National Aeronautics and
Space Administration

Space Technology Mission Directorate

Update

NAC TI&E Committee

Presented by:
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Associate Administrator, STMD

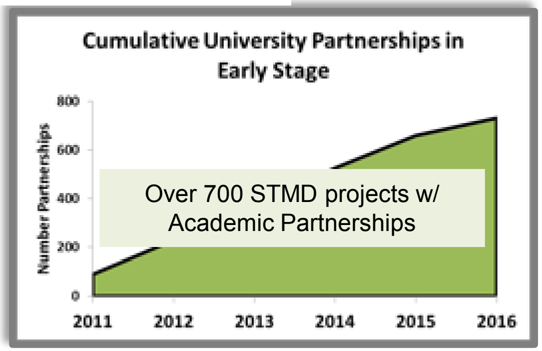
March 29, 2016

www.nasa.gov/spacetech

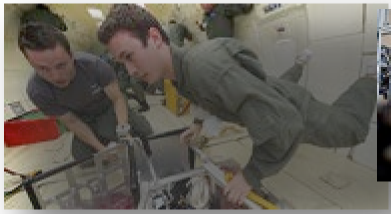
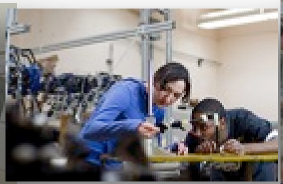
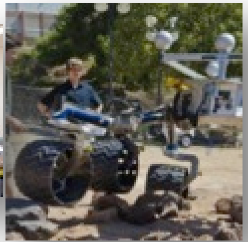
Space Technology…
…. an Investment for the Future

- 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.



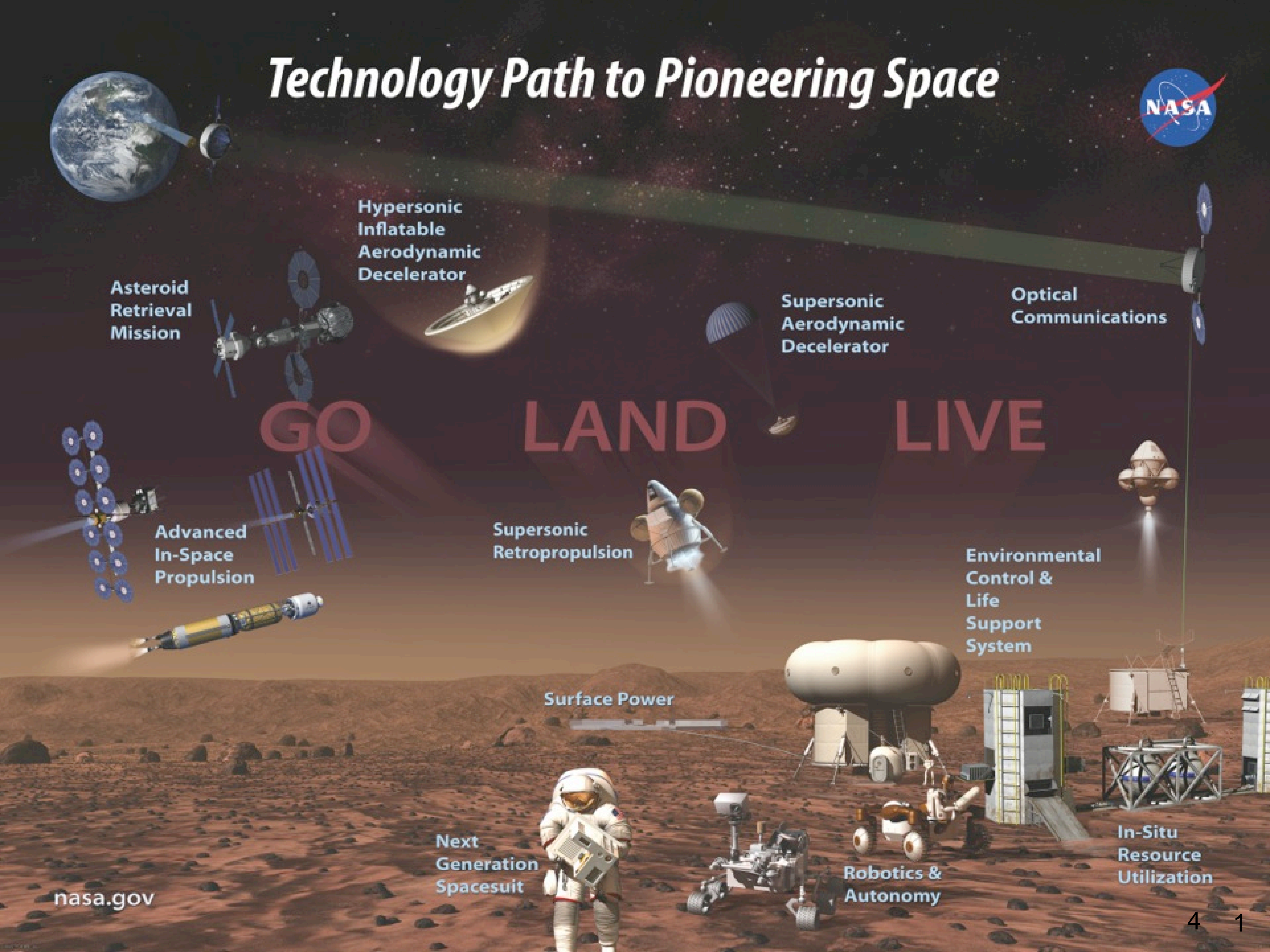
Value to NASA **Value to the Nation**

Benefits from STMD:
The NASA Workforce
Academia
Small Businesses
The Broader Aerospace Enterprise

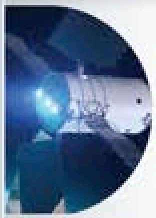
Guiding Principles of the Space Technology Programs

- **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


Technology Path to Pioneering Space
NASA
Hypersonic Inflatable Aerodynamic Decelerator
Asteroid Retrieval Mission
Supersonic Aerodynamic Decelerator
Optical Communications
GO
LAND
LIVE
Advanced In-Space Propulsion
Supersonic Retropropulsion
Environmental Control & Life Support System
Surface Power
In-Situ Resource Utilization
Next Generation Spacesuit
Robotics & Autonomy
nasa.gov

Enabling Future Exploration Missions

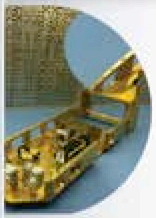
Space Technology focus investments in 8 thrust areas that are key to future NASA missions and enhance national space capabilities.



In- Space Propulsion

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 Space Comm

Substantially increase available bandwidth and data rates for near earth and deep space, currently limited by power and frequency allocation limits. Assure robust and reliable interconnected space network.

External Application: High bandwidth for Commercial and OGA Satellites

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

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 Space Structures

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)

Deep Space Navigation

Allows for more capable science and human exploration missions; enables more precise entry trajectories for inserting into orbits around planets and bodies like Mars, Europa, and Titan.

External Application: Next Generation GPS and build new industrial base

Space Observatory Systems

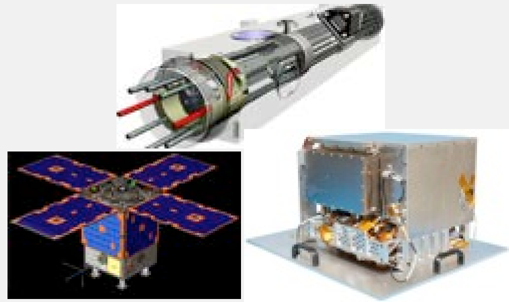
Allows for significant gains in science capabilities including: coronagraph technology to characterize exo-planets, advances in surface materials and better control systems for large space optics.

External Application: Industrial Materials, Earth Observation

THRUST AREAS

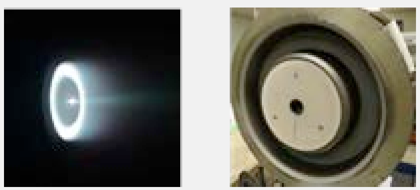
FY 2015-16 STMD Major Accomplishments

Solar Array Development and Testing



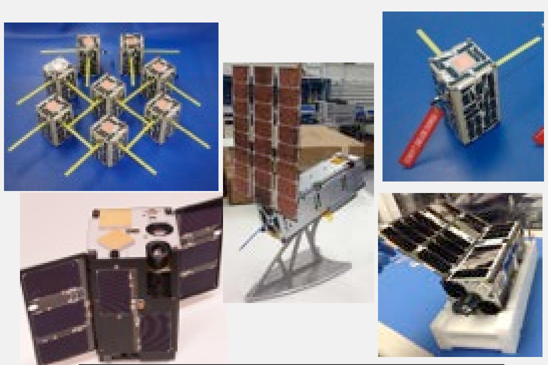
Deep Space Atomic Clock readies for flight test

Green Propellant Infusion Mission integration and prepped for launch

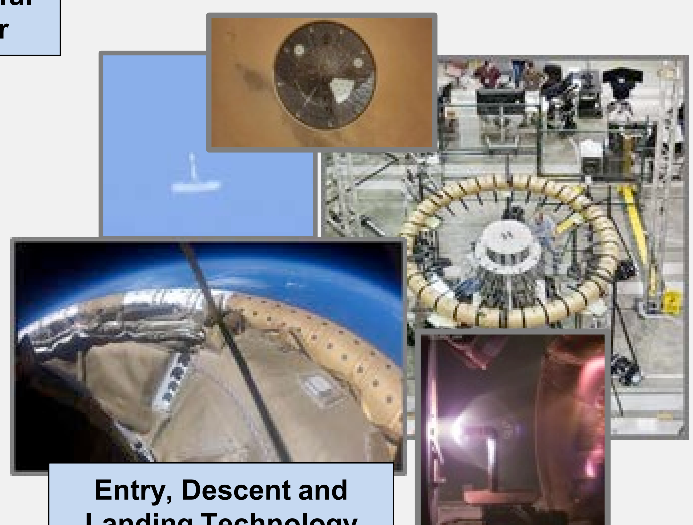


Advanced Thrusters and Successful testing a new 12.5k Hall Thruster

Laser Communication successful demonstration and systems integration



Small Spacecraft Mission Hardware Ready for Launch



Entry, Descent and Landing Technology

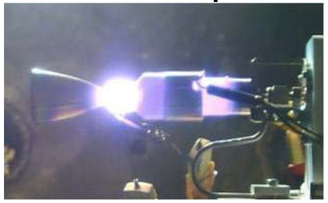
Creating New Markets and Spurring Innovation while Engaging the Brightest Minds

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:

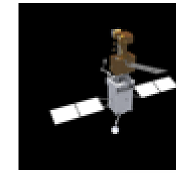
- Those at a "tipping point", where a final demonstration or validation would result in rapid adoption and utilization - - "STMD Tipping Point Solicitation"
- Those that could directly benefit from NASA's unique experience, expertise, facilities - - "STMD Announcement of Collaboration Opportunity (ACO)"

Results:

- Both Tipping Point and ACO were released **May 2015**
- 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**

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.

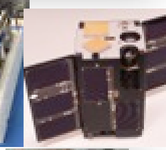


New **DSOC:** Initiate technology demonstration mission for Deep Space Optical Communications for potential demonstration on the next Discovery mission.

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).

