National Aeronautics and
Space Administration

Technology, Innovation & Engineering Committee Report
NASA Advisory Council

Presented by:
Dr. Bill Ballhaus, Chair

July 31, 2015

TI&E Committee Meeting Attendees
July 27-28, 2015

- Dr. William Ballhaus, Chair
- Mr. Gordon Eichhorst, Aperios Partners
- Mr. Michael Johns, Southern Research Institute
- Mr. David Neyland, Consultant
- Mr. Jim Oschmann, Ball Aerospace & Technologies Corp.
- Dr. Mary Ellen Weber, STELLAR Strategies, LLC

Absent: Dr. Matt Mountain, Association of Universities for Research in Astronomy

TI&E Committee Meeting Presentations July 27-28, 2015

- Joint Session with HEOMD (STMD Overview, HEO Tech Development Efforts, Hydrocarbon Engine Overview, NASA Launch Services Overview)
- Welcome Remarks
  - Dr. Charles Elachi, Director, JPL
- Space Technology Mission Directorate Status and Update
  - Mr. Stephen Jurczyk, Associate Administrator, STMD
  - Dr. James Reuther, Deputy Associate Administrator for Programs, STMD
- Update on Deep Space Optical Communications Project
  - Mr. Thomas Glavich, Project Manager, JPL
- Update on Deep Space Atomic Clock Project
  - Dr. Todd Ely, Principal Investigator, JPL
  - Mr. Allen Farrington, Project Manager, JPL
- Update on Low Density Supersonic Decelerator Project
  - Dr. Mark Adler, Project Manager, JPL
  - Dr. Ian Clark, Principal Investigator, JPL
- Chief Technologist Update
  - Dr. David Miller, NASA Chief Technologist
- Working Lunch with JPL NASA Space Technology Research Fellows

National Aeronautics and
Space Administration

Space Technology Mission Directorate

Joint HEO/TI&E NAC Committee Session

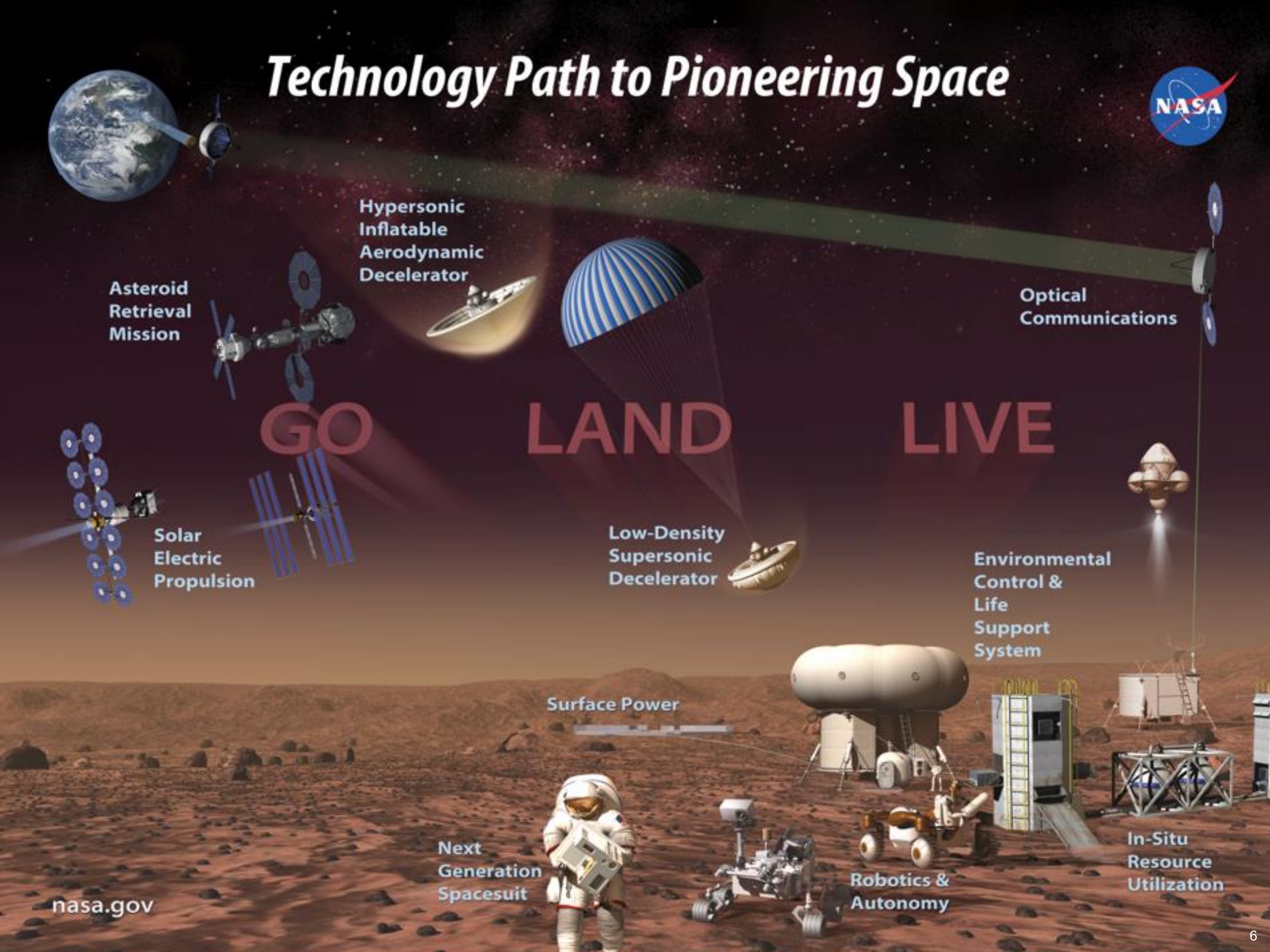
Mr. Stephen Jurczyk
Associate Administrator

July 2015

www.nasa.gov/spacetech

Guiding Principles of the Space Technology Programs

- **Adhere to a Stakeholder Based Investment Strategy:** NASA Strategic Plan; NASA Space Tech Roadmaps / NRC Report; NASA Mission Directorate / Commercial advocacy
- **Invest in a Comprehensive Portfolio:** Covers low to high TRL; Grants & Fellowships; SBIR & prize competitions; prototype developments & technology demonstrations
- **Advance Transformative and Crosscutting Technologies:** Enabling or broadly applicable technologies with direct infusion into future missions
- **Develop Partnerships to Leverage Resources:** Partnerships with Mission Directorates and OGAs to leverage limited funding and establish customer advocacy; Public – Private Partnerships to provide NASA resources and support to U.S. commercial aerospace interests
- **Select Using Merit Based Competition:** Research, innovation and technology maturation, open to academia, industry, NASA centers and OGAs
- **Execute with Lean Structured Projects:** Clear start and end dates, defined budgets and schedules, established milestones, lean development, and project level authority and accountability.
- **Infuse Rapidly or Terminate Promptly:** Operate with a sense of urgency; Rapid cadence of tech maturation; informed risk tolerance to implement / infuse quickly or terminate
- **Place NASA at technology's forefront – refreshes Agency's workforce:** Results in new inventions, enables new capabilities and creates a pipeline of NASA and national innovators, and refreshes the agencies technical capabilities / workforce


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

STMD & AES Development Objectives

Exploration Technology Development element in STMD

- Develop long-range foundational and transformative technologies and components to support exploration needs (GCD program)
- Conduct flight demonstration missions of high-priority exploration capabilities such as solar electric propulsion (TDM program)
- Mature technologies for infusion into mission-level programs and agency initiatives such as ISS, Orion, SLS, and ARM
- Leverage synergies with game-changing and crosscutting technologies to support multiple customers and mission applications such as SMD, other government agencies, and the commercial sector

Advanced Exploration Systems program in HEOMD

- Development of exploration systems to reduce risk, lower lifecycle cost, and validate operational concepts for future human missions beyond Earth orbit
- Demonstrate prototype systems in ground test beds, field tests, underwater tests, and ISS flight experiments
- Use and pioneer innovative approaches for affordable rapid systems development and provide hands-on experience for the NASA workforce
- Maintain critical competencies at the NASA Centers and provide NASA personnel with opportunities to learn new and transform skills
- Infuse new STMD/ETD-developed technologies into exploration missions and AES test beds
- Support robotic missions of opportunity to characterize destinations for human exploration

