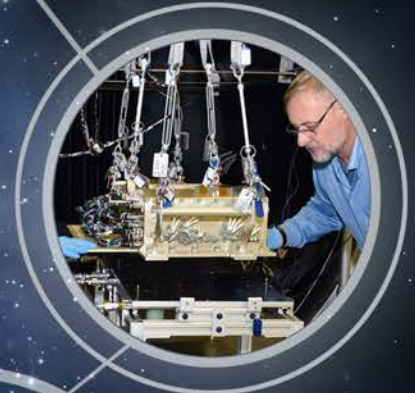


National Aeronautics and  
Space Administration



# Exploration Research and Technology Overview

## Presented to the ASEB/SSB Joint Meeting

Mr. James Reuter, Associate Administrator (Acting) for NASA STMD | 05.01.18

# Space Technology Pipeline

## Early Stage Innovation

- NASA Innovative Advanced Concepts
- Space Tech Research Grants
- Center Innovation Fund

## SBIR/STTR

## Partnerships & Technology Transfer

- Technology Transfer Program
- Prizes and Challenges
- iTech

## Mid TRL

## Technology Maturation

- Game Changing Development

## Technology Demonstration

- Technology Demo Missions
- Small Spacecraft Technology
- Flight Opportunities

## High TRL

## Low TRL



TECHNOLOGY PIPELINE



# 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

# 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

Budget Authority (\$ in millions)	Fiscal Year						
	Enacted	CR	Request	Notional			
	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
<b>EXPLORATION CAMPAIGN TOTAL</b>	<b>\$10,037.5</b>	<b>\$9,951.9</b>	<b>\$10,498.9</b>	<b>\$10,313.5</b>	<b>\$10,338.5</b>	<b>\$10,363.5</b>	<b>\$10,388.5</b>

\*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.

# 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.

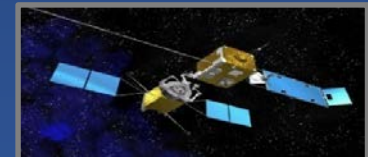
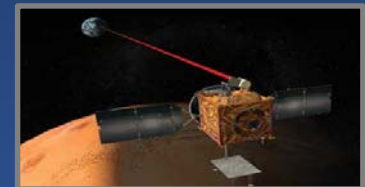
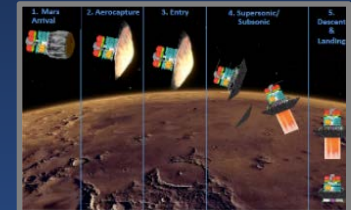
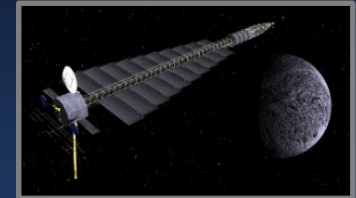
# ER&T Guiding Principles

- 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

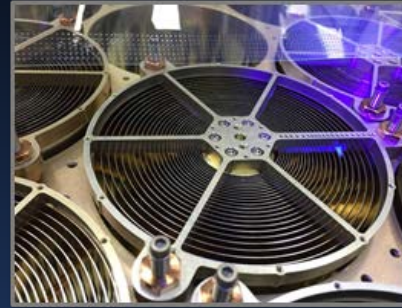


# FY 18 Accomplishments



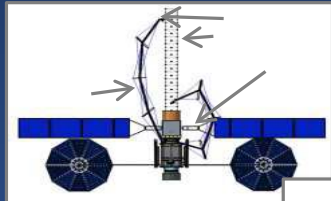
## Small Spacecraft

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.



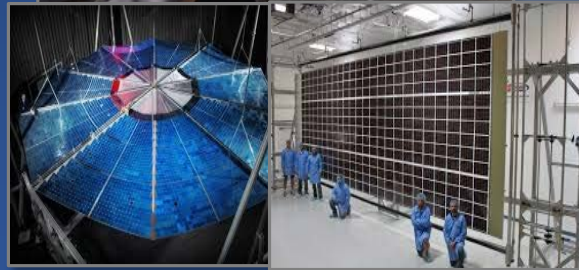
## Station Explorer for X-ray Timing and Navigation Technology (SEXTANT)

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.