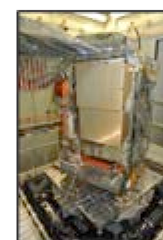


Green Propellant Infusion Mission: demonstrate propellant formula, thrusters, and integrated propulsion system, for higher performing, safe alternative to highly toxic hydrazine (1st Quarter-CY2017)

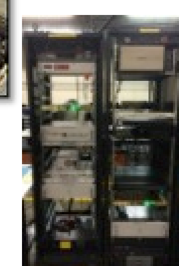
Deep Space Atomic Clock: New space clock improving navigational accuracy for deep space and improve gravity science measurements (1st Quarter-CY2017)

Deliver Small Spacecraft Technology: Conduct four demo missions in 2016

- Nodes – Deploy Nodes currently onboard ISS in 2016
- OCSD: 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

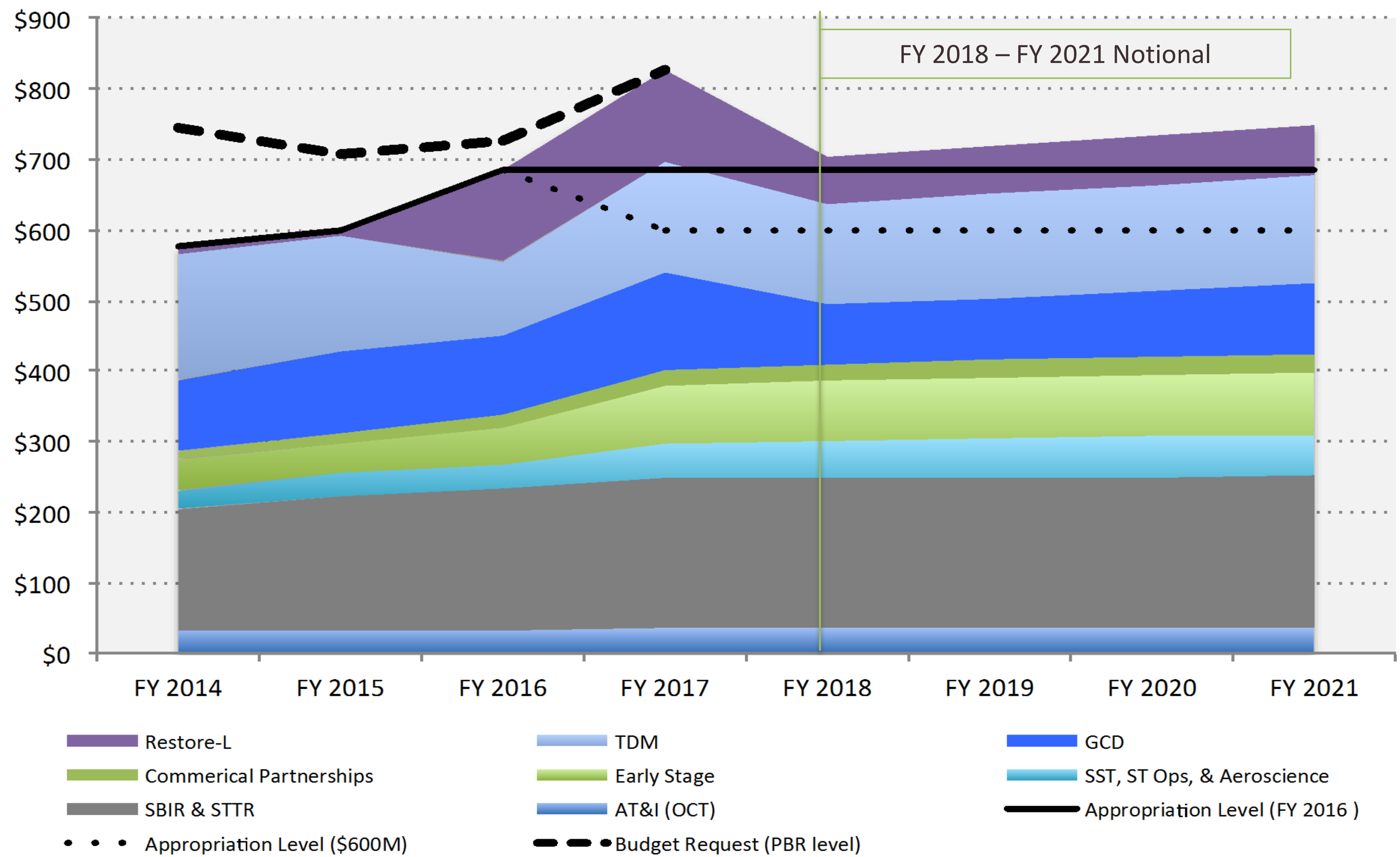


GCD Delivers Coronagraph, ISRU, SEXTANT (FY 2016 and 2017)



- 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.

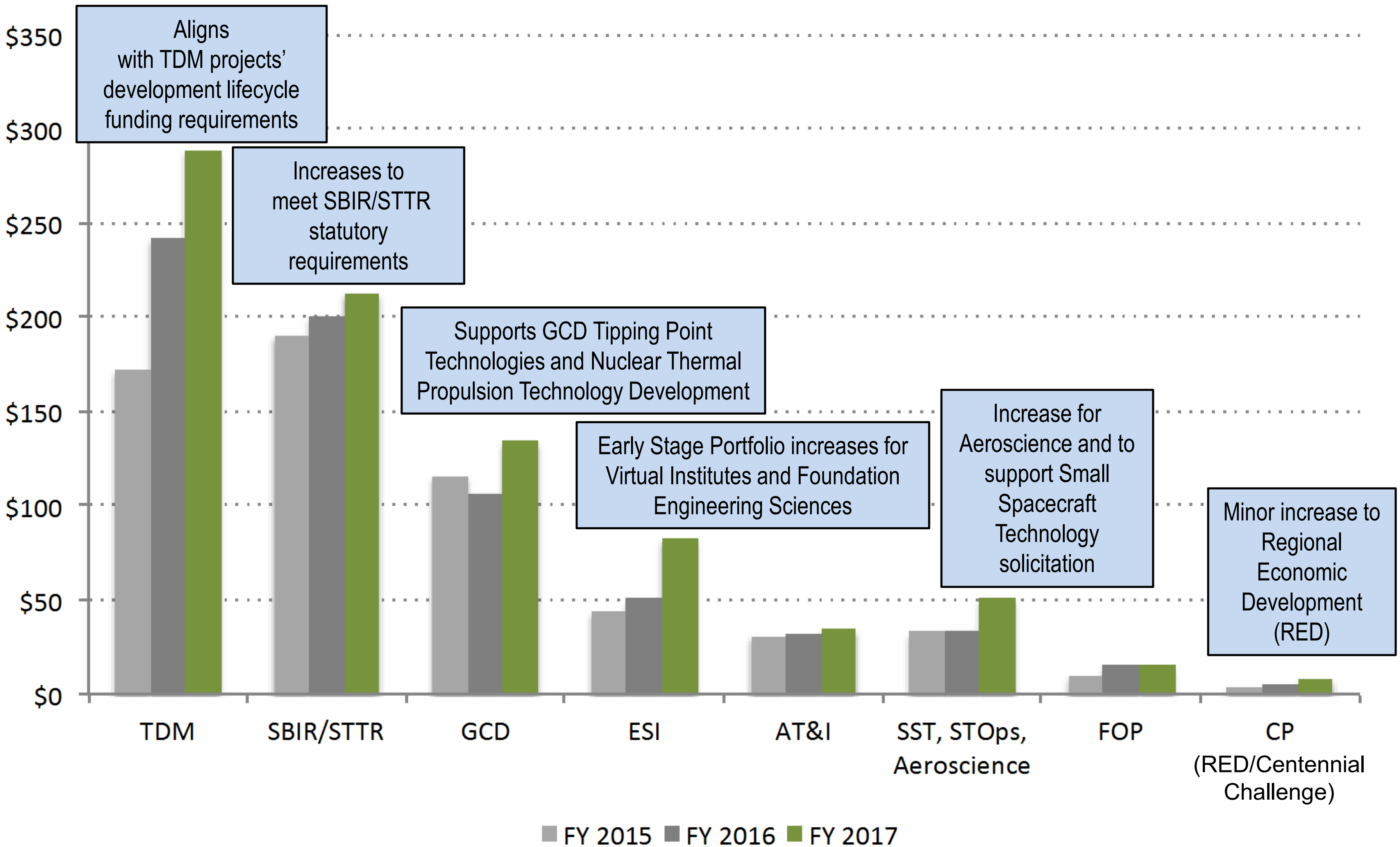
Budget History & FY 2017 Request



FY 2017 Budget Request

Budget Authority ($M)		FY 2015	FY 2016 Enacted	FY 2017 Total	Notional Plan FY 2018	FY 2019	FY 2020	FY 2021
Agency Technology & Innovation (AT&I)		**$31.3**		**$34.3**	**$35.0**	**$35.7**	**$36.4**	**$37.1**
SBIR & STTR		**$190.7**		**$213.0**	**$213.2**	**$213.5**	**$213.8**	**$213.8**
Space Technology Research & Development (STR&D)		**$378.3**		**$579.4**	**$456.2**	**$469.3**	**$482.7**	**$496.6**
STR&D	Early Stage	$43.6		$82.4	$83.8	$85.2	$86.7	$88.2
	Commerical Partnerships	$14.2		$22.9	$23.3	$23.8	$24.3	$24.8
	Game Changing Development (GCD)	$129.3		$158.4	$111.1	$117.6	$124.3	$131.2
	Technology Demonstration Missions (TDM)	$172.0		$288.9	$210.5	$214.8	$219.0	$223.4
	In-Space Robotic Servicing (ISRS) / Restore-L	*$10.0*	*$133.0*	*$130.0*	*$66.3*	*$67.6*	*$69.0*	*$70.4*
	All other TDM Projects	*$162.0*		*$158.9*	*$144.2*	*$147.1*	*$150.1*	*$153.1*
	Small Spacecraft Technologies (SST)	$19.3		$26.8	$27.3	$27.9	$28.4	$29.0
TOTAL SPACE TECHNOLOGY		**$600.3**	**$686.5**	**$826.7**	**$704.4**	**$718.5**	**$732.9**	**$747.5**

STMD Key Budget Drivers



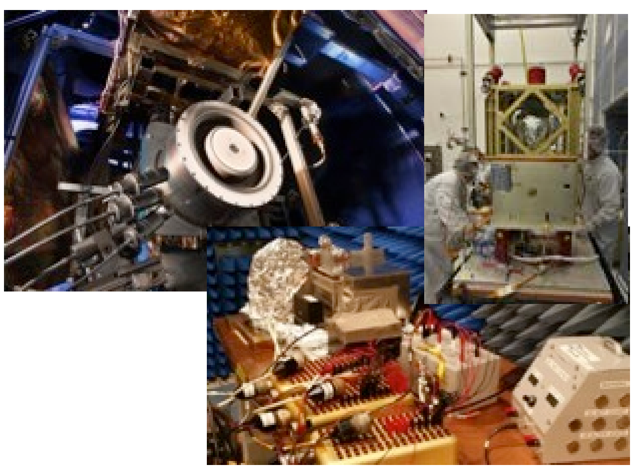
Technology Demonstration Missions

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.

GPIM & DSAC Missions

Green Propellant Infusion Mission (GPIM)

GPIM is a multi-partner effort between NASA and industry that will demonstrate dramatic improvements to overall propellant efficiency while reducing toxic handling concerns.

Objectives:

- Demonstrate the on-orbit performance of a complete AF-M315E propulsion system suitable for an ESPA-class spacecraft
- Demonstrate AF-M315E steady-state performance of delivered volumetric impulse at least 40% greater than hydrazine

Team:

- **Ball Aerospace** – Build spacecraft & host payload
- **Aerojet** – Green Propellant Propulsion Subsystem
- **NASA** – Modeling & Testing
- **AFRL** – Propellant Loading
- **AF SMC** – Ground Stations & Operations

Deep Space Atomic Clock (DSAC)

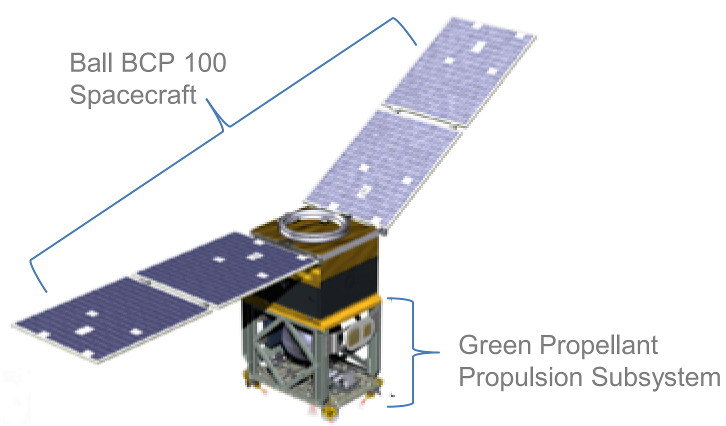
DSAC is a NASA JPL-led effort that will validate a miniaturized, ultra-precise mercury-ion atomic clock that is 100 times more stable than today's best navigation clocks.

Objectives:

- Develop advanced prototype (Demo Unit) mercury-ion atomic clock for navigation/science in deep space & Earth
- Focus on maturing the new technology – ion trap and optical systems – other system components (i.e. payload controllers, USO, GPS) size, weight, power (SWaP) dependent on resources/schedule

Team:

- **JPL** – Build clock system & operate payload
- **Surrey** – Host mission provider; integrate & operate OTB
- **Moog Broad Reach** – GPS Receiver
- **Frequency Electronics** – Ultra Stable Oscillator
- **Laboratory for Atmospheric Space Physics** – UV Detector



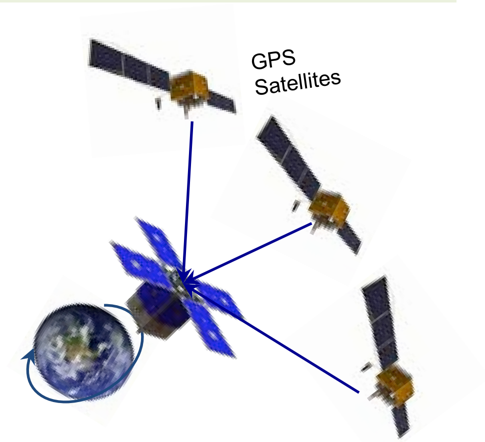
Mission Launch

Launch Provider
USAF STP-2

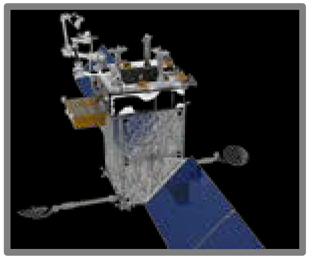
Rocket Vendor
SpaceX Falcon Heavy

Launch Site
KSC; Launch Complex-39A

Launch Date
1st Quarter – CY 2017



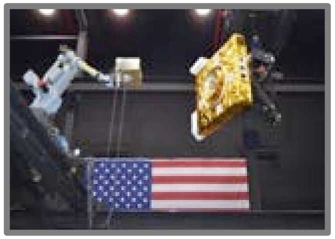
Restore-L Overview



NASA's Restore-L is a groundbreaking mission that uses robotic technology to rendezvous with and refuel a government-owned satellite in low Earth orbit, autonomously and via remote control.