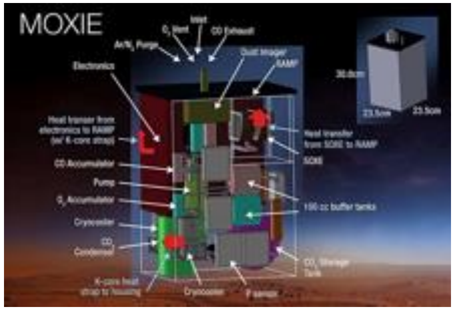
AES – STMD Cooperation Status

Three major categories of STMD and AES cooperation:

- **Deliveries:** STMD matures technology and delivers to AES for system-level evaluation
  - Examples include Rapid Cycle Amine, Variable Oxygen Regulator, EVA Gloves, and Resource Prospector Mission instruments

- **Partnerships:** STMD and AES co-fund the development of technologies that are of mutual interest
  - Examples include Mars Oxygen ISRU Experiment (MOXIE), Mars EDL Instrumentation 2 (MEDLI-2), and Spacecraft Oxygen Recovery

- **Coordinations:** STMD and AES define specific divisions of responsibility within a technical discipline area
  - Examples include nuclear systems and advanced manufacturing



Historical Consequences of STMD Funding Shortfalls

James Reuther

Deputy Associate Administrator for Programs

NASA Space Technology Mission Directorate

July 28, 2015

Funding Limitations Significantly Delay Critical Tech Demos

- **High Power Solar Electric Propulsion**
  - Critical and enabling for human mission to Mars (needed for beyond earth-moon system Exploration)
  - Immediate need for 25 kW to 50 kW flight demo needed with extensibility to 150 kW to 300 kW
  - Crosscutting with strong Science, OGA and Commercial interests
  - Key technologies: low-mass solar arrays, high power Hall thrusters and PPUs
- **Long Duration Cryogenic Propellant Storage and Transfer**
  - Critical and enabling for human missions to Mars (desirable for beyond LEO exploration, required for beyond earth-moon system exploration)
  - Immediate need for passive cooling & mass gaging demo for beyond LEO, 5 year need for active cooling for beyond earth-moon system
  - Crosscutting with Commercial and OGA interests
  - Key technologies: Passive cooling MLI blankets, Zero-G mass gaging, High power active cooling, Zero-G propellant transfer
- **Mars Large Entry Mass EDL System**
  - Critical and enabling for human missions to Mars
  - Minimum 15 mT to Mars surface needed for current human Mars surface mission studies
  - Immediate need to start scaled deployable entry system demo, 5 year need to start SRP demo
  - Key Technologies: Deployable 20m class entry system, flexible TPS, supersonic retro propulsion

Funding Limitations Significantly Delay Critical Tech Demos

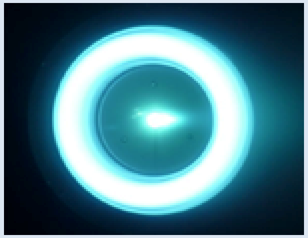
- **In-Situ Resource Utilization**
  - Mars atmospheric CO_2 to O_2 conversion critical and enabling for humans to Mars
  - Water from lunar and Mars regolith likely highly desirable
  - Immediately needed micro scale CO_2 to O_2 demonstration planned for Mars 2020
  - Large scale development system needed within 5 years
  - Key Technologies: atmospheric CO_2 to O_2 conversion, regolith water extraction and coversion
- **Highly-Reliable Closed-Loop Environmental Control and Life Support**
  - Critical and enabling for humans to Mars
  - Immediate need to start development ahead of complete system demonstration on ISS by 2020
  - Key Technologies: CO_2 removal, CO_2 to O_2 conversion, water and brine processing
- **Advanced Surface Power system**
  - Critical and enabling for humans to Mars
  - Minimum 20 kW surface power for ECLS and ISRU plant needed for human mission to Mars
  - Key technologies: Highly-reliable, low-maintenance fission power, Stirling cycle power converter, high specific energy batteries

Funding Limitations Significantly Delay Critical Tech Demos

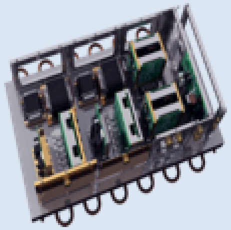
- **Optical Communications**
  - Deep Space Optical Communications critical for all future planetary missions – particularly for Mars and Europa missions where comm. Will be the limiting factor in the return of science data
  - GEO class optical system needed for next generation TDRS
  - Immediate need to perform demonstrations for both GEO and Deep Space systems
  - Strong crosscutting commercial, Astrophysics and OGA needs for GEO and LEO class systems
  - Key Technologies: GEO class relay system, vibration isolation, laser transmitters, and photon counting receivers for deep space system
- **Coronagraph for Exo-planet Atmospheric Characterization**
  - Critical need for a coronagraph for AFTA / WFIRST
  - Coronagraph development underway ahead of mission PDR
  - Success on AFTA / WFIRST will lead to eventual larger exo-planet mission
- **Icy Moon Lander Technologies**
  - Surface and sub-surface missions to our planets water worlds will require power, mobility, automation, instrumentation and communications capabilities that do not exist today
  - Immediate needs exist to begin technology development and leverage demonstration opportunities
  - Key Technologies: Deep Space Atomic Clock, High Performance Spaceflight Computing, Autonomous Landers, Icy Terrain Mobility and Penetration, Power generation and storage, Deep Space Optical Communications

STMD Investments in SEP

Thrusters

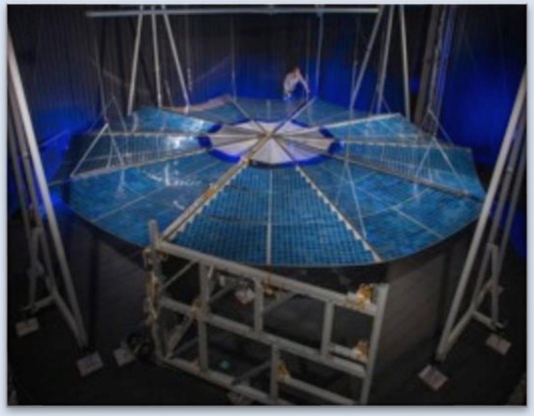


Power Processing Units



- Developed and tested high power Hall thruster 12.5 kW-class (2X current SOA)
- Magnetically shielded design to provide long life

Solar Arrays

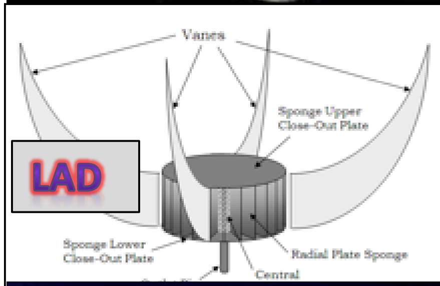


Designed, built and tested 25-kw-class advanced deployable Solar Array wings

- MegaFlex "fold out" array (ATK)
- Mega-ROSA "roll out" array (DSS)

Present Challenges for In-Space Cryogenic Systems

- We have no demonstrated capability to store cryogenic propellants in space for more than a few hours
  - SOA is Centaur's 9 hours with boil-off rates on the order of 30% per day
- We have no demonstrated, flight-proven method to gauge cryogenic propellant quantities accurately in microgravity
  - Need to prove methods for use with both settled and unsettled propellants
- We have no proven way to guarantee we can get gas-free liquid cryogens out of a tank in microgravity
  - Gas-free liquid is required for safe operation of a cryo propulsion system
  - Need robust surface-tension **liquid acquisition device (LAD)** analogous to those in SOA storable propulsion systems
  - Only known experience in the world is the single flight of the Russian Buran single flight (liquid oxygen reaction control system)
- We have no demonstrated ability to move cryogenic liquids from one tank (or vehicle) to another in space



Note → A flight demonstration with cryogenic propellant storage, expulsion, and transfer can remedy these problems (*and other more subtle ones*)!

