National Aeronautics and
Space Administration

# Space Technology Mission Directorate

## Technology Demonstration Missions Program Update for the NAC Technology, Innovation, and Engineering Committee

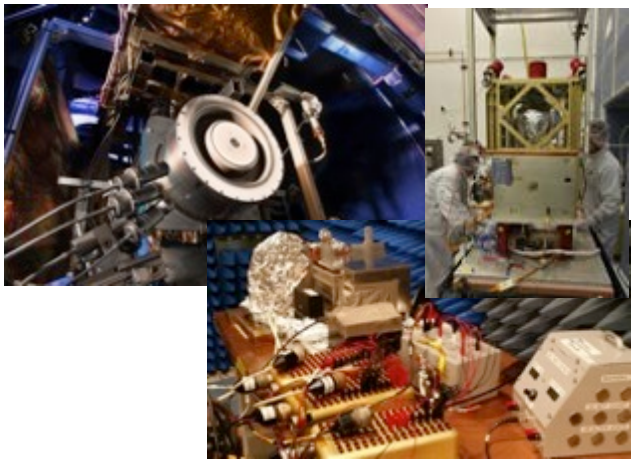
**Presented by:**
**Trudy Kortes**
**TDM Program Executive, STMD**

**March 29, 2016**

# Technology Demonstration Missions Program Overview

**Goal:**

***Bridge the gap*** *between early developments and mission infusion by maturing* ***crosscutting, system-level, technologies*** *through demonstration in a* ***relevant operational environment****. Demonstrations can be ground-based, atmospheric, or space-flight. (TRL~5-7)*



## FY 2015 Highlights

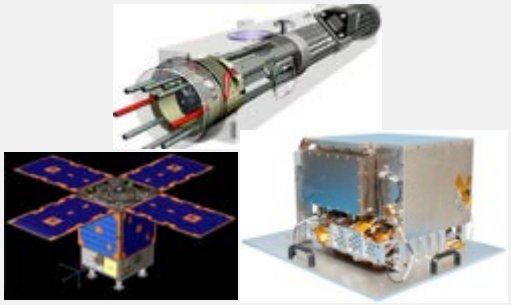
- **Green Propellant Infusion Mission:** Successfully fabricated five 1N thrusters and fully integrated and tested Green Propellant Propulsion Subsystem.
- **Deep Space Atomic Clock:** Payload integrated and began environmental testing, overcame significant technical challenge and keeping delivery schedule 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 and conduct delta PDR and KDP-C.
- 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.

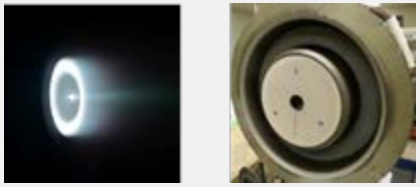
# FY 2015-16
# TDM Major Accomplishments

Solar Array Development and Testing

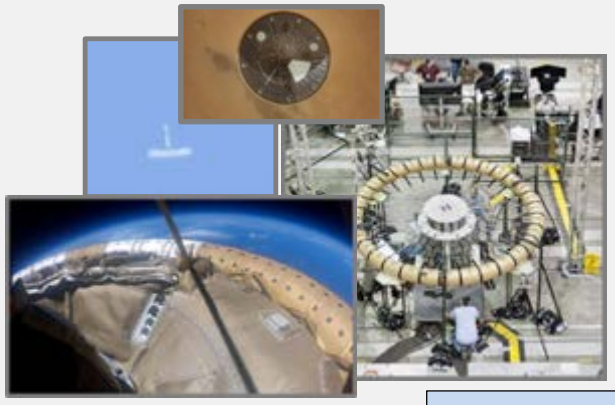


Deep Space Atomic Clock readies for flight test

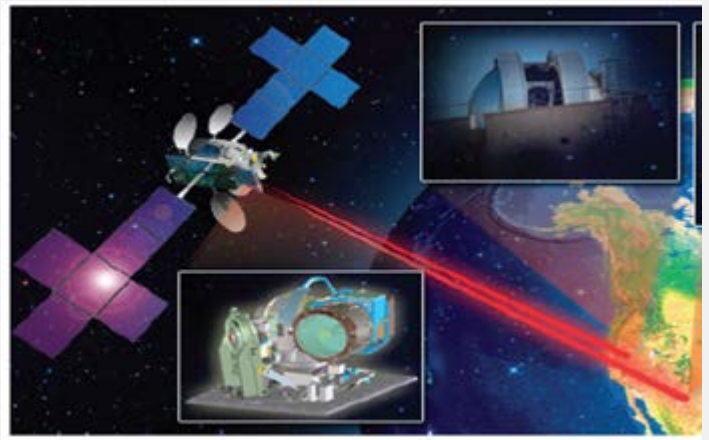
Green Propellant Infusion Mission integration and prepped for launch