The primary mission objective is to advance technologies critical for human and commercial spaceflight infrastructure including advancing the following to operational status:

- non-cooperative autonomous rendezvous capability
- robotic capture and servicing
- non-cooperative refueling

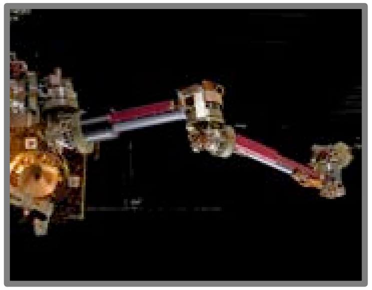


Benefits of the project include:

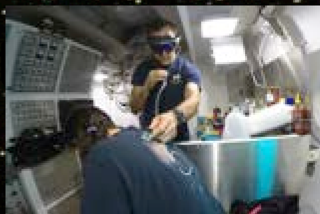
- Establishing the U.S. as the leader in space robotic servicing
- Transfer robotic servicing technologies to U.S. industry
- Feed technology and lessons learned forward for ARM

Preliminary schedule

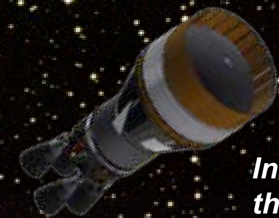
- FY 2016: Mission Concept Review (MCR) and Key Decision Point (KDP)-A
- FY 2017: System Requirements Review (SRR)/Mission Design Review (MDR), Key Decision Point (KDP-B)
- LRD notionally scheduled for late CY 2019, consistent with FY 2016 PL 114-113 direction, STMD will refine the project's plan and schedule at KDP-C as NASA establishes cost and schedule commitments for the Restore-L project



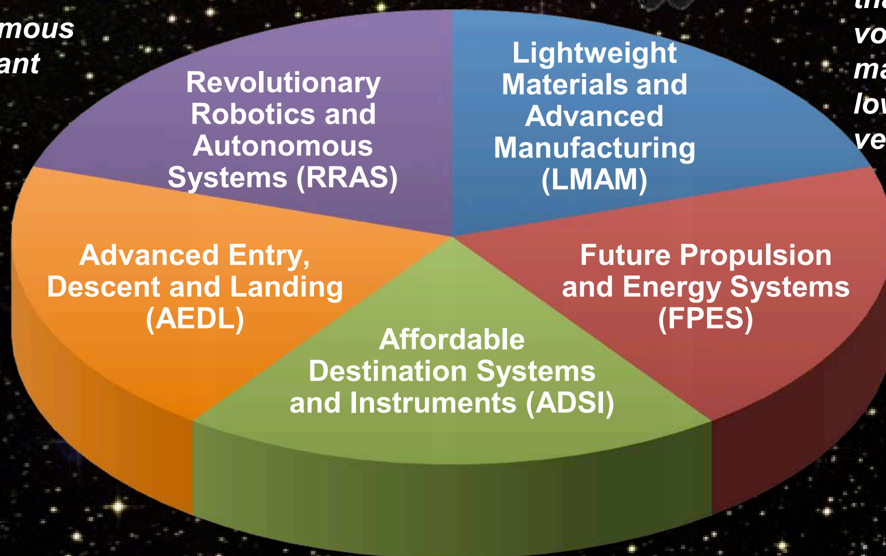
Game Changing Development Technology Themes



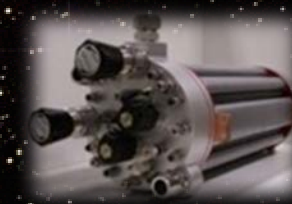
Enabling robotic and autonomous systems to operate in distant destinations



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

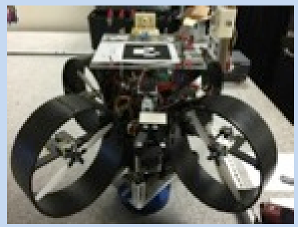
Ensuring customer driven innovative components and instruments

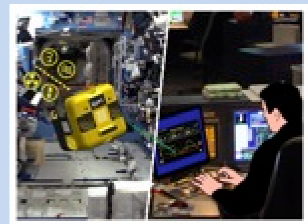
GCD FY 2016 Highlights

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.

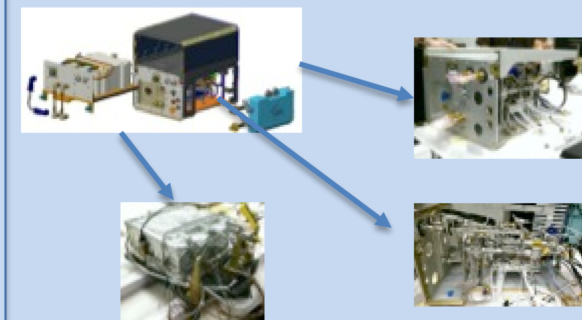
Human Exploration Telerobotics (HET) 2: Astrobee Prototype Testing Complete





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

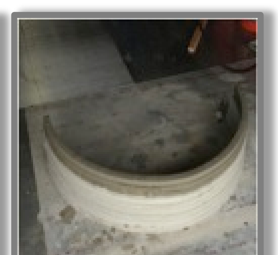
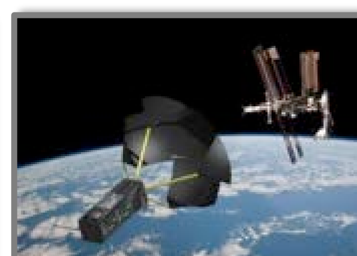
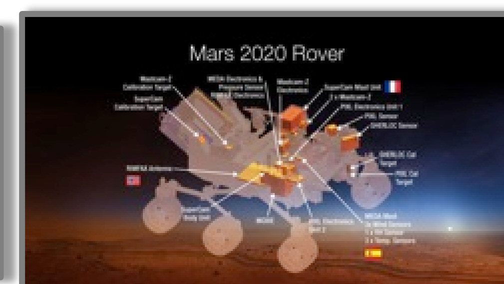
DSOC will

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

GCD FY 2017 Highlights

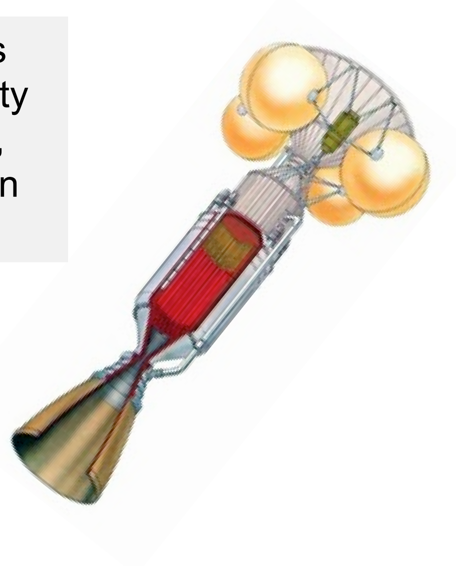
- **SEXTANT: NICER Launch (10/8/2016)**
- **Advanced Space Power Systems (ASPS):** Advanced Energy Storage Systems Phase III Award prototype test article delivery
- **Advanced Manufacturing Technologies (AMT)**: 3D Additive Construction Development Full Scale Demonstration complete
- **Technologies for Extreme Environments**
  - **Solar Power**
  - **Materials- Bulk Metallic Glass**
- **Initiate Nuclear Propulsion Technology project**
- **Heatshield for Extreme Entry Environment Technology (HEEET):** Engineering Test Unit (ETU) Build and Testing
- Competitively develop **High Performance Space Flight Computing**
- **MARS 2020:** Contributing to the mission through STMD technologies: **MEDLI-2, MOXIE, and TRN**



Nuclear Thermal Propulsion (NTP)

Goal: Address critical challenges relevant to establishing the viability of NTP as a faster, more efficient, and more affordable alternative on deep space exploration missions



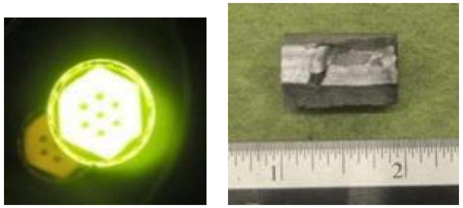
Why NTP?

- Faster transit times and reduced crew radiation hazards
- Reduced architectural mass and fewer SLS launches
- Decreased sensitivity to mission departure and return dates

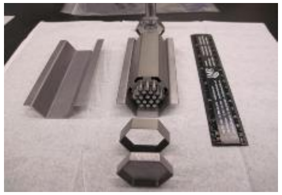
Key GCD Project Deliverables (FY16-18)

- Scale up production of isotopically pure tungsten
- Design, develop, and manufacture low enriched uranium fuel element segments suitable for testing
  - Goal to enable use of LEU for space reactors
- NTP engine design utilizing LEU fuel elements
- System-level assessment and cost estimate for a potential future NTP development and demonstration effort to assess NTP viability for human exploration transportation systems

Path to fielding an NTP *system that is* ***within NASA's resources*** *could depend on a shift from highly enriched uranium to* ***low enriched uranium (LEU) fuel elements***



7-hole W-UO_2 in CFEET and post testing up to 2500 C



HIP can assembly for pure W samples prior to welding

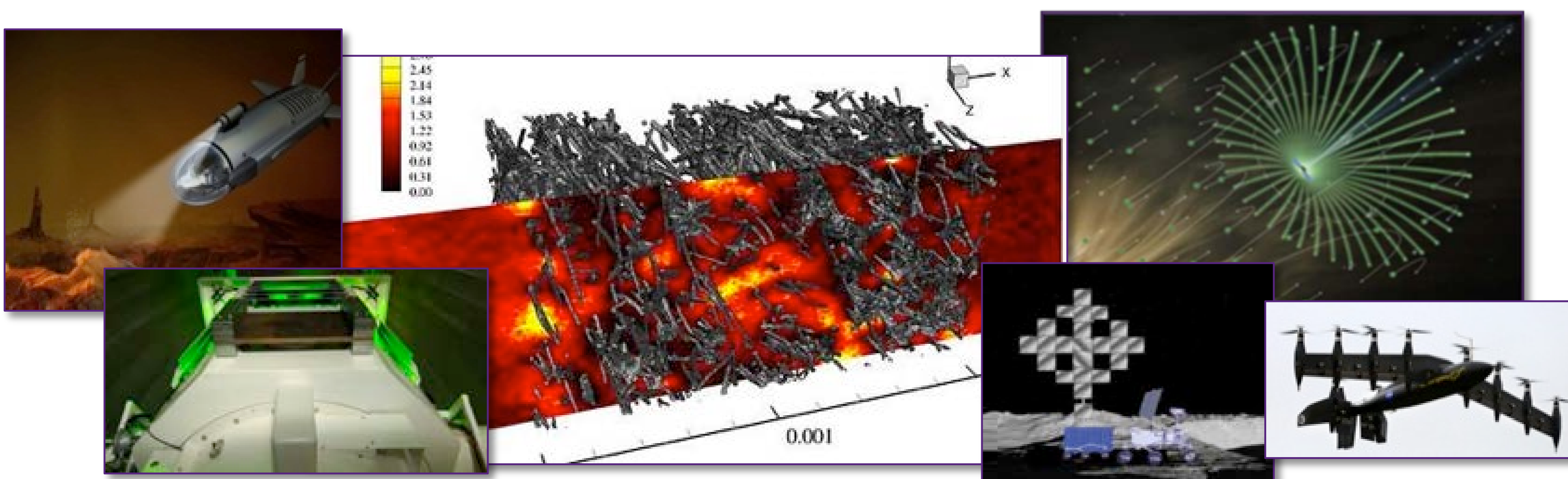
NTP Development Challenges Being Addressed

- Reactor fuel design that achieves higher temperature while minimizing erosion and fission product release
- Focus on establishing an NTP design based around LEU fuel elements to enable an affordable NTP system
- Mature critical technologies associated with LEU fuel element materials and manufacturing
- Evaluate the implications of using LEU on NTP engine design to establish that the engine can affordably meet the NTP performance requirements