CPST vs. eCryo

CPST

- Flight Demonstration utilizing SpaceX Dragon Trunk
- **Storage (Active and Passive) and Transfer Technologies evolve from TRL 5 to 7**
- Payload size: 224 kg LH2 (vs. 20 kg), 1.5 m diameter tank (vs. .3m diameter)
- Mission Duration: 1-2 months (vs. hours)
- Technologies Demonstrated on 1.5m tank:
  - Passive thermal control
  - 2 transfers using screen channel liquid acquisition devices
  - RFMG
- Technologies Developed:
  - High Accuracy Delta P Transducer
  - Valve Seat Leak Test
- Implementation
  - In-house payload build
  - Delivery Order on existing CRS Contract for the LV, S/C Bus, Mission Operations, and I&T
- Deliverables:
  - Micro-gravity data to anchor CFM models,
  - Industry workshops to share data,
  - Conference presentations

eCryo

- Ground Demonstration of a CFM technology portfolio
- **Passive Storage Technologies developed from 3 to 6**

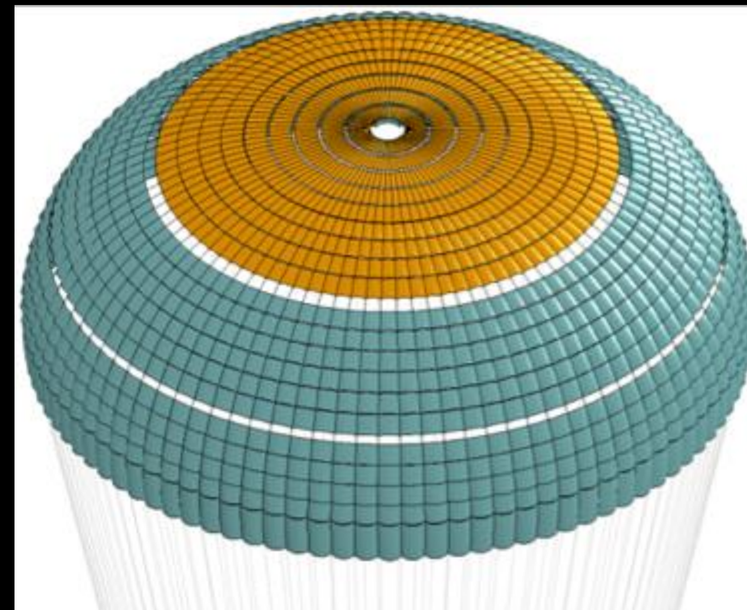
  No Active storage or Transfer technology development
- Ground Tank size: 4m diameter
- N/A.
- Technologies Demonstrated:
  - SHIIVER passive thermal control on 4m tank (MLI and Vapor Cooling)
  - RFMG on GSFC RRM3 Mission yielding flight data
- Technologies Developed:
  - High Accuracy Delta P Transducer
  - Valve Seat Leak Test
  - Super Insulation
  - IVF for SLS
- Implementation
  - In-house research and development
- Deliverables:
  - Industry workshops to share data,
  - Conference presentations,
  - Ground data to anchor CFM models

