National Aeronautics and
Space Administration

Space Technology Mission Directorate Program and Budget Update

Joint Meeting of the
Aeronautics and Space Engineer Board,
Space Studies Board

Presented by:
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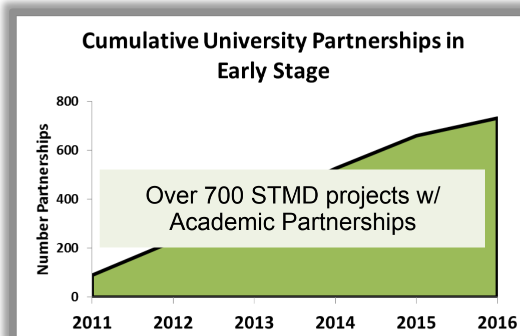
STMD
Deputy Associate Administrator for Programs

April 26, 2016

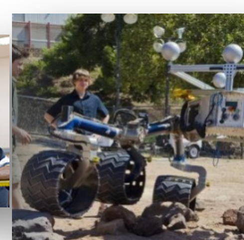
Space Technology…
…. an Investment for the Future

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

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

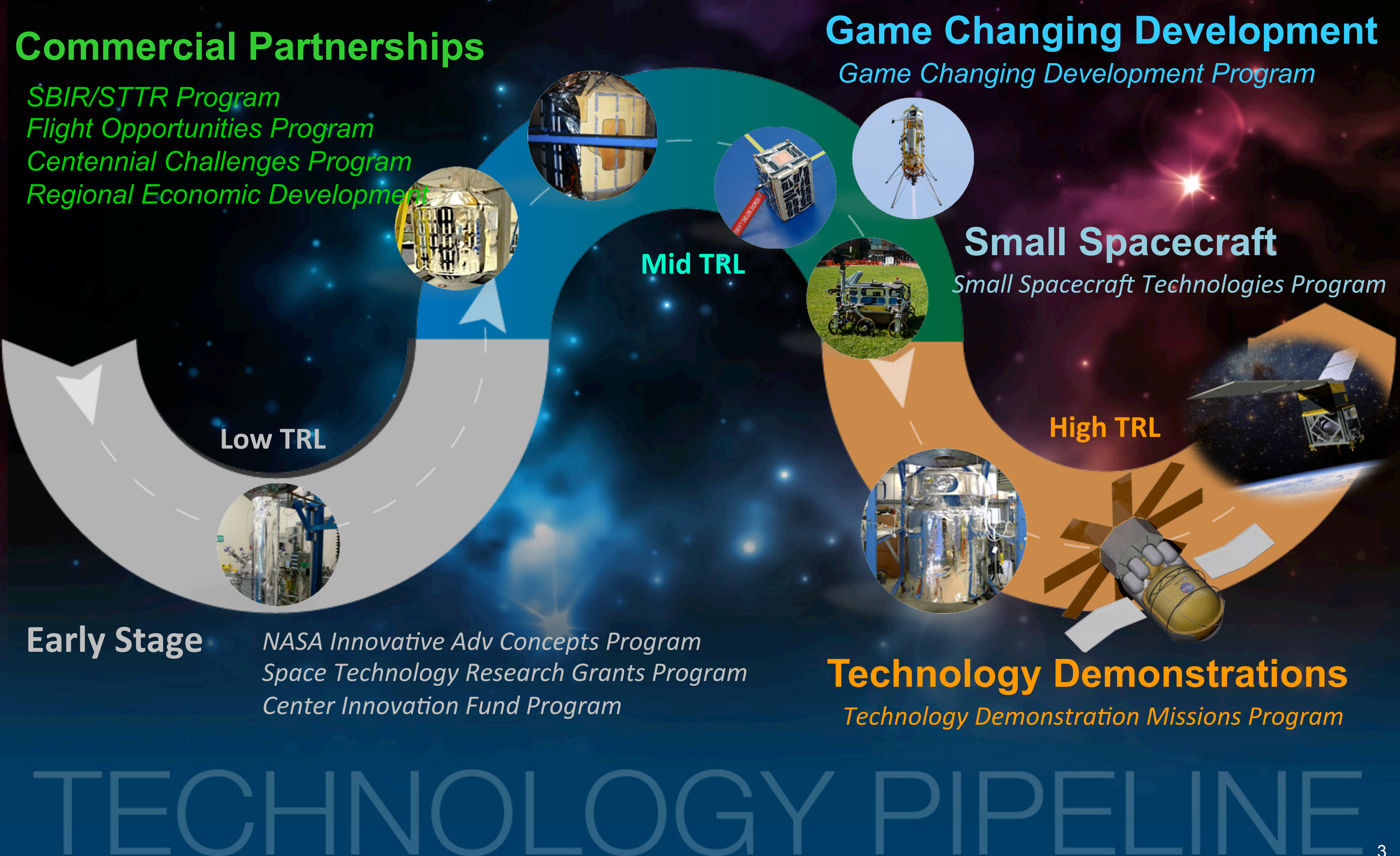


Value to NASA **Value to the Nation**



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

Space Technology Mission Directorate



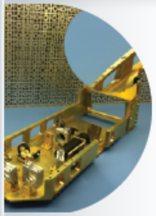
Enabling Future Exploration Missions

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

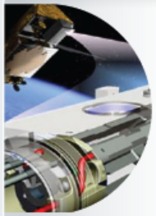
Extends our reach by helping us remotely explore planetary bodies, manage in-space assets and support in-space operations by enhancing the efficacy of our operations.

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.

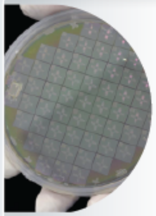
External Application: Industrial Materials and Composites for large structures (rockets, aircraft)



