National Aeronautics and
Space Administration

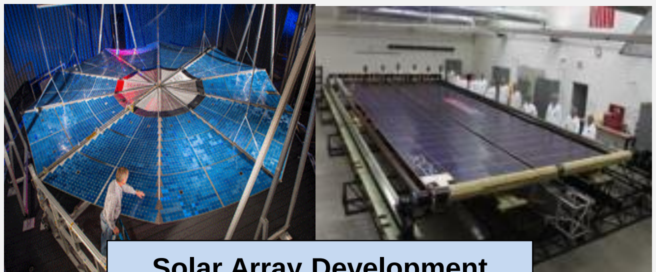
Space Technology Mission Directorate

FY 2016 President's Budget Overview

Presented by:
Dr. James Reuther
Deputy Associate Administrator for Programs, STMD

April 2015

STMD Successes To Date



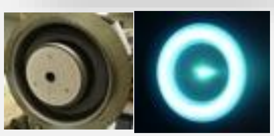
Solar Array Development and Testing

Composite Cryo Propellant Tank Testing

Utilizing ISS as a Technology Testbed

Advanced Thrusters and Electronics Development

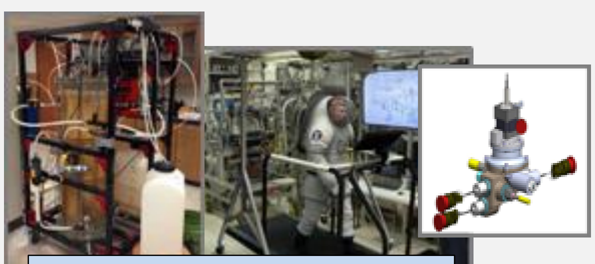
JPL H6 with magnetic shielding



GRC 300M with magnetic shielding

Entry, Descent and Landing Technology

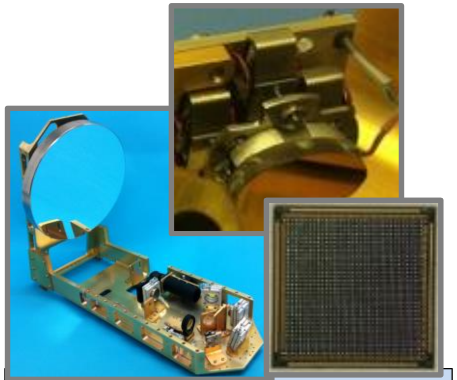
Creating New Markets and Spurring Innovation while Engaging the Brightest Minds



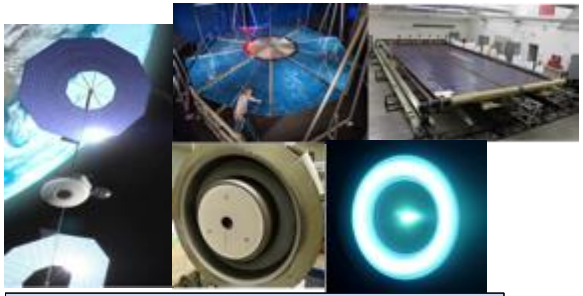
EVA Suit and ECLS Technologies

Looking Forward to Future Technology Successes

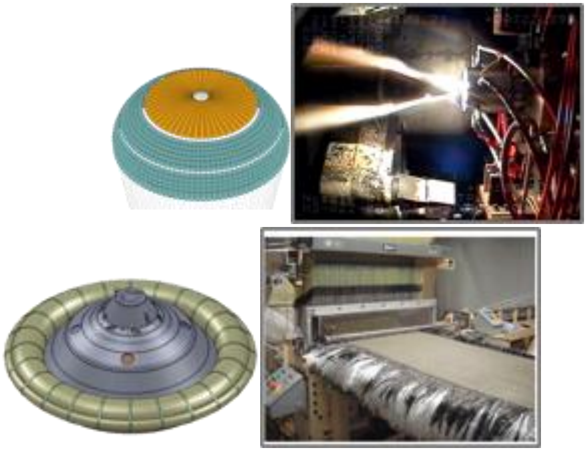
Flight Demo for Green Propellant Infusion Mission



