National Aeronautics and Space Administration

Marshall Technology Exposition

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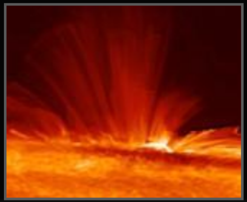

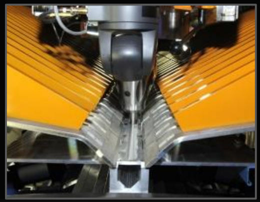
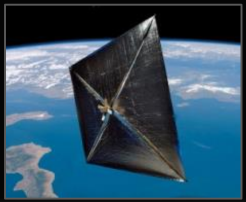


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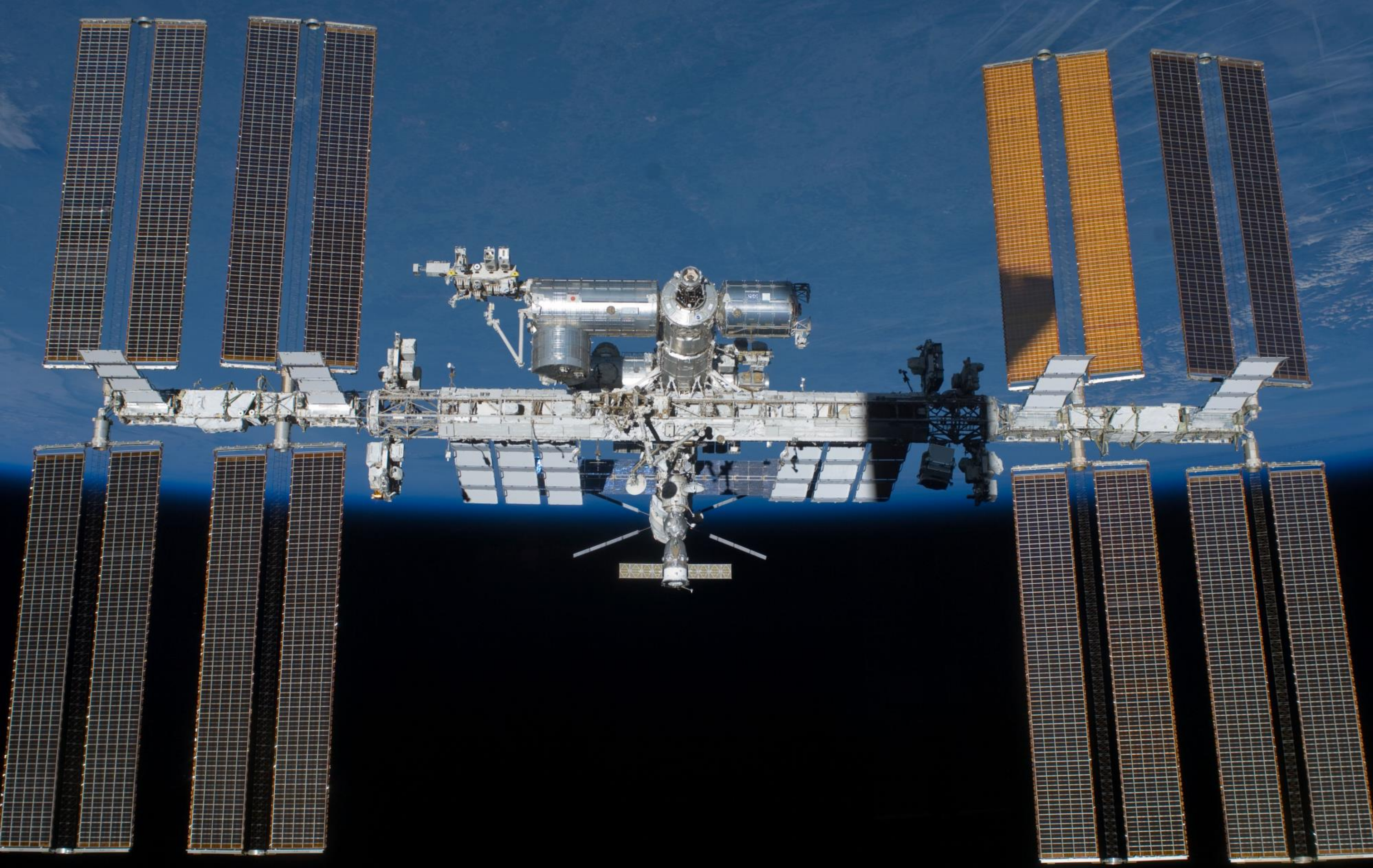
Destination Station



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Continue the discussion…

Meet the Panelists

Visit the Exhibits

Tell us what you think!

www.nasa.gov/marshallTECHexpo

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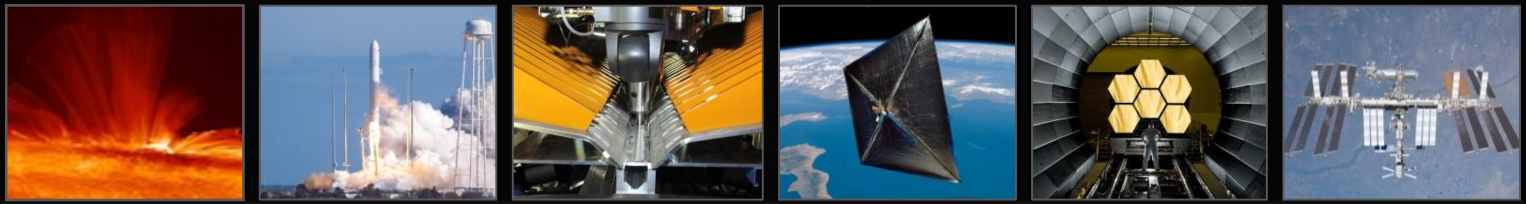
Applied Technologies for Exploration

Dr. Dale Thomas, Associate Director – Technical, NASA Marshall



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Applied Technologies for Exploration: Agenda

Opening Comments

- Dr. Dale Thomas, Associate Director—Technical, NASA Marshall Space Flight Center

Panelists' Comments

- Dr. Jessica Gaskin, Research Astrophysicist, Marshall
- Reginald Alexander, Advanced Concepts Office, Marshall
- Dr. Lisa Watson-Morgan, Chief Engineer, Marshall
- Dr. Fred Bickley, Spacecraft/Payload Integration and Evolution Office, Space Launch System Program Office, Marshall

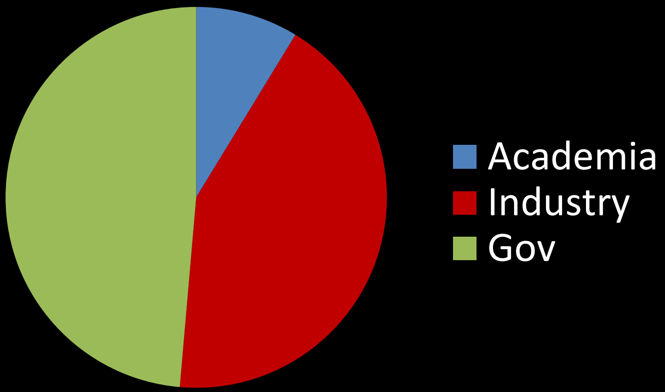
Q & A

Rocket Propulsion Additive Manufacturing (AM) Technology Interchange Meeting (TIM) – Sept. 3-5, 2014

- JANNAF Liquid Propulsion Subcommittee (LPS) Advanced Materials Panel hosted an Additive Manufacturing TIM at the Jackson Center in Huntsville, AL
  - Focus was on Additive Manufacturing for Rocket Propulsion
    - Understanding state-of-the-art Additive Manufacturing for fabricating parts for rocket propulsion applications - where are we today
    - *Understanding what is required to take AM parts to flight*
    - Organizations brought hardware for display




- 284 Attendees from 19 States



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Opportunities with Marshall

- Visit the Exhibit Hall
- Technology Partnership Opportunities Panel at 3:15 pm

Panel: Applied Technologies for Exploration

Dr. Jessica Gaskin, Research Astrophysicist, Marshall

Reginald Alexander, Advanced Concepts Office, Marshall

Dr. Lisa Watson-Morgan, Chief Engineer, Marshall

Dr. Fred Bickley, Spacecraft/Payload Integration and Evolution Office, Space Launch System Program Office, Marshall

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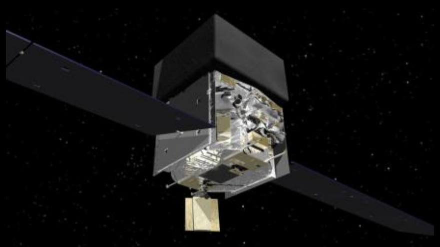
Applied Technologies for Exploration

Dr. Jessica A. Gaskin, Research Astrophysicist,
NASA Marshall

Science at Marshall

- X-Ray Astronomy
  - Behavior of matter and energy under extreme conditions (Supermassive Black Holes to exoplanets)
- Gamma-Ray Astronomy
  - Explore the structure of the Universe. Higher energy than x-rays, studies black holes, terrestrial gamma-ray flashes, pulsars and gamma-ray bursts.
- Heliophysics & Space Weather
  - Study magnetic activities on the photosphere and their coronal consequences (the role of magnetic fields as drivers for solar eruptions.
- Planetary Science
  - Lunar Mapping and Modeling Project, Robotic Lunar Lander Development Project to support human lunar exploration activities, science and landing site selection for robotic missions.

Chandra X-Ray Observatory (NASA, 1999)



Fermi, GLAST Burst Monitor (NASA + DOE + FGIJS, 2008)

HINODE (JAXA/NASA/PPARC 2006)

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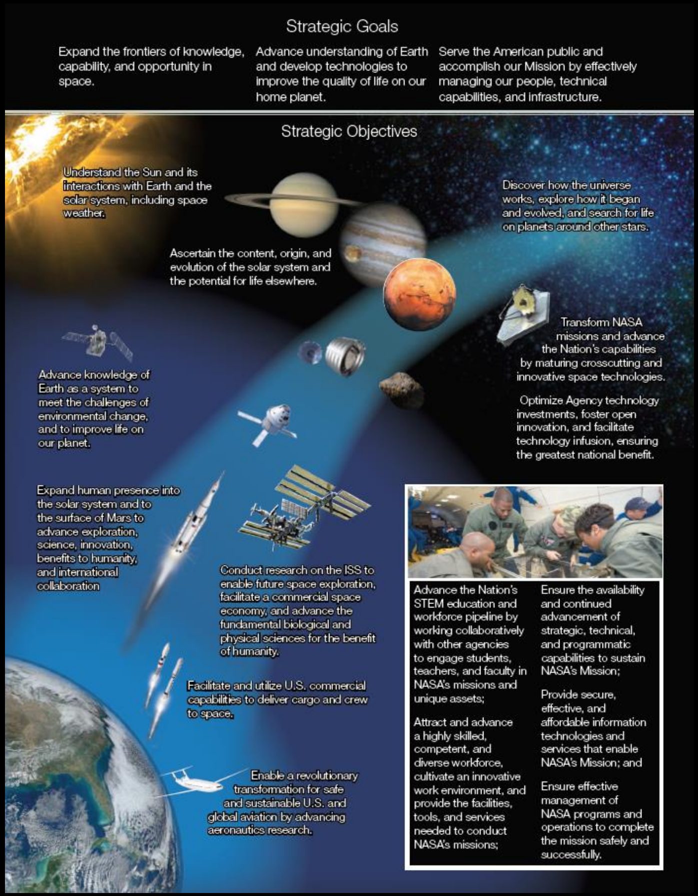
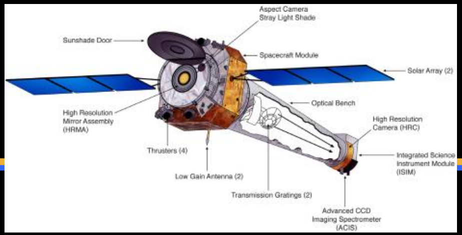
Science at Marshall

- X-Ray Astronomy
  - http://xanth.msfc.nasa.gov/
- Gamma-Ray Astronomy
  - http://gammaray.nsstc.nasa.gov/
- Heliophysics & Space Weather
  - https://science.msfc.nasa.gov/heliophysics
- Planetary Science
  - http://planetary.msfc.nasa.gov/Main.html

- NASA 2014 Strategic Plan:
  - http://www.nasa.gov/news/budget/



Designing for Science



- Missions must be designed around the science goals!

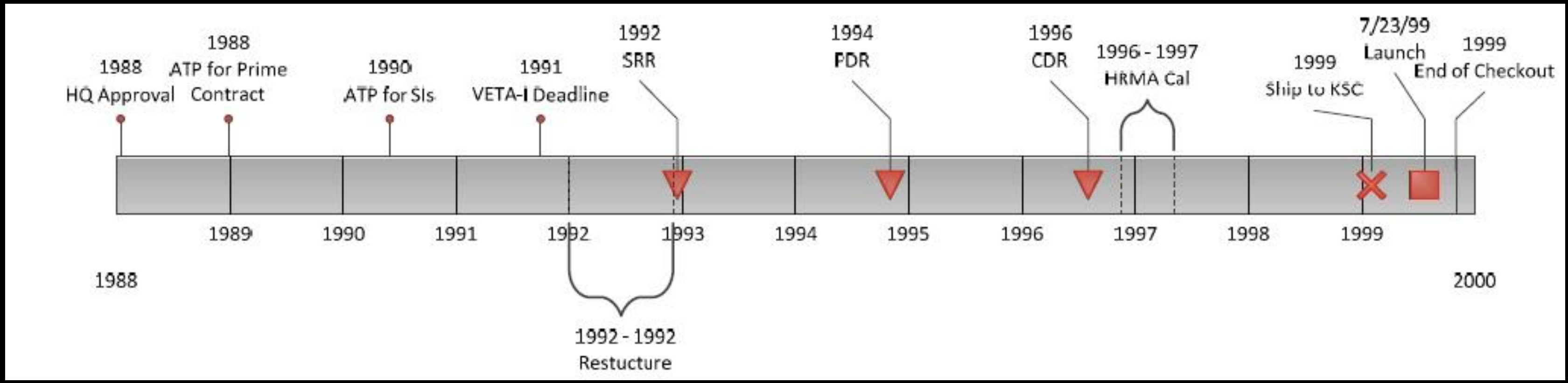
- Research & Development is critical
  - Can require long development times
  - Must be aligned with the desired science goals

"A key ingredient in Chandra's overwhelming scientific and programmatic success is the fact that Chandra was a science driven mission whose scientific requirements barely (if at all) changed throughout the time of its pre-development, i.e. from 1977 to 1992."

J. Arenberg SPIE 9144, 2014

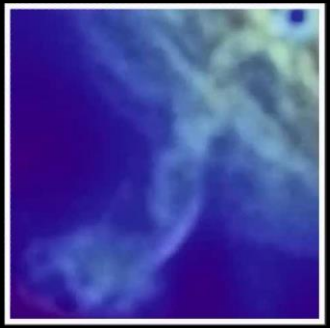
Chandra X-Ray Observatory

Chandra has been operating for 15 years! 10 years longer than its nominal flight.



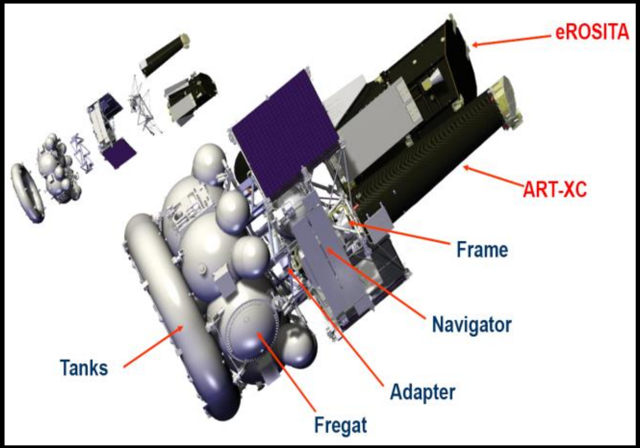
Top Level Chandra Program Timeline.

"Chandra, sometimes alone, but often in conjunction with other telescopes, has deepened, and in some instances revolutionized, our understanding of topics as diverse as protoplanetary nebulae; massive stars; supernova explosions; pulsar wind nebulae; the superfluid interior of neutron stars; accretion flows around black holes……, and feedback on growth and evolution of groups and clusters of galaxies; and properties of dark matter and dark energy." – Tananbaum et al, rep Prog. Phys. V77, 2014

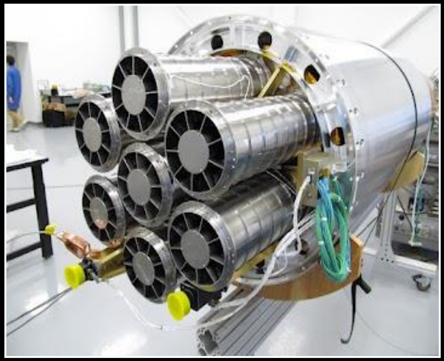


X-Ray Optics Programs at Marshall

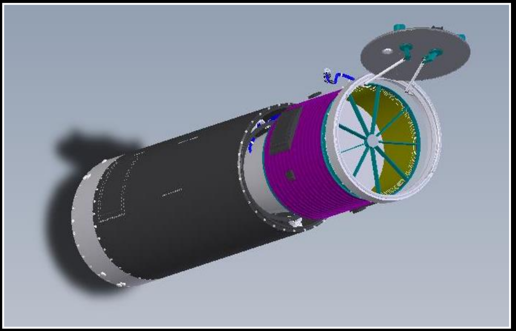
ART-XC (Satellite)



FOXSI (Rocket)



MicroX (Rocket)

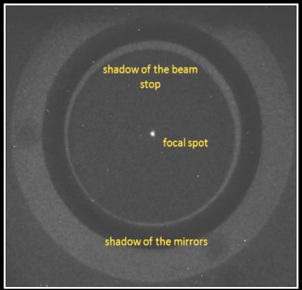


HEROES (Balloon)

Non-Astronomical Applications

Medical Imaging

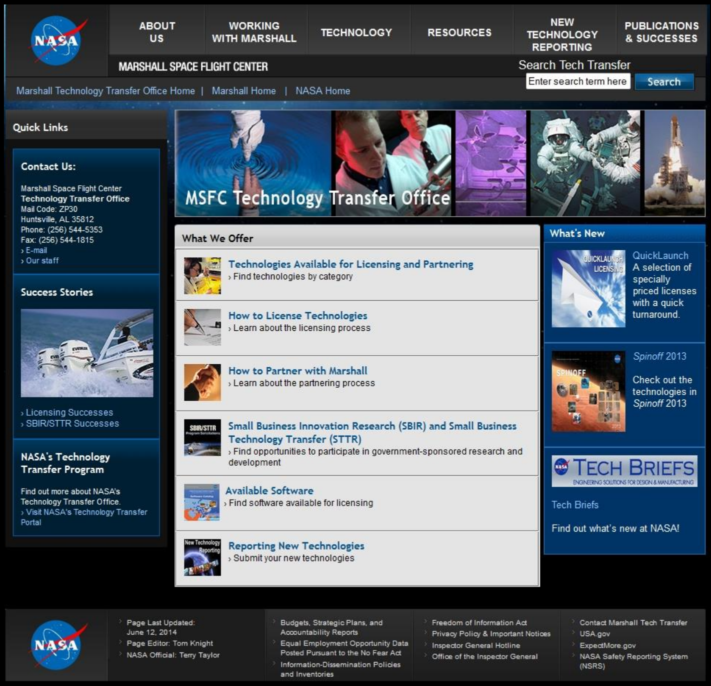
Neutron Imaging



HOW CAN YOU PARTICIPATE?