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

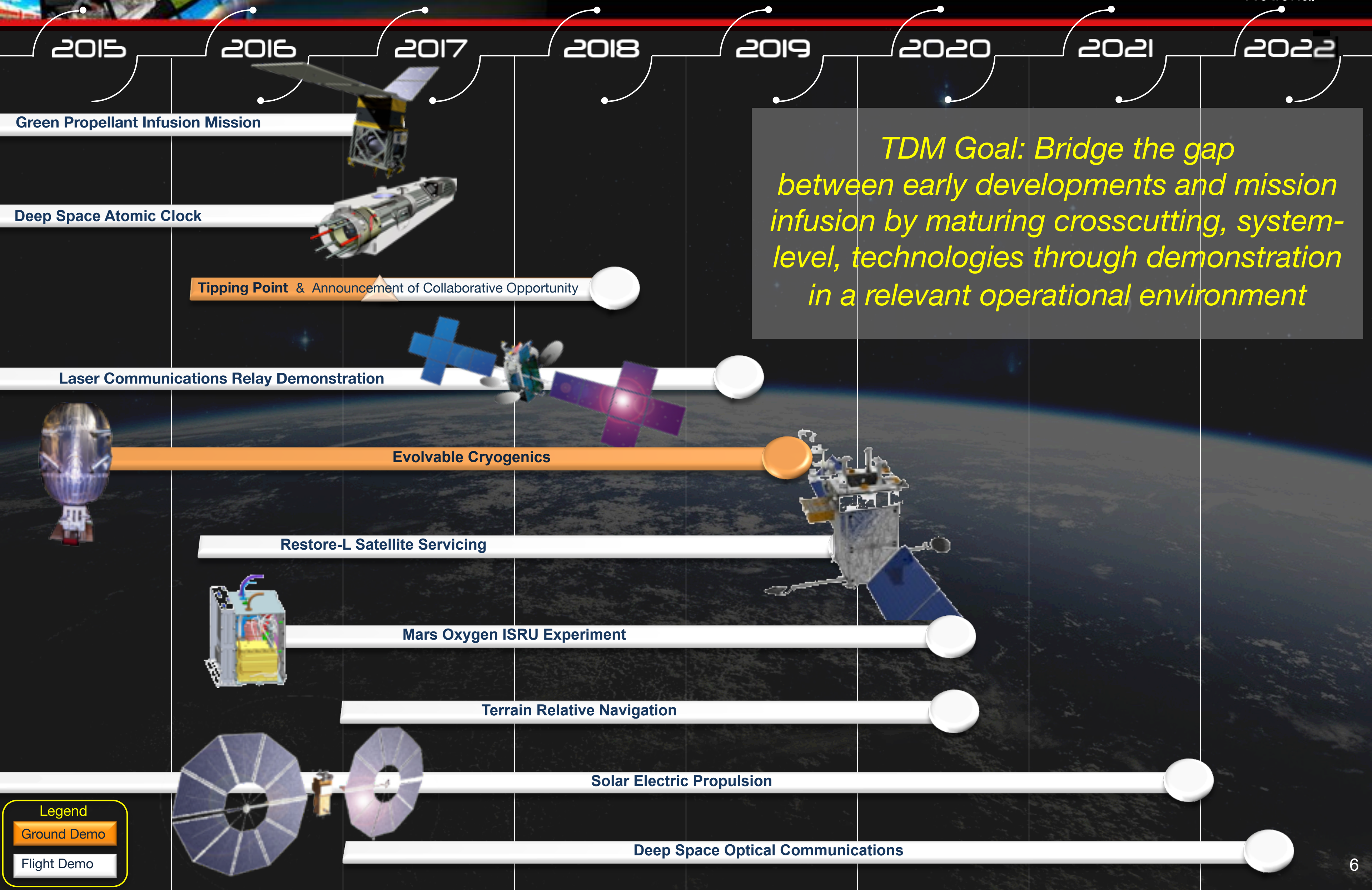
FY 2017 Budget Request

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

TDM Portfolio

Notional

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