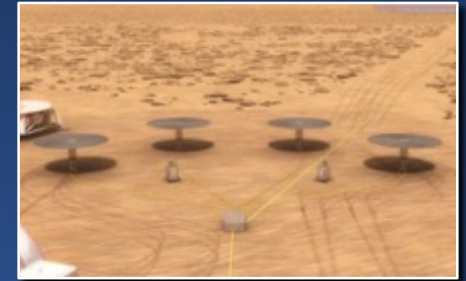
## In Space Robotics Manufacturing Assembly

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

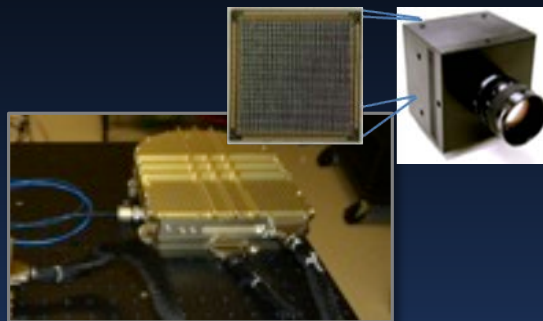


# FY 18 Accomplishments (Cont.)



## Laser Communication Relay Demonstration

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

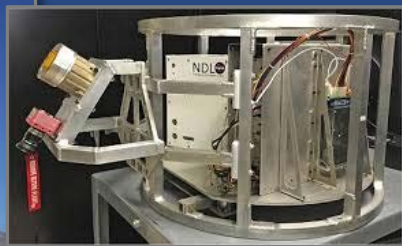


## Deep Space Optical Communication

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

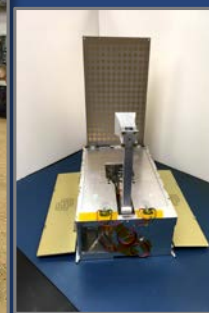
## SBIR/STTR Industry Day

Over 450 innovators from across the country participated in 2<sup>nd</sup> 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

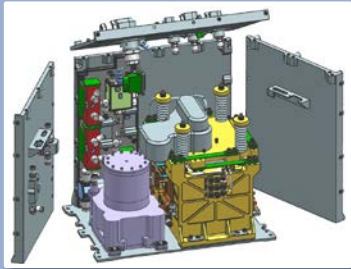


## Centennial Challenges Program

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

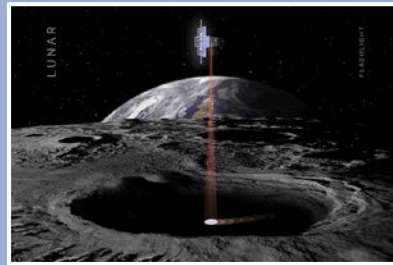
# FY 19 Milestones in Key Focus Areas

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



### MOXIE

November 2018  
Deliver to Mars  
2020 Project

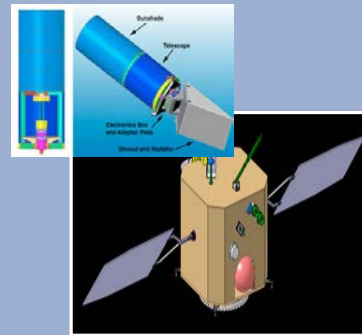


### Lunar Flashlight Flight Mission EM-1 December 2019



### Space Craft Oxygen Recovery (SCOR)

Technology efforts will be  
completed with prototype  
hardware delivered to NASA



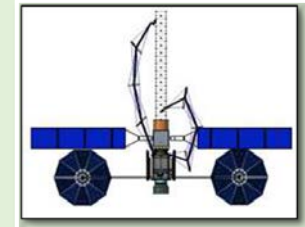
### Korea Pathfinder Lunar Orbiter (KPLO) 2019 Delivery of ShadowCam



### Lunar Infrared Flight Missions on EM-1 December 2019

## In-space manufacturing and on-orbit assembly

### Orbital ATK



### Space Systems Loral

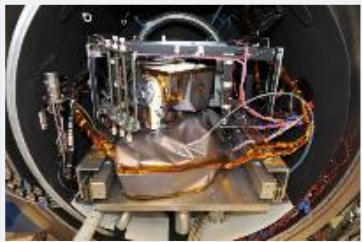
### Made In Space



**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

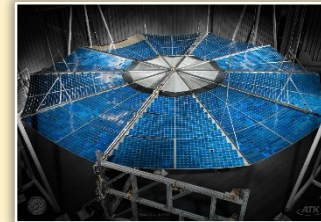
Completion of critical design

## 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 SHIVER testing



### Solar Electric Propulsion

Develop and test qualification hardware



### Lunar IceCube

Flight Mission EM-1  
December 2019

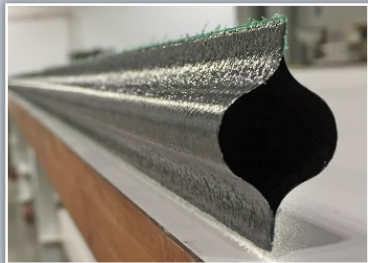


# FY 19 Milestones in Key Focus Areas

## Advanced materials

### Deployable Composite Boom March 2019

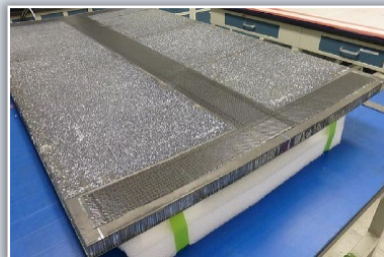
QM Boom structural characterization test



