National Aeronautics and
Space Administration

Space Technology Mission Directorate

NRC ASEB

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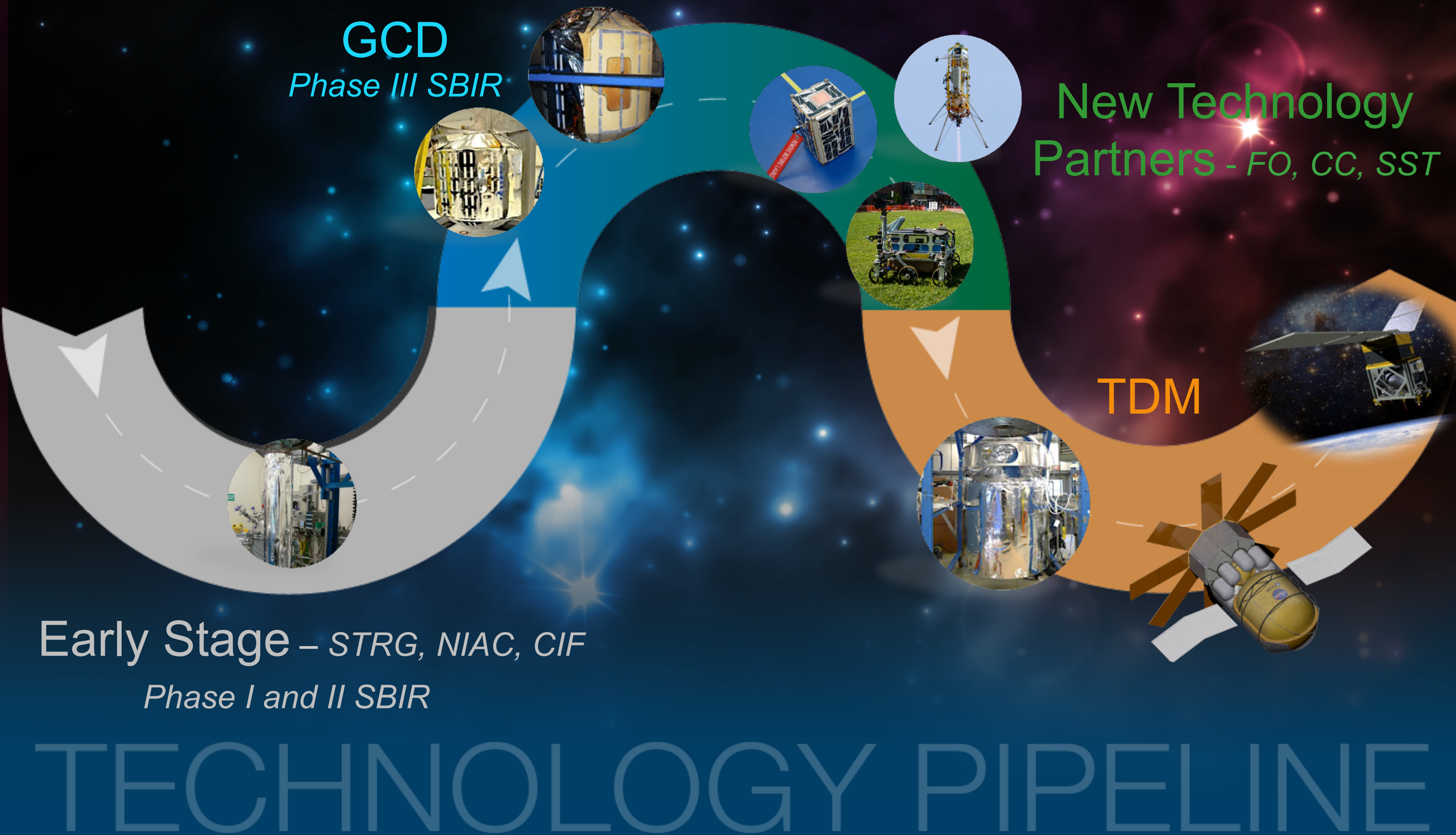
October 2014

www.nasa.gov/spacetech

GCD Enables the Space Technology Pipeline



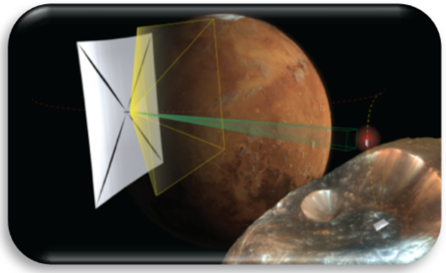
STMD Investment Themes

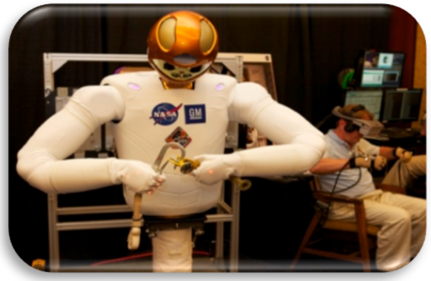
- **Alignment with NASA Mission Needs**
  - HEOMD near term and long term priorities
  - SMD technology development partnerships
  - ARMD investments
- **Support of Commercial Space Technology Needs**
  - Cross-cutting technologies significantly beneficial to industry
  - Potential for public / private partnerships
- **Promoting Early Stage Technologies and Innovation**
  - Strengthening NASA Relationship with Academia
  - Leveraging Small Business and NASA Center Innovation
- **New Space Technology Partners and Businesses**
  - Challenges and new business partnerships
  - Partnerships with other government agencies

Guiding Principles of the Space Technology Programs

Space Technology Programs

- **Adheres to a Stakeholder Based Investment Strategy:** NASA Strategic Plan, NASA Space Technology Roadmaps / NRC Report
- **Invests in a Comprehensive Portfolio:** Covers low to high TRL, student fellowships, grants, prize competitions, prototype developments, and technology demonstrations
- **Advances Transformative and Crosscutting Technologies:** Enabling or broadly applicable technologies with direct infusion into future missions
- **Selects Using Merit Based Competition:** Research, innovation and technology maturation, open to academia, industry, NASA centers and OGAs
- **Executes with Structured Projects:** Clear start and end dates, defined budgets and schedules, established milestones, and project level authority and accountability.
- **Infuses Rapidly or Fails Fast:** Rapid cadence of technology maturation and infusion, informed risk tolerance to implement quickly – or fail and terminate
- **Places NASA at technology's forefront – refreshes Agency's workforce:** Results in new inventions, enables new capabilities and creates a pipeline of innovators for National needs, and maintains the agencies technical competencies / workforce





HEOMD Alignment

- Using ISS as a demonstration platform
- Developing key technology supporting MPCV and SLS development
- Partnering with AES and SCaN to develop next generation capabilities
- Developing the technologies to send humans to Mars

STMD Demonstrations Inside ISS

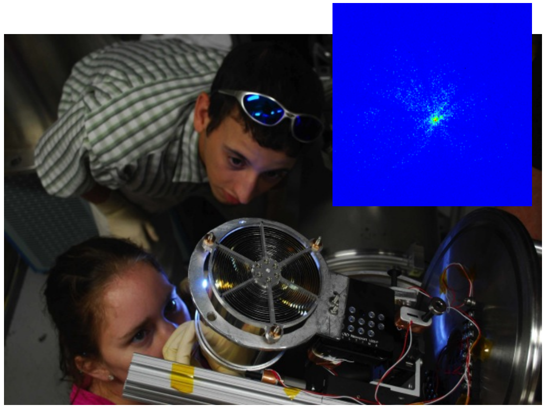
- ***Smart SPHERES and Tele-Robotics***
  - Smart SPHERES navigation demo
  - Tele-robotics demonstration from ISS
- ***Robonaut Legs***
  - Delivered to ISS on SpaceX-3
  - Recently integrated with R2
  - Provides R2 with extreme IVA mobility
  - Initial checkout scheduled for June 2014
- ***ISS SPHERES SLOSH Experiment***
  - Delivered to ISS on Orb-1
  - Performed experimental sessions to provide microgravity fluid slosh data to validate models
- ***3D Printer Demonstration***
  - Will launch to ISS on SpaceX-4 – next week
  - Demonstrate 3D printing of parts in microgravity
  - Produce on-demand replacement parts for future exploration missions





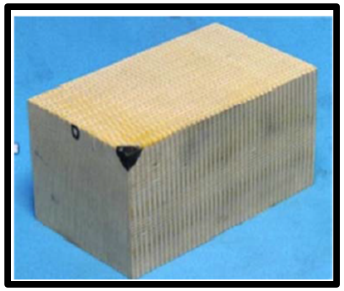
STMD Demonstrations Outside ISS

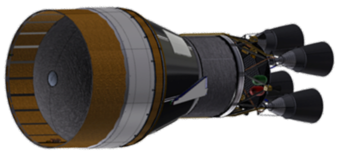
- ***Station Explorer for X-Ray Timing and Navigation (SEXTANT)***
  - Will be delivered to ISS in August 2016
  - Will demonstrate use of x-ray emitting neutron stars as beacons for spacecraft navigation
  - Leverages SMD’s NICER project to determine neutron star composition
- ***Phase Change Material (PCM) Heat Exchanger***
  - STMD will develop two full scale PCM heat exchangers for demonstration in microgravity on ISS
  - Wax-based PCM heat exchanger delivery to ISS set for FY16 with water-based unit to follow in FY17
  - Needed for Orion low Lunar orbit missions
- ***Advanced Solar Arrays***
  - Assessing the feasibility of utilizing ISS as demonstration platform for advanced solar arrays
  - ISS may benefit by potentially meeting future power needs

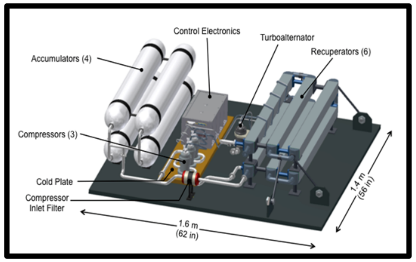


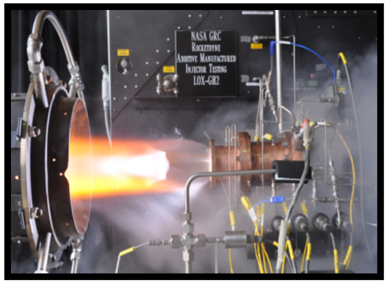
STMD Investments to Advance Future Capabilities of Space Launch System (SLS) & Orion

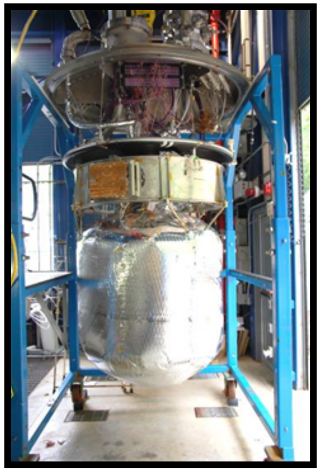
- Composite cryogenic propellant tanks (CCPT) and Composite Evolvable Upper Stage (CEUS), develops composite technologies for SLS upgrades
- Evolvable Cryogenics (eCryo) develops advanced cryogenic propellant management technologies, and high capacity cryocoolers for SLS future missions
- Additive manufacturing of upper stage injectors, combustion chambers and nozzles for potential SLS upgrades
- Phase change material heat exchangers for Orion in lunar orbit
- 3D Woven ablative TPS for Orion heat shield compression pads
- Advanced oxygen recovery for Orion upgrades