Technology Development for Deep Space Optical Communication



Solar Electric Propulsion Testing

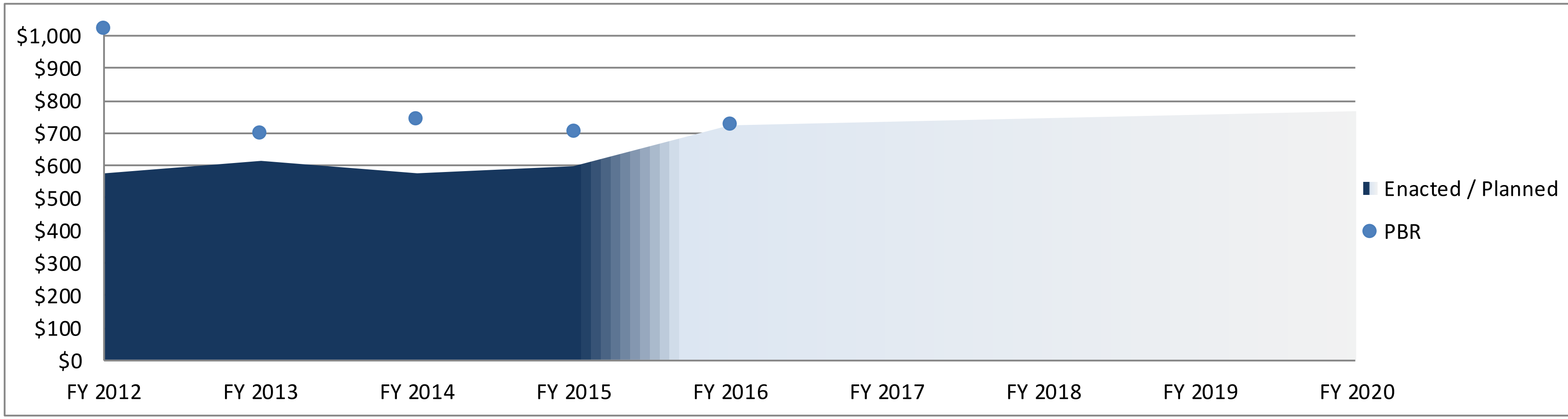


Completion of Entry, Descent and Landing Technology

Flight Demo for Deep Space Atomic Clock

Future Demos on ISS

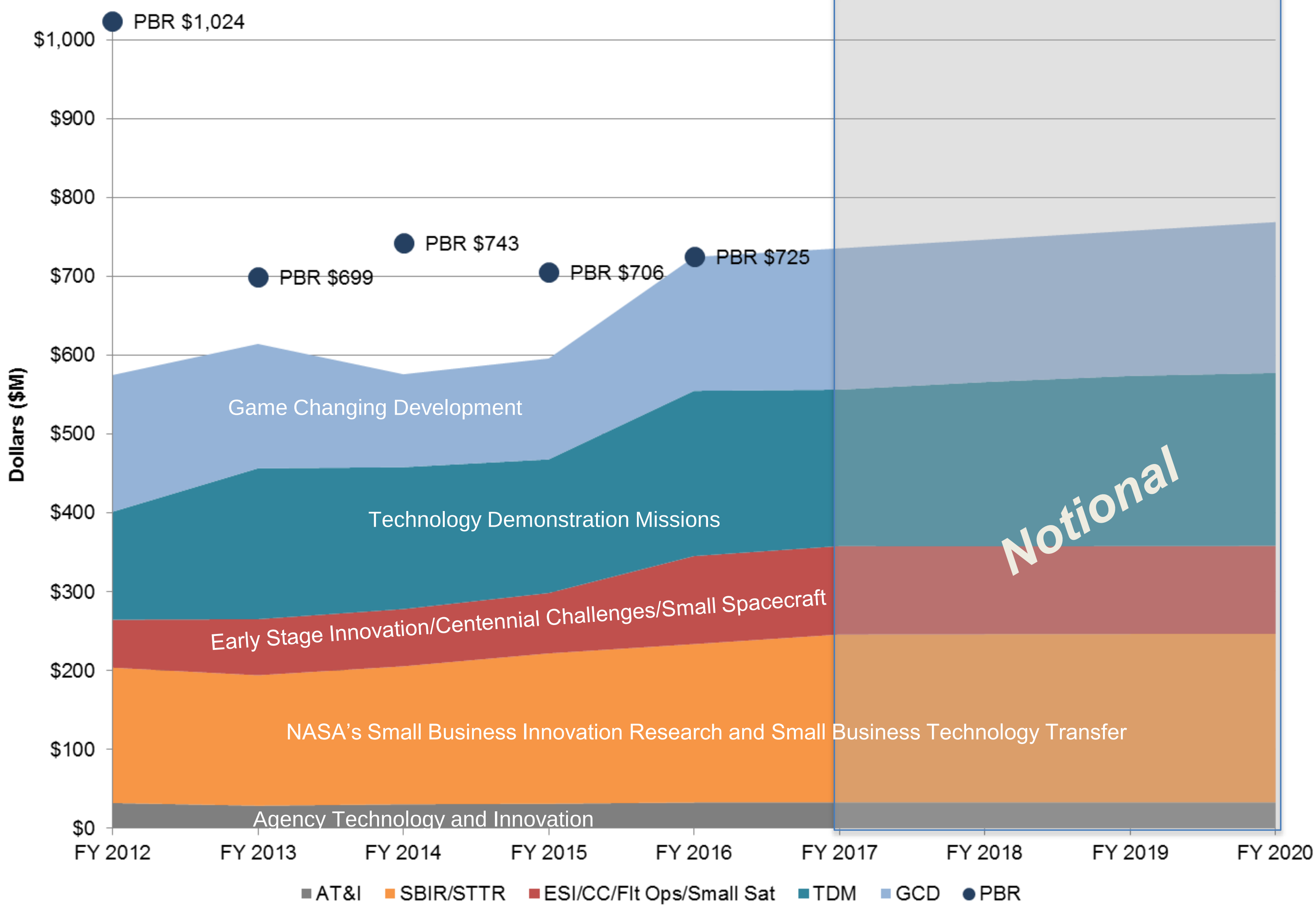
STMD FY 2016 President's Budget



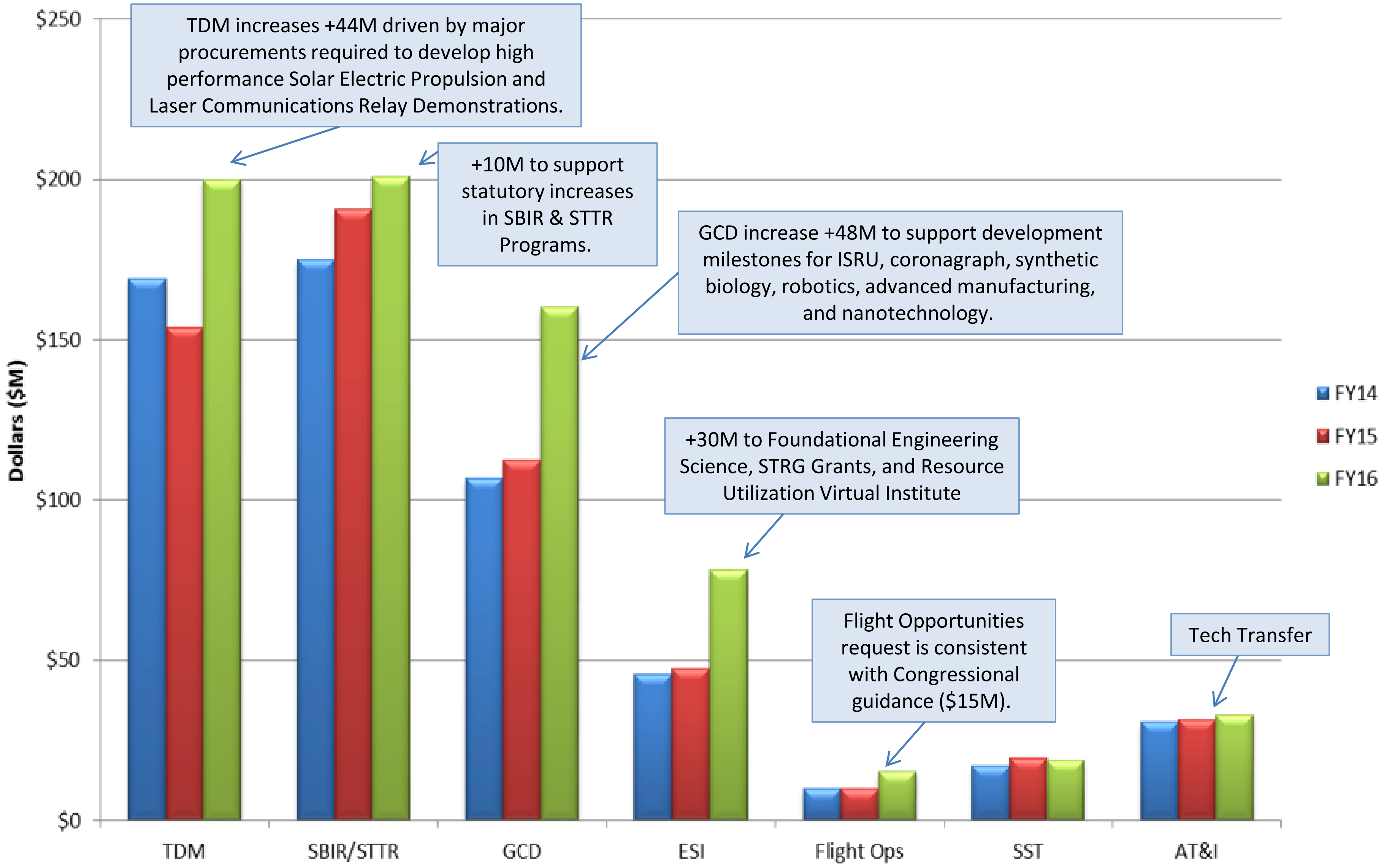
	Budget Authority ($M)	Actuals	IOP	PBR	PPBE16			
		FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020
OCT	Agency Technology & Innovation	31	31	33	33	33	33	33
Space Tech Mission Directorate	SBIR and STTR	175	191	201	213	213	213	214
	Space Technology Research & Development	370	374	491	490	500	511	522
	Early Stage Innovation	45		73	75	75	75	75
	Centennial Challenges	1		5	5	5	5	5
	Flight Opportunities	10		15	15	15	15	15
	Small Spacecraft	17		19	17	17	17	17
	Game Changing Development	118		170	179	181	184	191
	Technology Demonstration Missions	180		210	198	208	216	219
	Space Technology Total	576	596	725	736	747	758	769

