



# Space Technology Mission Directorate Overview

**Dr. Prasun N. Desai**  
Deputy Associate Administrator  
for Management  
Space Technology Mission Directorate

Presentation to the  
Planetary Protection Subcommittee  
June 2, 2016

# Space Technology...

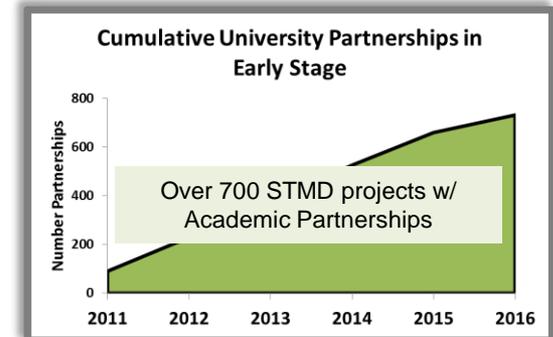
# ... an Investment for the Future



- Enables a **new class of NASA missions** beyond low Earth Orbit.
- **Delivers innovative solutions** that dramatically improve technological capabilities for NASA and the Nation.
- Develops technologies and capabilities that make NASA's missions **more affordable and more reliable**.
- Invests in the economy by **creating markets and spurring innovation** for traditional and emerging aerospace business.
- **Engages the brightest minds** from academia and small businesses in solving NASA's tough technological challenges.

## Addresses National Needs

A generation of studies and reports (40+ since 1980) document the need for regular investment in new, transformative space technologies.



## Value to NASA

## Value to the Nation



## Benefits from STMD:

The NASA Workforce  
Academia  
Small Businesses  
The Broader Aerospace  
Enterprise

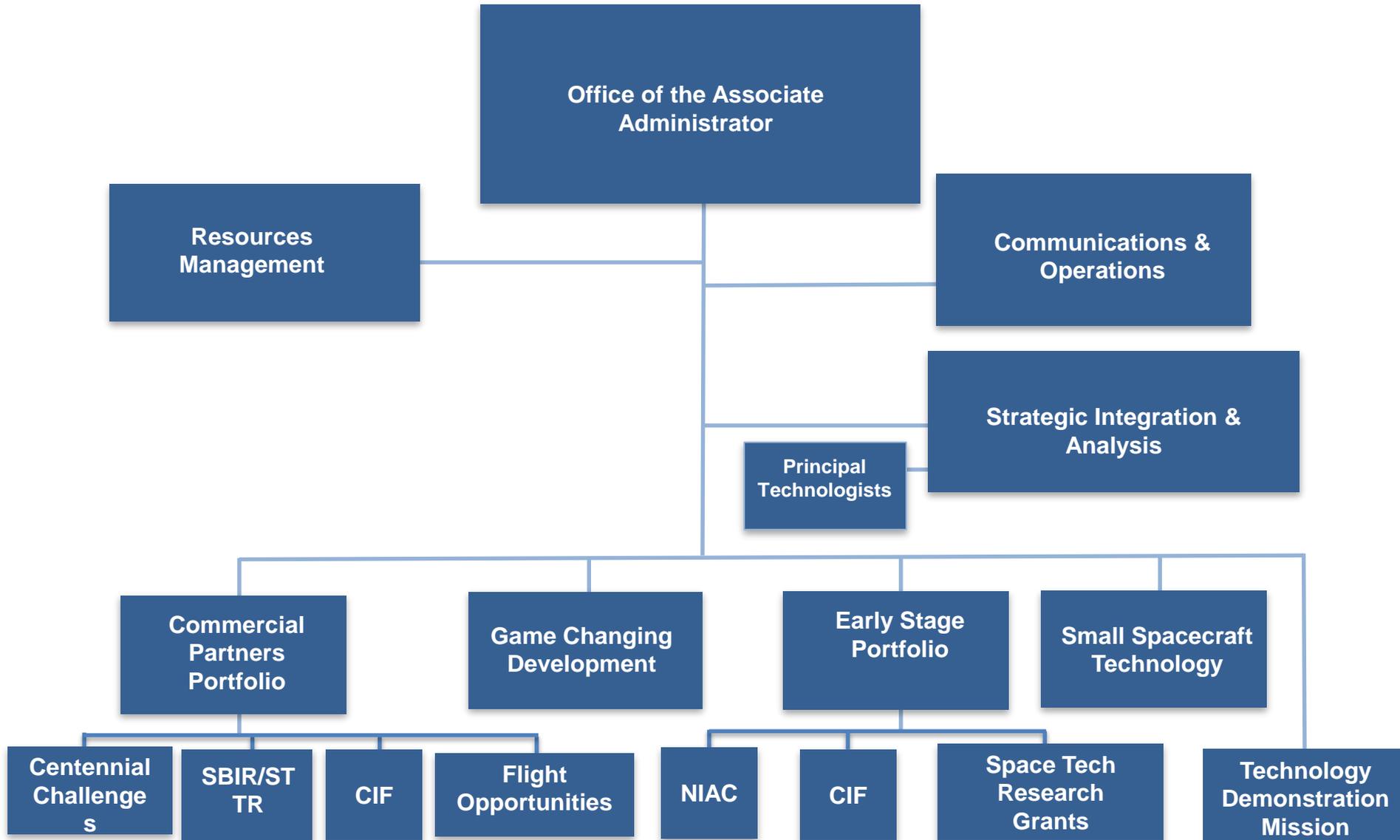


# Guiding Principles of the Space Technology Programs



- **Adhere to a Stakeholder Based Investment Strategy:** NASA Strategic Plan; NASA Space Tech Roadmaps / NRC Report; NASA Mission Directorate / Commercial advocacy
- **Invest in a Comprehensive Portfolio:** Covers low to high TRL; Grants & Fellowships; SBIR & prize competitions; prototype developments & technology demonstrations
- **Advance Transformative and Crosscutting Technologies:** Enabling or broadly applicable technologies with direct infusion into future missions
- **Develop Partnerships to Leverage Resources:** Partnerships with Mission Directorates and OGAs to leverage limited funding and establish customer advocacy; Public – Private Partnerships to provide NASA resources and support to U.S. commercial aerospace interests
- **Select Using Merit Based Competition:** Research, innovation and technology maturation, open to academia, industry, NASA centers and OGAs
- **Execute with Lean Structured Projects:** Clear start and end dates, defined budgets and schedules, established milestones, lean development, and project level authority and accountability.
- **Infuse Rapidly or Terminate Promptly:** Operate with a sense of urgency; Rapid cadence of tech maturation; informed risk tolerance to implement / infuse quickly or terminate
- **Place NASA at technology's forefront – refresh Agency's workforce:** Results in new inventions, enables new capabilities and creates a pipeline of NASA and national innovators, and refreshes the agencies technical capabilities / workforce

# Space Technology Mission Directorate (STMD) Organization





# Space Technology Portfolio



## Transformative & Crosscutting Technology Breakthroughs

## Pioneering Concepts/Developing Innovation Community

## Creating Markets & Growing Innovation Economy

### Technology Demonstration Missions

bridges the gap between early proof-of-concept tests and the final infusion of cost-effective, revolutionary technologies into successful NASA, government and commercial space missions.



### NASA Innovative Advanced Concepts (NIAC)

nurtures visionary ideas that could transform future NASA missions with the creation of breakthroughs—radically better or entirely new aerospace concepts—while engaging America’s innovators and entrepreneurs as partners in the journey.



### Centennial Challenges

directly engages nontraditional sources advancing technologies of value to NASA’s missions and to the aerospace community. The program offers challenges set up as competitions that award prize money to the individuals or teams that achieve specified technological challenge.



### Small Spacecraft Technology Program

develops and demonstrates new capabilities employing the unique features of small spacecraft for science, exploration and space operations.



### Space Technology Research Grants

to accelerate the development of “push” technologies to support future space science and exploration needs through innovative efforts with high risk/high payoff while developing the next generation of innovators through grants and fellowships.



### Flight Opportunities

facilitates the progress of space technologies toward flight readiness status through testing in space-relevant environments. The program fosters development of the commercial reusable suborbital transportation industry.



### Game Changing Development

seeks to identify and rapidly mature innovative/high impact capabilities and technologies that may lead to entirely new approaches for the Agency’s broad array of future space missions.



### Center Innovation Fund

stimulates and encourages creativity and innovation within the NASA Centers by addressing the technology needs of the Agency and the Nation. Funds are invested to each NASA Center to support emerging technologies and creative initiatives that leverage Center talent and capabilities.



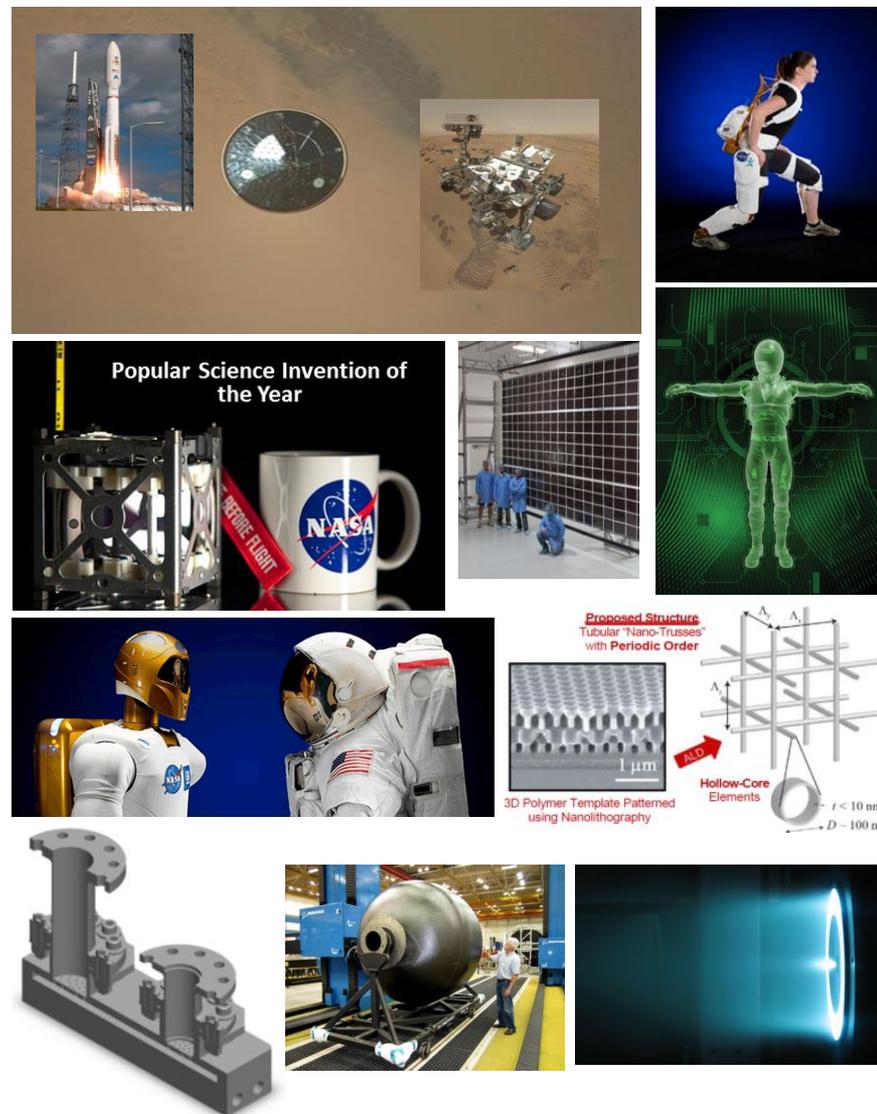
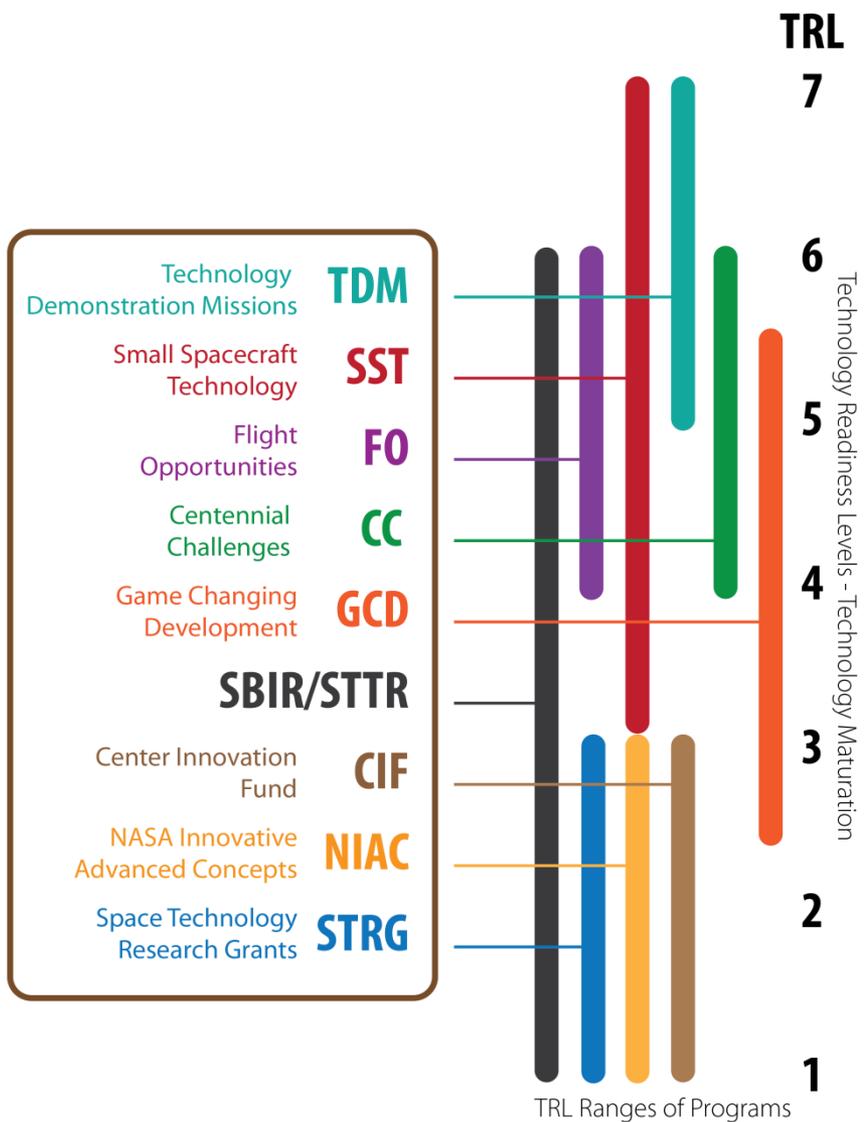
### Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR)