Restore-L Satellite Servicing

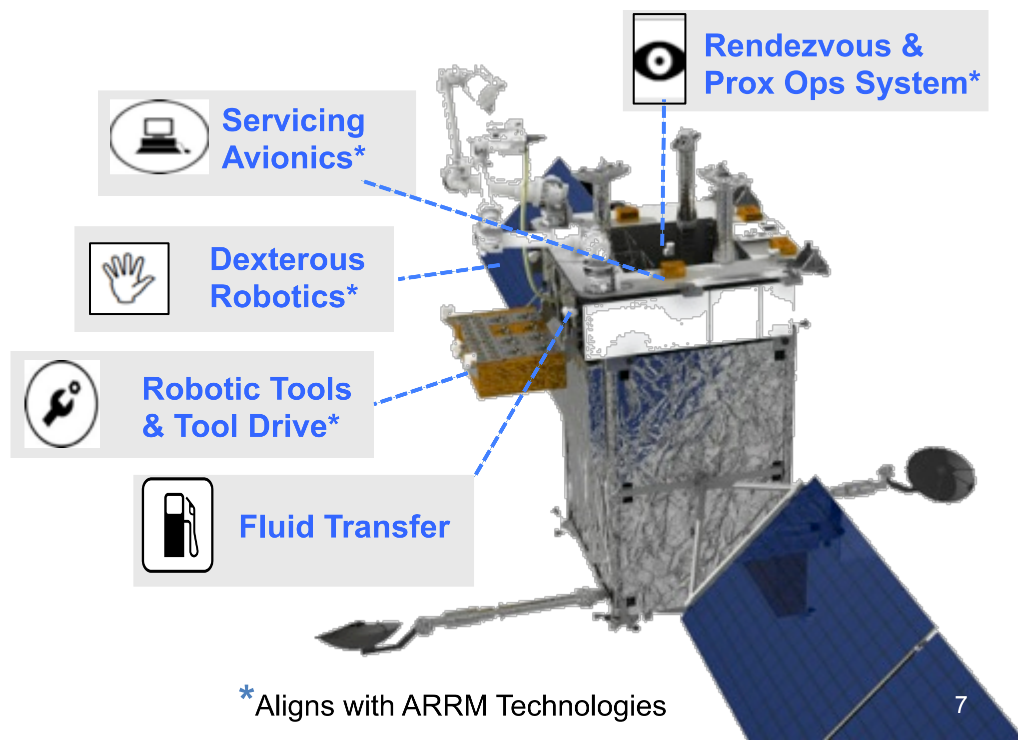
NASA's Restore-L is a groundbreaking mission that uses **robotic technology** to **rendezvous** with and **refuel** a government-owned satellite in low Earth orbit, autonomously and via remote control.