Advanced Thrusters and Successful testing a new 12.5k Hall Thruster



Entry, Descent and Landing Technology



Laser Communication component development and systems integration

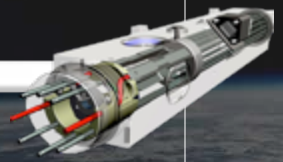
# TDM Portfolio

Was

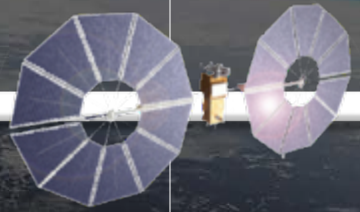
2014 2015 2016 2017 2018 2019 2020 2021

Low Density Supersonic Decelerator

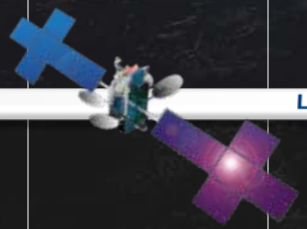
Green Propellant Infusion Mission



Deep Space Atomic Clock



Solar Electric Propulsion



Laser Communication Relay Demonstration

Evolvable Cryogenics

Composites for Exploration Upper Stage

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

Legend

Ground Demo

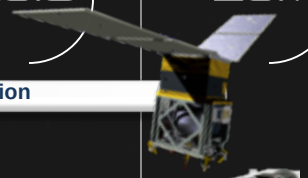
Flight Demo

# TDM Portfolio

Notional

2015 2016 2017 2018 2019 2020 2021 2022

Green Propellant Infusion Mission

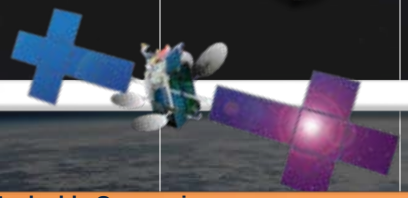


Deep Space Atomic Clock

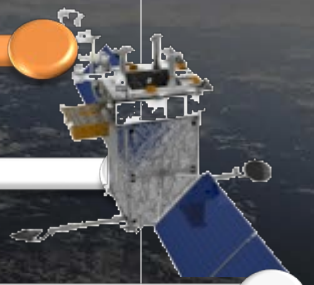
Tipping Point & Announcement of Collaborative Opportunity

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

Laser Communications Relay Demonstration



Evolvable Cryogenics

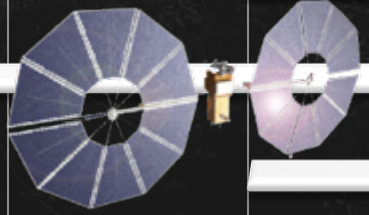


Restore-L Satellite Servicing

Mars Oxygen ISRU Experiment

Terrain Relative Navigation

Solar Electric Propulsion



Deep Space Optical Communications

Legend

Ground Demo

Flight Demo

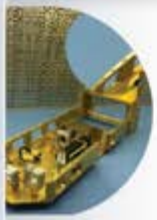
# Technology Drives Exploration
# TDM contributions

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

## High Performance 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 Optical 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

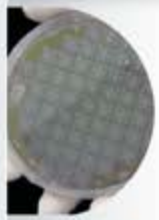
Targets large decreases in structural mass for launch vehicles and spacecraft materials using nanotech, composites and in space manufacturing capabilities.

*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

SEP H,S,I
GPIM I,O
eCryo H
LCRD H,I,O
DSOC H,S
MOXIE H,S
TRN S
LDSD H,S
IRMA I
Restore-L H,I,O
CEUS S
DSAC S,I

**H-Partnership with HEO**
**S-Partnership with SMD**
**I-Partnership with Industry**
**O-Partnership with OGA**

# 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)

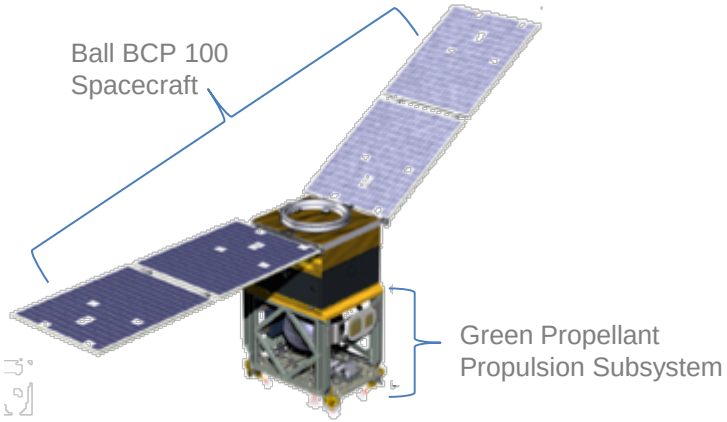
DSAC is a NASA JPL-led effort that will validate a miniaturized, ultra-precise mercury-ion atomic clock that is 100 times more stable than today's best navigation clocks.