Programs provide an opportunity for small, high technology companies and research institutions to develop





# STMD Utilizes a Portfolio Approach



# Space Technology Mission Directorate



## Commercial Partnerships

- SBIR/STTR Program
- Flight Opportunities Program
- Centennial Challenges Program
- Regional Economic Development

## Game Changing Development

Game Changing Development Program

## Small Spacecraft

Small Spacecraft Technologies Program

## Early Stage

- NASA Innovative Adv Concepts Program
- Space Technology Research Grants Program
- Center Innovation Fund Program

## Technology Demonstrations

Technology Demonstration Missions Program

Low TRL

Mid TRL

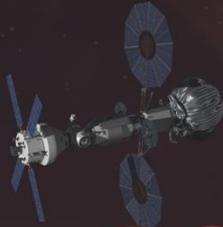
High TRL

TECHNOLOGY PIPELINE

# Technology Path to Pioneering Space



Asteroid Retrieval Mission



Hypersonic Inflatable Aerodynamic Decelerator



Supersonic Aerodynamic Decelerator



Optical Communications

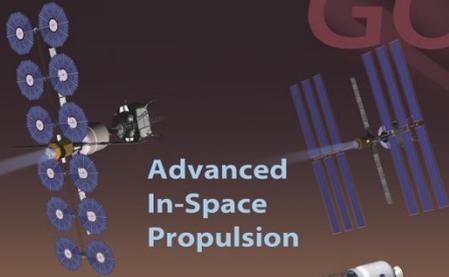


GO

LAND

LIVE

Advanced In-Space Propulsion



Supersonic Retropropulsion



Environmental Control & Life Support System



Surface Power



Next Generation Spacesuit



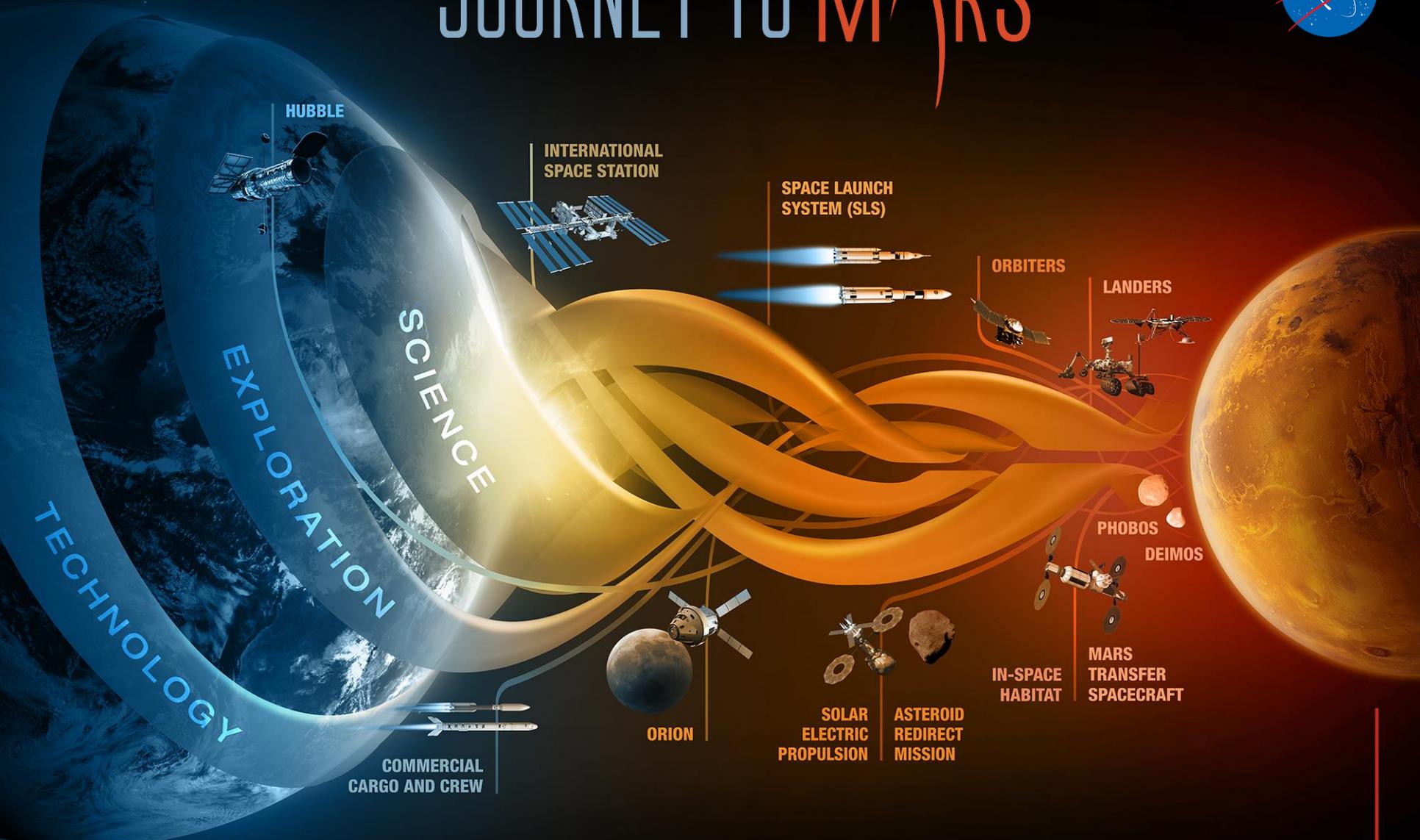
Robotics & Autonomy



In-Situ Resource Utilization



# JOURNEY TO MARS



MISSIONS: 6-12 MONTHS  
RETURN: HOURS

**EARTH RELIANT**

MISSIONS: 1 TO 12 MONTHS  
RETURN: DAYS

**PROVING GROUND**

MISSIONS: 2 TO 3 YEARS  
RETURN: MONTHS

**EARTH INDEPENDENT**

# STMD Investment Planning



STMD Strategic Alignment Framework

- Core values, guiding principles, implementation goals flowdown

STMD Strategic Themes

- Get There, Land There, Live There, Observe There, Invest Here

Strategic Guidance

- Stakeholder input: Space Technology Roadmaps, NRC recommendations, STIP, MD roadmaps, Roundtables, etc.

STMD Thrust Areas

- Focused areas of STMD investments

Content Generation

- Principal Technologists: Technology investment plans

Technology Portfolio Integration

- Crosscutting Investment strategy and content selection

STMD Programs

- Implementation instruments

STMD Strategic Themes

## Get There

Improve the ability to efficiently access and travel through space

## Land There

Enable the capability of landing more mass, more accurately, in more locations throughout the solar system

## Live There

Make it possible to live and work in deep space and on planetary bodies

## Observe There

Transform the ability to observe the universe and answer the profound questions in Earth and space sciences

## Invest Here

Enhance the nation's aerospace capabilities and ensure its continued technological leadership



National Science and Technology Priorities



# Enabling Future Exploration Missions



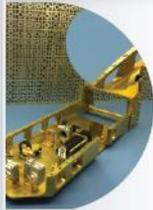
Space Technology focus investments in 7 thrust areas that are key to future NASA missions and enhance national space capabilities.



## Space Power and Propulsion

Create improvements in power generation and energy storage to allow for more capable science & human missions. Create improvements in thrust levels, specific power, and alternatives to traditional chemical propulsion systems for destination-agnostic, deep space exploration spacecraft systems.

**External Application:**  
Enhanced propulsion capabilities for Commercial and OGA Satellites



## High-Bandwidth Comm, Deep Space Navigation, Avionics

Substantially increase available bandwidth & data rates for near earth & deep space. Assure robust and reliable interconnected space network. Allow for more capable science & human missions; enable more precise entry trajectories for orbits around & Mars, Europa, Titan, and other bodies.

**External Application:**  
High bandwidth for Commercial and OGA Satellites. Next Gen GPS and build new industrial base.



## Advanced Life Support & Resource Utilization

Human exploration missions beyond low earth orbit will require highly reliable technologies (e.g. reclaiming water reuse of trash, air revitalization) to minimize resupply requirements and increase independence from earth.

**External Application:**  
Mining Industry and other closed environments; OGA



## Entry Descent and Landing Systems

Permits more capable science and future human missions to terrestrial bodies. Includes, hypersonic and supersonic aerodynamic decelerators, next-gen TPS materials, retro-propulsion, instrumentation and modeling.

**External Application:**  
Returning commercial assets from space and research from ISS



## Autonomy & Space Robotic Systems

Extends our reach by helping us remotely explore planetary bodies, manage in-space assets and support in-space operations by enhancing the efficacy of our operations.

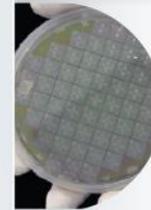
**External Application:**  
Human-safe Robotics for industrial use, disaster response, & overall autonomous operations



## Lightweight Structures & Manufacturing

Targets large decreases in structural mass for launch vehicles and spacecraft materials using nanotech, composites and in space manufacturing capabilities.

**External Application:**  
Industrial Materials and Composites for large structures (rockets, aircraft)



## Space Observatory Systems

Allows for significant gains in science capabilities including: coronagraph technology to characterize exoplanets, advances in surface materials and better control systems for large space optics.

**External Application:**  
Industrial Materials, Earth Observation

THRUST AREAS

# Capability Development Risk Reduction

= Plan/resources understood  
 = Plan/resources finalization required



Mission Capability		ISS	Cis-lunar Short Stay (e.g. ARM)	Cis-lunar Long Stay	Mars Robotic	Mars Orbit	Mars Surface
Working in Space and On Mars	In Situ Resource Utilization & Surface Power		Exploratory ISRU Regolith	Exploratory ISRU	Exploratory ISRU & Atmosphere	Exploratory ISRU	Operational ISRU & High Power
	Habitation & Mobility	Long Duration with Resupply	Initial Short Duration	Initial Long Duration		Resource Site Survey	Long Duration / Range
	Human/Robotic & Autonomous Ops	System Testing	Crew-tended	Earth Supervised	Earth Monitored	Autonomous Rendezvous & Dock	Earth Monitored
	Exploration EVA	System Testing	Limited Duration	Full Duration	Full Duration	Full Duration	Frequent EVA
Staying Healthy	Crew Health	Long Duration	Short Duration	Long Duration	Dust Toxicity	Long Duration	Long Duration
	Environmental Control & Life Support	Long Duration	Short Duration	Long Duration		Long Duration	Long Duration
	Radiation Safety	Increased Understanding	Forecasting	Forecasting Shelter	Forecasting Shelter	Forecasting Shelter	Forecasting & Surface Enhanced
Transportation	Ascent from Planetary Surfaces				Sub-Scale MAV	Sub-Scale MAV	Human Scale MAV
	Entry, Descent & Landing				Sub-Scale/Aero Capture	Sub-Scale/Aero Capture	Human Scale EDL
	In-space Power & Prop		Low power	Low Power	Medium Power	Medium Power	High Power
	Beyond LEO: SLS & Orion		Initial Capability	Initial Capability	Full Capability	Full Capability	Full Capability
	Commercial Cargo & Crew	Cargo/Crew	Opportunity	Opportunity	Opportunity	Opportunity	Opportunity
	Communication & Navigation	RF	RF & Initial Optical	Optical	Deep Space Optical	Deep Space Optical	Deep Space Optical
		EARTH RELIANT	PROVING GROUND			EARTH INDEPENDENT	



# Categories of Collaboration Between Mission Directorates

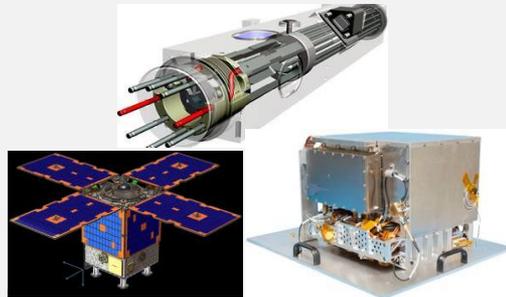


- **Deliveries:** STMD matures technology and delivers to HEOMD or SMD for system-level evaluation (e.g., RCA, VOR, EVA Gloves, RPM instruments, etc.)
- **Partnerships:** STMD, HEOMD and/or SMD co-fund the development of technologies that are of mutual interest (e.g., MOXIE, MEDA, MEDLI-2, TRN, SCOR, etc.)
- **Coordination:** STMD, HEOMD and/or SMD define specific divisions of responsibility within a technical discipline (e.g., entry descent & landing, nuclear systems, synthetic biology, advanced manufacturing, etc.)