NASA SBIR & STTR Programs: http://osbp.nasa.gov/SBIR-STTR.html

Licensing Marshall Technologies: https://techtran.msfc.nasa.gov/index.php



Marshall Technology Exposition

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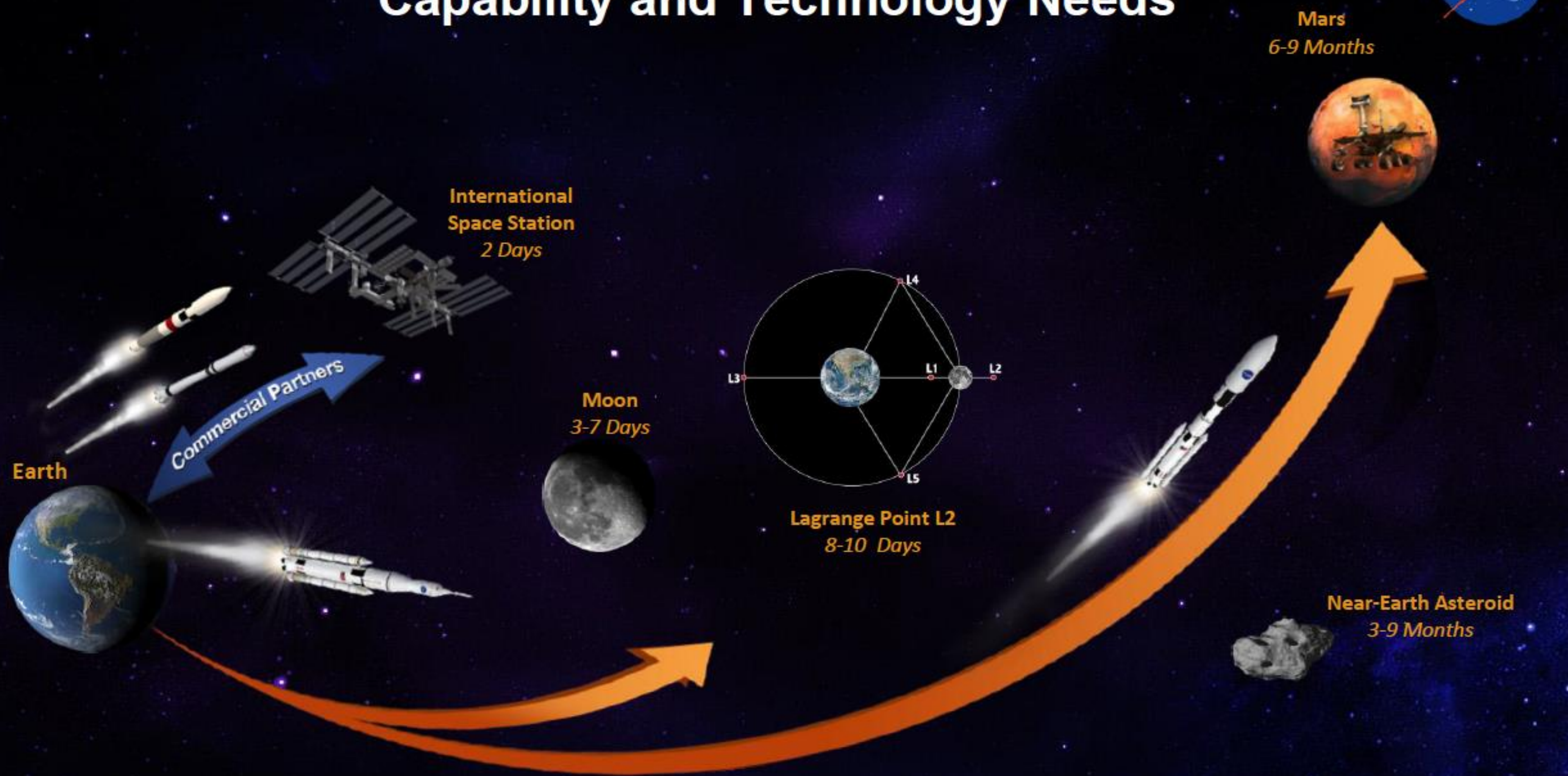
Applied Technologies for Exploration

Reginald Alexander, Advanced Concepts, NASA Marshall

Exploration Destinations Determine Capability and Technology Needs



Human Spaceflight Deep Space Challenge Examples

In Space Propulsion and Space Power

Crew Health, Medical, and Safety

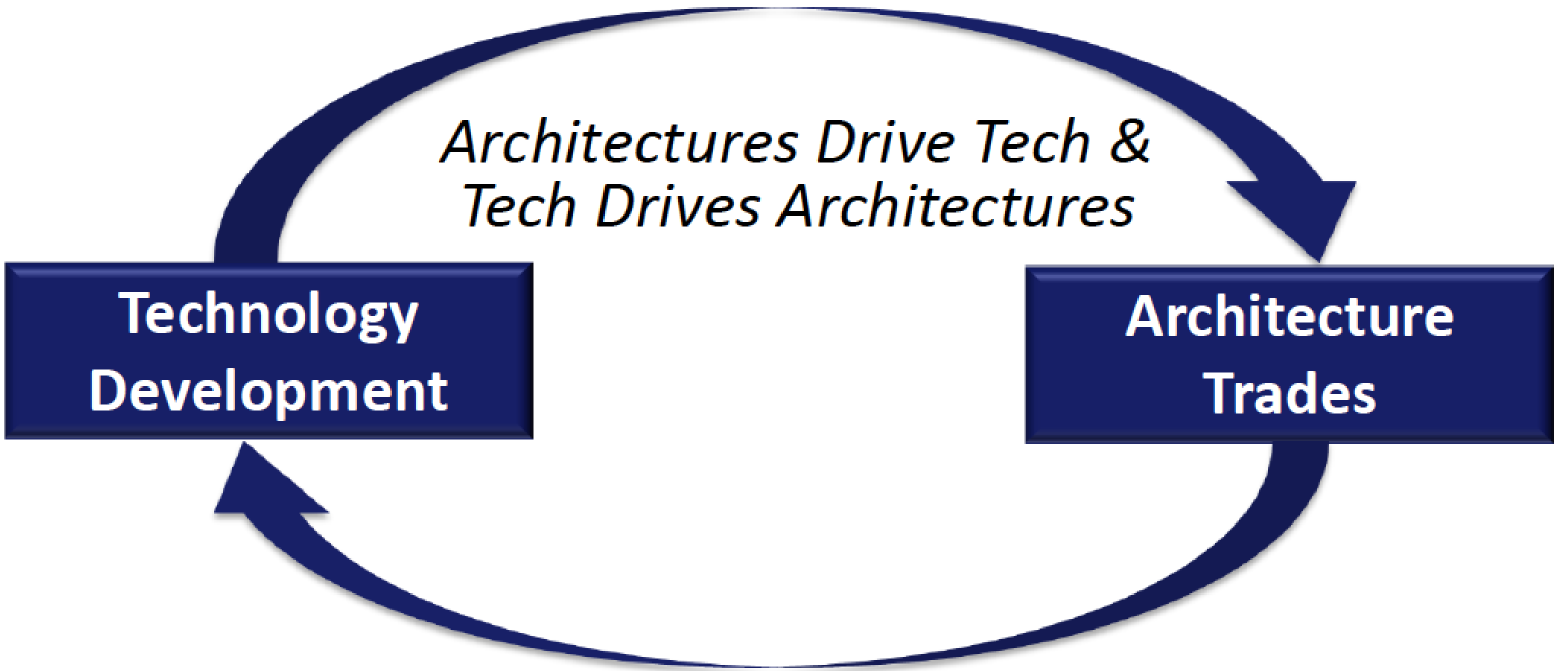
Robotics and Autonomous Systems

Entry, Descent and Landing

Habitation Systems* and Destination Systems, esp ECLSS and Space Radiation, *

Deep Space EVA

Architecture Trade – Technology Development Linkage



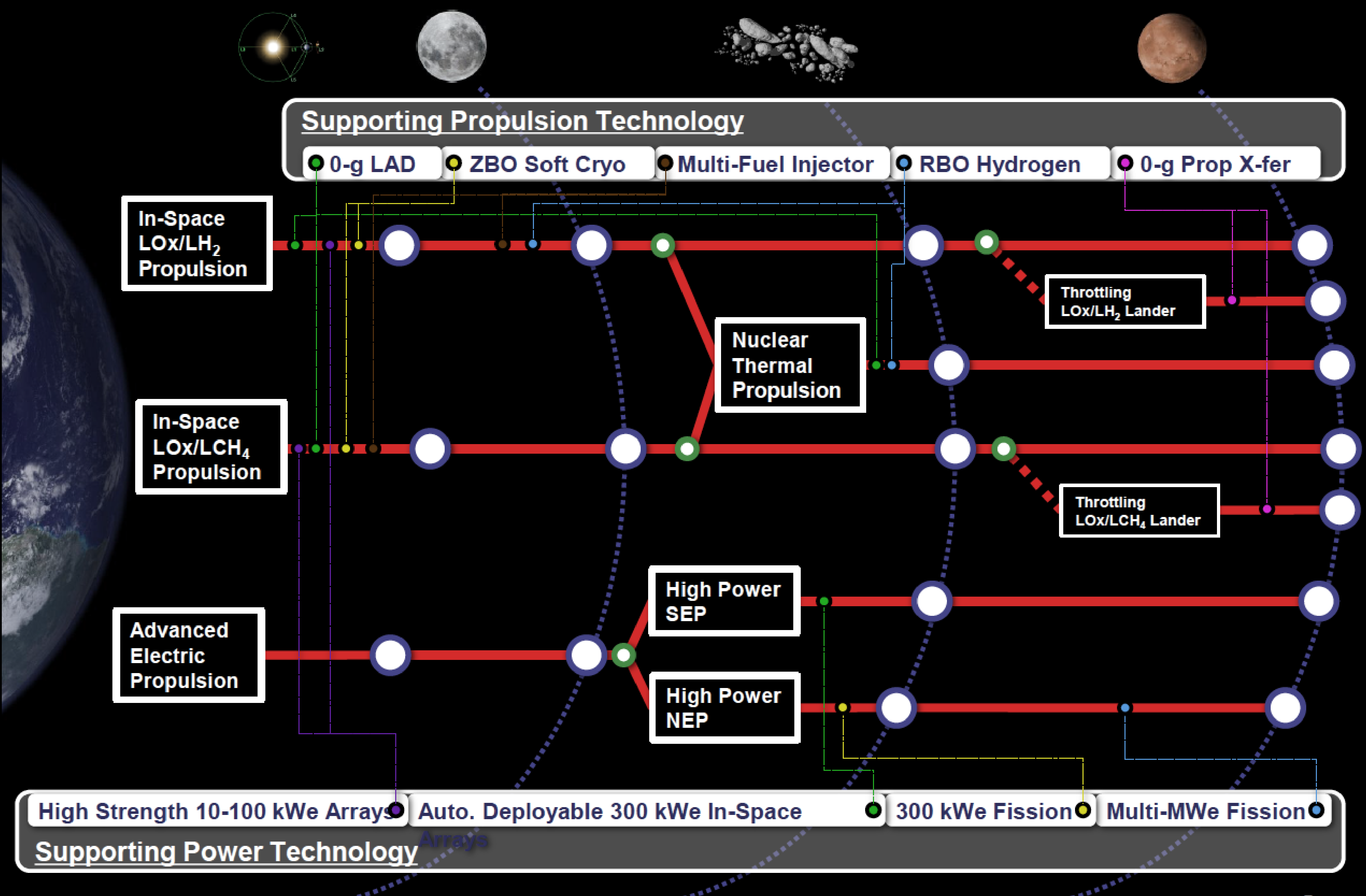
Today's technology investments can drive tomorrow's architecture solutions

- Investment in high-power nuclear fission reactors could drive us to NEP vs. high power SEP

The approach we take to performing a mission drives technology need

- Stage refueling would require development of 0-g propellant transfer, but low-cost modular propulsion would not

In-Space Propulsion Technology Trade Space



Chemical (Cryogenic) In-Space Propulsion

Cryogenic Fluid Management Needs	Near-Term T Demo Mission (2017)	Medium-Term Exploration Missions (ca. 2020's)	Far-Term Exploration Missions (ca 2030's)
Propellant Storage Duration	Days	Weeks	Months to Years
Thermal Control	• Reduced Boil-off Oxygen • Reduced Boil-off H2	• Zero Boil-off Oxygen • Zero Boil-off Methane • Reduced Boil-off H2	• Zero Boil-off Oxygen • Zero Boil-off Methane • Zero Boil-off Hydrogen
Propellant Gauging Strategy	• Settled Gauge • Attempt Unsettled Gauge	• Settled Gauge • Unsettled Gauge	• Settled Gauge • Unsettled Gauge
Propellant Acquisition Strategy	• Settled Expulsion • Attempt Surface Tension Devices	• Settled Expulsion • Liquid Acquisition Devices	• Settled Expulsion • Liquid Acquisition Devices
Resupply Capability	• Intra-vehicular Subscale Demo	• Inter-vehicular transfer Demo	• Operational Capability

Long-Duration Cryogenic Propellant Storage

Capability Description:

- State of the art is 9 hours of subcritical oxygen/hydrogen storage in LEO
- Need ability to store subcritical oxygen, methane and hydrogen for months to years
- Requires both passive and active technologies

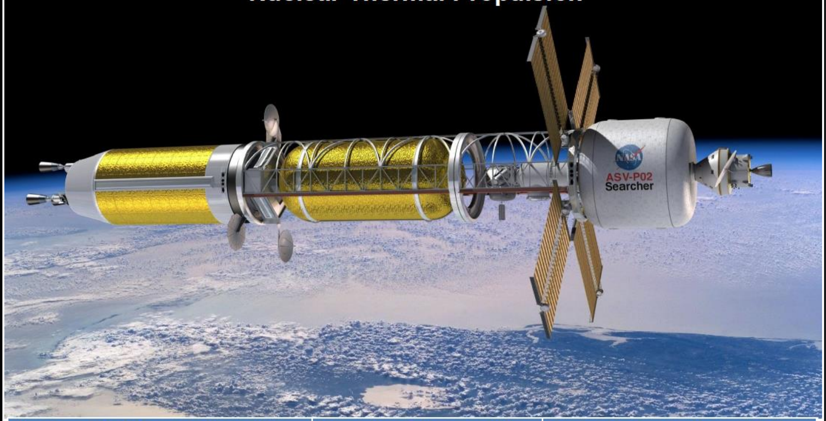
Performance Characteristics:

- Zero Boil Off for > 400 days
- LO2 Storage: < 8W per W of heat removal at 90K.
- LH2 Storage: < 120W per W of heat removal at 20K
- Cryocooler mass < mass of propellant saved

Destinations Supported: NEA, Mars, and lunar missions. Required for both chemical and nuclear thermal missions.

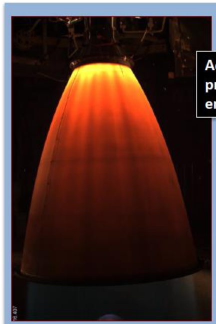
Current TRL Estimate: 3-4

Nuclear Thermal Propulsion

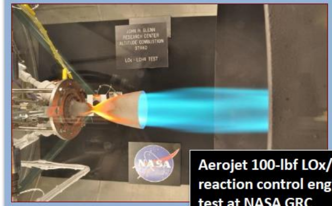


Prototype Flight/Science Missions-2020's	Human/Cargo Missions- 2030's	Far Term Exploration- Beyond 2030's
Isp ~ 875 seconds with Hydrogen	Isp ~ 900 seconds with Hydrogen	Isp ~ 1000 seconds with Hydrogen
Thrust ~ 7,500 lbf with single engine	Thrust ~ 25,000 lbf per engine	Thrust ~25,000 lbf per engine
Power ~ 150 MW with single engine	Power ~ 550 MW per engine	Power ~ 575 MW per engine

In-Space Liquid Oxygen / Liquid Methane Engines



Aerojet LOx/LCH4 5,500-lbf pressure-fed workhorse engine in test at NASA WSTF



Aerojet 100-lbf LOx/LCH_4 reaction control engine in test at NASA GRC

Capability Description: In-Space delta-V and Reaction Control Engines propulsion capability based on oxygen/methane propellants

Performance Characteristics:

- Improves ground operations compared to conventional storables, due to low toxicity
- Approximately 10% increase in performance (specific impulse) compared to conventional storables

Destinations Supported: Lunar, Mars, NEA

Current TRL Estimate:

- Pump-fed Main Engine - TRL 4
- Pressure-fed Main Engine - TRL 5
- Reaction Control Engine – TRL 6

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Advanced Exploration Systems Applied Technologies for Exploration Chief Engineer's Office

Lisa Watson-Morgan, Chief Engineer, NASA Marshall

Chief Engineers and Technology

- Responsible for the technical authority of projects
- Not typically associated with the formulation of technology development
- More aligned with systems engineering and integration of complex systems
- The Science and Technology Project Office and Flight Programs and Partnerships Office are each responsible for Advanced Exploration Systems (AES) projects with the goal of proving out the technology in preparation for future Exploration missions.