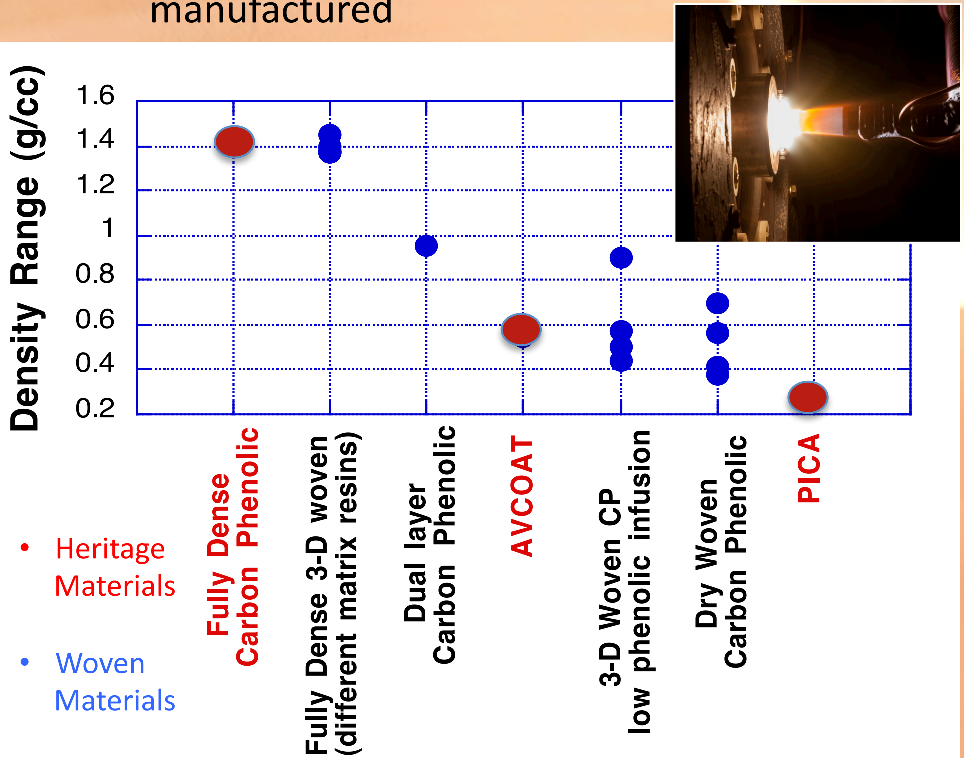




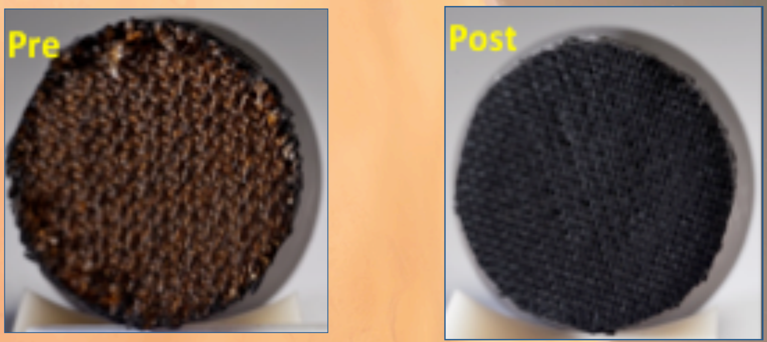
Woven Thermal Protection System (WTPS)

Thermal Protection Systems (TPS) are required for all atmospheric entry missions (science & human exploration)

- **Woven TPS can be tailor the material composition for a given mission**
  - Densities from 0.4 to 1.4 g/cc have been manufactured



- **Highly compliant ablative WTPS materials containing phenolic resins (dry woven, no resin infusion)**
  - Reduces TPS integration challenges
  - Addresses common TPS cracking issues
- **WTPS will reduce the TPS mass for future exploration missions**
  - Performance / mass based upon properties
  - Orion Compression Pads as first application
  - Ability to tailor TPS through the thickness
- **WTPS has moved from CIF to GCD**

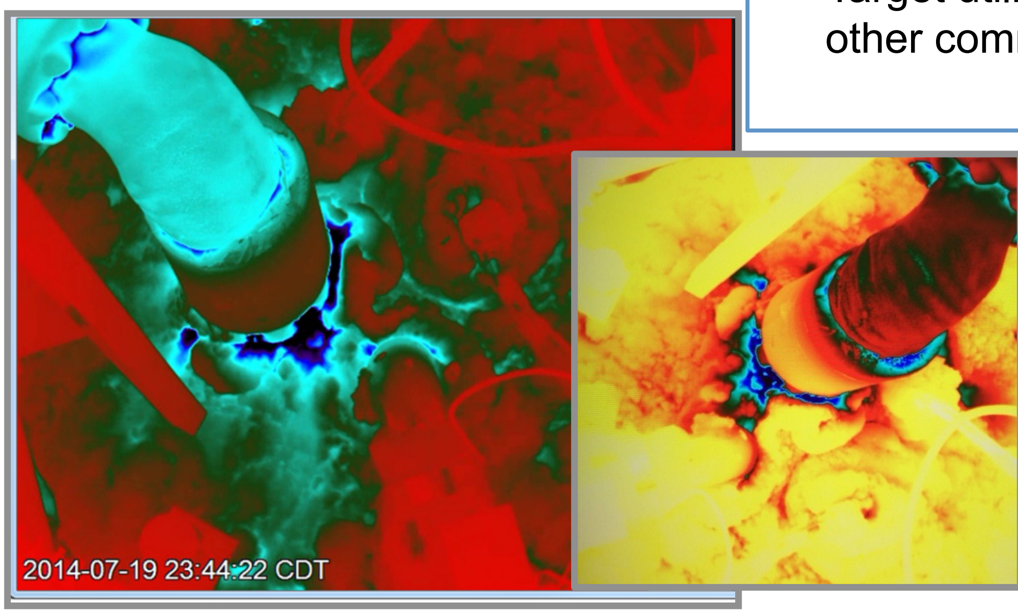


Dry Woven WTPS
2" diameter 1650 W/cm^2, 1.3 atm

Test Success: Composite Cryotank Technology Demonstration

Successfully Completed Cryogenic Testing of 5.5 m Tank

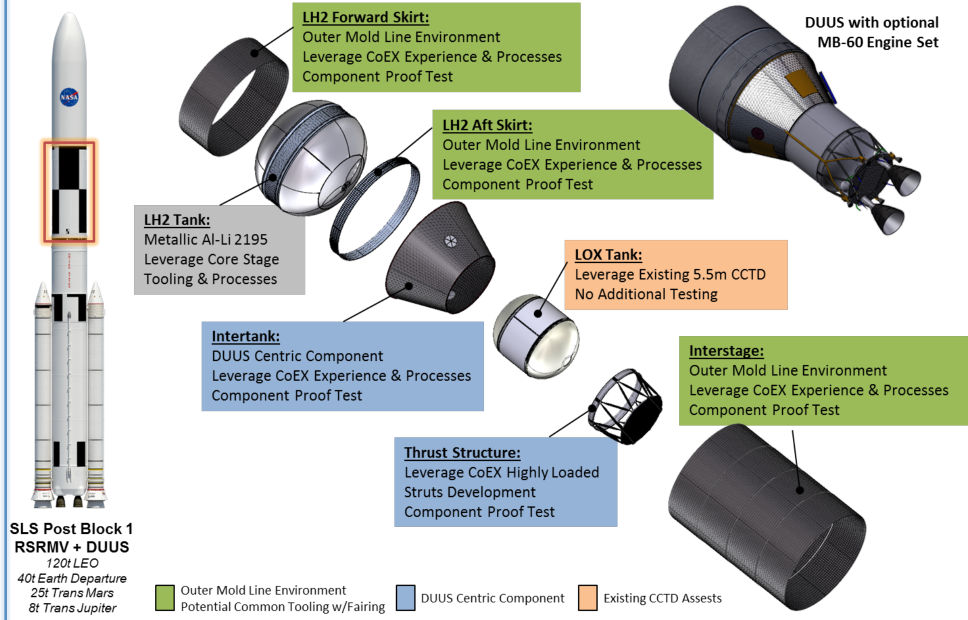
- Tank pressurized to ~ 60 psi with LH2 through multiple cycles and the 5,000 micro strain test objective was achieved
- Compared to current SoA metallic propellant tanks, Composites offer: > 30% mass & 25% cost reduction
- Employed out-of-autoclave fabrication for scale-ability and affordability
- Target utilization on SLS upper stage upgrade and other commercial vendors

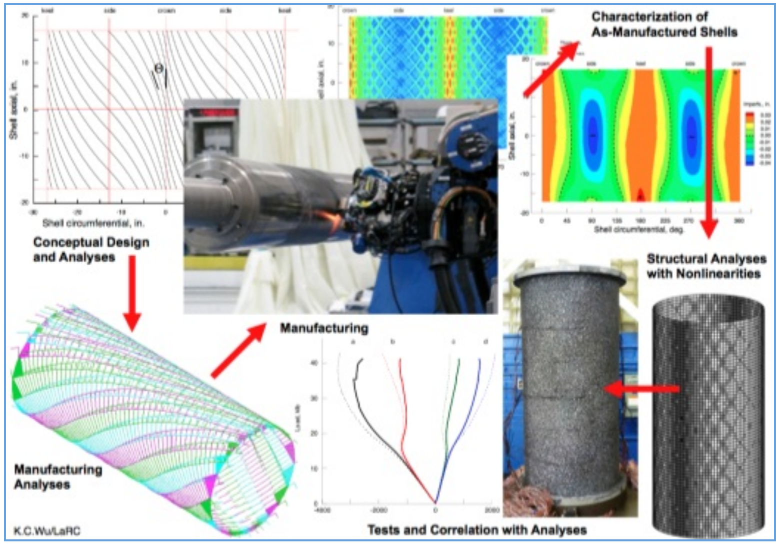


Composite Exploration Upper Stage

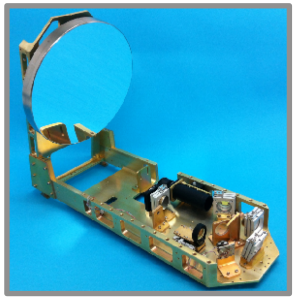
Objective: The Composite Exploration Upper Stage (CEUS) Initiative will develop a prototype SLS composite upper stage components.

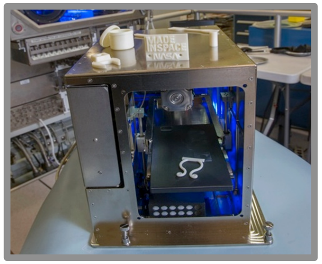
Description: The initiative is a cooperative effort between STMD, SLS and AES including multiple NASA Centers. The initiative will leverage collaborations with DoD, industry and academia to maintain U.S. leadership in launch vehicle structures.