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

- autonomous rendezvous capability with a satellite not designed for servicing
- robotic capture and servicing
- non-cooperative refueling

Preliminary schedule:

- FY 2016: MCR and KDP-A
- FY 2017: SRR/MDR and KDP-B
- FY 2019: LRD (notional)



*Aligns with ARRM Technologies

Solar Electric Propulsion

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

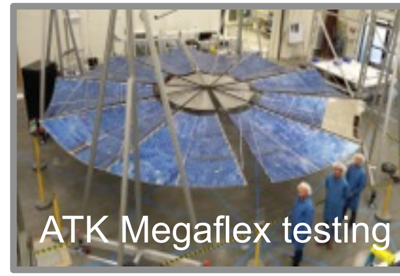
- Reduced mass and more efficient packaging of solar arrays for more capable and affordable commercial satellites (2x lighter and 4 times less stowed volume for amount of electricity produced than commercially available arrays)
- High-power Hall thrusters with magnetic shielding for all-electric commercial satellites and other applications (2.5x power level of highest powered electric thrusters in use; withstands 4x more radiation exposure)
- SEP technology demonstration is planned for the Asteroid Redirect Robotic Mission (ARRM)

Electric Thrusters and Power Processing Unit (PPU)

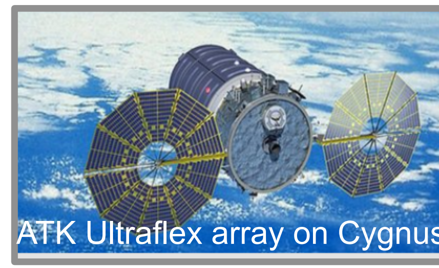
- Demonstrated full performance compatibility between thruster and PPUs
- Electric Propulsion System Procurement RFP released in July 2015
- ***NASA selected Aerojet Rocketdyne to design and develop an advanced electric propulsion system, April 2016***

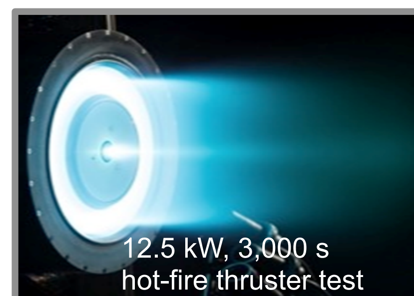
Infusion Successes:

- Space Systems Loral signed agreement with DSS for STMD developed ROSA solar arrays on future commercial communication satellites (CDR completed; targeting GEO satellites launching in 2018)
- Orbital ATK flew Ultraflex array on Cyngus cargo spacecraft in December 2015 that employed STMD-sponsored technology advancements

