Exploration Research and Technology Overview

Presented to the NASA Advisory Council

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

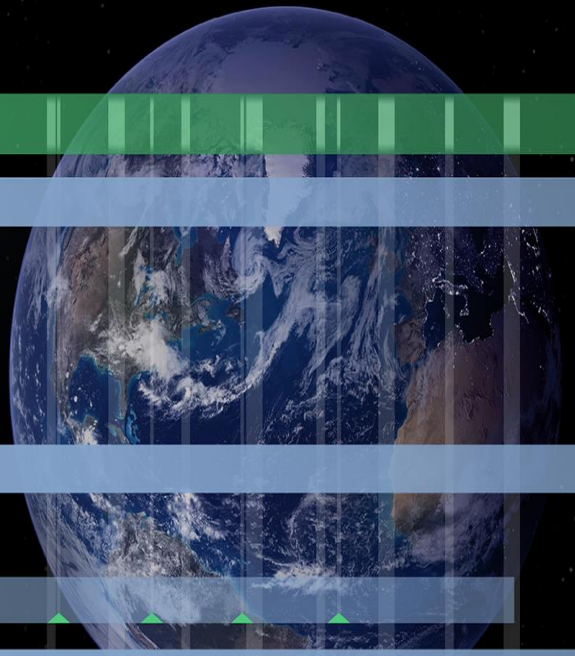
Space Policy Directive-1:

- “Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations.”

	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)

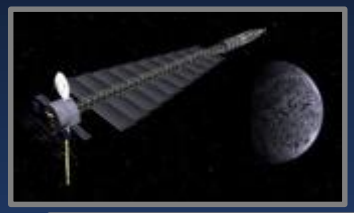
- Research & development of new technologies and capabilities that enhances and enables deep space exploration.
- Enables greater focus on innovative ways to further humankind's exploration from conception to testing to spaceflight.
- Consolidates Space Technology Mission Directorate and Advanced Exploration 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

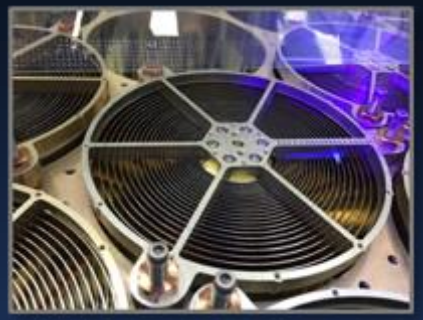





FY 18 Accomplishments

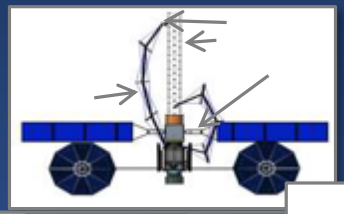
Small Spacecraft

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.



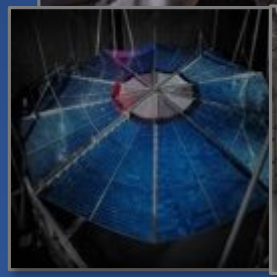
Station Explorer for X-ray Timing and Navigation Technology (SEXTANT)

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

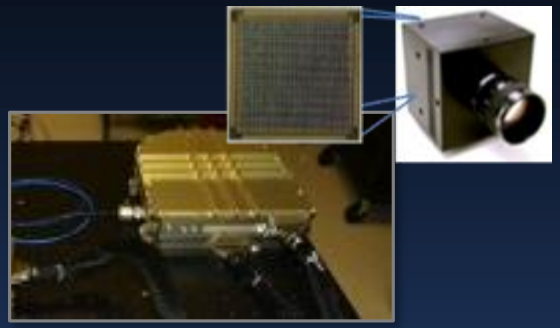
Kilopower

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

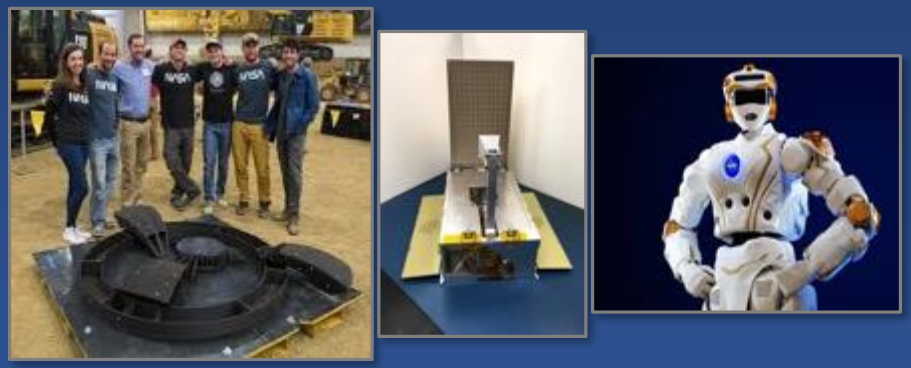
Completed ground testing to retire risk for its demonstration flight and began formulation for flight demonstration on the Psyche mission

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

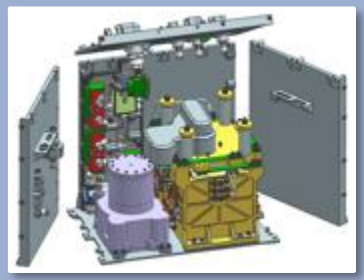


Centennial Challenges Program

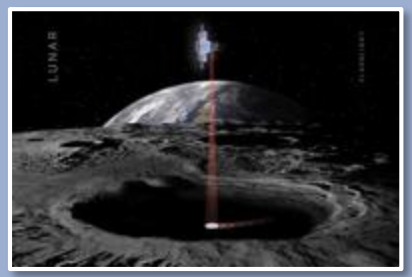
Awarded more than $1.5 million for technology solutions toward the Cube Quest, 3D Printed Habitat and the Space Robotics Challenges.

