National Aeronautics and
Space Administration

Space Technology Mission Directorate

Overview of STMD Human Exploration Content

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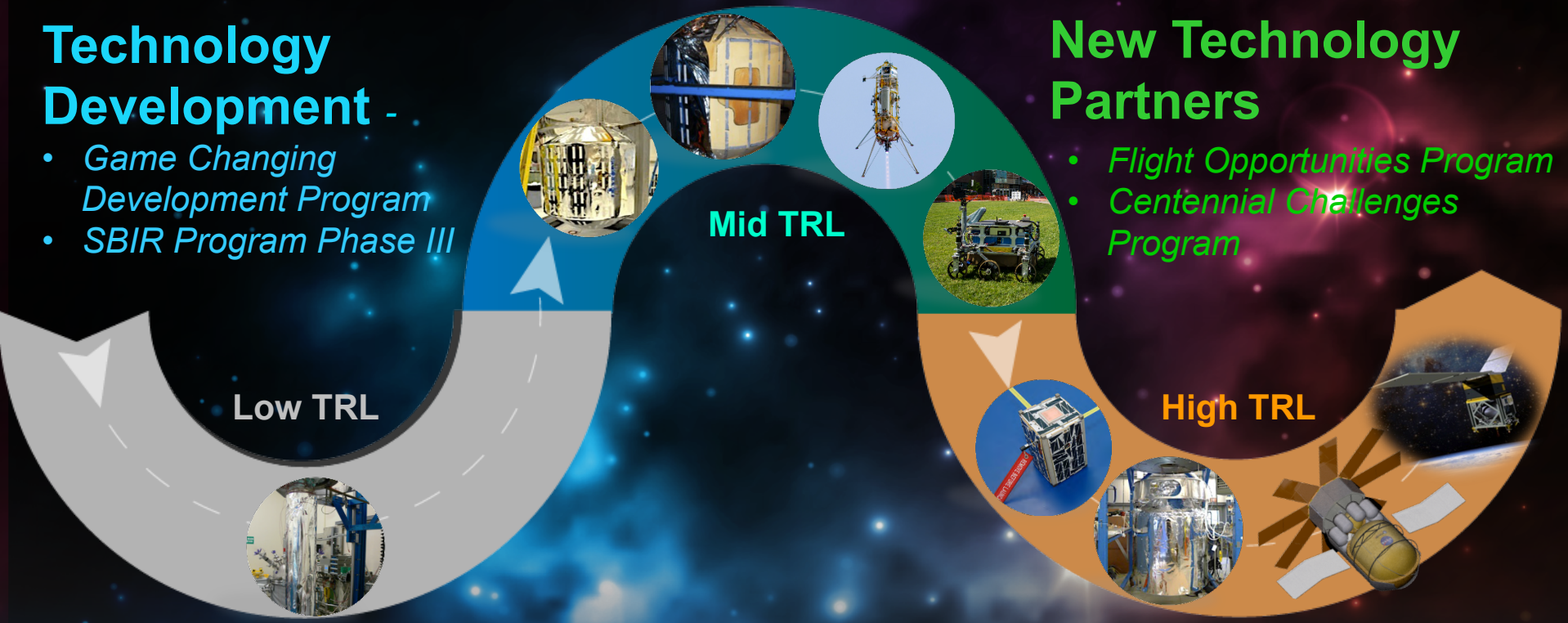
Deputy Associate Administrator
for Programs

5 May 2015

GCD Enables the Space Technology Pipeline

Technology Development -

- *Game Changing Development Program*
- *SBIR Program Phase III*



New Technology Partners

- *Flight Opportunities Program*
- *Centennial Challenges Program*

Early Stage

- *NASA Innovative Adv Concepts Program*
- *Space Tech Research Grants Program*
- *Center Innovation Fund Program*
- *SBIR Program Phases I & II*

Technology Demonstrations

- *Technology Demonstration Systems*
- *Small Spacecraft Technologies*

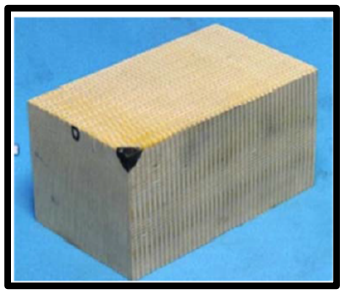
TECHNOLOGY PIPELINE

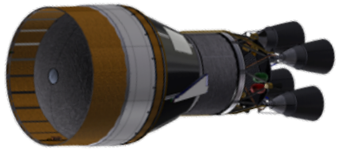
HEOMD Alignment

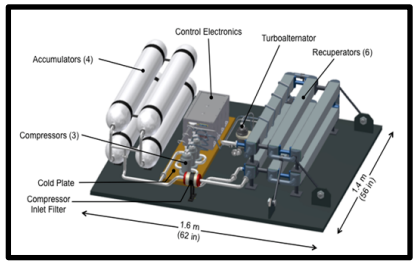
- Use ISS as a technology demonstration platform
- Develop targeted technologies to advance future capabilities of Orion and SLS
- Partner with AES and SCaN to develop next-generation capabilities
- Develop critical technologies for human exploration of Mars