Early Stage Portfolio

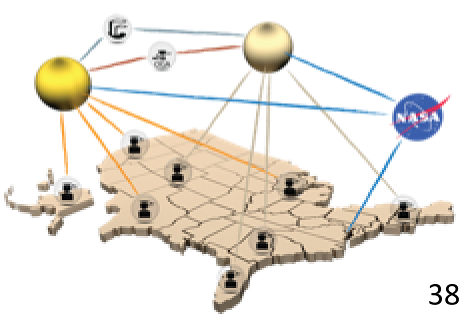
- **STMD's Early Stage Portfolio (ESP) emphasizes creativity and innovation, pushing boundaries and challenging limits**
  – ESP represents about 10% of the STMD budget
  – Consists of 3 formal programs (NIAC, CIF, STRG) and various early stage activities (TRL 1-4)
  – Strategically engages top researchers 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



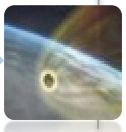
STMD Virtual Institutes

- **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

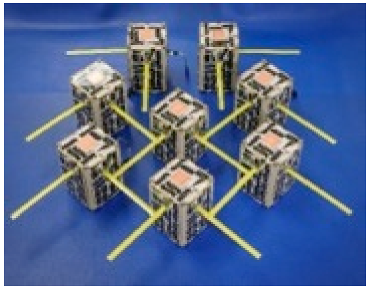


Small Spacecraft Technology
Upcoming Flight Demonstrations

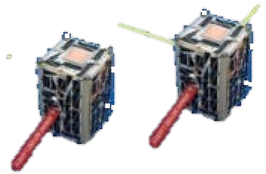
START DATE		2015	2016	LAUNCH
2012	**EDSN** — A low-cost cubesat swarm for distributed science observations			**Nov 3, 2015**
2014	**Nodes** — EDSN with enhanced communication capabilities			**Dec 6, 2015**
2013	**OCSD** — Laser communications, formation flight, and propulsion	**A**	**B&C**	**Oct 8, 2015 & May 2016**
2013	**CPOD** — Autonomous rendezvous and docking			**Late 2016**
2013	**ISARA** — High band-width communications			**May 2016**
2014	**Maraia** — Suborbital test of a small re-entry capsule			**Nov 6, 2015**



FLIGHT HARDWARE



EDSN



Nodes

OCSD

CPOD

Maraia

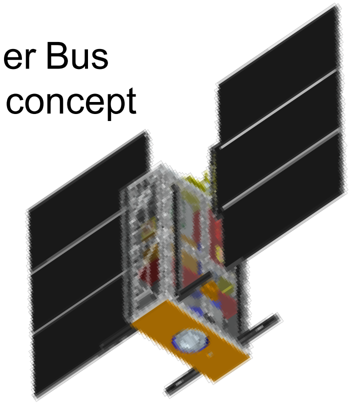
ISARA
Engineering Unit

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

Small Spacecraft Technology Flight Demonstrations Planned for 2016-2018

Utilizing Pathfinder 6U Cubesat Bus

Pathfinder Bus
reference concept



Propulsion

1) Miniaturized Electrospray Thruster - SBIR CRP – Busek Co.

2) RF Ion Thruster - SBIR Phase II – Busek Co.

3) **Green Propellant Thruster 2015 Tipping Point Award - Aerojet Rocketdyne**

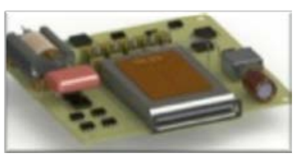
4) **Hydros Thruster - 2015 Tipping Point Award - Tethers Unlimited**

Attitude Control and Pointing

5**) Hyper-XACT Star Tracker - 2015 Tipping Point Award - Blue Canyon**

6) **Reaction Sphere - 2015 Tipping Point Award - Northrop Grumman**

1



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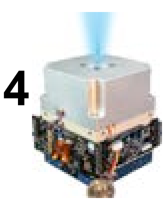

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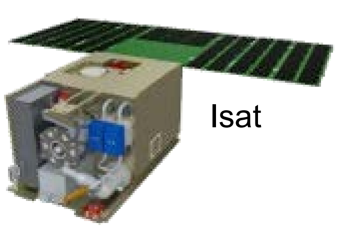
6

7) Small Hall Thruster with Iodine Propellant – Isat 12U cubesat in development by NASA Marshall

7



Isat

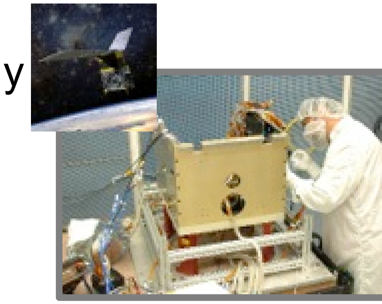
Additional demonstrations under consideration
Advanced Laser Communications
Future Tipping Point, SBIR, and University technology payloads
Partnerships with DARPA and other organizations

Snapshot of Space Technology Partners

NASA

THE AEROSPACE CORPORATION
AEROJET ROCKETDYNE
tyvak NANO-SATELLITE SYSTEMS LLC
MSNW
BRM Bally Ribbon Mills
saft
APPLIED DEFENSE SOLUTIONS
BUSEK
BOEING
406 AEROSPACE
ILC DOVER
MADE IN SPACE
Orbital ATK
Ball Ball Aerospace & Technologies Corp.
PUMPKIN INCORPORATED
Honeywell
LOCKHEED MARTIN
L3
DRAPER LABORATORY
mezzo TECHNOLOGIES
Masten
COBHAM
TELEDYNE BROWN ENGINEERING, INC A Teledyne Technologies Company
ASTER LABS
HONEYBEE ROBOTICS
AS AIRBORNE SYSTEMS
nanocomp TECHNOLOGIES, INC.
UP Aerospace
BAE SYSTEMS
United Technologies
DSS Deployable Space Systems
Dynetics
QUEST THERMAL GROUP
SURREY SATELLITE TECHNOLOGY LTD
QUEST THERMAL GROUP
Symmetricom
MOOG
ANALEX CORPORATION
Nammo
Virgin Galactic
OCEANEERING®
SNC SIERRA NEVADA CORPORATION Space Systems
PLANETARY SYSTEMS CORPORATION
SPACE SYSTEMS LORAL
MIT Lincoln Laboratory
Frequency Electronics, Inc.
POWERSAFE TECHNOLOGY CORPORATION
Micro Aerospace Solutions
SOUTHERN RESEARCH INSTITUTE
BCT
SE SEAKR Engineering, Inc.
Princeton Lightwave
Microcosm Inc
Generation Orbit
SIERRA LOBO
IFOS
STINGER GHAFFARIAN TECHNOLOGIES
ADCOLE
GeoOptics
TETHERS UNLIMITED
FREEDOM PHOTONICS
team textile engineering and manufacturing

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)

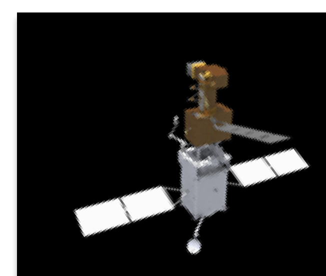
Purchasing major subsystems for **Solar Electric Propulsion and Laser Communications demonstrations**

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 as promised including Composite Cryotank, Advanced Solar Arrays, High Power Electric Propulsion Thrusters, High Performance Thermal Protection Systems and Small Spacecraft Technologies
- 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

FY 2017 Budget Request maintains balance within existing resources, retains customer-driven focus on needed technology with emphasis on partnering with industry

- Solicits U.S. aerospace community for new round of "tipping point' technologies
- Conducts 6 in-space demonstrations: deep space atomic clock for advanced navigation and outer planetary science investigations, green propellant alternative to hydrazine, and four small spacecraft demos; and continues development of space-to-ground laser communications for FY 2019 in-space demonstration
- Continue formulation activities for a full-scale in-space demonstration of on-orbit robotic satellite servicing
- Initiate a new in-space demonstration project to provide high bandwidth optical communications capabilities for future robotic and human deep space exploration missions
- Advance spacecraft technologies such as life-support, thermal management, and thermal protection system, and surface systems technologies such as in-situ resource utilization and power generation enabling deep-space human exploration missions
- Continues engagement with U.S. universities through graduate student research fellowships and faculty awards, Cultivates small businesses via for SBIR/STTR

National Aeronautics and
Space Administration

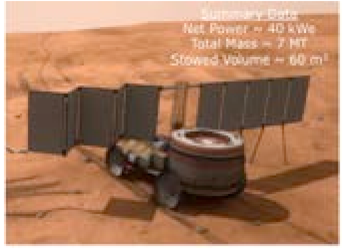
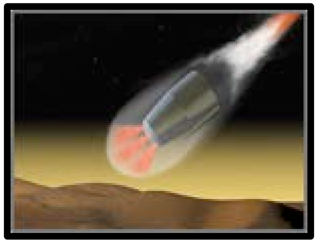
Technology Drives Innovation

www.nasa.gov/spacetech

BACKUP

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



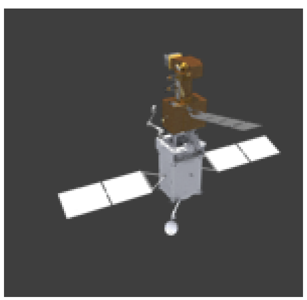

STMD Investments to Advance Science Missions

- **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

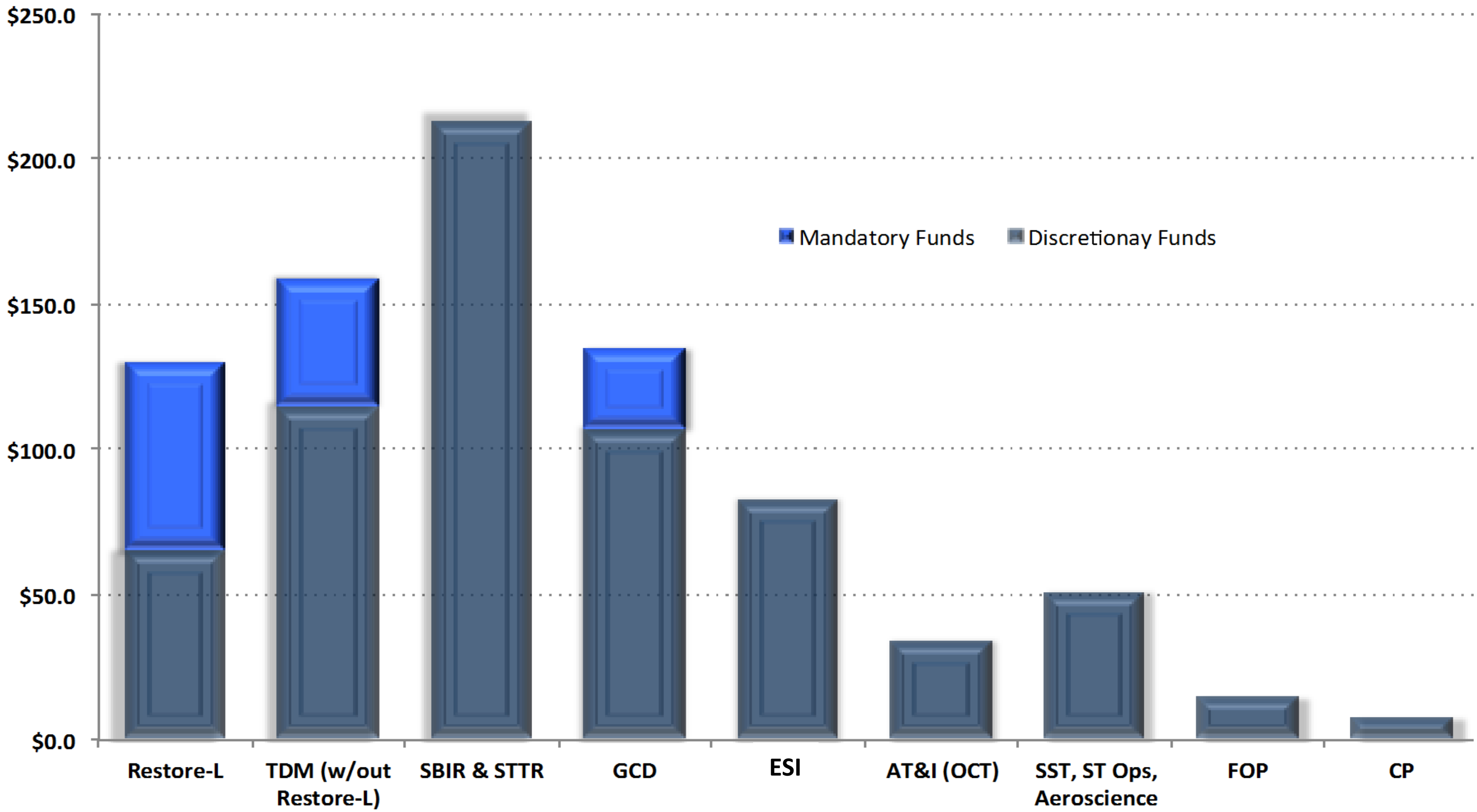
- **Propulsion & Power**
  - Green Propellant Infusion Mission – improved spacecraft performance & reduced toxicity and ground processing costs
  - Solar Electric Propulsion (SEP) – enabling increased power, reduced mass and longer life for commercial communication satellites