In Space Manufacturing

- **3D Print:**

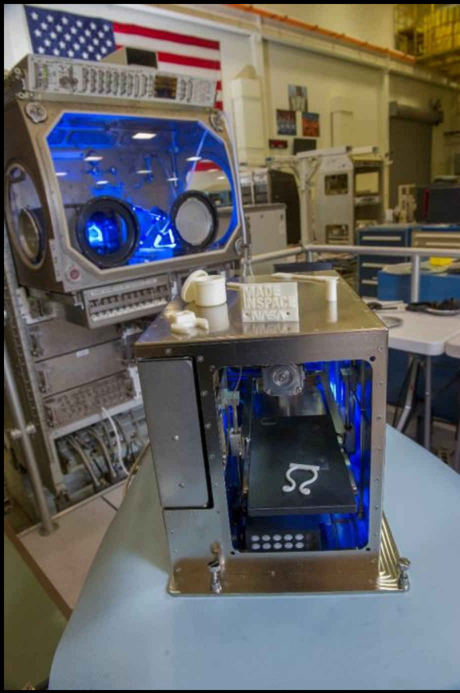
The 3D Printer is on ISS and ready for installation into MSG. 21 parts will be produced to characterize the operation of the printer. Remaining work includes receiving the parts on ground, doing a materials characterization to compare the flight parts to ground produced parts. Information will be used for the production of the permanent print facility on ISS.

- **3D Scanner:**

A 3D structured light scanner will be flown on ISS to digitally model parts that have been produced by the 3D printer for verification. The digital file will be analyzed on the ground to ensure the part produced meets the dimension requirements. Future use may include the scanning of parts on ISS and uploading the digital file to the 3D printer to produce a duplicate part.

- **Material characterization:**

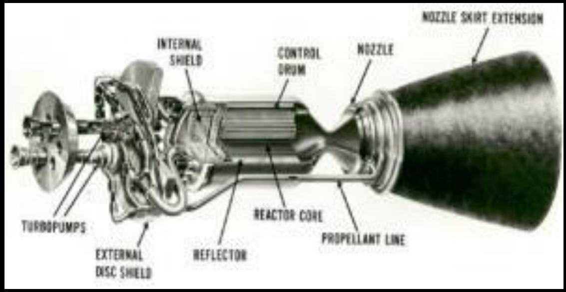
Manufacturing companies consider their additive manufacturing techniques proprietary, so the information required to compare materials and build parameters in order to improve an additive manufactured part is not available; this task will define the build variables and begin the population of a database, which will be used to characterize and optimize additive manufactured materials and parts. Later resulting in a parts catalog for on-orbit use.

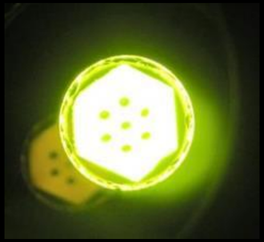


Made in Space 3D Printer and Microgravity Science Glovebox – proving ground for exploration

Nuclear Thermal Propulsion

- Nuclear Fuels Maturation and Production Development
- Affordable Development Strategy
  - Energy comes from fission, not chemical reactions
- Initial systems will have specific impulses roughly twice that of the best chemical systems
  - Reduced propellant (launch) requirements, reduced trip time
  - Enabling for sustained human exploration beyond earth orbit
- Fabricate short (~3") cermet fuel element and test in the Compact Fuel Element Environmental Test (CFEET) System
- Focus for the last 3 years on a human rated operational system with application to Mars. Now the emphasis is toward a sub scale flight demonstration in the mid 2020's that has evolution potential to the human rated system

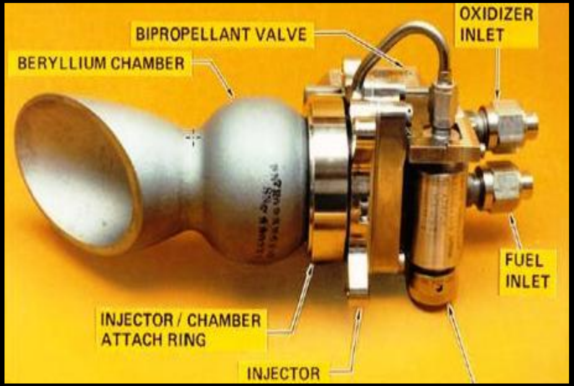




7-hole W-UO_2 in CFEET and post testing up to 2400 C

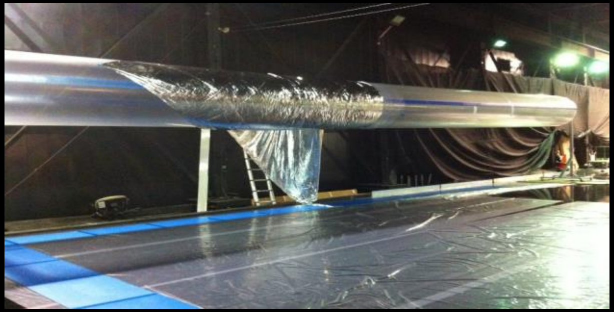
Lander Technology Advancement

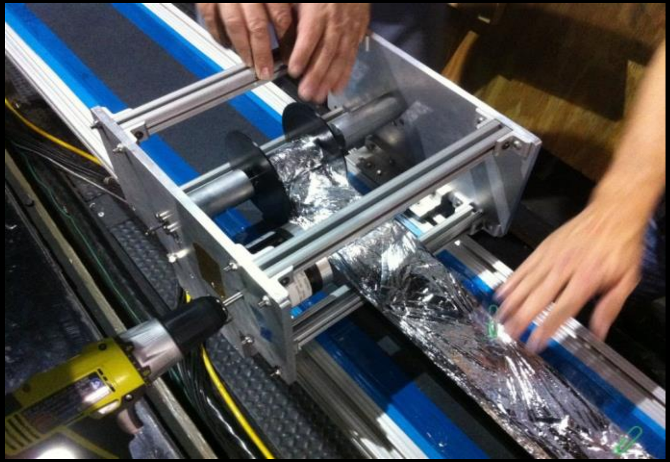
- Peace Keeper Reutilization - NASA has committed to reutilize Peace Keeper hardware, many of the avionics were shredded to comply with international treaties. Lander Technologies is developing PK valve driver hardware to operate the PK hardware for future missions.
- Common Avionics architecture – Identify new processor boards that can be utilized in space that have more capability and less cost than currently available space-flight heritage hardware. Example, replace the flight proven RAD750 process with a Giga-byte dual processor board that needs to be demonstrated in flight before industry can readily use it as off the shelf technology for other missions. NASA will reduce the cost for others by porting the Giga-byte processor to a VI-Works platform that easily integrates into other flight systems.
- Autonomous Landing Hazard Avoidance Technology (ALHAT) - using laser technology, develop a sensor/guidance system that can robotically land a vehicle on another planet and avoid craters, rocks, and other obstructions that would interfere with the success of a robotic mission.



Lunar Flashlight and Near Earth Asteroid Scout

- Development of solar sails that can be used for long duration missions to a near earth asteroid and double as a reflector on the dark side of the moon to look for water in dark craters and recesses on the lunar surface.
- Small cold gas propulsion capability in cube sats that are launched on the SLS vehicle. Currently, LSP does not allow cold gas propulsion systems for cube sats on ELV's for NASA. New capability for NASA and access to deep space.





Packing efficiency test in building 4619 flat floor

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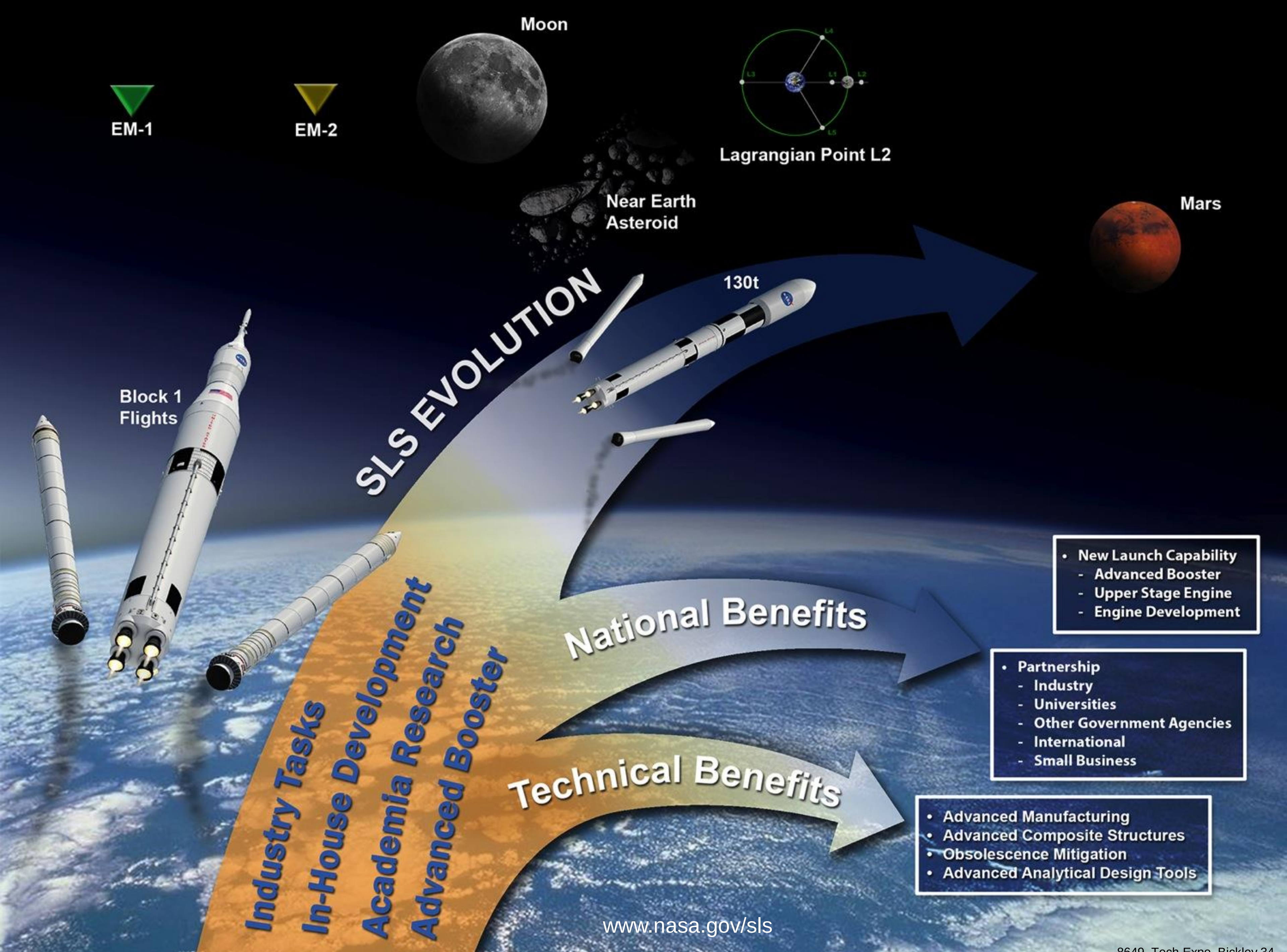
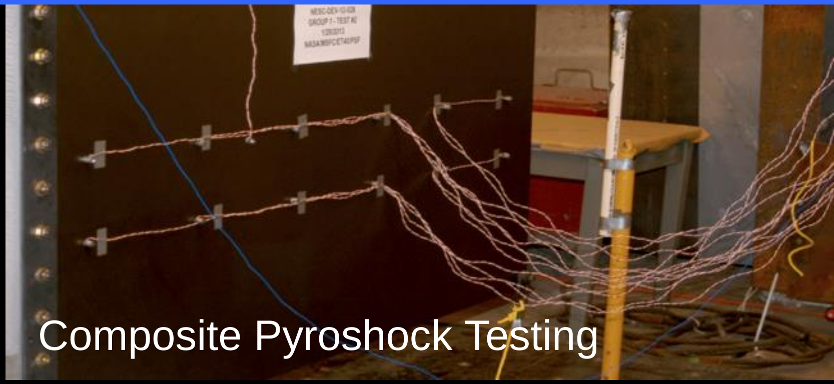
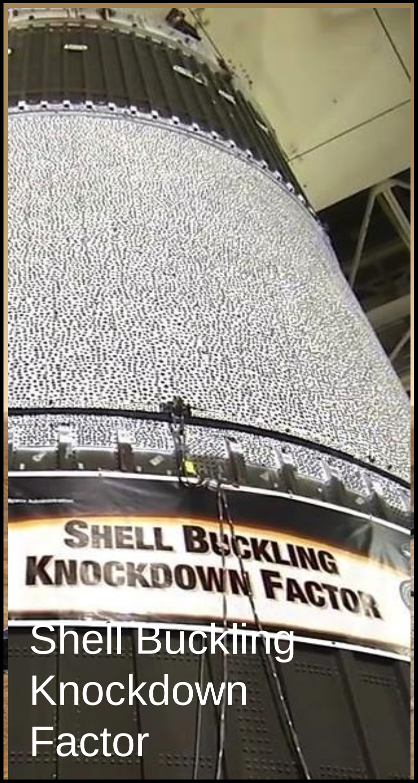
Applied Technologies for Exploration

Dr. Fred Bickley, Spacecraft/Payload Integration and Evolution Office, SLS Program Office, NASA Marshall


Moon
EM-1
EM-2
Lagrangian Point L2
Near Earth Asteroid
Mars
130t
Block 1 Flights
SLS EVOLUTION
National Benefits
Technical Benefits
Industry Tasks
In-House Development
Academia Research
Advanced Booster
• New Launch Capability
- Advanced Booster
- Upper Stage Engine
- Engine Development
• Partnership
- Industry
- Universities
- Other Government Agencies
- International
- Small Business
• Advanced Manufacturing
• Advanced Composite Structures
• Obsolescence Mitigation
• Advanced Analytical Design Tools
www.nasa.gov/sls

Advancing the State of the Art





Questions / Discussion

Lunch!

- Pre-ordered lunches in the Davidson Center hall
- Lunch also available in the Mars Grill
- Sit out on the Apollo Terrace
- Visit the Exhibits

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Afternoon Kickoff

Jose Matienzo, Manager, Marshall Exchange, NASA Marshall

Tracy Lamm, Chairperson, National Space Club – Huntsville Chapter

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Keynote Address:

Technology Drives Exploration

Dr. Michael Gazarik, Associate Administrator, NASA
Space Technology Mission Directorate, NASA HQ

National Aeronautics and
Space Administration

Space Technology Mission Directorate

Marshall Space Flight Center Technology and Innovation Day

Michael Gazarik, Ph.D.
Associate Administrator
Space Technology Mission Directorate

October 27, 2014

Technology Drives Exploration

Space Technology Guiding Principles:

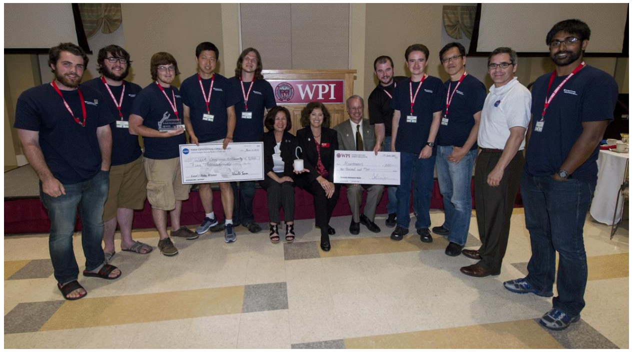
Addressing **tough technology problems for NASA** including in-space propulsion, deep space navigation, lightweight structures and entry, descent and landing

Responding to **aerospace industry challenges** in areas such as in-space communications, propulsion, manufacturing, robotics and materials through contracts, grants and public private partnerships

Leveraging limited funding through **partnering and cost sharing** to maximize investment in tight budget environment

Employing Small Businesses, academia and partnerships to **foster innovation, tapping into the Nation's entrepreneurs** to tackle key challenges

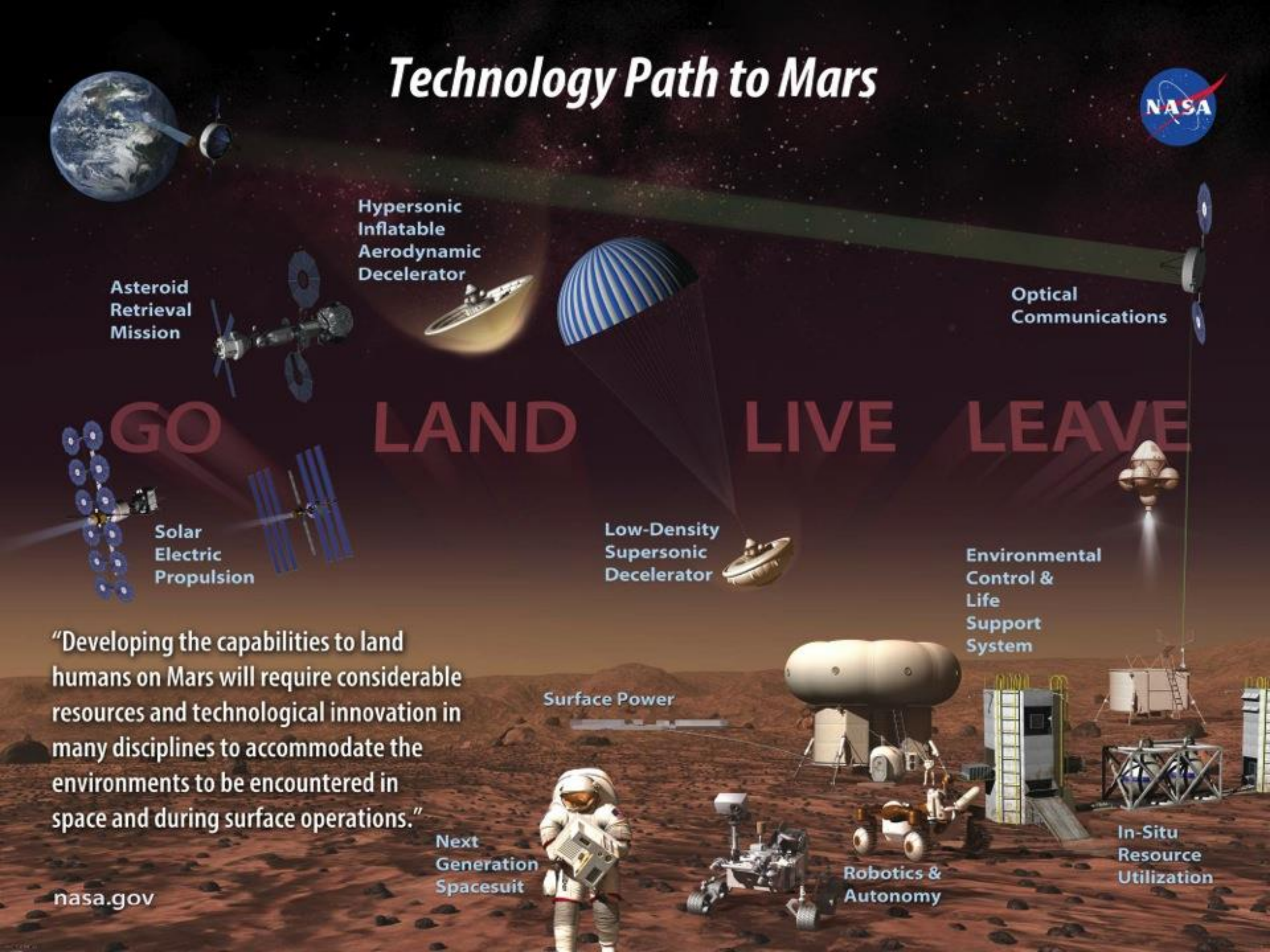
Utilizing prize competitions to address challenges including: robotics, deep-space cubesat operations, autonomous systems, additive manufacturing, and Europa ice excavation



Space Technology Strategic Themes

- ❖ ***Getting There***: Improve the Nation's capabilities for access and travel through space.
- ❖ ***Land There***: Develop and demonstrate technologies that enable landing more mass, more accurately, in more locations throughout the solar system
- ❖ ***Live There***: Develop and demonstrate technologies to live and work in deep space and on planetary bodies
- ❖ ***Observe There***: Develop and demonstrate technologies that transform the ability to observe the universe and answer the profound questions in earth and space sciences





Technology Path to Mars
NASA
Hypersonic Inflatable Aerodynamic Decelerator
Asteroid Retrieval Mission
Optical Communications
GO
LAND
LIVE
LEAVE
Solar Electric Propulsion
Low-Density Supersonic Decelerator
Environmental Control & Life Support System
"Developing the capabilities to land humans on Mars will require considerable resources and technological innovation in many disciplines to accommodate the environments to be encountered in space and during surface operations."
Surface Power
Next Generation Spacesuit
Robotics & Autonomy
In-Situ Resource Utilization
nasa.gov

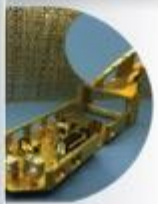
Deep Space Exploration is Near

Space Technology will focus investments in 8 thrust areas that are key to future NASA missions and enhance national space capabilities.