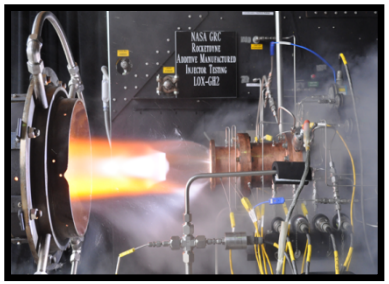
Advancing Future Capabilities of Orion and SLS

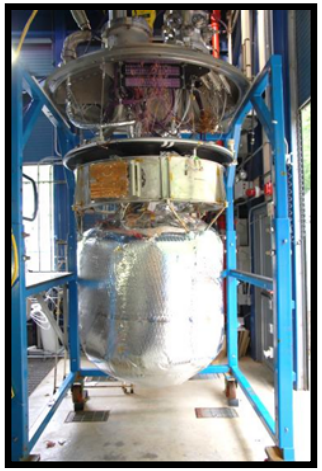
- Composite Cryogenic Propellant Tank and Composite Evolvable Upper Stage projects developing composite technologies for future SLS upgrades
- Evolvable Cryogenics (eCryo) project developing advanced cryogenic propellant management technologies for future SLS missions
- Additive manufacturing projects developing low-cost components for upper-stage engines for potential SLS infusion
- Phase Change Material Heat Exchanger project developing lightweight heat exchangers for potential use in Orion thermal control system
- 3-D Woven Ablative Thermal Protection System project developing compression pad for Orion crew module / service module interface
- Advanced Oxygen Recovery solicited projects developing technologies for long-duration life support systems





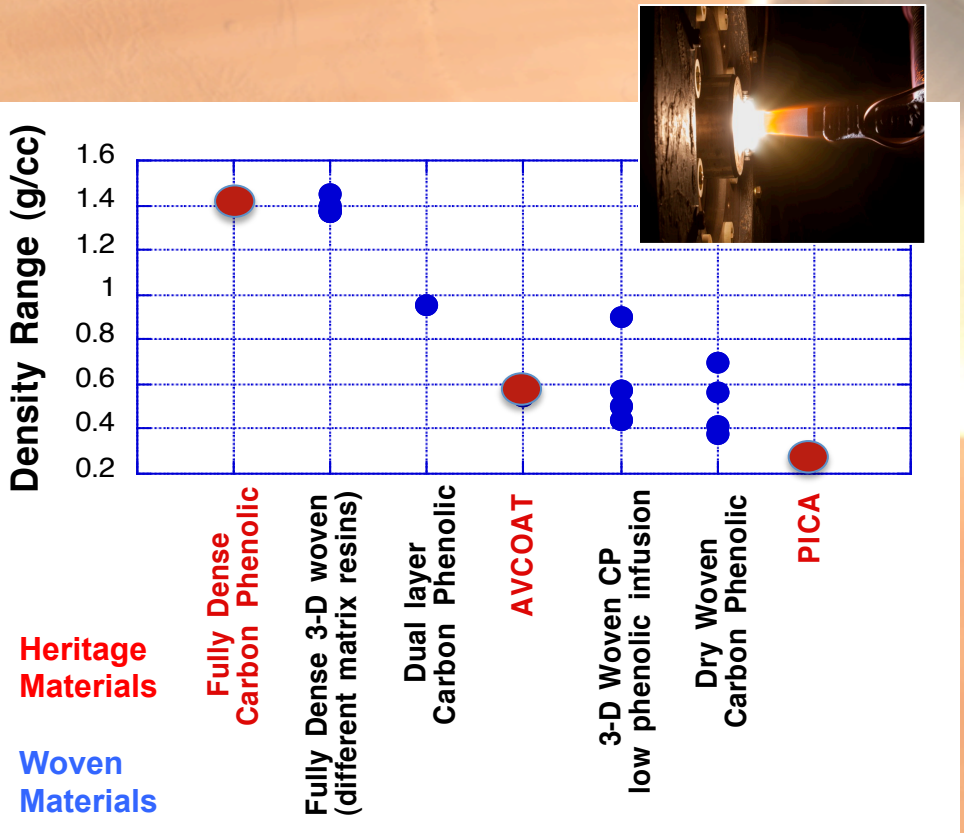






Woven Thermal Protection System

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



- **Highly compliant ablative woven TPS materials containing phenolic resins (dry woven, no resin infusion)**
  - Reduces TPS integration challenges
  - Addresses common TPS cracking issues
- **Woven TPS will reduce mass for future exploration missions**
  - Orion compression pads are first application
  - Improved performance / mass
  - Ability to tailor TPS through the thickness
- **Example of successful transition from a Center Innovation Fund to Game Changing**

Dry Woven TPS
2” diameter, 1650 W/cm^2, 1.3 atm

Phase Change Material Heat Exchangers

- The thermal control system for a vehicle in low Lunar orbit requires a supplemental heat rejection device
- Large-scale flow-through phase change materials heat exchangers have not been demonstrated in microgravity
  - Orion has identified this as a key project risk for EM-2
- STMD is developing phase change material heat exchangers for demonstration on ISS and use on Orion
  - Baseline heat exchanger with wax
  - Enhanced heat exchanger with water
- Water-based version is advantageous for exploration missions
  - 45% reduction in heat exchanger volume
  - 40% reduction in heat exchanger mass