# FY 2015-16 STMD Major Accomplishments



**Solar Array Development and Testing**



**Deep Space Atomic Clock readies for flight test**

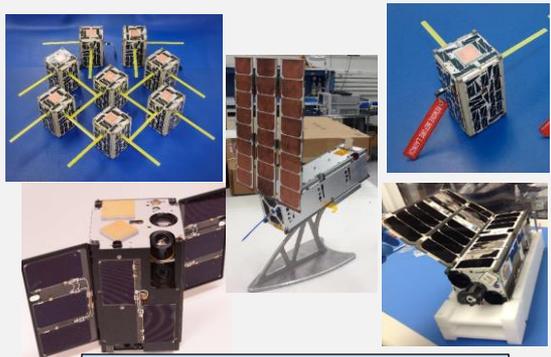
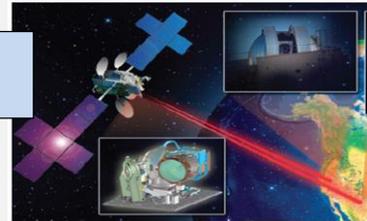


**Green Propellant Infusion Mission integration and prepped for launch**

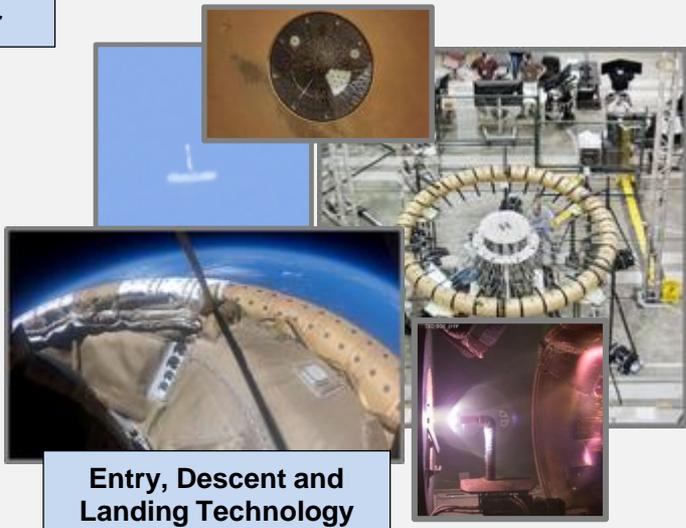


**Advanced Thrusters and Successful testing a new 12.5k Hall Thruster**

**Laser Communication successful demonstration and systems integration**



**Small Spacecraft Mission Hardware Ready for Launch**



**Entry, Descent and Landing Technology**



**Creating New Markets and Spurring Innovation while Engaging the Brightest Minds**

# Key Activities in FY 2016- 2017



New

**Restore-L:** Continue Formulation of technology demonstration for a low-Earth orbit satellite servicing mission, completing SRR/MDR in 2016 to support 2019 launch.

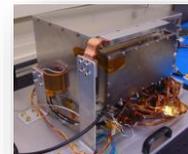


New

**DSOC:** Initiate technology demonstration mission for Deep Space Optical Communications for potential demonstration on the next Discovery mission.

## Laser Communications Relay Demonstration (FY 2016 and FY 2017)

- Develops and assembles flight unit and conducts integrated testing to support late CY 2019 launch.



**Solar Electric Propulsion:** Develop electric propulsion subsystem hardware to support Asteroid Redirect Robotic Mission (KDP-B currently scheduled for Q4 FY 2016).

**Green Propellant Infusion Mission:** demonstrate propellant formula, thrusters, and integrated propulsion system, for higher performing, safe alternative to highly toxic hydrazine (1<sup>st</sup> Quarter-CY2017)



**Deep Space Atomic Clock:** New space clock improving navigational accuracy for deep space and improve gravity science measurements (1<sup>st</sup> Quarter-CY2017)



## Deliver Small Spacecraft Technology: Conduct four demo missions in 2016

- Nodes – Deploy Nodes currently onboard ISS in 2016
- OCSA: Demonstrating in-space laser communications using 2 cubesats (Oct 2015 & May 2016)
- ISARA: Uses a deployed solar array as a Ka-band radio antenna reflector (May 2016)
- CPOD: Proximity operations and docking demo with 2 cubesats (NET Sep 2016)
- iSat: Complete Iodine Hall Thruster Critical Design Review in Spring 2016



## GCD Delivers Coronagraph, ISRU, SEXTANT (FY 2016 and 2017)

- Game Changing Development delivers two coronagraph technologies for WFIRST/AFTA consideration (Occulting Mask Coronagraph and PIAACMC Coronagraph)
- Complete Critical Design Review in Sept. 2016 for Mars Oxygen In-Situ Resource Utilization Experiment payload on Mars 2020.
- SEXTANT delivery of ICER Unit launched to the ISS.
- Develop Nuclear Thermal Propulsion technologies in collaboration with Department of Energy and industry.



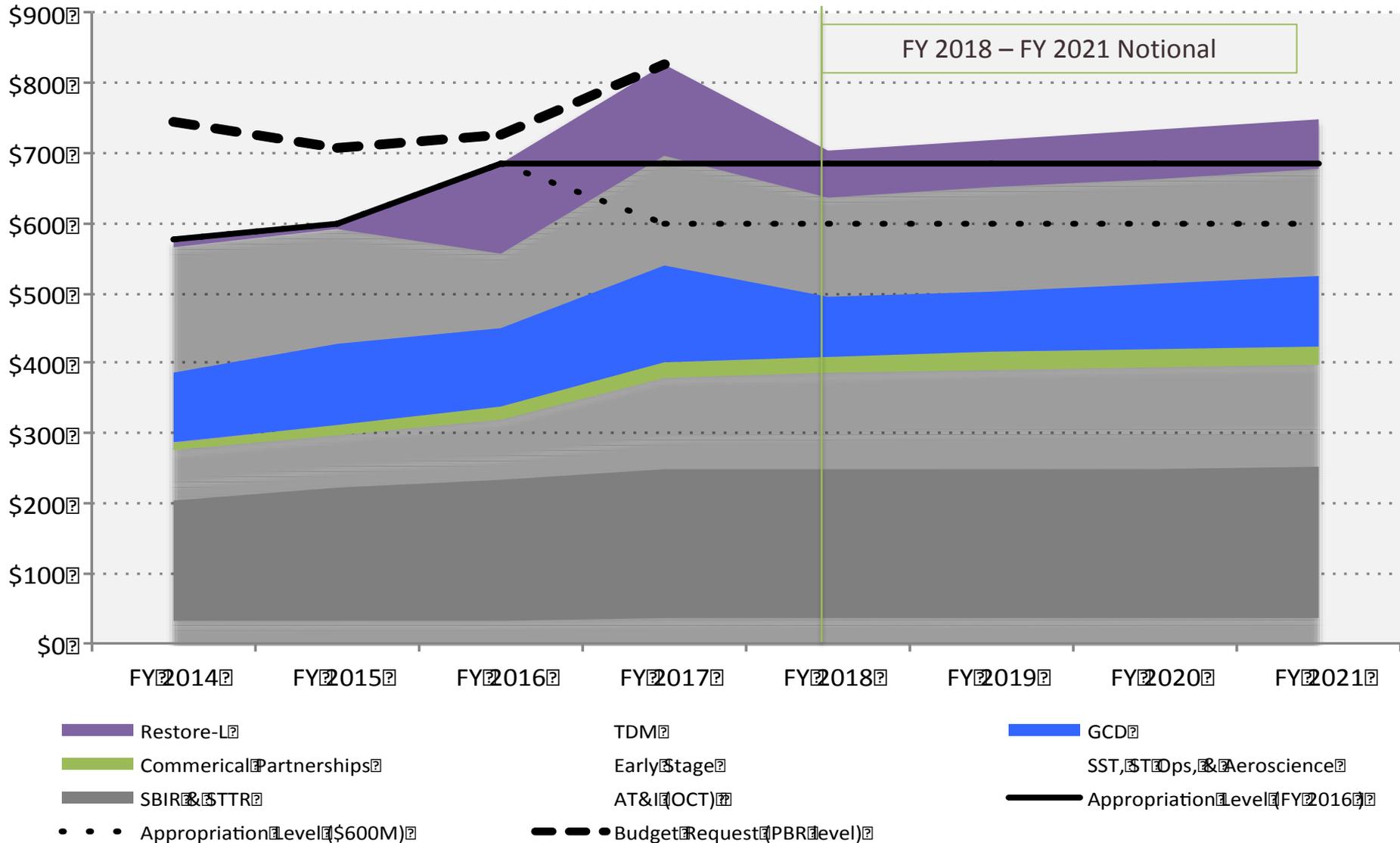
# FY 2017 Budget Request



Budget Authority (\$M)		FY 2015	FY 2016	Notional Plan				
			Initial Op Plan	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Agency Technology & Innovation (AT&I)		\$31.3	\$31.5	\$34.3	\$35.0	\$35.7	\$36.4	\$37.1
SBIR & STTR		\$190.7	\$200.9	\$213.0	\$213.2	\$213.5	\$213.8	\$213.8
Space Technology Research & Development (STR&D)		\$378.3	\$451.0	\$579.4	\$456.2	\$469.3	\$482.7	\$496.6
S T R & D	Early Stage	\$43.6	\$51.0	\$82.4	\$83.8	\$85.2	\$86.7	\$88.2
	Commerical Partnerships	\$14.2	\$19.9	\$22.9	\$23.3	\$23.8	\$24.3	\$24.8
	Game Changing Development (GCD)	\$129.3	\$123.8	\$158.4	\$111.1	\$117.6	\$124.3	\$131.2
	Technology Demonstration Missions (TDM)	\$172.0	\$236.0	\$288.9	\$210.5	\$214.8	\$219.0	\$223.4
	<i>In-Space Robotic Servicing (ISRS) / Restore-L</i>	\$10.0	\$133.0	\$130.0	\$66.3	\$67.6	\$69.0	\$70.4
	<i>All other TDM Projects</i>	\$162.0	\$103.0	\$158.9	\$144.2	\$147.1	\$150.1	\$153.1
Small Spacecraft Technologies (SST)		\$19.3	\$20.3	\$26.8	\$27.3	\$27.9	\$28.4	\$29.0
<b>TOTAL SPACE TECHNOLOGY</b>		<b>\$600.3</b>	<b>\$683.4</b>	<b>\$826.7</b>	<b>\$704.4</b>	<b>\$718.5</b>	<b>\$732.9</b>	<b>\$747.5</b>



# Budget History & FY 2017 Request



# Technology Demonstration Missions

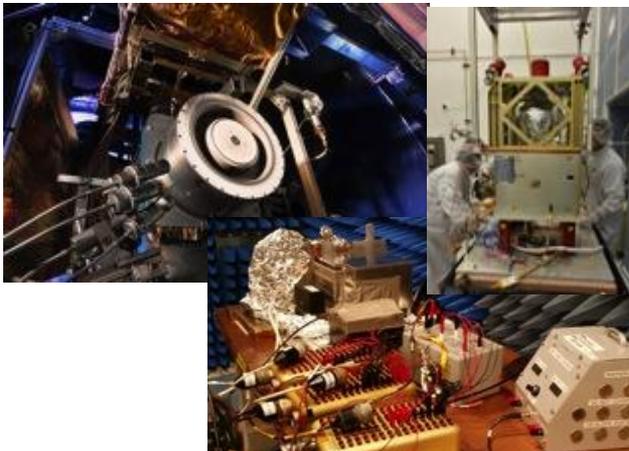


## Goal:

Bridge the gap between early developments and mission infusion by maturing crosscutting, system-level, technologies through demonstration in a relevant operational environment.