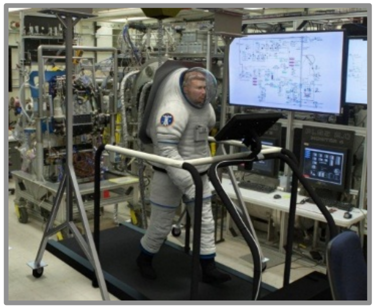




Partnerships with HEOMD Advanced Exploration Systems (AES) or Space Communications and Navigation (SCaN)



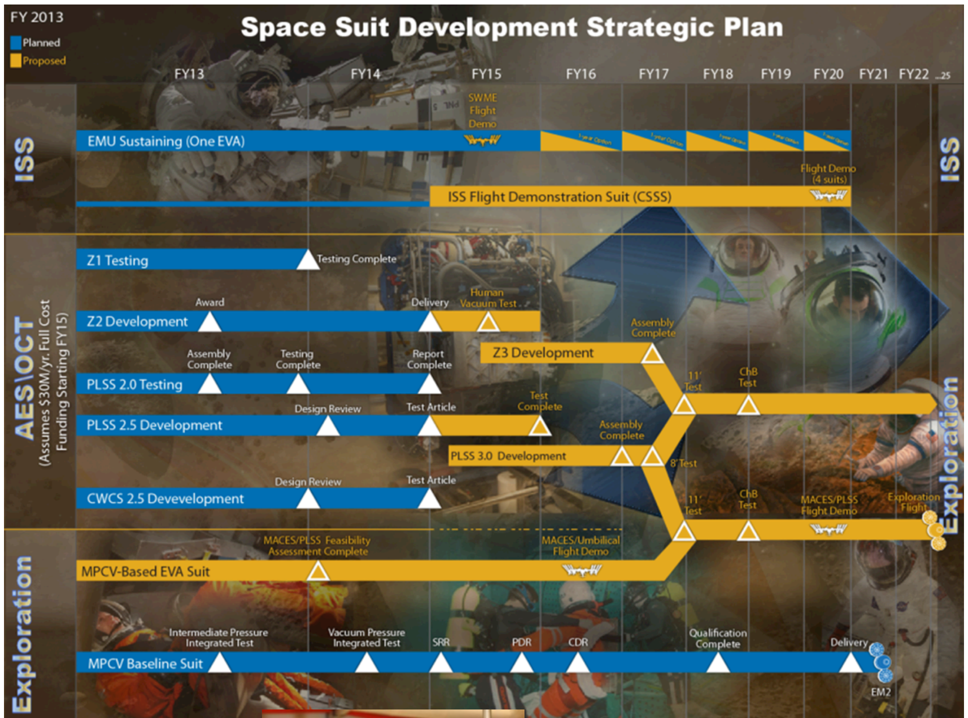


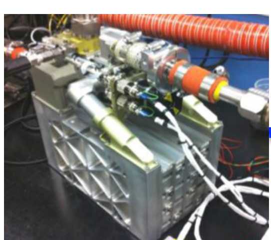


- **LCRD** – Partnership with SCaN to develop optical communications upgrade for the deep space network
- **DSAC** – Partnership with SCaN for higher precision navigation for future missions and upgraded GPS capability
- **Advanced Mobility Rover** – Partnership with AES for develop a prototype autonomous / remotely operated exploration rover
- **Advanced Power Storage** – Partnership with AES to develop improved batteries for longer duration, more capable EVAs
- **Oxygen ISRU for Mars 2020** – Partnership with AES and SMD to demonstrate oxygen production from Mars atmosphere
- **MEDLI for Mars 2020** – Partnership with AES and SMD to gather more aerothermal performance data
- **Inflatable Airlock** – Partnership with AES to develop soft hatch technology for an inflatable airlock
- **PCM Heat Exchanger** – Partnership with AES, ISS and Orion
- **Spacecraft Oxygen Recovery** – Partnership with AES for future closed loop oxygen recovery
- **Advanced PLSS Components** – Partnership with AES to deliver component technologies for next generation EVA suits

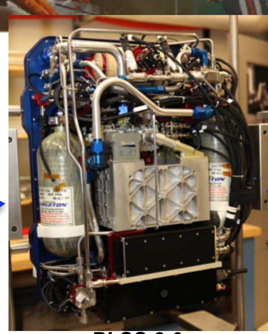
STMD's Contribution to PLSS Development for Advanced Suits

STMD has Develop Two Advanced Components for the Personal Life Support System (PLSS)





RCA 2.0



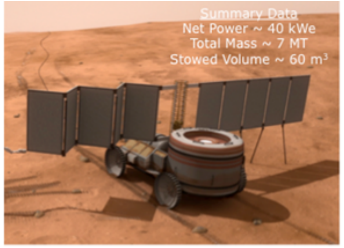
PLSS 2.0

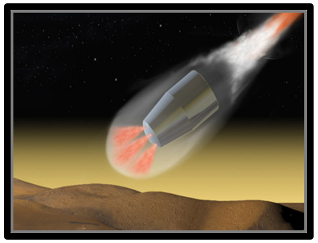
VOR 2.0

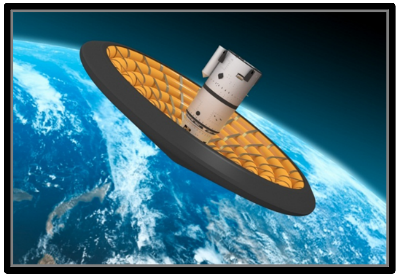
- **Rapid Cycle Amine (RCA) – Integrated CO_2 and humidity control system**
  - Eliminates off-suit regeneration which requires ancillary hardware/ consumables
  - Eliminates CO_2 scrubbing as an EVA duration limitation
  - 67% mass reduction as compared to the state of the art
- **Variable Oxygen Regulator (VOR) – Regulates Oxygen Pressure**
  - Enables more flexible EVA suit design (relaxed pre-breathing protocols, compatibility with suit ports)
  - Increases pressure settings from two to over 4,000
- **PLSS 2.0 hardware has already delivered & infused for testing**
- **PLSS 3.0 hardware delivery by the end of FY 2014 for infusion into PLSS 3.0 testing**

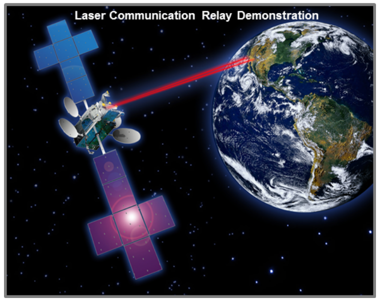
STMD Investments to Advance Human Exploration of Mars

- High Powered SEP – cargo & logistics transportation to Mars
- Small Fission Power / Stirling Cycle – Mars surface power
- HIAD / ADEPT – deployable entry systems for large downmass
- LDSD – supersonic aerodynamic decelerators & supersonic retro-propulsion for the descent of large landed mass at Mars
- Woven TPS – more efficient & flexible TPS materials for entry
- Closed loop air & water recovery – reduced consumables
- Mars atmospheric ISRU (oxygen) – life support and ascent vehicle oxidizer
- Humanoid robotics – enhanced exploration / reduced crew load
- Optical communications – high bandwidth communications

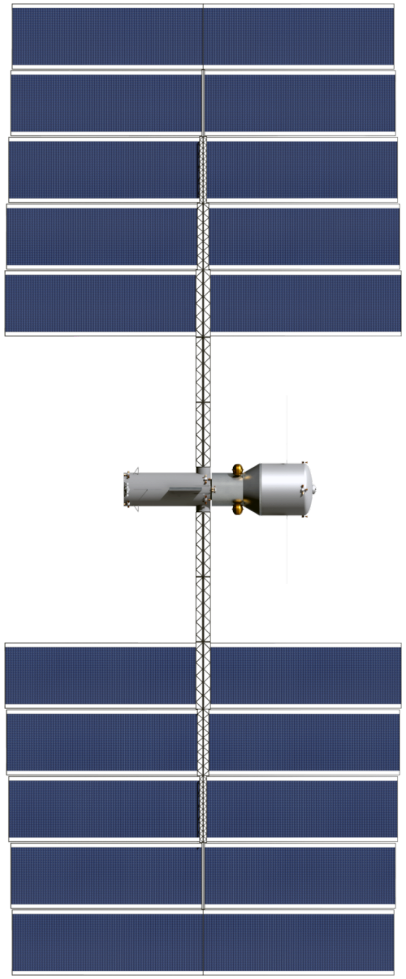








Solar Electric Propulsion for Mars Missions (Eventual HEOMD Objective System)



Major technology development needs

- Very high propellant usage efficiency
- Reduces number of SLS launches needed for a human Mars mission (~1/2) by splitting crew and cargo transit
- Very low thrust compared to chemical and nuclear thermal options so transit times are long and inappropriate for crew and accommodations

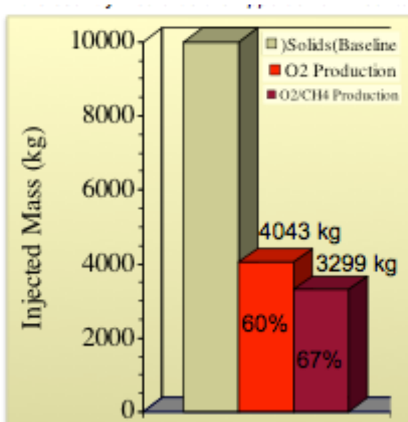
Major technology development needs

- Very large solar arrays 300kW or greater
- High-power (15kW - 50kW class) thruster development
- Power processing system development
- Propellant tank development

In Situ Resource Utilization (ISRU) for Mars Exploration

Overview/Background:

- The *in situ* production of propellant and consumable oxygen enables more affordable and sustainable Mars exploration
  - Reduced Earth-launch mass & cryogenic storage burden
  - Reduced burden on Mars' Entry, Descent, and Landing (EDL) systems
  - ISRU enables 200mt initial mass to LEO savings for single Mars mission*

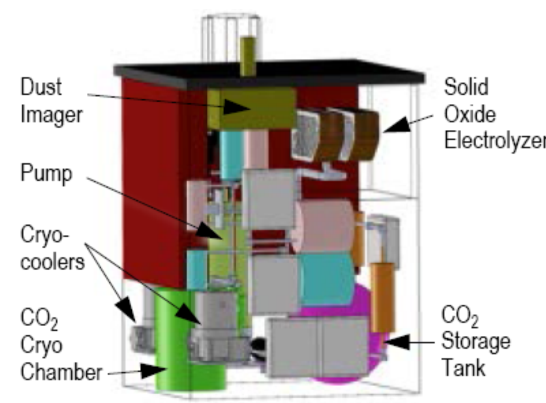


Ref: Stancati, et. al. "In Situ Propellant Production for Improved Sample Return Mission Performance," AAS 79-117, 1979

*Aerojet report

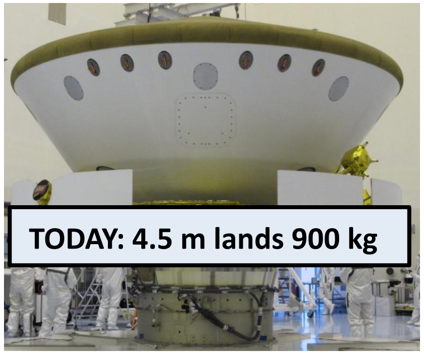
Approach:

- STMD partnered with SMD & AES to develop & demonstrate an ISRU payload for Mars 2020 mission
  - Successful precursor demonstration will mitigate risks associated with relying on ISRU for future Mars' exploration missions
  - MIT-led ISRU demonstration selected using Mars 2020 Instrument AO
  - Will produce oxygen with 99.6% purity for the equivalent of 50 sols
  - STMD / AES will each provide $15M



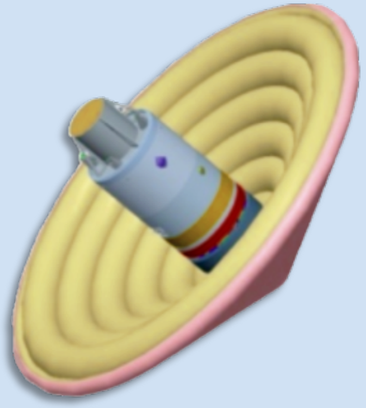
Entry Systems for Human Mars Missions

- **1970's Viking era technology is "broken" beyond MSL-sized spacecraft**
  - Rigid aeroshells constrained by launch shrouds cannot provide enough surface area to slow down a human-scale Mars lander (40,000 kg, 8 x 8 x 20 m)
  - Parachute technology (size and material) is too limited to apply
  - Can only access 30-40% of Mars—need to land below "sea level"



STMD is investing in entry system to enable Human Mars missions

Hypersonic Inflatable Aerodynamic Decelerator (HIAD)

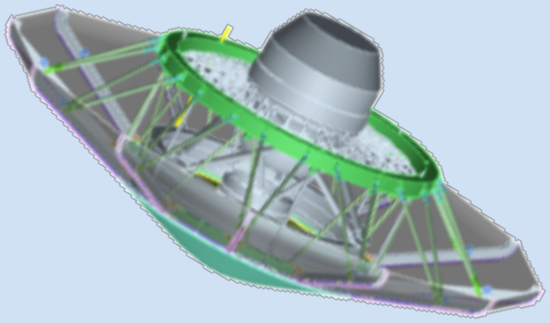


- Inflatable tori with overlaid Thermal Protection System
- Flight tested at 3 m scale (IRVE-II,3)
- ~TRL 4 for human scale

Both systems are folded for launch and deployed before Mars entry, providing the essentially rigid aerodynamic surface and heating protection needed for hypersonic deceleration, at a scale of 25-30 m.

