Exploration Research and Technology Overview

Presented to the NASA Advisory Council (TI&E Committee)

Mr. James Reuter, Associate Administrator (Acting) for NASA STMD | 03.26.18

NASA's Exploration Focus

- Provides \$19.9B, including \$10.5B to lead an innovative and sustainable campaign of exploration and lead the return of humans to the Moon for long-term exploration and utilization followed by human missions to Mars and other destinations.

- Refocuses existing NASA activities towards exploration, by redirecting funding to innovative new programs and providing additional funding to support new public-private initiatives.

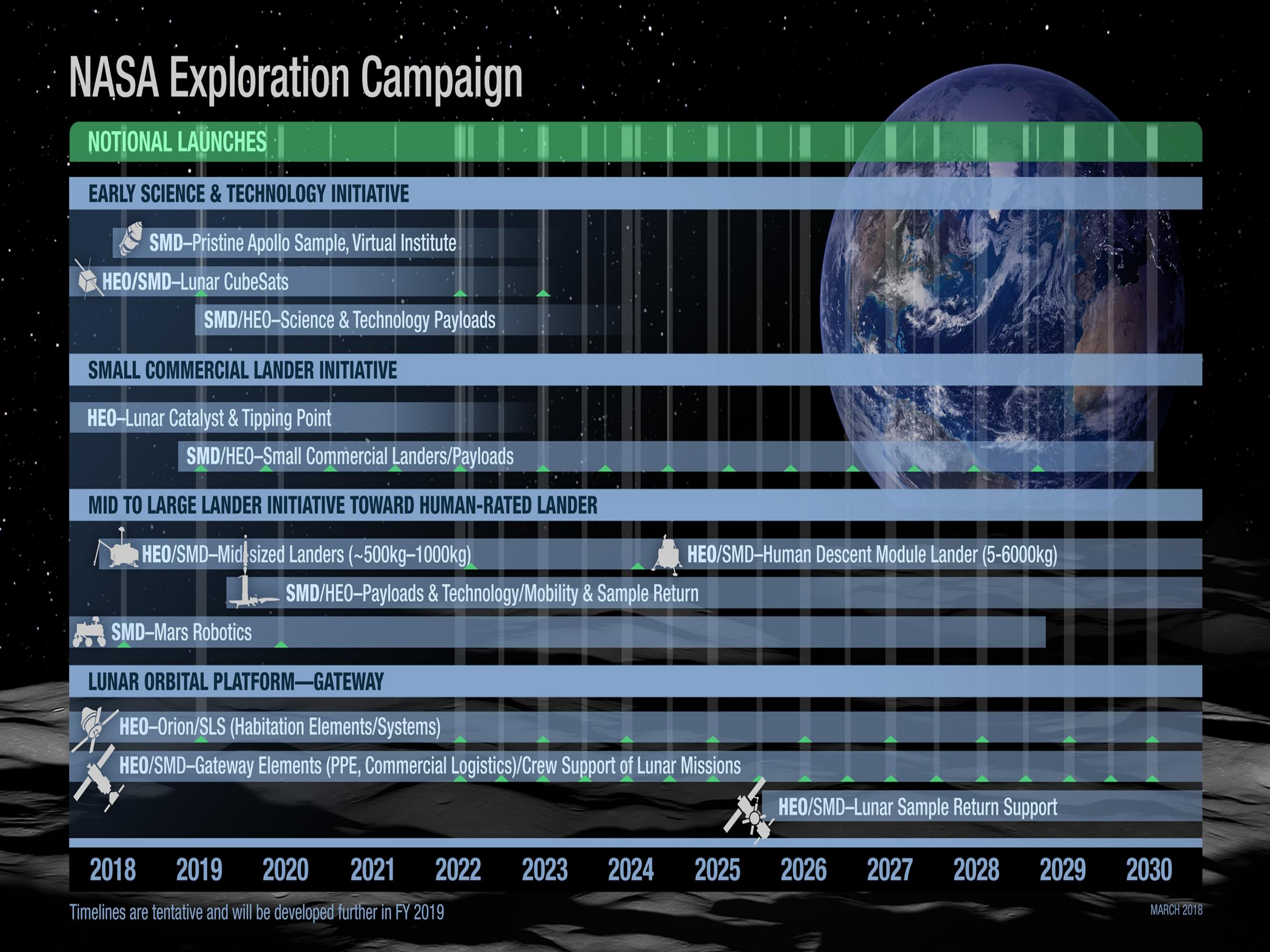
- Conducts uncrewed SLS/Orion first flight in 2020, leading to Americans around the Moon in 2023. This will be the first human mission to the moon since Apollo 17 in 1972, and will establish U.S. leadership in cislunar space.

Exploration Campaign

- Prioritize human exploration and related activities
- Expand Exploration by
  - Providing funding to start transition of low Earth orbit human space flight operations to commercial partners
  - Pursuing a Cislunar strategy that establishes U.S. preeminence to, around, and on the Moon, including commercial partnerships and innovative approaches, to achieve human and science exploration goals

	Fiscal Year						
	Enacted	CR	Request		Notional		
Budget Authority ($ in millions)	2017	2018	2019	2020	2021	2022	2023
Deep Space Exploration Systems	$4,184.0	$4,222.6	$4,558.8	$4,859.1	$4,764.5	$4,752.5	$4,769.8
Exploration Research and Technology	$826.5	$820.8	$1,002.7	$912.7	$912.7	$912.7	$912.7
LEO and Spaceflight Operations	$4,942.5	$4,850.1	$4,624.6	$4,273.7	$4,393.3	$4,430.3	$4,438.0
Exploration Campaign CoF	$45.5	$22.4	$44.8	$0.0	$0.0	$0.0	$0.0
Elements of Science	$39.0	$36.0	$268.0	$268.0	$268.0	$268.0	$268.0
EXPLORATION CAMPAIGN TOTAL	$10,037.5	$9,951.9	$10,498.9	$10,313.5	$10,338.5	$10,363.5	$10,388.5

*Elements of Science includes funding for the new Lunar Exploration and Discovery program and technology development and studies related to future exploration-related Mars missions.


NASA Exploration Campaign
NOTIONAL LAUNCHES
EARLY SCIENCE & TECHNOLOGY INITIATIVE
SMD–Pristine Apollo Sample, Virtual Institute
HEO/SMD–Lunar CubeSats
SMD/HEO–Science & Technology Payloads
SMALL COMMERCIAL LANDER INITIATIVE
HEO–Lunar Catalyst & Tipping Point
SMD/HEO–Small Commercial Landers/Payloads
MID TO LARGE LANDER INITIATIVE TOWARD HUMAN-RATED LANDER
HEO/SMD–Mid-sized Landers (~500kg–1000kg)
HEO/SMD–Human Descent Module Lander (5-6000kg)
SMD/HEO–Payloads & Technology/Mobility & Sample Return
SMD–Mars Robotics
LUNAR ORBITAL PLATFORM—GATEWAY
HEO–Orion/SLS (Habitation Elements/Systems)
HEO/SMD–Gateway Elements (PPE, Commercial Logistics)/Crew Support of Lunar Missions
HEO/SMD–Lunar Sample Return Support
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
Timelines are tentative and will be developed further in FY 2019
MARCH 2018

New Exploration Research & Technology (ER&T)

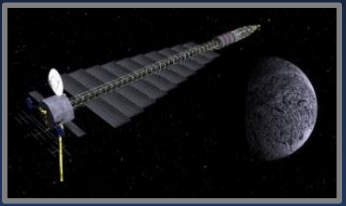
- Research & development of new technologies and capabilities that enhances and enables deep space exploration.
- Enables greater focus on innovative ways to further humankind’s exploration from conception to testing to spaceflight.
- Consolidates Space Technology Mission Directorate and Advanced Exploration Systems content, integrating and refocusing these activities toward Space Exploration.
- ER&T also includes the Human Research Program (HRP), which continues to conduct cutting edge research on the effect of spaceflight and the space environment on the human body.

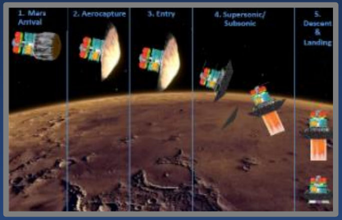
ER&T Guiding Principles

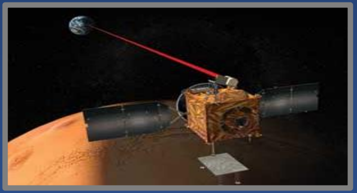
- Provide ER&T programs and projects with a clear primary customer, and a focus on supporting exploration (while continuing to leverage and support U.S. industry).
- ER&T will fund projects along the entire Technology Readiness Level spectrum
- Ensure a continuing focus on lower Technology Readiness Level activities.
- Embrace competition and public-private partnerships (with commercial industry, universities, and other government agencies) that meet NASA exploration needs and foster commercial expansion in LEO, cislunar space, and beyond.
- Where appropriate, ER&T will work with the Science Mission Directorate on exploration-related technology and research that also has relevance to achieving science goals.

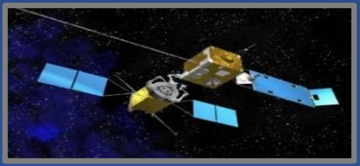
ER&T Key Technology Focus Areas

- ❖ Advanced environmental control and life support systems and In-Situ Resource Utilization
- ❖ Power and propulsion
- ❖ Advanced communications, navigation and avionics
- ❖ In-space manufacturing and on-orbit assembly
- ❖ Advanced materials
- ❖ Entry, Descent and Landing
- ❖ Autonomous operations
- ❖ Research to enable humans to safely and effectively operate in various space environments



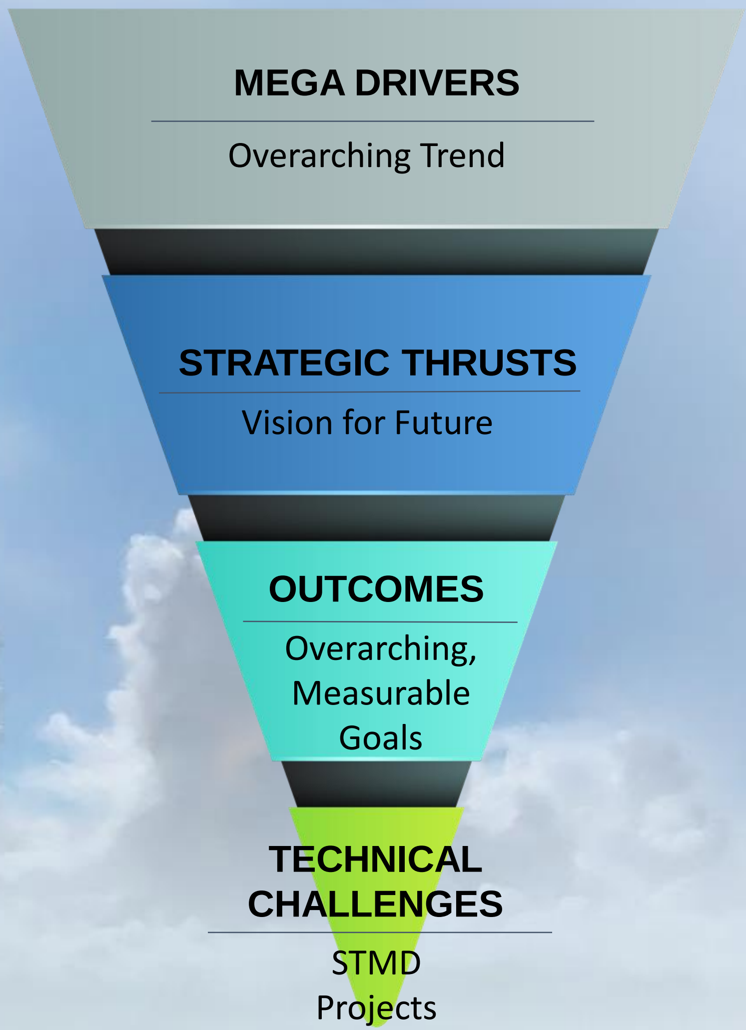






STMD Strategic Framework

Planned Framework



Definitions

Overarching trends that have, are, and will largely shape the course of civilian space research over many years. They are a product of analysis of space industry trends and conversations with STMD customers (e.g. HEOMD, SMD, commercial space, U.S. industry, & other governmental agencies).

Altogether the Strategic Thrusts constitute a vision for the future of civilian space, representing STMD's overarching view of the civilian space community's response to the Mega-Drivers.

Measurable goals within the Strategic Thrusts that STMD chooses to pursue through joint efforts across the space community. These are goals that STMD can play a significant role in enabling, but are more than NASA alone can achieve.

Represents the product and/or capability to be delivered by STMD to enable the community-level outcomes. STMD projects and solicitations are formulated to directly address Technical Challenges.

Mega Drivers

Increasing Access

Major Trends:

- Lowering **costs**
- Increasing launch **availability**
- Increasing use of **reusability**
- Decreasing **travel time**
- Diversifying **platforms** (e.g. CubeSats)
- Increasing demand for beyond-LEO crewed missions
- New accessible **destinations**

Accelerating Pace of Discovery

Major Trends:

- **Major discoveries** of potentially life-harboring icy moons and exoplanets
- Growing urgency for **Earth-Moon-Sun science** discovery and understanding
- Humanity's desire for ambitious **exploration** of the solar system and ultimately interstellar travel

Democratization of Space

Major Trends:

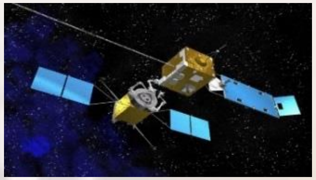
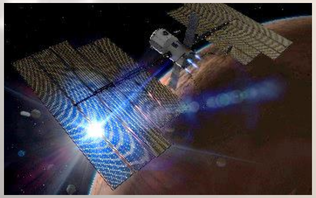
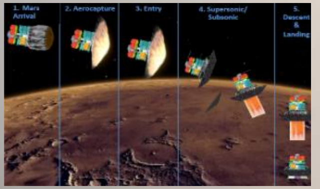
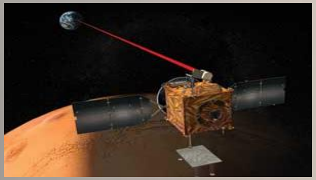
- Broadening **participation** spectrum, from governments to citizens
- Growth in **private investment** in space
- **Public-private partnerships**
- **International** collaborations

Growing Utilization of Space

Major Trends:

- Space market **diversification** (e.g. servicing, manufacturing, mining, debris removal, tourism)
- Space industry **growth** well surpassing U.S. average GDP growth
- Space-based solutions addressing growing **global challenges**
- Increasing **safety** and **resiliency**

Strategic Thrusts

October		Now
ST1. Expand Utilization of Near-Earth Space		***ST1. Accelerate the Industrialization of Space***
ST2. Enable Efficient & Safe Transportation Through Space		***ST2. Enable Safe and Efficient Transportation Into and Through Space***
ST3. Increase Access to Planetary Surfaces		***ST3. Increase Access to Planetary Surfaces***
ST4. Enable the Next Generations of Science Discoveries		***ST4. Expand Capabilities through Robotic Exploration and Discovery***
ST5. Enable Humans to Live & Explore in Space and on Planetary Surfaces		***ST5. Enable Humans to Live and Work in Space and on Planetary Surfaces***
ST6. Grow & Utilize the U.S. Industrial and Academic Base		***ST6. Grow and Utilize the U.S. Industrial and Academic Base***

Outcomes

STMD develops technologies to enable the following outcomes:

	2020s	2030s	2040s +
ST1 *Industrialization*	Reliable, industrial-scale, in-space refueling, reconfiguration, and maintenance services introduced.	Commercially viable research and manufacturing infrastructure deployed in cis-lunar space.	Demonstrated robotic assembly of systems in space using parts manufactured with space resources.
ST2 *Transport*	Affordable and responsive launch systems introduced for delivering the next generation of small and cube satellite platforms to space.	More efficient and affordable propulsion systems deployed to enable more capable and faster deep space robotic missions.	Routine, low-cost transportation to and from Mars.
ST3 *Entry, Descent, & Landing*	Precisely and affordably land commercial and NASA payloads on the Moon.	Routine landings of people on the Moon. People safely and precisely landed on Mars.	People landed safely, routinely, and affordably on the Moon and Mars.
ST4 *Exploration Pathfinding*	Robotically scout and prepare potential sites for future human missions to the Moon to inform site selection and mission planning.	Demonstrate ISRU propellant production, storage, and transfer on Mars.	Demonstrate technologies to support a sustained human presence on Mars and beyond.
ST5 *Live & Work*	People exploring previously inaccessible locations on and around the Moon.	A sustainable and increasingly independent human outpost established on the Moon. Initial Human presence on the surface of Mars.	Routinely visit new sites across Mars to conduct human exploration and science.
ST6 *Industry & Academia*	Commercial provision of routine sub-orbital flights.	Commercially viable research, manufacturing, and habitation facilities deployed in space.	Public access to other planetary surfaces enabled.