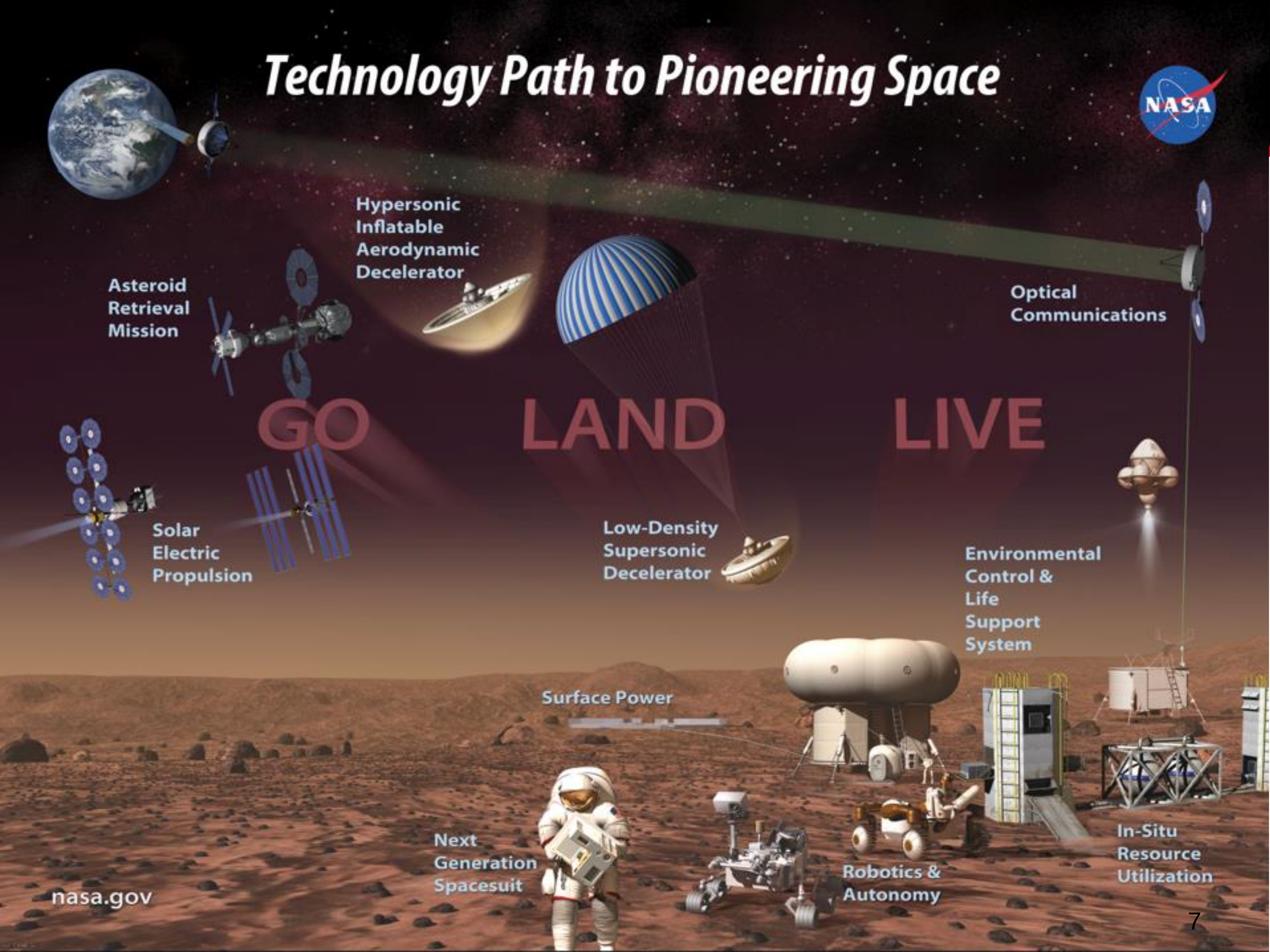
|--------------NOTIONAL--------------|

Funding Transitions



FY 2016 Key Budget Drivers




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

CY Major Events & Milestones

Space Technology Research and Development

Access and Travel through Space

- Developing high-powered solar electric propulsion **(FY15-16 Major Procurements)**
- Fast transit in-space propulsion technologies **(FY16 New Start)**

Landing More Mass, More Accurately

- Conducting a high-altitude, supersonic demonstration of advanced parachutes and inflatable entry, descent and landing technologies **(June 2015 and June 2016)**

Enables Living and Working in Deep Space

- Advance life-support **(ISS Demo FY16)**
- Thermal management **(ISS Demo FY16)**
- Thermal protection systems

Understanding and investigating our Solar System

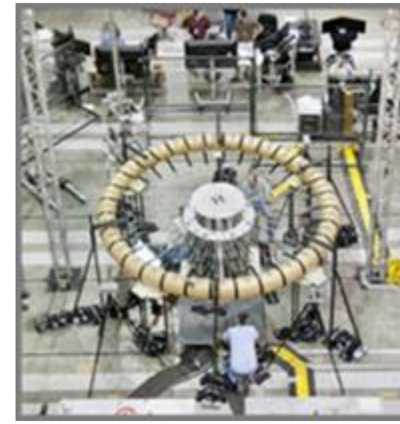
- Landing and mobility; Radiation protection and accommodating power needs
- Deep space atomic clock for advanced navigation and outer planetary science investigations **(In Space Demo FY16)**
- Four small spacecraft demos of pioneering new technologies **(FY15-16 In Space Demos)**

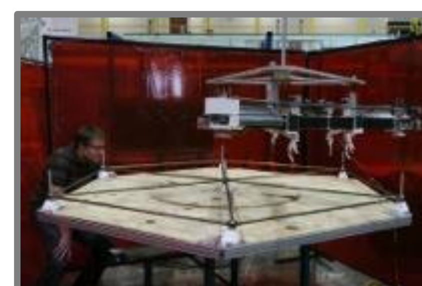
Improves US aerospace industry capabilities