### 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



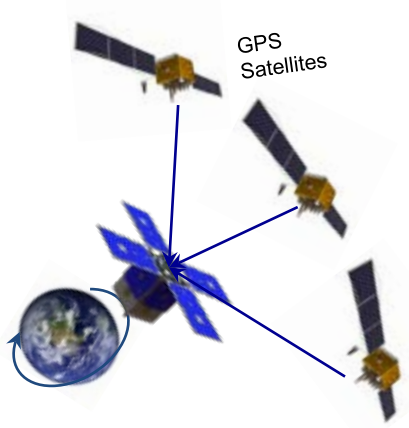

## Mission Launch

**Launch Provider**
USAF STP-2

**Rocket Vendor**
SpaceX Falcon Heavy

**Launch Site**
KSC; Launch Complex-39A

**Launch Date**
NET January 2017



# Green Propellant Thruster Technology Qualification

New in STMD

Announcement of Collaborative Opportunity awarded to Aerojet Rocketdyne in Partnership with GRC and GSFC

This project will **revise the GR-1 thuster design** to implement improvements (injector design, catalyst bed diameter optimization) from issues uncovered during GPIM.

This thuster will be the **first in a new non-toxic propellant propulsion product line** for use by NASA, DOD, and others in space propulsion applications.

# In-Space Robotic Manufacturing & Assembly

New in STMD

In November 2015 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 a space environment test

# Restore-L Satellite Servicing

New in STMD

NASA

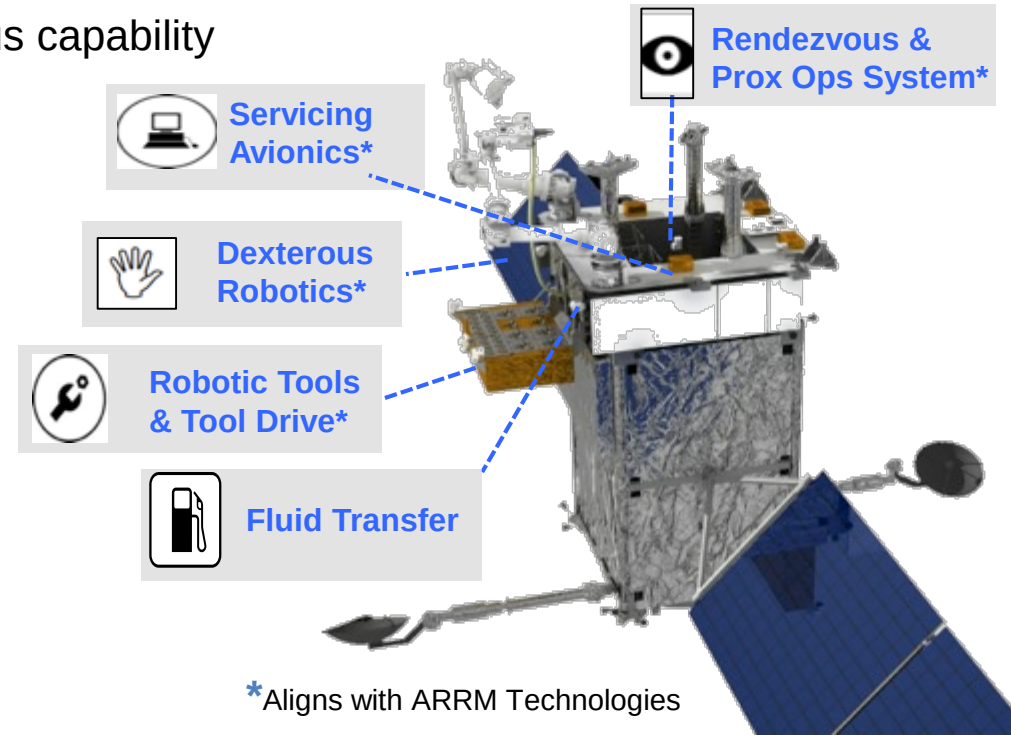
NASA's Restore-L is a groundbreaking mission that uses **robotic technology** to **rendezvous** with and **refuel** a government-owned satellite in low Earth orbit, autonomously and via remote control.