Example Outcomes – Subset of Preliminary Content

Path Forward

Planned Framework	Development Timeline	Current Status
MEGA DRIVERS Overarching Trend	May 2017 - Aug 2017	**Vetting** with external community
STRATEGIC THRUSTS Vision for Future	Jun 2017 - Feb 2018	**Refining** in response to proposed budget guidance
OUTCOMES Overarching, Measurable Goals	Jun 2017 - Apr 2018	**Refining** and **decomposing**
TECHNICAL CHALLENGES STMD Projects	Dec 2017 - Dec 2018	In **development**, evolving priorities and ongoing activities

FY 18 Accomplishments

Small Spacecraft

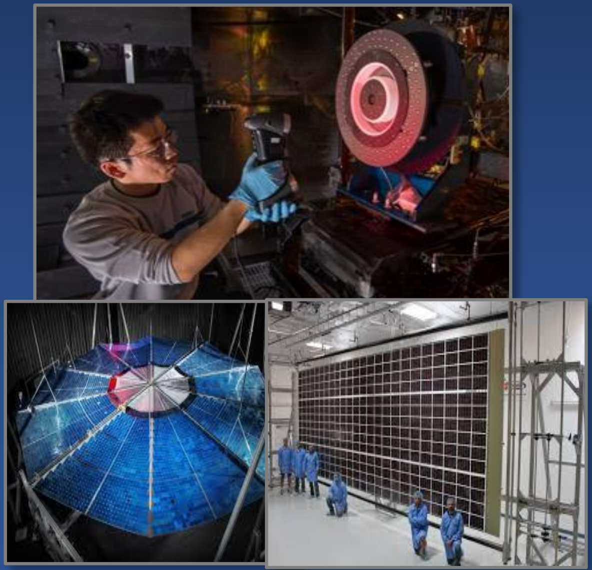
Two small spacecraft (Integrated Solar Array and Reflect Antenna and Optical Communication and Sensor Demonstration) missions were successfully launched aboard Orbital ATK’s Cygnus spacecraft.

Station Explorer for X-ray Timing and Navigation Technology (SEXTANT)

Aboard ISS demonstrated fully autonomous X-ray navigation in space — a capability that could revolutionize NASA’s ability in the future to pilot robotic spacecraft to the far reaches of the solar system and beyond.

In Space Robotics Manufacturing Assembly

All 3 contractors completed design, build and test/demo phases in year 1 successfully



Solar Electric Propulsion

Completed preliminary design review for Power & Propulsion Element qualification system

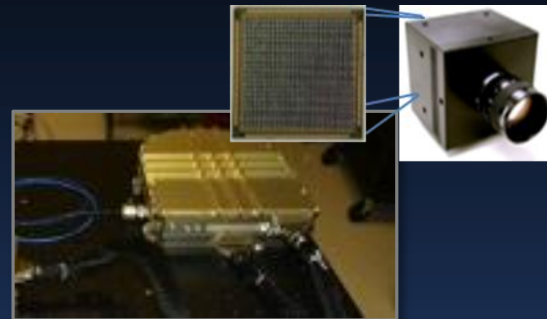
Kilopower

Testing began on 1 kW ground demonstration system- could be used for an affordable fission nuclear power system to enable long-duration stays on planetary surfaces.

FY 18 Accomplishments (Cont.)

Laser Communication Relay Demonstration

Successfully entered into the implementation phase and began system I&T to support a 2019 launch on STPSat-6



Deep Space Optical Communication

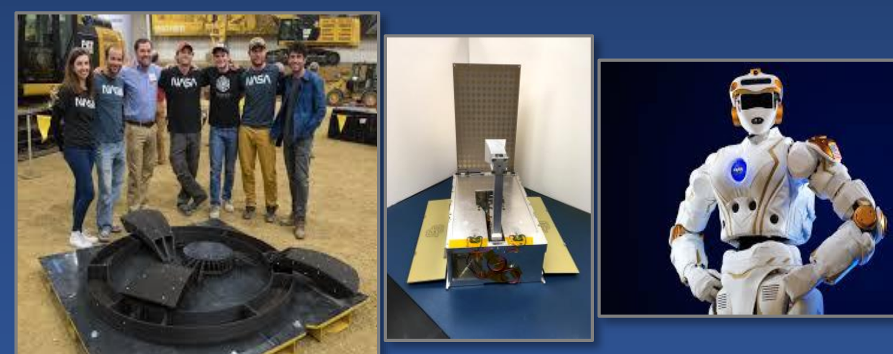
Completed ground testing to retire risk for its demonstration flight and began formulation for flight demonstration on the Psyche mission

SBIR/STTR Industry Day

Over 450 innovators from across the country participated in 2nd workshop

Flight Opportunities Testing for Precision Landing Technologies

Successful flight test of a Navigation Doppler Lidar and Lander Vision System for future robotic and crewed missions

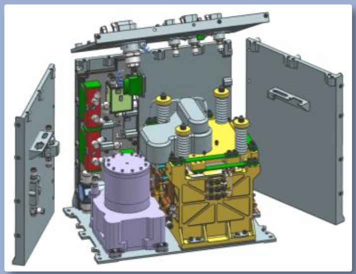


Centennial Challenges Program

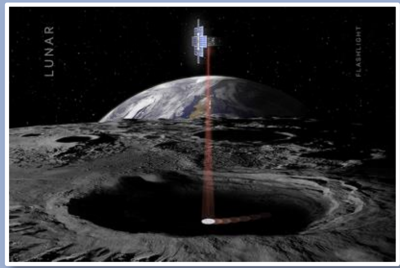
Awarded more than $1.5 million for technology solutions toward the Cube Quest, 3D Printed Habitat and the Space Robotics Challenges.

FY 19 Milestones in Key Focus Areas

Advanced environmental control and life support systems and In-Situ Resource Utilization



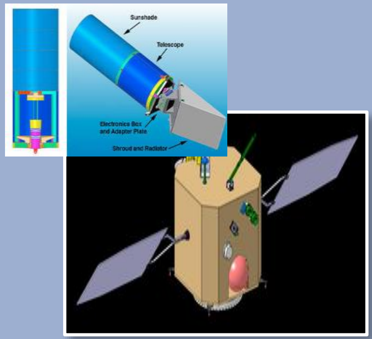
MOXIE
November 2018
Deliver to Mars
2020 Project



Lunar Flashlight
Flight Mission EM-1
December 2019

Lunar Infrared
Flight Missions on EM-1
December 2019

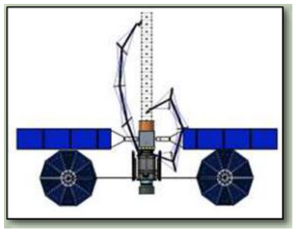
Space Craft Oxygen Recovery (SCOR)
Technology efforts will be completed with prototype hardware delivered to NASA



Korea Pathfinder Lunar Orbiter (KPLO)
2019 Delivery of ShadowCam

In-space manufacturing and on-orbit assembly

Orbital ATK



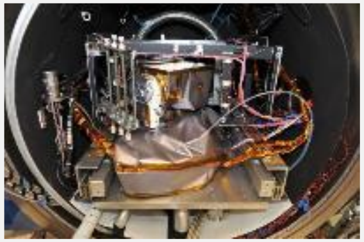
Space Systems Loral

Made In Space

In Space Robotic Manufacturing and Assembly
In 2019 will transition one or more concepts from ground to flight demonstration

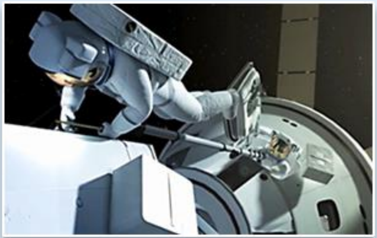
FY 19 Milestones in Key Focus Areas

Advanced communications, navigation and avionics



Laser Comm Relay Demo
June 2019
Complete KDP-E and launch

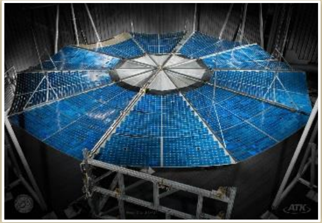
Deep Space Optical Comm
June 2019
Complete CDR for the flight terminal



High Performance Spaceflight Computing (HPSC)
April 2019
Completion of critical design

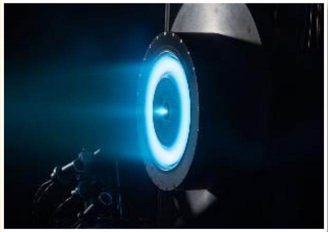
Power and propulsion technologies for exploration

Nuclear Thermal Propulsion
June 2019
System testing in NTREES and **later in 2019** risk mitigation and feasibility assessment for ground demo



Extreme Environment Solar Power
September 2019
Deliver test articles

eCryo
July 2019
Complete SHIIVER testing



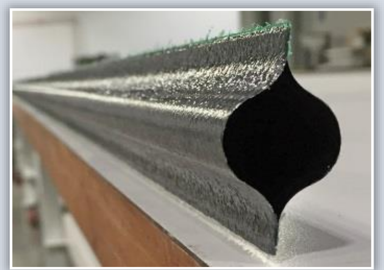
Solar Electric Propulsion Develop and test qualification hardware

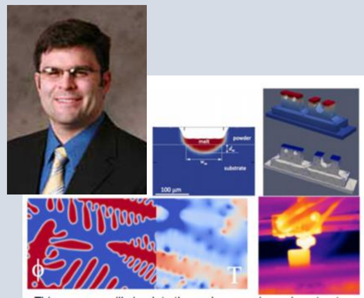
Lunar IceCube
Flight Mission EM-1
December 2019

FY 19 Milestones in Key Focus Areas

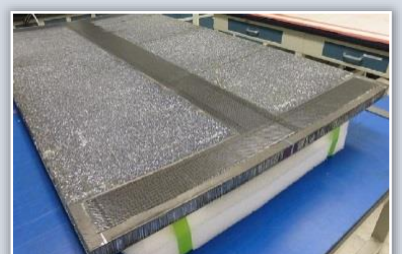
Advanced materials

Deployable Composite Boom
March 2019
QM Boom structural characterization test



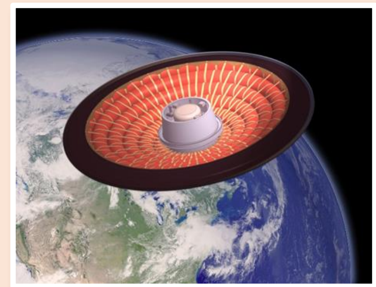


Early Stage Innovation 2017
Daniel Lewis -
Develop an integrated thermal-chemical-microstructural simulation approach for additive manufacturing

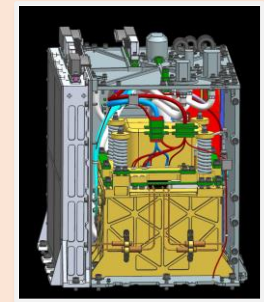


Composite Technology for Exploration
July 2019
Complete testing of longitudinal and circumferential joint manufacturing and testing

Entry, Descent, and Landing



Low Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) 2019: KDP-C and CDR



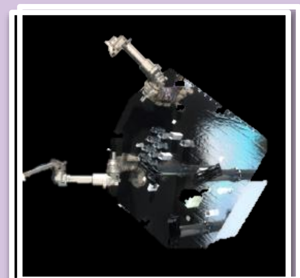
Terrain Relative Navigation (TRN)
February 2019
Deliver to Mars 2020 Project

MEDLI2
April 2019
Hardware Delivery for integration on Mars 2020 entry system

SPLICE
March 2019
Complete NDL ETU environmental testing

FY 19 Milestones in Key Focus Areas

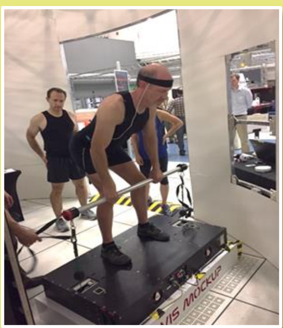
Autonomous Operations



Satellite Servicing
Continues development and ground testing including robotics, tools, avionics, sensors

Astrobee
September 2018
Operations Demo aboard ISS

Research to enable humans to safely and effectively operate in various space environments



Advanced Exploration Exercise System
Develop and complete testing in preparation for ISS deployment

Release NASA research solicitations to national biomedical research community to better address exploration spaceflight health, performance, and space radiation risks, adding to over 170 research tasks already active within HRP

ER&T Program Structure

- **Early Stage Innovation and Partnerships**
  - *Space Technology Research Grants Program (Fellowships, Faculty Research and Institutes)*
  - *NASA Innovative Advanced Concepts (NIAC) Program Phase I and II*
  - *Center Innovation Funds (CIF)/Early Career Initiative (ECI)*
  - *Technology Transfer Program*
  - *Prizes and Challenges*
  - *Innovation Connector (iTech)*
  - *Agency Technology and Innovations (AT&I)*
- **Technology Maturation** – *Game Changing Development Program*
- **Technology Demonstration**
  - *Technology Demonstration Mission Program*
  - *Small Spacecraft Technology Program*
  - *Flight Opportunities Program*
- **Human Research Program**
- **SBIR & STTR Program**

ER&T FY 2019 Budget

Budget Authority ($M)	FY 2017 Op Plan	FY 2018 CR Plan	FY 2019	Notional Plan			
				FY 2020	FY 2021	FY 2022	FY 2023
Early Stage Innovation and Partnerships	**$ 89.7**		**$ 108.4**	**$ 103.0**	**$ 107.0**	**$ 107.0**	**$ 107.0**
Agency Technology and Innovation	$ 8.2		$ 8.2	$ 8.2	$ 8.2	$ 8.2	$ 8.2
Early Stage Innovation	$ 54.6		$ 72.1	$ 66.7	$ 72.7	$ 72.7	$ 72.7
Partnerships and Technology Transfer *	$ 26.9		$ 28.1	$ 28.1	$ 26.1	$ 26.1	$ 26.1
Technology Maturation	**$ 135.0**		**$ 216.5**	**$ 178.6**	**$ 180.8**	**$ 183.3**	**$ 183.5**
Technology Demonstration	**$ 262.8**		**$ 332.7**	**$ 293.1**	**$ 286.9**	**$ 284.4**	**$ 284.2**
Small Spacecraft, Flight Opportunities & Other Tech Demonstration	$ 83.6		$ 222.2	$ 223.2	$ 223.2	$ 234.2	$ 238.9
Restore/In-Space Robotic Servicing (ISRS)	$ 130.0		$ 45.3	$ 45.3	$ 45.3	$ 45.3	$ 45.3
Laser Comm Relay Demo (LCRD)	$ 25.7		$ 17.2				
Solar Electric Propulsion (SEP)	$ 23.4		$ 48.1	$ 24.6	$ 18.4	$ 4.9	
Human Research Program	**$ 140.0**		**$ 140.0**	**$ 140.0**	**$ 140.0**	**$ 140.0**	**$ 140.0**
SBIR and STTR	**$ 199.0**		**$ 205.0**	**$ 198.0**	**$ 198.0**	**$ 198.0**	**$ 198.0**
TOTAL	**$ 826.5 ****	**$ 820.8****	**$ 1002.7**	**$ 912.7**	**$ 912.7**	**$ 912.7**	**$ 912.7**