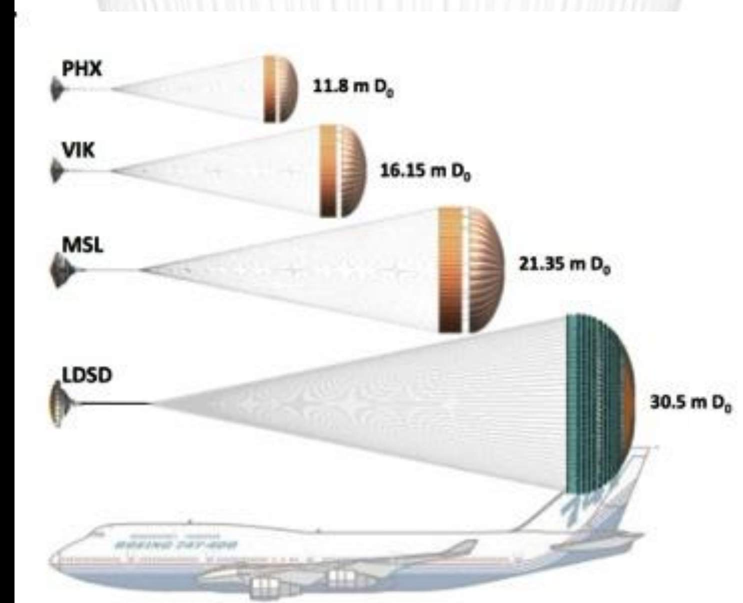
Low-Density Supersonic Decelerators

An Update

Dr. Mark Adler
Dr. Ian Clark

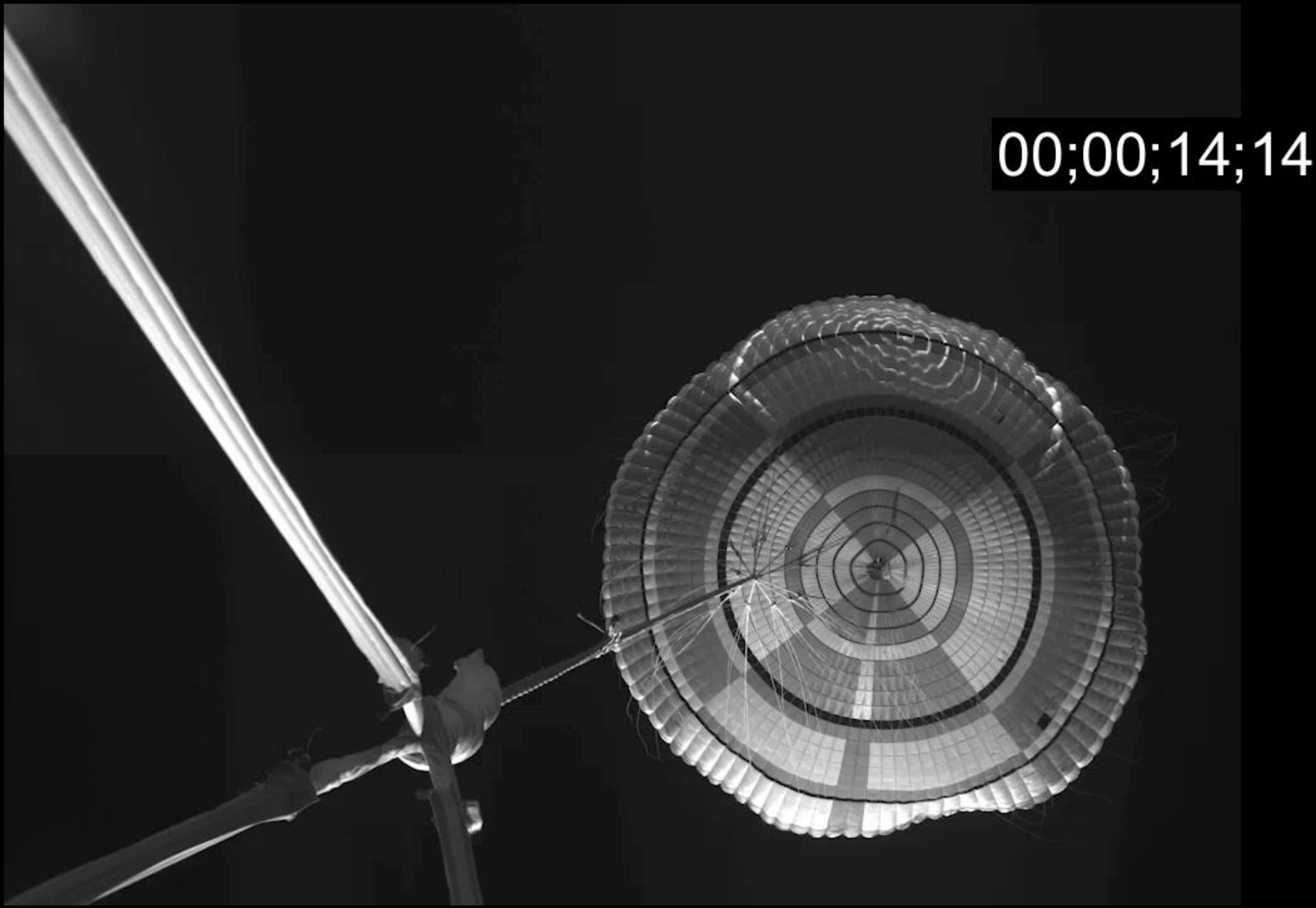
30.5m Supersonic Parachute



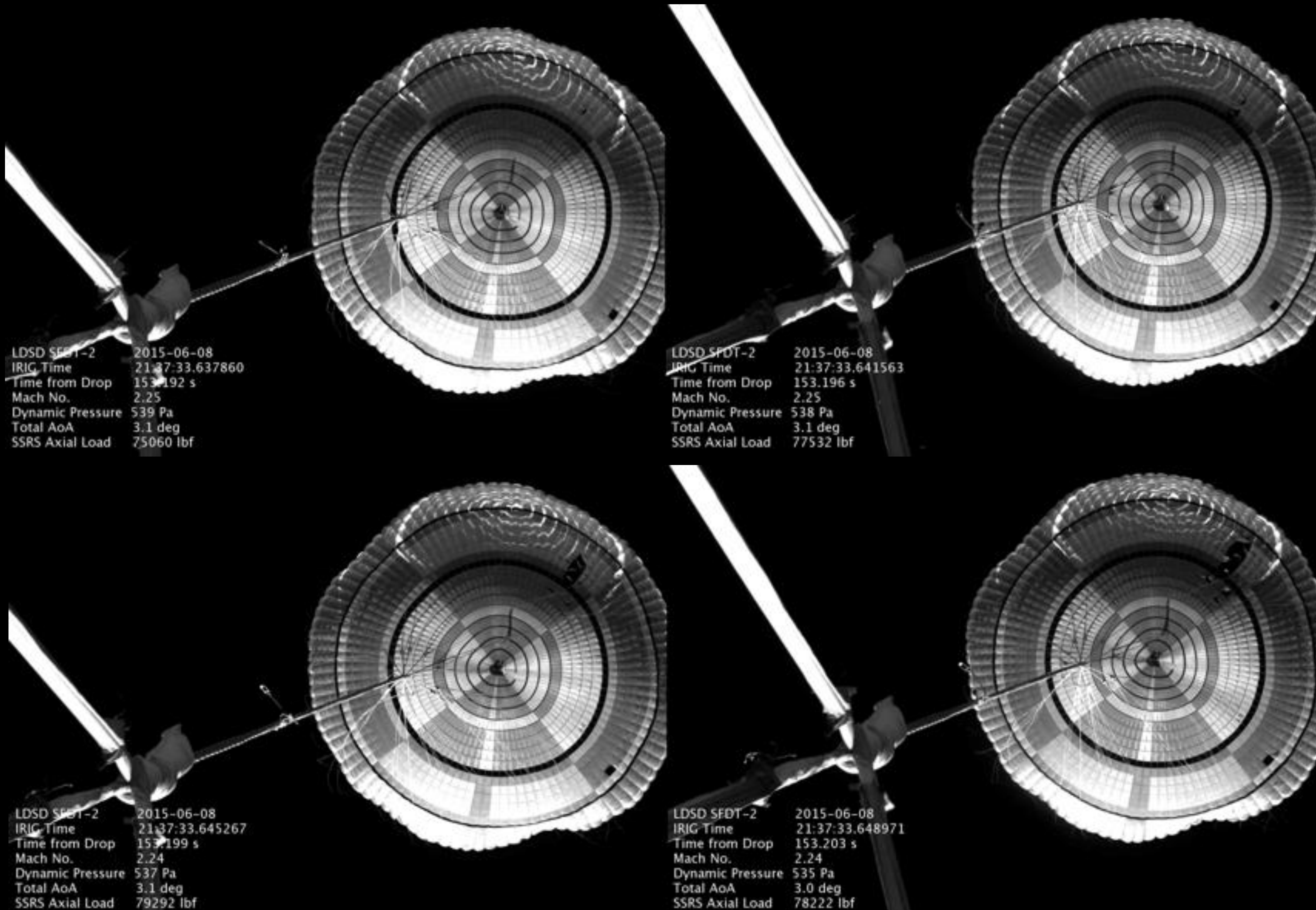


SFDT2 High Altitude Supersonic Flight

SFDT2 High Resolution Deployments



SFDT2 Damage Progression



SFDT-2 Investigation Status

- SFDT-1 yielded best set of data on a supersonic parachute, ever
- SFDT -2 was even better

- Parachute advanced through inflation process much further than in SFDT-1 and ultimately failed at full inflation
  - SFDT-1 remedy was successfully demonstrated

- Three families of hypotheses being actively worked for SFDT-2 parachute
  - Material and fluid inertial forces significantly larger than expected
  - Pressure forces significantly larger than expected and asymmetric
  - Material/Seam and Joint strength not as expected under loading environment

- *We are in the midst of a paradigm shift in our understanding of supersonic parachutes*

Key LDSD Accomplishments in the Past Year

Technologies

- Successfully conducted 2nd Supersonic Flight Dynamics Test
- Successfully matured two separate supersonic decelerators to TRL-6
    - SIAD-R and ballute both largest ever of their kind and both exceeded performance expectations
- Successfully conducted structural and inflation test of 8m SIAD-E
    - SIAD-E progressing towards TRL-5
- Successfully conducted three separate structural tests of a 30.5 m parachute
    - Each test yielded valuable insight into design and construction details of large parachutes
- Continued to rewrite the textbook on supersonic parachutes
    - Lessons learned have been shared with industry and numerous flight projects utilizing soft good decelerators

Documentation

- Presented over two dozen papers at aerospace technical conferences
    - Including five full sessions at the AIAA Aerodynamic Decelerator Systems Conference
- Completed 400+ page SFDT-1 Post-Test Report
- Completed draft of SIAD-R Technology Archive Report
    - Continuing to progress on other Technology Archive Report

2015 NASA Technology Roadmap

Technology Roadmap Updated

<u>Considers</u>
- Updates in Science Decadal surveys
- Human Exploration capability work
- Advancements in technology

<u>Includes:</u>
- State-of-art
- Capability needs
- Performance goals

<u>Expanded Scope:</u>
Aeronautics technology
Autonomous systems
Avionics
Information technology
Orbital debris
Radiation
Space weather

<u>2015 Technology Roadmaps Facts</u>:

<u>340 people contributed (authored content)</u>. This included input from all NASA Centers, organizations, industry and government. Others provided edits during Center and HQ reviews.

The 2015 NASA Technology Roadmaps are comprised of:
16 sections
15 technical areas
2,100 pages
1,273 technology candidates

Since the 2012 Roadmaps were released, the 2015 Roadmaps have been expanded to include:
- ✓ 1 new Technology Area, TA 15 Aeronautics
- ✓ 7 new level 2 Technology Areas
- ✓ 66 new level 3 Technology Areas
- ✓ 1,273 Technology Candidate Snapshots
- ✓ Detail about crosscutting technologies (requested in NRC's previous roadmap review)

- ✓ 2015 draft Technology Roadmaps Released to the Public on May 11, 2015
- ✓ <u>Request for Information Closed and Comments Incorporated</u>

Final 2015 NASA Technology Roadmaps Released

Roadmap Next Steps

National Research Council Status

- Statement of Work (SOW) was Approved by NASA Technology Executive Council (NTEC) – Focus of SOW to prioritize new technologies in 2015 Technology Roadmaps
- **NRC Contract Awarded on 05-27-2015**
- Currently, NRC is putting together the committee

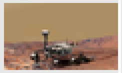
- Schedule
  - 8/10/2015 Committee membership approved
  - 9/28/2015 First Meeting, Washington, D.C.
  - 11/1/2015* Second Meeting, location TBD
  - 1/1/2016* Third Meeting, location TBD
  - 3/1/2016* Fourth Meeting, location TBD
  - 4/1/2016 Development of Consensus Draft
  - 5/1/2016 Report Sent to External Review
  - 7/15/2016 Report Review Complete
  - 8/1/2016 Report Delivered to Sponsor (Prepub)
  - 10/1/2016 Report Delivered to Sponsor (Published copies)

Note: NASA Updates the Strategic Technology Investment Plan (STIP) every 2 years.
We are currently updating the STIP. We will be using 2015 new technology candidates and 2013 NC priorities for FY2016 STIP. The STIP in FY2018 will include NRC's 2016 recommendations.