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

Preliminary schedule:

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

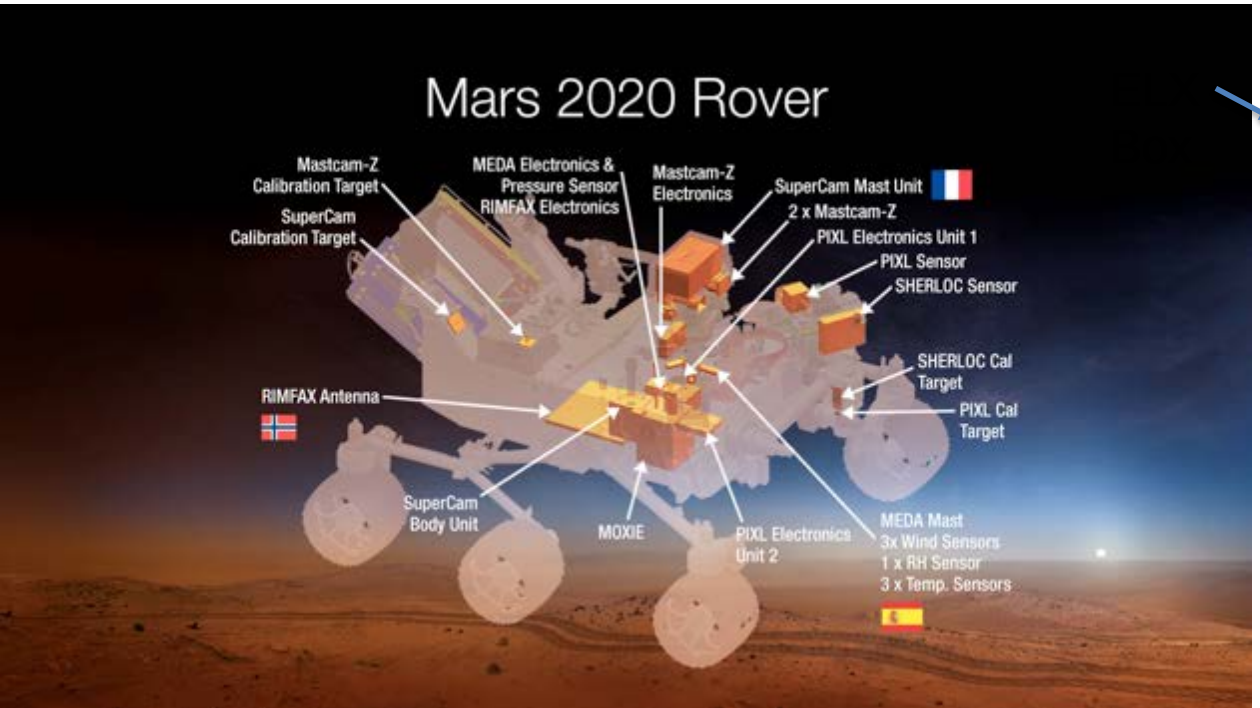


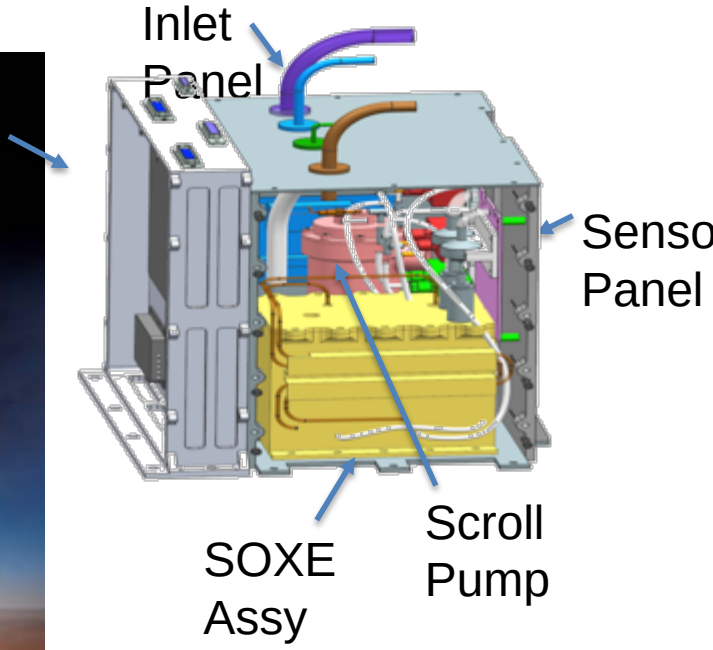

*Aligns with ARRM Technologies

# Mars Oxygen ISRU Experiment

New in TDM

- MOXIE is the development of an instrument that converts CO2 to O2 with a target 99.6% purity, with a minimum operational life and O2 production rate
- Supports Mars 2020 via partnership with SMD and HEO to design, build, assemble, test, and deliver a flight unit
- Rover platform to Martian surface for 1 year with a variety of instruments
- Project management at JPL and principal investigation at MIT