* Does not provide funding for Regional Economic Development (RED) in FY 19 and out-years
** Note: FY 2017 and FY 2018 numbers do not include any AES core funding

FY 2019 Early Stage Innovation

Budget Authority ($M)	FY 2017 Op Plan	FY 2018 Planning	FY 2019	Notional Plan			
				FY 2020	FY 2021	FY 2022	FY 2023
Early Stage Innovation	$ 54.6		$ 72.2	$ 66.7	$ 72.7	$ 72.7	$ 72.7

- Space Technology Research Grants
  - All solicitations for faculty led research will request proposals in several of the key areas of focus
  - Plan to release a solicitation for the next two Space Technology Research Institutes in FY18 – institute research and technology requirements will align with two of the key areas of focus
- Center Innovation Fund
  - Will direct Centers to solicit internal proposals aligned with Exploration objectives and the key areas of focus
- NASA Innovative Advanced Concepts
  - Will indicate strong preference for proposals that study advanced concepts to advance Exploration objectives

Technology Maturation (GCD) Restructure

Current Structure	Alignment to Key Areas of Focus (work in progress)
Advanced Life Support & ISRU	Advanced environmental control and life support systems & ISRU
Space Power & Propulsion	Power & Propulsion (includes NTP)
Lightweight Structures & Manufacturing	Advanced Materials
	Manufacturing & Assembly
Autonomy & Robotic Systems	Autonomous Operations
Space Observatory Systems	
Entry, Descent & Landing Systems	Entry, Descent & Landing Systems (includes Lander technologies)
High Bandwidth Comm, Nav and Avionics	Advanced Comm, Nav and Avionics

- **Adjusting FY 2019 content to better align with the Exploration Key Areas of Focus**

Mapping of TDM Projects to Key Areas of Focus

Key Areas of Focus	TDM Project
Advanced Comm, Nav and Avionics	Deep Space Atomic Clock (DSAC)
	Laser Comm Relay Demo (LCRD)
	Deep Space Optical Communication (DSOC)
Power & Propulsion	Green Propellant Infusion Mission (GPIM)
	eCryo
	Solar Electric Propulsion (SEP)
	Cryo Fluid Management (CFM)
Entry, Descent & Landing (includes lander technologies)	Terrain Relative Navigation (TRN)
	LeO-based Flight Test Inflatable Dec (LOFTID)
In-Space Manufacturing & Assembly	Restore-L/In-Space Robotic Servicing
	In-Space Robotic Manufacturing & Assembly (IRMA)
Advanced environmental control and life support systems & ISRU	Mars Oxygen ISRU Experiment (MOXIE)

Projects in Formulation or Execution / Projects in Pre-Formulation

Public-Private Partnerships: Tipping Point Technologies

- **Tipping Point:**
  - Increased focus on **collaboration** with the commercial space sector
  - Fixed price contracts with milestone payments
  - Requires a **minimum 25 percent contribution** from corporation or customer
  - Leverage emerging marks and capabilities to meet NASA's strategic goals AND focus on **industry needs**
  - **Increase likelihood of infusion** into a commercial space application
  - Substantial benefit to both **commercial and government sectors**
- **Tipping Point Technology Topics – 2016 (9 awards)**
  - Robotic In-Space Manufacturing and Assembly of Spacecraft/Space Structures (3 awards)
  - Low Size, Weight and Power Instruments for Remote Sensing Applications (2 awards)
  - Small Spacecraft Attitude Determination and Control Sensors and Actuators (2 awards)
  - Small Spacecraft Propulsion Systems (2 awards)
- **Tipping Point Technology Topics – 2017 (6 awards)**
  - Small Launch Vehicle Technology Development (6 awards)
  - Small Spacecraft Capability Demonstration Missions (0 awards)
- **Tipping Point Technology Topics – 2018 (5 to 10 awards anticipated)**
  - For this Appendix, offerors have the option to address the broader STMD Strategic Thrust (ST) areas which provide a higher-level strategic implementation structure that serve to guide future investment plans for the Directorate. They encompass a broad range of space technologies to meet future needs and are used to set priorities, focus resources, strengthen common goals, and establish agreement around community-level outcomes.
    - **ST1: Expand Utilization of Space**
    - **ST2: Enable Efficient and Safe Transportation Into and Through Space**
    - **ST3: Increase Access to Planetary Surfaces**

Planning to release the Tipping Point solicitation annually

Public-Private Partnerships: Announcement of Collaborative Opportunity

- **Announcement of Collaborative Opportunity (ACO):**
  - Focus on industry-developed space technologies that can advance the commercial space sector and benefit NASA Exploration missions
  - NASA provides technical expertise and test facilities, as well as hardware and software to aid industry partners in maturing technologies
  - Non-Reimbursable Space Act Agreements (no funds exchanged)

- **2015 Technology Topics – (13 awards)**
  - Suborbital Reusable and Small Satellite Launch Systems Development (4 awards)
  - Wireless Power Transfer Development (0 awards)
  - Thermal Protection System Materials and Systems Development (3 awards)
  - Green Propellant Thruster Technology Qualification (3 awards)
  - Small, Affordable, High Performance Liquid Rocket Engine Development (3 awards)

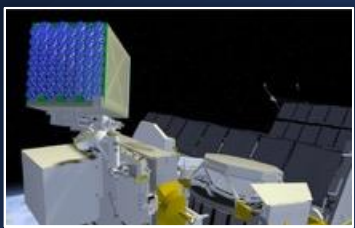
- **2017 Technology Topics – (10 awards)**
  - Small Launch Vehicle Technology Development (3 awards)
  - Reliable Electronics Technology Development (3 awards)
  - Advanced Communications Technology Development (2 awards)
  - In-space Propulsion Technology Development (2 awards)

- **Planning to release the ACO every other year – next anticipated release early 2019**

Technology Maturation

FY 2018 Highlights

SEXTANT
November 2017
Experiment #1 complete

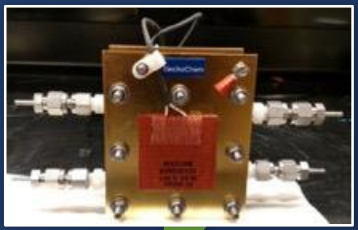


Adaptable, Deployable Entry and Placement
May 2018
UP Aerospace
SL-12–FOP

Affordable Vehicle Avionics Launch
May 2018
UP Aerospace
SL-11–FOP

Astrobee
September 2018
Operations demo

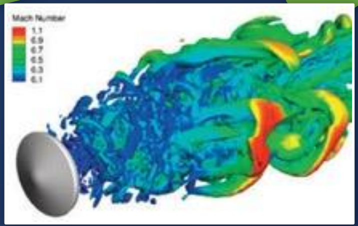
Next Generation Launch Support: Spacecraft Oxygen Recovery
September 2018
Deliver Phase II prototype



Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct

ACME
April 2018
Demo to Army Corps of Engineers

Advanced Near Net Shape Technology
August 2018
Fabrication trials
10-ft dia. Integrally Stiffened Cylinder



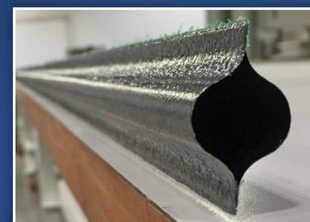
Entry Systems Modeling: Dynamic Computational Fluid Dynamics Task
September 2018
Model levitation

Cryocooler
NET September 2018
Complete characterization and endurance testing

FY 2019 HIGHLIGHTS

SPLICE
March 2019
Complete NDL ETU environmental testing

Deployable Composite Boom
March 2019
QM Boom structural characterization test



MEDLI2
April 2019
Hardware Delivery to Lockheed Martin

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct

Nuclear Thermal Propulsion
June 2019
System testing in NTREES

Composite Technology Exploration
July 2019
Complete testing of longitudinal joint manufacturing

Extreme Environment Solar Power
September 2019
Deliver test articles

FY 2018 GCD Technology Portfolio

Futures and Program Support Excluded

Lightweight Structures & Manufacturing (19%)
- Additive Construction w/ Mobile Emplacement (ACME)*
- Bulk Metallic Glass Gears (BMGG)*
- Low Cost Upper Stage (LCUS)*
- **Rapid Analysis & Manufacturing Propulsion Technology (RAMPT)**
- In-Space Manufacturing
- Advanced Near Net Shape Technology (ANNST)
- Composites Technology for Exploration (CTE)
- Deployable Composite Booms (DCB)
- **Automated Reconfigurable Mission Adaptive Digital Technology (ARMADAS)**

HB Comm, Navigation & Avionics (9%)
- Affordable Vehicle Avionics (AVA)*
- High Performance Spaceflight Computing (HPSC)
- Station Explorer for X-Ray Timing & Navigation Tech (SEXTANT)
- **New ACOs (5)**

Space Observatory Systems (4%)
- Advanced 1.65 micron seed laser for Lidar remote sensing of methane (TP)
- Nanosats for Advanced Gravity Mapping and Crosslink Occultation (TP)
- Chronograph

Space Power & Propulsion (29%)
- Extreme Environment Solar Power (EESP)
- Nuclear Thermal Propulsion (NTP)
- Kilopower
- Deep Space Engine (DSE)
- **Sub-Kilowatt Electric Propulsion (SKEP)**
- **New ACOs (2)**
- Continuing ACOs (3)

Autonomy & Robotic Systems (10%)
- Astrobee
- Mixed Reality Crew
- **Distributed Autonomy**
- **Autonomous Medical Operations (AMO)**
- **Autonomous Pop-Up Flat Folding Explorer Robotics (PUFFER)**

Advanced Life Support & ISRU (5%)
- SpaceCraft Oxygen Recovery (SCOR)
- Thick Galactic Cosmic Rays Shielding*
- Mars Environmental Dynamics Analyzer (MEDA)
- ISRU Broad Agency Announcement

Entry Descent & Landing Systems (25%)
- Adaptable, Deployable Entry & Placement Technology (ADEPT)*
- **Safe & Precise Landing Integrated Capabilities Evolution (SPLICE)**
- Entry Systems Modeling (ESM)
- Heat shield for Extreme Entry Environment Technology (HEEET)*
- Entry, Descent & Landing Architecture*
- Mars Entry, Descent and Landing Instrumentation 2 (MEDLI 2)
- Conformal Ablative Thermal Protection Systems (TPS)

BOLD – New Start   * - Completing in FY18   TP – Tipping Point   ACO – Announcement of Collaborative Opportunity

FY 2019 Technology Maturation Portfolio

Futures, Program Support, To Be Awarded ACOs & TPs Excluded

Advanced Materials, Manufacturing & Assembly (12%)
- Rapid Analysis & Manufacturing Propulsion Technology (RAMPT)
- Advanced Near Net Shape Technology (ANNST)*
- Composites Technology for Exploration (CTE)*
- Deployable Composite Booms (DCB)*
- Automated Reconfigurable Mission Adaptive Digital Technology (ARMADAS)
- In Space Manufacturing

Communication, Navigation & Avionics (11%)
- High Performance Spaceflight Computing (HPSC)
- **Advanced Memory**
- **Single Board Computing**
- Disruption Tolerant Network (DTN)
- Digital TV (DTV)
- Ka-Band Objects Observation and Monitoring (KABOOM)
- Continuing ACO (1)

Autonomous Operations (9%)
- Distributed Autonomy
- Autonomous Operations (AMO)
- Autonomous Pop-Up Flat Folding Explorer Robot (PUFFER)*
- Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES)

Power & Propulsion (31%)
- Extreme Environment Solar Power (EESP)*
- Nuclear Thermal Propulsion (NTP)
- Sub-Kilowatt Electric Propulsion (SKEP)
- Deep Space Engine
- Kilopower*
- AES Modular Power Systems (AMPS)
- **Next Step Broad Agency Announcement (BAA) - Propulsion**
- Tank Health Monitoring
- Continuing ACO (1)

- **Entry, Descent & Landing (EDL) (29%)**
- EDL Systems
- Safe & Precise Landing Capabilities Evolution (SPLICE)
- Entry Systems Modeling (ESM)
- Mars EDL Instrument 2 (MEDLI2)
- Lander Technology

Advanced ECLSS & ISRU (9%)
- Space Craft Oxygen Recovery (SCOR)*
- **Broad Agency Announcement (BAA) – ISRU**
- Mars Environmental Dynamics Analyzer (MEDA)
- **Microgravity Plant Growth**
- Korean Pathfinder Lunar Orbiter (KPLO)

BLUE Text – Incorporated AES Projects **BOLD** – New Start * - Completing in FY19 TP – Tipping Point ACO – Announcement of Collaborative Opportunity

Kilopower Reactor Using Stirling TechnologY (KRUSTY)

Need:

Currently available power systems limit future robotic and human exploration destinations. Solar array- based power systems require constant solar exposure or require supplemental storage sources such as batteries. Fuel cell based power systems require consumables (not efficient for missions where resupply is not possible). Nuclear power has the potential to provide safe, abundant, efficient, and reliable power anywhere within the solar system.

Critical Technology:

- High Enriched Uranium Core Fabrication (shape, mass, and chemistry are key)
- Heat Pipes. A design that allows for operation on the ground and in zero gravity.
- Novel integration of available U-235 fuel form, passive sodium heat pipes, and flight ready Stirling convertors to demonstrate at the Nevada Nuclear Security Site. This will be the first-of-a-kind full nuclear system demonstration of space fission power with dynamic conversion at 1kW$_c$ class power levels.