High Power Solar Electric Propulsion

Deep space human exploration, science missions with investments in advanced solar arrays and advanced electric propulsion systems, high-power Hall thrusters and power processing units.

***Application:** Improved Affordability of commercial and OGA Satellites*



Space Optical Comm

Substantially increase available bandwidth for near Earth space communications currently limited by power and frequency allocation limits. Increase communications throughput for deep space missions.

***Application:** More bandwidth for Commercial and OGA Satellites*

Advanced Life Support & Resource Utilization

Technologies for human exploration mission including Mars atmospheric In-situ resource utilization, near closed loop air revitalization and water recovery, EVA gloves and radiation protection.

***Application:** More bandwidth for Commercial and OGA Satellites*

Mars Entry Descent & Landing Systems

Permits more capable science and future human missions to Mars. Includes, hypersonic and supersonic aerodynamic decelerators, next-gen TPS materials, retro-propulsion technology, instrumentation and modeling.

***Application:** Returning research from ISS and other assets from space*

Space Robotic Systems

Creates future humanoid robotics, autonomy and remote operations technologies to substantially augments the capability of future human space flight missions.

***Application:** Human safe Robotics for industrial use, Disaster Response, and Autonomous Operations*

Lightweight Space Structures

Targets substantial increases in launch mass, and allow for large decreases in needed structural mass for spacecraft and in-space structures.

***Application:** Industrial Materials and Composites for large transportation structures*

Deep Space Navigation

Allows for more capable science and human exploration missions using advanced atomic clocks, x-ray detectors and fast light optical gyroscopes.

***Application:** Next Generation GPS & launch vehicles*

Space Observatory Systems

Allows for significant gains in science capabilities including: coronagraph technology to characterize exoplanets, advances in surface materials and better control systems for large space optics.

***Application:** Industrial Materials, Earth Observation*

THRUST AREAS

Space Technology Portfolio

Transformative & Crosscutting Technology Breakthroughs

Technology Demonstration Missions bridges the gap between early proof-of-concept tests and the final infusion of cost-effective, revolutionary technologies into successful NASA, government and commercial space missions.

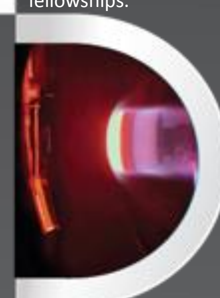
Small Spacecraft Technology Program develops and demonstrates new capabilities employing the unique features of small spacecraft for science, exploration and space operations.

Game Changing Development seeks to identify and rapidly mature innovative/high impact capabilities and technologies that may lead to entirely new approaches for the Agency's broad array of future space missions.

Pioneering Concepts/Developing Innovation Community

NASA Innovative Advanced Concepts (NIAC) nurtures visionary ideas that could transform future NASA missions with the creation of breakthroughs—radically better or entirely new aerospace concepts–while engaging America's innovators and entrepreneurs as partners in the journey.

Space Technology Research Grants seek to accelerate the development of "push" technologies to support future space science and exploration needs through innovative efforts with high risk/high payoff while developing the next generation of innovators through grants and fellowships.



Center Innovation Fund stimulates and encourages creativity and innovation within the NASA Centers by addressing the technology needs of the Agency and the Nation. Funds are invested to each NASA Center to support emerging technologies and creative initiatives that leverage Center talent and capabilities.

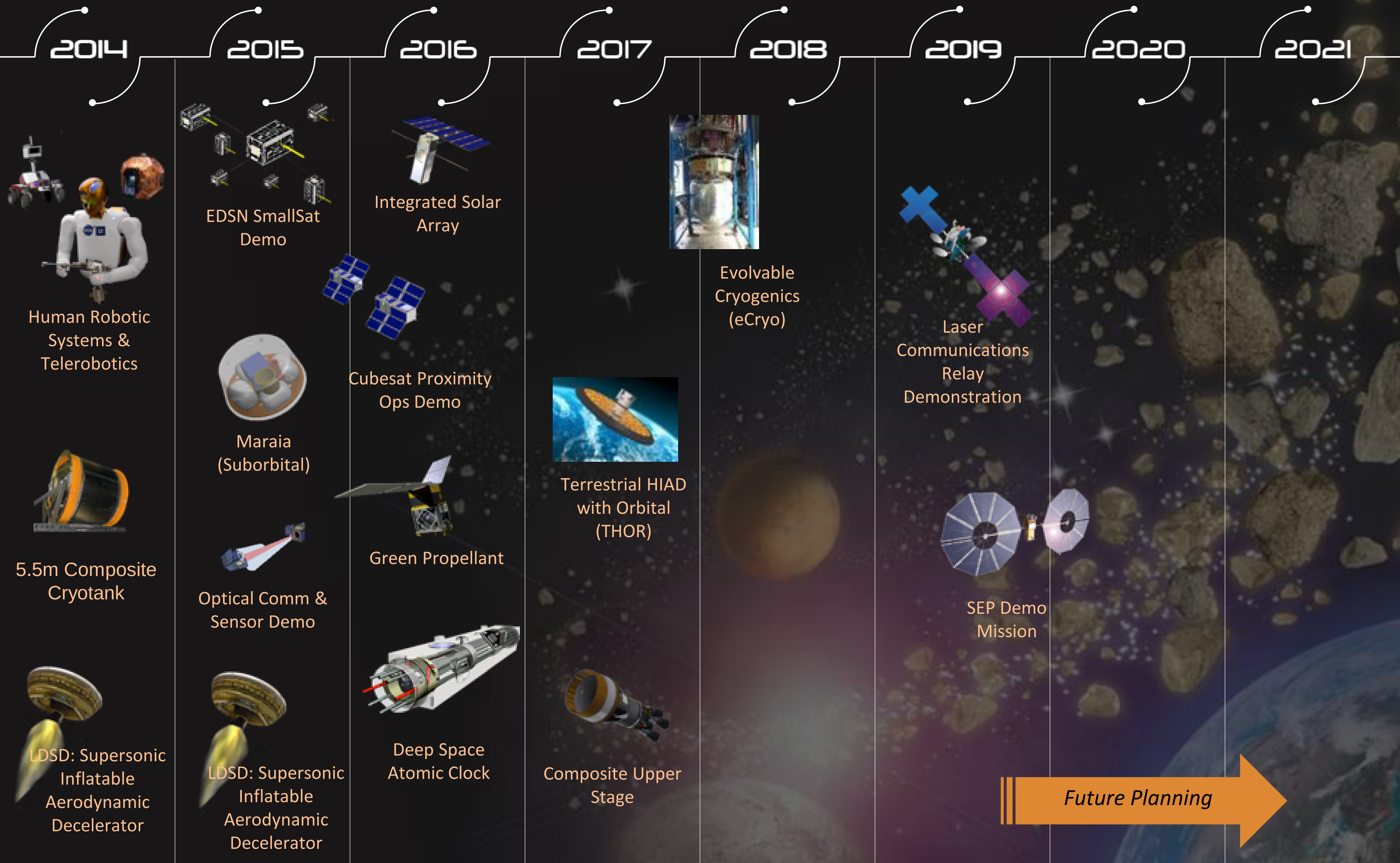
Creating Markets & Growing Innovation Economy

Centennial Challenges directly engages nontraditional sources advancing technologies of value to NASA's missions and to the aerospace community. The program offers challenges set up as competitions that award prize money to the individuals or teams that achieve a specified technology challenge.

Flight Opportunities facilitates the progress of space technologies toward flight readiness status through testing in space-relevant environments. The program fosters development of the commercial reusable suborbital transportation industry.

Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs provide an opportunity for small, high technology companies and research institutions to develop key technologies addressing the Agency's needs and developing the Nation's innovation economy.

CY Major Events & Milestones



Snapshot of Space Technology Partners

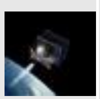
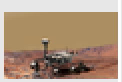
STMD invests in more than 50 companies totaling over $300M

AEROSPACE
PUMPKIN INCORPORATED
tyvak NANO-SATELLITE SYSTEMS LLC
MSNW
BRM Bally Ribbon Mills
saft
APPLIED DEFENSE SOLUTIONS
BUSEK
AS AIRBORNE SYSTEMS
4O6 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.
Dynetics The Power of Solutions
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
SOUTHERN RESEARCH INSTITUTE
ADCOLE
Masten
Frequency Electronics, Inc.

STMD Partners with Universities to Solve The Nation's Challenges

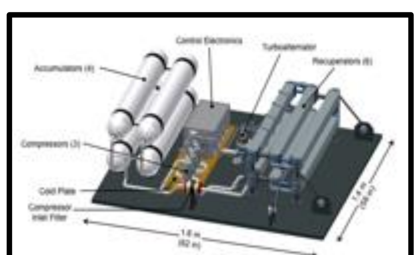
U.S. Universities have been *very* successful in responding to STMD's competitive solicitations

- 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*

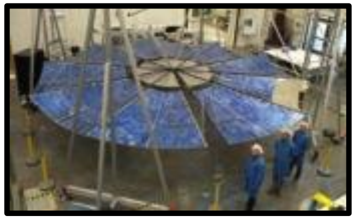
STMD Investments to Advance Future Capabilities of Space Launch System (SLS) & Orion

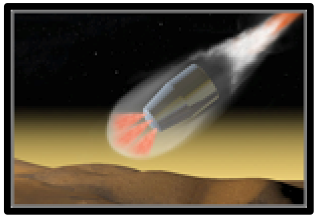
- Composite cryogenic propellant tanks and dry structures for SLS block upgrades
- Evolvable Cryogenics (eCryo) develops advanced cryogenic propellant management technologies for SLS future missions.
- Composite Evolvable Upper Stage (CEUS) helps to develop composite structures technologies for the SLS.
- Additive manufacturing and testing of upper stage injectors, combustion chambers and nozzles
- Phase change material heat exchangers for Orion in lunar orbit
- 3D Multifunctional Ablative TPS (3D MAT); Woven TPS infusion for Orion heat shield compression pads
- Develop high capacity cryocooler to enable zero boil-off of liquid hydrogen
- Advanced air revitalization for Orion upgrades

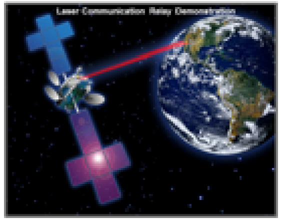


STMD Investments to Advance Human Exploration of Mars

- High-powered solar electric propulsion – cargo and logistics transportation to Mars
- eCryo-chemical advanced cryogenic - in-space propulsion for crew transportation
- Advanced large-scale composite structures (CEUS) - for large In-Space transfer stages for crew transportation
- Composite cryogenic propellant tanks and dry structures – exploration upper stage
- Small Fission Power / Stirling Engine Power – Mars surface power
- Aerodynamic decelerators – deployable entry systems for large mass landers
- Supersonic decelerators - descent of large landed masses at Mars
- Supersonic retro-propulsion – large mass Mars landing and reusable launch vehicles
- Woven thermal protection system – more efficient and flexible TPS materials for entry
- Advanced close loop Air revitalization and water recovery – reduced consumables
- Mars atmospheric ISRU (oxygen) – life support and ascent vehicle oxidizer
- Humanoid robotics – enhanced exploration and crew workload relief
- Advanced mobility rover – remotely operated exploration
- Optical communications – high bandwidth communications at Mars



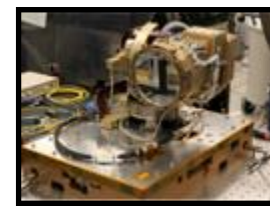




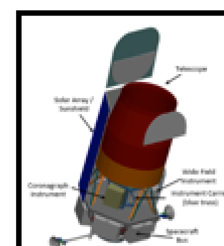
Advancing Science Mission Capabilities

- **Entry, Descent, & Landing**
  - Instrumentation & Entry Systems Modeling – Mars EDL systems design
  - Woven Thermal Protection System – Venus, Mars & Outer Planets
  - Low Density Supersonic Decelerator – increased mass to Mars surface
  - Hypersonic Inflatable Aerodynamic Decelerator & Adaptable, Deployable Entry Placement Technology – deployable heat shields for Venus and Mars provides much lower entry loads

- **Propulsion & Power**
  - Green Propellant Infusion Mission - alternative to hydrazine
  - Solar Electric Propulsion – enabling new science missions
  - Solar Sail – enables unique vantage points for heliophysics
  - Small Fission – power for outer planet missions



- **Communication & Navigation**
  - Deep Space Optical Comm & Laser Communication Relay Demo – up to 10x data return for planetary and near-Earth missions
  - NICER/SEXTANT & Deep Space Atomic Clock – navigation using celestial x-ray sources & highly accurate deep space navigation



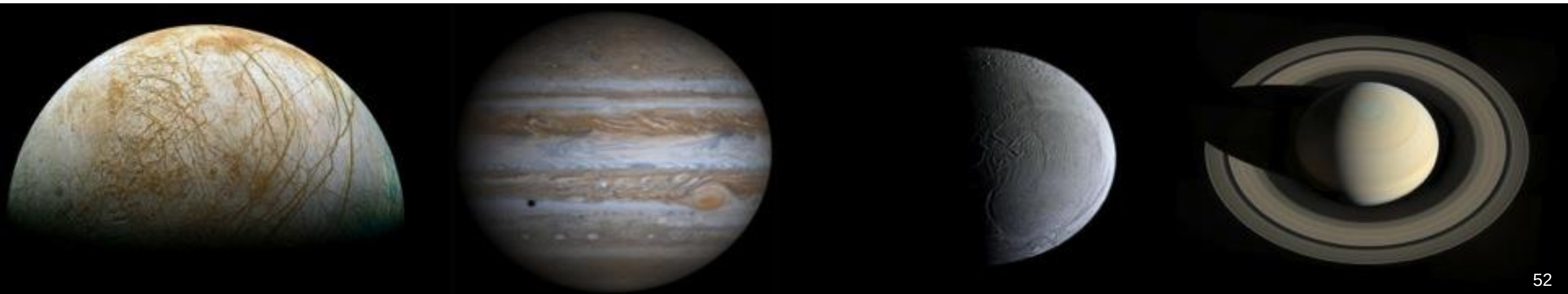
- **Instruments, Sensors, & Thermal**
  - High Performance Spaceflight Computing – broadly applicable to science missions
  - AFTA / WFIRST Coronagraph – to perform direct observations of exoplanets and determining their atmospheric content

STMD Investments to Advance Planetary Science

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)
- Deep Space Optical Communications (DSOC)
- Deep Space Atomic Clock (DSAC)
- Heatshield for Extreme Environment Technology (HEEET)
- Green Propellant

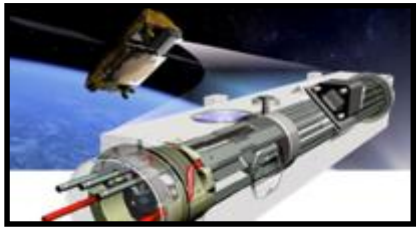
Space Technology Investments for Outer Planetary Exploration:
- Solar and nuclear power
- Radiation protection
- Landing
- Navigation and communication



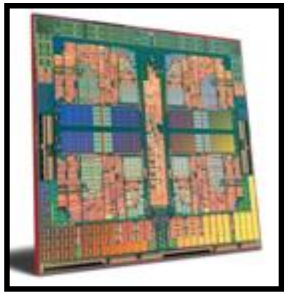
STMD - Aerospace Industry Alignment Examples

- **Structures and Materials**
  - Composite Tanks & Structures – for improved launch vehicle performance
  - Hypersonic Entry Technology – for orbital down mass capability

- **Propulsion & Power**
  - Green Propellant Infusion Mission – improved spacecraft performance & reduced toxicity and ground processing costs
  - Solar Electric Propulsion – enabling increased power, reduced mass and longer life for commercial communication satellites



- **Communication & Navigation**
  - Laser Communications – replacing radio frequency based gateway links with optical links and reduces spectrum utilization on commercial satellites
  - Deep Space Atomic Clock – 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 – to perform environmentally hazardous tasks and operate within terrestrial settings

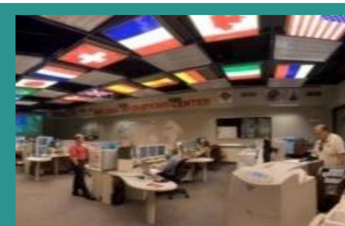
Marshall’s Role in Agency Missions

Four Core Technology Themes

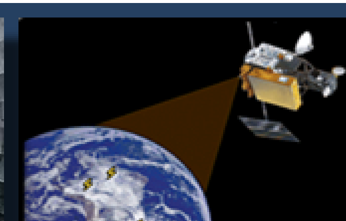
Space Transportation/Launch Vehicle Technology and Development