# Terrain Relative Navigation

New in STMD

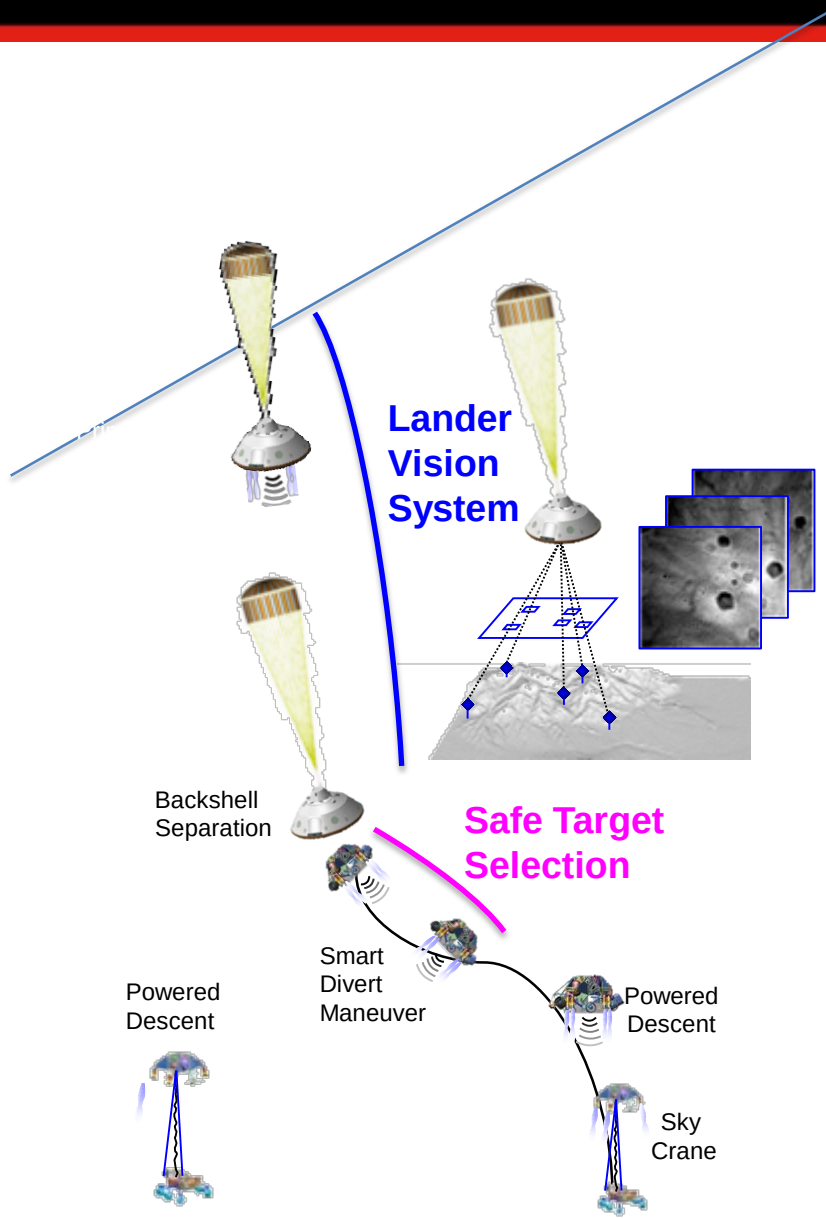
TRN provides the capability to avoid large scale landing hazards during entry, descent, and landing operations

- Enables safe access to scientifically compelling landing sites
- Provides capability to land near pre-deployed assets
- Reduces post-landing surface drive distances
- All current human and robotic precursor mission architectures for Mars exploration require TRN; baselined on Mars 2020

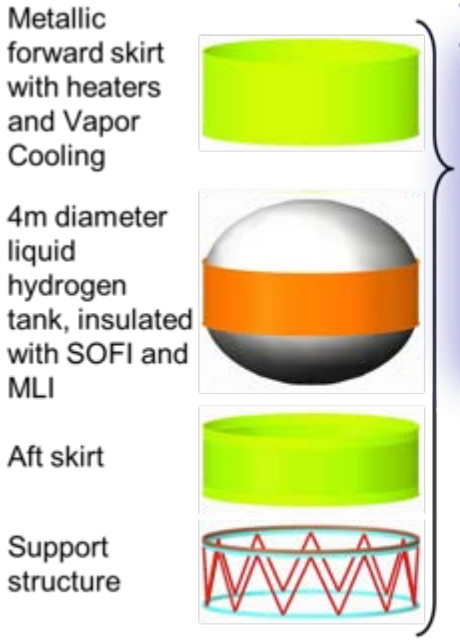
STMD is funding technology development of

- Lander Vision System
- Safe Target Divert Selection logic
- Implementation on Mars 2020
- This includes both hardware and software development and field test efforts.