Potential Applications for the Technology:

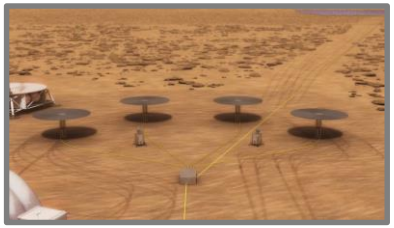
- Lunar surface operations
- High Power NEP: Mars cargo delivery, fast Mars crew transport
- Human Mars surface missions
- Planetary orbiters and landers in areas where solar power is ineffective

Accomplishments

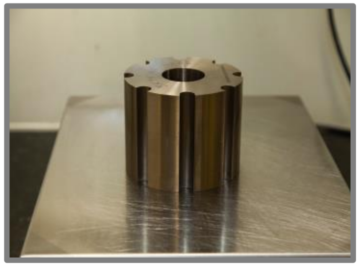
- Y-12 National Security Complex completed the highly enriched uranium core sections and delivered to NNSS (three sections required to make 1 experiment core)
- Successful dry run of kilopower assembly completed with both NASA and NNSS personnel
- Successful non-nuclear system test conducted at GRC.
- Successful component critical test of the reactor was performed

Final Test

Full Power test (28-hour full power test: A simulated, compressed mission profile simulates start up, ramp up to full power, hold for many hours of steady state operation at 800 C, reactor transients, shut down). Test will complete in March of 2018



Artist concept



HEU uranium core sections

KRUSTY Assembly with Simulated Reactor Core on Comet Mock-up in GRC Hangar – September 2017

Safe & Precise Landing Integrated Capabilities Evolution (SPLICE)

Need:

Technologies to enable landing to within 10’s to 100 meters of targeted surface sites (including landing in proximity of pre-positioned surface assets for sample return and human exploration). Current landing technologies enable surface footprints on order of kilometers

Critical Technology:

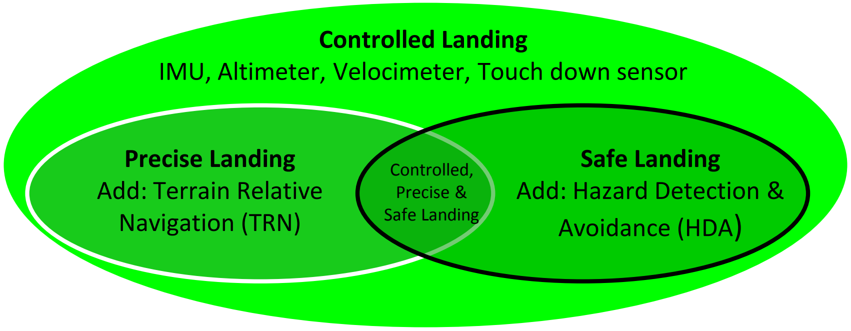
- Navigation Doppler Lidar (NDL) Environmental Test Unit
- 3D Lidar suitable for multi-mission Hazard Detection System (HDS)
- Flight Qualified processing for multi-mission Precision Landing & Hazard Avoidance (PL&HA)

Applications for the Technology:

- Precision Landing and Hazard avoidance technologies have commercial space applications for companies interested in landing payloads on the Moon or Mars
- NDL technologies have dual application to on-orbit autonomous rendezvous & docking
- CATALYST companies have expressed interest in PL&HA once technology is developed and matured

Deliverables/Schedule

- FY18: NDL ETU Design Complete, KDP: ETU fabrication, PL&HA requirements matrix and prototype G&N algorithms complete
- FY19: ETU Assembly Complete, Environment Tests Complete, High-Speed Flight Tests Complete, multi-mission HDS Lidar and ILS assessment
- FY20: Prototype HDS algorithms, 3D Lidar Analysis
- FY21: HDS Proof of Concept, Flight Campaign



SPLICE TRL Objectives	Existing TRL	TRL Plan
NDL – Controlled Landing	4/5 (via COBALT)	6
Multi-Mission HDS – Safe Landing	2	3
PL&HA HSPC-based Avionics	2	4
6DOF PL&HA G&N Algorithms	2	5/6

SPLICE technologies tie entry uncertainty to a safe & precise landing

Nuclear Thermal Propulsion

NTP Project goal: Determine the feasibility and affordability of developing a low enriched uranium (LEU) NTP system

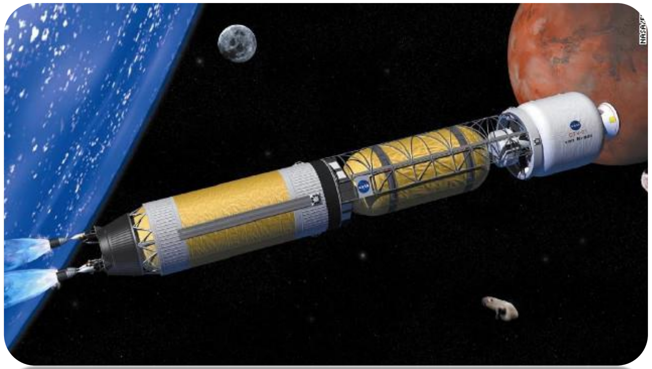
Additional Critical Technology Required: Near zero boiloff for long term on-orbit cryogenic LH_2 storage

Risk Mitigation Phase:

- Evaluate the implications of using LEU fuel on NTP engine design
- Fuel element, reactor, and engine conceptual designs and feasibility analyses
- Mature critical technologies associated with LEU fuel element materials & manufacturing
- Develop an exhaust capture method to facilitate ground testing

NTP key potential benefits:

- Faster transit times
- Reduced architectural mass
- Increased mission flexibility

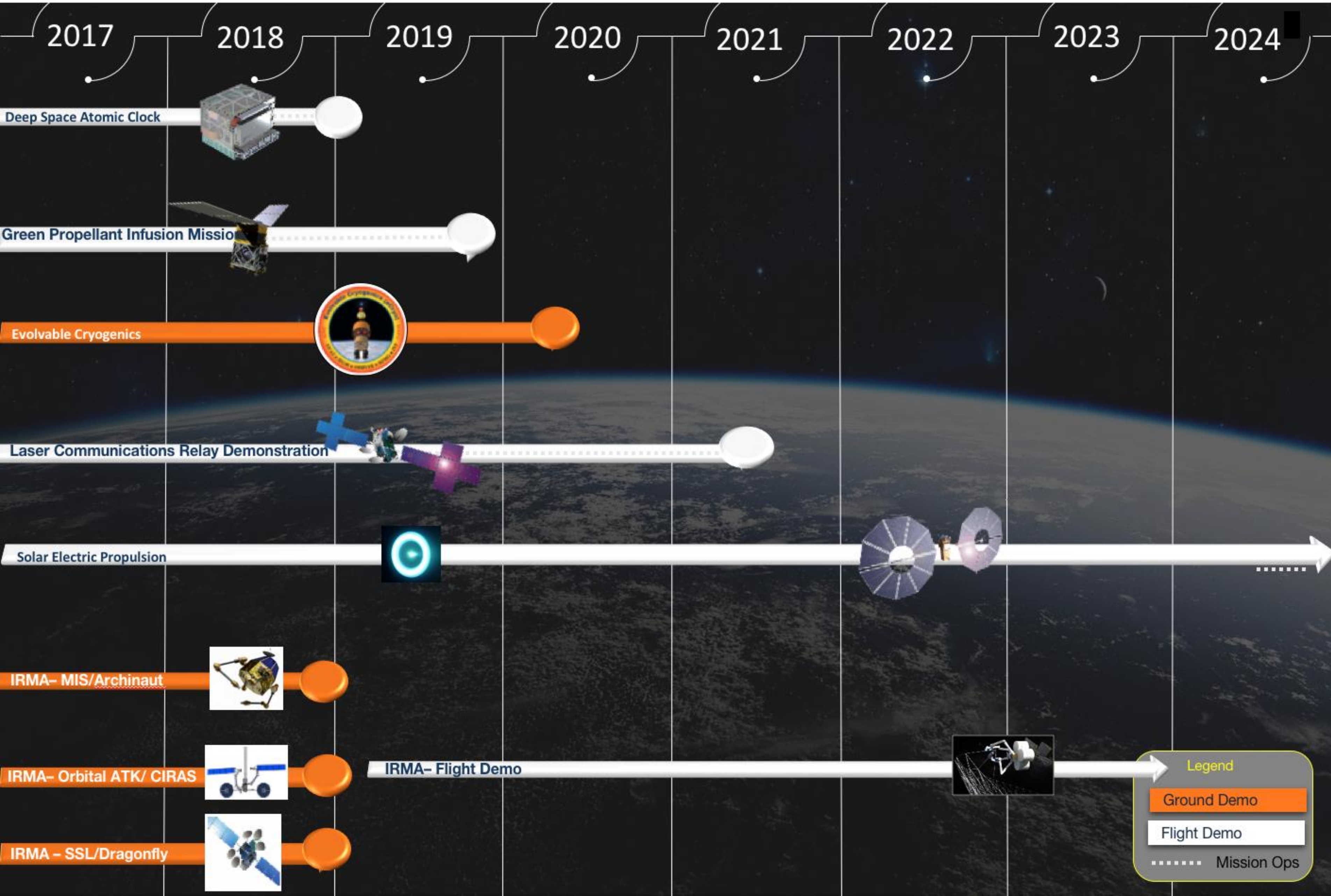


Nuclear thermal rocket engine concept

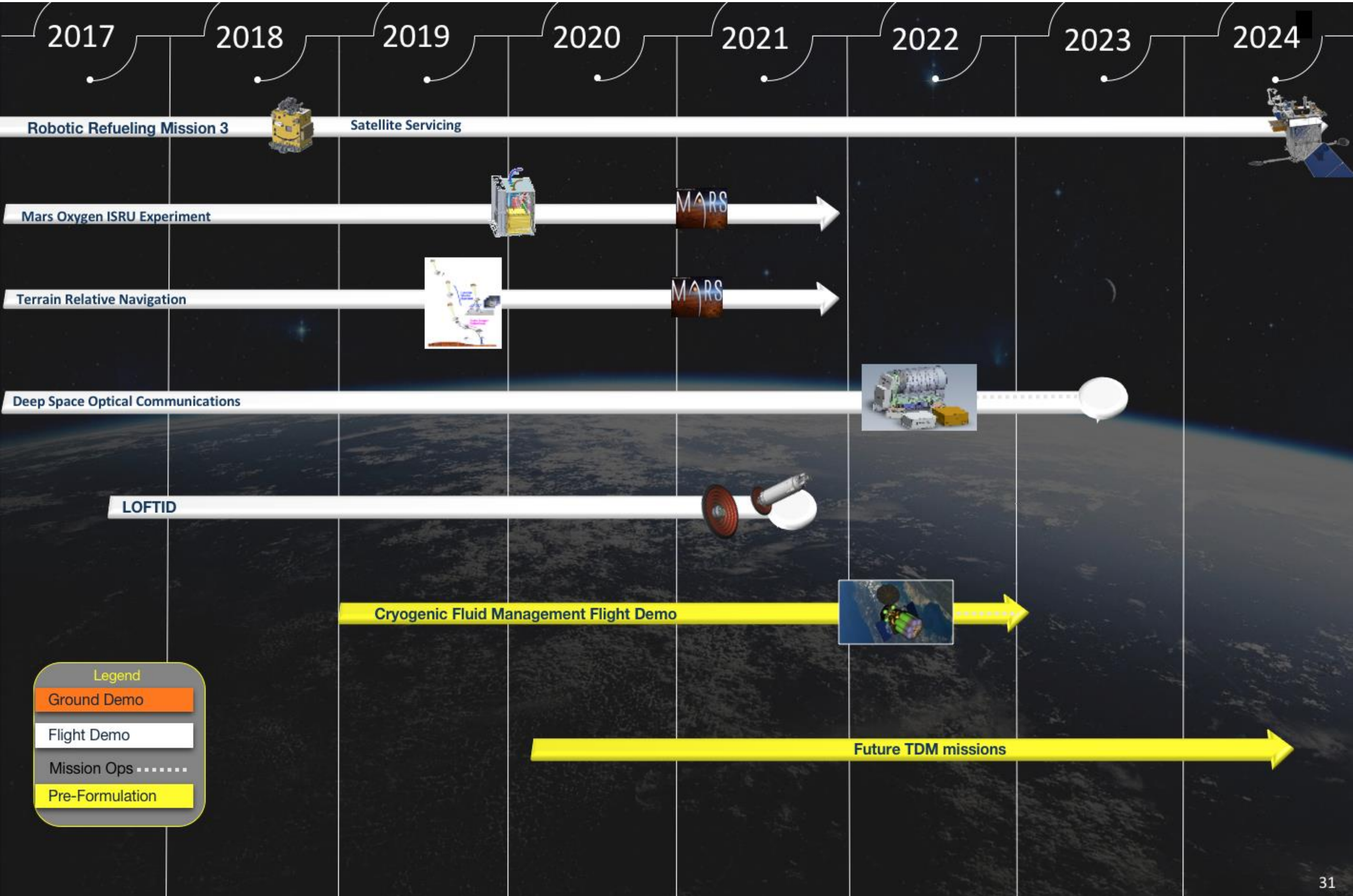
NASA will evaluate potential future technology and systems development activities based on the outcome of the risk mitigation phase

Technology Demonstration

TDM Portfolio at a Glance



TDM Portfolio at a Glance



In Space Robotic Manufacturing and Assembly

Two-year ground based risk reduction project to advance in space manufacturing and assembly technologies for infusion into exploration missions

Objectives:

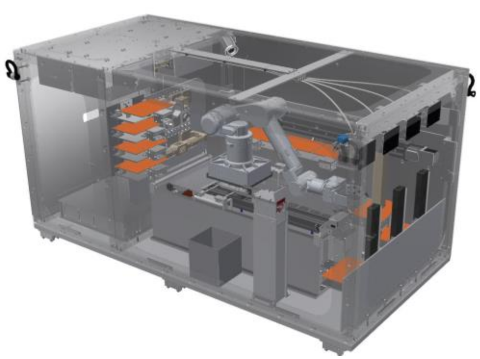
- Demonstrate additive manufacturing techniques, robotic joining methods, repeatable interfaces for in space structural assembly, and other processes and procedures necessary to build and assemble large in space structures.

Current Status:

- All three IRMA contractors, Made-In-Space, Orbital ATK, and Space Systems Loral completed design, build and test/demo phases in year 1 successfully. MIS demonstrated ESAMM and GBMASH element, Orbital demonstrated NINJAR and Talisman elements, and SSL demonstrated their Robotic Reflector.
- All three contractors have moved into option year 2 to refine design and requirements, some will hold tests in a thermal vacuum environment, and others will reach critical design review.

Deliverables/Schedule

- FY18: Year 1, base period complete
- FY19: Year 2, option period complete



MIS GBMASH,
SSL Dragonfly Concept,
OATK Talisman 2.0 Arm

Low Earth Orbit Flight Test of an Inflatable Decelerator

Orbital entry (7-11km/s) flight test of technologies resulting in the capability to land 20T planetary mass and will mature inflatable aeroshell for NASA heavy down-mass missions, and commercial applications.

Objectives:

- Perform a high energy flight test of a scaled-up Hypersonic Inflatable Aerodynamic Decelerator (HIAD).
- Validate thermal and structural models, and mature understanding of the HIAD technology.
- High Mass EDL is the most significant challenge for human Mars missions and requires multiple demonstrations to validate; LOFTID enables that necessary investment.

Current Status:

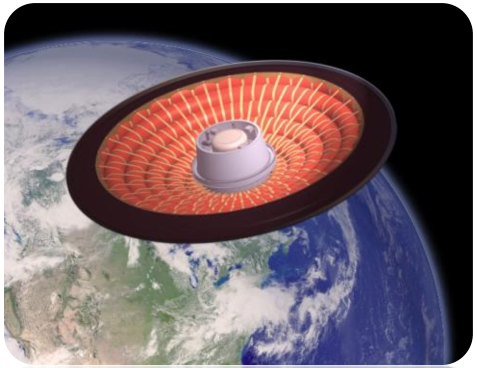
- Developing a Technical Exchange Document agreement with ULA that will become an annex to the Collaborations for Commercial Space Capabilities Contract.
- Cost sharing collaboration between NASA and United Launch Alliance (ULA) to fly a NASA-built HIAD reentry vehicle (RV) – non reimbursable Space Act Agreement
- Will be flown as a secondary payload on an Atlas V launch vehicle delivering its primary payload to Earth orbit.
- After the primary payload is released, the Centaur upper stage will orient, spin-up, and deorbit the RV for an Earth reentry.
- Will test HIAD technology at a scale (6m) and entry conditions relevant to identified Earth and Mars mission infusion
- Working towards SRR in FY18 Q2 and KDP-B to follow; EDU is in development

Deliverables/Schedule

- FY18: SRR, KDP-B, and PDR complete
- FY19: KDP-C and CDR
- FY20: Delivery to ULA and FRR
- FY21: Launch aboard ULA Landsat 9 mission

Commercial Infusion Potential:

- High mass return to Earth from LEO (in space materials processing, ULA 1st stage recovery)
- Flexible Thermal Protection System spinoffs



Cryogenic Fluid Management (CFM)

Need:

- Multiple Exploration missions identified as well as potential commercial applications
- Fluids include oxygen, methane, hydrogen (hard cryo)
- Missions include Launch Vehicle upper stage extended operations, in-space transportation stage, ascent/descent stage, nuclear thermal propulsion, in-situ resource utilization system applications.