- Validating large-scale composite structures to reduce the structural mass launch vehicles **(FY17 Ground Test)**
- Continue progress toward in-space demonstration of high bandwidth, space-to-ground laser communications **(FY19 In Space Demo)**
- Green Propellant-safer alternative to hydrazine. **(In Space Demo FY16)**
- Solar Electric Propulsion to enable orbit maneuvering and accommodate increasing power demands for satellites

Collaborate with other government agencies and industry partners

- High performance spaceflight computing, robotics for extreme environments, advanced manufacturing





Advancing Deep Space Capabilities: Progress through ISS and Testbeds

Live There

- **Environmental control and life support system**
  - Competitively selected four **oxygen recovery** technology development efforts (SOA = 40%, new methods > 75%)
  - ISS demonstration of prototype oxygen recovery system after technology down select
- **Extravehicular activity (EVA) suits**
  - High fidelity ground test bed at JSC evaluating EVA life support technologies (**Rapid Cycle Amine CO_2 removal, & Variable Oxygen Regulator**)
  - **EVA gloves** with increased durability & reduced crew exertion for evaluation with future EVA
- **Habitats**
  - **Inflatable habitat** demonstration on ISS in 2015
  - Ground work on airlock including a **soft hatch** continues in 2015
- **Modular surface power**
  - Ground demonstration in 2017 of a **1kW-scale Stirling-cycle fission power** system
- **Radiation protection**
  - Experimental & analytical development of **peak intensity and duration forecast models**
  - Improving environment awareness through Flight Missions (MSL) and ISS and improving knowledge and better understanding of long-term risks

Land There

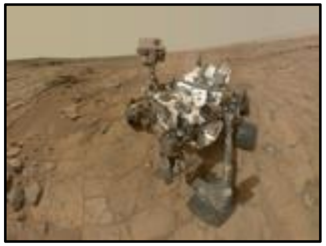
- **Entry, descent and landing**
  - Developed low-cost, high-speed, high-altitude testbed - high-altitude balloons and rocket powered test vehicle
  - 2 mT to 5 mT capability to Mars surface – **supersonic parachutes and inflatable decelerators** - Mars Sample Return and stepping stone to > 10 mT capability
  - Partnering with SpaceX to **obtain supersonic retro-propulsion** data to validate analytical models

Go There

- **Cryogenic storage and transfer**
  - Ground testbed to **mature cryogenic storage and transfer technologies**

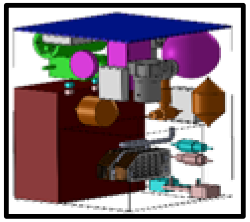
Advancing Deep Space Capabilities: Progress through Missions

Mars Science Laboratory (MSL)



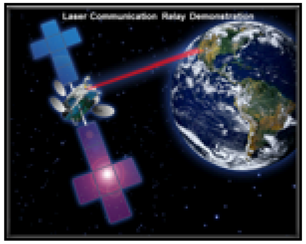
- First-ever comprehensive **entry, descent, and landing (EDL)** measurements on flight through Martian atmosphere in 2012 landing
- Understanding the Martian environment: measurements of water, atmosphere, and radiation

Mars 2020



- **In-situ resource utilization (ISRU):** Demonstrate oxygen conversion on Mars 2020
- Continue EDL measurements on landing and include first-ever measurements on backshell

Discovery 2014

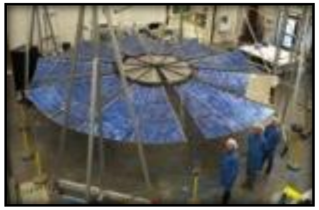


- **Thermal protection system (TPS):** New class of materials (woven TPS) in development for Venus entry in Discovery 14 Opportunity
- **Deep-space optical communications**: First-ever demonstration of high-bandwidth communications from deep-space

Orion EM-1

- **Thermal Protection System:** Variant of woven TPS will be flown on EM-1 mission as the compression pads.

Asteroid Redirect Mission



- **In-space propulsion and power:** high-power solar electric propulsion demonstration
- Possible demonstration of high-power solar arrays on ISS

STMD Examples Aligned with HEOMD Needs

Solar Electric Propulsion (SEP)

Enabling for ARM and humans to Mars

Technologies: Advanced Solar Arrays, High-Power Hall thrusters & PPUs

Life Support and Resource Utilization

Mars Oxygen ISRU – testing on Mars 2020 and needed for humans to Mars

Next Gen. Life Support – Space suit components; Highly reliable closed loop air revitalization; Radiation dosimeter, modeling, forecasting and shielding

Entry, Descent and Landing Technologies

LDSD – allows up to 15 mt Mars landed mass

Woven TPS – potential use on Orion and later Mars entry system

ADEPT – deployable entry systems for large heat shields

Space Launch System (SLS) Technologies

eCryo – long duration cryogenic storage for SLS upper-stage

Composite Exploration Upper Stage (CEUS)– upper-stage use to increase SLS payloads

Other Key Exploration Technologies

Human Robotic Systems (R2, R3 & R5) – to reduce crew workload

Nuclear Fission systems for Mars surface power

Optical Communications (LCRD & DSOC) & Deep Space Navigation (DSAC)