## Demonstrations:

- **Spaceflight** of new technologies including: a space-borne atomic clock, laser communications relay, “green” propellant demonstrator.
- **Ground-based and atmospheric demonstrations** of a supersonic parachute and inflatable decelerator, solar sail and cryogenic propellant storage and transfer technologies.



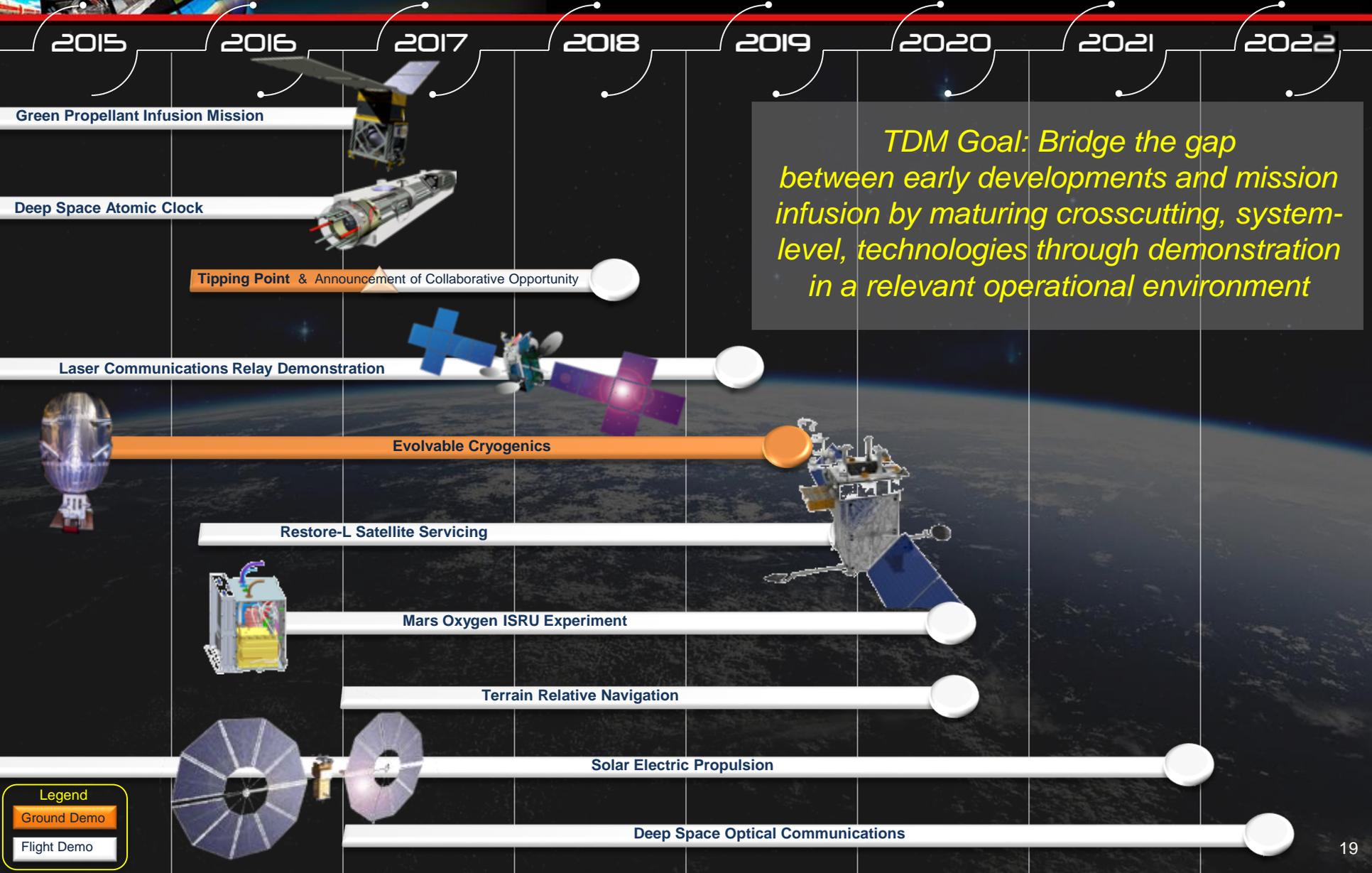
## FY 2015 Highlights

- **Green Propellant Infusion Mission:** Successfully fabricated five 1N thrusters and fully integrated and tested Green Propellant Propulsion Subsystem.
- **Deep Space Atomic Clock:** Payload integrated and began environmental testing, overcame significant technical challenge and keeping delivery schedule on-track.
- **Solar Electric Propulsion:** Successfully completed functional test of 12.5kW class Hall thruster and test of 300Vin & 120Vin power processing units.
- **Laser Communication Relay Demonstration:** Hardware development is proceeding and all major flight procurements are underway.
- **Evolvable Cryogenics:** Completed formulation, approved to implementation phase, radio frequency mass gauge proceeding on plan, other elements in work.
- **Low Density Supersonic Decelerator:** Successfully conducted second stratospheric supersonic flight dynamic tests at Pacific Missile Range Facility in Kauai.
- **Composites for Exploration Upper Stage:** Completed SRR and KDP-B. Automated Fiber Placement capabilities established at LaRC and MSFC.

## FY 2016 - 17 Plans

- Launch **Green Propellant Infusion Mission** and **Deep Space Atomic Clock**.
- Key components built, tested, and delivered for **Laser Communication Relay Demo** payload integration.
- Fabricate and test **Solar Electric Propulsion** thrusters and power processing engineering development unit.
- Hold **Restore-L** Mission Concept Review, continue technology development and engineering of key subsystems such as dexterous robotics and rendezvous & proximity operations systems and issue solicitation for spacecraft bus.

# TDM Portfolio



*TDM Goal: Bridge the gap between early developments and mission infusion by maturing crosscutting, system-level, technologies through demonstration in a relevant operational environment*

**Legend**  
Ground Demo  
Flight Demo

# STMD Public-Private Partnerships



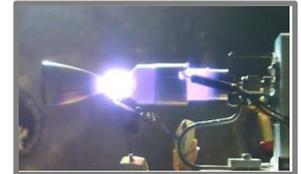
*STMD continues to foster partnerships with the commercial space sector for expanding capabilities and opportunities in space.*

## Objective:

Deliver critical space technologies needed for future missions by leveraging previous investment by U.S. industry and providing new opportunities for collaboration that accelerate development and utilization.

## Market Research Revealed Two Categories of Industry-led Space Technologies:

- Those at a “tipping point”, where a final demonstration or validation would result in rapid adoption and utilization - - “STMD Tipping Point Solicitation”
- Those that could directly benefit from NASA’s unique experience, expertise, facilities - - “STMD Announcement of Collaboration Opportunity (ACO)”



## Results:

- Both Tipping Point and ACO were released **May 2014**
- Topics included: Robotic In-Space Manufacturing, Small S/C Systems, Remote Sensing Instrumentation, Advanced Thermal Protection, Launch Systems Development
- **Nine** Tipping Point and **Thirteen** ACO industry-led projects selected **November 2015**
- Issue new Tipping Point solicitation in **late FY16 and ACO in FY17**



# Technology Demonstration Through Tipping Point Partnerships



In November, STMD selected 3 new TDM projects through the 'Tipping Point' solicitation that will be led by U.S. private sector companies to advance space technologies at the tipping point in their development. The following are new TDM Phase 1 projects:

## Robotic In-Space Manufacturing and Assembly of Spacecraft and Space Structures

- **Orbital ATK** (Dulles, Virginia) for the project entitled "Public-Private Partnership for Robotic In-Space Manufacturing and Assembly of Spacecraft and Space Structures" - will perform an integrated ground demonstration including robotically deployed rigid backbone and upgraded TALISMAN system
- **Space Systems Loral** (Palo Alto, California) for the project entitled "Dragonfly: On-Orbit Robotic Installation and Reconfiguration of Large Solid RF Reflectors" - will modify existing antenna/robotic equipment to perform a high fidelity antenna assembly ground demonstration to provide next generation of performance advancements in GEO ComSats
- **Made in Space, Inc.** (Moffett Field, California) for the project entitled "Versatile In-Space Robotic Precision Manufacturing and Assembly System" - will utilize the Archinaut in-space additive manufacturing and assembly system in the space environment via ISS



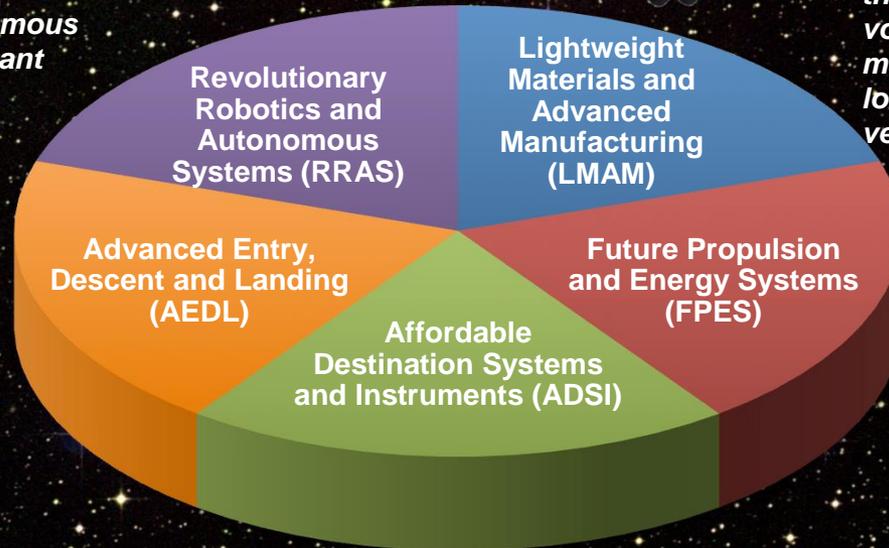
# Game Changing Development Technology Themes



*Enabling robotic and autonomous systems to operate in distant destinations*



*Innovating materials and structures that significantly reduce launch volume and minimizes system mass; manufacturing that enables lower cost spacecraft and launch vehicles*



*Enabling EDL missions to new (scientific) destinations, advancing aerosciences and materials to lower the cost and improve the efficiency of EDL systems, and developing the next generation of capabilities to enable human missions to Mars.*



*Providing viable, affordable, and efficient propulsion and energy systems technologies to enable deep space science and exploration*



*Ensuring customer driven innovative components and instruments*

# Game Changing Development Program\*



- Entry Systems Modeling
- Mars Entry Descent and Landing Instrument (MEDLI-2)
- Propulsive Descent Technology
- Heatshield for Extreme Entry Environment TPS (HEEET)
- Conformal Ablative TPS
- Hypersonic Inflatable Aerodynamic Decelerator (HIAD)
- Adaptable, Deployable Entry Placement Technology (ADEPT)

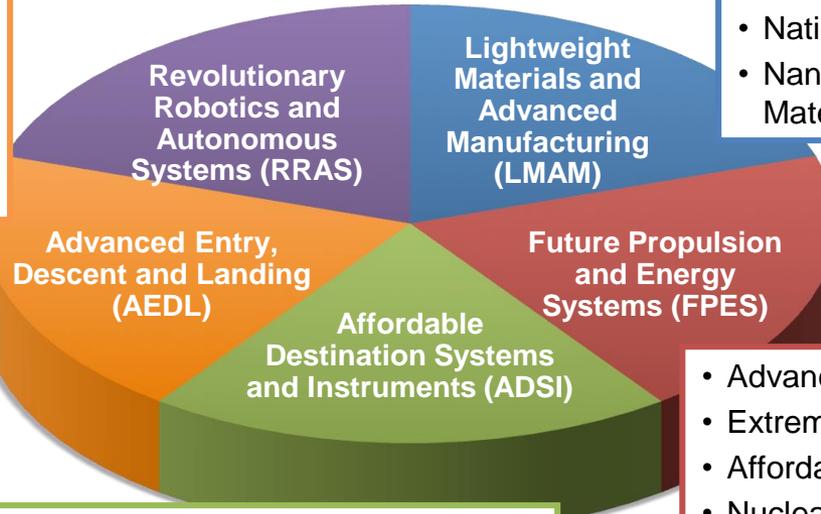
## AEDL

- Resource Prospector Rover
- National Robotics Initiative
- Pop-Up Flat Folding Explorer Robotics (PUFFER)
- Astro Bee
- Autonomous Cryo Loading Operations

## RRAS

- Low Cost Upper Stage
- Additive Construction for Mobile Emplacement
- Bulk Metallic Glass
- Manufacturing Initiative
- Materials Genome Initiative
- National Center for Advanced Manufacturing
- National Nanotechnology Institute
- Nanotechnology: Ultra-light Core Materials; Wires and Cables

## LMAM



- High Performance Spaceflight Computing (HPSC)
- Ultra-Low Temperature Batteries
- Ultra-Low Temperature Radiation Hard Electronics
- Station Explorer for X-Ray Timing and Navigation Technology (SEXTANT)
- Landing Guidance Navigation and Control
- Icy Body Mobility

