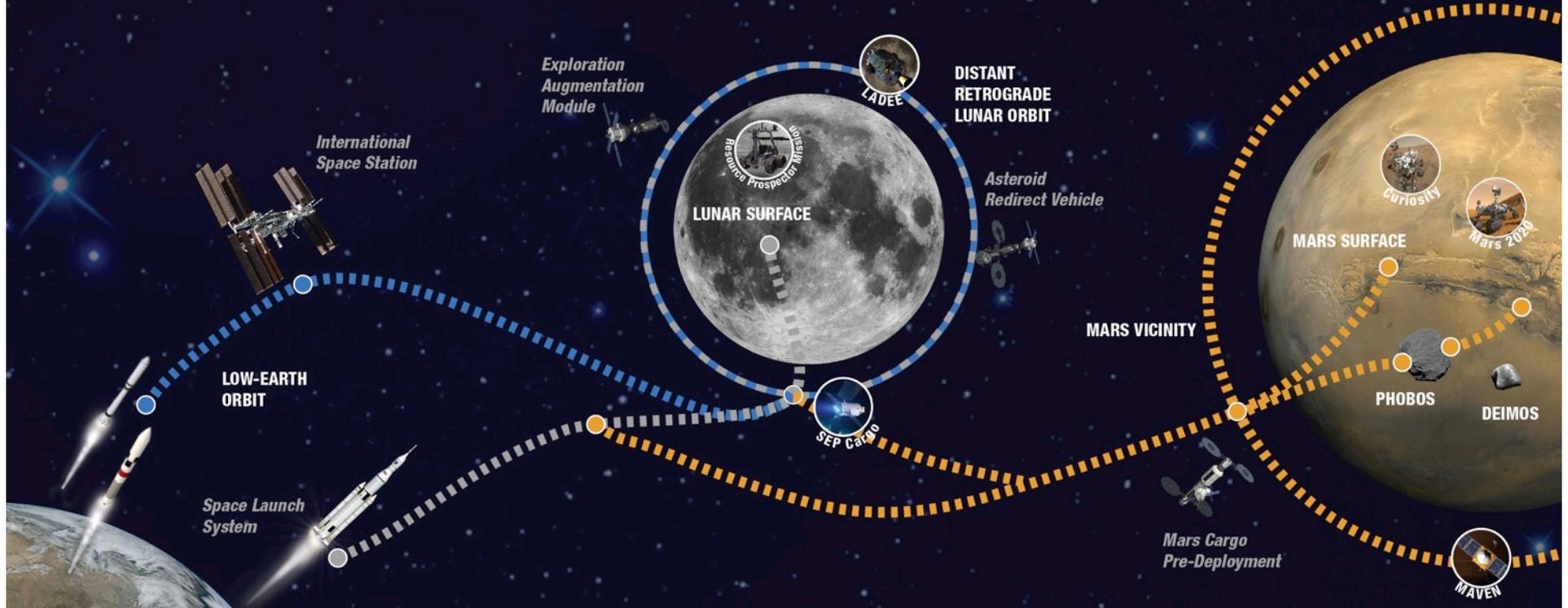
A Pathways Approach to Exploration



EARTH DEPENDENT

PROVING GROUND

EARTH INDEPENDENT



THE TRADE SPACE

Across the Board | Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities

Cis-lunar Trades |

- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

Mars Vicinity Trades |

- Split versus monolithic habitat
- Cargo pre-deployment
- Mars Phobos/Deimos activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses

Human Space Exploration Pathway Evaluation Criteria



- Sustainability
 - Leverage existing assets
 - Development of multi-mission use systems
 - Near term cadence of missions
 - Resource utilization
 - Develops infrastructure needed to enable solar system pioneering
- Exploration and Science objective satisfaction
 - Solar system planetary body exploration and discovery
 - Human health and research
- Risk
 - Human health
 - Technology development
 - System reliability
 - Critical events
- Affordability - executable with current budget with modest increases
- Partnerships
 - Commercial
 - International
 - Academia
 - Other Government Agencies

A space-themed background featuring a dark starry sky. In the lower-left foreground, the blue and white horizon of Earth is visible. The middle ground is filled with numerous small, grey, irregularly shaped asteroids or debris floating in space. A faint, glowing arc of light is visible in the upper right quadrant.

A DEEPER VISION, **A BOLDER MISSION**, ONE STEP AT A TIME

Step One:
2014