- **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

Discretionary and Mandatory Funding
Total FY 2017 Mandatory Fund = $136.1M



Solar Electric Propulsion

Developing & demonstrating SEP components for NASA exploration missions and commercial applications

- Reduced mass and more efficient packaging of solar arrays for more capable and affordable commercial satellites
- High-power Hall thrusters with magnetic shielding for all-electric commercial satellites and other applications
- SEP technology demonstration is planned for the Asteroid Redirect Robotic Mission (ARRM)

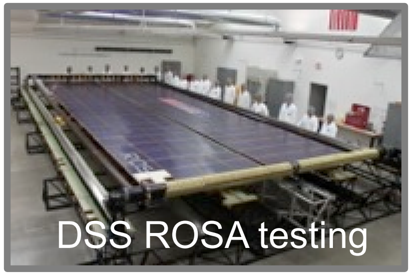
Electric Thrusters and Power Processing Unit (PPU)

- Demonstrated full performance compatibility between thruster and PPUs
- Electric Propulsion System Procurement RFP released in July 2015, final proposals received and under evaluation
- Anticipated award in late Spring 2016

Infusion Successes:

- Space Systems Loral signed agreement with DSS for STMD developed ROSA solar arrays on future commercial communication satellites
- Orbital ATK flew Ultraflex array on Cyngus cargo spacecraft in December 2015 that employed STMD-sponsored technology advancements


ATK Megaflex testing


DSS ROSA testing


ATK Ultraflex array on Cygnus


12.5 kW, 3,000 s
hot fire thruster test

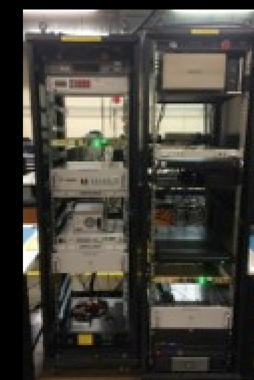
Optical Communication for Space

FY15	FY16	FY17	FY18	FY19
Engineering Model Assembly & Test & Flight Units Fabrication	Flight Units Assembly & Test	Complete Flight Unit Assembly & Test	Flight Payload Integration & Test	Mission Integration & Test & Hosted Spacecraft Notional Launch Readiness

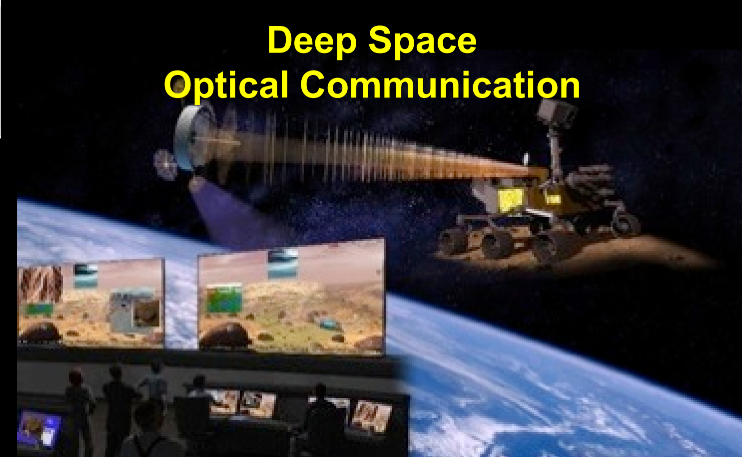
LCRD Optical Lab @ Goddard

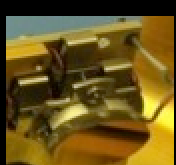
Controller Electronics (CE)
Engineering Development Unit (EDU)

Ground Modem

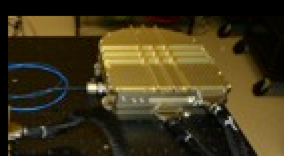


FY15	FY16	FY17	FY17+
Complete Laboratory Testing of Photon Counting Camera	Deliver Optics and Laser Transmitter Assembly	Ground Demo of DSOC System	TDM DSOC: Targeted for Discovery 2014

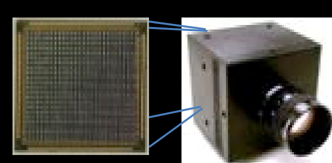




Point-Ahead Mirror

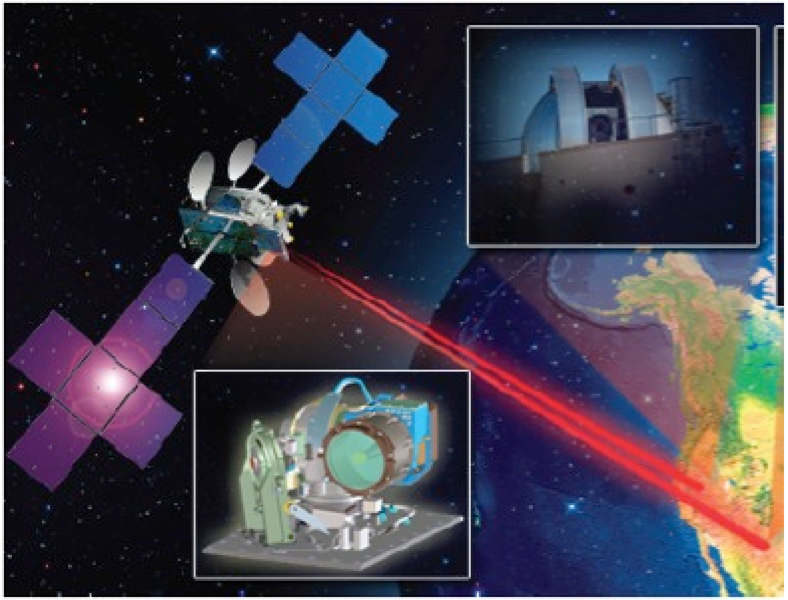


Laser Transmitter



Photon-Counting Camera

Laser Communication Relay Demonstration



Demo Description:

- Two-year flight demonstration to advance optical communications technology toward infusion into operational systems while growing the capabilities of industry

Objectives:

- Demonstrate bidirectional optical communication between GEO and Earth
- Measure and characterize system performance over a variety of conditions
- Provide on-orbit capability for test and demonstration of standards for optical relay communications
- Transfer laser communication technology to industry for future missions
- DoD Partnership to add encryption capability

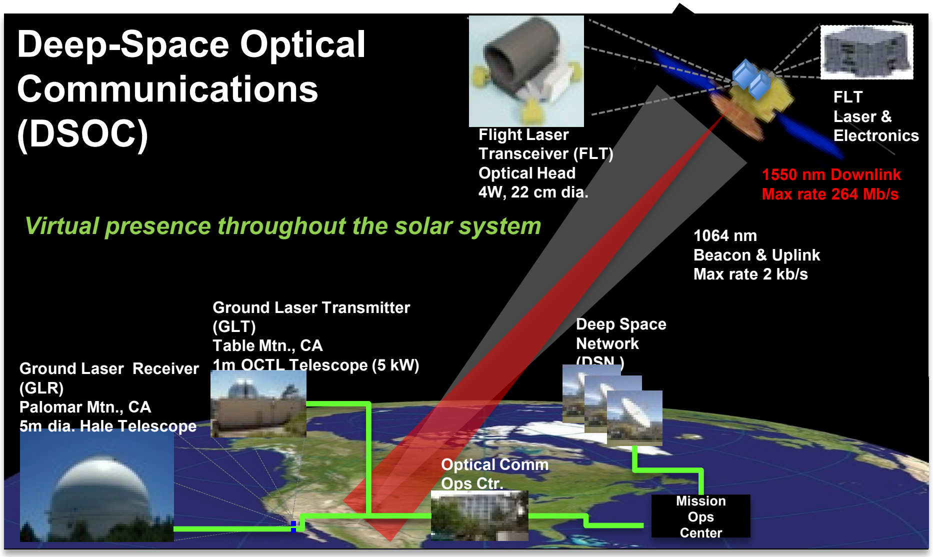
Anticipated Benefits:

- A reliable, capable, cost effective optical comm technology for infusion into future operational systems

Anticipated Mission Use:

- Next-gen TDRS and near-earth science; ISS & human spaceflight
- LCRD project is taking major steps toward commercialization and infusion into industry

Deep Space Optical Communications



Objective: Perform technology demonstration of deep-space optical communication capable of providing high bandwidth downlinks from outside cis-lunar space in order to improve the state of the art by 10x the current data rate obtained by RF (Ka-band) systems.

- **Mature key technologies to TRL 6: isolation assembly, photon counting detector array, high efficiency laser amplifier.**
- **Develop a Flight Laser Transceiver (FLT) to demonstrate maximum downlink rate of 267 Mb/s using photon-efficient techniques and operating while pointing close to the Sun**
- **Develop and demonstrate corresponding Ground System**
- **Retire risk of operating high-rate deep-space optical communication services on future NASA missions**

Programmatic and Technical Approach:

- Provide hardware as government furnished equipment (GFE) to SMD's Discovery Program and demonstrate on Discovery 14 mission.
- Develop FLT and implement Ground System based on TRL-6 maturation achieved under STMD/GCD & TDM, HEOMD/SCaN and SMD funded effort
- Deploy Ground System to support technology demonstration operations for 2-years

FY17 - FY18 Key Milestones:

FY17 Complete preliminary design and support Discovery PDR (Phase A/B)

FY18 Complete critical design and start build of FLT (Phase C/D)

FY19-20 Complete Operations Readiness Review and ATLO

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

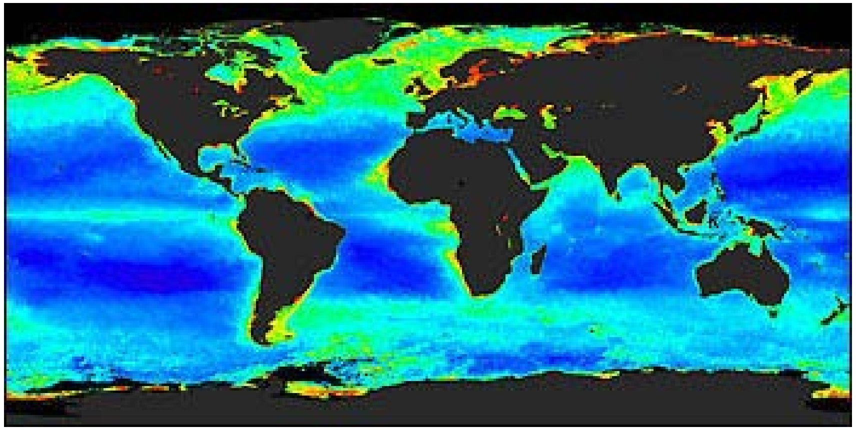
- **Orbital ATK** (Dulles, Virginia) for the project entitled “Public-Private Partnership for Robotic In-Space Manufacturing and Assembly of Spacecraft and Space Structures” - will perform an integrated ground demonstration including robotically deployed rigid backbone and upgraded TALISMAN system
- **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

GCD Tipping Point Awards

In November, STMD selected 2 companies through the 'Tipping Point' solicitation that will advance space technologies at the tipping point in their development:

Low Size, Weight and Power (SWaP) Instruments for Remote Sensing Applications

- **Geo Optics LLC** (Pasadena, California) for the project entitled "EGO-XO: Nanosats for Advanced Gravity Mapping and Crosslink Occultation"
- **Freedom Photonics LLC** (Goleta, California) for the project entitled "Advanced 1.65 Micron Seed Laser for LIDAR Remote Sensing of Methane"



GCD Announcement of Collaborative Opportunity (ACO) Awards

STMD also announced the selection of 7 new GCD partnerships with U.S. industry through the Announcement of Collaborative Opportunity (ACO) solicitation, “ Utilizing Public-Private Partnerships to Advance Emerging Space Technology System Capabilities”.