Both systems can be used on robotic exploration missions at 6-10 m scale.

Adaptive Deployable Entry and Placement Technology (ADEPT)

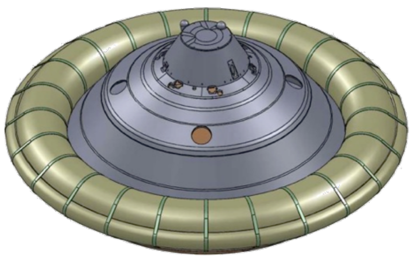


- Mechanically-deployed structure with carbon fabric "skin"
- Ground test of 6 m in FY16
- ~TRL 2 for human scale

Low Density Supersonic Decelerators – Descent Phase

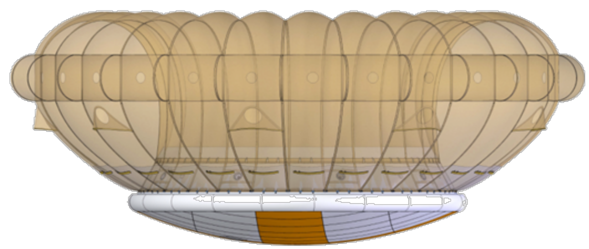
LDSD's technologies will serve as the foundation of supersonic decelerators for the next several decades

SIAD-R



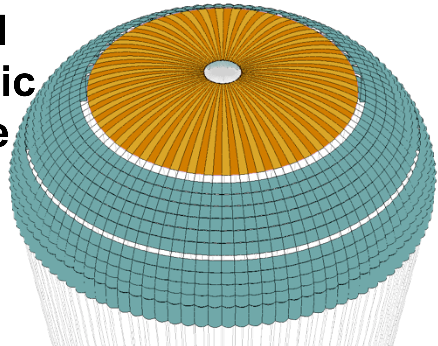
- 6 m, Mach 3.75 inflatable decelerator
- Negligible aeroelastic deformation
- 50% increase in drag area over MSL

SIAD-E



- 8 m, Mach 3.75 inflatable decelerator
- Ram-air inflated, flexible structure
- 2.25x drag area of MSL

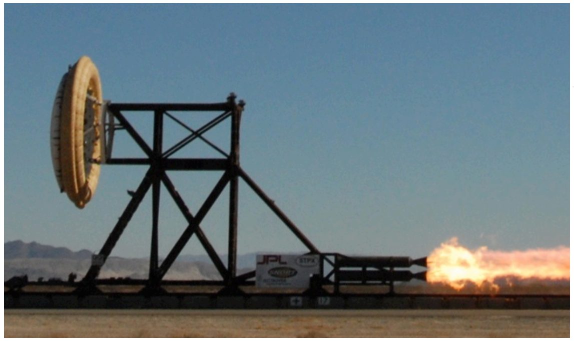
Advanced Supersonic Parachute



- 30.5 m, Mach 2.5 parachute
- Extensible to reefing and clusters
- 2.5x drag area of MSL parachute

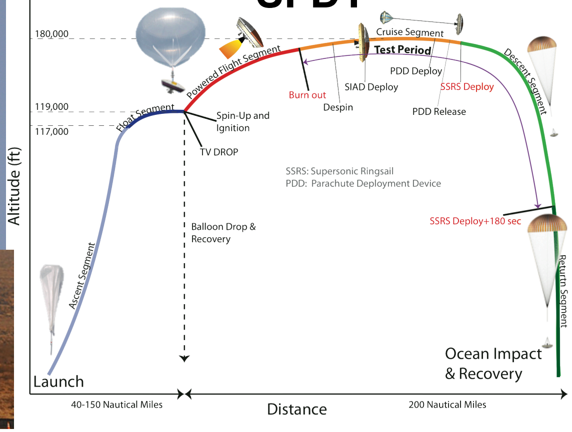
LDSD is developing the infrastructure necessary to enable the qualification and future development of supersonic decelerator technologies

SDV



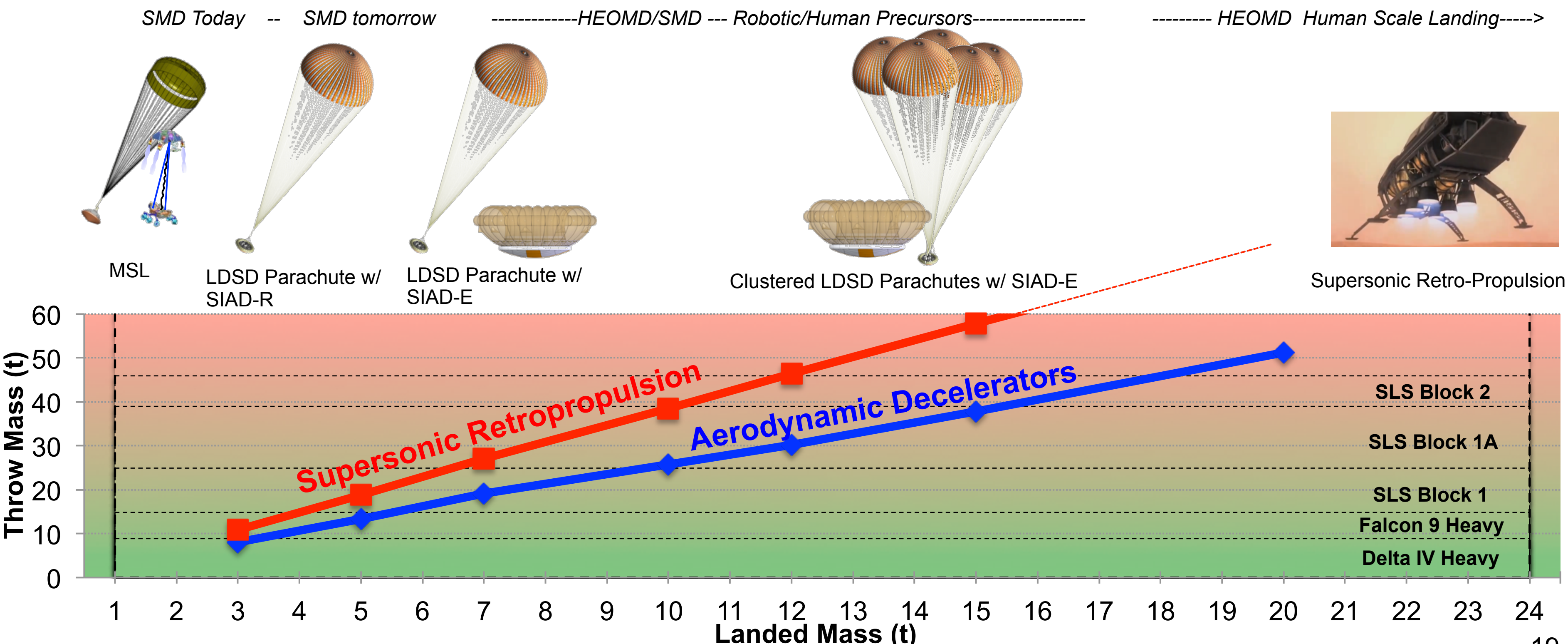
PDV

SFDT



Mars Infusion Opportunities: Out-Years

- Aerodynamic decelerators (Parachutes and SIADs) are launch mass efficient for delivering large landed masses on Mars
  - Proposed HEOMD Nuclear Power demonstration payload is ~6t
  - Aero decelerators may make such a payload launch-able on a Falcon 9 Heavy
  - Straight SRP would require an SLS
- Systems studies indicate that SIADs are critical to the transition to SRP even at landed masses that preclude their use all the way to subsonic conditions

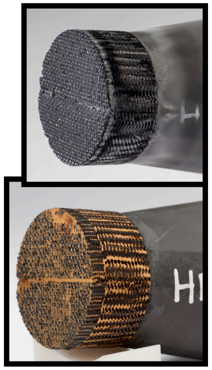


Test Success:
Low Density Supersonic Decelerator

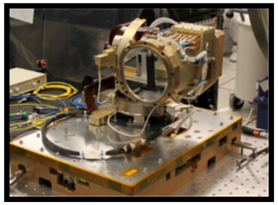
Successful LDSD flight test meeting all success criteria for the first flight

- Largest blunt body aeroshell ever flown supersonically
- Largest ballute ever successfully flown at supersonic conditions
- Largest supersonic parachute ever deployed
- Unprecedented quantity and quality of data collected

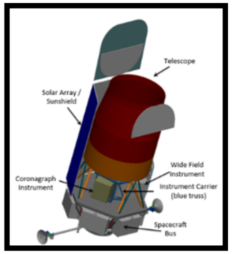
Advancing Science Mission Capabilities



- **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



STMD Investments to Advance Planetary Science – Discover Solicitation

Discovery 2014

- ***Maturing novel communication technology to provide order of magnitude higher data rates for deep space exploration***
- ***Developing low-mass, high performing Thermal Protection System material for planetary entry missions***

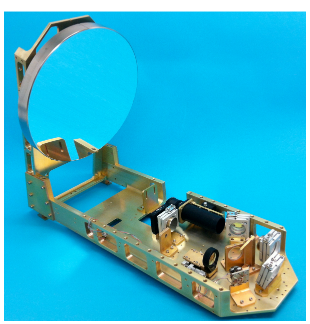
Space Technology Investments for Discovery AO 2014:

- Advanced Solar Arrays (ASA)
  - More affordable, lower mass and more compact arrays
  - Technology risk will not impact proposal rating
- Deep Space Optical Communications (DSOC)
  - Order of magnitude higher communication rates out to Jupiter
  - STMD will GFE flight hardware for Discover
  - SMD will provide $30M incentive
- Deep Space Atomic Clock (DSAC)
  - Order of magnitude improvement in Guidance and Navigation without need for two way communications
  - Dramatic increase in gavimetric measurements – for icy moons
  - Technology risk will not impact proposal rating
- Heatshield for Extreme Environment Technology (HEEET)
  - Low mass (40%), high performance TPS material for planetary entry or aero-braking missions
  - SMD will provide $10M incentive
- Green Propellant (GPIM)
  - Increased ISP and volume performance relative to hydrazine
  - Reduced toxicity for improved handling costs
  - Technology risk will not impact proposal rating

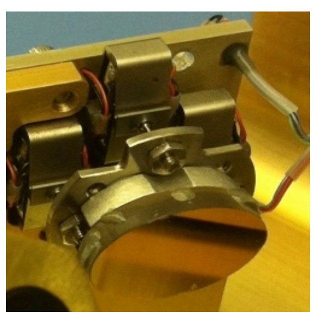
Deep Space Optical Communication System

Approach:

- Partner with SMD and HEOMD to develop and demonstrate a highly capable Deep Space Optical Communication (DSOC) system
  - STMD/GCD ($15M) is partnering with SMD ($4.5M) and HEOMD ($2.8M) to advance DSOC to TRL 6 for infusion into Discovery 2014
  - STMD/TDM is developing DSOC flight hardware and will provide it GFE to Discovery 2014 ($50M)
  - SMD is providing $30M incentive to include DSOC in Discovery 2014 proposal



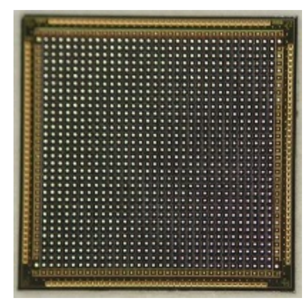
Optics Assembly



Point-Ahead Mirror

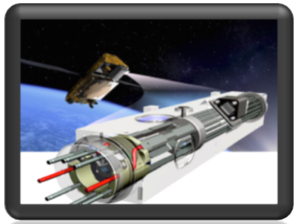
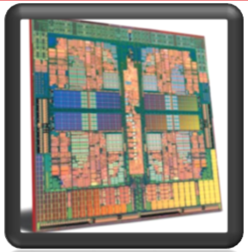
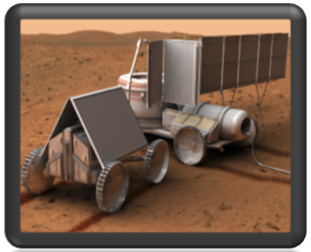
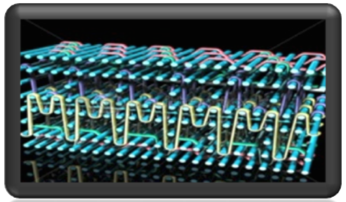
Overview/Background:

- Existing technologies cannot support the high data rates (i.e. high definition video) required for future deep space exploration missions
  - STMD has developed solutions to three "tall-tent-pole" technologies
  - The solution being pursued will demonstrate an **tenfold data rate increase** of an equal mass, volume, and power MRO Ka-Band telecom system from Mars distances



Photon Counting Space Receiver

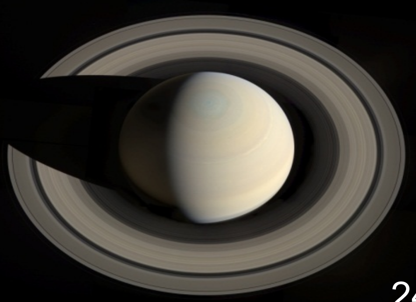
STMD Investments to Advance Outer Planetary Exploration

Technologies in FY15

- Deep Space Optical Communications
- Deep Space Atomic Clock
- High Performance Space Computing
- Small Nuclear Fission / Sterling Power (kilo-power)
- Woven TPS for aerocapture and outer-planetary entry
- Europa Ice Penetration Challenge



Deep Space Atomic Clock (DSAC)

Demo Description:
Develop an advanced prototype mercury-ion atomic clock (TRL 7) and demonstrate for a year in space.

Objectives:
- Demonstrate less than 2.0E-15 AD at One Day
- Demonstrate 10m OD in a One-Way Configuration
- Build a physics package less than 7kg and 30W

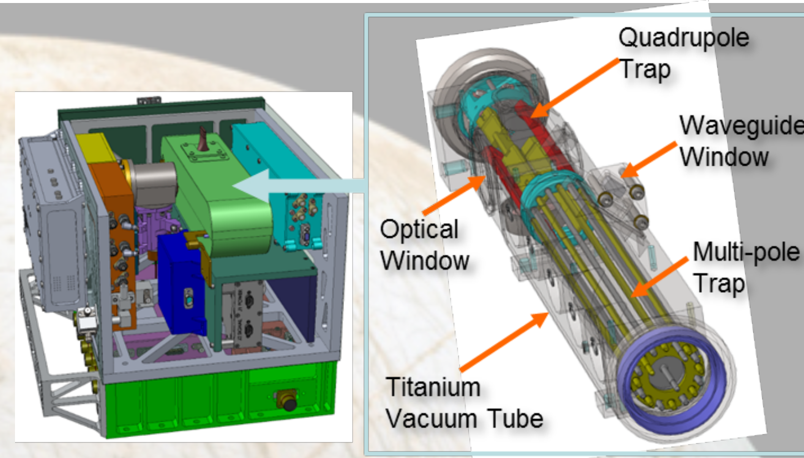
Anticipated Benefits:
Enable shift to 1-Way radio navigation (from 2-Way)
- Enables multiple spacecraft per aperture tracking
- More efficient deep space tracking (15% at Jupiter, 25% at Saturn)

Fundamental to autonomous radio navigation
- Needed for fully autonomous aerobraking operations
- On-board radio navigation for human exploration

Increase navigation & radio science tracking data accuracy by 10 times and quantity by 2 times
- Enhance Europa Clipper gravity ocean characterization
- Improve clock performance for future GPS by 100×

Anticipated NASA Mission Use: Europa Clipper, 2022 Mars Orbiter, Future Discovery and New Frontiers Missions

Anticipated DOD & OGA Use: GPS, Future Milsatcom, NRO



Project Start Date: Oct 2011
Est. Launch Date: Sep 2015
Project End Date: Sep 2016

TRL Start: 5
TRL End: 7

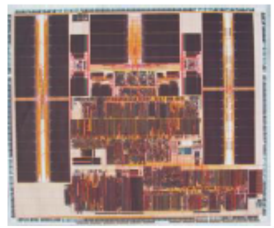
Lead Center: JPL
Contractors:
- SST-US- Host Mission Provider (Surrey OTB) (CO)
- BRE (Moog) – GPSR (AZ)
- FEI – USO (NY)
- Symmetricom – Synthesizer (MA)
- LASP – UV Detector (CO)

NASA MD Funding/Resources: HEOMD/SCaN
Access to Space – SST-US OTB, USAF STP II

SURREY SATELLITE TECHNOLOGY LTD · MOOG BROAD REACH · Symmetricom · LASP

High Performance Space Flight Computing

- **The state of the art in spaceflight computing is the RAD750**
  - 133 MHz, 200 MOPS, 200 Krad, and 5 Watts
  - Power PC single core architecture
  - Flown on most SMD missions



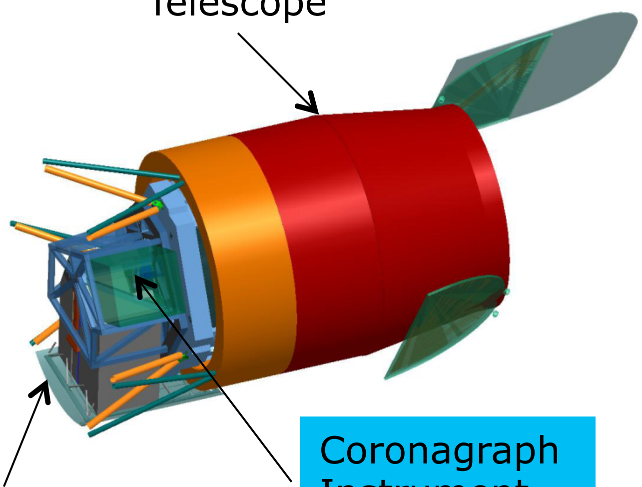
RAD750

- **The Objective is to Develop a more Capable Replacement**
  - Greater than 100x improved floating point performance and power efficiency over RAD750
  - Multicore architectures
  - Provide both general purpose and some DSP capability as well as interoperability with co-processors
  - Are conducive to power scaling at core level and thread-based fault tolerance
  - Allow flexible operation; dynamic trades for computational performance, energy management, and fault tolerance

- **Project will develop NASA's next generation flight computing system**
- **Enabling for human-robotic teaming, onboard science data processing, real-time precision control, and autonomous operations in uncertain environments.**
- **Development approach involves a competitive selection process in partnership with AFRL**
  - BAA released with contracts awarded to BAE, Honeywell, and Boeing
  - First phase will complete in FY 2014 and will result in hardware architecture designs evaluated against NASA-provided benchmarks
  - Second phase will initiate in FY 2015 and conclude in FY 2017 with the delivery of TRL 6 multi-core hardware chip(s)

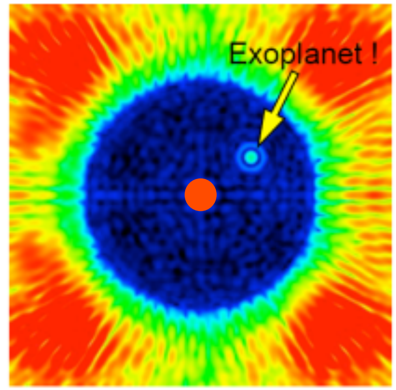
AFTA Coronagraph Instrument Astrophysics Partnership

Telescope

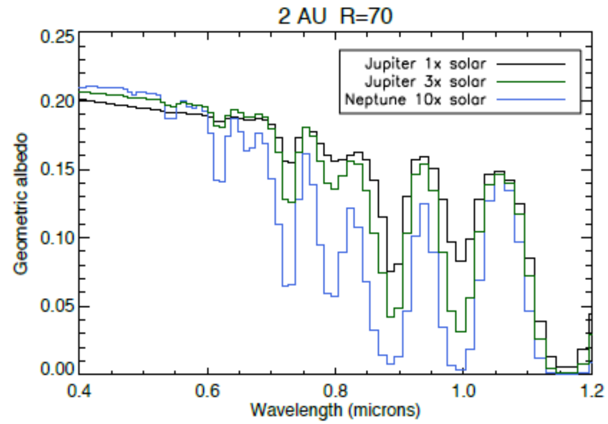


Wide field instrument

Coronagraph Instrument



Exoplanet Direct imaging



Exoplanet Spectroscopy

Bandpass	400-1000 nm	Measured sequentially in five 18% bands
Inner Working Angle	100 mas	at 400 nm, 3 λ/D driven by challenging pupil
	250 mas	at 1 um
Outer Working Angle	1 arcsec	at 400 nm, limited by 64x64 DM
	2.5 arcsec	at 1 um
Detection Limit	Contrast $=10^{-9}$	Cold Jupiters, not exo-earths. Deeper contrast looks unlikely due to pupil shape and extrememe stability requirements.
Spectral Resolution	70	With IFS, ~70 across the spectrum.
IFS Spatial Sampling	17 mas	This is Nyquist for λ400 nm.

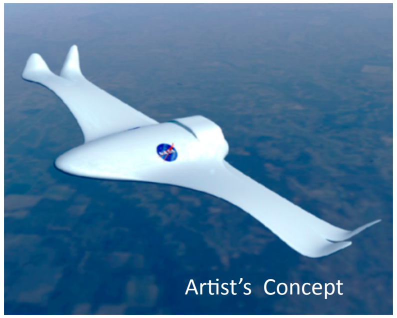
WFIRST final report May 23, 2013
http://wfirst.gsfc.nasa.gov/

AFTA Coronagraph Instrument will:

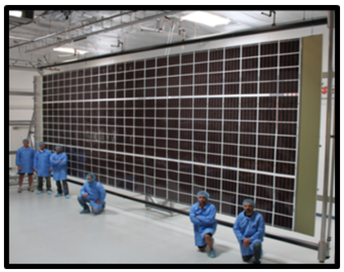
- Characterize the spectra of over a dozen radial velocity planets.
- Discover and characterize up to a dozen more ice and gas giants.
- Provide crucial information on the physics of planetary atmospheres and clues to planet formation.
- Respond to decadal survey to mature coronagraph technologies, leading to first images of a nearby Earth.