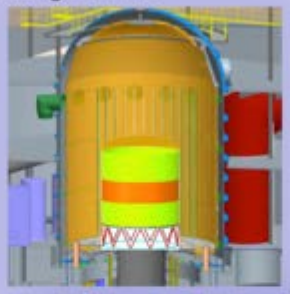
Preliminary design is complete and moving in to detail design phase



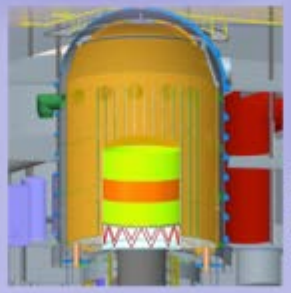
# Evolvable Cryogenics




Thermal performance testing in B-2:



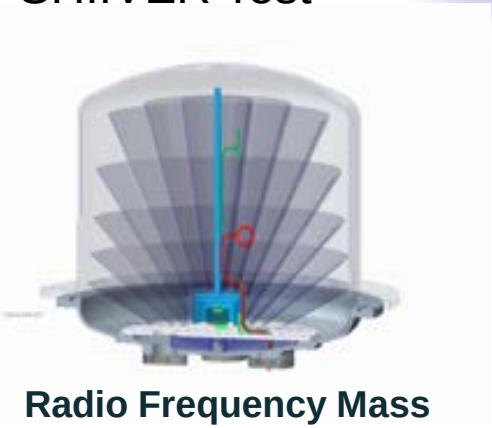
Acoustic vibration test at RATF:



Repeat thermal performance testing in B-2

**Integrated Vehicle Fluid (IVF) System Assessment for SLS**

SHIIVER Test



**Radio Frequency Mass Gauge (RFMG)**

eCryo develops, integrates and validates cryogenic fluid management (CFM) technologies at a scale relevant to and meeting the mission needs for SLS Stages and Exploration Systems

- Testing ranges from components to entire systems
- Ground-based project leveraging CFM competencies and facilities at GRC and MSFC

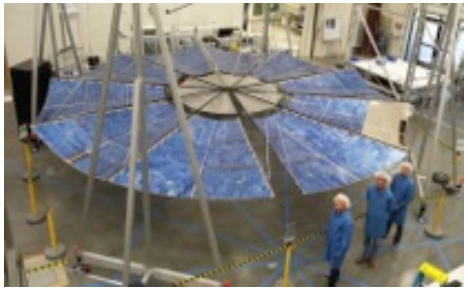
# Solar Electric Propulsion

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

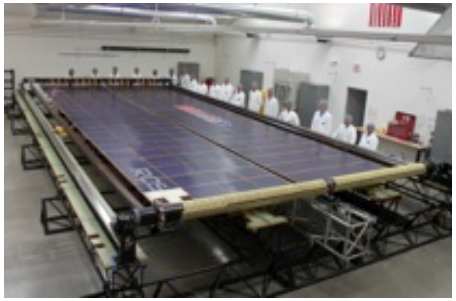
- Reduced mass and more efficient packaging of solar arrays for more capable and affordable commercial satellites
- High-power Hall thrusters with magnetic shielding for all-electric commercial satellites and other applications

**Infusion Successes:**

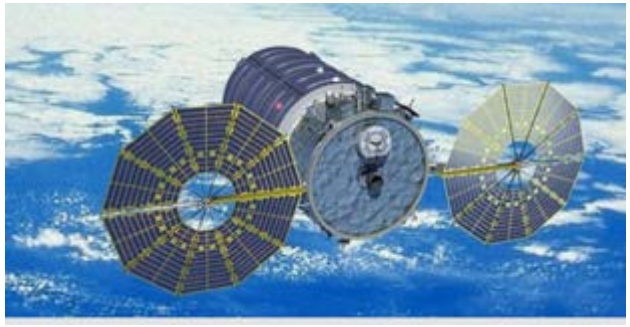
- Space Systems Loral signed agreement with DSS for STMD developed ROSA solar arrays on future commercial communication satellites
- Orbital ATK flew Ultraflex array on Cyngus cargo spacecraft in December 2015 that employed STMD-sponsored technology advancements



ATK Megaflex testing



DSS ROSA testing

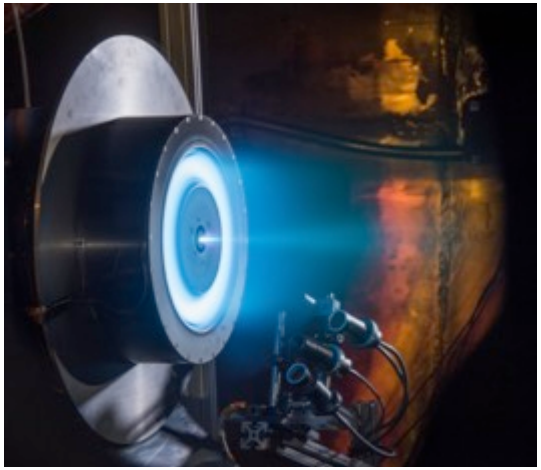


ATK Ultraflex array on Cygnus

# Solar Electric Propulsion Thrusters

## Electric Thrusters and Power Processing Unit (PPU)

Demonstrated full performance compatibility between thruster and PPUs



Hall Effect Rocket with Magnetic Shielding Technology Development thruster with radiator