Partnering with Universities to Solve the Nation's Challenges

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

- STMD-funded university space technology research spans the entire roadmap space
- More than **130** U.S. universities have led (*or are STTR partners on*) more than **550** awards <u>since 2011</u>
- In addition, there are many other partnerships with other universities, NASA Centers and commercial contractors

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

TI&E Committee Observation

STMD University Engagement:

- During the mid-2000s, NASA's university engineering research programs were decimated.
- STMD has reestablished contacts with the university community through the Space Technology Research Grants program, including the NASA Space Technology Research Fellowship program.
- Committee met at lunch with 15 Fellows working at JPL this summer from universities across the nation
- Committee very impressed with technical knowledge and capabilities of the Fellows

TI&E and HEO Committee Finding

- The Space Technology and Human Exploration and Operations Mission Directorates recognize that they have common exploration, technology, and operational needs and goals. Their two communities are working and interfacing together and this collaboration can serve to optimize future mission success.
- Specific technology advances have been defined that enable NASA's future exploration missions.
  - Strategic Space Technology Investment Plan (2012)
- When Space Technology was established, a plan was formulated including well-defined deliverables and the necessary budget to execute the program.
- However, STMD has consistently lacked the sufficient discretionary resources to deliver all the technology developments required across the TRL spectrum to meet NASA's critical future mission goals.

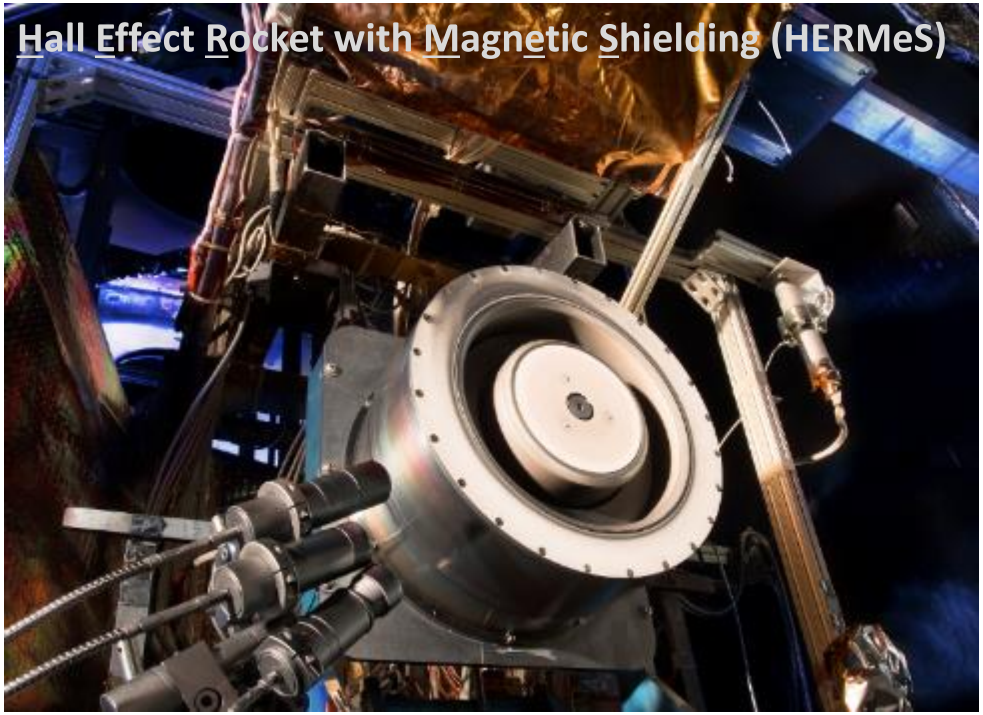
Is a human mission to Mars slipping year for year as a result?

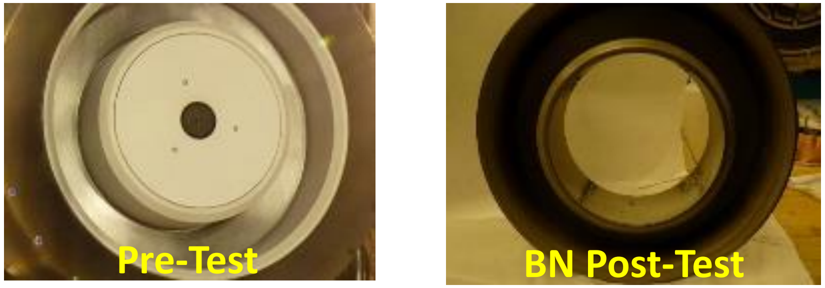
BACK-UP

Hall Thruster & Power Processing Unit (PPU) Development and Risk Mitigation

- Two 12.5 kW Hall Thruster Technology Development Units
  - Validated design methodology & tools
  - Reduced mission and flight hardware development risks
- 2 Brassboard PPUs
  - 300Vin/800Vout (MFR reference)
  - 120Vin/800Vout (Post-MCR reference)

Demonstrated full, integrated performance compatibility of 120-V and 300-V PPUs with 12.5-kW Hall Effect Thruster

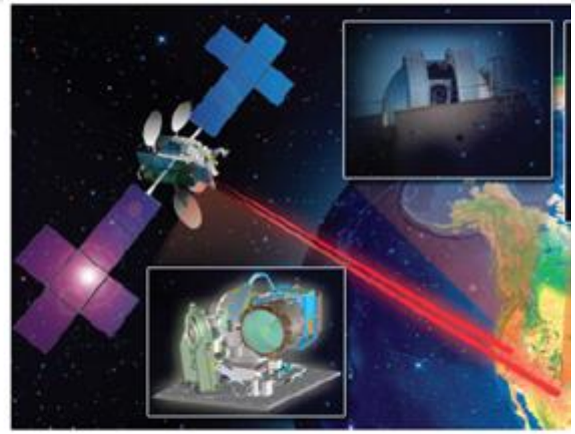




Post-test BN discharge chamber shows carbon deposition consistent with magnetically shielded operation

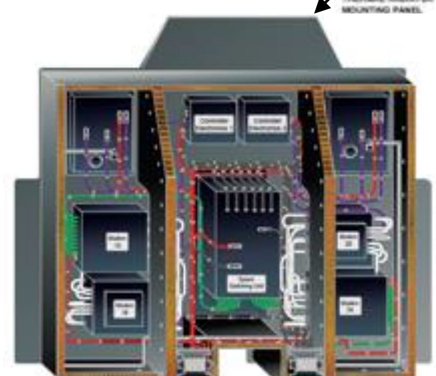
Laser Communications Relay Demonstration

- Demo Description:
  - A minimum two year flight demonstration to advance optical communications technology toward infusion into Deep Space and Near Earth operational systems, while growing the capabilities of industry sources.
- Objectives:
  - Demonstrate bidirectional optical communications between geosynchronous Earth orbit (GEO) and Earth
  - Measure and characterize the system performance over a variety of conditions
  - Develop operational procedures and assess applicability for future missions
  - Transfer laser communication technology to industry for future missions
  - Provide an on orbit capability for test and demonstration of standards for optical relay communications
- Anticipated Benefits:
  - A reliable, capable, & cost effective optical communication technology for infusion into future operational systems
- Anticipated NASA Mission Use:
  - Next Generation TDRS, Deep Space and Near Earth Science
  - ISS and Human SpaceFlight
- Attractive partnering arrangement with Space Systems/Loral as a hosted payload on a commercial telecom satellite and DoD partner for encryption.