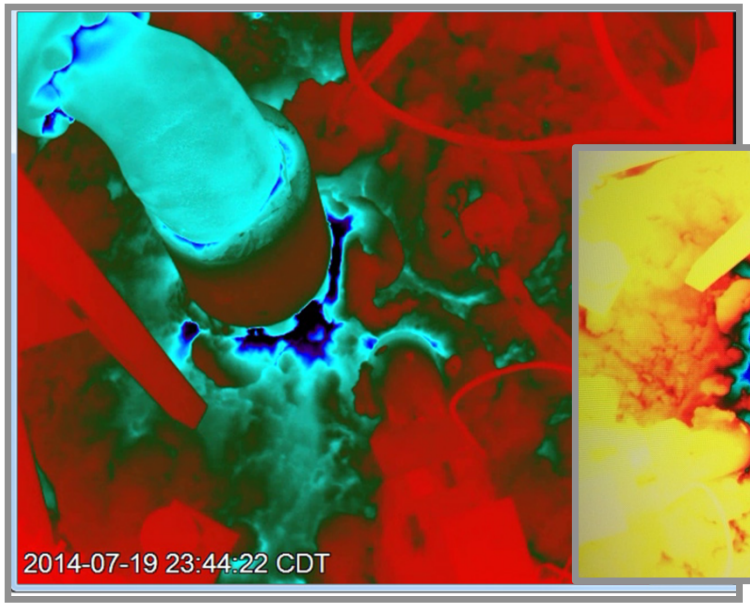
- Heat exchanger developed via partnership (cost sharing) between GCD, SBIR, AES, and ISS
  - Subcontract to vendor for wax-based version (delivery to ISS in 18 mo)
  - Subcontract to SBIR firm for water-based version (delivery to ISS in 33 mo)
- Heat exchangers will be assessed on ISS and infused into Orion for EM-2

Wax-Based PCM HX

Water-Based PCM HX

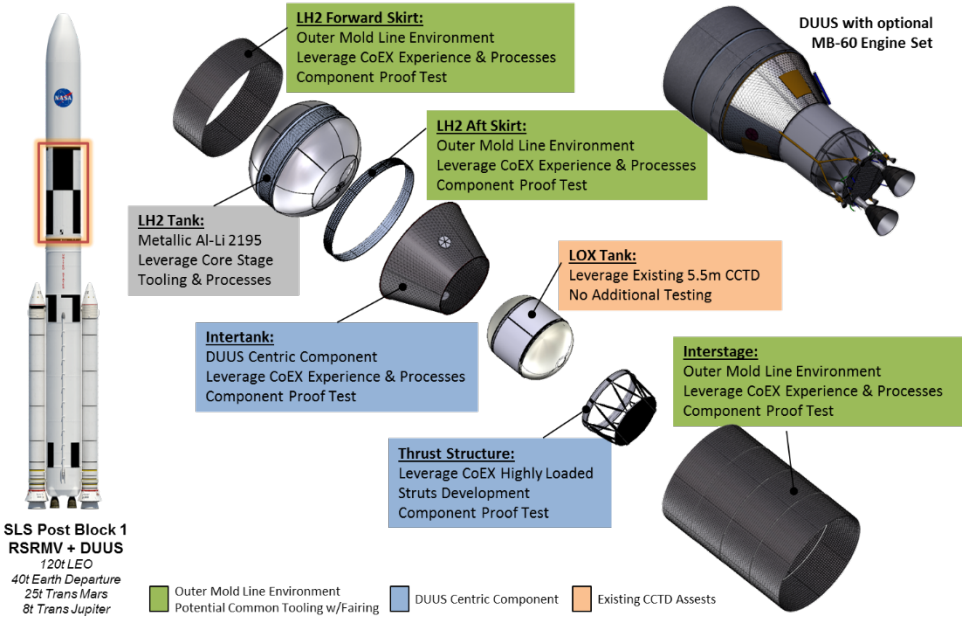
Composite Cryogenic Propellant Tank Test Success

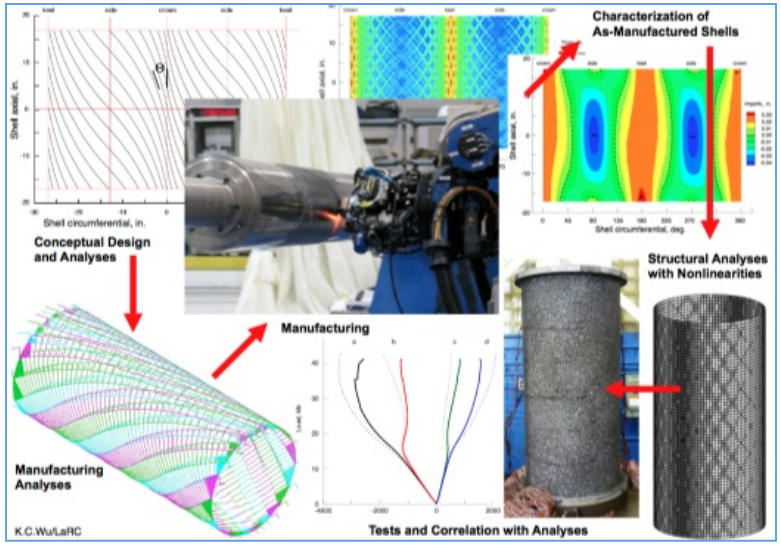
- Successfully completed cryogenic testing of 5.5 m tank
  - Tank pressurized to ~60 psi with LH2 through multiple cycles
  - 5000 microstrain test objective was achieved
- Compared to metallic propellant tanks, composites offer 30% mass and 25% cost reduction
- Employed out-of-autoclave fabrication for scalability and affordability
- Target utilization is SLS upper stage upgrade and commercial vendors