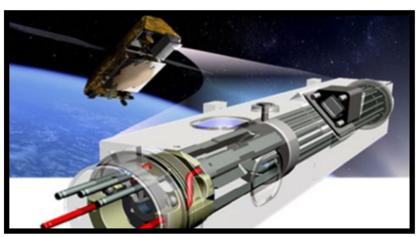
STMD-ARMD Synergies

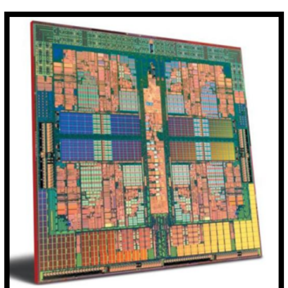
- **Aviation Safety**
  - External hazard sensors; pressure sensitive paint; wing tip vortex sensors
  - SBIR projects
- **Fundamental Aeronautics**
  - Advanced EDL - Computation (HEDL)
  - Parachutes under LDSD; Wings under Silent and Efficient Supersonic Bi-Directional Flying Wing
  - Advanced Manufacturing ; Nanotechnology ; Computational Materials ; Low mass cable harness structural health monitoring
  - Advanced composites/lightweight materials
  - SBIR projects
- **Airspace Systems:**
  - SBIR projects
- **Aeronautics Test Technologies:**
  - SBIR projects
- **Integrated System Research Project:**
  - UAS Challenge
  - SBIR projects



STMD Cross-Cutting Technologies Supporting the Aerospace Industry



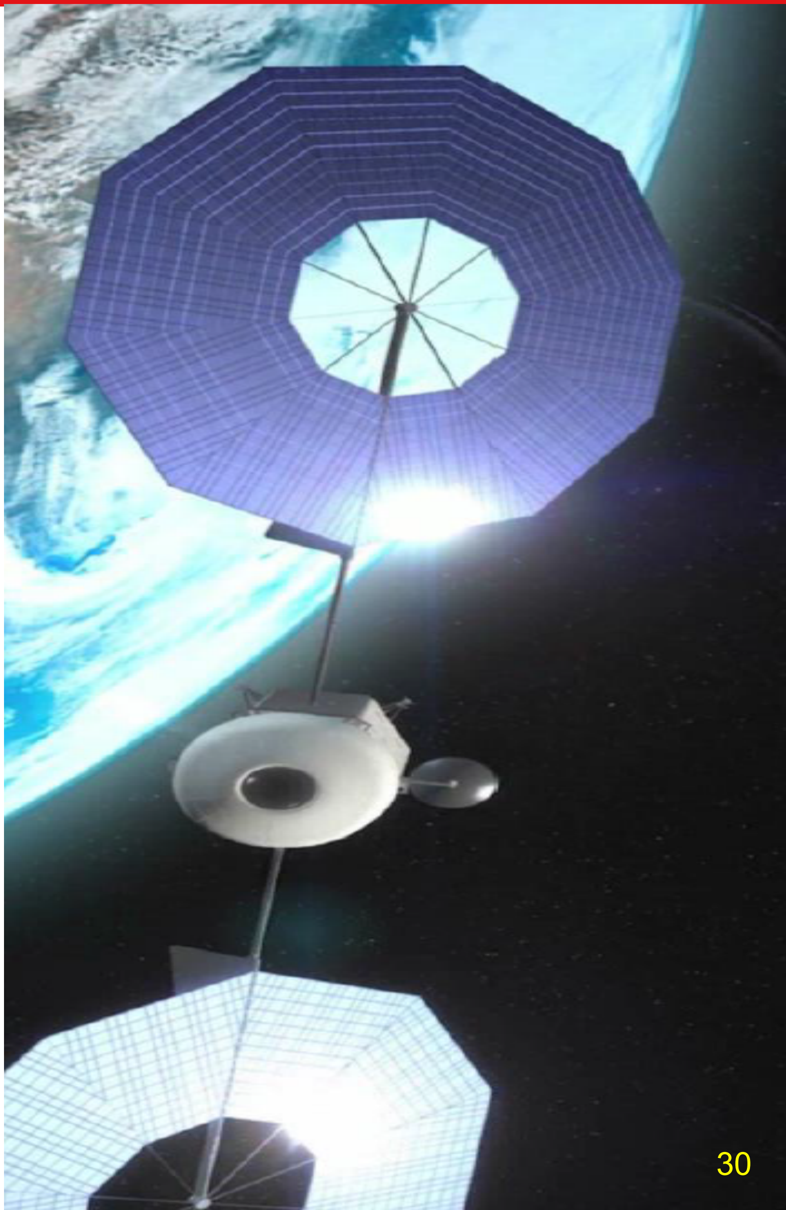




- **Structures and Materials**
  - Composite Tanks & Structures – for improved launch vehicle performance
  - HIAD – for orbital down mass capability
- **Propulsion & Power**
  - Green Propellant Infusion Mission – improved spacecraft performance & reduced toxicity and ground processing costs
  - Solar 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
  - DSAC – improved timing for next generation GPS satellites
- **Instruments, Sensors, & Robotics**
  - High Performance Spaceflight Computing – for more capable radiation hard avionics for commercial communication satellites
  - Human Robotic Systems (R5) – to perform environmentally hazardous tasks and operate within terrestrial settings

Cross-Cutting SEP Development and Demonstration Objectives

- Develop & demonstrate a 25kW to 50kW class SEP tug
  - **Extendable to 300kW for deep space human exploration**
  - Directly **applicable to SMD & OGA missions**
  - A first demonstration mission targeted for the **Asteroid Robotic Redirect Mission**
- Develop & demonstrate SEP component technologies with commercial benefit
  - Reduced mass, efficient packaging, deployable solar arrays for improved **commercial satellite affordability and potential ISS retrofitting**
  - High power Hall thrusters for **all electric commercial satellites**



STMD Solar Array Investments

- Two teams selected through competitive NRA for Solar Array development
- Solar array deployment tested in thermal vacuum conditions
- NASA/STMD augmented the development efforts with NASA civil servant labor
- Both contractors satisfied all objectives and are ready for space flight demonstrations

ATK MegaFlex:

Contract start Oct 2012; ground testing complete Apr 2013

$6.5M total investment

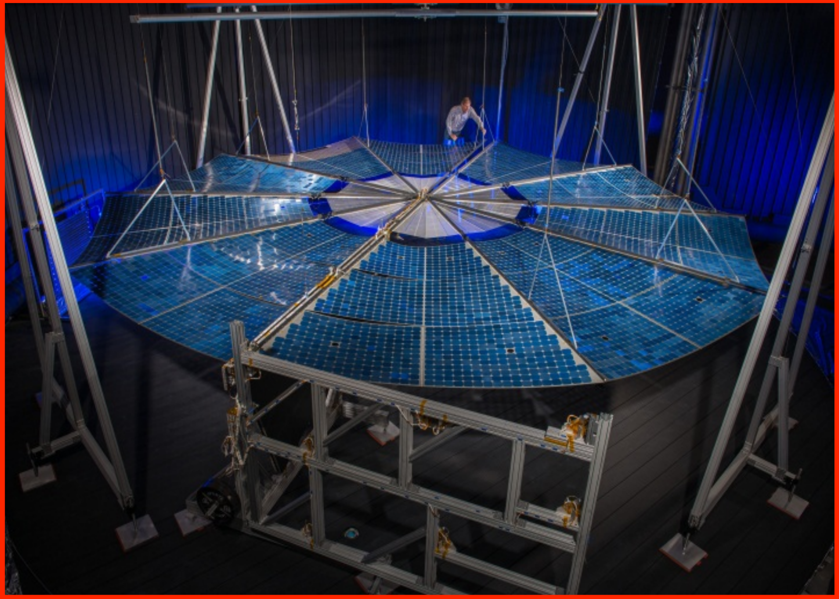
Critical vacuum deploy testing at GRC Plumbrook

DSS Roll Out Solar Array (ROSA):

Contract start Oct 2012; ground testing complete Jun 2013

$4.7M investment (leverages initial SBIR contract)

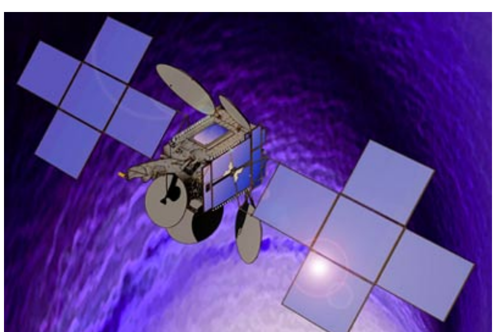
Critical vacuum deploy testing at ????



Commercial Satellite Solar Arrays

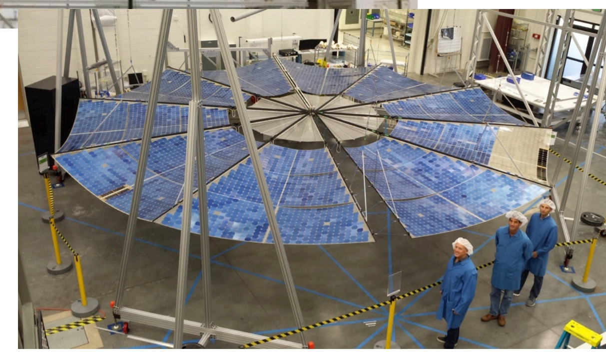
Current commercial satellites use large composite fold-out panels

- Arrays are lightweight but still require significant mass due to the composite panels and deployment mechanisms
- Satellite launch costs are proportional to mass thus mass reduction draw serious interest
- The arrays fold up onto the sides of square satellites but must fit within cylindrical launch shrouds
- Fitting larger power requirements (> 25kW) require larger expensive or unavailable shrouds



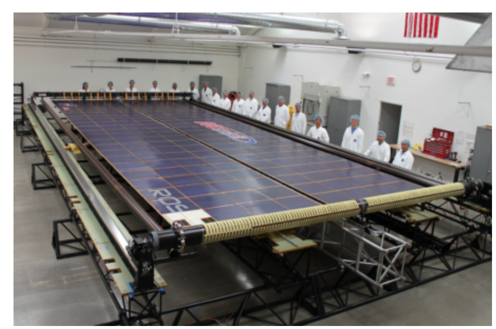
Solar Array Investment Has Commercial Potential

- **STMD developed advanced Solar Arrays offer significant benefits to commercial satellites**
  - Advanced arrays reduce mass by ½ or more relative to SOA arrays, improving affordability
  - Packaging volume is 1/3 of SOA arrays, fitting within “D” shaped shroud / satellite gaps, allowing power increase
  - Manufacture automation of new arrays reduce costs 35%
- **Array commercialization is virtually assured**
  - SSL working with DSS to develop arrays for satellites
  - Lockheed Martin used IRAD to develop its own advanced ROSAs
- **Additional interest for advanced arrays beyond commercial satellites**
  - Multiple teams likely to propose advanced arrays for SMD Discovery
  - USAF funding the demo of small-scale DSS ROSA on ISS as a precursor to use for future DoD satellites
  - ISS has strong interest in retrofitting using advanced arrays

ATK MegaFlex Engineering Development Unit

DSS ROSA Engineering Development Unit




Laser Communication Relay Demonstration (LCRD) Mission Architecture

- SCaN/STMD Mission
- Commercial Spacecraft Host
- Flight Payload
  - Two Lunar Laser Communication Demonstration (LLCD) based Optical Modules
  - Two Multi-Rate Differential Phase Shift Keying Modems based on a MIT Lincoln Laboratory Design with Pulse Position Modulation functionality added
  - Two Optical Module Controllers
  - High Speed Electronics to interconnect the two terminals, perform data processing, and to interface with the host spacecraft
- Two Optical Communications Ground Stations
  - Upgraded JPL Optical Communications Telescope Laboratory (Table Mountain, CA)
  - Upgraded LLCD Lunar Laser Ground Terminal (White Sands, NM)
- LCRD Mission Operations Center
  - Connected to the two LCRD Optical Communications Ground Stations
  - Connected to the Host Spacecraft Mission Operations Center