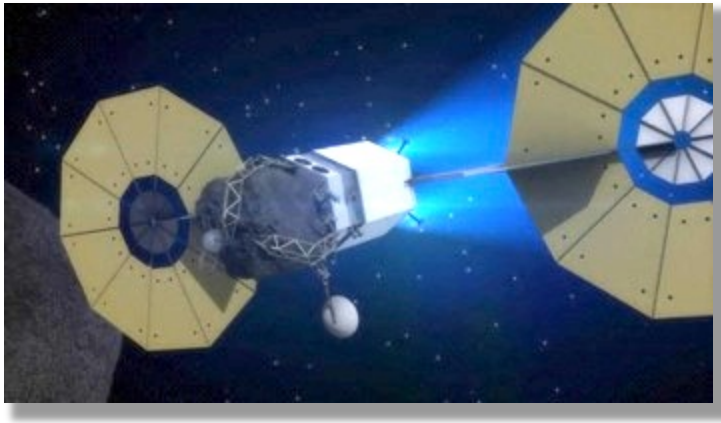
12.5 kW, 3,000 s hot-fire thruster test in GRC Vacuum Facility-5

**Electric Propulsion System Procurement**

- RFP released in July 2015, final proposals received and under evaluation
- Anticipated award in late Spring 2016

| FY15 | FY16 | FY17 | FY18 | FY19 |
|---|---|---|---|---|
| RFP Issued – July<br>Proposals Due - Sept | Contract Award - May<br>EDU Design Begins | EDU Fabrication & Testing | Flight Unit Fabrication & Testing | Flight Units Delivered |

# Solar Electric Propulsion Flight Demonstration



SEP technology demonstration is planned for the Asteroid Redirect Robotic Mission (ARRM)

ARRM Acquisition Plan:
Spacecraft – including solar arrays and power system will be procured from industry
Electric Propulsion strings (thruster, power processing unit, and propellant feed system) will be furnished by NASA through co-development with industry

STMD-funded SEP team:

- Managing procurement of electric propulsion string contract
- Continuing in-house engineering and preparation for co-development with two thruster test development units (TDU 1 & 2)
- Supporting ARRM Team extensively in propulsion and power engineering, vehicle systems engineering, requirements definition, and mission flight design

# Optical Communication for Deep Space

## Laser Communication Relay Demonstration

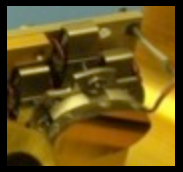
| FY15 | FY16 | FY17 | FY18 | FY19 |
|---|---|---|---|---|
| Engineering Model Assembly & Test & Flight Units Fabrication | Flight Units Assembly & Test | Complete Flight Unit Assembly & Test | Flight Payload Integration & Test | Mission Integration & Test & Hosted Spacecraft Notional Launch Readiness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

LCRD Optical Lab @ Goddard

Controller Electronics (CE)
Engineering Development Unit (EDU)