## ADSI

- Thick Gamma Cosmic Ray Shield
- SpaceCraft Oxygen Recovery
- High Performance EVA Gloves
- TPS Phase Change Material
- High-Capacity Cryocooler
- Synthetic Biological Membrane

- Advanced Energy Storage Systems
- Extreme Environment Solar Power
- Affordable Vehicle Avionics
- Nuclear Thermal Propulsion
- Iodine Hall Thruster
- Upper Stage Engine Testing
- Design & Manufacture Cryo Prop Tank for Air Launched Liquid Rocket
- Flight Qualification of 5N Green Monopropellant Thruster

## FPES

\* Not a complete project list



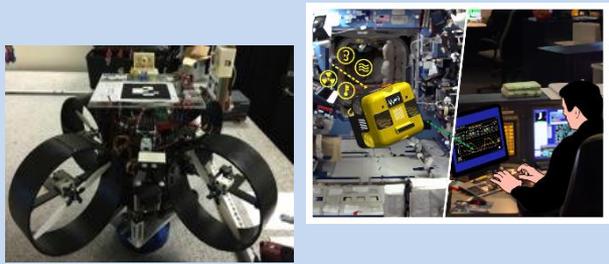
# GCD FY 2016 Highlights

## Heatshield for Extreme Entry Environment TPS (HEEET) Delivery of the Manufacturing Development Unit



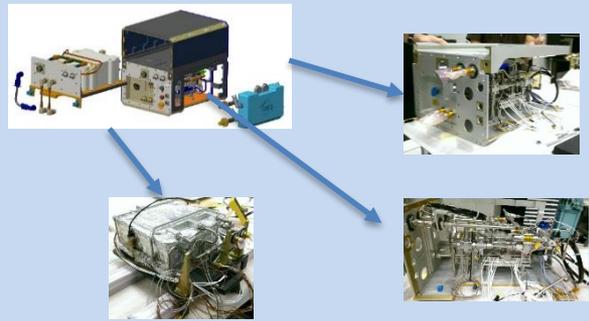
HEEET is developing an efficient and innovative Thermal Protection System that can protect science payloads during entry where the heating is 2 orders of magnitude higher than for Space Shuttle or Mars missions. The ablative thermal protection system has already been recommended for use by SMD in Discovery AO and will enable missions to Saturn, Venus and the Outer Planets.

## Human Exploration Telerobotics (HET) 2: Astrobee Prototype Testing Complete



Design, develop, and ground test new free-flying robot for ISS IVA scenarios Partner with HEOMD (AES program and ISS SPHERES Facility)

## Phase Change Material Heat Exchanger (PCM HX) ISS Demonstration



Demonstration of a wax-based PCM HX on the ISS; scheduled to fly in FY 2016. Partners: AES, ISS, UTS; Potential Infusion: Orion

## SEXTANT: Delivery of NICER Unit



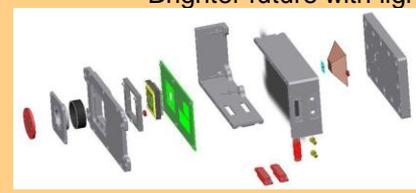
NICER

- SEXTANT will
  - enable GPS-like autonomous navigation anywhere in Solar System, and beyond, using millisecond period X-ray emitting neutron stars (Millisecond Pulsars) as beacons
  - explore utility of pulsar-based time scale, and potential to maintain clock synchronization over long distances

## DSOC: Delivery of TRL 6 Photon Counting Camera

DSOC will

- Enhance NASA's deep-space telecommunications at least 10x without increasing mass, power, volume and/or spectrum.
- Enable human exploration and higher resolution science instruments
- Brighter future with light based technology

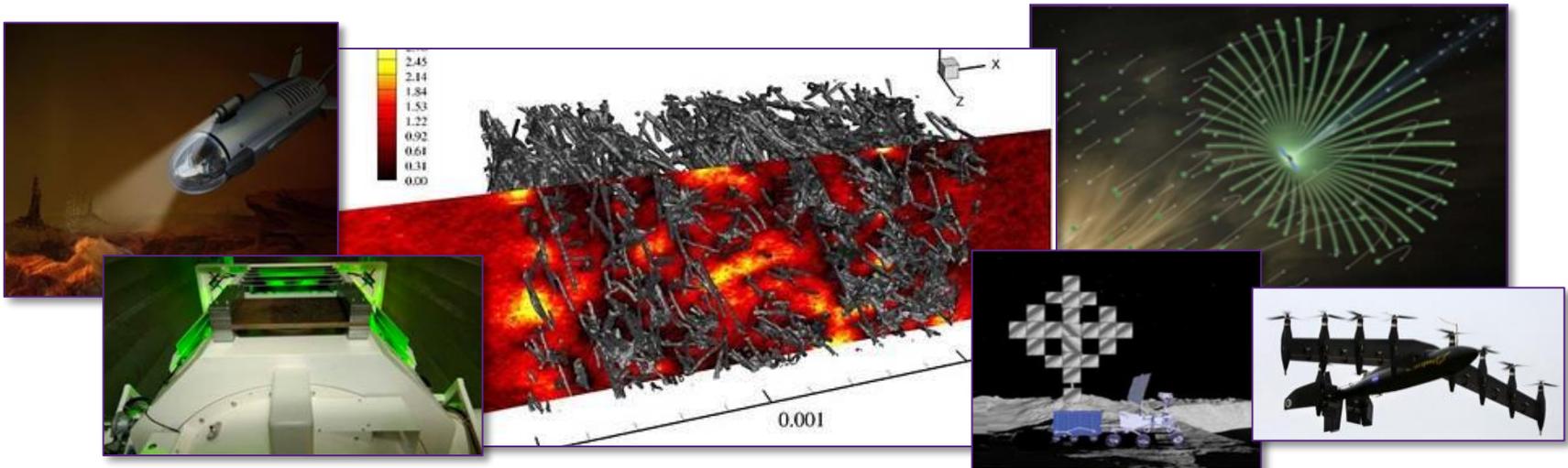




# Early Stage Portfolio



- ▶ **STMD's Early Stage Portfolio (ESP) emphasizes creativity and innovation, pushing boundaries and challenging limits**
  - ESP represents about 10% of the STMD budget
  - Consists of 3 formal programs (NIAC, CIF, STRG) and various early stage activities (TRL 1-4)
  - Strategically engages top researchers in academia, all NASA Centers, small businesses and new partners, and aerospace and other industries
  - Workshops and outreach to increase visibility and progression of early STMD efforts
- ▶ **ESP emphasis is “Beyond the Next...” to develop exciting advanced concepts, diverse new technologies, and breakthrough future capabilities**



# Space Technology Research Grants (STRG)



**Engage Academia:** tap into the talent base, challenging faculty and graduate students to examine the theoretical feasibility of ideas and approaches that are critical to making science, space travel, and exploration 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



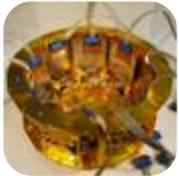
## Early Career Faculty

- Focused on supporting outstanding faculty researchers early in their careers as they conduct space technology research of high priority to NASA's Mission Directorates

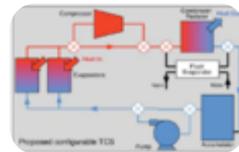
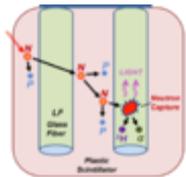
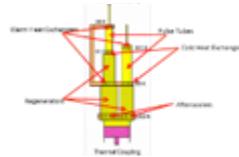
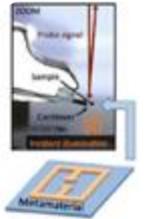


## Early Stage Innovations

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



**Reinvigorate the pipeline of high-risk/high-payoff low-TRL space technologies**





# STRG Universities

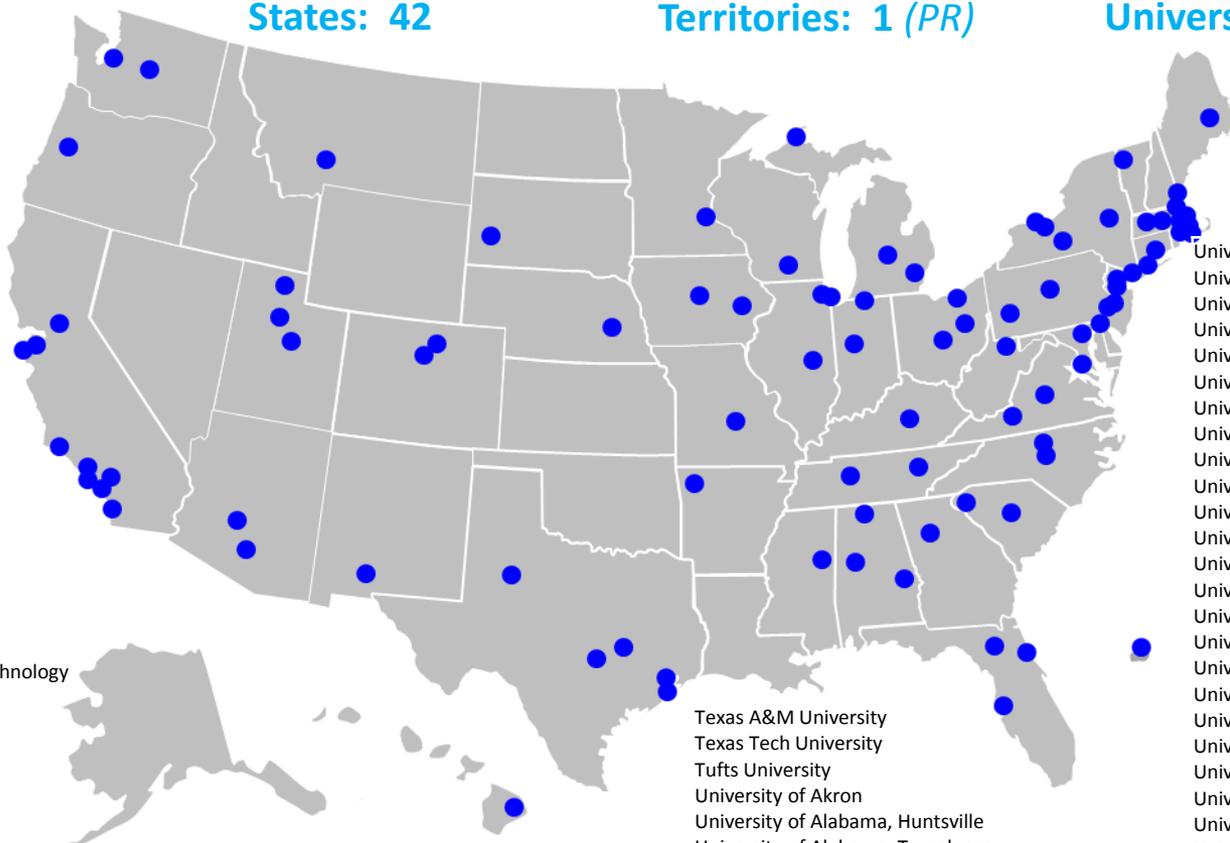


**Awards: 373**

**States: 42**

**Territories: 1 (PR)**

**Universities: 95**



- Arizona State University
- Auburn University
- Boston University
- Brigham Young University
- Brown University
- California Institute of Technology
- Carnegie Mellon University
- Case Western Reserve University
- Clemson University
- Colorado State University
- Columbia University
- Cornell University
- Duke University
- Florida Institute of Technology
- Georgia Institute of Technology
- Harvard University
- Illinois Institute of Technology
- Iowa State University
- Johns Hopkins University
- Massachusetts Institute of Technology
- Michigan State University
- Michigan Technological University
- Mississippi State University
- Missouri University of Science and Technology
- Montana State University
- New Jersey Institute of Technology
- New Mexico State University
- New York University
- North Carolina State University
- Northeastern University
- Northwestern University

- Ohio State University
- Oregon State University
- Pennsylvania State University
- Princeton University
- Purdue University
- Rochester Institute of Technology
- Rutgers University
- South Dakota School of Mines and Technology
- Stanford University
- State University of New York, College of Nanoscale Science & Engineering
- State University of New York, Stony Brook

- Texas A&M University
- Texas Tech University
- Tufts University
- University of Akron
- University of Alabama, Huntsville
- University of Alabama, Tuscaloosa
- University of Arizona
- University of Arkansas
- University of California, Berkeley
- University of California, Davis
- University of California, Irvine
- University of California, Los Angeles
- University of California, San Diego
- University of California, Santa Barbara
- University of Colorado, Boulder
- University of Delaware
- University of Florida
- University of Hawaii

- University of Houston
- University of Illinois, Urbana-Champaign
- University of Iowa
- University of Kentucky
- University of Maine
- University of Maryland
- University of Massachusetts, Amherst
- University of Massachusetts, Lowell
- University of Michigan
- University of Minnesota
- University of Nebraska, Lincoln
- University of New Hampshire
- University of Notre Dame
- University of Pennsylvania
- University of Puerto Rico, Rio Pedras
- University of Rochester
- University of South Carolina
- University of South Florida
- University of Southern California
- University of Tennessee
- University of Texas, Austin
- University of Utah
- University of Vermont
- University of Virginia
- University of Washington
- University of Wisconsin, Madison
- Utah State University
- Vanderbilt University
- Virginia Polytechnic Institute & State University
- Washington State University
- Washington University, St. Louis
- West Virginia University
- William Marsh Rice University
- Worcester Polytechnic Institute
- Yale University

STRGP Element	To-date	Currently Active
NSTRF	301	~ 200
ECF	25	25
ESI	31	30

# NASA Innovative Advanced Concepts (NIAC)



## NASA INNOVATIVE ADVANCED CONCEPTS

### GOAL:

NIAC funds early studies of visionary, novel, long term concepts - aerospace architectures, systems, or missions and inspires new technology development across many scientific disciplines with high potential for breakthroughs.