LCRD is a hosted payload on an SSL commercial telecom satellite

Payload Enclosure mounted on Earth Deck of typical SSL telecom satellite



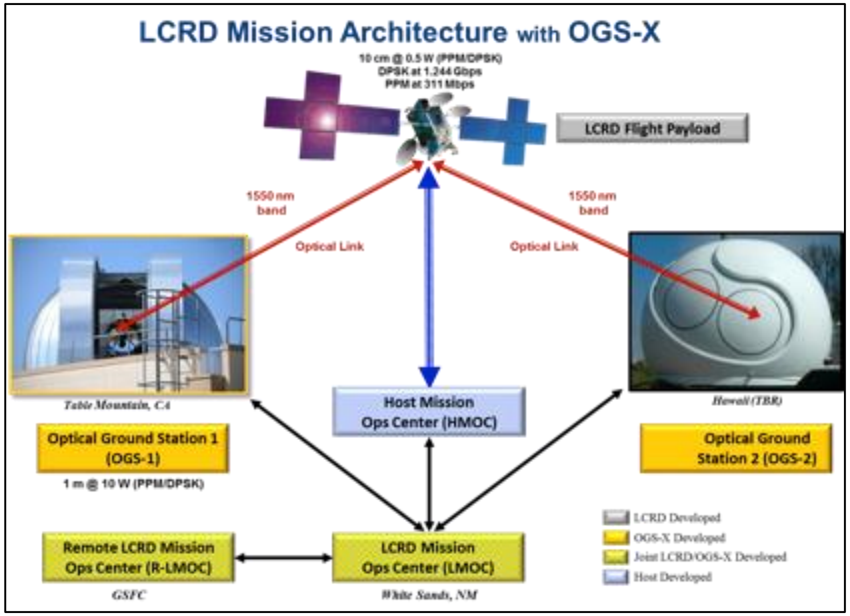
Enclosure Rear View illustrates layout, structural, thermal maturity

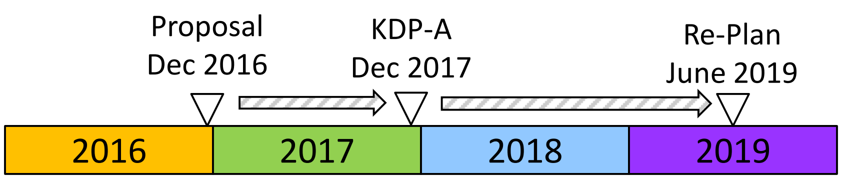
Budgetary Challenges in Conducting a Comprehensive Large-Scale Demonstration

- Government-estimated SEP Module cost ($433M) significantly exceeds STMD in-guide budget profile ($229M)
- ARRM Budget Lifecycle and phasing presents significant challenges to timely perform mission. Launch initially June 2019, slipped to Dec. 2020.
- STMD in-guide covers: All SEP activities in FY15-16, all Ion Propulsion activities FY15-21, civil servant-only SEP mission design/studies FY15-21
- STMD in-guide gaps: SEP DDT&E - Power, Structures/mechanisms, Thermal, SE&I, RCS
  - Part of Power gap includes SEP Power Solar Array contract, not funded beyond FY16 (STMD funds are short $40M)
- <u>In general</u>, cost estimates from BAA studies indicate:
  - A 40 to 50 kW-class SEP demonstration requires approximately $400M
  - A 30 kW-class SEP demonstration requires approximately $250M
  - If less funding is available in the STMD budget, a major cost-sharing partnership is required to accomplish a demonstration of this scale.
- Continued lack of full funding for STMD and indecision on fully funding ARRM has delayed progress towards a high powered SEP demonstration

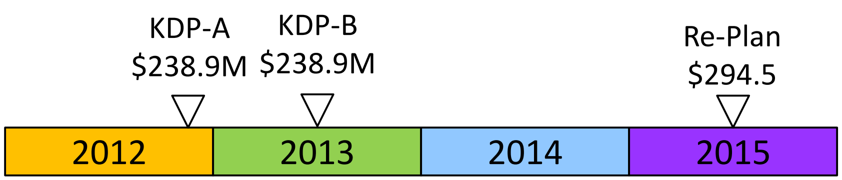
Current Effort After Post KDP-B Re-Plan

- In addition to the de-scopes taken prior to KDP-A, LCRD was directed to take additional de-scopes and other changes during the re-plan activity (directed February 2014 and completed March 2015)
  - Content removed/de-scoped from LCRD Budget:
    - JPL Ground Station 1 starting in FY15 – Moved to SCaN Optical Ground Station Extension (OGS-X), five years of operation (two years base plus three years extended operations)
    - De-scoped White Sands GS-2
    - Deviation approved for EVM
    - De-scoped E&PO
    - Payload I&T moved from GSFC to SSL after Electrical/Optic Integration Test Bed
    - Post launch checkout Science/Technology, Mission Ops, and LMOC Sustaining moved to SCaN OGS-X post checkout (L+60 days)
  - Encryption scope added October 2014 (no waiver for encryption requirements), to be funded through SCaN and tracked separately
- Re-plan budgets were constrained by STMD funding levels for FY15 and FY16, with LCC at $294.5M, including encryption
- Notional Launch Readiness Date slipped to June 2019