FY 19 Milestones in Key Focus Areas

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



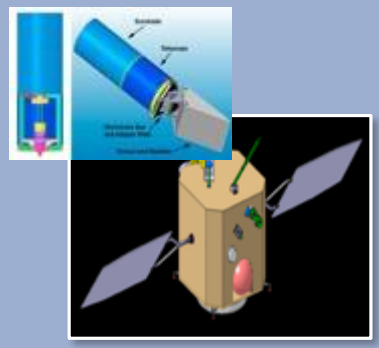
MOXIE
November 2018
Deliver to Mars 2020 Project



Lunar Flashlight
Flight Mission EM-1
December 2019

Lunar Infrared
Flight Missions on EM-1
December 2019

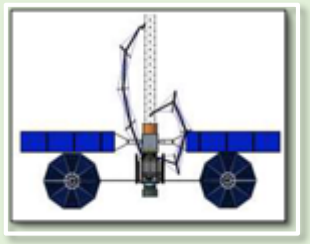
Space Craft Oxygen Recovery (SCOR)
Technology efforts will be completed with prototype hardware delivered to NASA



Korea Pathfinder Lunar Orbiter (KPLO)
2019 Delivery of ShadowCam

In-space manufacturing and on-orbit assembly

Orbital ATK



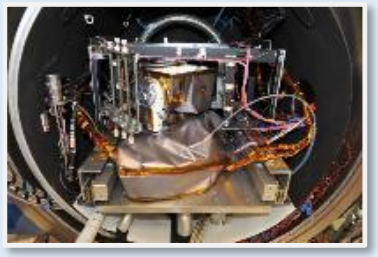
Space Systems Loral

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

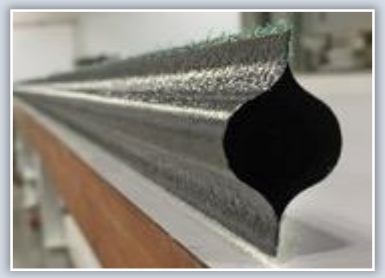
Solar Electric Propulsion Develop and test qualification hardware

Lunar IceCube
Flight Mission EM-1
December 2019

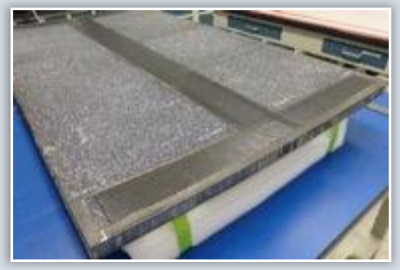
FY 19 Milestones in Key Focus Areas

Advanced materials

Deployable Composite Boom
March 2019
QM Boom structural characterization test



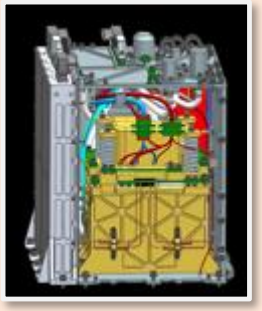
Early Stage Innovation 2017
Daniel Lewis -
Develop an integrated thermal-chemical-microstructural simulation approach for additive manufacturing



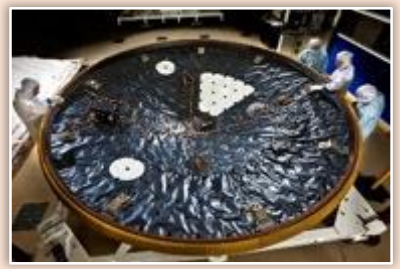
Composite Technology for Exploration
July 2019
Complete testing of longitudinal and circumferential joint manufacturing and testing

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

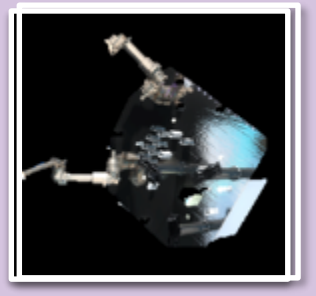


MEDLI2
April 2019
Hardware Delivery for integration on Mars 2020 entry system

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

TDM Portfolio at a Glance

2017 2018 2019 2020 2021 2022 2023 2024

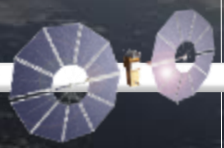
Deep Space Atomic Clock

Green Propellant Infusion Mission

Evolvable Cryogenics

Laser Communications Relay Demonstration

Solar Electric Propulsion



IRMA– MIS/Archinaut

IRMA– Orbital ATK/ CIRAS

IRMA– Flight Demo

IRMA – SSL/Dragonfly

Legend

Ground Demo

Flight Demo

Mission Ops

TDM Portfolio at a Glance

2017 2018 2019 2020 2021 2022 2023 2024

Robotic Refueling Mission 3

Satellite Servicing

Mars Oxygen ISRU Experiment

Terrain Relative Navigation

Deep Space Optical Communications

LOFTID

Cryogenic Fluid Management Flight Demo

Future TDM missions

Legend

- Ground Demo
- Flight Demo
- Mission Ops
- 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**

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.