CFM Elements					
Technologies	Current TRL	TRL at end of Cryo	Gravity Dependant (Y/N)	Path to TRL 6	"Cross Cutting" or "Fluid Specific"
Low Conductivity Structures	5	5	No	Ground Test	Cross Cutting
High Vacuum Multilayer Insulation	5	6	No	Ground Test	Cross Cutting
Tube-On-Shield BAC	5	5	No	Ground Test	Cross Cutting
Valves, Actuators & Components	5	5	No	Ground Test	Cross Cutting
Helium Pressurization	5	5	Yes	Flight Demo	Cross Cutting
MPS Line Chilldown	5	5	Yes	Flight Demo	Cross Cutting
Pump Based Mixing	5	5	Yes	Flight Demo	Cross Cutting
Termodynamic Vent System	5	5	Yes	Flight Demo	Cross Cutting
Tube-On-Tank BAC	5	5	Yes	Flight Demo	Cross Cutting
Unsettled Liquid Mass Gauging	5	6	Yes	Flight Demo	Cross Cutting
Liquid Acquisition Devices	5	5	Yes	Flight Demo	Fluid Specific
Advanced External Insulation	3	3	No	Ground Test	Can Be Both
Automated Cryo-Couplers	3	3	No	Ground Test	Cross Cutting
Cryogenic Thermal Coating	3	3	No	Ground Test	Cross Cutting
High Capacity, High Efficiency Cryocoolers 90K	3	3	No	Ground Test	Cross Cutting
Soft Vacuum Insulation	3	3	No	Ground Test	Cross Cutting
Structural Heat Load Reduction	3	3	No	Ground Test	Cross Cutting
Propellant Tank Chilldown	3	3	Yes	Flight Demo	Cross Cutting
Transfer Operations	4	4	Yes	Flight Demo	Cross Cutting
High Capacity, High Efficiency Cryocoolers 20K	3	3	No	Ground Test	Fluid Specific
Liquefaction Operations (MAV & ISRU)	3	3	No	Ground Test	Fluid Specific
Para to Ortho Cooling	4	4	No	Ground Test	Fluid Specific
Vapor Cooling	4	6	No	Ground Test	Fluid Specific
Propellant Densification	4	4	No	Ground Test	Fluid Specific
Autogenous Pressurization	4	4	Yes	Flight Demo	Fluid Specific

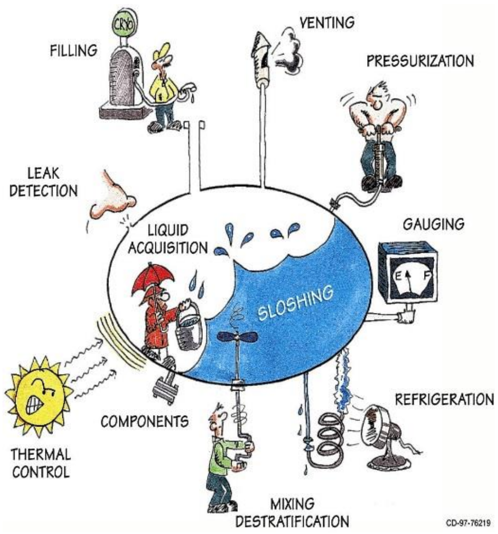
Can achieve TRL 6 through ground testing.

Flight Demo required to achieve TRL 6.

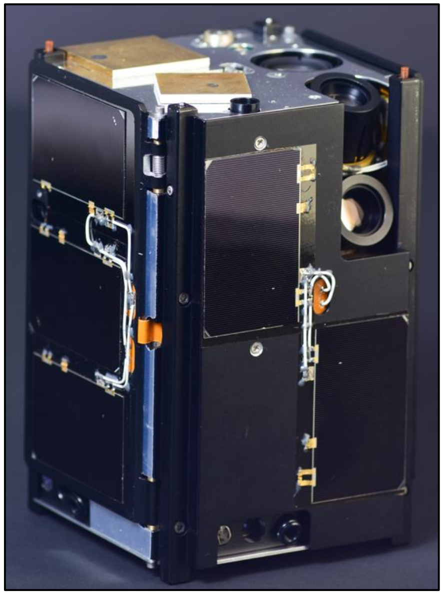
Technology “Long Poles” Development is needed.

Status:

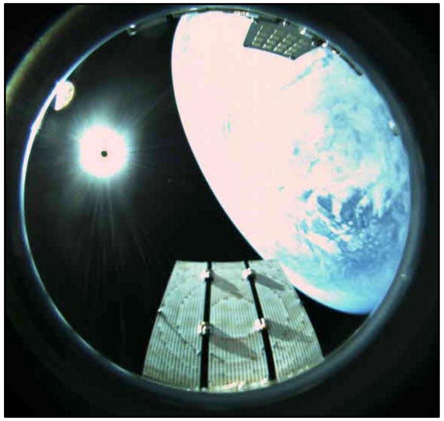
- NASA CFM community (GRC, MSFC, JSC) developed a detailed roadmap of CFM tech dev needs.
- 25 critical CFM technology elements identified, including which could be satisfied via ground demo vs. flight demo.
- Request for Information released in late 2017 to inform implementation and determine the extent of any potential commercial “tipping point” interest – limited results
- CFM team followed up with multiple industry visits to gain a better perspective on interest, needs and candidate combined industry/NASA approaches
- NASA will accelerate the start of the Cryogenic Fluid Management demonstration mission



Small Spacecraft Technology and Exploration



One of two OCSD laser comm. spacecraft currently on obit



View from ISARA spacecraft showing deployed reflectarray

Small, Affordable, Rapid & Transformative

Develop and demonstrate the capabilities that enable small spacecraft to achieve **exploration missions** in unique and more affordable ways.

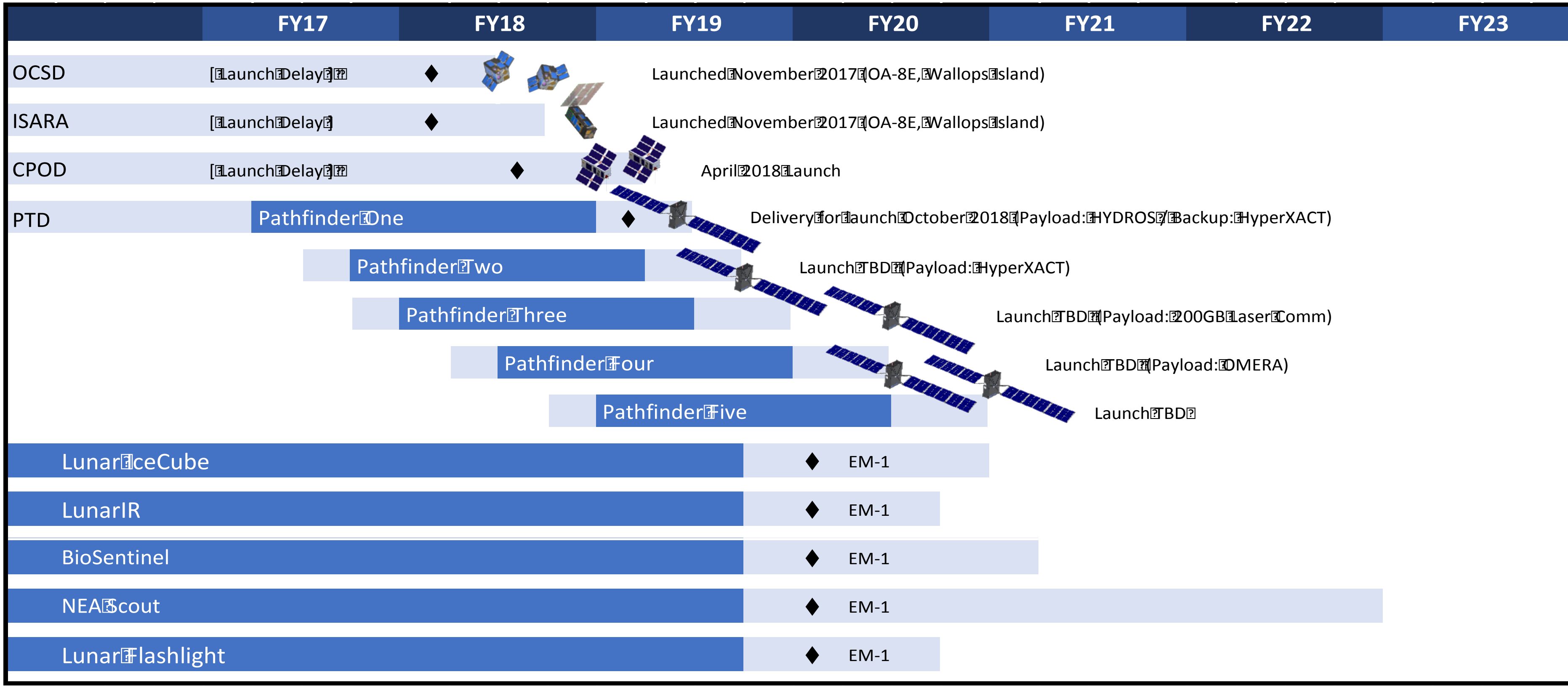
- Enable **new mission architectures** through the use of small spacecraft.
- Expand the reach of small spacecraft to **new destinations**.
- Enable the **augmentation of existing assets and future missions** with supporting small spacecraft.
- Provide **access to space** for the U.S. CubeSat community (academia, government, and non-profits).
- **Small Spacecraft and CubeSats provide a very low-cost platform to address Exploration strategic knowledge gaps**

Low-cost platforms provide responsive in-space testing of new capabilities applicable to exploration, as well as science and the commercial space sector. NASA supports and harnesses the rapid pace of innovation in the small spacecraft community through public-private partnerships, the leveraging of advances in industry and academia, and technology transfer that supports new companies and creates new lines of business.

Three spacecraft currently on orbit in early FY 2018 with an additional demonstration mission to be delivered for launch in spring. **Ten missions under development and scheduled for launch in FY 2019 and 2020**. All missions blend public investment in new technologies with the capabilities of private industry.

Small Spacecraft Technology and Exploration

Upcoming Major Flight Demonstration Missions



Project Phase — Pre Phase A / Post Initial Launch Capabilities & Operations — Authority To Proceed to Initial Launch Capabilites

Launch ♦

Mission Key

OCSD: Optical Communications and Sensor Demonstration
ISARA: Integrated Solar Array and Reflectarray Antenna
CPOD: CubeSat Proximity Operations Demonstration
PTD: Pathfinder Technology Demonstrator

Lunar IceCube: Prospect for lunar volatiles and water
LunarIR: Lunar surface characterization
BioSentinel: Long duration impact of radiation beyond Low Earth Orbit
NEA Scout: Reconnaissance flyby of a Near Earth Asteroid
Lunar Flashlight: Map water and volatiles at the lunar south pole

Commercial Flight Partners

Space Technology Suborbital Demonstration

Small Launch Vehicle Capability Development

REDDI-F1
Grants & CA

NASA-Internal
IDIQ Contracts

ACO/TP
Partnerships

Parabolic

VTVL

Balloons

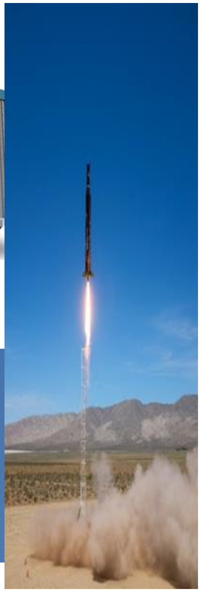
sRLV

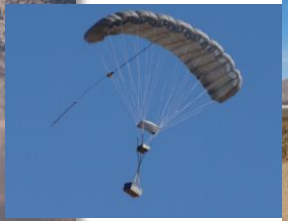
Technology Payload Selections To Date (Selections as of 2018-02-01) (AFO& REDDI NRA Appendices and ACO, MISSE and Tipping Point)

AFO # /NRAs	# Proposals selected	# Techs flown	# Payload / Flights
AFO 1	**16** (12 parabolic; 2 sRLV; 2 parabolic/sRLV)	**15**	**136**
AFO 2	**9** (4 parabolic; 4 sRLV; 1 parabolic/sRLV)	**6**	**50**
AFO 3	**24** (16 parabolic; 5 sRLV; 2 balloon; 1 balloon/sRLV)	**19**	**113**
AFO 4	**2** (1 sRLV; 1 balloon)	**2**	**5**
GCD-NRA 1	**14** (14 sRLV)	**8**	**22**
AFO 5	**13** (9 parabolic; 2 balloon; 1 sRLV; 1 balloon/sRLV)	**10**	**40**
AFO 6	**21** (14 parabolic; 3 balloon; 2 sRLV; 1 parabolic/sRLV; 1 balloon/sRLV)	**18**	**61**
GCD-NRA2	**11** (9 sRLV; 2 balloon)	**2**	**2**
TDM-AFO 7	-0- Orbital	**0**	**0**
SMD-USIP 2013	**4** (2 parabolic; 1 balloon; 1 sRLV)	**4**	**13**
AFO 8	**13** (11 parabolic; 2 sRLV)	**13**	**61**
REDDI FY14 F1	**6** (5 parabolic; 1 sRLV)	**5**	**15**
REDDI FY15 F1	**7** (4 parabolic; 2 sRLV; 1 parabolic/sRLV)	**5**	**13**
SMD-USIP 2015	**2** (2 sRLV)	**0**	**0**
REDDI FY16 F1	**11** (6 parabolic; 3 sRLV; 2 balloon)	**7**	**22**
REDDI FY16 F1(B)	**5** (1 parabolic; 2 sRLV; 2 balloon)	**1**	**2**
REDDI FY17 F1(A)	**9** (4 parabolic; 2 sRLV; 1 balloon; 1 parabolic/sRLV; 1 balloon/sRLV)	**0**	**0**
Selections to Date	**167**	**115**	**555**

Call/Solicitation	# Proposals selected
ACO 2015	**5** (Small launch capability dev)
TIPPING POINT 2016	**6** (Small launch capability dev)
ACO 2017	**3** (Small launch capability dev)
MISSE-9 and MISSE-10	**10** (ISS)
MISSE-11	**5** (ISS)
Selections to date	**29**







Early Stage Innovation and Partnerships

Space Technology Research Grants- *Opportunities to Propose*

Engage Academia: *tap into **spectrum** of academic researchers, from graduate students to senior faculty members, to examine the theoretical feasibility of ideas and approaches that are critical to making exploration as well as space travel and science more effective, affordable, and sustainable.*

NASA Space Technology Research Fellowships

- **Graduate student research in space technology**; research conducted on campuses and at NASA Centers and not-for-profit R&D labs

Early Career Faculty

- Focused on supporting outstanding faculty researchers early in their careers as they conduct **space technology research of high priority to Exploration and other Mission Directorates**