Minimalistic Advanced Softgoods Hatch– to reduce structural mass

STMD Examples Aligned with SMD Needs

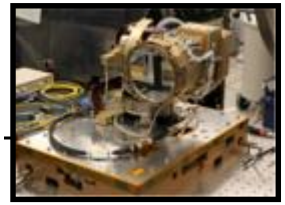
Entry, Descent, & Landing

- MEDLI, MEDLI+ & Entry Systems Modeling – Mars EDL systems design
- Woven TPS (HEEET) – Venus, Mars & Outer Planets
- Low Density Supersonic Decelerator – Increased mass to Mars surface
- Hypersonic Inflatable Aerodynamic Decelerator (HIAD) & Adaptable, Deployable Entry Placement Technology (ADEPT) – deployable heat shields for Venus and Mars provides much lower entry loads

Propulsion & Power

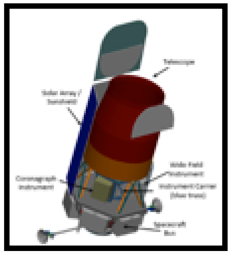
- Green Propellant Infusion Mission (GPIM)- alternative to hydrazine
- Solar Electric Propulsion (SEP) – enabling new science missions
- Small Fission – power for outer planet missions

Communication & Navigation



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

Instruments, Sensors, & Thermal



- High Performance Spaceflight Computing – broadly applicable to science missions
- AFTA / WFIRST Coronagraph – to perform direct observations of exoplanets and determining their atmospheric content

Technologies at a Tipping Point

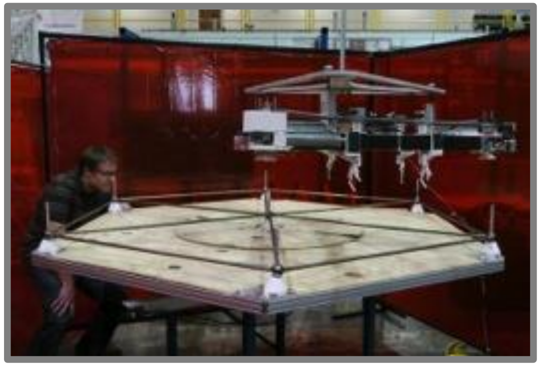
Space Technology will solicit the aerospace community for technologies at the "tipping point"

- Award one or more new demonstration missions
- Crosscutting appeal to both enhance NASA's future capabilities while enabling new commercial space endeavors
- Looking for investment that has high rate of return
- Maturation will lead to broad adoption
- Industry co-investments and partnerships encouraged

Possible Topics:

- In-space robotic assembly of spacecraft space structures
- Brine processing for life support
- High performance spaceflight computing
- Advanced space memory
- Solid state thermal power
- Advanced in-space propulsion

RFI Released on February 3, 2015 and Response Deadline on March 19, 2015

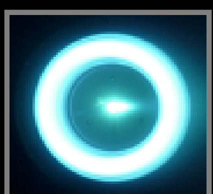


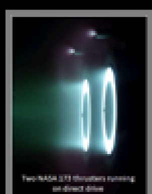
Technology Investment: High Power Solar Electric Propulsion

Deployable Solar Arrays

- Direct replacement of flat composite panel technology
- Half the mass
- Triple the packaging efficiency

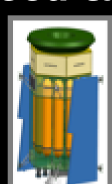
Thrusters and PPUs

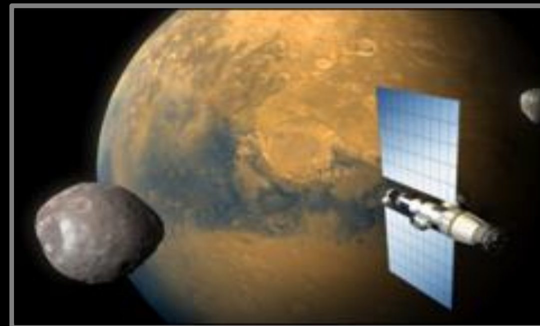




- Magnetic shielding for endurance
- Higher voltage – higher ISP
- Variable ISP/thrust – power throttling