### SCOPE:

Very early concepts: Technology Readiness Level 1-2 or early 3; 10+ years focus

### SUPPORTS 2 STUDY PHASES:

**Phase I:** up to \$100K, ~9 months to 1 year, for concept definition and initial analysis in a mission context.

**Phase II:** up to \$500K, ~2 years for further development of the most promising Phase I concepts, comparative mission analysis, pathways forward.

2014-15 Funding to **14** U.S. States



[www.nasa.gov/niac](http://www.nasa.gov/niac)

2014-2015  
NIAC FELLOWS

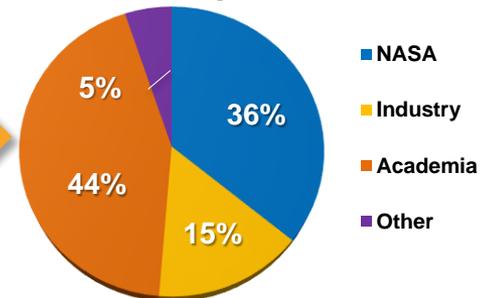
39 Total Proposals Selected & Funded (2014-2015 Ph I & Ph II)

14 = NASA Funded Studies  
25 = NON-NASA Funded Studies

14 = GOV'T Funded Studies  
25 = NON-GOV'T Funded Studies

2014 Ph I = 12  
2014 Ph II = 5  
2015 Ph I = 15  
2015 Ph II = 7

2014-2015: Organizational Breakdown

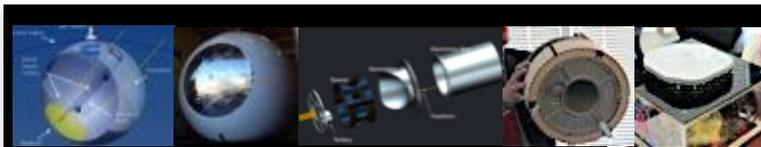


### Upcoming FY 2016:

- Will award limited Phase I NIAC awards
- Will select promising NIAC Phase I concepts for NIAC Phase II studies

### FY 2016-17:

- NASA will initiate new Phase I NIAC awards
- Further develop the most promising concepts for NIAC Phase II studies



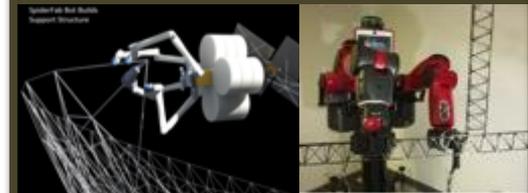
### LBR: Adaptive Optics



NIAC FELLOW Chris Walker, University of Arizona

- Highly aspheric, fast optics, star tracker, inertial guidance system
- High rate data link to Earth, strong spectral signature for H<sub>2</sub>O
- Mounted internal hardware on inflatable structure
- Extreme deformability
- Spectrochip II: Qualcomm To fly in 2018-19 from Antarctica

### Robotic Assembly + Additive Manufacturing



NIAC FELLOW ROBERT HOYT,  
Tethers Unlimited

Mobile robot, radically different way of deploying large space systems on orbit

### Carbon Fiber Trusselator

- ↑ performance per cost
- ↑ packing efficiency
- ↑ launch savings
- ↑ resolution
- ↑ power
- ↑ sensitivity
- ↑ bandwidth
- With a very small amount of material, it can make incredibly large structures on orbit



# STMD Virtual Institutes



## ► Why Virtual Institutes?

- To complement existing STMD university grants with sustained research (~5 years) in key areas
- Better coordinate efforts in large, complex, multi-disciplinary tasks, efficiently involving experts from a wide range of fields/orgs in a single distributed research structure

## ► Implementation

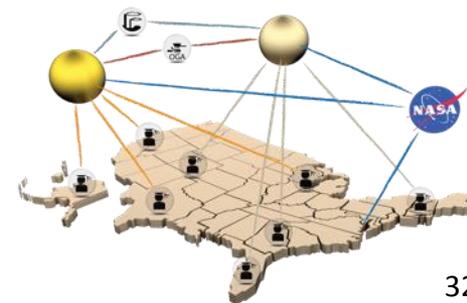
- NASA identifies VI research focus areas, competitively selects lead universities, and provides research collaborators (RCs)
- VI Lead Universities: they define and manage all research tasks (great majority if not all tasks envisioned to go to university researchers) toward the agreed VI focus area objectives
- RCs work with leads to define research and technology activities and review progress
- Future virtual institutes to be added on a rolling basis, ideally with a regular annual or biennial cadence (April solicitation, February awards)

## ► Schedule

- Issued RFIs (May & Sept 2015) to gauge interest and invite inputs – 26 responses
- July 2016 – Preparing for pilot solicitation, planned released July 2016
- Initial pilot (1-2 VIs) to start as early as practical (target Q1 2017)

## ► Possible Initial Candidate Research Focus Areas

- In-Situ Resource Utilization, Additive Manufacturing, Autonomy
- Material Science, Life Support Systems, Engineering Biology



# Early Stage Infusion Successes



## STRG

### Space Robotic Assembly of Large Structures

Robotic assembly of large structures in space using intelligent precision robots

*NSTRF to TDM (partnered w/ Orbital ATK); Fellow now works at NASA (LaRC)*

### Understanding Failure Modes

New analytic model significantly improved predictions of time to failure through metal growth in ceramic capacitors

*NSTRF to industry; Fellow is now lead engineer for electronic parts at SpaceX*

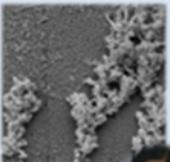
### Robotic Grip-and-Release

Invented a new hybrid controllable adhesive, combining electrostatic and gecko-like effects

*NSTRF to Perception Robotics for factory robotic assembly lines; Fellow now works at JPL*



Erik Komendara



Jaemi Herzberger



Donald Ruffato



## CIF

### Woven Thermal Protection System

Lightweight, high-performance TPS design using 3D woven fibers manufactured by Bally Ribbon Mills

*CIF (ARC) to GCD, to Orion*

### Amorphous Metal Gears

Gears made of bulk metallic glass (BMG), new metal alloys with high wear resistance. BMGs could replace planetary rovers' life-limiting gears

*CIF (JPL) to GCD, patent and spin-off company (Amorphology, LLC)*

### Distributed Electric Propulsion

DEP could significantly improve aircraft efficiency, emissions, noise, and operating costs

*CIF (LaRC) to ARMD to demo reduction in cruise energy; partners – Joby Aviation, ESAero, GA Tech Univ., and NASA AFRC, ARC, GRC*



## NIAC

### SpiderFab

Tethers Unlimited's revolutionary approach to large space systems via additive manufacturing and robotic on-orbit assembly

*NIAC to SBIR, and basis for a new TDM project awarded under the FY15 Tipping Point solicitation*

### Atom Interferometry

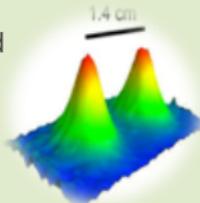
NASA partnership with Stanford Univ. pushing boundaries in physics; extreme precision will improve Earth science, could later detect gravity waves

*Precursor work in DARPA, to NASA GSFC IRAD, to CIF, to NIAC, currently in SMD Instrument Incubator for geodesy applications*

### Contour Crafting

USC concept to use Moon or Mars soil for concrete to 3D print buildings autonomously; received multiple innovation awards and international interest

*NIAC to GCD, partners – Army Corps of Engineers, NASA MSFC & KSC; commercial interest in terrestrial applications*



# Partnering with Universities to Solve the Nation's Challenges

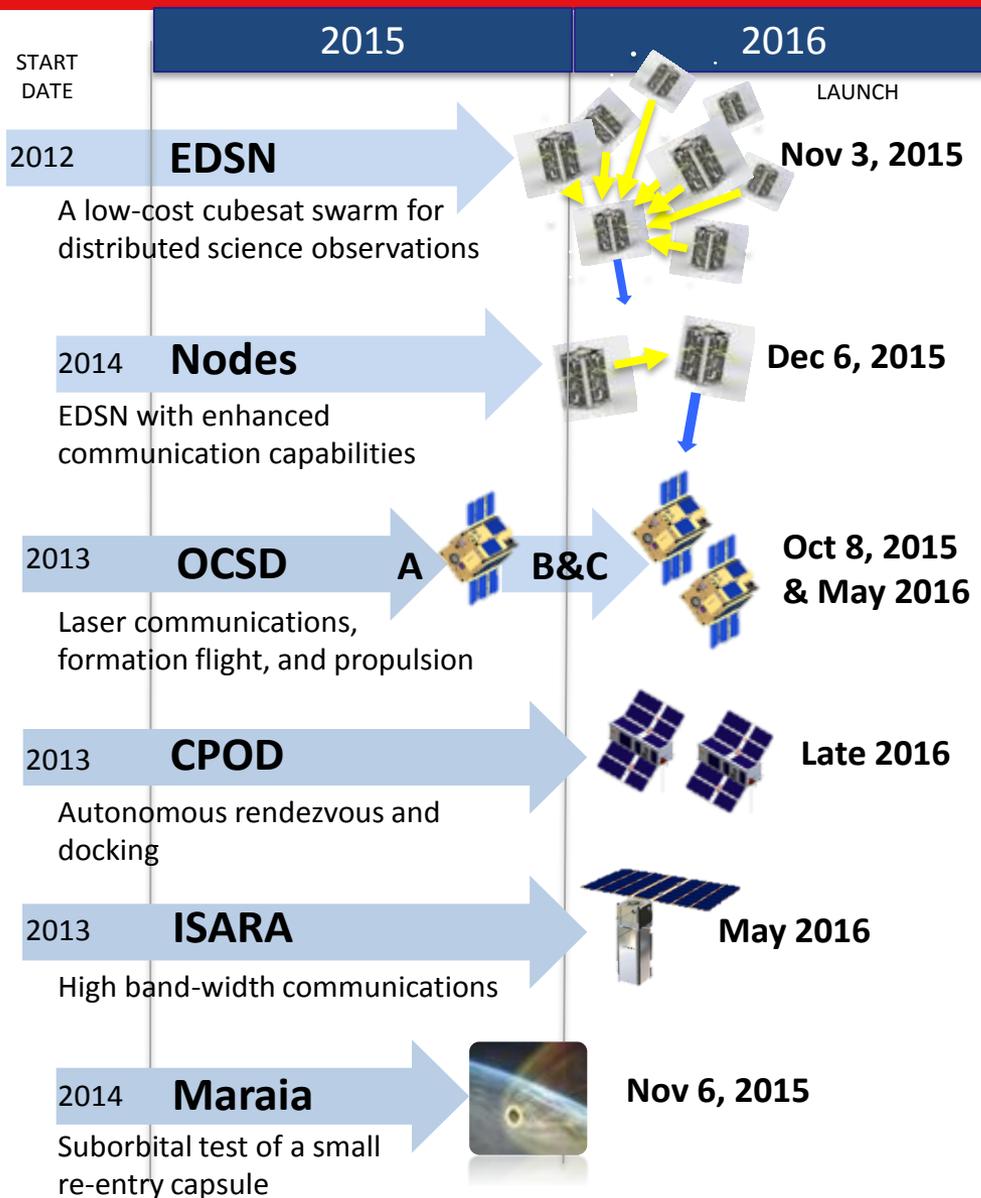


## U.S. Universities have been very successful in responding to STMD's competitive solicitations

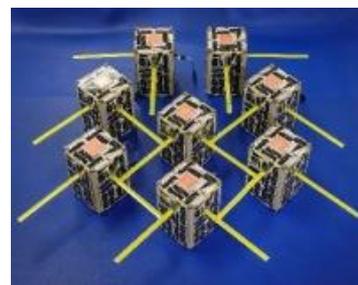
- STMD-funded university space technology research spans the entire roadmap space
- More than **135** U.S. universities have led (*or are STTR partners on*) more than **900** awards since 2011
- In addition, there are many other partnerships with other universities, NASA Centers and commercial contractors
- **FY 2017** request will enable and increase in awards to academia.