LCRD Notional Launch Readiness Date Change



LCRD LCC

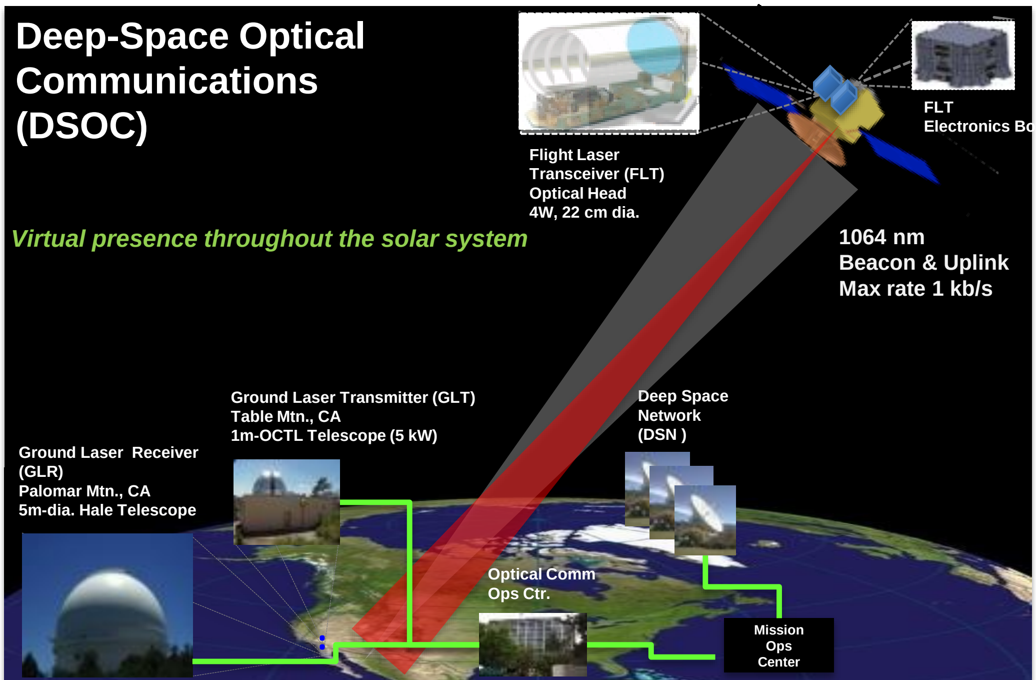
Deep Space Optical Communications

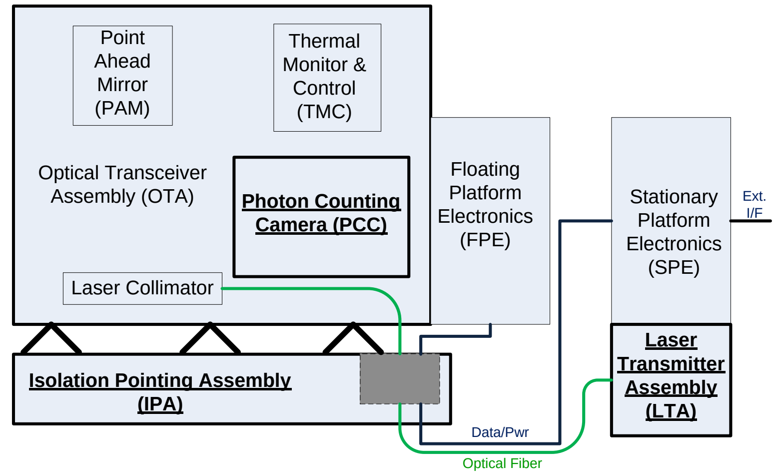
28 July 2015
Tom Glavich

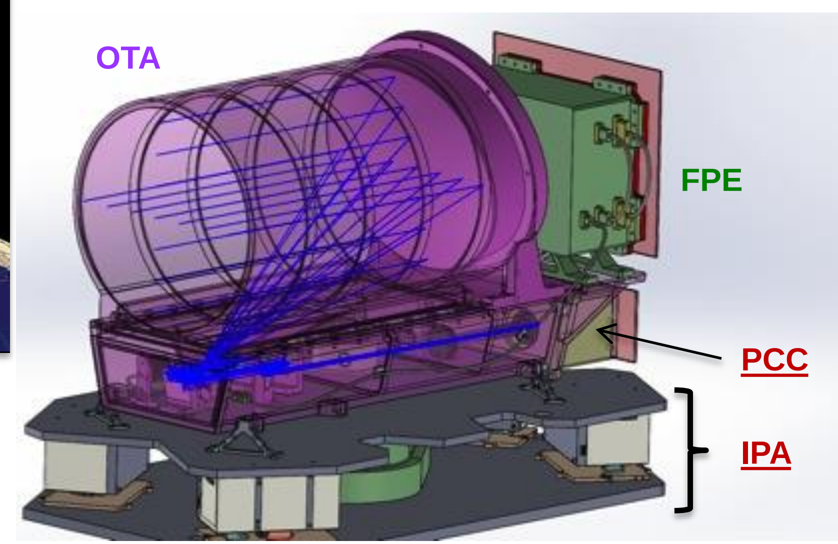
Deep Space Optical Communication Project

- The Deep Space Optical Communication Project is in transition from a technology development effort to a flight demonstration.
- DSOC is part of the Discovery 2014 AO
  - Flight Component specifications were part of the Tech Day Presentations
  - We are on a path that will have the DSOC System at TRL 6 in time to support Discovery 14 selected payloads review and delivery cycle
- The DSOC Project includes three segments
  - Ground Uplink Station
  - Flight Laser Transceiver
  - Ground Receiving Station

DSOC System







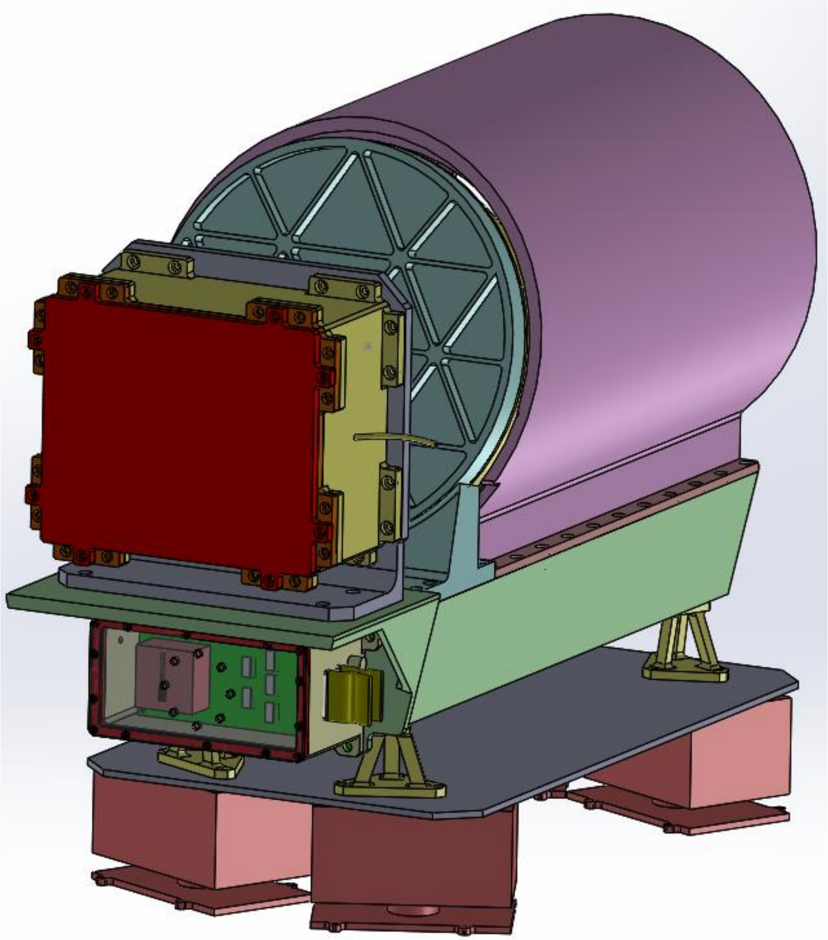
Flight Laser Transceiver

Deep Space Optical Communication Technology Challenges

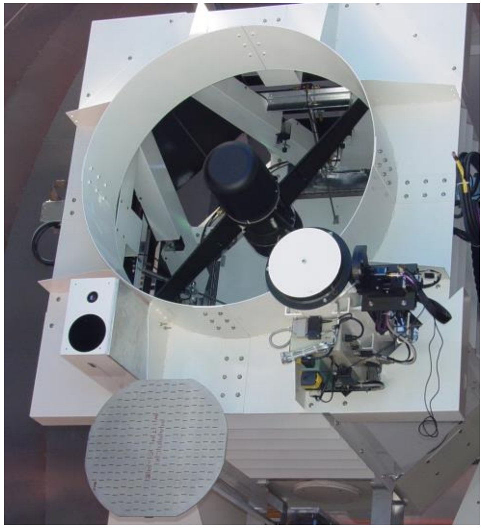
- Deep Space Optical Communications are different from near earth communications
  - One way light times are minutes rather than seconds
  - Distances are large enough that signals are photon limited
- Communication Scenario
  - Uplink signal communicates with DSOC flight terminal by dead reckoning, providing a beacon and uplink data
    - Uplink signal at the spacecraft is photon limited
  - The flight system tracks the beacon, and using spacecraft ephemeris and attitude information calculates the point ahead angle required for downlink
  - The downlink beam is directed to where Earth will be
  - The downlink beacon is photon limited on arrival at Earth
  - The sun is often very near the field of regard of the Flight Terminal

DSOC Major Components

Flight Terminal



OCTL Uplink



Palomar 5 meter Telescope

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Deep Space Atomic Clock Mission Overview

Todd Ely
Principal Investigator

Allen Farrington
Project Manager

July 2015

NASA's DSAC Technology Demonstration Mission

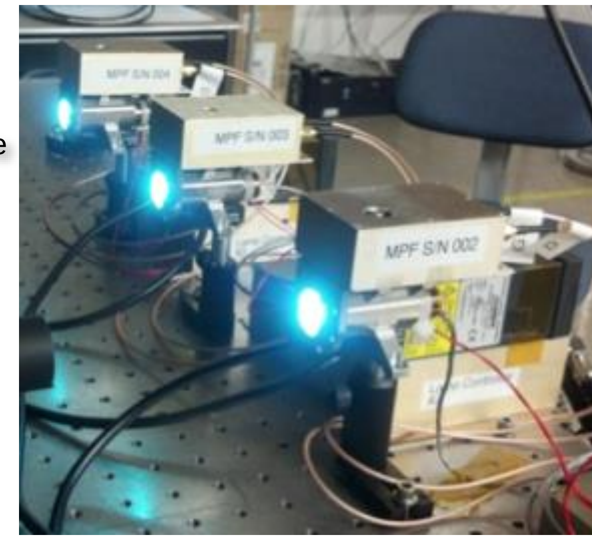
DSAC Demonstration Unit

Multi-pole Trap

Quadrupole Trap

Titanium Vacuum Tube

Mercury UV Lamp Testing



Develop advanced prototype ('Demo Unit') mercury-ion atomic clock for navigation/science in deep space and Earth

- Perform year-long demonstration in space beginning mid-2016 – advancing the technology to TRL 7
- 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
- Identify pathways to 'spin' the design of a future operational unit (TRL 7 → 9) to be smaller, more power efficient – facilitated by a detailed report written for the next DSAC manager/engineers

For More Information, Contact: Todd.A.Ely@jpl.nasa.gov, Website: http://www.nasa.gov/mission_pages/tdm/clock/