Composite Exploration Upper Stage Project

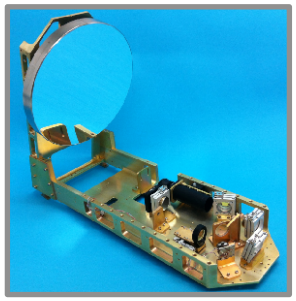
- The Composite Exploration Upper Stage project will build 8.4-meter diameter composite hydrogen tank skirts as pathfinders for eventual SLS composite upper stage elements
- The project is a partnership between STMD, AES, and SLS and it will leverage collaborations with industry, academia, and DOD

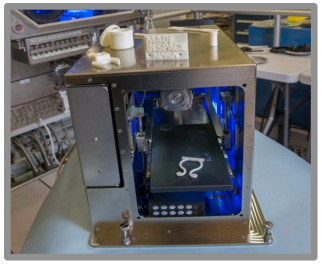




Partnerships with AES and SCaN

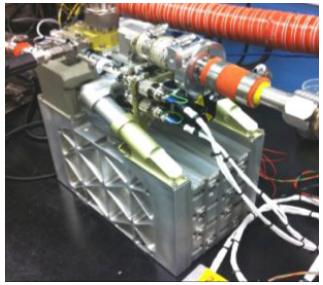
- **Laser Communications Relay Demo** – Partnership with SCaN to develop optical communications upgrade for Deep Space Network
- **Deep Space Atomic Clock** – Partnership with SCaN for higher precision navigation for future missions and upgraded GPS capability
- **Advanced Mobility Rover** – Partnership with AES to develop a prototype autonomous or 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
- **Mars Entry, Descent, & Landing Instrumentation (MEDLI) 2** – Partnership with AES and SMD to gather aerothermal performance data
- **Soft Goods Hatch for Inflatable Airlock** – Partnership with AES to develop soft hatch technology for an inflatable airlock
- **Phase Change Material Heat Exchanger** – Partnership with AES, ISS and Orion to develop lightweight heat exchanger
- **Advanced Oxygen Recovery** – Partnership with AES for future closed loop oxygen recovery
- **Advanced Portable Life Support System Components** – Partnership with AES to deliver component technologies for next-gen EVA suits



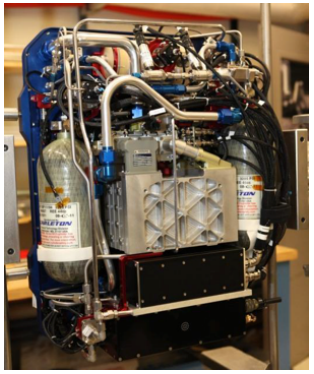


High-Performance EVA Technologies for PLSS and Other Uses

- **STMD is developing high-performance EVA technologies for Portable Life Support System and other implementations**
  - **Variable oxygen regulator**
    - Reduced mass regulator that enables more flexible EVA suit design
    - Increases pressure settings from 2 to more than 4000
    - FY 2015 deliverable to AES
  - **Rapid cycle amine**
    - Integrated CO2 and humidity control system
    - Eliminates consumables and need for off-suit regeneration
    - FY 2015 deliverable to AES
  - **High performance EVA gloves**
    - Longer life gloves with improved mobility and reduced risk of crew injury
    - FY 2016 deliverable to HEOMD



Rapid cycle amine



Portable life support system

Variable oxygen regulator

Soft Goods Hatch for Inflatable Airlock

State of the Art:

- NASA Advanced Inflatable Airlock program (2003)
- Androgynous Docking Airlock Module proposal (2009)

Problem / Technical Challenges:

- Soft goods hatch to reduce mass
- Compact packaging and storage
- Depressurization/pressurization

Collaborators: LaRC, JSC, ARC, industry

Objective: Develop and demonstrate critical airlock technologies: hatch, seal, and packaging

Approach: Leverage existing work from structures efforts in NASA and industry. Target focus on hatch system to reduce mass and volume.

Impact:

- Airlock with minimal impact on launch volume
- Alleviate need to decompress primary vehicle for EVA's (and hard vacuum requirements for internal equipment) **30% atmosphere loss per cycle.**
- Reduce mass compared to traditional airlocks

Deliverables:

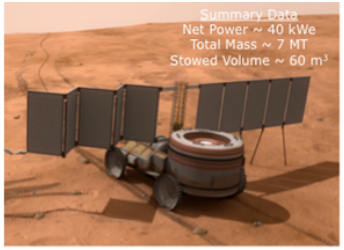
- Trade systems results (FY14): Consider all ultralightweight airlock concepts and down select
- Concept development for hatch and support structure (FY15)
- Demonstrate hatch and support structure (FY16)

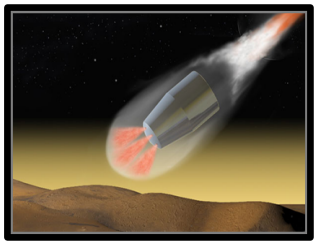
Tech Infusion: AES / Exploration Augmentation Module