Propulsion Systems Technology and Development

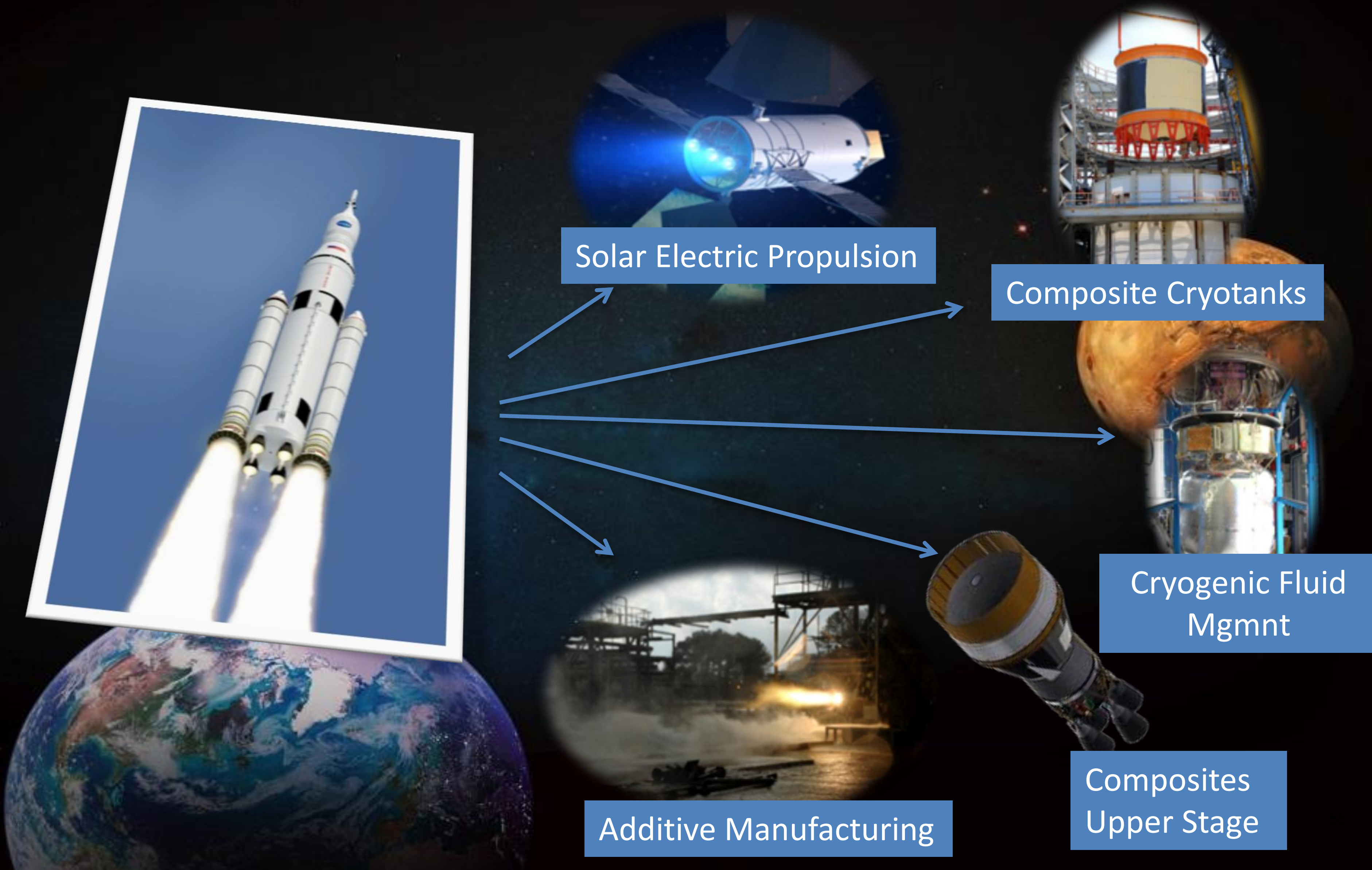

Space Systems Technology, Development, and Integration




Scientific Research

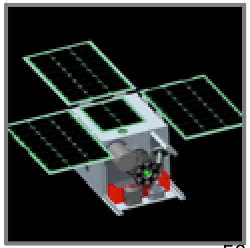
Space Technology Mission Directorate
Aligning to Marshall's Core Themes



Technology Drives Exploration: Huntsville Will Lead the Way

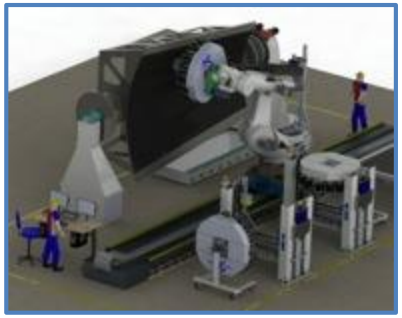
- Critical technologies are converging
  - Substantial growth in aerospace composites markets projected in next decade
  - Materials, structures and manufacturing technologies leveraging the explosion in computational capabilities and advances in simulation
  - Key technology developments in DoD and Aerospace industry
- Pioneered Composite Cryotank Technology
  - Fabricated a 5.5m composite cryotank using automated fiber placement technology
  - Potential for 25% cost savings and greater than 30% mass savings
- Cryogenic Fluid Management is critical to future exploration missions
- Ultra-lightweight core materials fabrication at scale and in more complex geometries
- Advanced propulsion for small spacecraft - enabling "professional grade" applications and deep-space operations



Composites for Exploration Upper Stage

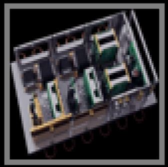
Composites Opportunities



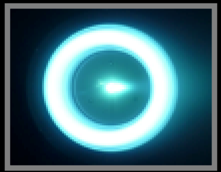
Technology Investment:
High Power Solar Electric Propulsion

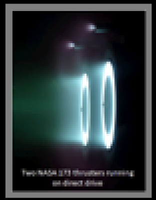
Solar Arrays

Power Processing Units (PPUs)

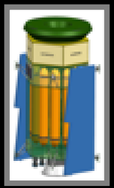


Thrusters

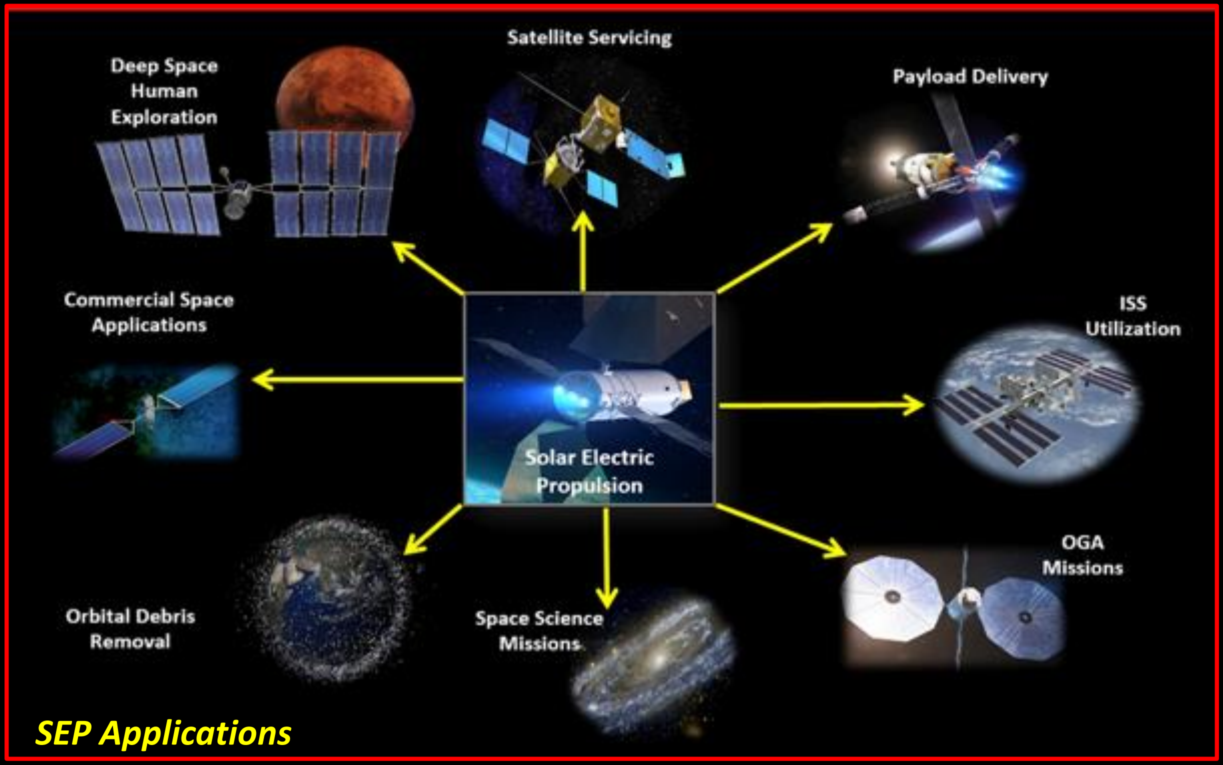




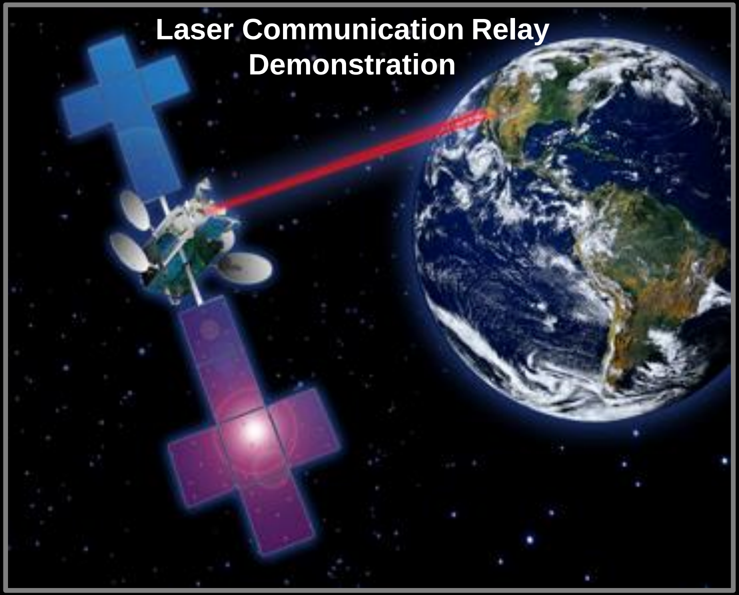
Propellant Feed System & Storage Tanks



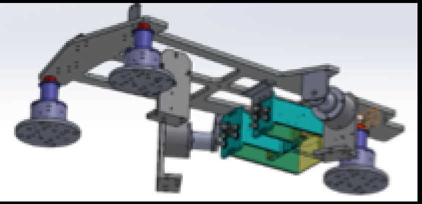
SEP "Space Tugboat"



Technology Investment: Optical Space Communication

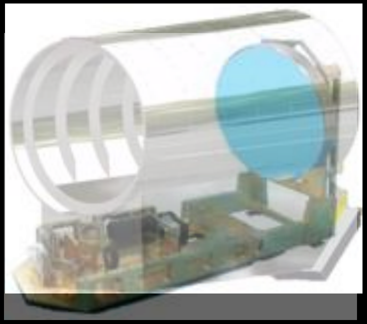


Spacecraft Disturbance Isolation

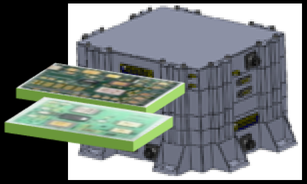


Point-Ahead Mirror

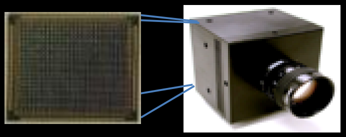
Flight Laser Transceiver



Electronics & Control



Photon-Counting Camera



Laser Transmitter

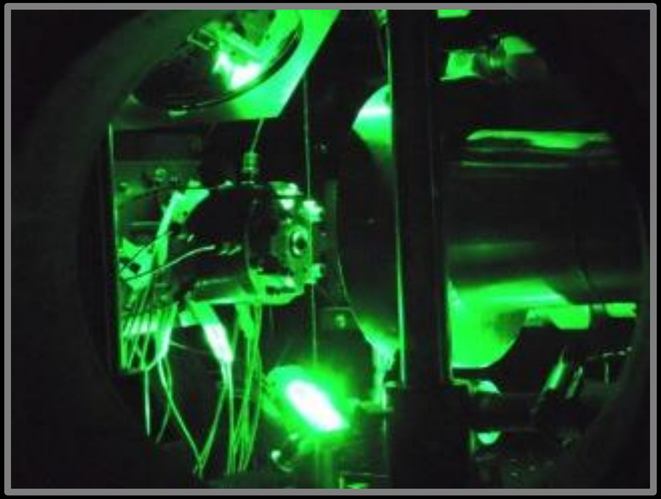
Technology Investment: Deep Space Atomic Clock

Technology Investment: Advanced Thermal Protection Systems

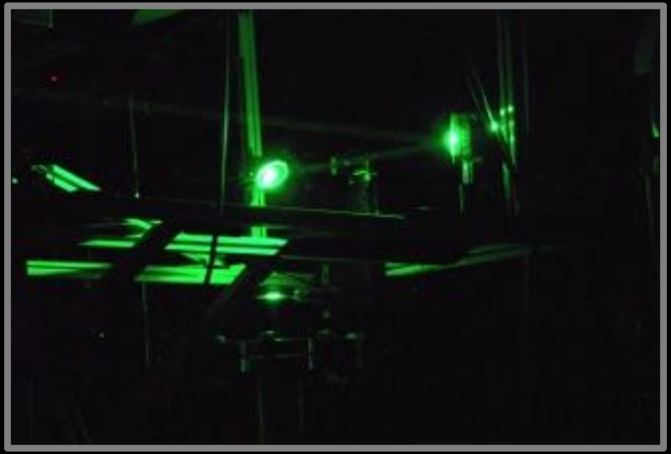
3-D MAT Compression Pad preform weaving at Bally Ribbon Mills

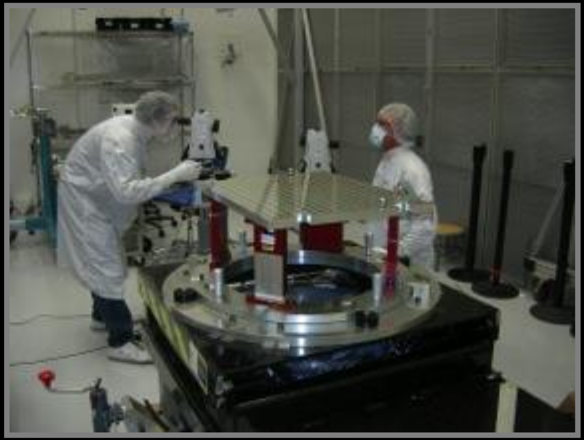
A scalable, 3-D, multi-layer preform weaving at Bally Ribbon Mills

Technology Investment: Green Propellant Infusion Mission



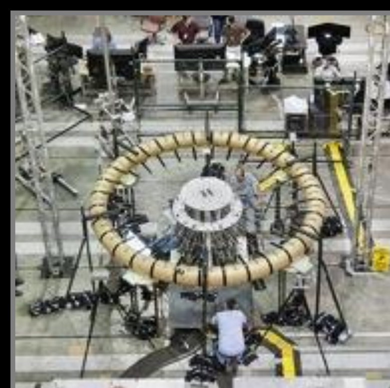
1N thruster plume chemistry using laser diagnostics