Propellant Feed & Storage

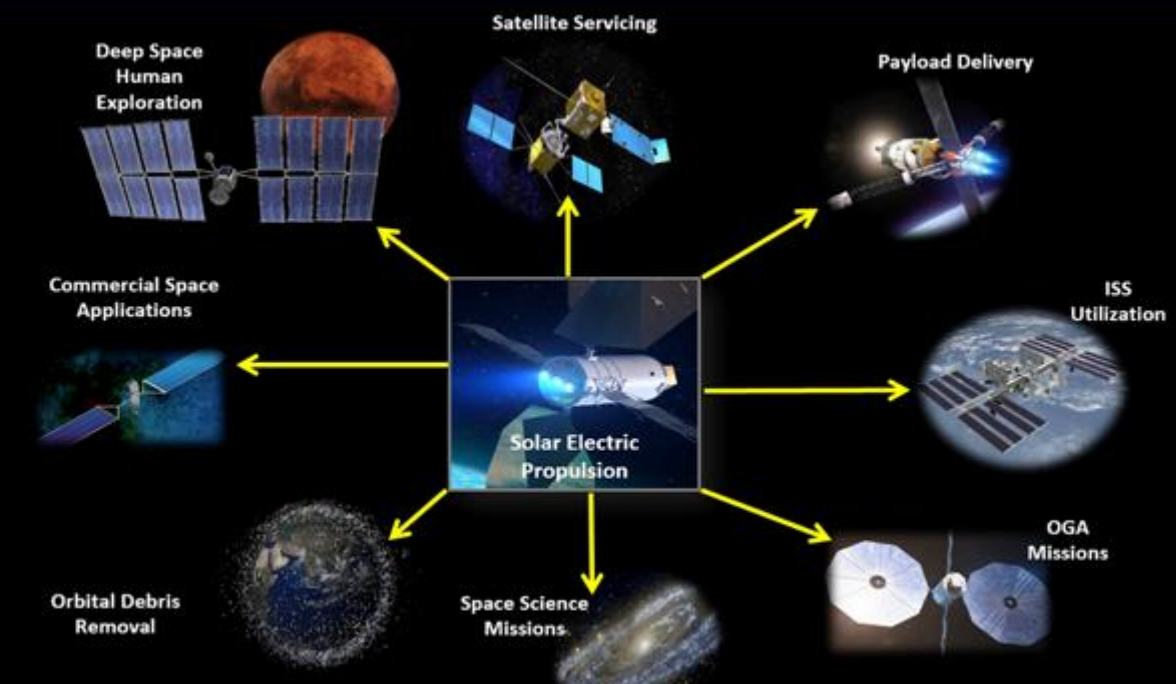




SEP – In-Space Tug

Diverse Applications

- Commercial Sats
- Orbital maneuvering
- Deep Space Exploration
- Asteroid Retrieval
- Science and Orbital Debris



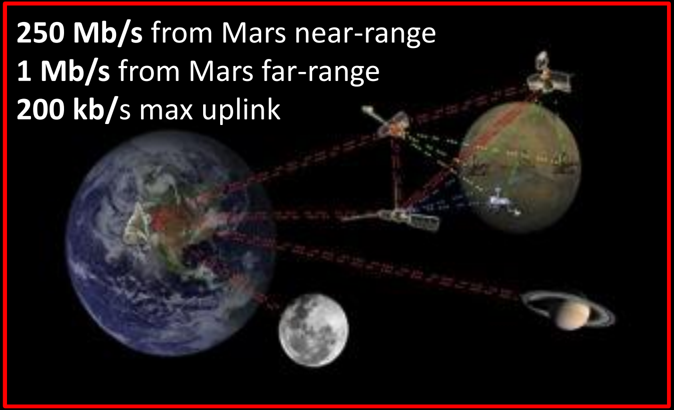
SEP Applications

Technology Investment: Optical Space Communication

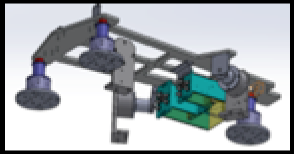
GEO to Earth Symmetric Bi-Directional Relay

- GEO Comm. Trunk Lines
- Point-to-Point Terrestrial Augment
- Highly Secure
- Difficult to Jam

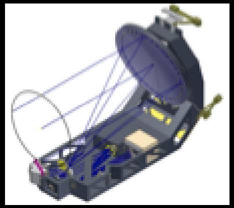
Deep Space – Mars and Jupiter Data Downlink



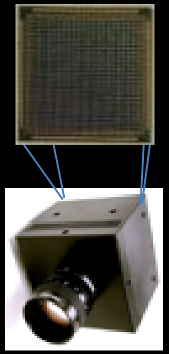
Spacecraft Disturbance Isolation



Flight Optical Transceiver



Ground & Flight Photon-Counting Detectors



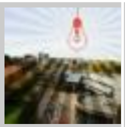
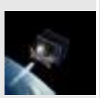
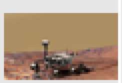
LEO to Ground & LEO Cross-Links

- Use of Integrated Photonics
- High Bandwidth Downlink of Data to Fixed Ground Terminals
- High Bandwidth Crosslinks between LEO Constellations
- LEO to GEO Links Viable
- Much Lower Mass and Power
- Highly Secure / Difficult to Jam

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 **130** U.S. universities have led (*or are STTR partners on*) more than **550** awards <u>since 2011</u>
- In addition, there are many other partnerships with other universities, NASA Centers and commercial contractors

Program	# awards	# University-led awards	Upcoming Opportunities
Space Technology Research Grants 	295	295	• Early Career Faculty • Early Stage Innovations • NASA Space Technology Research Fellowships ***Annually***
NIAC 	93	26	• NIAC Phase I • NIAC Phase II ***Annually***
Game Changing Technology Dev 	37	14	Various topics released as Appendices to SpaceTech-REDDI ***Annually***
Small Spacecraft Technology 	22	13	Smallsat Technology Partnerships – new in 2013 – annual opportunities beginning in 2015
Flight Opportunities 	117	50	Tech advancement utilizing suborbital flight opportunities – NRA to U.S. Universities, non-profits and industry are planned. ***Twice Annually***
STTR 	*192*	*181 w/ univ partners*	*Annual STTR solicitation*
Centennial Challenges 	*4 Challenges (2 university-run)*	*40 teams (9 univ-led, 1 univ-led winner)*	• *One or more challenges annually* • ***Challenge competitions** with a **procurement track** to fund **university teams** via grants*