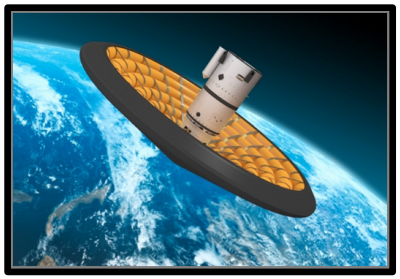
Potential Customers: AES, Orion, Space-X, others

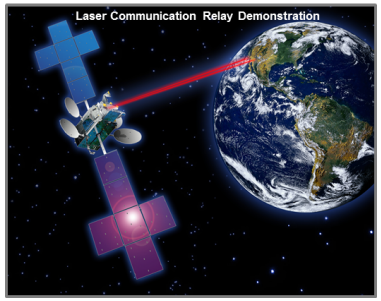
STMD Investments To Advance Human Exploration of Mars

- **High Power Solar Electric Propulsion** – Mars cargo and logistics transportation
- **Small Fission Power / Stirling Cycle** – Mars surface power
- **Hypersonic Inflatable Aerodynamic Decelerator (HIAD) and Adaptable Deployable Entry Placement Technology (ADEPT)** – Deployable entry systems for large payloads
- **Low Density Supersonic Decelerator** – Aerodynamic decelerator for Mars payloads
- **Supersonic Retropropulsion** – Descent phase for large payloads at Mars
- **Woven Thermal Protection System** – Efficient and flexible TPS materials for Mars entry
- **Closed Loop Air & Water Recovery** – Consumable reduction for long-duration missions
- **Mars Oxygen In Situ Resource Utilization Experiment (MOXIE)** – life support and ascent vehicle oxidizer
- **Humanoid Robotics** – Reduce work load on crew and multiply workforce for long-duration missions
- **Optical communication** – High bandwidth communication for long-duration missions
- **Advanced Spaceflight Computing** – New high-performance radiation hardened processor for deep space missions





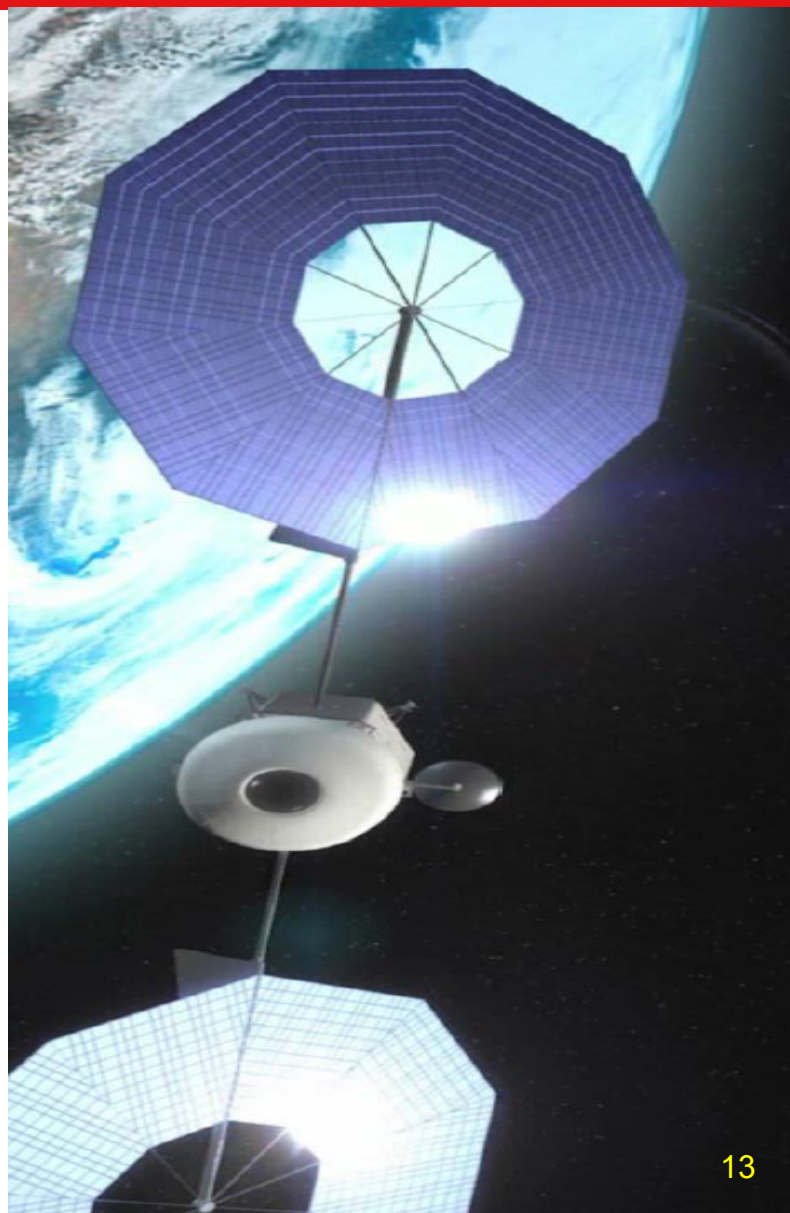




High Power Solar Electric Propulsion

Cross-cutting SEP development and demonstration objectives:

- **Develop & demonstrate a 25-50 kW class SEP tug**
  - Extensible to 150-300 kW for deep space human exploration
  - Directly applicable to SMD & other government agency missions
  - First demonstration targeted for the Asteroid Redirect Mission
- **Develop & demonstrate SEP component technologies that benefit the commercial sector**
  - Deployable solar arrays with reduced mass and efficient packaging for improved commercial satellite affordability and potential ISS retrofitting
  - High-power Hall thrusters for all-electric commercial satellites