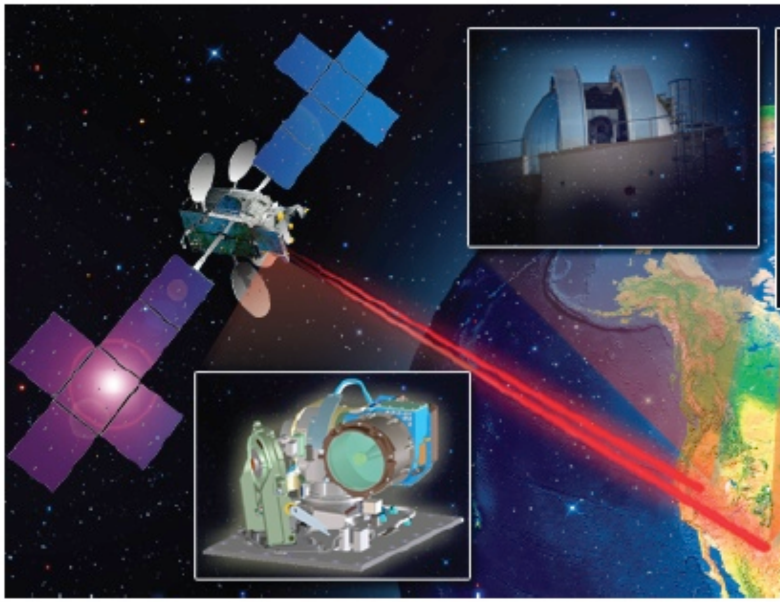

ATK Megaflex testing

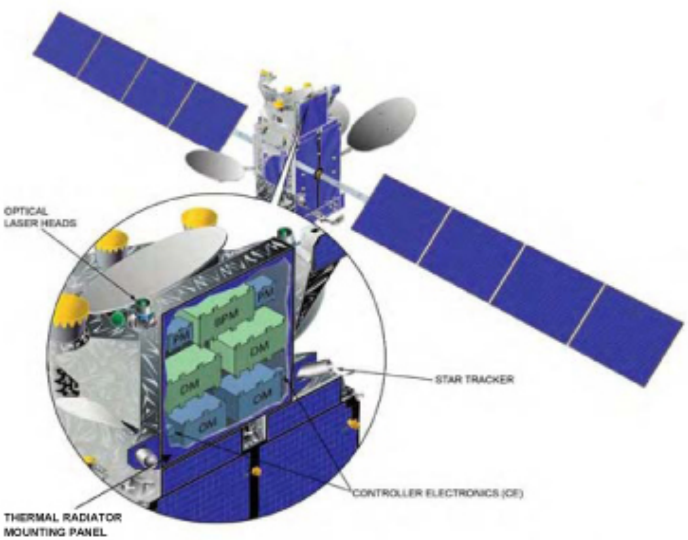

DSS ROSA testing


ATK Ultraflex array on Cygnus


12.5 kW, 3,000 s
hot-fire thruster test

Laser Communication Relay Demonstration





<u>Demo Description (STMD/HEOMD)</u>:

- Two-year flight demonstration to advance optical communications technology toward infusion into operational systems while growing the capabilities of industry (FY2019 Launch Readiness Date)

<u>Objectives</u>:

- 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

<u>Anticipated Benefits:</u>

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

<u>Anticipated Mission Use:</u>

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

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)

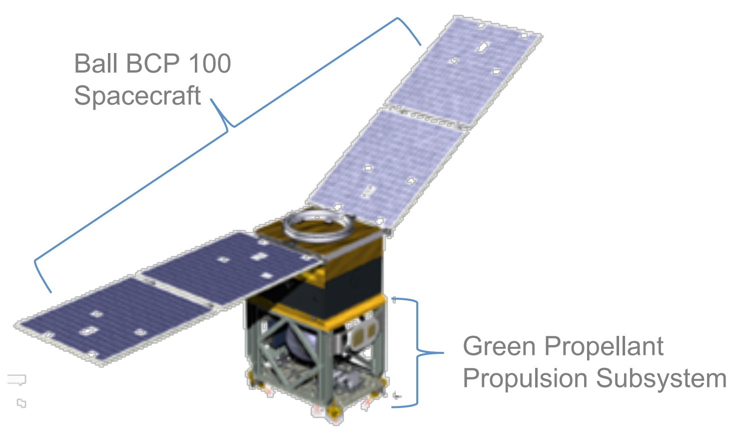
DSAC is a NASA JPL-led effort that will validate a miniaturized, ultra-precise mercury-ion atomic clock that is 100 times more stable than today's best navigation clocks.