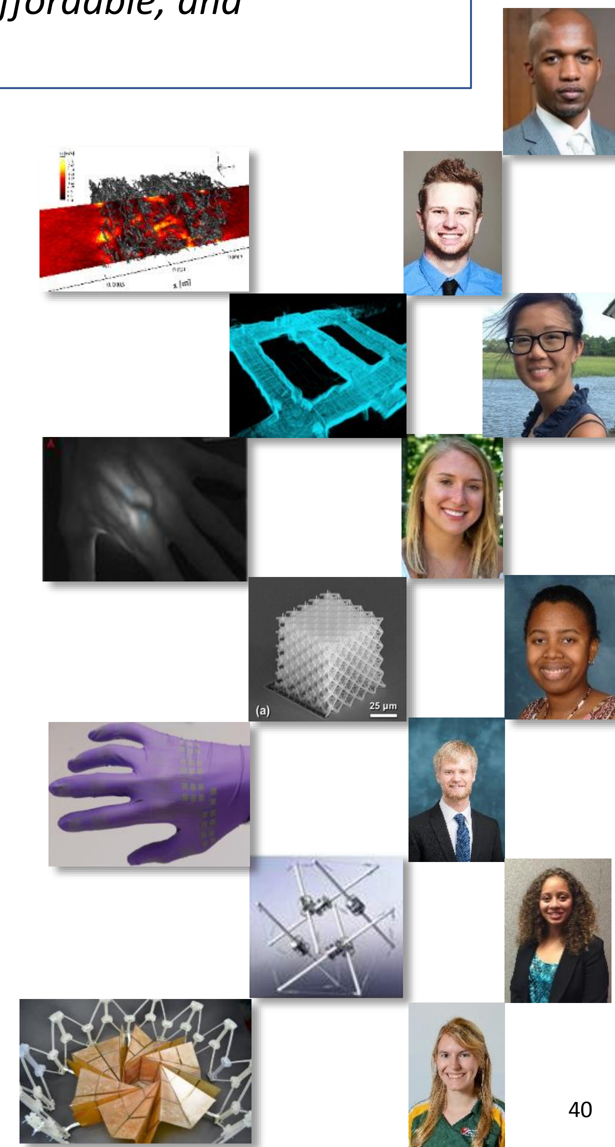
Early Stage Innovations

- University-led, possibly multiple investigator, **efforts on early-stage space technology research of high priority to Exploration and other Mission Directorates**
- Paid teaming with other universities, industry and non-profits permitted

Space Technology Research Institutes

- University-led, integrated, multidisciplinary teams focused on high-priority **early-stage space technology research for several years**

Accelerate development of groundbreaking
high-risk/high-payoff low-TRL space technologies



Space Technology Research Institutes 2016 Highlights

Center for the Utilization of Biological Engineering in Space (CUBES)

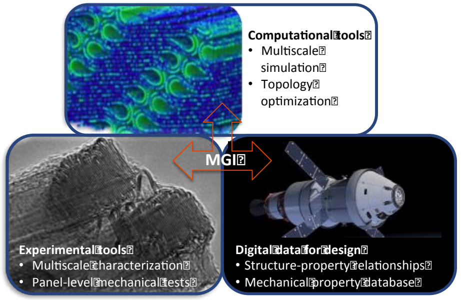
Adam Arkin, PI, UC Berkeley

- The team, which includes > 10 faculty, has held its first major planning meeting; is holding regular, executive meetings; and launched its seminar series
- Have shown that carbon fixing bacteria can grow in broad spectrum light and use wavelengths not used by plant feed stocks, thereby increasing the potential energy efficiency of the integrated system.
- An initial design to optimize photosynthesis in rice was created and will be tested in Quarter 3.

Institute for Ultra-Strong Composites by Computational Design (US-COMP)

Gregory Odegard, PI, Michigan Tech

- The full team, including all faculty (> 20), administrative assistants, research staff, 3 post-docs, 28 PhD students, 5 M.S. and 10 U.G. students, have been integrated and are actively working on the project.
- Integration plan – organizational tool, timeline *and* deliverable document – was developed.



CUBES Participants:

UC Berkeley
UC Davis
U Florida
Utah State
Stanford
Physical Sciences, Inc.

US-COMP Participants:

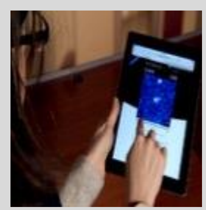
Michigan Tech	Georgia Tech
Florida State	University of Minnesota
University of Utah	Penn State University
MIT	University of Colorado
Florida A&M University	Virginia Commonwealth
Johns Hopkins University	Nanocomp Technologies
	Solvay
	Air Force Research Lab

Both awards are in place, and kickoff meetings with NASA and OGAs have been held

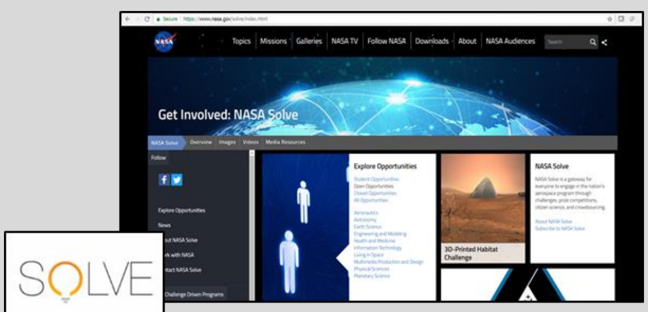
STMD Prizes and Challenges Activities

	DREAM IT. MAKE IT. WIN IT. NASA Centennial Challenges	CoECI NTL NASA Tournament Lab	International Space Apps Challenge	Citizen Science	CoECI NASA@WORK
Duration	Years	Months	Days/Weeks	Months	Weeks
Prizes	\$100sK to \$Ms	\$1K to \$250K	Recognition	Recognition	NASA-themed
Products	Technology demos	Ideas, design, software	Software apps/tech concepts	Scientific observations and analysis	Ideas, info searches
Who	Mainly USA	Worldwide	Worldwide	Worldwide	NASA

SOLVE These opportunities can be accessed by the public on NASA Solve website: www.nasa.gov/solve



NASA Crowdsourcing Initiatives



Strengthen NASA's ability to conduct prizes and challenges and other crowdsourcing activities

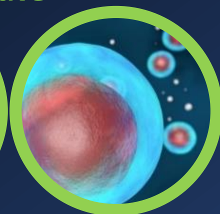
- Provide expertise to facilitate the development of NASA crowdsourcing projects
- Fund new types of prizes and challenges in support of NASA's mission
- Maintain NASA's crowdsourcing community of practice
- Support and grow use of NASA@Work, NASA's internal crowdsourcing platform
- Share participatory opportunities with the public through the NASA Solve website, Twitter, and list serve
- Fund and manage the Centennial Challenges program (separate program budget)
- **Prioritize challenge topics to align with NASA's Exploration Campaign objectives**

Centennial Challenges Program

Program Goal: Stimulate research and technology solutions to support NASA Exploration and other missions and inspire new national aerospace capabilities through public prize competitions.

Active

Developing

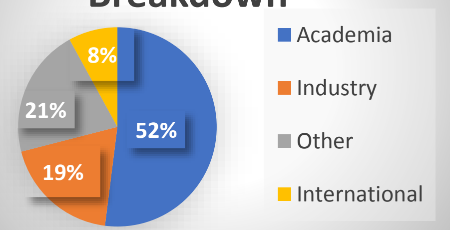


Cube Quest $5,000,000	3D-Printed Habitat $3,100,050	Vascular Tissue $500,000	Space Robotics $900,000	CO_2 to Sugar $550,000
Flight-qualified CubeSats near and beyond the moon	**Additive construction technology for space**	**Viable thick tissue for research**	**Advance robotics software and autonomy**	**Bio-manufacturing from in-situ resources**
$460,000 awarded to date	$741,024 awarded to date	9 U.S. teams currently registered	$555,000 awarded in Phase 1	Enable bio-manufacturing of products in space
Innovative propulsion and communication	240 teams: 167 U.S. and 73 International	Innovation in engineered tissue that can stay viable for more than 30 days	92 Teams: 79 U.S. and 13 international	Announcement expected in FY18
3 payload slots on SLS EM-1	Collaboration w/Bradley Univ., Caterpillar Inc., Bechtel Corp, Brick and Mortar Ventures	Collaboration with New Organ Alliance	Phase 2 under development	HEOMD/STMD collaboration
15 U.S. teams			Collaboration with Space Center Houston and Nine Sigma	NASA-led Challenge
NASA-led Challenge				

Plans for FY19

- **Prioritize challenge topics to align with NASA's Exploration Campaign objectives**
- Five (5) challenges with continuation in FY19
- Four (4) NEW challenges in formulation for FY19/FY20
- Increase pool of ideas for future challenge competitions
- Increase collaborations with other NASA Mission Directorates and other government agencies

CY 2017 Team Breakdown



Team Distribution

NIAC: NASA Innovative Advanced Concepts

GOAL

Targeting technologies that spawn disruptive innovations making space exploration more effective, affordable, and sustainable. NIAC funds early studies of visionary, long term concepts - aerospace architectures, systems, or missions and inspires new technology development across many scientific disciplines.

RESEARCH STUDIES

43 Proposals Selected (2016-2017 Phase I and Phase II)

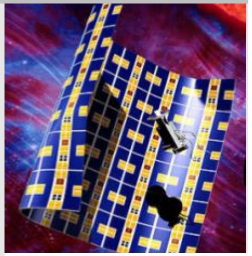
158 Research Studies to date, representing diverse, multidisciplinary sciences

BRANECRAFT

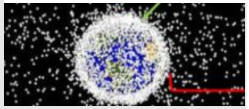
ORBITAL DEBRIS MITIGATION & NOVEL NANOTECHNOLOGY

Siegfried Janson, *Aerospace Corp.*

Start from low Earth orbit, rendezvous with a space debris, wrap around it, drop altitude, release object & retrieve more orbit debris



AEROSPACE
Assuring Space Mission Success



- **GO THIN: Flat Membrane Spacecraft**
- **Reshaping the future of small satellites**
  Cost savings + multi-use, 3x3 feet, weighs 3 oz.
- **Uses printing technologies, nano-electrospray thrusters, thin film solar cells between layers**
- **Integrated 'muscles' wrap around debris**

Decrease collisions from space debris to existing satellite systems

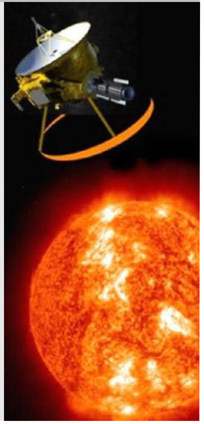
SOLAR WHITE

MATERIAL FOR EXTREME THERMAL PROTECTION & CRYOGENICS

Robert Youngquist
NASA Kennedy Space Center

Solar Surfing, Superconductor operation, Cryogenics, Solar Shielding

Novel Coating: "Solar White"



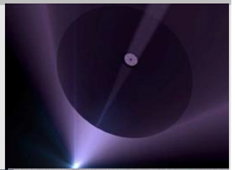
- **Advancing thermal protection systems**
- **May reflect 99.9% of the Sun's energy**
- **80% better than current materials**
- **Enable long term cryogenic storage**
- **Allow superconductor operation in space**
- **Reduce solar/radiative heating in vehicles**
- **Potential LOX/LN2 deep space storage**

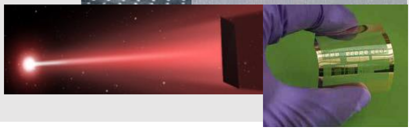
DEEP-IN

DEEP SPACE EXPLORATION WITH STAR CHIP

Prof. Philip Lubin, University of California, Santa Barbara

STARLIGHT: Directed energy for interstellar travel with photonic propulsion





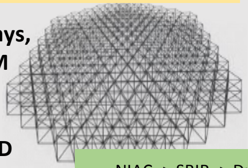
- **GO SMALL: Get there faster for future interstellar travel**
- **Destination: Proxima Centauri or beyond**
- **Big Idea: Make it Smaller**
- **Interstellar probes with solar sails and laser power, photon propulsion**
- **Ultra thin body with smaller, more powerful, & more cost-efficient electronics**

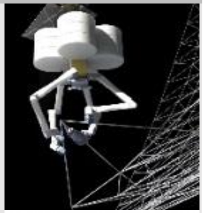
SPIDERFAB

IN SPACE ADDITIVE MANUFACTURING

Robert Hoyt
Tethers Unlimited

Construction of large structures in space, significant cost savings manufacturing on orbit





TETHERS UNLIMITED

- **Manufacturing of large antennas, solar arrays, sensors, high performance boom for COMM satellites**
- **Spin off: tresselator carbon fiber trusses**
- **Spin Off: Refabricator- recycling system + 3D printer to make satellite parts/tools for long duration missions**
- **Long term vision of GlobalFi, direct to smartphone broadband data service**

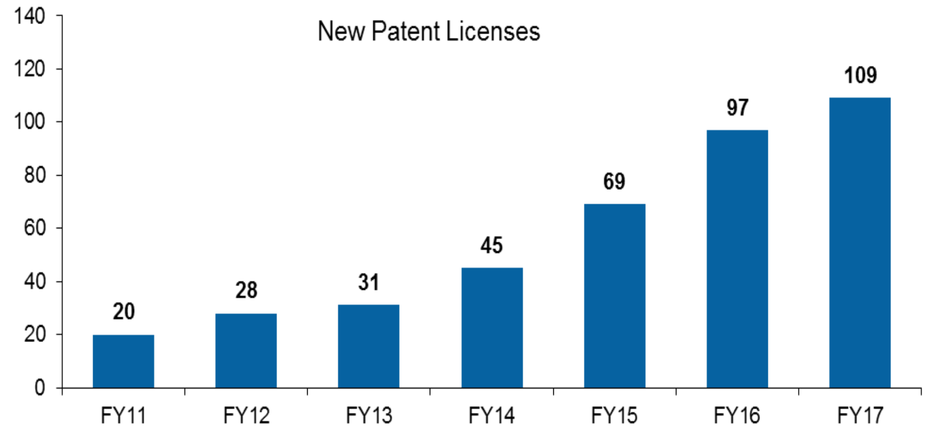
NIAC -> SBIR -> Dragonfly Tipping Point -> DARPA Seedling -> DARPA OrbWeaver -> DARPA Constructable Platform -> MakerSat SBIR

Technology Transfer Program

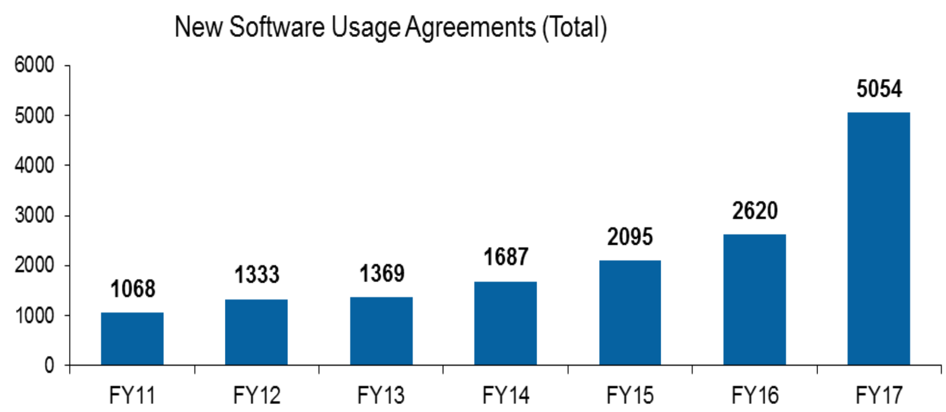
$18.4M for management of the Agency's Invention Portfolio for the purposes of **commercialization** and government usage, including:

- Assessment of all new technology from civil servants, contractors, and grantees to determine technical feasibility and commercial application
- Intellectual Property protection and portfolio management
- Patent licensing, agreements, and software release

This activity results in significant U.S. economic benefit, including the creation of new products and services and jobs



Each of the patent licenses represents a NASA technology being transformed into a commercial product by a domestic company.



Each software release represents time savings, safety improvements, and full utilization of federal resources.