<u>**Nanosatellite and Suborbital Reusable Launch Systems Development**</u>

Generation Orbit Launch Services, Inc. (Atlanta, Georgia) for “Technology Maturation and Flight Validation for Air Launched Liquid Rockets”

<u>**Thermal Protection System (TPS) Materials and Systems Development**</u>

Intelligent Fiber Optic Systems Corp. (Santa Clara, California) for “Validation of Fiber Optic Temperature Sensor Arrays for Thermal Protection System Materials”

T.E.A.M, Inc. (Woonsocket, Rhode Island) for “Development and Characterization of 3D Woven Thermal Protection System via Arc Jet Testing”

Boeing (Huntington Beach, California) for “Arc Jet Exposure of Ablative and Non-Oxide CMC TPS for Planetary Probe and Sample Return Applications”

<u>**Green Propellant Thruster Technology Qualification**</u>

Busek Co., Inc. (Natick, MA) for “Flight Qual of Busek’s 5N Green Monopropellant Thruster”

Orbital ATK (Elkton, Maryland) for “Green Propellant Thruster Technology Qualification”

<u>**Small, Affordable, High Performance Liquid Rocket Engine Development**</u>

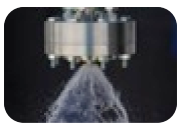
Exquadrum, Inc. (Adelanto, California) for “Risk-Reduction Testing for the DESLA Upper Stage Engine”

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.*





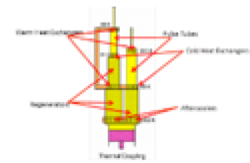


NASA Space Technology Research Fellowships

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

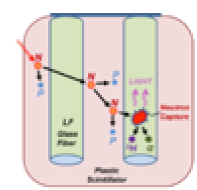
Early Career Faculty

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

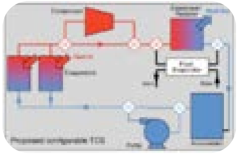


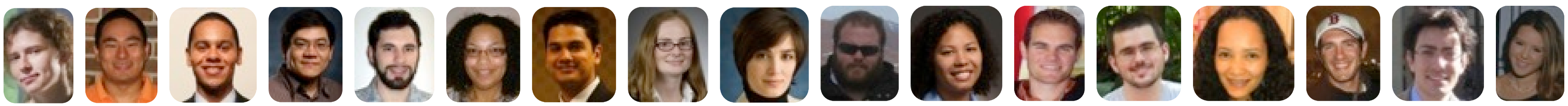
Early Stage Innovations

- 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



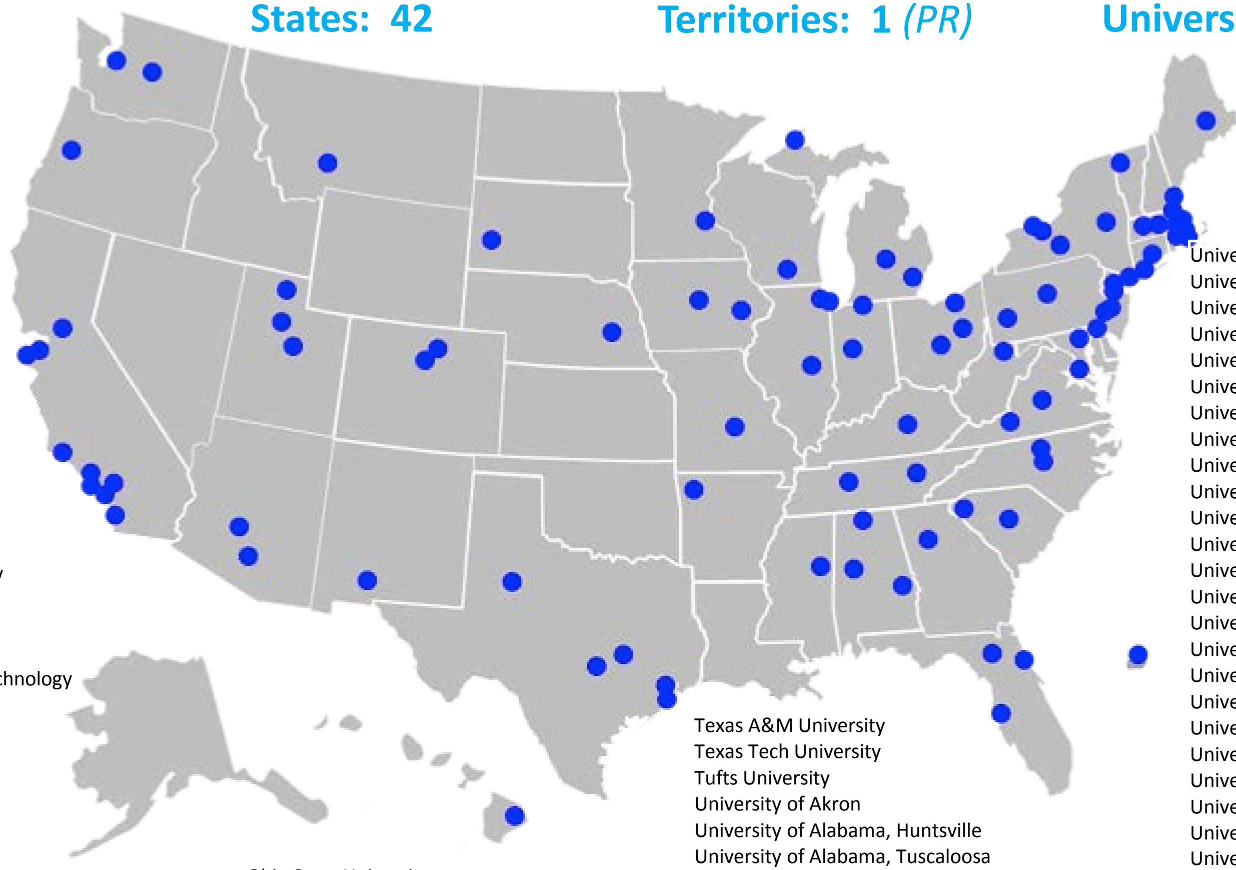
Reinvigorate the pipeline of high-risk/high-payoff low-TRL space technologies





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

2014 – 2015 NIAC FELLOWS

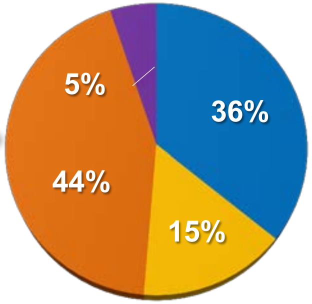
39 Total Proposals Selected & Funded (2014-2015 Ph I & Ph II)

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



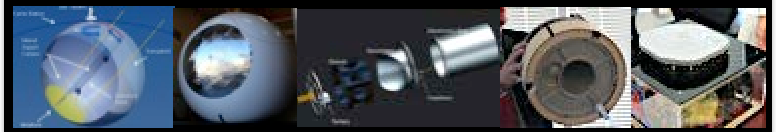
- NASA
- Industry
- Academia
- Other

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



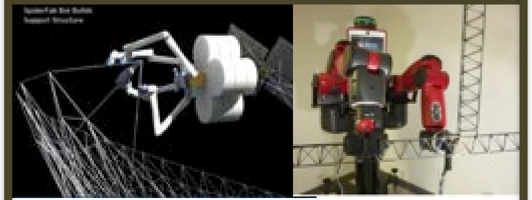
LBR: Adaptive Optics

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 H2O
- Mounted internal hardware on inflatable structure
- Extreme deformability
- Spectrochip II: Qualcomm

To fly in 2018 19 from Antarctica

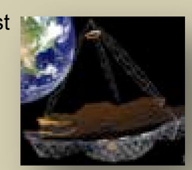
Robotic Assembly + Additive Manufacturing



NIAC FELLOW ROBERT HOYT, Tethers Unlimited

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

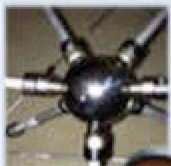
Carbon Fiber Trusselator



- ↑ 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

Early Stage Infusion Successes

STRG

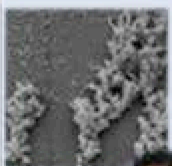


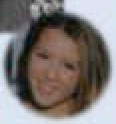
Erik Komendara

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)



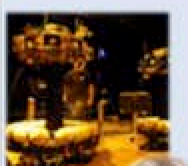


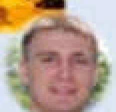
Jaemi Herzberger

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





Donald Ruffato

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

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

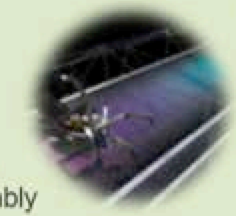
CIF (JPL) to GCD, patent and spin-off company (Amorphology, LLC)

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

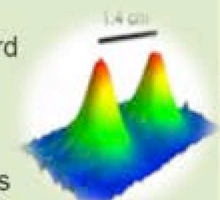
NIAC



SpiderFab

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

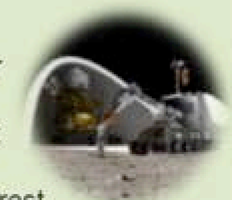
NIAC to SBIR, and basis for a new TDM project awarded under the FY15 Tipping Point solicitation



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

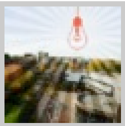
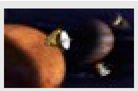
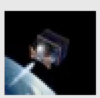
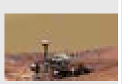
USC concept to use Moon or Mars soil for concrete to 3D print buildings autonomously; received multiple innovation awards and international interest

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 <u>since 2011</u>
- 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	
Space Technology Research Grants		373	373	• Early Career Faculty • Early Stage Innovations • NASA Space Technology Research Fellowships	***Annually***
NIAC		117	38	• NIAC Phase I • NIAC Phase II	***Annually***
Game Changing Technology Dev		50	18	Various topics released as Appendices to SpaceTech-REDDI	***Annually***
Small Spacecraft Technology		34	21	Smallsat Technology Partnerships Cooperative Agreement Notice (released as Appendix to SpaceTech-REDDI)	***Annually***
Flight Opportunities		139	67	Tech advancement utilizing suborbital flight opportunities – NRA to U.S. Universities, non-profits and industry are planned.	***Twice Annually***
STTR		263	246 w/ univ partners	*Annual STTR solicitation*	
Centennial Challenges		*4 Challenges (2 university-run)*	*40 teams (9 univ-led, 2 univ-led winners)*	• *One or more challenges annually* • ***Challenge competitions** with a **procurement track** to fund **university teams** via grants*	

Small Spacecraft Technology Pathfinder Technology Demonstrations

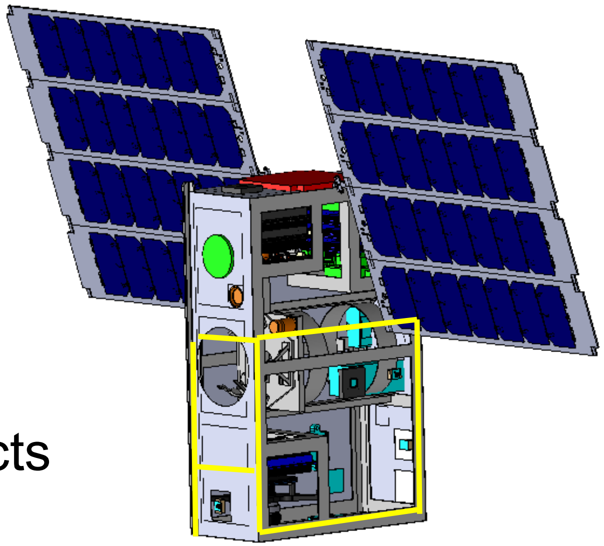
New initiative to procure commercial cubesat bus to enable rapid cadence of affordable technology demonstrations and to foster the development of the small spacecraft industry

Basic 6U cubesat bus to support demonstrations of new capabilities in *propulsion, communications, control and other systems*

Issued RFI in July2015 for industry comment

RFP being released in February 2016
for up to 5 satellites

Initial technology payloads will derive
from Tipping Point selections and SBIR projects



Example cubesat platform concept for
accommodating various technology payloads

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:

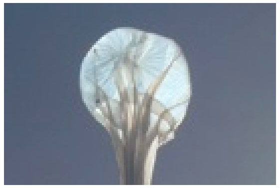
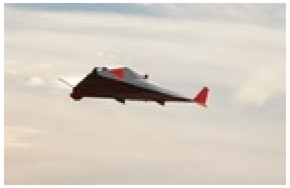
- FY11-FY14:Unfunded payloads selected though Announcements of Flight Opportunities (AFO)
- FY14-FY17:SpaceTech REDDI NRA to make funds available for purchase of commercial flights
- Collaborating with Science Mission Directorate (e.g., USIP) and other NASA programs to make space available for technologies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

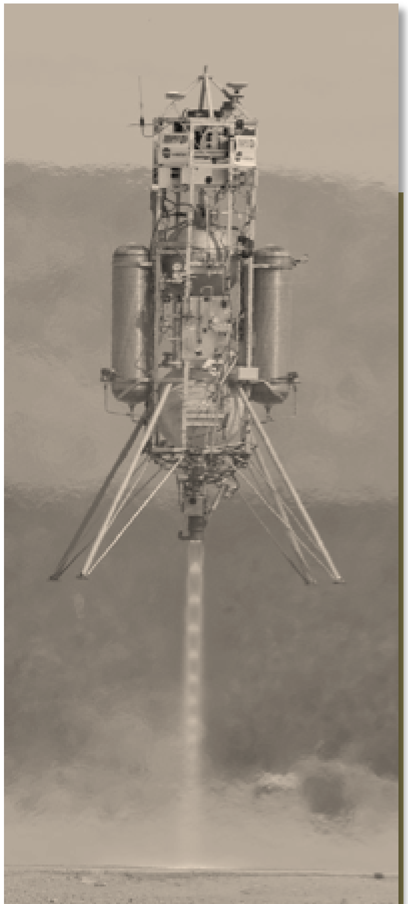
Plans for FY 2016 to FY 2017

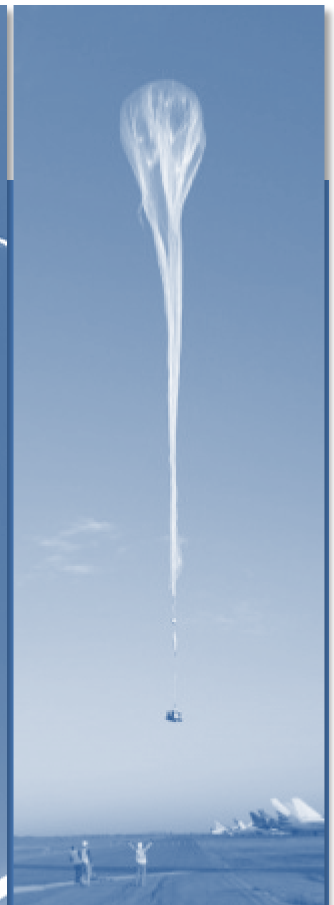
- Program expects to on-ramp at least one new flight provider before the end of Calendar Year 2016
- Program plans to release technology payload solicitations semi-annually
- Program plans to solicit internal payloads requiring flights from NASA programs
- With increasing demand for flights, the program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