Technology Investment: Hypersonic Decelerators

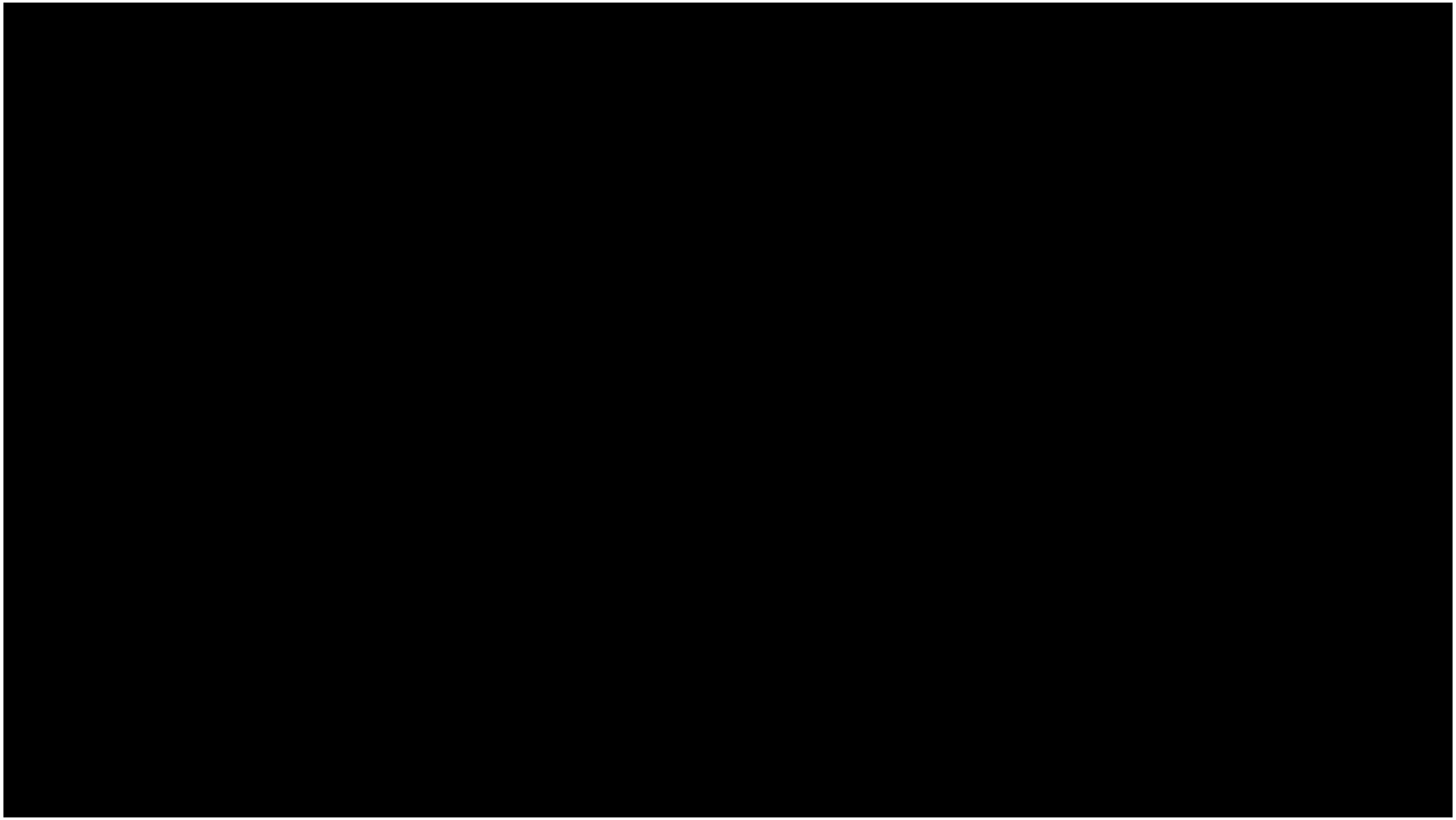
Supersonic Retro Propulsion



Hypersonic Inflatable Aerodynamic Decelerator

Hypersonic Inflatable Demonstration from ISS

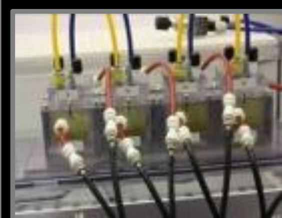
SRP Video



Technology Investment: Advanced Life Support and In-Situ Resource Utilization





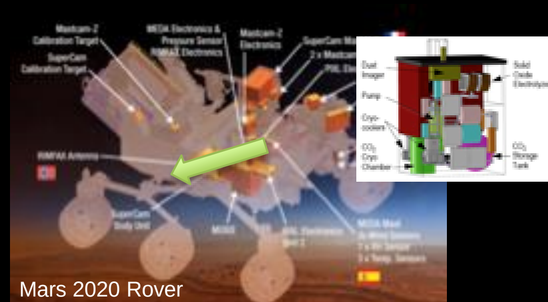


Alternate Water Processor


Life Support aboard ISS


Advanced Oxygen Recovery

Variable Oxygen Regulator 3.0



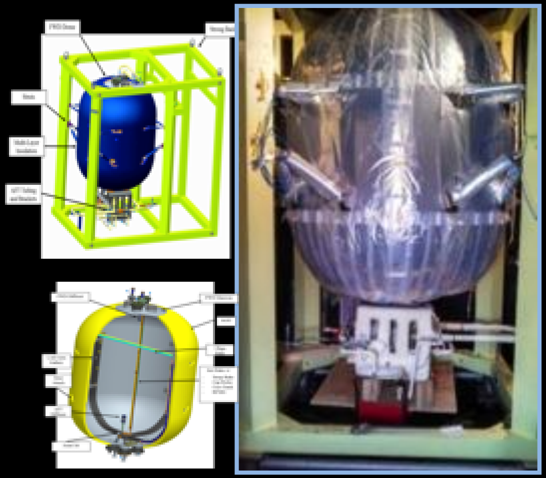
Mars Oxygen ISRU Experiment (MOXIE)


Portable Life Support System Integrated Test

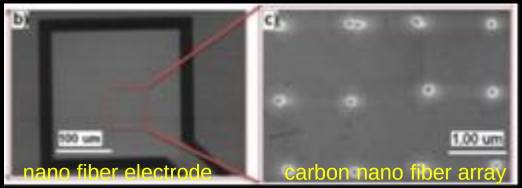
Technology Investment:
Advanced Launch Systems

Additive Manufacturing for combustion chambers and nozzles

Composite Cryotank and dry structures



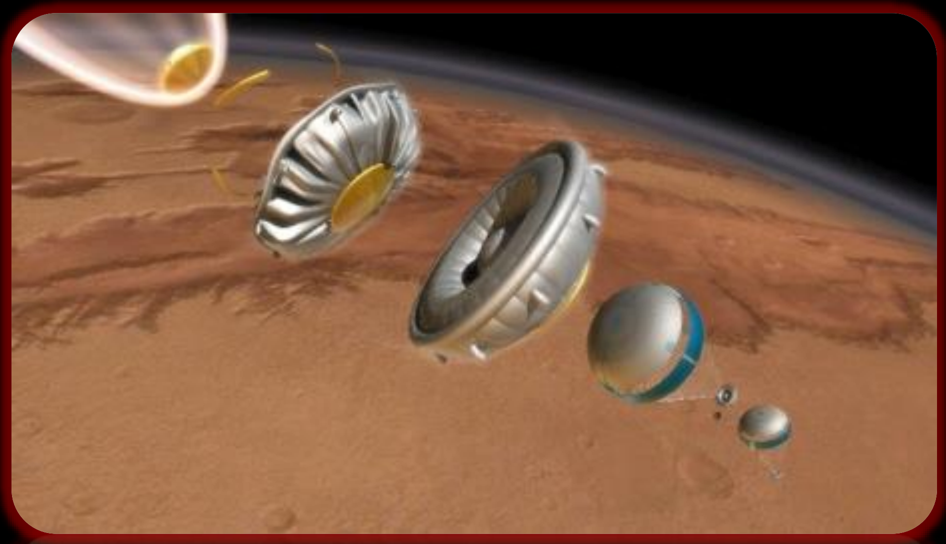
eCryo for upper stage



Nanotechnology

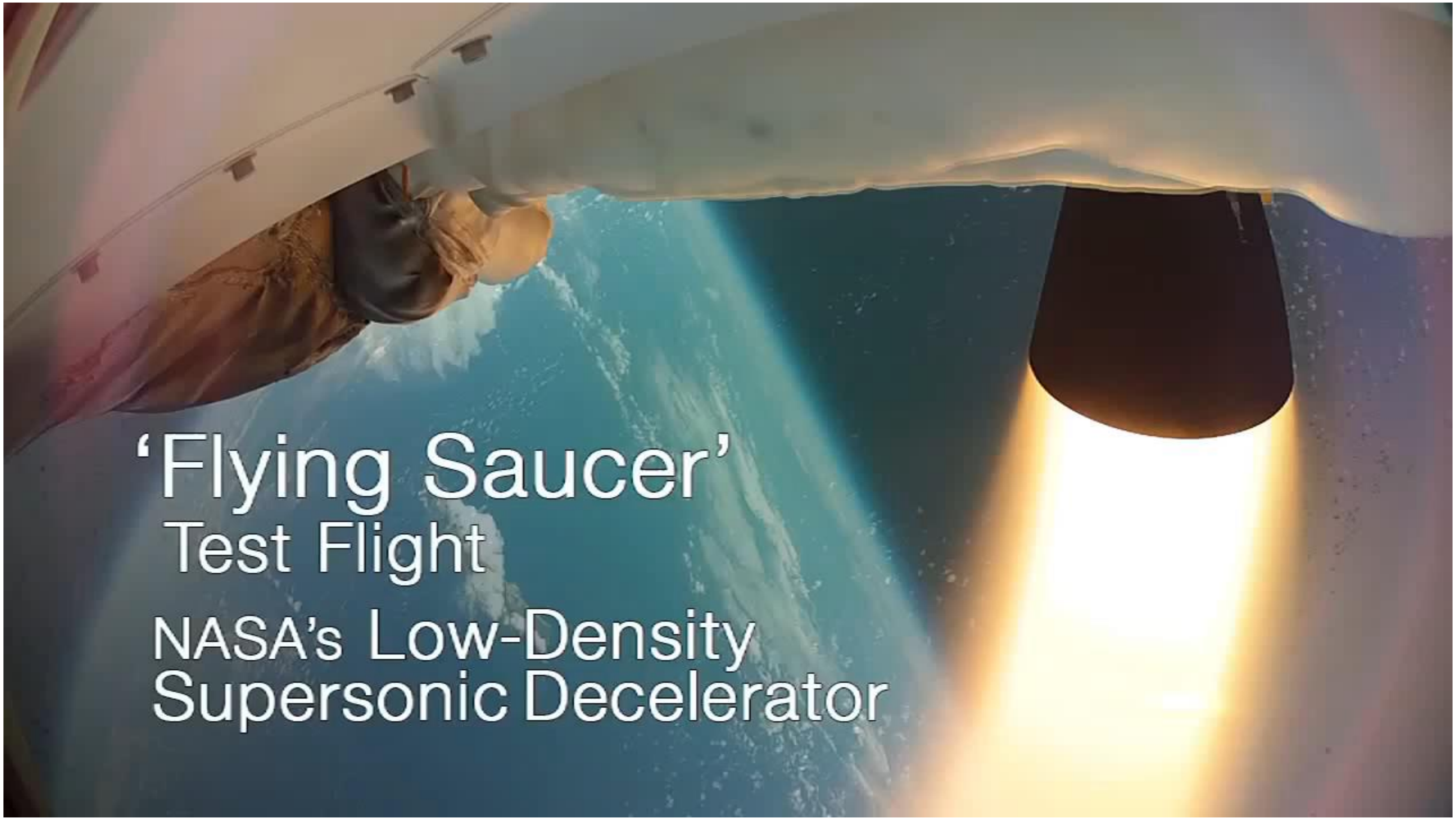
Composites for upper stage

Test Success:
Low Density Supersonic Decelerator



Successful LDSD flight test - Creating new knowledge and developing new capability

LDSD Video


'Flying Saucer'
Test Flight
NASA's Low-Density
Supersonic Decelerator

A Look Ahead

- Technology Demonstration Mission Program
  - BAA (topic areas under consideration)
- Solar Electric Propulsion
  - SEP tug
  - High powered solar arrays
  - Electric propulsion system
  - Low-cost solar arrays
- Advanced In-Space Propulsion
- Ultra Lightweight Composite Core Materials
- Outer Planet Exploration Technologies
  - Icy surface landings
  - Radiation protection
  - Robotics
  - Navigation
  - Communication
- Advanced Manufacturing

Technology Drives Exploration
#321Techoff

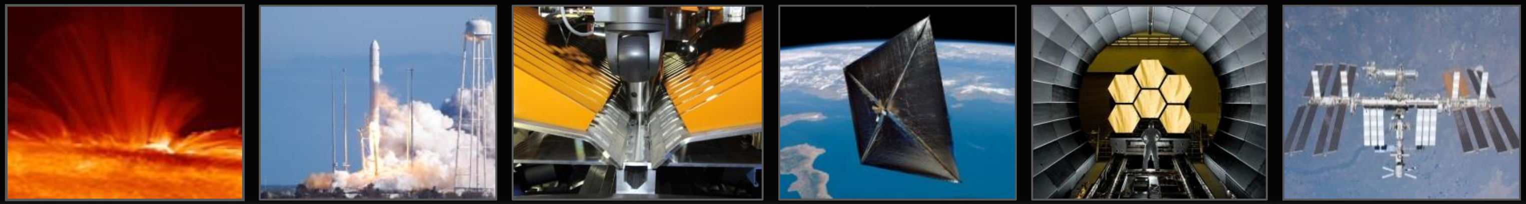
National Aeronautics and Space Administration

Marshall Technology Exposition

Join us on the journey

Emerging Space Technology Developments

Moderator: Dr. David Miller, NASA Chief Technologist



marshall

Applied Technologies for Exploration: Agenda

Opening Comments

– Dr. David Miller, NASA Chief Technologist

Panelists' Comments

– Steve Gaddis, Program Director, Game Changing Development, NASA Langley
– Dr. Tom Koshut, Associate Vice President of Research, UAHuntsville
– Dr. Dan Schumacher, Director, Science and Technology Office, NASA Marshall
– Dr. Andrew Keys, Chief Technologist, NASA Marshall

Q & A

Marshall Technology Exposition

Join us on the journey

Emerging Space Technology Developments

Steve Gaddis, Program Director, Game Changing Development, NASA Langley

Marshall Technology Exposition

Join us on the journey

Emerging Space Technology Developments

Dr. Tom Koshut, Associate Vice President for Research,
The University of Alabama in Huntsville

Technology Development Landscape in Academia

- **Motivation:**
  - Need Challenging, State-of-the-Barely-Possible, Technical Problems to Inspire Students, Faculty, and Research Staff.
  - *Tools:* NASA/DOD Missions, Agency S&T Roadmaps, NSF/DOE Programs

- **Innovation:**
  - Research Universities Develop Subject Matter Excellence, Convolve with Unbounded Perspectives and Curiosity, Apply Towards the Generation of New Knowledge
  - *Tools:* PhD Faculty, Grad Students, Internal R&D, Sponsored Research

- **Dissemination:**
  - Share Innovation and Maximize Its Application
  - Build and Strengthen Communities of Critical Mass
  - Seek and Facilitate Interdisciplinary Collaboration
  - *Tools:* Peer-review Journals, Symposia, Colloquia, Seminars, Patents, Licenses, Industry/University Cooperative Research Centers, EPSCoR, SBIR/STTR

- **Education:**
  - Transform Students into Next-Generation Critical-thinkers/Problem-solvers
  - Faculty Bring State-of-the-Art Research into the Classroom
  - Providing Cutting-edge Research Experiences for Students
  - *Tools:* Challenging Curricula, Faculty/Peer/Global Engagement, Extracurriculars

UAH as a Research & Technology Partner

- UAH has achieved status in the "Very High Activity" research category (RU/VH) by the Carnegie Foundation for the Advancement of Teaching, placing UAH among a select group of only 73 public universities in America
- Ranks 14th in the Nation as measured by NASA-funded Research Expenditures (consistently ranks in the Top 15) and 16th in the Nation as measured by DOD-funded Research Expenditures (FY12 NSF Survey Data)
- Federally-financed R&D Expenditure Rankings (FY12 NSF Survey Data):
  - 5th in Aeronautical/Astronautical Engineering
  - 13th in Computer Sciences
  - 17th in Atmospheric Sciences
  - 22nd in Astronomy
  - 8th in Business and Management
  - 25th in Political Science
- UAH ranked #2 among Alabama Universities in Federally-financed R&D Expenditures
- UAH Propulsion Research Center named 3rd "Most Awesome Lab" by *Popular Science* magazine as part of its "Best Places to Pursue Science" feature.

UAH Intellectual Capital

- **7 Colleges:** Business, Education, Engineering, Honors, Liberal Arts, Nursing, Science

- **Research Centers:**
  - Center for Applied Optics (CAO)
    - Nano and Micro Devices Center (NMDC)
  - Center for Cybersecurity Research and Education (CCRE)
  - Center for Management and Economics Research (CMER)
  - Center for the Management of Science and Technology (CMOST)
  - Center for Modeling, Simulation, and Analysis (CMSA)
  - Center for Space Plasma and Aeronomic Research (CSPAR)
  - Earth System Sciences Center (ESSC)
  - Humanities Center (HC)
  - Information Technology Systems Center (ITSC)
  - Propulsion Research Center (PRC)
  - Research Institute (RI)
    - Aerophysics Research Center
    - Reliability and Failure Analysis Laboratory
  - Rotorcraft Systems Engineering and Simulation Center (RSESC)
  - Small Business Development Center (SBDC)
  - Systems Management and Production Center (SMAP)

- **Support Offices:** Technology Commercialization, Sponsored Programs, Research Security, Proposal Development, C&G Accounting, Communications, Government Relations, Office of Counsel

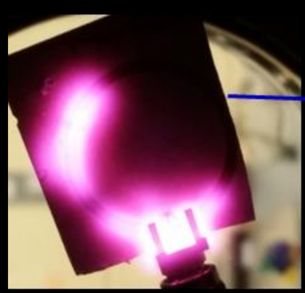
UAH Enabling Research Facilities

Leveraging Resources for Collaboration

- Access to Federal Grant Opportunities Reserved for Universities (MRI, DURIP, MURI, IUCRC, EPSCoR, STTR)
- PhD Faculty Research Effort in PhD-granting Colleges
- Start-up Funds for New PhD Faculty
- Discretionary Funds for Targeted Investments
- Budgeted Support for Research Centers
- Regular, Competitive Internal Funding Investments
- State of Alabama Investments
- Alabama State EPSCoR, Alabama Innovation Fund, etc.
- Proposal Development Assistance, IP Commercialization Assistance, Contract T&C Negotiation
- IRB, IACUC, EH&S
- Export Control/ITAR Training and Compliance
- NISPOM Compliance/Security Clearance Assistance

Example Emerging Space Technologies at UAH

- Advanced Composites for Aerospace Structures
- Pulsed Fusion Propulsion Systems
- Advanced Manufacturing – 3D Printing
- Nowcasting and Forecasting Radiation Environment in Space
- Cybersecurity for Aerospace Vehicle Control Systems
- EM Field-based Radiation Protection Systems for Crewed Missions
- Printable Plasma Generator for 3D-printed Micro Thruster.
- Laser-based Asteroid Deflection and Debris Mitigation Technologies
- Electromagnetic-Field Plasma-Assisted Combustion
- Laser-based Communication and Power Transfer



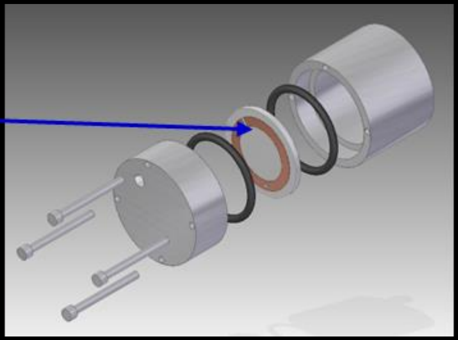
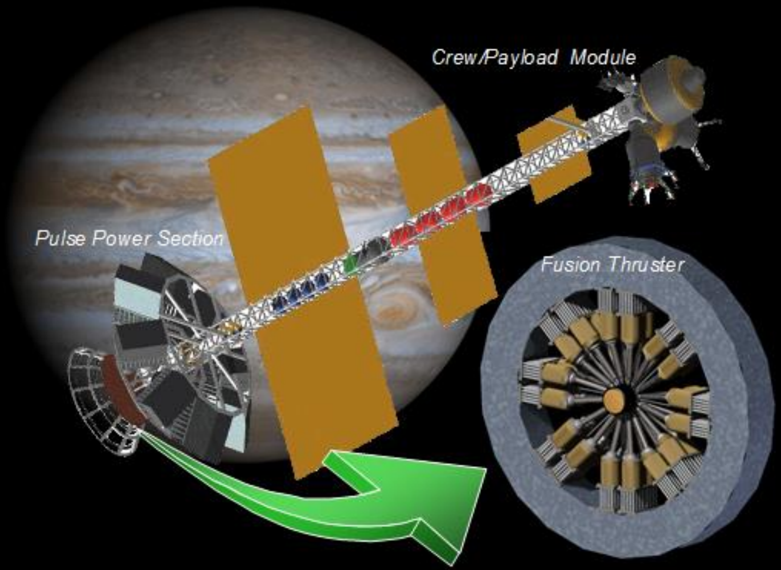


Image Courtesy: Dr. Gabe Xu, UAH MAE Dept.