Human Research Program

Human Research Program Overview

- Develop human health and performance standards, countermeasures, knowledge, technologies, and tools across various disciplines to enable safe, reliable, and productive human space exploration
  - **ISS Medical Project:** mission planning, integration and implementation for HRP research studies aboard ISS and in spaceflight analog environments
  - **Space Radiation:** research on exposure effects and limits to ensure crewmembers can safely live and work in space without exceeding permissible exposure limits for radiation health risks
  - **Human Health Countermeasures:** responsible for understanding physiologic effects of spaceflight and developing countermeasures to detrimental changes
  - **Exploration Medical Capability:** develop biomedical capabilities, autonomous technologies, and advanced information systems for in-flight monitoring, diagnosis, and treatment of medical events
  - **Human Factors and Behavioral Performance:** improve human-system interactions with spacecraft equipment, procedures, and habitat to increase crew safety and performance in the space environment; and assess the impact of space travel on human behavioral health, and develop interventions and countermeasures to ensure optimal health and performance

Human Exploration and Operations

Human System Risk Board: Human System Risks Disposition for all Design Reference Missions

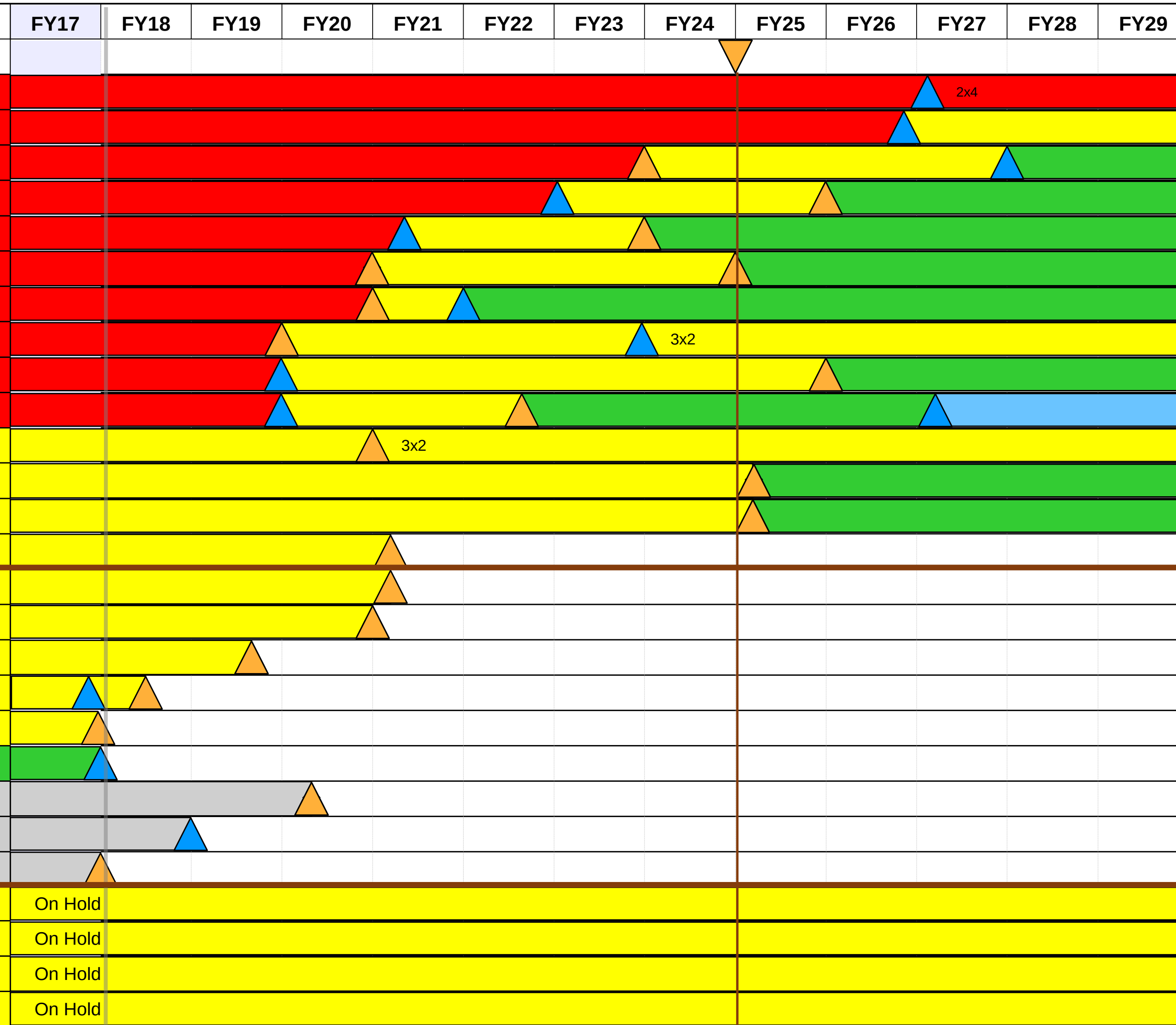
Human System Risks	In Mission Risk - Operations						Post Mission Risk - Long Term Health					
	Low Earth Orbit	Low Earth Orbit	Deep Space Sortie	Lunar Visit/ Habitation	Deep Space Journey/ Habitation	Planetary Visit/ Habitation	Low Earth Orbit	Low Earth Orbit	Deep Space Sortie	Lunar Visit/ Habitation	Deep Space Journey/ Habitation	Planetary Visit/ Habitation
	6 Months	1 Year	1 Month	1 Year	1 Year	3 Years	6 Months	1 Year	1 Month	1 Year	1 Year	3 Years
SANS	A	A	A	A	RM	RM	A	A	A	A	RM	RM
Renal Stone Formation	A	A	A	A	RM	RM	A	A	A	A	RM	RM
Inflight Medical Conditions	A	A	A	RM	RM	RM	A	A	A	RM	RM	RM
Cardiac Rhythm Problems	A	A	A	A	RM	RM	A	A	A	A	A	A
Acute and Chronic CO_2	A	A	A	A	RM	RM	A	A	A	A	A	A
Cognitive or Behavioral Conditions	A	RM	A	RM	RM	RM	A	A	A	A	A	RM
Space Radiation Exposure	A	A	A	A	RM	RM	A	A	A	RM	RM	RM
Inadequate Food and Nutrition	A	A	A	A	A	RM	A	A	A	A	A	RM
Medications Long Term Storage	A	A	A	A	A	RM	A	A	A	A	A	RM
Bone Fracture	A	A	A	A	A	RM	A	A	A	A	A	A
EVA Operations	A	A	A	RM	A	RM	A	A	A	RM	A	RM
Psychosocial Adaptation within a Team	A	A	A	A	RM	RM	A	A	A	A	A	A
Inadequate Human-System Interaction Design	A	A	A	RM	RM	RM	A	A	A	A	A	A
Injury from Dynamic Loads	A	A	RM	RM	RM	RM	A	A	RM	RM	RM	RM
Hypobaric Hypoxia	RM	RM	A	RM	RM	RM	RM	RM	A	RM	RM	RM
Sleep Loss	A	A	A	A	RM	RM	A	A	A	A	RM	RM
Toxic Exposure	A	A	A	A	A	A	A	A	A	A	A	A
Altered Immune Response	A	A	A	A	A	RM	A	A	A	A	A	RM
Host-Microorganism Interactions	A	A	A	A	A	RM	A	A	A	A	A	RM
Reduced Aerobic Capacity	A	A	A	A	A	RM	A	A	A	A	A	RM
Reduced Muscle Mass, Strength	A	A	A	A	A	RM	A	A	A	A	A	RM
Sensorimotor Alterations	A	A	A	RM	RM	RM	A	A	A	A	A	RM
Electrical Shock	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R	A/R
Hearing Loss Related to Spaceflight	A	A	A	A	A	A	A	A	A	A	A	A
Injury from Sunlight Exposure	A	A	A	A	A	A	A	A	A	A	A	A
Urinary Retention	A	A	A	A	A	A	A	A	A	A	A	A
Back Pain	A	A	A	A	A	A	N/A	N/A	N/A	N/A	N/A	N/A
Decompression Sickness	A	A	A	A	A	A	A	A	A	A	A	A
Celestial Dust Exposure	N/A	N/A	TBD	A	TBD	TBD	N/A	N/A	TBD	A	TBD	TBD
Orthostatic Intolerance	A	A	A	A	A	A	A	A	A	A	A	A

A/R - Accepted/Retired A - Accepted (with current, Standards, Countermeasures, Monitoring) RM - Requires Mitigation TBD - not determined

Green – low/very low consequence Yellow - low to medium consequence Red – high consequence

Human Research Program
Integrated Path to Risk Reduction

Risks	LxC
Space Radiation Exposure (Cancer Biological CMs)	3x4
Space Radiation Exposure (Degen/CVD/Late CNS)	3x4
Cognitive or Behavioral Conditions (BMed)	3x4
Inadequate Food and Nutrition (Food)	3x4
Team Performance Decrements (Team)	3x4
Spaceflight Associated Neuro-Ocular Syndrome (SANS/VIIP)	3x4
Renal Stone Formation (Renal)	3x4
Human-System Interaction Design (HSID)	3x4
Medications Long Term Storage (Stability)	2x4
Inflight Medical Conditions (Medical)	3x4
Injury from Dynamic Loads (OP)	3x3
Altered Immune Response (Immune)	3x3
Host-Microorganism Interactions (Microhost)	3x3
Reduced Muscle Mass, Strength (Muscle)	3x3
Reduced Aerobic Capacity (Aerobic)	3x3
Sleep Loss and Circadian Misalignment (Sleep)	3x3
Orthostatic Intolerance (OI)	3x2
Bone Fracture (Fracture)	1x4
Cardiac Rhythm Problems (Arrhythmia)	3x2
Space Radiation Exposure (Acute Radiation SPE)	2x2
Concern of Intervertebral Disc Damage (IVD)	TBD
Celestial Dust Exposure (Dust)	TBD
Concern of Effects of Medication (PK/PD)	TBD
Sensorimotor Alterations (SM)	3x3
Injury Due to EVA Operations (EVA)	3x3
Hypobaric Hypoxia (ExAtm)	3x3
Decompression Sickness (DCS)	3x2



ISS Required
ISS Not Required
Milestone Requires ISS
Ground-based Milestone
ISS Mission Milestone
High LxC
Mid LxC: Requires Mitigation
Low LxC
Optimized
Insufficient Data

Human Research Program: FY 2019 Plans

- Implement a research plan with international partners that fully utilizes ISS biomedical research capabilities to maximize research on mitigating crew health and performance risks for exploration missions
- Release NASA research solicitations to national biomedical research community to better address exploration spaceflight health, performance, and space radiation risks, adding to over 170 research tasks already active within HRP
- Leverage resources and expertise through collaborative research with other NASA programs, international partners and other U.S. agencies such as DoD, DOE, NSF, and NIH
- Develop and complete testing of an advanced exploration exercise system in preparation for ISS deployment as part of exploration system maturation plans
- Support AES NextSTEP Habitation development to define and evaluate exploration habitats for the LOP-G including accommodation of advanced exercise and autonomous medical systems
- Continue leveraging resources through partnerships including international partnering on the effects of isolation and confinement on crew behavioral health and performance with Russia, DLR, and ESA

Crew testing wearable medical monitoring system on exploration exercise device in habitat mockup

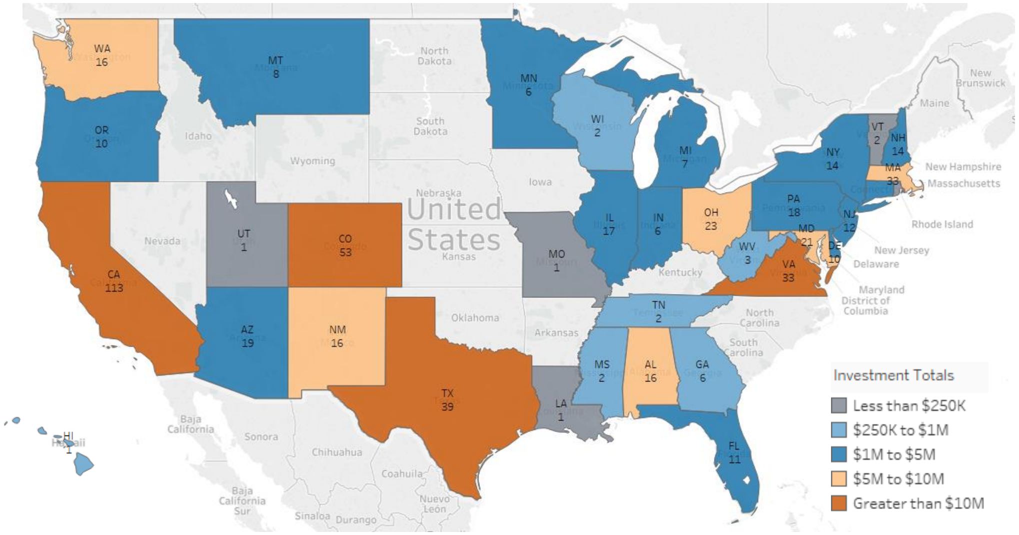
NASA Space Radiation Laboratory (at DOE Brookhaven National Laboratory) conducts research to improve understanding of space radiation health effects

SBIR/STTR Program

Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR)

- Annual Solicitations for Phase I awards
- Phase II proposed 6 months later for SBIR and 12 months for STTR
  - Phase II Extended: Cost sharing opportunity to promote extended R&D efforts of current Phase II contracts.
- Phase III: Infusion of SBIR/STTR technologies to NASA missions.
  - Contract funded from sources other than the SBIR/STTR programs and may be awarded without further competition.

FY 2017 Awards:



FY 2017 Awards:

- SBIR Awards: 338 Phase I and 133 Phase II
- STTR Awards: 61 Phase I and 19 Phase II awards

Program Activities at a Glance:

- Conducted the program's first two industry days in Sept. 2016 and July 2017; 200 people in person and hundreds more online; over 140 one-on-one meetings between companies and NASA representatives to increase small business understanding of NASA's needs
- Successfully engaged with the broader NASA SBIR/STTR community on strategic planning and opportunities to improve upon performance against the Program goals. This exercise resulted in the development of goals, objectives, and tactics with performance scorecard metrics for the center offices, mission directorates, PMO, and the program as a whole.
- Released the program's first RFI; The RFI resulted in over 270 ideas for new subtopics being submitted, over 100 pieces of feedback on subtopics from the FY17 solicitation, and over 150 small businesses responding to questions about programmatic improvements.

FY 2018-2019 Plans:

- **Solicitations will emphasize Exploration Campaign technology focus areas while continuing to support subtopics developed by the Science and Aeronautics Mission Directorates.**
- Improve Solicitation Development strategy that includes refining previous years subtopics using RFI feedback and allowing ample cycle time to see results (2-3 year RFI cycle).
- The program continues its Electronic HandBook (EHB) modernization work releasing appropriate modules aligned to the master program schedule. As of January 2018, the proposal submission module that firms use is coming to a successful close. Simultaneously, the review and selection module is underway with additional modules releasing later in the year.

NASA is implementing Stottler Henke Associates SBIR developed AuroraTM technology to schedule the ground-based activities that prepare the Space Launch System missions. More details on this Human Exploration success story can be found here: https://sbir.gsfc.nasa.gov/sites/default/files/Success_Story_StottlerHenke.pdf

ER&T Summary

- Focuses investments in research and technologies applicable to deep-space exploration, prioritizing environmental control and life support and ISRU; power and propulsion; advanced materials; communications, navigation and avionics; robotic assembly and manufacturing; entry, descent and landing; autonomous systems, and enabling humans to live and work in the space.
- Delivers flight hardware for demonstration of in-situ resource utilization, and entry, descent and landing technologies for the MARS 2020 mission.
- Begins fabrication of flight hardware for high-powered solar electric propulsion system that will enable efficient in-orbit transfer and accommodate increasing power demands for satellites.
- Completes Laser Communications Relay Demonstration mission payload to support 2019 Launch Readiness.
- Funds public-private partnerships to flight demonstrate robotic in-space manufacturing technologies used to build large structures in a space environment.
- Delivers 2 CubeSats selected via NEXTStep Phase One, and 3 robotic precursor technologies missions, and 2 Pathfinder Technology flight Demonstrator missions.
- Continues cutting edge research on the effects of spaceflight to the human body using the ISS and supports Deep Space Exploration habitat design and development to ensure crew health and performance.
- Continues pilot opportunities to accelerate small businesses ability to advance the commercial aerospace sector and NASA missions (with an emphasis on exploration) through the SBIR/STTR programs.