Successful Industry Partnerships

Non-toxic “green” propellant is less harmful to the environment, increases fuel efficiency, and diminishes operational hazards. Image Credit: Aerojet Rocketdyne

Green Propellant

Aerojet conducted concurrent IR&D investments to support lab work in developing1N thrusters. Ball Aerospace contributed the software to incorporate those thrusters on the bus

Cryotank

Boeing contributed significant institutional enhancements and conducted concurrent IR&D

Supersonic Retro Propulsion

SpaceX sharing performance data for Falcon 9 controlled descents. NASA providing EDL expertise and is providing imagery data for 2 SRP demonstrations. NASA is gaining key data that will validate SRP models for future Mars entry trajectories

SBIR/STTR

NASA encourages use of SBIR/STTR technologies by offering matching funds to further validate tech before Phase 3; Small Businesses have also leveraged state tax incentives to supplement efforts funded by NASA

Emerging Aerospace

Working with suborbital and microgravity flight vendors to address obstacles to commercial operation. NASA purchasing flights for tech in development by academia, industry and NASA so they may be tested in relevant flight environments

Centennial Challenges

Allied Partners contribute significant resources to support implementation of NASA challenges

Snapshot of Space Technology Partners

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
ASTER LABS
DRAPER LABORATORY
UP Aerospace
Princeton Lightwave
COBHAM
TELEDYNE BROWN ENGINEERING, INC
A Teledyne Technologies Company
L'GARDE Est. 1971
nanocomp TECHNOLOGIES, INC.
BAE SYSTEMS
United Technologies
DSS Deployable Space Systems
QUEST THERMAL GROUP
SURREY SATELLITE TECHNOLOGY LTD
QUEST THERMAL GROUP
Symmetricom
MOOG
ANALEX CORPORATION
Nammo
OCEANEERING
BOEING
PLANETARY SYSTEMS CORPORATION
SIERRA LOBO
ATK
SEAKR Engineering, Inc.
Frequency Electronics, Inc.
STINGER GHAFFARIAN TECHNOLOGIES
LOCKHEED MARTIN
SPACE SYSTEMS LORAL
Virgin Galactic
Orbital
SNC SIERRA NEVADA CORPORATION Space Systems
POWERSAFE TECHNOLOGY CORPORATION
MIT Lincoln Laboratory
Microcosm Inc
ADCOLE
Masten

STMD Early Stage Technology Portfolio

STMD Early-Stage Goals:

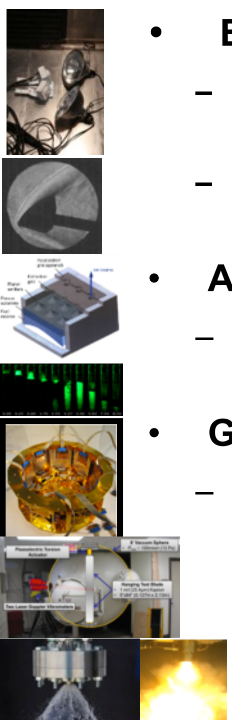
- Perform advance studies of visionary, advanced concepts - aerospace architectures, or systems; and inspire new technology development for long term space futures.

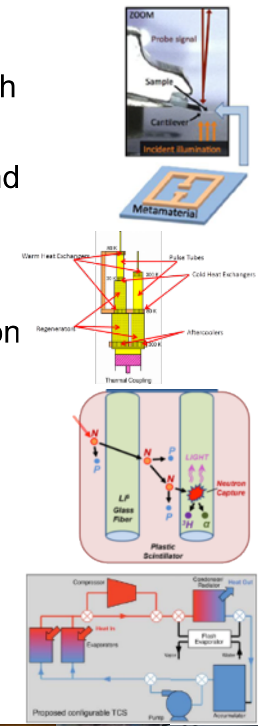
- Engage academia - faculty and graduate students - to examine new ideas and test their feasibility - making science and exploration more capable, affordable, and reliable. Develop partnerships and collaborations between NASA and academia.

- Provide opportunities for small businesses, high technology companies, NASA Centers and research institutions to develop innovations addressing Agency's needs and promote the Nation's innovation driven economy.

STMD University Engagement

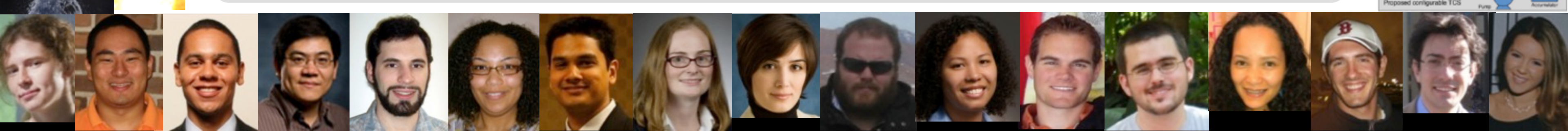
University Research Integrated throughout STMD Portfolio





- **NASA Space Technology Research Fellowships**
  - Space technology research efforts conducted by graduate students tied to Technology Area Roadmaps; research conducted on university 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 and collaboration with NASA, OGAs and FFRDCs permitted
- **Advanced Concept Studies, Center Partnerships, and Challenges**
  - Engaging university community in visionary early studies, projects at NASA Centers around the nation and open challenges trying to change the way that NASA makes progress
- **Game Changing Technology Development**
  - Mid-level TRL technology development in focused areas such as energy storage, micro-propulsion, robotics, technology payloads for suborbital testing.

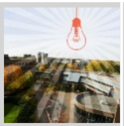
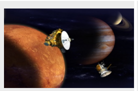
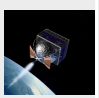
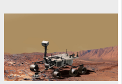
~ Reinvigorate the pipeline of high-risk/high-payoff space technologies across the Technology Readiness Spectrum ~



STMD Partners with Universities to Solve The Nation's Challenges

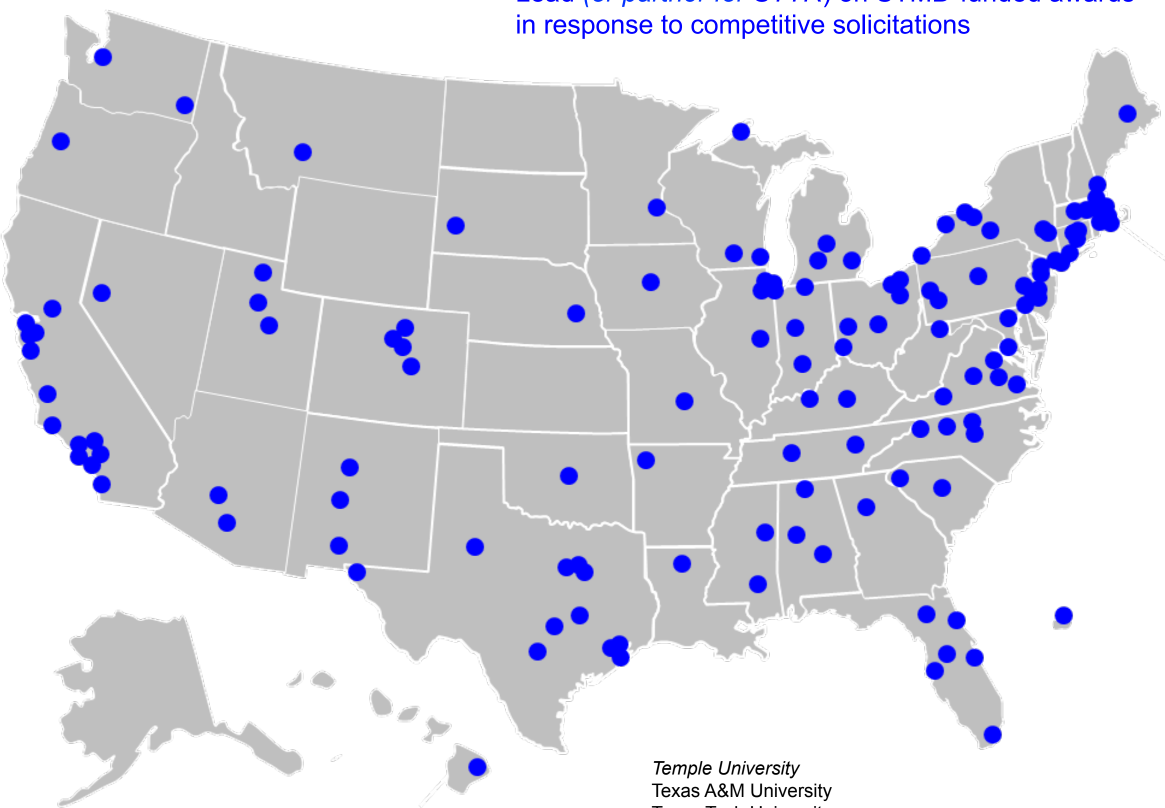
U.S. Universities have been *very* successful in responding to STMD's competitive solicitations

- 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 since 2011
- 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 	284	284	• 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 Cooperative Agreement Notice every two years, with the next opportunity 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*

STMD Engages Academia

Lead *(or partner for STTR)* on STMD-funded awards in response to competitive solicitations



Appalachian State University
Arizona State University
Auburn University
Boston University
Brigham Young University
Brown University
California Institute of Technology
California Polytechnic State University
California State University – Northridge
Carnegie Mellon University
Carnegie Mellon University-Silicon Valley
Carthage College
Case Western Reserve University
Clemson University
College of William and Mary
Colorado School of Mines
Colorado State University
Columbia University
Cornell University
Drexel University
Duke University
Embry-Riddle Aeronautical University
Florida Institute of Technology
Gannon University
George Mason University
Georgia Institute of Technology
Harvard University
Illinois Institute of Technology
Indiana University, Bloomington
Iowa State University
John Carroll University
Johns Hopkins University
Kent State University
Louisiana Tech University
Massachusetts Institute of Technology
Michigan State University
Michigan Technological University
Mississippi State University
Missouri University of Science & Technology
Montana State University
New Jersey Institute of Technology
New Mexico Institute Of Mining And Technology
New Mexico State University
North Carolina State University
Northeastern University
Northwestern University
Ohio State University
Oregon State University

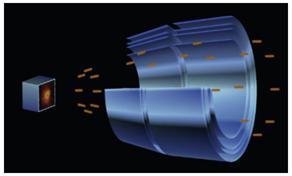
Pennsylvania State University
Princeton University
Purdue University
Rensselaer Polytechnic Institute
Rochester Institute of Technology
Rutgers University
South Carolina Research Foundation
South Dakota School of Mines and Technology
Southern Methodist University
Stanford University
State University of New York at Buffalo
State University of New York, College of Nanoscale Science & Engineering
State University of New York at Stony Brook

Temple University
Texas A&M University
Texas Tech University
United States Air Force Academy
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 California, Santa Cruz
University of Central Florida
University of Cincinnati
University of Colorado, Boulder