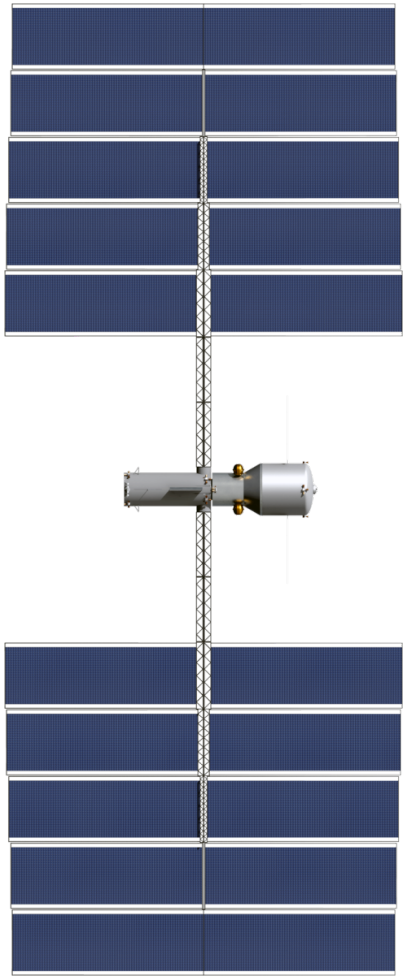
Solar Electric Propulsion for Mars Missions

Major considerations related to using SEP for Mars missions:

- Very high propellant usage efficiency (specific impulse 2000 to 4000+ s)
- Reduces number of SLS launches needed for human Mars mission by as much as 50% by splitting crew and cargo transit
- Developing key technologies (arrays, thrusters) to meet emerging industry needs can provide a stepping stone to scaling up for exploration missions
- Very low thrust compared to chemical and nuclear thermal options so trip times are too long for crew transport

Major technology development needs:

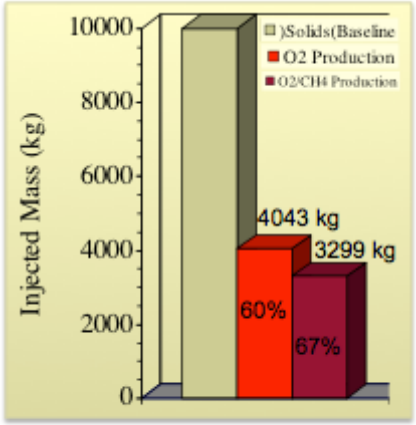
- Very large solar array (100+ kW) development / demonstration
- High-power (50-100 kW class) thruster development / demonstration
- Power processing system development / demonstration
- Propellant tank development / demonstration



Mars Oxygen In Situ Resource Utilization Experiment (MOXIE)

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*

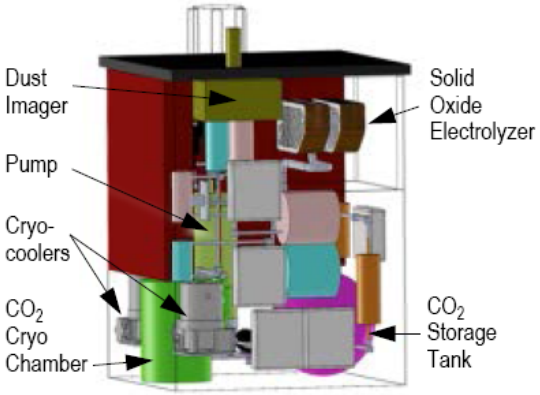


Ref: Stancati, et. al. "In Situ Propellant Production for Improved Sample Return Mission Performance," AAS 79-117, 1979

*Aerojet report

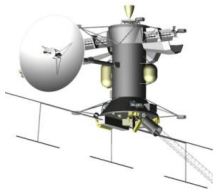
Approach:

- STMD is partnered with AES & SMD to develop and demonstrate an ISRU payload on the 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 $15 M

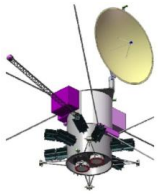


Small Fission Technology Demonstration

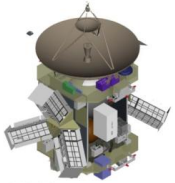
- Reliable, affordable, long-life, and abundant power is required for future exploration missions
- Fission power has been identified as a critical NASA need
- Project will demonstrate a compact, low cost, scalable fission reactor for science and human exploration
- Approach:
  - Novel integration of available U-235 fuel form, passive sodium heat pipes, & Stirling converters
  - Reduces NASA dependence on Pu-238
  - Enables SMD decadal survey missions
  - Provides modular option for human Mars missions



Jupiter Europa Orbiter

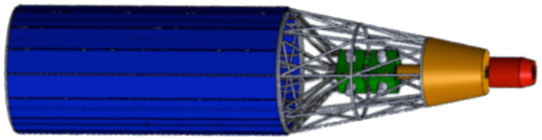


Kuniper Belt Object Orbiter

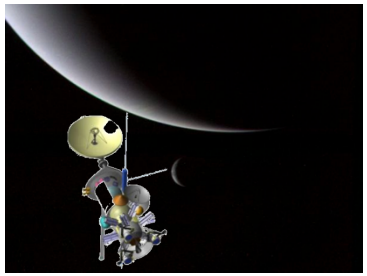


Trojan Tour

- Proposed system is directly applicable to SMD missions and scalable for HEOMD missions
  - Provides 10x the power of current RPS
  - Environmentally insensitive