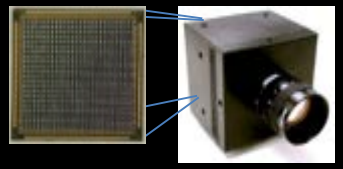
Ground Modem

| 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

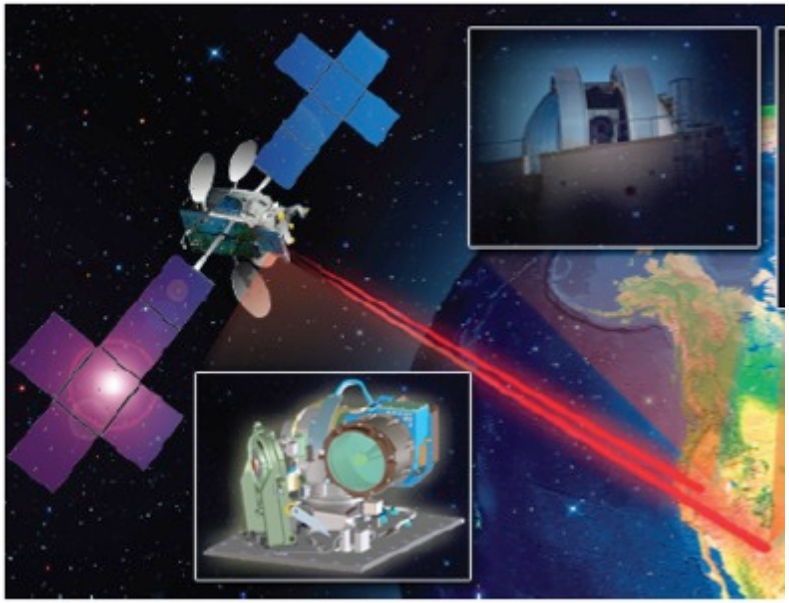
Laser Transmitter



Photon-Counting Camera

## Deep Space Optical Communication

# 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:

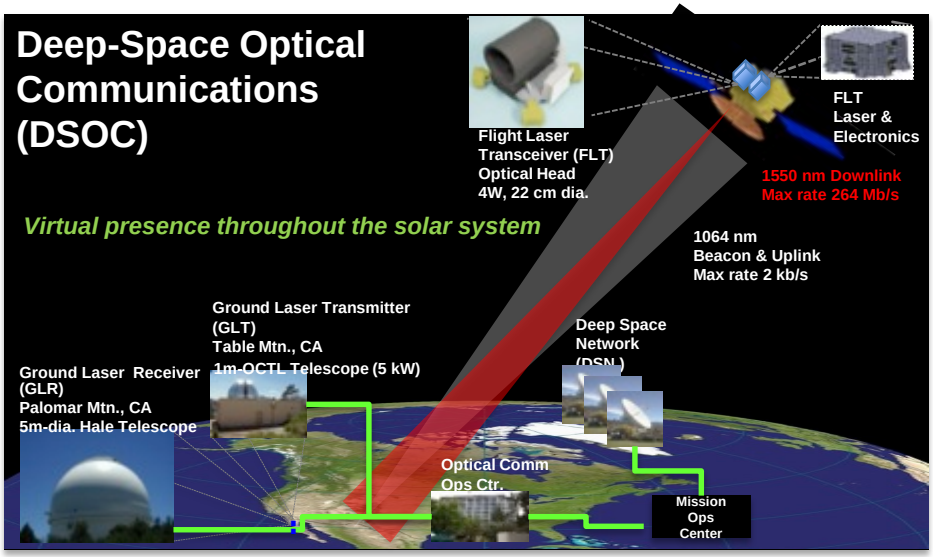
- A reliable, capable, cost effective optical comm technology for infusion into future operational systems

## 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 Communication

New in TDM




## 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

**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**

## 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

# TDM Infusion Successes


1N AR Thrusters

## 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

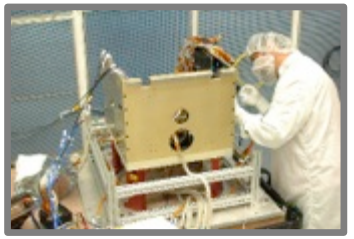
- A revolutionary deep space optical communication system has been developed under GCD and will be transitioned to TDM in FY17. DSOC technology has been offered for demonstration on **Discovery-class missions** and was included in four of the five proposals recently selected by SMD for further study.

## 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.

# Upcoming TDM Milestones in 2016-17

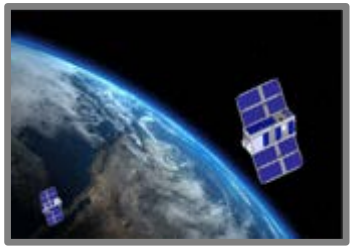
Demonstrate **Green Propellant** formula, thrusters, and integrated propulsion system, for higher performing, safe alternative to highly toxic hydrazine. (Launch STP-2 NET Jan. 2017)



Demonstrate **Atomic Clock,** improving navigational accuracy for deep space (Launch STP-2 NET Jan. 2017)

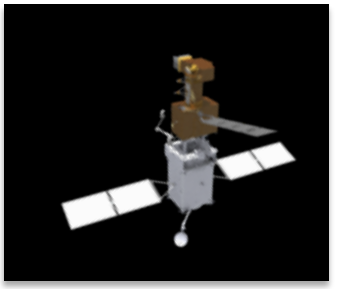
**Laser Communications Relay Demonstration** develops and assembles flight unit and conducts integrated testing to support late CY 2019 launch.

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



Continue **eCryo** on testing and demo paths that will lead to obtaining valuable CFM storage, transfer and gauging data.

**Restore-L** begins mission formulation to advance satellite servicing technologies, completing MCR & SRR in 2016 to support 2019 launch.



Initiate **Deep Space Optical Communication** demonstration for potential demo on Discovery mission.

**IRMA, MOXIE**, and **TRN** Officially begin as technology demonstration projects.