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



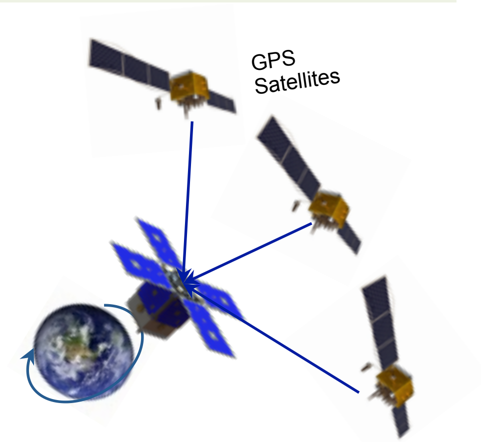
Mission Launch

Launch Provider
USAF STP-2

Rocket Vendor
SpaceX Falcon Heavy

Launch Site
KSC; Launch Complex-39A

Launch Date
1st Quarter – CY 2017

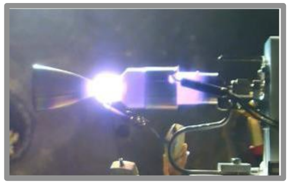


STMD Public-Private Partnerships

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**

Game Changing Development Program*

AEDL

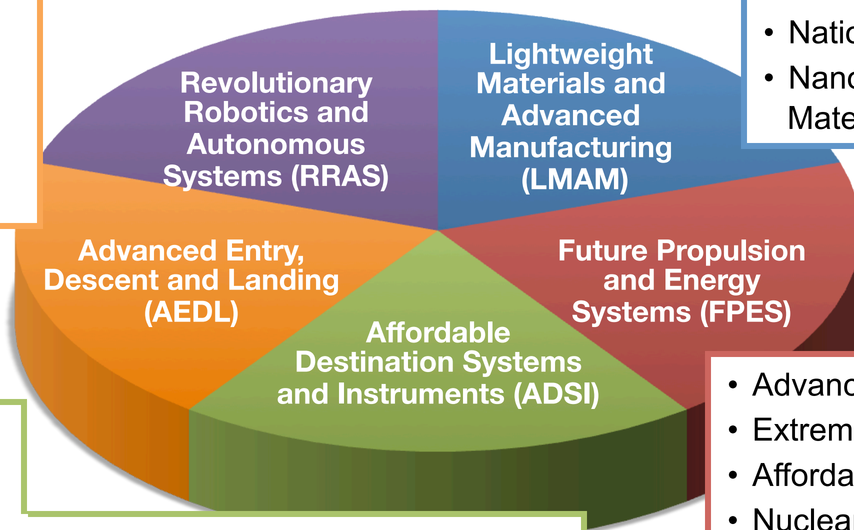
- Entry Systems Modeling
- Mars Entry Descent and Landing Instrument (MEDLI-2)
- Propulsive Descent Technology
- Heatshield for Extreme Entry Environment TPS (HEEET)
- Conformal Ablative TPS
- Hypersonic Inflatable Aerodynamic Decelerator (HIAD)
- Adaptable, Deployable Entry Placement Technology (ADEPT)

RRAS

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

LMAM

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



ADSI

- High Performance Spaceflight Computing (HPSC)
- Ultra-Low Temperature Batteries
- Ultra-Low Temperature Radiation Hard Electronics
- Station Explorer for X-Ray Timing and Navigation Technology (SEXTANT)
- Landing Guidance Navigation and Control
- Icy Body Mobility
- Thick Gamma Cosmic Ray Shield
- SpaceCraft Oxygen Recovery
- High Performance EVA Gloves
- TPS Phase Change Material
- High-Capacity Cryocooler
- Synthetic Biological Membrane

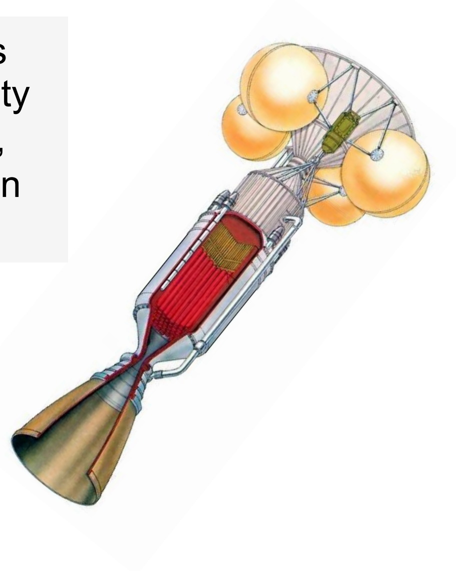
FPES

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

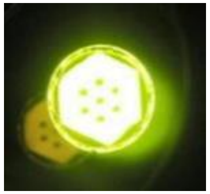
* Not a complete project list

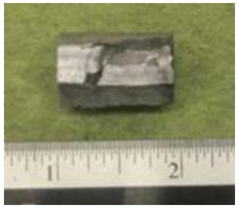
Nuclear Thermal Propulsion (NTP)

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

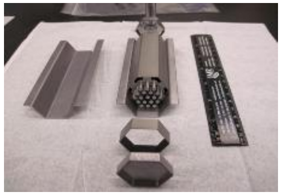


Path to fielding an NTP *system that is* ***within NASA's resources*** *could depend on a shift from highly enriched uranium to* ***low enriched uranium (LEU) fuel elements***





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



HIP can assembly for pure W samples prior to welding

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

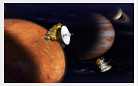
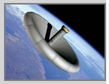
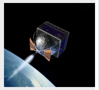
NTP Development Challenges Being Addressed