Small Fission Power System



- Development effort is collaboration between GRC, MSFC, Los Alamos, and Oak Ridge with SMD support for Stirling power convertors and DOE/NNSA support for fuel & test facility
- Three-year and three-step development process to demonstrate small fission power
  - First Year – Component tests
  - Second Year – Non-nuclear integrated test
  - Third Year – Nuclear integrated test

Advanced Oxygen Recovery for Spacecraft Life Support

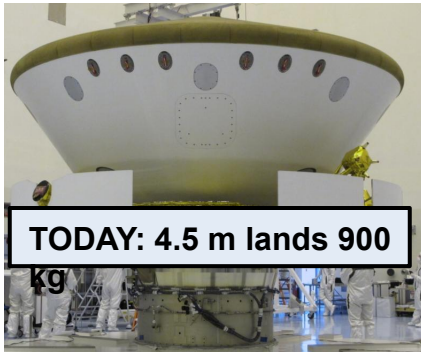
- NASA state-of-the-art spacecraft oxygen recovery is the Sabatier process
  - Carbon dioxide reacted with hydrogen (H_2) to produce water & methane (CH_4)
  - CH_4 is vented resulting in a net loss of H_2
  - Without additional H_2, O_2 is lost as unreacted CO_2
  - Sabatier has poor reliability & recovers only ~42% of the available oxygen
- Future exploration missions require reliable life support with a higher level of loop closure
- Development approach:
  - Four projects aimed at building and testing engineering development units incorporating reliable technologies offering at least 75% oxygen recovery were selected in Oct 2014
  - Two teams will advance to the development of prototypes for performance evaluation by HEOMD
  - Development schedule allows for an ISS demonstration in ~2021

Advanced reactor testing at MSFC

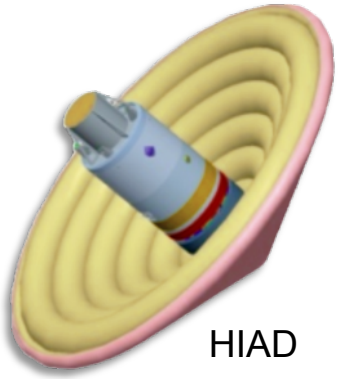
Reactor cartridge containing catalyst & solid carbon product

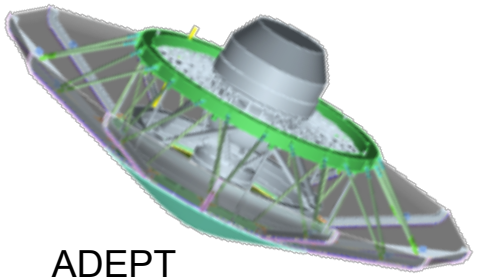
Entry Systems for Human Mars Missions

- 1970s Viking-era entry, descent, and landing technologies are inadequate for payloads larger than MSL-sized spacecraft
  - Rigid aeroshells constrained in size by launch shrouds do not provide enough surface area to slow down a human-scale Mars lander (20,000-40,000 kg)
  - 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 systems to enable human Mars missions
  - **Hypersonic inflatable aerodynamic decelerator (HIAD)**
    - Inflatable tori with overlaid thermal protection system
    - Flight tested at 3 m scale (IRVE-2, IRVE-3 projects)
    - Currently about TRL 4 for human scale
  - **Adaptive deployable entry and placement technology (ADEPT)**
    - Mechanically deployed structure with carbon fabric skin
    - Flight test of 1 m article planned for FY16
    - Currently about TRL 2 for human scale


HIAD

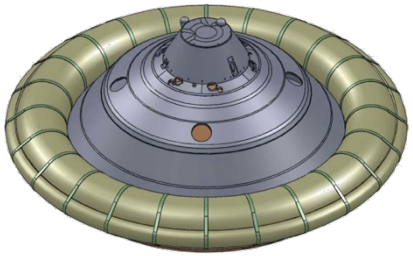

ADEPT

- Both systems are folded for launch and deployed before Mars entry to provide an essentially rigid aerodynamic surface and the heating protection needed for hypersonic entry

Descent Systems for Human Mars Missions

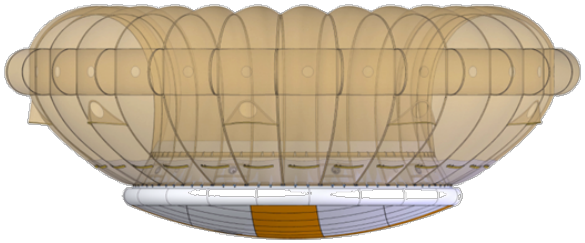
LDSD's technologies will serve as the foundation of supersonic decelerators for the next several decades

SIAD-R



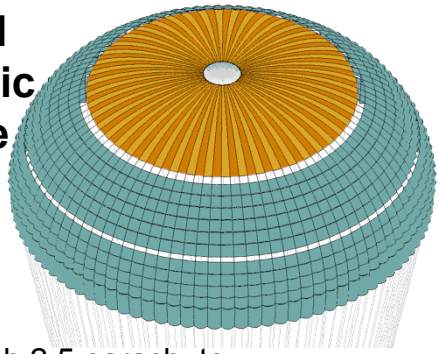
- 6 m, Mach 3.75 inflatable decelerator
- Negligible aeroelastic deformation
- 50% increase in drag area over MSL