### Early Stage Innovation 2017

Daniel Lewis -

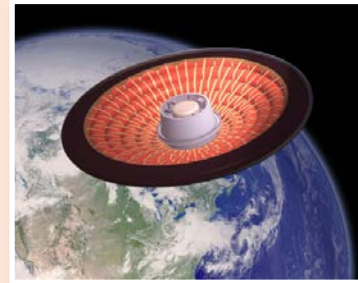
Develop an integrated thermal-chemical-microstructural simulation approach for additive manufacturing



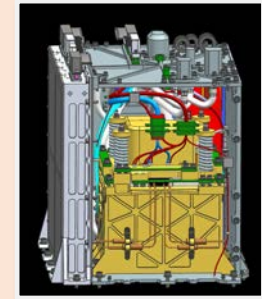
### Composite Technology for Exploration July 2019

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

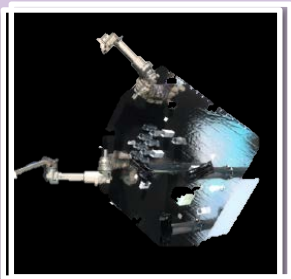


### SPLICE March 2019

Complete NDLETU 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



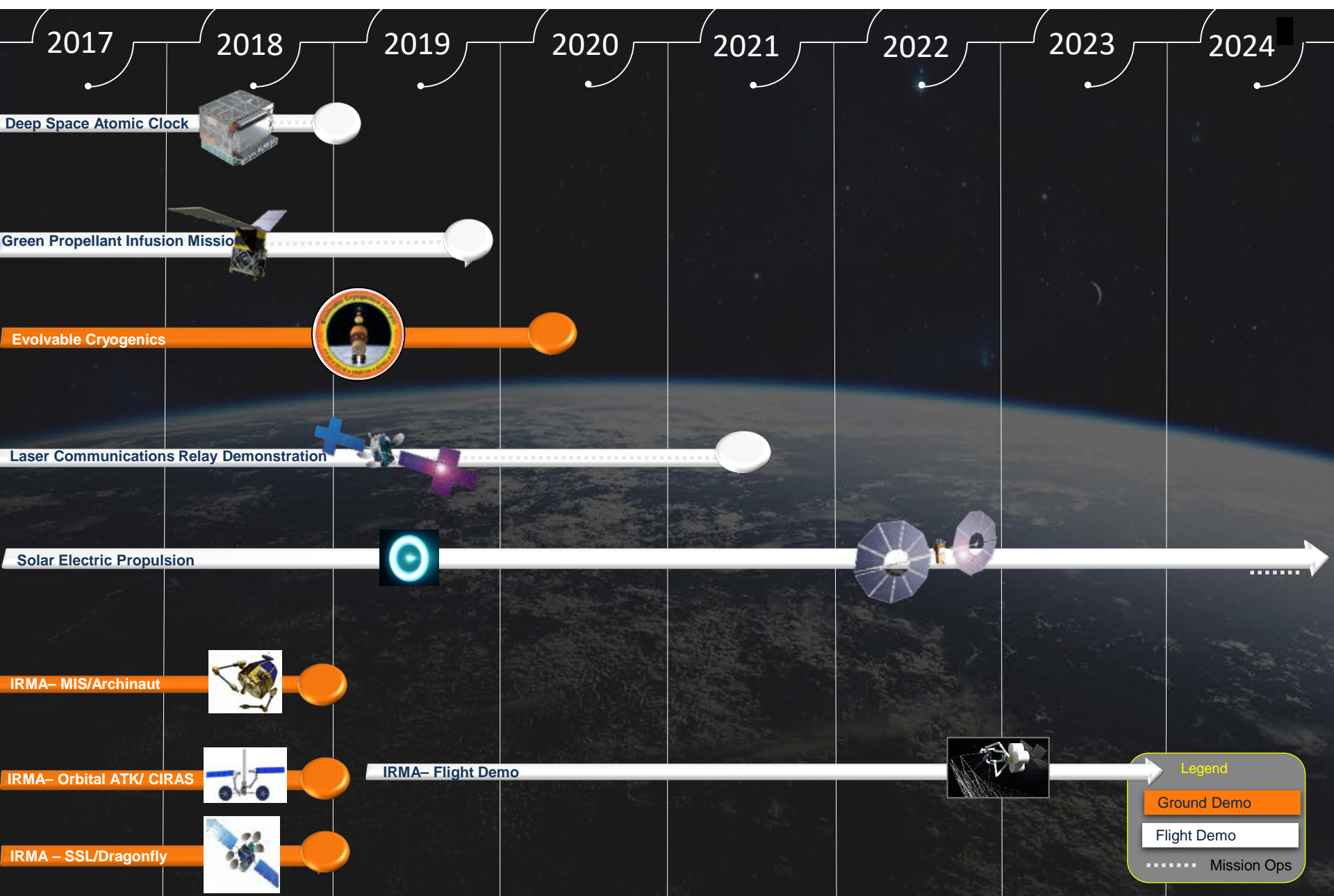
### Advanced Exploration Exercise System