Charger-1 Fusion Propulsion Research

Technical Approach:

- Develop liquid injection of lithium and lithium deuteride wires to impulsively form and implode wire array targets as a step towards high-repetition rate z-pinch fusion
- Initiated with the receipt of the 3 terawatt (TW) DECADE Module-2 from the Defense Threat Reduction Agency in May of 2012.
- A 570 kJ pulsed power machine capable of delivering >2 MA to an electrical load for pulses of 50 to 500 μs.



Objectives:

- Round-trip time to Mars of ~7 months
- Robust exploration of solar system on timescales of years

Collaborators:

- UAH, State of Alabama
- NASA/MSFC
- Boeing Company, L3 Communications
- Oak Ridge National Laboratory
- Y-12 National Security Complex
- Others

Image Courtesy: Dr. Jason Cassibry, UAH MAE Dept.

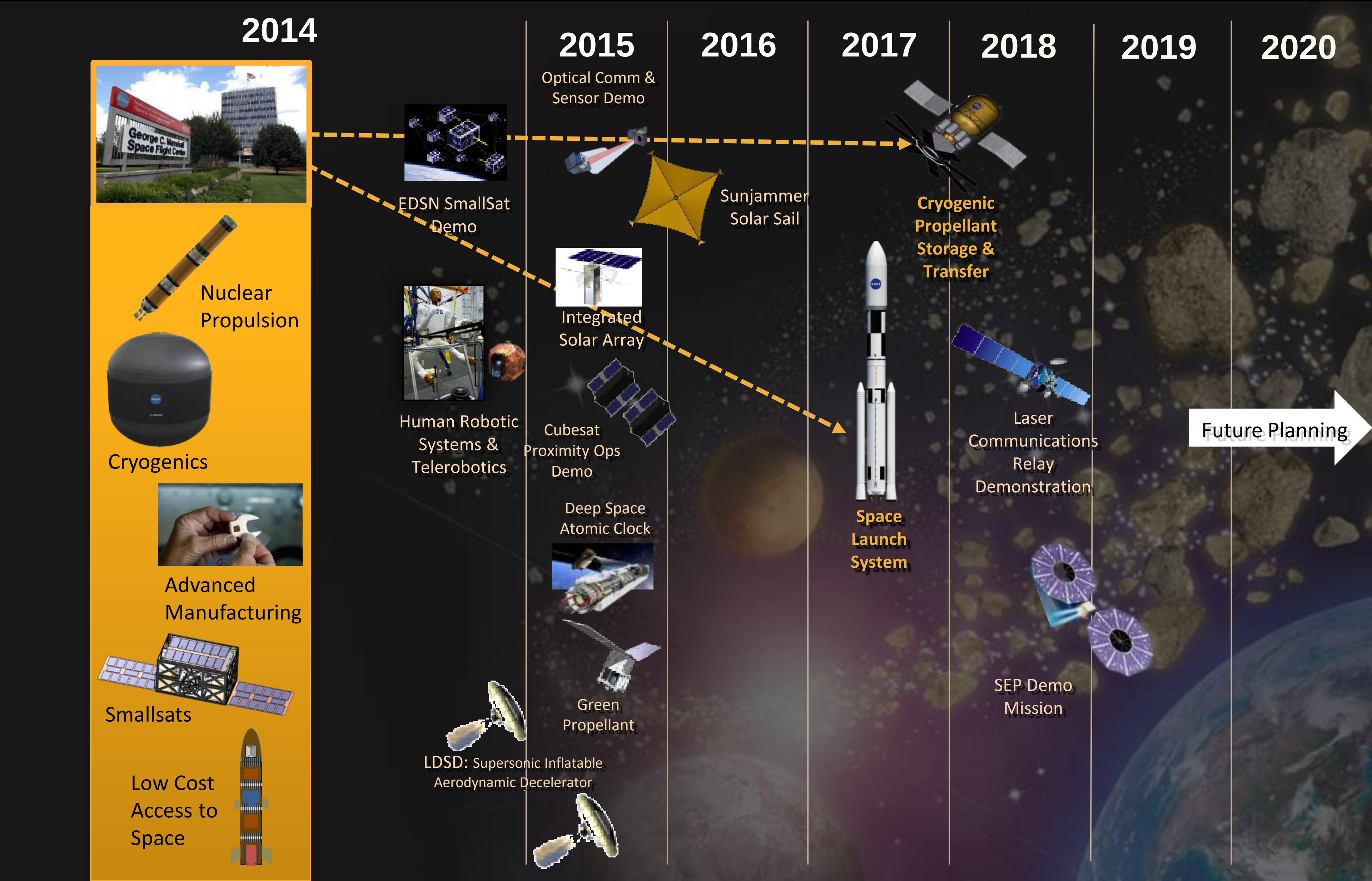
Marshall Technology Exposition

Join us on the journey

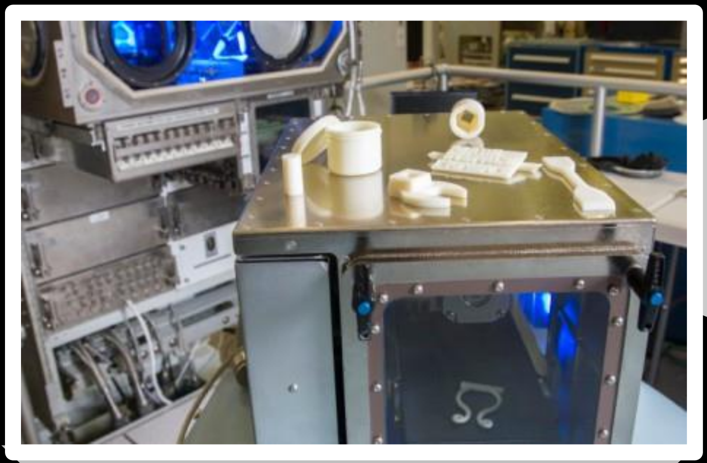
Emerging Space Technology Developments

Dr. Dan Schumacher, Director, Science and Technology Office, NASA Marshall

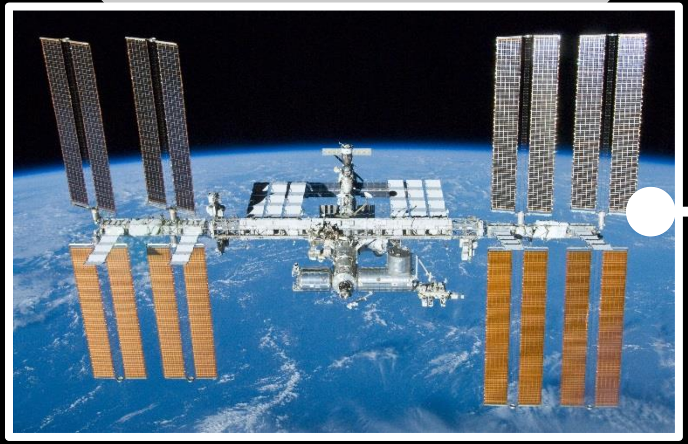
Technology Events and Milestones



Tech Development- Advanced Manufacturing

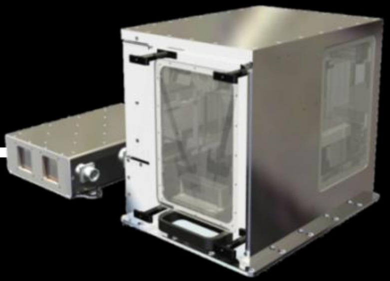


In 2013, MSFC test fires 3D printed rocket fuel injector.



3D space printer is awaiting its Space-X launch in Sept. to ISS.

Marshall completed its verification testing in May.



Marshall received 3D space printer in March.

Tech Development- Cryogenics

In 2013, Marshall successfully tested a 8-ft/2.4m composite cryotank.

In March, the 5.5m composite cryotank arrived via super guppy.

Testing of the 5.5m tank began in May and concludes in August.

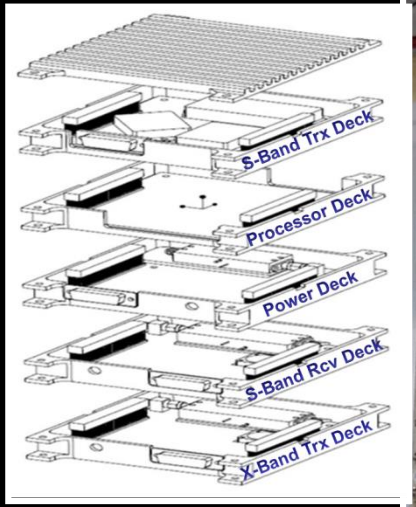
Engineering Development Unit

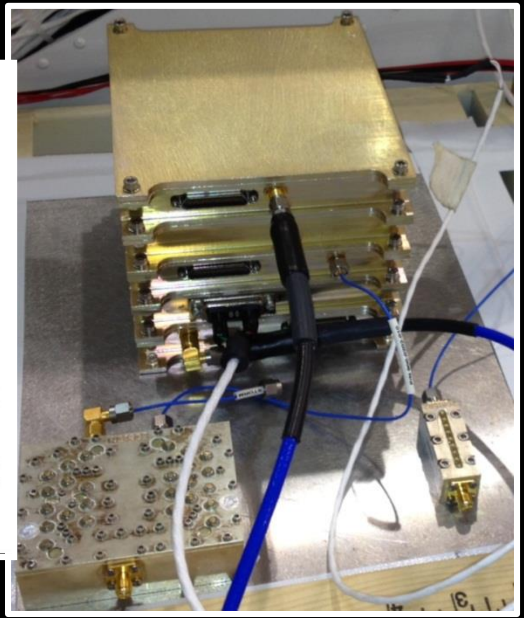
Marshall completed hydrogen and nitrogen testing of the EDU in July.

Tech Development- Smallsats

FASTSAT

2010-2012 Marshall-built and launched nanosatellite from a microsattelite





PULSAR

Programmable Ultra Lightweight System Adaptable Radio

iSAT

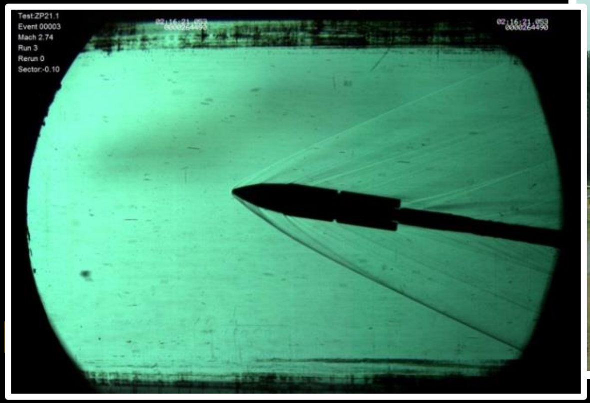
Iodine Satellite

Tech Development- Low Cost Access to Space

Hi-C

High Resolution Coronal Imager

Marshall Nanolaunch



SWORDS

Engine Testing

Tech Development- Nuclear Propulsion

Demonstrate the Viability of Nuclear Propulsion Technologies

Marshall Technology Exposition
Join us on the journey

Emerging Space Technology Developments

Dr. Andrew Keys, Chief Technologist, NASA Marshall

Marshall's Role in Agency Missions

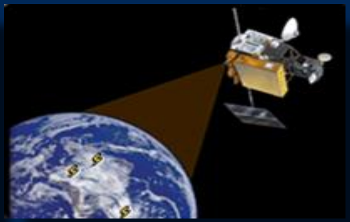
Four Core Technology Themes

Space Transportation/Launch Vehicle Technology and Development

Propulsion Systems Technology and Development

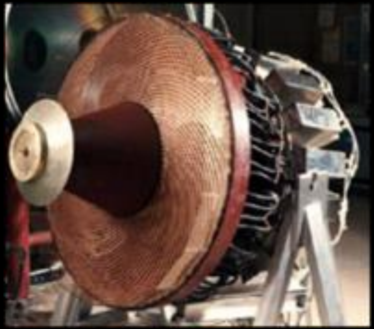
Space Systems Technology, Development, and Integration

Scientific Research



Marshall Technology Emphasis Areas

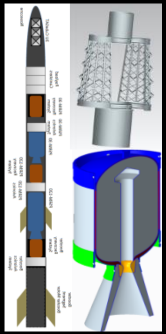

Advanced In-Space Propulsion and Cryogenic Technologies


In-Space Propulsion (Pulse Power, Electric)


In-Space Propulsion (Nuclear)

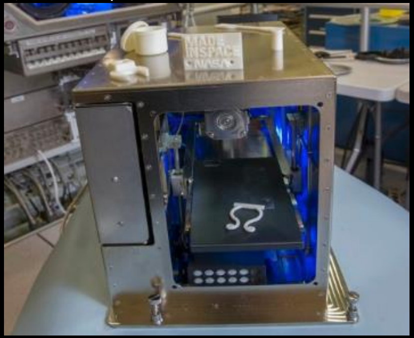

In-Space Propulsion (Solar Sail, Tethers)


Affordable, Innovative Technologies for Landers and Sample Return

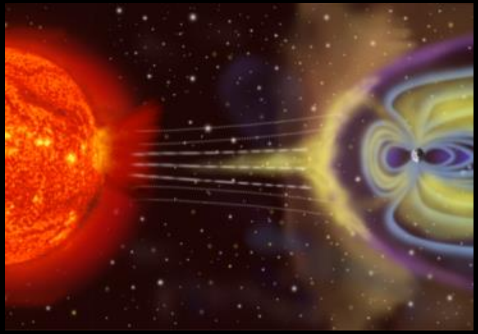

Low Cost Responsive Launch for Small Payloads


Innovations and technologies supporting small, affordable ISS payloads


In-Space Habitation Technologies with emphasis on
Nodes and Life Support Systems


Advanced manufacturing with emphasis on in-situ fabrication and repair


X-ray Astrophysics and Telescope Systems


Space environments, space weather prediction and assessment


Small Satellite and Small Spacecraft Technologies


Rapid, innovative, affordable manufacturing of propulsion components

Benefitting Life on Earth – Technology Spinoffs

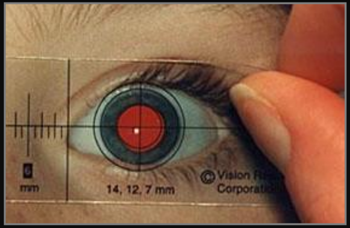
Technologies developed at Marshall touch our lives in many ways.

Space technology improves neonatal care

Weather & Climate Monitoring

High-pressure fire hose nozzles

Kevlar™ Body Armor



Improving Vision Screening

Healing Treatments

Water Filtration Systems

Science and exploration improves our lives and our planet.

Questions / Discussion

Continue the discussion…

Meet the Panelists

Visit the Exhibits

Tell us what you think!

www.nasa.gov/marshallTECHexpo

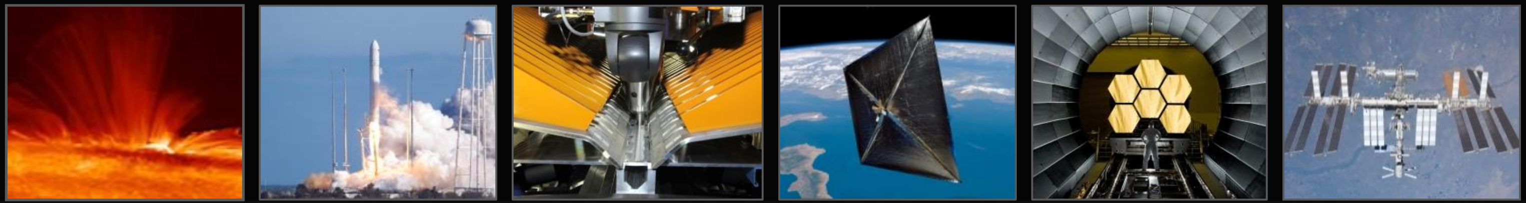
National Aeronautics and Space Administration

Marshall Technology Exposition

Join us on the journey

Technology Partnership Opportunities

Moderator: Earl Pendley, Office of Procurement, NASA Marshall



marshall

Applied Technologies for Exploration: Agenda

Opening Comments

- Earl Pendley, Office of Procurement, NASA Marshall

Panelists' Comments

- Scott Hutchins, Technical Lead for Marshall Cooperative Agreement Notice, Center Strategic Development and Integration Office, NASA Marshall
- Sam Ortega, Manager, Centennial Challenges, NASA Marshall
- Terry Taylor, Manager, Technology Transfer Office, NASA Marshall
- Chris Crumbly, Manager, Spacecraft/Payload Integration and Evolution Office, Space Launch System Program Office, NASA Marshall
- Jody Singer, Director, Flight Programs and Partnerships Office, NASA Marshall

Q & A

Marshall Technology Exposition

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Technology Partnership Opportunities

Scott Hutchins, Technical Lead for Marshall Cooperative Agreement Notice, Center Strategic Development and Integration Office, NASA Marshall

Dual-Use Technology Development at Marshall

Cooperative Agreement Notice (CAN)

- Enhances Marshall's ability to collaborate with industrial and academic partners in the joint pursuit of high-technology solutions.
- Solicits Cooperative Agreement project partnerships to develop or advance mutually beneficial (dual-use) technologies
- Competitively selected opportunity
  - Two-step process
  - Shared project resources
    - Cash or in-kind contributions, or a combination the two
  - Interactive relationship

FY14 Dual-use Technology Development

Cooperative Agreement Notice (CAN)

Inaugural Marshall CAN solicitation in FY14

- 5 technology focus areas offered
- Good Step-1 White paper response from diverse set of organizations
- Three Step-2 project proposals were submitted and selected for Cooperative Agreements

FY15 Dual-use Technology Development

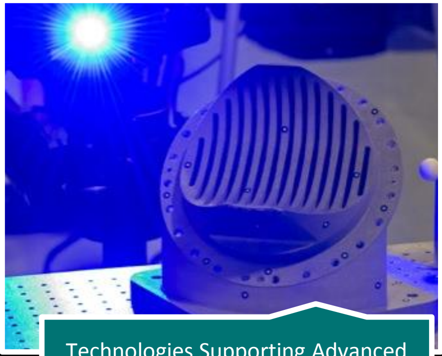
Cooperative Agreement Notice (CAN)

FY15 solicitation released on Aug 8, 2014

- Posted on NASA NSPIRES and FedBizOpps
- Three opportunities to respond (Oct. 1, Feb. 4, June 3)
  - Two-step process
- Marshall project contribution value from $20K - $100K
- Project duration up to 12 months
- 8 technology interest areas identified