Five IDIQ Flight Providers

Masten Space Systems	Near Space Corporation	World View	UP Aerospace	Virgin Galactic
Xombie, Xodiac	*Small/Nano Balloon System*	*Tycho-20, Tycho-285*	*SpaceLoft-XL*	*SpaceShipTwo*





VTOL

Balloon

sRLV

Flight Opportunities ACO Awards

- **Topic 1 Nanosatellite and Suborbital Reusable Launch Systems Development (FO Awards)**
  - Technology Maturation and Flight Validation for Air Launched Liquid Rockets -- Generation Orbit Launch Services, Inc./NASA AFRC
  - LauncherOne Collaborative Opportunity to Advance Emerging Space Capabilities -- Virgin Galactic LLC /NASA ARC
  - Spyder: A Dedicated CubeSat Launcher Project -- UP Aerospace, Inc./NASA MSFC

- **Topic 5 Small, Affordable, High Performance Liquid Rocket Engine Development**
  - Enhancement of Nanosat Launch Vehicle Booster Main Engine Using 3D Additive Manufacturing Techniques – Garvey Spacecraft Corp /NASA MSFC
  - Hydrogen Peroxide/Kerosene Engine Development – Dynetics, Inc./NASA MSFC

STMD Market Research RFI – http://goo.gl/1OLpF4

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 1st 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

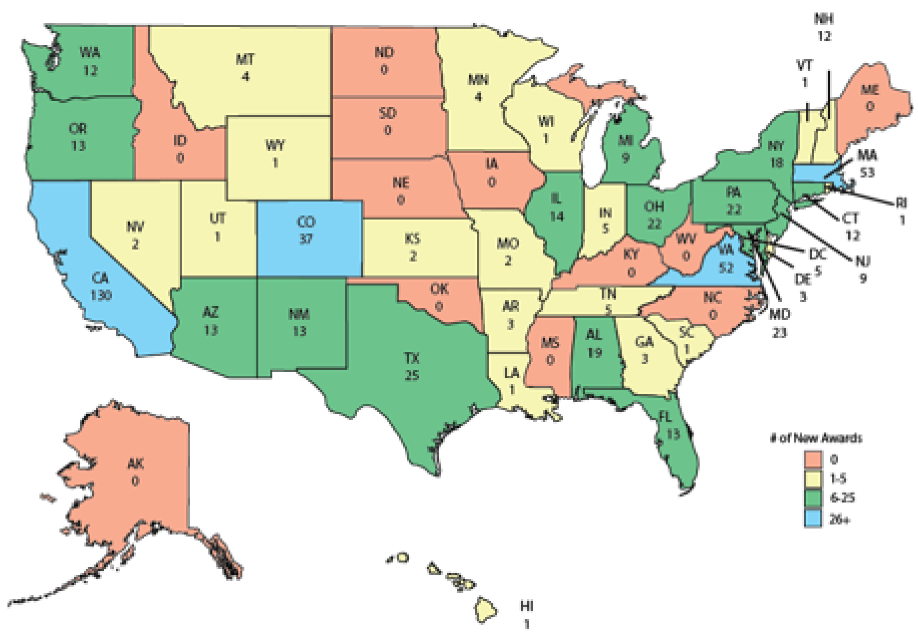
- 165 entries received for the Design challenge; 94 met requirements
- Awards to be Presented 9/26 at World Makers Faire

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.

STMD & AES Development Objectives

Exploration Technology Development element in STMD

- Develop long-range foundational and transformative technologies and components to support exploration needs (GCD program)
- Conduct flight demonstration missions of high-priority exploration capabilities such as solar electric propulsion (TDM program)
- Mature technologies for infusion into mission-level programs and agency initiatives such as ISS, Orion, SLS, and ARM
- Leverage synergies with game-changing and crosscutting technologies to support multiple customers and mission applications such as SMD, other government agencies, and the commercial sector

Advanced Exploration Systems program in HEOMD

- Development of exploration systems to reduce risk, lower lifecycle cost, and validate operational concepts for future human missions beyond Earth orbit
- Demonstrate prototype systems in ground test beds, field tests, underwater tests, and ISS flight experiments
- Use and pioneer innovative approaches for affordable rapid systems development and provide hands-on experience for the NASA workforce
- Maintain critical competencies at the NASA Centers and provide NASA personnel with opportunities to learn new and transform skills
- Infuse new STMD/ETD-developed technologies into exploration missions and AES test beds
- Support robotic missions of opportunity to characterize destinations for human exploration

AES – STMD Coordination Approach

- Program content is aligned with the highest priority technology needs identified in exploration mission architecture studies Background
  - The Human Architecture Team (HAT) & Strategic Knowledge Gaps create an integrated set of phased technology priorities & DRMs for STMD/ETD & AES
  - AES & STMD/ETD Coordination Approach
- Several AES and STMD/ETD efforts are integrally linked to foster collaboration and provide a direct technology infusion path
  - STMD/ETD projects focus on development of component technologies (e.g. GCD/PLSS) and system-level technology demonstrations (e.g. TDM/SEP)
  - AES efforts integrate mature technologies from STMD/ETD, particularly GCD, and perform design and prototyping of future exploration systems
  - STMD has developed a "Mission Use Agreement" document that specifies the technology infusion path (including requirements, milestones, resources)
  - STMD and AES have created MOUs for jointly funded and managed projects
- Frequent coordination ensures tight program cooperation
  - AES participates in STMD project formulation, status, and content decision meetings
  - HEOMD is a member of the STMD PMC where project status and decisions occur
  - STMD participates in the selection of AES efforts & attends AES mid-year and annual reviews
  - Regular leadership meetings occur between AES and STMD management
  - NASA Technology Executive Council (NTEC) coordinates technology investments across the Agency

TDM Infusion Successes

TDM → Industry

- New class of green monopropellant thrusters have been developed and ground tested in preparation for pending spaceflight demonstration. Led by Ball Aerospace, the thrusters are already being marketed by **Aerojet Rocketdyne**.

GCD → TDM → NASA Missions

- A revolutionary deep space optical communication system has been developed under GCD and will be transitioned to TDM in FY17. DSOC technology has been offered for demonstration on **Discovery-class missions** and was included in four of the five proposals recently selected by SMD for further study.

Early Stage → TDM → Industry

- A University of Colorado student, under an NSTRF project, developed an approach to robotic assembly of large structures in space using intelligent precision robots. This has been transitioned to NASA and **Orbital ATK** as a new TDM project awarded under the FY15 Tipping Point solicitation.

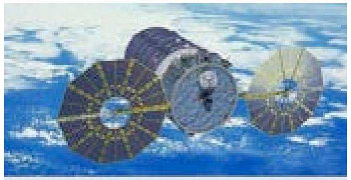
GCD Infusion Successes

- 3D Printer in Zero G (partnership between AES and STMD
  - Demonstrated on ISS
  - Industry Partner Infusion into follow on work for robotics in-space manufacturing and assembly (TDM Tipping Point)

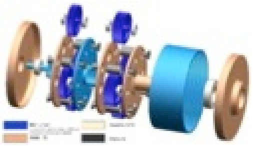
- Composites Cryotank
  - The Boeing Company is using the project technology for a new DARPA experimental vehicle

- Phase Change Material Heat Excanger
  - Potential infusion in Orion EM2 mission; PCM HX CDR CY2017
  - Industry Partner, UTAS, seeking infusion into Blue Origin, Space X, and Boeing

- Deep Space Optical Communications
  - Transitions to TDM in FY 2017
  - Potential demonstration on Discovery-class missions



- Advanced high-power solar arrays:
  - Orbital ATK and DSS independently developed high power solar arrays
  - Technology is being incorporated into future spacecraft by Space Systems Loral and others.
  - Potential use for ARM and SEP vehicles for the Journey to Mars



- Bulk Metallic Glass gears with high wear resistance
  - Began as a CIF, currently being further matured within GCD
  - Collaborating with industry to fabricate new alloys developed for gear components

- Woven Thermal Protection System
  - Began as a CIF project, further matured and tested within GCD
  - Technology is being infused on Orion as compression pads between the Crew and Service Modules

FY 2017 GCD Investment Priorities

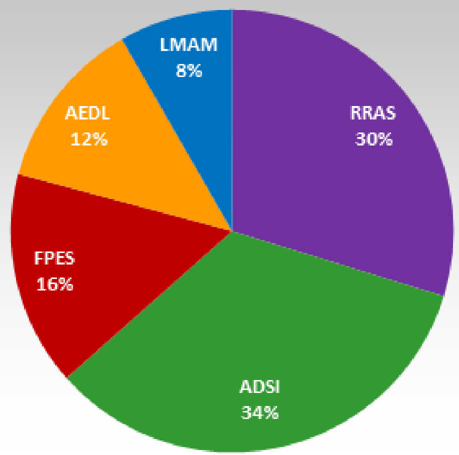
STMD Thrust: Lightweight Space Structures:

GCD Theme: Lightweight Materials and Advanced Manufacturing

Advanced Manufacturing Technology:
- Bulk Metallic Glass Gears – Develop gearboxes capable of reliable operations at extremely low temperatures. Complete long duration life testing.
- Low Cost Upper Stage Engine – In-house effort to develop low cost, additively manufactured upper stage engine technologies. Complete mechanical testing of selective laser melting deposited GRCop.

Nanotechnology:
- Ultralightweight Core for Composites – Downselect to most promising composite core technology for large-scale development/demonstration.
- Advanced Insulation for Lightweight Wires & Cabling – In-house maturation of promising aerogel-based insulation material for wires and cabling. Complete evaluation of several aerogel formulations.

Budget Distribution for FY 2017



STMD Thrust: High Performance Space propulsion

GCD Theme: Future Propulsion and Energy Systems

Nuclear Thermal Propulsion
- Develop technology efforts that will enable viable, affordable and fast NTP propulsion system options.

Advanced Space Power Systems
- Advanced Energy Storage Systems – Demonstrate high performance and safe operation with a significant increase in specific energy and energy density

Extreme Environment Solar Power
- Competitively develop low intensity, low temperature solar cell technology for deep space exploration. Complete Phase II downselect.

STMD Thrust: High Bandwidth Space Optical Comm; Advanced Life Support and Resource Utilization

GCD Theme: Affordable Destination Systems and Instruments

Next Generation Life Support: Competitively develop spacecraft oxygen recovery technologies capable of reliably recovering 75% of oxygen. Assess Phase I deliverables and complete Phase II downselect.

Deep Space Optical Communication: Mitigate development risks associated with optical communication system capable of order of magnitude greater data rates. Complete TRL6 demonstration for Discovery 2014 infusion.

Spaceflight Computing: Competitively develop flexible operations, lower power computer with 75x improved performance over RAD750. Release solicitation and award contract.

SEXTANT: enable GPS-like autonomous navigation anywhere in Solar System, and beyond, using millisecond period X-ray emitting neutron stars (Millisecond Pulsars) as beacons

STMD Thrust: Entry Descent and Landing Systems

GCD Theme: Advanced Entry, Descent, and Landing

Woven Thermal Protection Systems: Mitigate development risks associated with woven TPS material for future planetary exploration missions. Complete TRL6 development/demonstration for infusion into Discovery 2014.

Mars Entry, Descent, and Landing Instrument (MEDLI): Partnership with HEOMD and SMD to develop Mars 2020 hardware to acquire critical EDL data for Mars and future exploration missions. Complete TPS flight lot certification.

STMD Thrust: Space Robotics Systems

GCD Theme: Revolutionary Robotics and Autonomous Systems

Human Robotic Systems
- Rover Technology – Design and develop rover for HEOMD's Resource Prospector project. Deliver final terrestrial prototype rover to HEOMD.
- National Robotics Initiative – Continue supporting NASA's participation in the National Robotics Initiative.

Human Exploration Telerobotics
- ISS Freeflyer – Design and develop ISS freeflyers to replace SPHERES saving significant crew time by offloading routine tasks. Complete development of two flight hardware units.