Develop and complete testing in preparation for ISS deployment



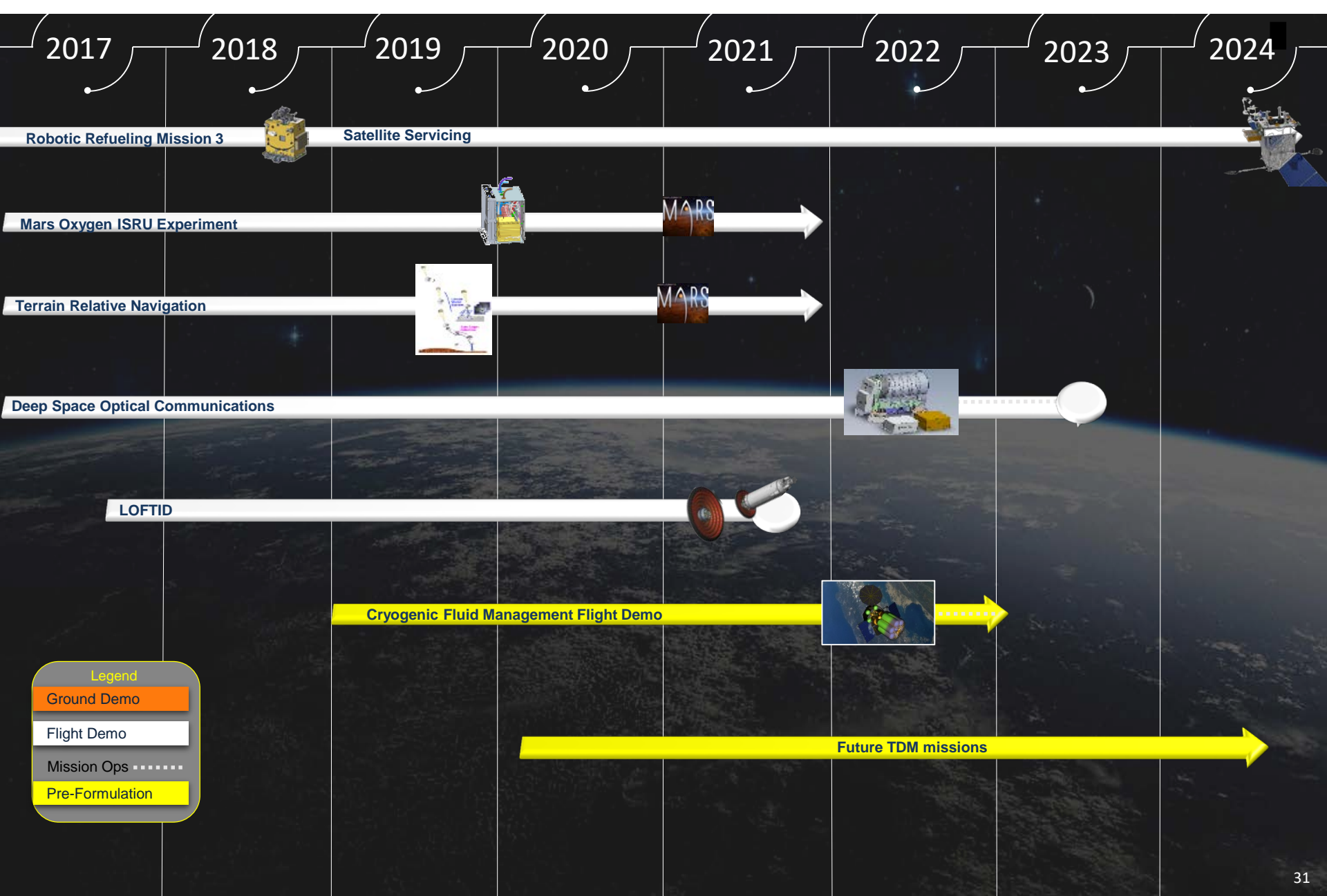
**Release NASA research solicitations to national biomedical research community** to better address exploration spaceflight health, performance, and space radiation risks, adding to over 170 research tasks already active within HRP

# TDM Portfolio at a Glance





# TDM Portfolio at a Glance



# 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**



# 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 qualification 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.