SIAD-E



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

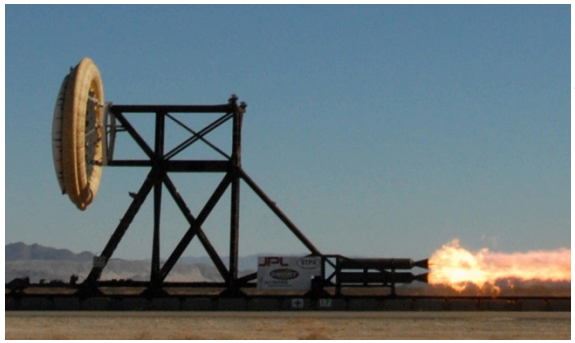
Advanced Supersonic Parachute



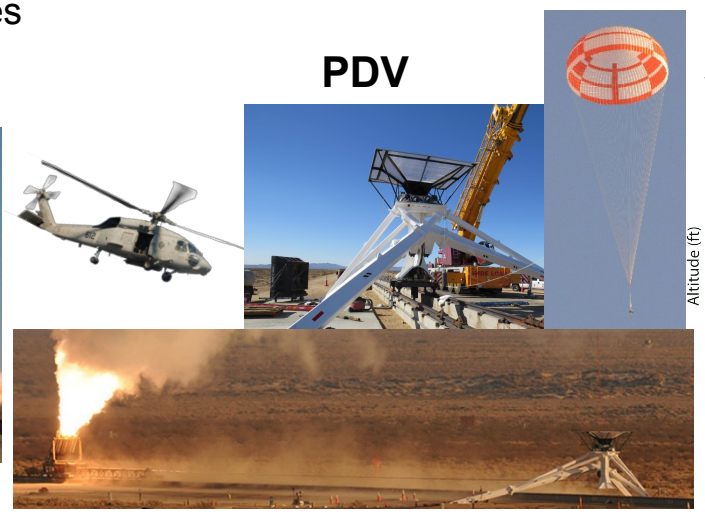
- 30.5 m, Mach 2.5 parachute
- Extensible to reefing and clusters
- 2.5x drag area of MSL parachute

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

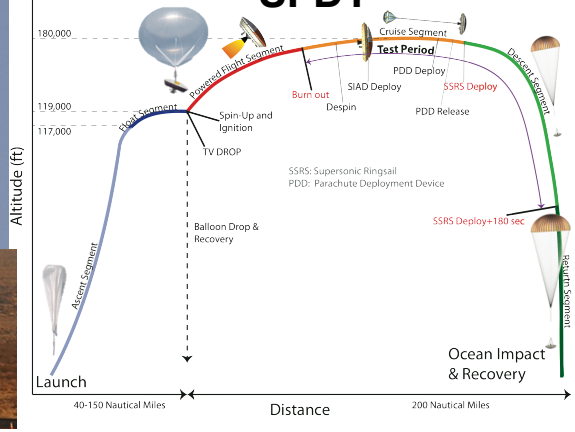
SDV



PDV



SFDT



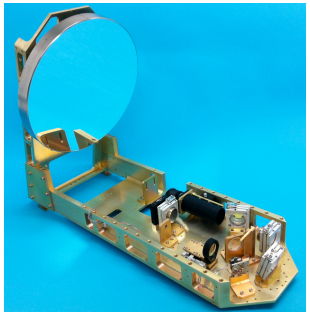
Deep Space Optical Communication

- Existing communications technologies cannot support the high data rates (for example, high definition video) required for future deep space exploration missions

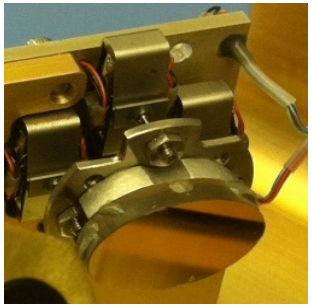
- STMD is developing solutions to the three key technologies:
  - Spacecraft disturbance isolation platform for sub-microradian pointing
  - Photon-counting space receiver to increase sensitivity by 10x and uplink from 100 b/s to multi-Mb/s
  - Ground receiver detector array suitable for multi-meter Earth optical receiver antenna

- STMD is partnering with HEOMD and SMD to develop and demonstrate a DSOC system
  - STMD/GCD, HEOMD, and SMD are co-funding the advancement of DSOC to TRL 6 for infusion into Discovery 2014
  - SMD is providing $30 M incentive to include DSOC in Discovery 2014 proposal; STMD/TDM will develop DSOC flight hardware and will provide it as GFE to Discovery 2014

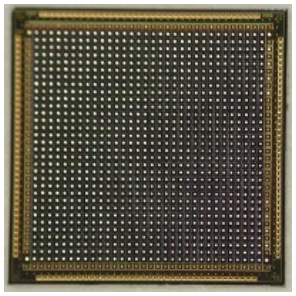
- The solution being pursued will demonstrate a tenfold data rate increase over an equal mass, volume, and power Mars Reconnaissance Observer Ka-band communication system



Optics assembly



Point-ahead mirror



Photon-counting space receiver

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