Pop Up Exploration Robots: Develop folding, impact absorbing robots to enable new science by providing future missions with low-cost access to new terrains. Complete final field demonstration.

Smallsat Technology Partnerships
University-NASA Collaboration

Cooperative agreements with US universities to develop and demonstrate new technologies and capabilities for small spacecraft in collaboration with NASA.

- Two year projects
- Up to $100,000 per year, per university
- Up to 1.0 FTE in NASA labor per year

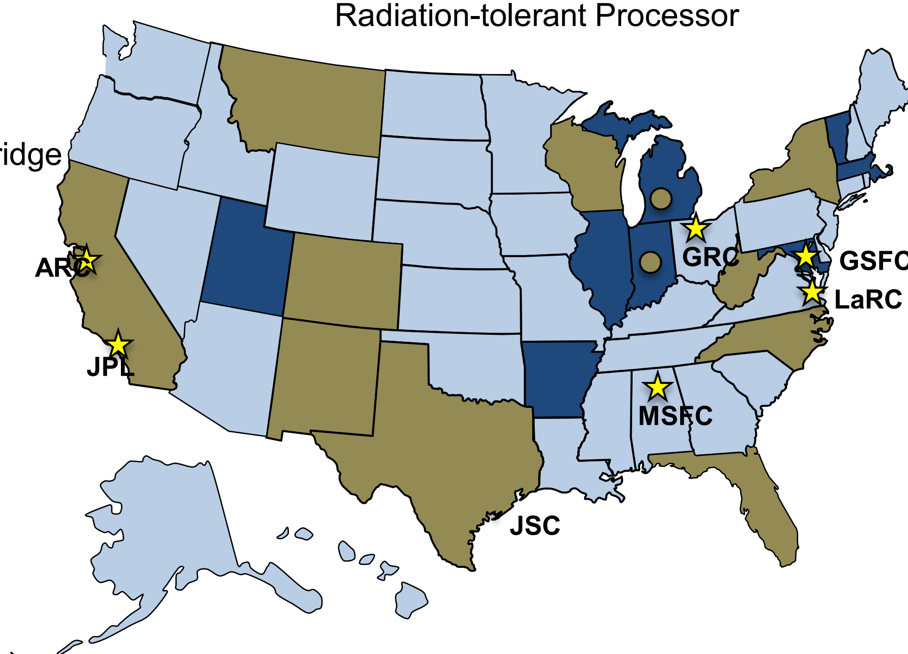
Planning annual call for proposals

Montana State/Goddard
Radiation-tolerant Processor

California State U-Northridge/JPL
Low-temperature Capacitor

2013 Selections

U of Rochester
U of New Mexico
U of Texas-El Paso
California State U, Northridge
U of Colorado
Western Michigan U
U of Texas
Purdue U
Montana State U
U of Florida
U of Houston
Appalachian State U
Texas A&M U
West Virginia U
Marquette U



2015 Selections

U of Vermont
Worcester Polytechnic Institute
U of Arkansas
U of Michigan
U of Maryland
Utah State U
U of Illinois
Purdue U

NASA Centers

Two of the 2013 selected teams have since been awarded NASA launch opportunities for their projects

Entry, Descent and Landing (EDL)

Goals:

Enable EDL missions to new scientific destinations, advance aerosciences and materials to lower the cost and improve the efficiency of EDL systems, and develop a new generation of capabilities to enable the Journey to Mars.

Infusion Paths:

- **Robotic Science** missions that explore Mars, other planets, moons, and/or return samples to Earth
- **Human Exploration** missions to beyond LEO, that bring humans back to Earth at high speed, or explore other surfaces, including Mars
- **Commercial Endeavors** where advanced EDL systems improve efficiency, lower operating cost, or enable new markets

FY 2015 Highlights

- **Low Density Supersonic Decelerator:** Successfully conducted second supersonic flight test of the Supersonic Inflatable Aerodynamic Decelerator and ballute, bringing them to infusion readiness
- **Heatshield for Extreme Entry Environment TPS (HEEET):** Successfully conducted seam and acreage testing to Saturn and Venus conditions, in arcjets at Ames and Arnold Engineering Development Center. (Incentivized in Discovery 14)
- **MEDLI-2:** Established the measurement objectives and requirements for the Mars 2020 heatshield and backshell instrumentation; conducted initial testing.
- **Hypersonic Inflatable Aerodynamic Decelerator (HIAD):** Evaluated flexible structure scale-up for booster recovery and Mars application.
- **Adaptable, Deployable Entry and Placement Technology (ADEPT):** Successfully conducted ~1-meter scale aero loads wind tunnel test and full-shape arcjet proof-of-concept test at Ames.
- **Entry Systems Modeling (ESM):** Generated database to improve shock-layer chemistry and radiation predictions, completed coupled CFD tool and roughness database, delivered TES-5 hardware. NEQAIR named NASA Software of the Year.

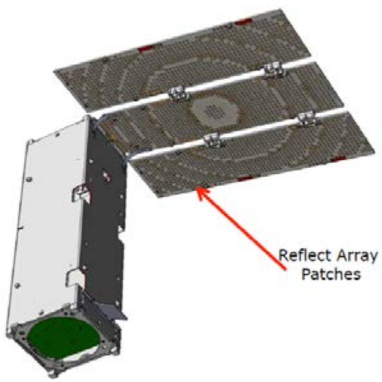
FY 2016 - 17 Plans

- **Propulsive Descent Technologies (PDT):** Pursue partnership opportunities to demonstrate supersonic retro-propulsion; an enabling technology to support the large landing mass requirements needed for human exploration missions to Mars.
- Complete testing with the US Forestry Service and transition to commercial production of next-generation personnel fire tents (**CHIEFS**).
- Fabricate, integrate, test 1-meter engineering test unit aeroshell with **HEEET** TPS.
- Begin procurement and development of sensors in **MEDLI-2**.
- Initiate parachute modeling, test magnetic suspension of wind tunnel models, complete TPS modeling tool, and flight test Exo-Brake in 2017, within **ESM**.
- Incentivize **multiple EDL technologies** in New Frontiers-4 solicitation.

Small Spacecraft Technology Infusion Successes

Integrated Solar Array and Reflectarray Antenna

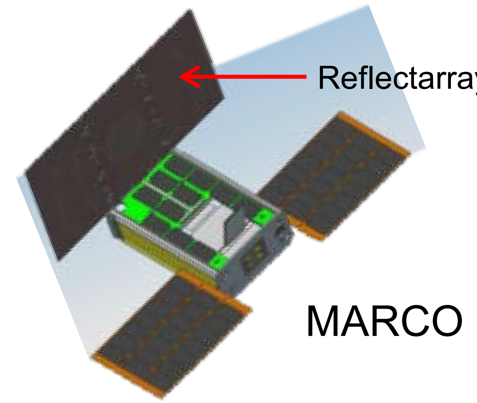
ISARA



JPL, Aerospace Corporation, Pumpkin Inc.

Increased Ka-band communication and potential radar remote sensing for low-cost but effective science missions

Reflectarray technology being used for JPL's MARCO cubesat deep space radio relay demonstration.

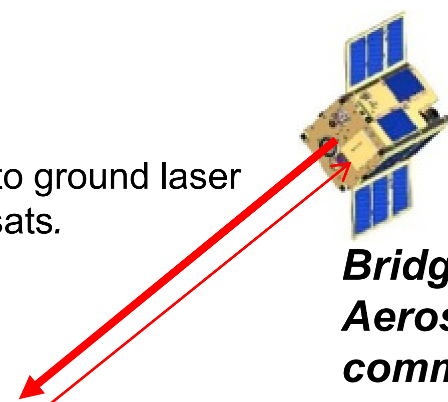


Optical Communications and Sensor Demonstration

OCSD

Aerospace Corporation

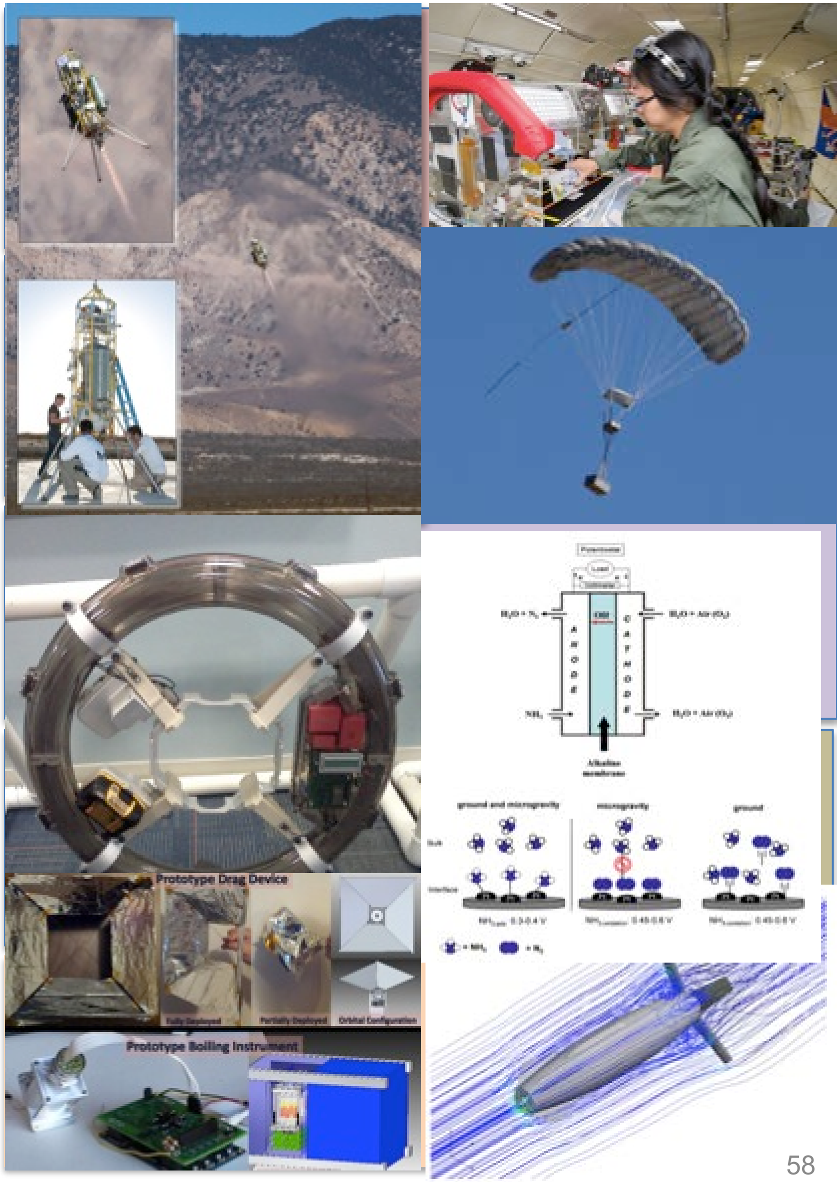
Dramatic improvement in space to ground laser communications with 1.5U cubesats.
Goal is 200 Mbps or higher



Bridgesat, Inc. has partnered with the Aerospace Corp. to commercialize the laser communications technology developed for OCSD.

Announcement of Flight Opportunities(AFO) and NRA Selections To Date

AFO # /NRAs	# Proposals selected
AFO 1	**16** (12 parabolic; 2 sRLV; 2 parabolic/sRLV)
AFO 2	**9** (4 p; 4 sRLV; 1 p/sRLV)
AFO 3	**24** (16p; 5 sRLV; 2 balloon; 1 balloon + sRLV)
AFO 4	**2** (1 sRLV; 1 balloon)
GCD-NRA 1	**14** sRLV
AFO 5	**13** (9 p; 2 b; 1 sRLV;1 b/ sRLV)
AFO 6	**21** (14 p; 3b; 2 sRLV; 1 p/sRLV; 1 b/sRLV
GCD-NRA2	**10** sRLV
TDM-AFO 7	-0- Orbital
SMD-USIP	**4** (2p; 1b; 1 sRLV)
AFO 8	**13** (11p; 2sRLV)
REDDI FY14 F1	**7** (6p; 1sRLV)
REDDI FY15 F1	**8** (6p; 2sRLV; 1p/sRLV)
Selections to-date	**141**



High Performance Space Flight Computing FY 2017 Investment Priority

High Performance Space Flight Computing (HPSC):

Space-based computing has not kept up with the needs of current / future NASA missions. NASA has extreme requirements for low power and energy management, and fault tolerance

Objectives:

We are developing a next-generation flight computing system that addresses NASA and other government agency computational performance, energy management and fault tolerance needs through 2030

Technology Infusion:

- Engage NASA SMD and HEOMD mission customers representing NASA mission use cases as developed in the HPSC Formulation study report
    - Technology experiment and/or mission use on Earth observing instruments and future planetary missions, including Discovery and New Frontiers programs
- Engage SMC via AFRL for USAF / DoD mission customer imaging and autonomy applications
- HPSC capability is relevant to high data rate instruments, mission-critical real-time calculations, platform autonomy