Backup Charts

Laser Communication Relay Demonstration

A two year flight demo to revolutionize the way data is sent and received through space by advancing optical communication technology for infusion into Deep Space and Near Earth operational systems

Objectives:

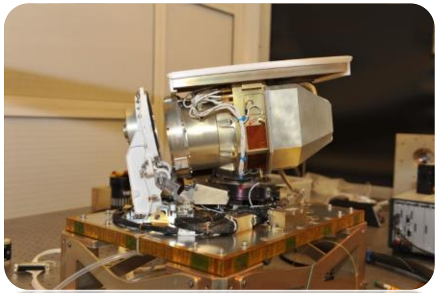
- Demonstrate bidirectional optical communications between geosynchronous Earth orbit (GEO) and Earth.
- Measure and characterize system performance over a variety of conditions.
- Develop operational procedures and assess applicability for future missions.
- Transfer laser communication technology to industry for future missions.
- Provide an on orbit capability for test and demonstration of standards for optical relay communications.

Current Status:

- LCRD completed its Critical Design Review in December, 2016 and is in its implementation phase
- Payload integration is nearing completion
- Interface Compatibility Testing complete demonstrating command of payload from remote command center
- Environmental payload testing is set to begin early Spring 2018
- Delivery to Orbital ATK is scheduled for Summer, 2018 and is manifested to fly on STP-Sat6 Space Vehicle with the Air Force Space Test Program STP-3 Mission.

Deliverables/Schedule

- FY18: Complete Payload Integration and Testing, Payload delivery to spacecraft provider, SIR/PSR and KDP-D
- FY19: FOR/ORR and KDP-E, Launch
- FY20: On Orbit Operations
- FY21: Mission Completion, Final Report



LCRD Flight Optical Module

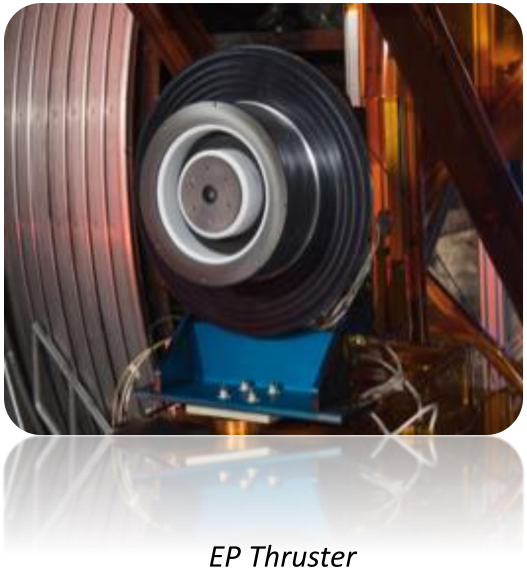
Solar Electric Propulsion

Spaceflight demo of 30-50kW class solar electric propulsion for primary propulsion

Objectives:
- Demonstrate high-power (HP) Solar Array and Solar Electric Propulsion (SEP) technology in relevant space environments.
- Observe and characterize performance of integral HP-SEP system including thrusters, arrays, bus, and payloads as they operate as an integrated system and as they respond to the in-space environment.
- Demonstrate HP SEP servicing and/or transport bus.
- Qualify next generation SEP bus.

Current Status:
- AEPS Preliminary Design Review completed in August, 2017.
- SEP Testbed development is underway
- SEP is planned to fly on the Power Propulsion Element

Deliverables/Schedule
- FY18: Complete Critical Design Review and KDP-C of the Advanced Electric Propulsion System
- FY19: Complete AEPS Contract (Aerojet Rocketdyne) base period (thrusters through qualification), begin thruster life testing
- FY20 and FY21: Continue and complete thruster life testing



EP Thruster in testing

Deep Space Optical Communication

Spaceflight demonstration to laser communication to achieve order of magnitude improved data rate performance from deep space with comparable mass and power to state of the art telecommunications systems.

Objectives:

- Achieve 10 to 100 times greater data-rate performance from deep space with comparable mass and power to state-of-art radio frequency telecommunications systems.
- Retire the implementation risks of utilizing optical communications technology on deep space missions

Current Status:

- System Requirements Review and Mission Definition Review and KDP-B recently completed.
- Project requirements approved and long lead procurements proceeding

Deliverables/Schedule

- FY18: SRR/MDR and KDP-B complete
- FY19: PDR and KDP-C complete
- FY20: CDR and KDP-D complete
- FY 21: KDP-E and Delivery to spacecraft
- FY22: Launch aboard Psyche
- FY 23: DSOC demonstration complete

Artwork depicting space craft carrying DSOC orbiting 16 Psyche

Small Spacecraft Technology and Exploration Accomplishments


Nodes deployment from ISS


CubeSat ELaNa payload

Nodes: Inter satellite networking demonstration launched March 2016 and successfully completed all on-orbit objectives.

Optical Communications and Sensor Demonstration (OCSD): Compact laser communications demonstration launched in November 2017. Checkout and test operations in progress.

Integrated Solar Array and Reflectarray Antenna (ISARA): High bandwidth easily stowed radio frequency antenna demonstration launched in November 2017. Checkout and test operations in progress.

Cubesat Proximity Operations Demonstration (CPOD): Proximity operations and docking demonstration ready for launch. Flight Readiness Review held July 2016 and launch currently scheduled for April 2018.

Pathfinder Technology Demonstrator (PTD) Series: Series of low cost subsystem demonstration missions in partnership with industry. Critical Design Review held December 2017.

Other Partnerships: Public Private Technology Development Partnerships with Blue Canyon Technologies for an attitude determination and control system and Tethers Unlimited for a water fueled thruster concluding development and preparing for PTD test flights. Among the university partnerships selected between 2013 and 2016, five have already gone on to suborbital or orbital flight opportunities in other NASA programs.

CubeSat Launch Initiative: Since its inception, 58 CubeSats have been flown on 16 ELaNa Missions. Five upcoming ELaNa CubeSat launches totaling 26 cubesats schedule to be deployed in 2018

Flight Opportunities Overview

- The Flight Opportunities program strives to advance the operational readiness of crosscutting space technologies while also stimulating the development and utilization of the U.S. commercial space industry, particularly for the suborbital and small launch vehicle markets
- **7 companies** contracted to provide integration and flight services on commercial reusable sub-orbital vehicles (Blue Origin, Masten, Near Space Corp, UP Aerospace, Virgin, World View, ZERO-G)
- **Technologies selected** via two mechanisms
  - ***SpaceTech REDDI NRA*** - Awardees receive funding to purchase flights from U.S. commercial flight vendors
  - ***NASA Internal Call for Payloads*** - Provide suborbital flight demonstrations for technologies from NASA and other government agencies
- **Public Private Partnerships** with 11 commercial space companies developing dedicated small launch vehicle technologies
- **Collaborating** with other Mission Directorate programs to provide testing of technologies (e.g., Science Mission Directorate's USIP)

FY2017 Highlights

- Space Technology Testing
  - Zero Gravity Corporation conducted initial payload flights for Research, Development, Demonstration, and Infusion (REDDI) grantees (Nov 2016 & Mar 2017)
  - NASA Cooperative Blending of Autonomous Lander Technologies (COBALT) tested on Masten Space System's Xodiac, April 2017
  - Near Space Corporation conducted testing of 1090 MHz ADS-B (May 2017) and demonstration of HASS vehicle as an sRLV surrogate (Sep 2017)
  - World View successfully demonstrated its Altitude Control technology (Aug 2017)
  - Selected payloads for 2 Materials International Space Station Experiment (MISSE) calls
- Industry Small Launch Vehicle Technology Development
  - 6 Tipping Point selections for SmSat Launcher Tech Development, Feb 2017
  - 5 SmSat Launcher Tech Dev Projects through SBIR 2017 Phase 1 awards, April 2017

FY2018-19 Plans

NASA will prioritize Flight Opportunities to align with NASA's Exploration Campaign objectives

- Continue to fund annual technology payload awards
  - Bi-annual REDDI F1A & F1B NRAs
  - Internal payloads for NASA payloads
- Support commercial small launch vehicle capability development
  - Initiate ACO 2017 activities
  - Tipping Point 2018 planned








Flight Opportunities Impacts – On Board *ISS Testing*

Gecko Grippers – NASA JPL

Parabolic flights in 2014 & 2015

A novel approach to grappling non-cooperative objects in microgravity

- Flights helped researchers adjust design and demonstrate functionality in a realistic operational environment
- Deployed to ISS in 2016

Additive Manufacturing Facility – Made In Space

Parabolic flights in 2011 & 2013

Enabling production of critical components in micro-gravity

- In-flight observations enabled hardware/software modifications and rapid optimization for operation in microgravity
- Deployed to ISS in 2014, permanent installation on ISS in 2016

Radiation Tolerant Computing – Montana State

Sounding rocket flights in 2014 and 2016

Improving hardware reliability in the presence of ionizing radiation

- Flights provided exposure to relevant environments that proved the robustness of the system
- Deployed to ISS in 2016

Flight Opportunities Impacts

Lander Vision System – NASA JPL

Vertical take-off/vertical landing tests in 2013

Increasing Access to Planetary Surfaces

- Testing provided rapid, low-cost means to validate technology and prove its ability to successfully direct entry, descent, and landing of spacecraft on any space target
- Selected for Mars 2020 mission and further research via SPLICE (Safe & Precise Landing Integrated Capabilities Evolution)

Microgravity Propellant Gauging Using Modal Analysis – Carthage College

Parabolic flights in 2017

Enabling Efficient & Safe Transportation Through Space

- In-flight testing helped determine how to mitigate and compensate for sloshing under unsettled microgravity conditions
- Slated to fly on NASA's Orion Exploration Mission-3

High-Altitude Electromagnetic Sounding of Earth and Planetary Interiors – Southwest Research Institute

Balloon flight in 2017

Enabling the Next Generations of Science Discoveries

- Demonstrated feasibility of high-altitude electromagnetic sounding measurements for potential use in planetary exploration
- 2nd balloon flight planned for 2018

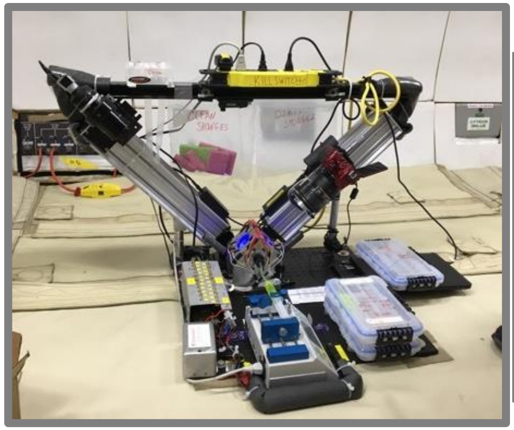
Flight Opportunities Impacts

Flow Boiling Heat Transfer Effects – University of Maryland

Parabolic flights in 2017

Enabling Humans to Live/Explore in Space and on Planets

- Collected data on upward and downward flows in microgravity, expanding data models of two-phase thermal systems required for spacecraft weight and space constraints
- Selected for mission on International Space Station to continue data collection



Protein-Drop Pinning in Microgravity – RPI and NASA

Parabolic flights in 2017

Enabling Humans to Live/Explore in Space and on Planets

- In-flight testing furthered understanding of the impact of shear on protein aggregation to identify more efficient mixing methods to produce pharmaceuticals/organic materials in a space environment
- Selected for International Space Station mission to continue data collection

OSIRIS-Rex Low-Gravity Regolith Sampling Tests – Lockheed Martin Inc. / University of Arizona

Parabolic flights in 2012

Enabling the Next Generations of Science Discoveries

- Demonstration of sample acquisition in relevant low-g environment to contribute to achieving TRL 6 prior to OSIRIS-REx PDR in 2013
- Launched September 8, 2016, returning sample to Earth September 24, 2023

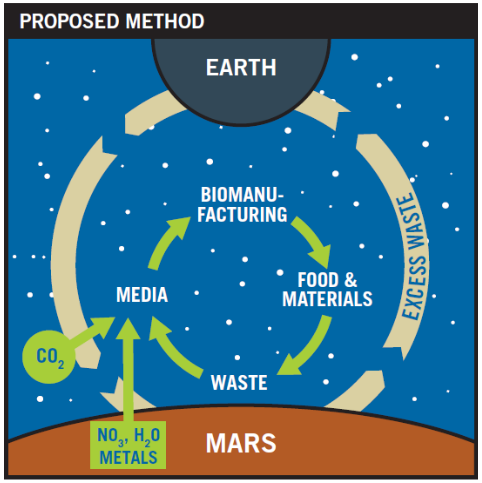
ECF/ESI Highlights

Mark Blenner – ECF15

Clemson University

Synthetic Biology for Recycling Human Waste into Nutraceuticals, and Materials: Closing the Loop for Long-Term Space Travel

- Using in situ materials and mission wastes such as CO_2 and urine to make water, plastics, foods, and medicines
- First to demonstrate the use of untreated human urine as a very effective nutrient supply in his biomanufacturing system
- Developed tools to produce Polyhydroxyalkonoate (PHA) linear polymers which can be used to make 3D-printed materials and tools in space



Mark Cutkosky – ESI15

Stanford University

Assistive Free-Flyers with Gecko-Inspired Adhesive Appendages for Automated Logistics in Space

- Developed “gecko gripper” to catch wide range of arbitrary surfaced objects in space, such as debris
- Gripper tested in zero-G flights as well as ISS, thin film samples are being tested by SSL Loral and JAXA
- Gripper with new wrist assembly now designed to integrate with NASA’s Astrobee free flying robot

Technology Transfer Program

Finding NASA technology is easy through our online portal, technology.nasa.gov. Licensing fast and straightforward through an online application system. We also offer programs for emerging entrepreneurs like Startup NASA and a university program, T2U (Tech Transfer University).

NASA's software inventory is available—without cost—to industry, academia and other government agencies on software.nasa.gov, the Federal Government's first and only comprehensive software inventory.

Our commercialization success stories are published annually in our Spinoff report and online at spinoff.nasa.gov.

Agency Technology and Innovation: Office of the Chief Technologist

Request of $8.2M for ongoing activities as follows:

- **Provides the strategy, leadership, and coordination that guides NASA's technology and innovation activities**
  - Develops and implements NASA agency-wide technology policies, roadmaps, integration framework and Strategic Technology Investment Plan (STIP).
  - Coordinates technology needs across the NASA Mission Directorates
- **Documents, Tracks, and Analyzes NASA's technology investments**
  - Chairs the NASA Technology Executive Council, collaborating on an enterprise management approach to agency technology development.
  - Conducts independent analysis of emerging technology trends and and readiness levels to provide insight into emerging new technology and innovation areas relevant to NASA's missions.
- **Lead's NASA participation in the Science and Technology Forum Partnership**
  - Coordinates technical interchanges and working groups with other Government agencies and industry to foster collaboration on advancement of critical technologies of benefit to the Nation.
- **Provides Agency-level leadership and coordination of NASA's Innovation Framework and champions NASA's culture of Innovation**
  - Pilot new, innovative approaches to technology development and innovation best practices, measuring success and graduating successful projects to other agency programs for maturation.

Strategies, Roadmaps, and Studies

Facilitates Technical Interchanges and Working Groups

Keeping our finger on the pulse of NASA technology development

Technology Roadmaps

Strategic Technology Investment Plan

DoD NRL FAA DARPA

NRO Space Command DoE AFRL

Technology partnerships