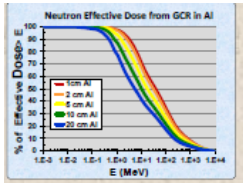
University of Connecticut
University of Delaware
University of Florida
University of Hartford
University of Hawaii
University of Houston
University of Houston Clear Lake
University of Illinois at Urbana-Champaign
University of Kentucky
University of Louisville
University of Maine
University of Maryland
University of Massachusetts
University of Massachusetts, Amherst
University of Massachusetts, Lowell
University of Miami
University of Michigan
University of Minnesota
University of Nebraska, Lincoln
University of Nevada
University of New Hampshire
University of New Mexico
University of Notre Dame
University of Oklahoma
University of Pennsylvania
University of Pittsburgh
University of Puerto Rico, Rio Pedras
University of Rochester
University of South Florida
University of Southern California
University of Southern Mississippi
University of Tennessee
University of Texas at Austin
University of Texas at Dallas
University of Texas at El Paso
University of Texas, Arlington
University of Texas-San Antonio
University of Utah
University of Virginia
University of Washington
University of Wisconsin-Madison
Utah State University
Vanderbilt University
Villanova University
Virginia Commonwealth University
Virginia Tech
Wake Forest University
Washington State University
West Virginia University
Western Michigan University
William Marsh Rice University
Worcester Polytechnic Institute
Wright State University
Yale University

Some Recent STRG Accomplishments

Autonomous navigation software was tested in a robot which traversed over 60 km in the Atacama Desert in Chile (NSTRF)

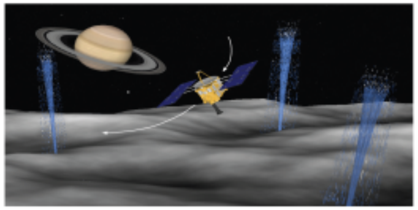


ZnO thin film transistors to simplify the control of future X-ray telescopes to achieve sub-arcsecond angular resolution (ESI)

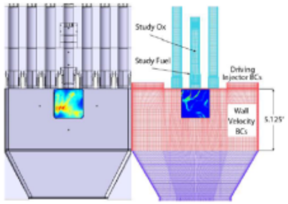


State-of-the-art model to assess potential effectiveness of emerging technologies for human radiation dosimtery (ESI)

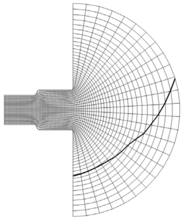
Polarization-sensitive receiver successfully installed on ACT telescope and saw first light in a test observation of Saturn (NSTRF)



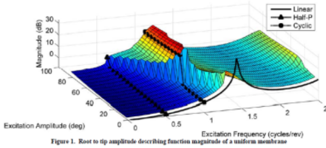
Novel motion planning algorithm which represents a significant advancement in the state-of-the-art for real-time planning of spacecraft trajectories in dynamic, high-dimensional environments (ECF)



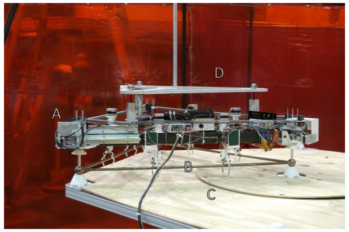
Seven-injector model to provide detailed insight into combustion instability in rocket engines (NSTRF)



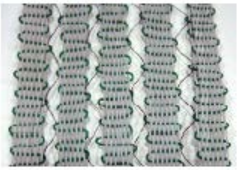
A more accurate model of Hall thruster discharge channel erosion at high discharge voltages (NSTRF)



Blade structure strategies for mitigating undesirable nonlinear high-amplitude torsional responses of heliogyro blades (NSTRF)

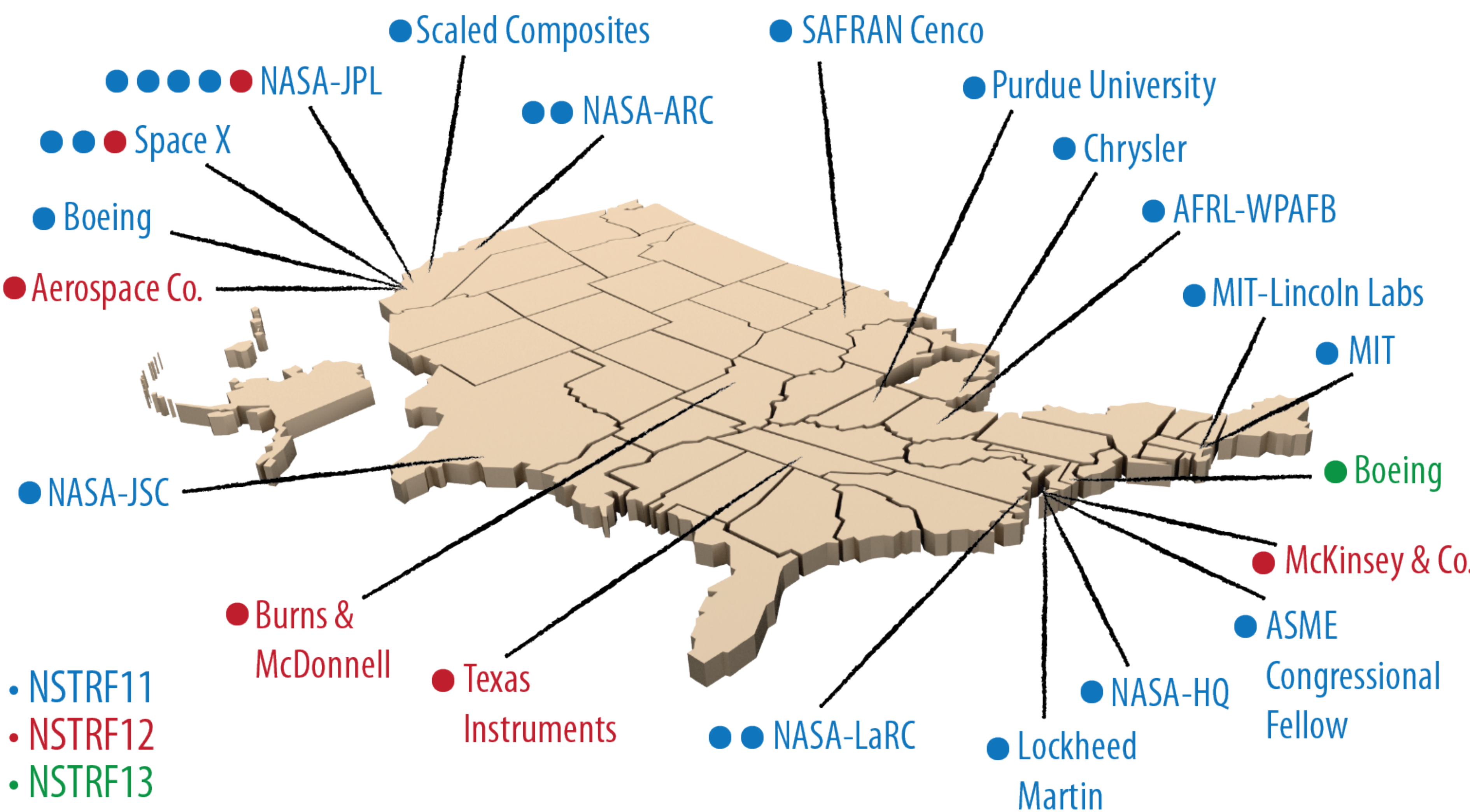


Assembly of a 2D truss using Intelligent Precision Jigging Robots to demonstrate methods for on-orbit precision assembly of very large structures (NSTRF)



Models integrating active and passive materials capable of achieving 30 kPa (4.3 PSI) compression to improve spacesuit mobility (NSTRF)

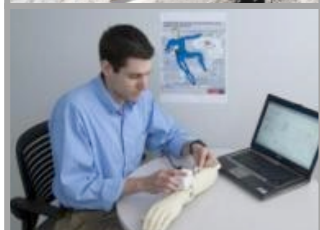
NSTRF completions – Where are they now?



Early Stage Portfolio: NIAC Benefits to the Nation

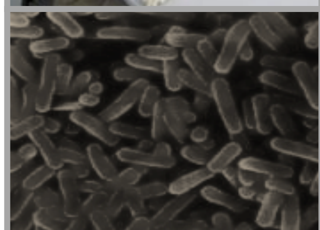
3D PRINTING THE HOME OF THE FUTURE

Emergency Construction for natural disasters, eradicate slums in developing countries



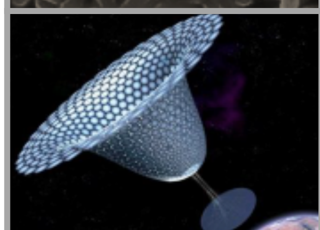
IMPROVING HEALTH WITH SPACESUIT TECHNOLOGY

Medical rehabilitation and physical therapy for those affected by stroke, spinal cord injuries, brain injuries, and the elderly



BACTERIAL BATTERIES

Novel Energy Source: Bacterial Microbes to power microbots



SPACE-BASED SOLAR POWER

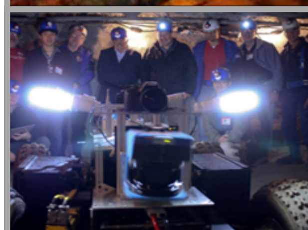
Power transmission to Earth during power outages, after natural disasters, to those in remote areas or by the military

NAVIGATION

Gravitational waves on the atomic level could lead to technology for better steering of military submarines or aircraft

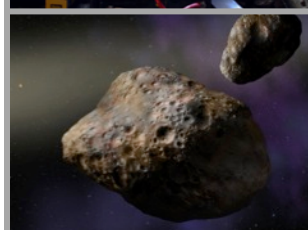
US NAVY Chief Technology Office

NIAC Fellows collaborating with and reporting new NIAC technology research to the CTO



ROBOTICS

Autonomous robots with radar, lasers and other advanced sensors serving as scouts for rescuers responding to underground mine disasters



Space Based “X-rays”

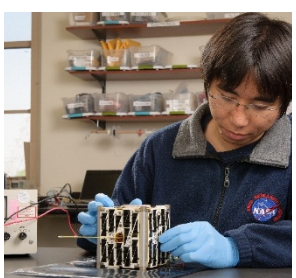
Muon tomography could help planetary defense experts analyze NEO’s, with space mining, or to assess volcanic activity and volatility.

New Technology Partner Activities

NASA STMD is fostering and engaging new technology partners and marketplaces with investments in innovative new technologies, sub-orbital flight opportunities, new challenges and private and government partnerships with the goal of changing the traditional space paradigm.

STMD investments in:

- Small Spacecraft Technologies that develops and demonstrates new capabilities employing the unique features of small spacecraft for science, exploration and space operations.
- Facilitating the progress of space technologies toward flight readiness status through testing in space-relevant, micro-gravity, environments. These activities foster development of the commercial reusable suborbital transportation marked while maturing space technologies.
- Offering challenges set up as competitions that award prize money to the individuals or teams that achieve a specified technology challenge to directly engage nontraditional sources to advance space technologies of value to NASA’s missions and to the aerospace community.

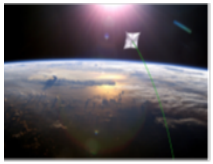
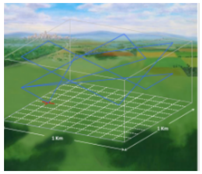
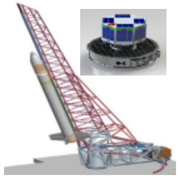
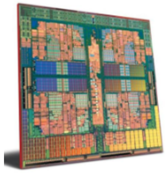


Working with Other Government Agencies

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)**
- Solar Sail Demonstration partnership with **NOAA**
- **AFRL** collaboration Phase I of a High Performance Space Computing for a low power multi-core processor increasing performance a 100 fold.
- UAS Airspace Operations Prize Challenge coordinated with **FAA**
- 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** on use of 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***.

Technology Drives Exploration
#321Techoff