Program	# awards	# University-led awards	Upcoming Opportunities
 <b>Space Technology Research Grants</b>	373	373	<ul style="list-style-type: none"> <li>• Early Career Faculty</li> <li>• Early Stage Innovations</li> <li>• NASA Space Technology Research Fellowships</li> </ul> <i>Annually</i>
 <b>NIAC</b>	117	38	<ul style="list-style-type: none"> <li>• NIAC Phase I</li> <li>• NIAC Phase II</li> </ul> <i>Annually</i>
 <b>Game Changing Technology Dev</b>	50	18	Various topics released as Appendices to SpaceTech-REDDI <i>Annually</i>
 <b>Small Spacecraft Technology</b>	34	21	Smallsat Technology Partnerships Cooperative Agreement Notice (released as Appendix to SpaceTech-REDDI) <i>Annually</i>
 <b>Flight Opportunities</b>	139	67	Tech advancement utilizing suborbital flight opportunities – NRA to U.S. Universities, non-profits and industry are planned. <i>Twice Annually</i>
 <b>STTR</b>	263	246 w/ univ partners	<i>Annual STTR solicitation</i>
 <b>Centennial Challenges</b>	4 Challenges (2 university-run)	40 teams (9 univ-led, 2 univ-led winners)	<ul style="list-style-type: none"> <li>• One or more challenges annually</li> <li>• <b>Challenge competitions</b> with a <b>procurement track</b> to fund <b>university teams</b> via grants</li> </ul>

# Small Spacecraft Technology Upcoming Flight Demonstrations



## FLIGHT HARDWARE



**EDSN**



**Nodes**



**OCSD**



**CPOD**



**Maraia**



**ISARA**  
Engineering Unit

**EDSN:** Edison Demonstration of Smallsat Networks  
**ISARA:** Integrated Solar Array and Reflectarray Antenna  
**OCSD:** Optical Communications and Sensor Demonstration  
**CPOD:** Cubesat Proximity Operations Demonstration



# Flight Opportunities

## Budget:

- FY2016: \$15M

## Goals:

- Matures technologies by providing affordable access to space environments
- Facilitates the development of the commercial reusable suborbital transportation industry

## Flights:

- **Five companies** on contract to provide integration and flight services aboard commercial reusable sub-orbital vehicles (Masten, Near Space Corp, UP Aerospace, Virgin, and World View)
- Uses suborbital/parabolic flights to carry payloads in reduced gravity and near the boundary of space

## Payloads:

- FY11-FY14: Unfunded payloads selected through Announcements of Flight Opportunities (AFO)
- FY14-FY17: SpaceTech REDDI NRA to make funds available for purchase of commercial flights
- Collaborating with Science Mission Directorate (e.g., USIP) and other NASA programs to make space available for technologies appropriate for the available platforms within the program

## Highlights: FY2015 & Early FY2016

- UP Aerospace Corporation successfully launched SpaceLoft-9 (SL-9) with four payloads in October 2014 from the New Mexico Spaceport; SL-10 flight with four payloads in November 2015
- Masten Space Systems completed in December 2014 a flight campaign for a JPL landing technology that could be considered for use in Mars 2020 mission.
- World View flew PAMSS and a cosmic ray calorimeter developed by Gannon U. on their Tycho-20 high-altitude balloon (March 2015)
- Near Space Corporation (NSC) flew Airborne Systems Guided Parafoil twice to an altitude of about 60,000 ft; autonomous steering/landing within 33m (12km range) - 70m (46km range) from programmed impact point (Aug 6 and Aug 8, 2015)
- Conducted three parabolic flight campaigns on NASA C9 in FY2015 and additional three campaigns in FY2016 before its retirement at end of Jan 2016
- Program has engaged emerging commercial space companies through an Announcement of Collaborative Opportunity (Topics 1&5) released on 21 June 2015 and made five awards in November 2015

## Plans for FY 2016 to FY 2017

- Program expects to on-ramp at least one new flight provider before the end of Calendar Year 2016
- Program plans to release technology payload solicitations semi-annually
- Program plans to solicit internal payloads requiring flights from NASA programs
- With increasing demand for flights, the program will support additional flights on suborbital reusable platforms, conducting one or more flights every month





# Five IDIQ Flight Providers



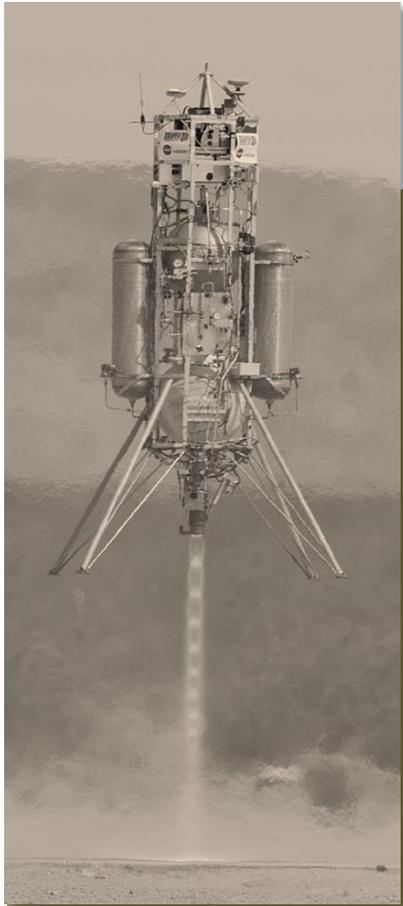
**Masten Space Systems**  
*Xombie, Xodiac*

**Near Space Corporation**  
*Small/Nano Balloon System*

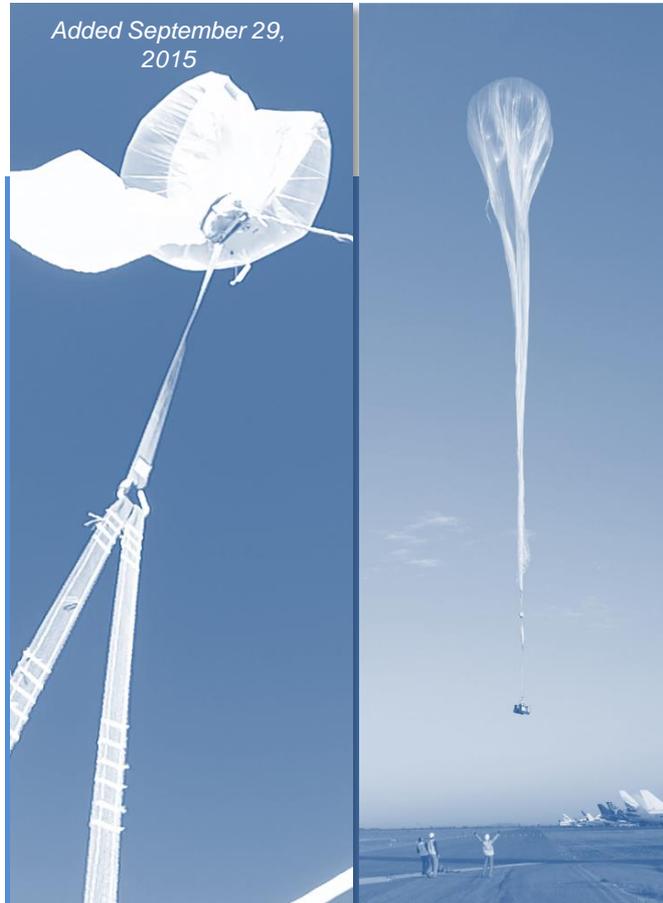
**World View**  
*Tycho-20, Tycho-285*

**UP Aerospace**  
*SpaceLoft-XL*

**Virgin Galactic**  
*SpaceShipTwo*



**VTOL**



**Balloon**



**sRLV**



# Centennial Challenges



**Goal:** Engage non-traditional participants such as makers, non-government funded entities, and educational institutions to achieve the nation's challenging technology goals.

**How:** Offers competitive challenges that award prize money to the individuals or teams that achieve the specified technology requirements.

## ACCOMPLISHMENTS

Sample Return Robot Challenge demonstrates robots that can locate and retrieve samples from a wide and varied terrain without human control or terrestrial navigation aids.

- In 2015, 14 teams competed Level I; two competed for Level 2 June 9-12, 2015.
- West Virginia University accomplished Level II and was awarded \$100,000.

Cube Quest Communications and Propulsion Challenge will demonstrate communication and propulsion technologies relevant to trans-lunar space exploration.

- 13 Teams Participated in Ground Tournament I (Aug. 2015)
- 5 Teams met Ground Tournament I requirements and won \$20K each

Mars Ascent Vehicle Challenge demonstrates the ability to autonomously recover, load, and launch a simulated Mars sample cache.

- Competition held April 7-11, 2015; 15 Teams Participated
- North Carolina State Univ awarded \$25,000 for 1<sup>st</sup> Place and Tarleton State Univ awarded \$15,000 for second place.

3D Printed Habitat Challenge/ Competitions advances additive construction technology to create sustainable housing on Earth and beyond with America Makes/ Challenge

- 165 entries received for the Design challenge; 94 met requirements
- Awards to be Presented 9/26 at World Makers Faire

## FY 2016-17 PLANS

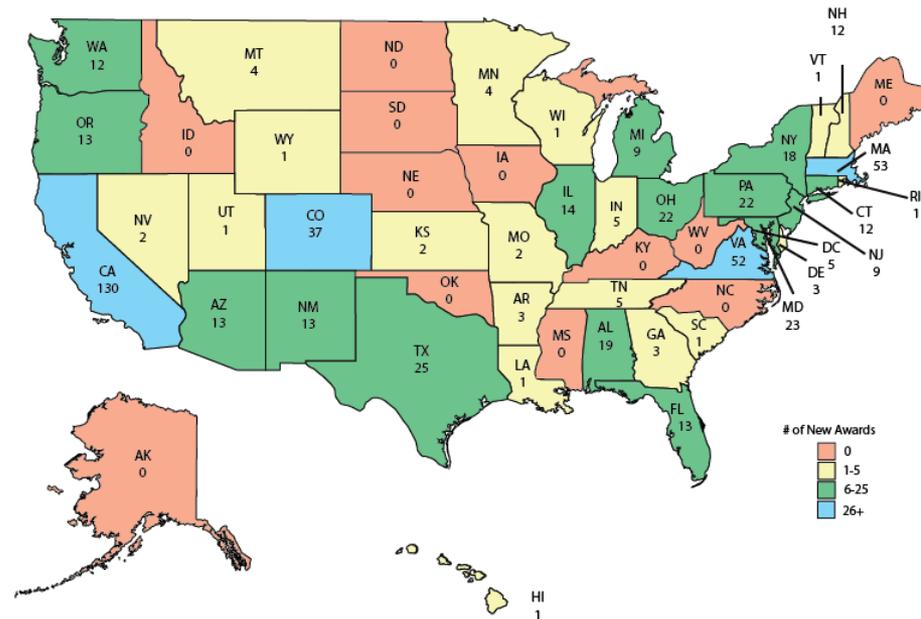
- Sample Return Robot, CubeQuest Challenges, and 3D Printing will continue
- Announce and open new challenge focused on humanoid robotics
- Additional topics being reviewed for potential challenges include: tissue engineering, airship technology, planetary sample cache rendezvous and capture, and technologies to enable future exploration of Europa and Venus.



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



Fiscal Year 2015 SBIR/STTR Awards (Phase I, II, & II-E)



Provides the small business sector and research institutions with an opportunity to compete for funding to develop technology for NASA and commercialize that technology to spur economic growth.

- Annual Solicitations for Phase I awards
- Phase II proposed 6 months later
  - 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 2015 Awards:

- SBIR Awards: 325 Phase I and 119 Phase II; 7 Phase I Selects and 10 Phase II Selects
- STTR Awards: 50 Phase I and 21 Phase II
- Phase II-E Awards: 31 SBIR/STTR Phase II-Es were awarded, leveraging \$5.36 M funds from non-SBIR sources

**FY 2016 Plans:** NASA **increases** the SBIR investment by 0.1 percent to 3.0 percent of Extramural R&D; STTR investment **increases** to 0.45 percent of Extramural R&D.

**FY 2017 Plans:** NASA **increases** the SBIR investment by 0.2 percent to 3.2 percent of Extramural R&D; STTR investment reached SBA Reauthorization goal of 0.45 percent of Extramural R&D in FY16 and therefore remains the same moving forward. Increase use of Commercialization Readiness Program pilot authority.

# SBIR Success Stories



## Technology

## Maturation Path

## Infusion

Deployable Vegetable Production Unit  
(VEGGIE)  
Orbital Technologies Corporation  
(Madison, WI)

- Discovered as Phase I SBIR, primary work focused on developing and evaluating several candidate methods for fabricating a deployable vegetable production system,
- Phase II focused on development of VEGGIE prototype.
- Received Non-SBIR Phase III funding of \$325,080

- VEGGIE flown on the ISS, humans aboard successfully consumed first food crop cultivated in space on August 10, 2015.