Improving the Probability of Infusion

Ideas and Concepts

Conduct early stage workshops to generate awareness, interest and understanding of promising technologies ripe for maturation

- Focused on specific topic areas to attract participation from appropriate stakeholders
- Workshops highlight successful SBIR and STRG activities
- Audience consist of NASA Mission Directorate representatives, Principal Investigators, Program Executives, and various technical experts

Mature and Validate

Technology Infusion Plans for every mid-TRL project

- Over 25 mid-TRL projects with infusion plans
- Awareness and engagement with early-stage work; relationships and engagement with flight programs and industry
- 50% of mid-TRL projects have partnerships and/or MOU's
- Technologies embedded in customer's solicitations

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

Demonstrate and Infuse

Demonstration relevant, needed technology

- Understand and actively work non-technical barriers to infusion
- Reduce risks relevant to infusion (real and perceived)
- Mission infusion managers
- Technology Infusion Groups
- Partnering
- Customer focused
- Maintain focus on infusion throughout lifecycle
- Work at all levels

Technology Workshops

Planetary Science — **May 2014**

50 participants
2 Days at JPL
Highlighted 25 SBIR Phase II projects scheduled to complete in the next 12 months

Composite Cryotank — **March 2015**

~ 50-100 Participants
2 Days in HSV, AL
Highlights technology accomplishments and lessons learned from Composite Cryotank development

Space Physics — **March 2015**

~20 researchers highlighting various sensor and detector technologies that will complete in the next 12 months

Earth Science — **Summer 2015**

Highlighting various sensor and subsystem technologies that will complete in the next 12 months relative to Earth Science

Human Exploration — **Fall 2015**

Highlighting various systems and subsystem components that will complete in the next 12 months pertaining to Human Exploration

Recent Requests For Information

Recently closed (responses received):

- Partnerships for industry-led development of **suborbital reusable and nano orbital launch systems** (FO) (closed 20 Nov 2014)
- Public-Private partnerships on **power beaming technologies** (GCD) (closed 31 Jan 2015)
- Public-Private partnerships in **cryogenic storage & transfer technology** development and assessment (GCD) (closed 7 Feb 2015)
- Public-Private partnerships for **lightweight power & data cables** (GCD) (closed 19 Mar 2015)
- **Industry-developed tipping point technologies** (STMD) (closed 19 Mar 2015)

Currently open (awaiting responses):

- Public-Private partnership in the development and assessment of high performance **thermal protection system materials** (GCD) (closes 16 Apr 2015)

Soon to be released:

- Advanced **in-space propulsion for fast transit** (STMD)

Under consideration:

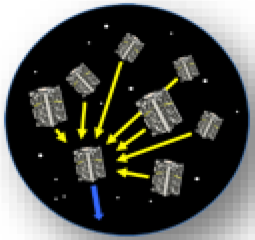
- Small cryogenic liquid rocket engine development and testing
- Optical communication technologies

Key Milestones in 2015-16

Green Propellant: demonstrates propellant formula, thrusters, and integrated propulsion system, for higher performing, safe alternative to highly toxic hydrazine. (Launch STP-2 NET 5/2016)

Deep Space Atomic New space clock improving navigational accuracy for deep space (Launch STP-2 NET 5/2016)

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



Small Spacecraft Technology: Four small spacecraft demonstration missions:

- EDSN: Small spacecraft swarm operating as a network for distributed science observations.
- 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

Delivers Low Density Supersonic Decelerators

- Conducts second supersonic flight demonstrations of a ring-sail parachute and a supersonic inflatable aerodynamic decelerator.

Space Technology Delivers

Space Technology is delivering new technologies and capabilities

- Delivered new capability and created new knowledge as promised with LDSD flight tests, Composite Cryotank Test Data, Solar Arrays, and Green Propellant
- Major deliverables, demos and tests this spring and next year for Small Spacecraft, Green Propellant, Deep Space Atomic Clock, and Low Density Supersonic Decelerators
- Preparing for large investment in solar electric propulsion

FY 2016 Budget Request maintains balance within existing resources, retains customer-driven focus on needed technology with emphasis on partnering with industry

- Solicits the U.S. aerospace community for technologies at the "tipping point"
- Continues development of a high-powered solar electric propulsion capability to meet demands by U.S. aerospace industry, and for future NASA exploration missions
- 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
- Initiates development of foundational technologies to support future outer planets icy moons missions
- Support SLS and Orion with advance composite structures, thermal management, and thermal protection systems
- Continues engagement with a broad swath of U.S. universities through graduate student research fellowships, early-career faculty awards, Cultivates small businesses as home for SBIR/STTR

BACK UP SLIDES

Snapshot of Space Technology Partners

NASA

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

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 Phase I of a High Performance Space Computing for a low power multi-core processor increasing performance by 100 fold.
- Working with the **USAF Operationally Responsive Space Office (ORS)** for launch accommodations for the Edison Demonstration of Smallsat Networks (EDSN) mission
- 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 ***45 activities*** with ***43 other government agencies***, and ***10 activities*** with ***14 international organizations***. STMD is sharing rides for ***13 activities***.