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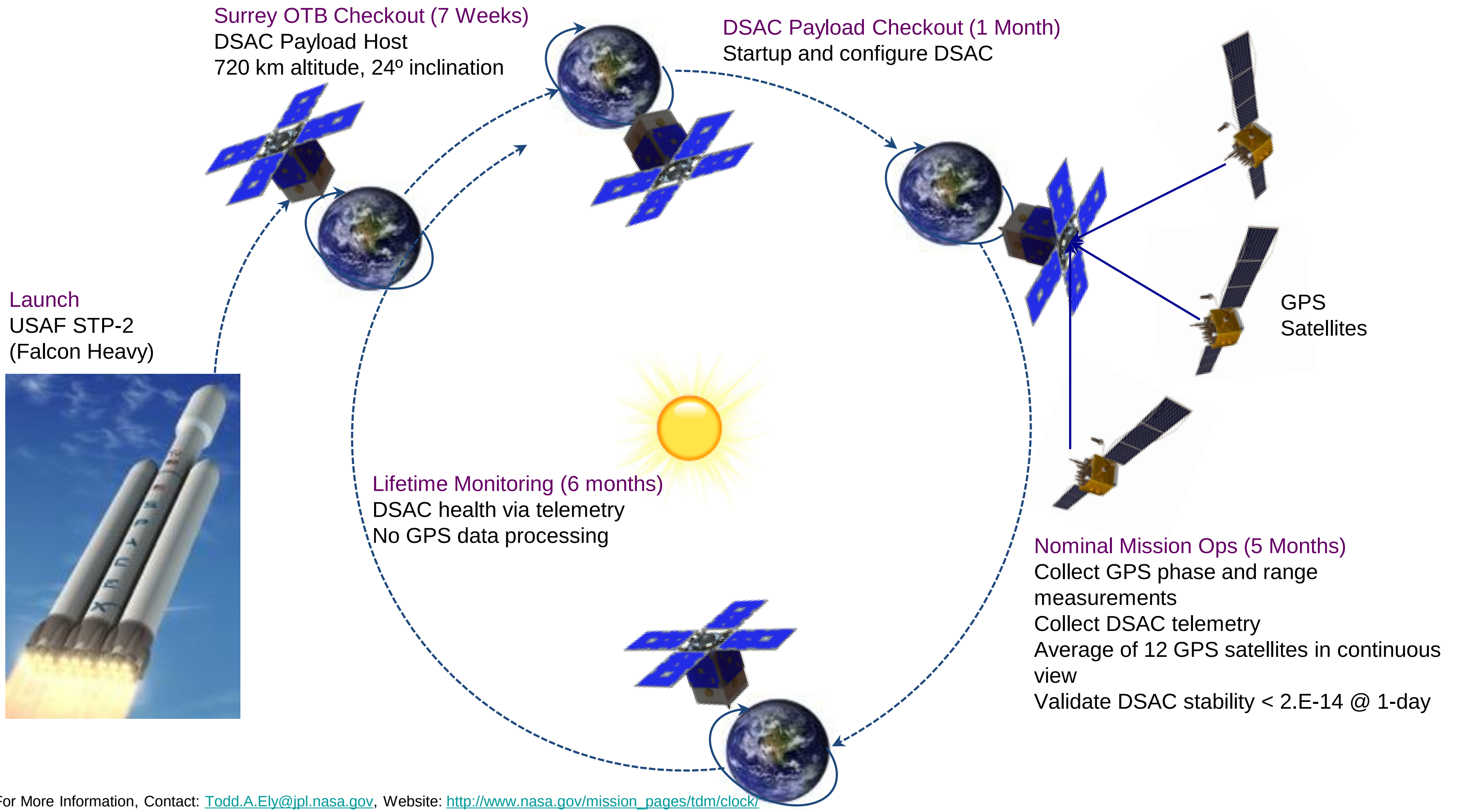
Jet Propulsion Laboratory
California Institute of Technology

Deep Space Atomic Clock Project

Mission Architecture and Timeline

Launch September 2016 with one-year demonstration



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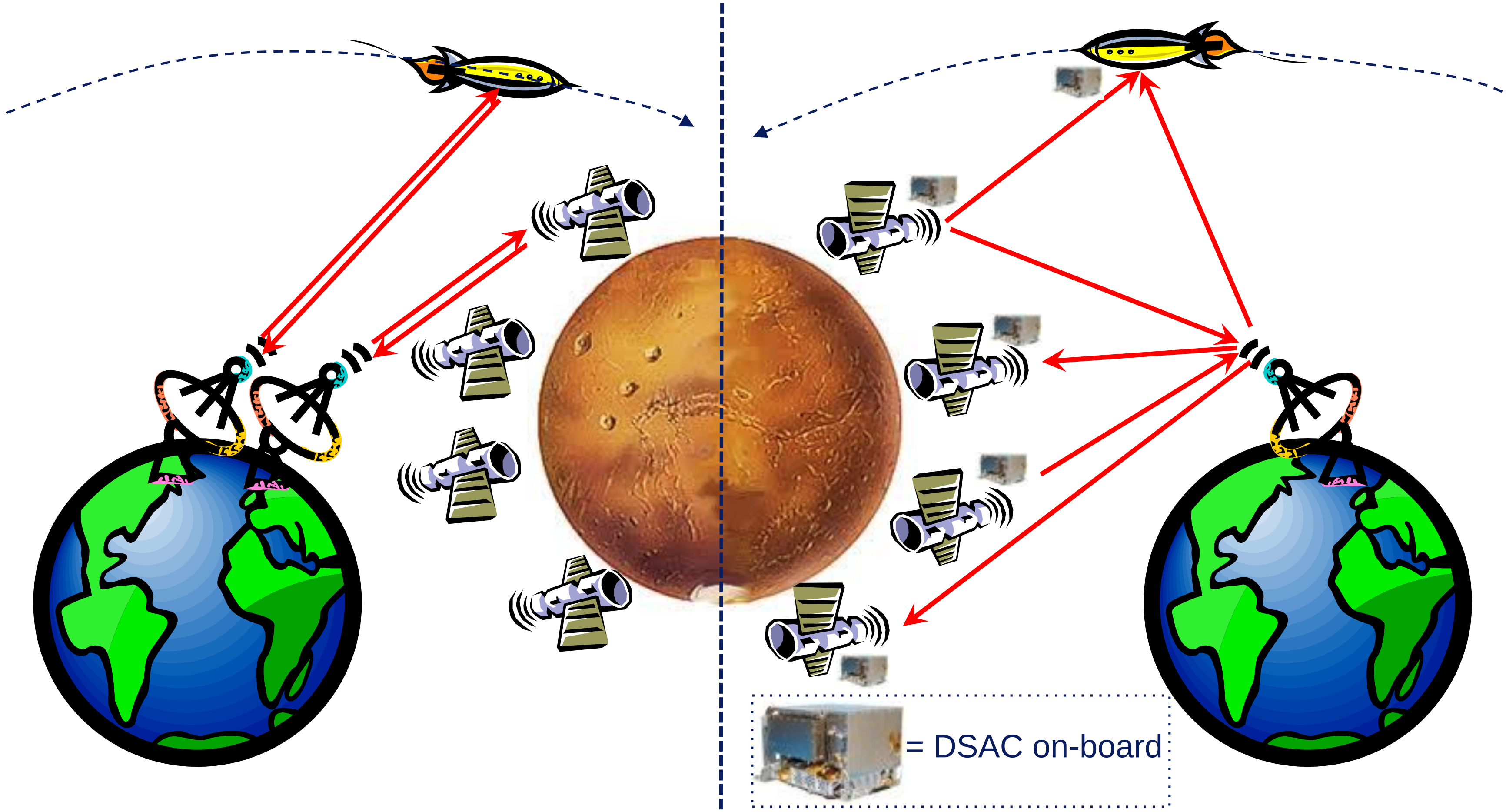
Deep Space Atomic Clock Project

Broad Benefits for Enhanced Exploration
Enables Multiple Space Craft Per Aperture Tracking at Mars

Today's 2-Way Radio Navigation | *Tomorrow's 1-Way Radio Navigation*



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