Web-based Hurricane Storm Surge  
And Flood Forecasting  
Using Optimized Ifsar Bald Earth  
Dems  
Worldwinds, Inc.  
(Picayune, MS)

- SBIR Phase I to test development of a remote sensing and climatological scientific capabilities into practical tools for public and private sector decision makers.
- Technology matured as Phase II SBIR

- Developed analysis software that can produce optimized Digital Elevation Maps (DEMs) for any region and hurricane flood atlases for any coastal area.
- Supports the SMD's Applied Sciences Program, Natural Disasters Application Area.
- Supports implementation of the Coastal Wind and Water Event Database by the DHS.

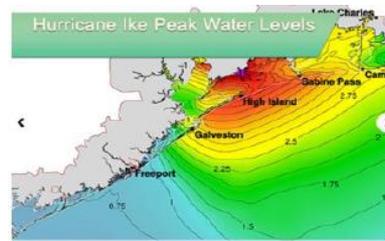
ISS Universal Battery Charging  
Station  
Aurora Flight Sciences  
(Cambridge, MA)

- Initialized as Phase I to develop system requirements and preliminary designs.
- Universal Battery Charger (UBC) developed in Phase II.
- Enhancements made to UBC under Phase II-E award.

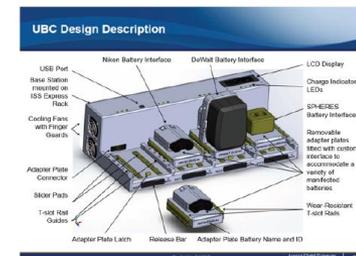
- Scheduled to launch on SpaceX-8 in February 2016 to be used on the ISS. The technology will be used to charge the popular SPHERES (Synchronized Position Hold, Engage, Reorient, Experimental Satellites) units.



Deployable Vegetable Production System  
(VEGGIE)



ADCIRC Hydrodynamic Modeling



Features of ISS Battery Charging  
Station

# Snapshot of Space Technology Partners



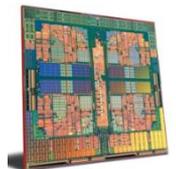
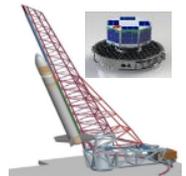
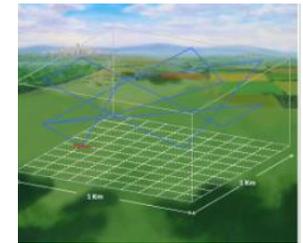
# Working with Other Government Agencies



## Currently, significant engagements include:

- Green Propellant Infusion Mission partnership with **Air Force Research Laboratory (AFRL)** propellant and rideshare with **DoD's Space Test Program (STP)**
- **AFRL** collaboration on a High Performance Space Computing for a low power multi-core processor increasing performance by 100 fold
- Laser Communications and Relay Demonstration partnership with multiple other government organizations
- Partnership with **DARPA** on "Next Generation Humanoid for Disaster Response"
- Collaboration with **ARPA-e/Dept. of Energy** in new battery chemistries to aide in battery tech development
- Collaboration with **Space Missile Command** developed a Hosted Payload IDIQ contract mechanism for low cost access to space

STMD has fostered **61 activities with 42 other government organizations**, and **4 activities with 5 international organizations**.



# STMD Investments to Advance Human Exploration



## ➤ Propulsion Systems

- Solar Electric Propulsion (SEP) - enabling for ARM and cargo & logistics transportation to Mars
- Nuclear Thermal Propulsion (NTP)

## ➤ Life Support and Resource Utilization

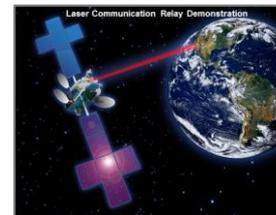
- Mars atmospheric ISRU – life support and ascent vehicle oxidizer
- Highly reliable closed loop air revitalization; space suit components

## ➤ Entry, Descent and Landing (EDL) Technologies

- Supersonic retro-propulsion – enabling for very large landed mass
- Low Density Supersonic Decelerator (LDSD)
- Woven TPS – more efficient & flexible TPS materials for entry

## ➤ Other Key Exploration Technologies

- eCryo – long duration cryogenic storage
- Optical communications – high bandwidth communications
- Human robotics systems – reduce crew workload



# STMD Investments to Advance Science Missions



## ➤ **Entry, Descent and Landing (EDL) Technologies**

- MEDLI & Entry Systems Modeling – Mars EDL systems design
- Low Density Supersonic Decelerator (LDSD)
- Adaptable, Deployable Entry Placement Technology (ADEPT) – deployable head shields provide much lower entry loads
- Woven TPS – more efficient & flexible TPS materials for entry

## ➤ **Communication and Navigation**

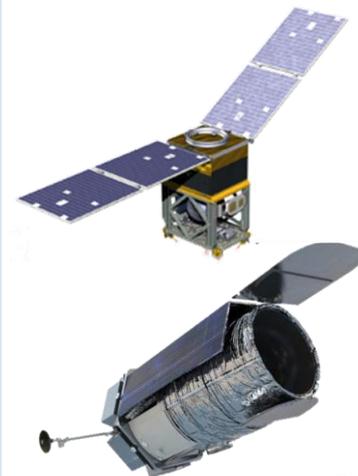
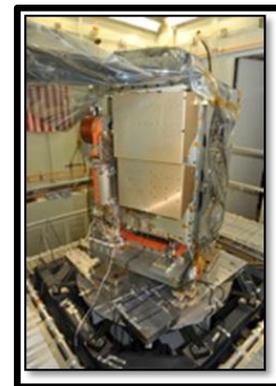
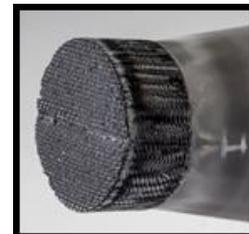
- Deep Space Optical Comm (DSOC) & Laser Communication Relay Demo (LCRD) – up to 10x data return
- Deep Space Atomic Clock (DSAC) and NICER/SEXTANT – highly accurate deep space navigation, higher duty cycle for DSN data

## ➤ **Propulsion and Power**

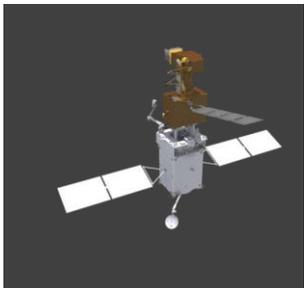
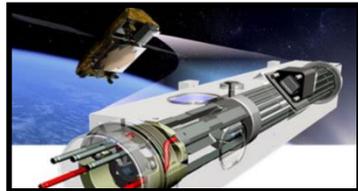
- Green Propellant Infusion Mission (GPIM) – alternative to hydrazine
- Solar Electric Propulsion (SEP) – enabling new science missions

## ➤ **Instruments and Sensors**

- WFIRST Coronagraph – perform direct observations of exo-planets and determining their atmospheric content
- High Performance Spaceflight Computing – more capable radiation hard avionics applicable to science missions



# STMD - Aerospace Industry Alignment

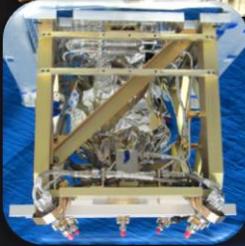
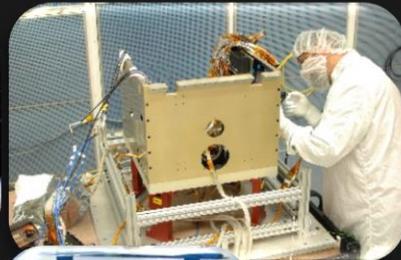


- **Structures and Materials**
  - Advanced Manufacturing and Lightweight Materials
  - In Space Robotic Manufacturing and Assembly of Space Structures
- **Propulsion & Power**
  - Green Propellant Infusion Mission – improved spacecraft performance & reduced toxicity and ground processing costs
  - Solar Electric Propulsion (SEP) – enabling increased power, reduced mass and longer life for commercial communication satellites
- **Communication & Navigation**
  - LCRD – replacing RF based gateway links with optical links and reduce RF spectrum utilization on commercial satellites
  - Deep Space Atomic Clock – improved timing for next generation GPS satellites
- **Instruments, Sensors, & Robotics**
  - Restore-L – autonomous robotic satellite servicing capabilities
  - High Performance Spaceflight Computing – for more capable radiation hard avionics for commercial communication satellites
- **Flight Opportunities and Small Spacecraft**
  - Flight Opportunities – enable suborbital and nano launch commercial enterprises
  - Small Spacecraft – enable rapid cadence of affordable tech demos and foster the development of small spacecraft industry

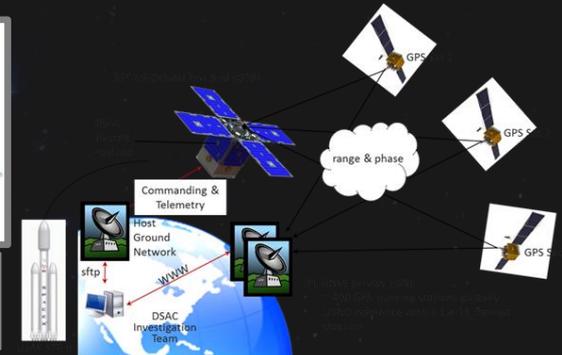
# Key Milestones in 2016-17



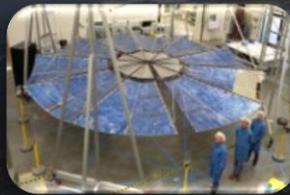
**Green Propellant Infusion Mission**



**Deep Space Atomic Clock**



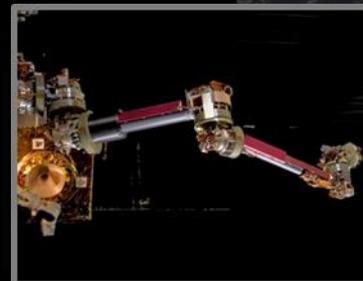
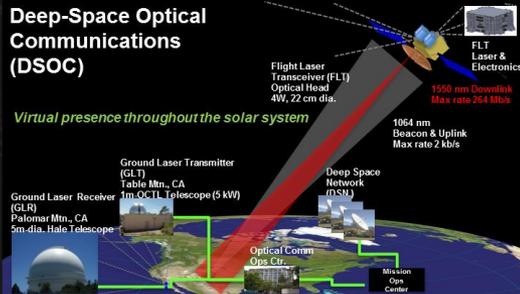
**Solar Electric Propulsion**



**Small Spacecraft Technology**



**Laser Communication Relay Demonstration**



**Restore L Satellite Servicing**

# Key Milestones in 2016-17



**Green Propellant:** demonstrates propellant formula, thrusters, and integrated propulsion system, for higher performing, safe alternative to highly toxic hydrazine. (1st Quarter – CY 2017)

**Deep Space Atomic** New space clock improving navigational accuracy for deep space (1st Quarter – CY 2017)

Purchasing major subsystems for **Solar Electric Propulsion and Laser Communications demonstrations**

**Restore-L** begins mission formulation to advance satellite servicing technologies.

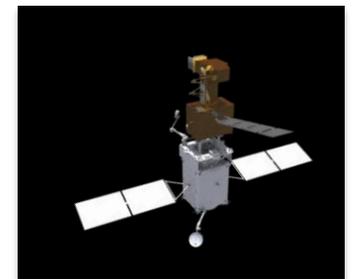
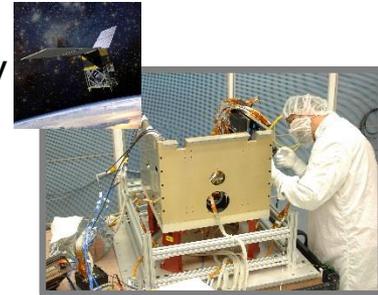
Initiate **Deep Space Optical Communication** demonstration to provide high bandwidth communications for future deep space exploration.

**Small Spacecraft Technology:** Three small spacecraft demonstration missions:

- ISARA: Uses a deployed solar array as a Ka-band radio antenna reflector
- OCSD: Demonstrating in-space laser communications using 2 cubesats.
- CPOD: Proximity operations and docking demo with 2 cubesats

**Establishing Public-Private Partnerships:** Tipping Point and Announcement of Collaborative Opportunity solicitations awards in FY16.

- Issue new Tipping Point solicitation in late FY 2016 and ACO in FY 17.



# Space Technology Drives Exploration



- Space Technology is delivering new technologies and capabilities
- Delivered new capability and created new knowledge
- Well coordinated and aligned with Mission Directorate requirements
- Major deliverables, demos and tests during the next year in TDM, GCD, and SST programs
- Continue advancements in high risk, high payoff research and technology development in Early Stage Portfolio engaging the Centers, industry and academia
- Strengthen Commercial Partnerships via Tipping Point and Flight Opportunities solicitations
- Advance spacecraft technologies: life-support, thermal management, thermal protection system; surface systems technologies (in-situ resource utilization and power generation) enabling deep-space human exploration missions
- Continues engagement with U.S. universities, cultivates small businesses via for SBIR/STTR



**Technology Drives Innovation**

[www.nasa.gov/spacetech](http://www.nasa.gov/spacetech)