- 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

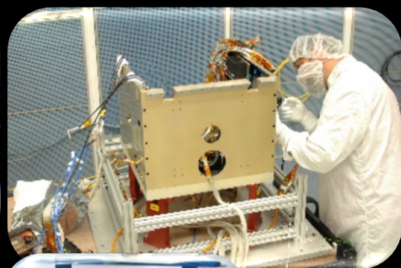
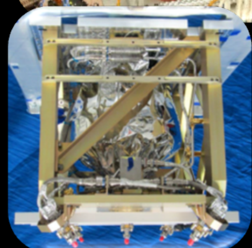
Partnering with Universities to Solve the Nation's Challenges

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

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

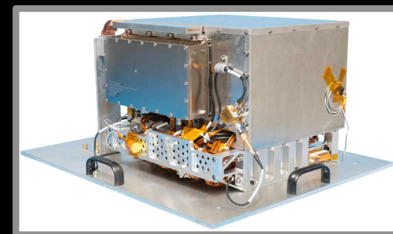
Program	# awards	# University-led awards	Upcoming Opportunities
Space Technology Research Grants 	373	373	• Early Career Faculty • Early Stage Innovations • NASA Space Technology Research Fellowships ***Annually***
NIAC 	117	38	• NIAC Phase I • NIAC Phase II ***Annually***
Game Changing Technology Dev 	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*

Key Milestones in 2016-17

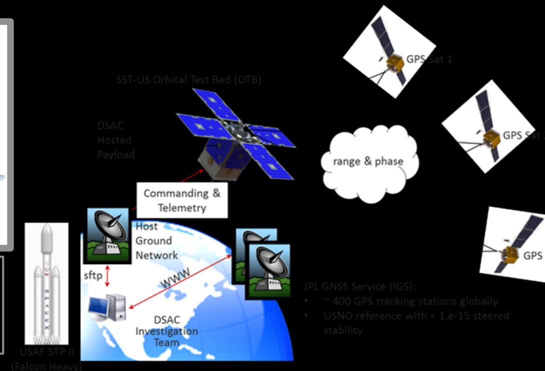




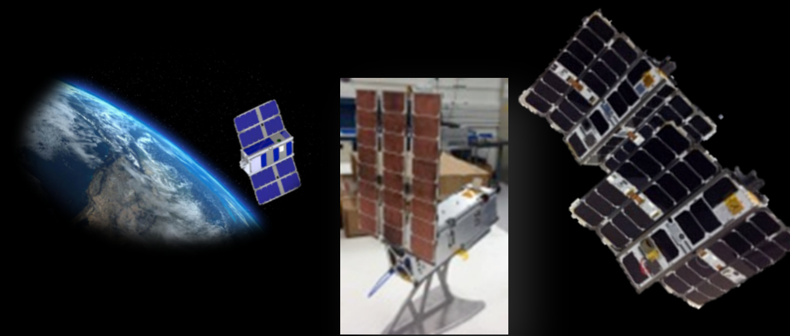
Green Propellant Infusion Mission

Solar Electric Propulsion



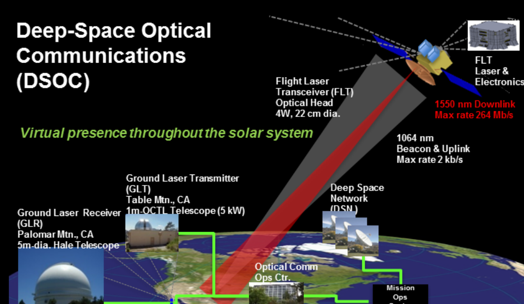
Deep Space Atomic Clock

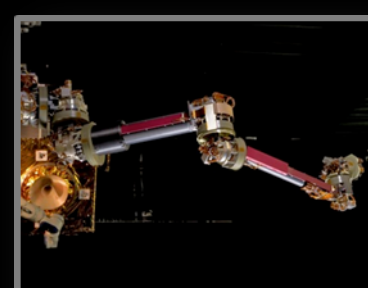
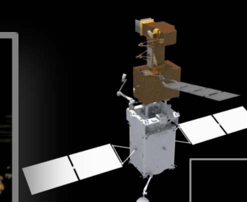




Small Spacecraft Technology

Laser Communication Relay Demonstration



Restore L Satellite Servicing

National Aeronautics and
Space Administration

Technology Drives Exploration