FY15 Marshall Dual-Use Technology CAN Technology Interest Areas

Innovative/Advanced Propulsion System Technologies



Technologies Supporting Advanced Manufacturing, Structures, and Materials

Avionics Technologies Supporting Spacecraft & Satellite Systems

Technologies Supporting Space Environments Research to Applications

Technologies Benefitting from ISS Utilization or Demonstration

Technologies Benefitting Program Development, Project Management, and Systems Engineering

Technologies Supporting ECLS

Aerodynamic Research Technology Needs

Marshall Technology Exposition

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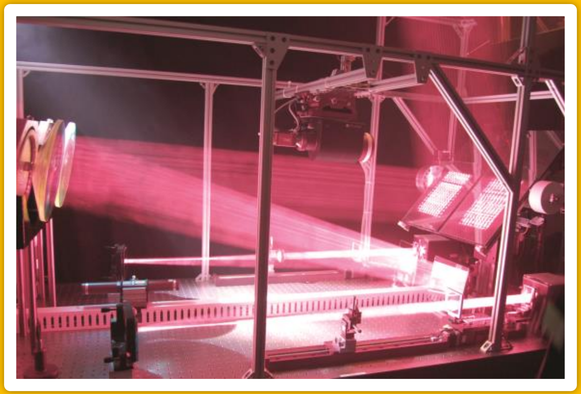
Technology Partnership Opportunities

Sam Ortega, Centennial Challenges

NASA'S CENTENNIAL CHALLENGES:


When they win, you win.

www.nasa.gov/**winit** @NASAPrize /NASACC NASAPrize

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National Aeronautics and Space Administration

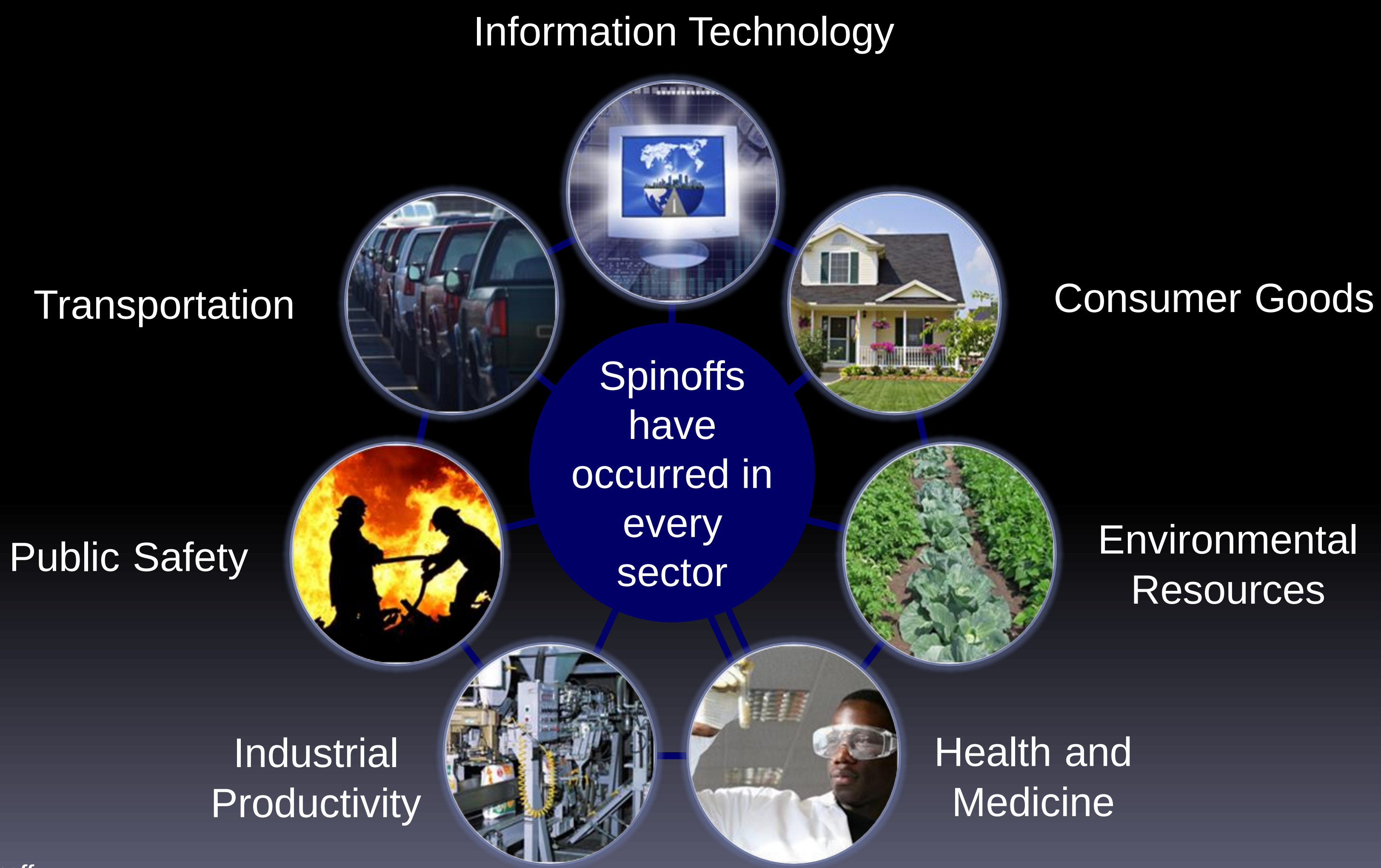
TECHNOLOGY TRANSFER PROGRAM

BRINGING NASA TECHNOLOGY DOWN TO EARTH

Mr. Terry L. Taylor
Manager, Technology Transfer Office
NASA Marshall Space Flight Center

Marshall Technology Exposition
10/27/2014

NASA has recorded over 1,800 spinoff technologies that benefit our lives in a variety of ways since 1974



NASA's Patent Portfolio - 15 Categories

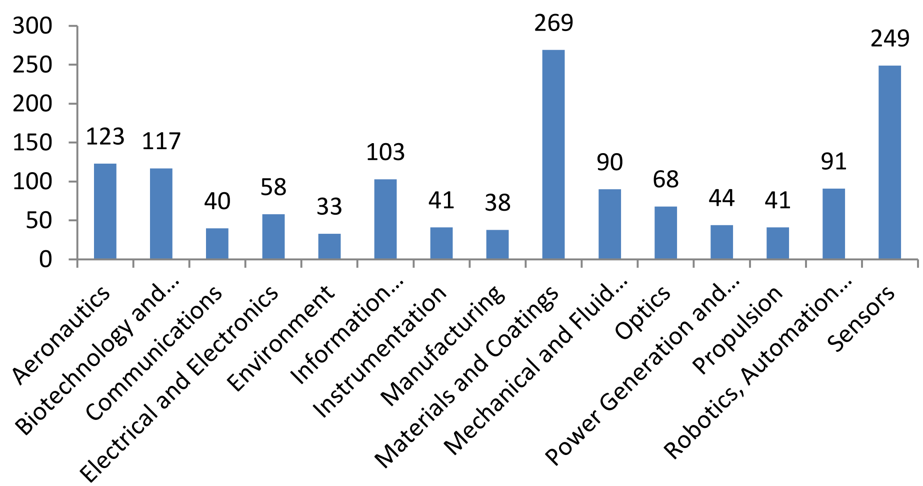
"Bringing NASA Technology Down to Earth"

- Power Generation
- Environment
- Instrumentation
- Health, Medicine, and Biotechnology
- Materials and Coatings
- Propulsion
- Electrical/Electronics
- Sensors
- Information Technology and Software
- Robotics, Automation
- Mechanical and Fluid Systems
- Communications
- Optics
- Aeronautics
- Manufacturing

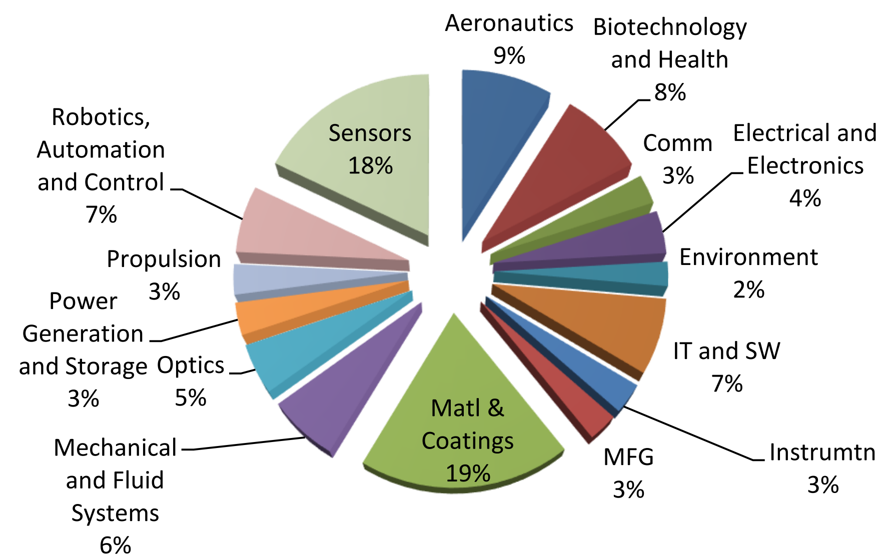
NASA’s Patent Portfolio

“Bringing NASA Technology Down to Earth”

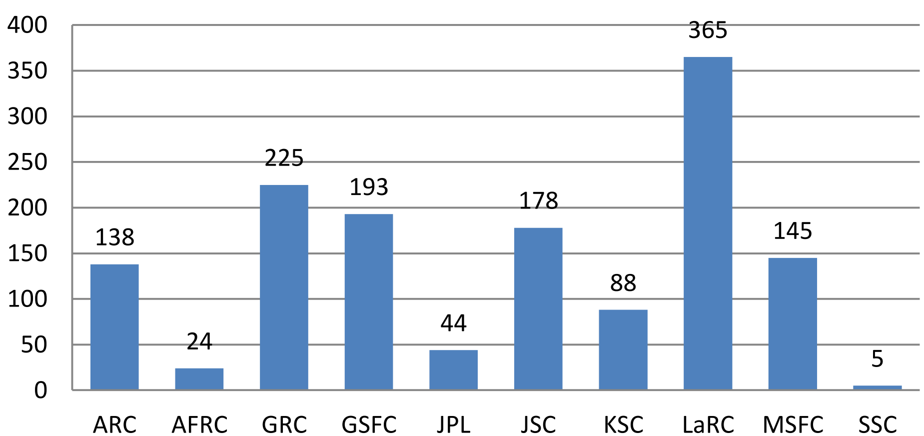
NASA's Patent Portfolio by Technology



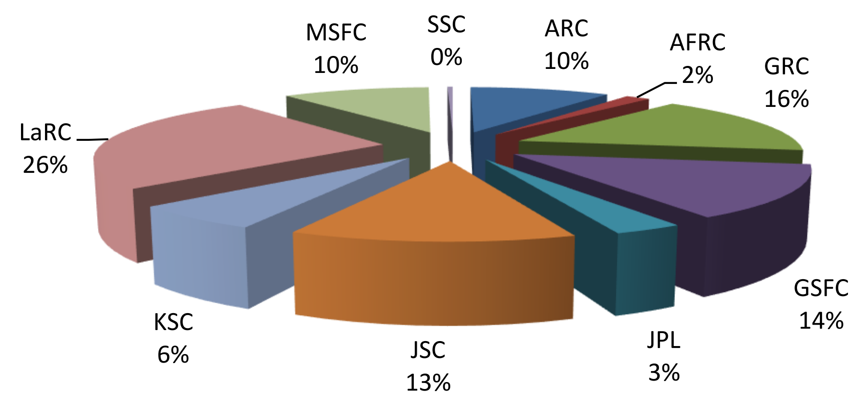
NASA's Patent Portfolio



NASA’s Patent Portfolio by Center



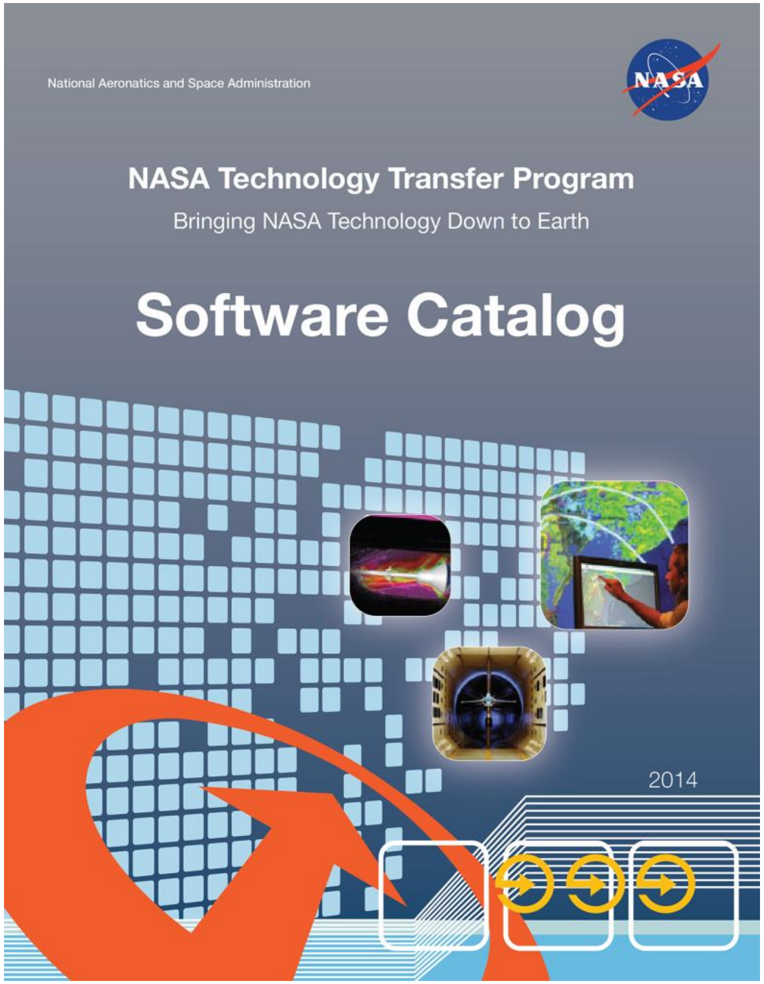
% Portfolio Contribution by Center



NASA has 1405 Active Patents & Apps

NASA Software Catalog (NEW!)

Software accounts for 30% of all reported NASA inventions…



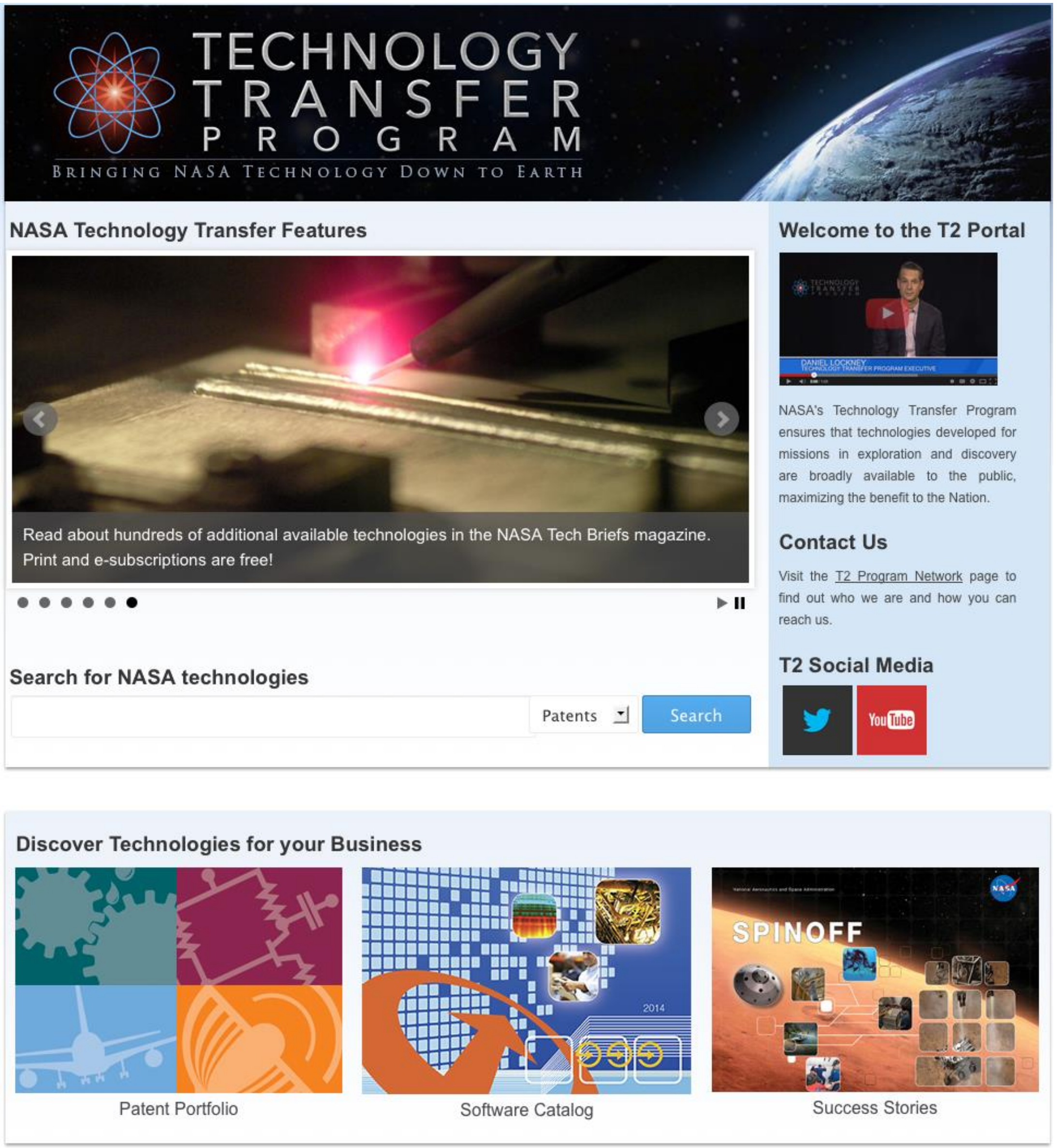
Search / Download the new NASA Software Catalog at http://technology.nasa.gov !!!

- PDF First Edition available in print and online. Released April 9, 2014.
- 1000+ codes/tools from all 10 Field Centers
- Organized into 15 Technical Categories
- PDF Updated Daily – always current

Featured in Wired Magazine, Newsweek, Gizmodo, and 50+ other publications. Praise from White House.

NASA Technology Transfer Portal (NEW!)

"Bringing NASA Technology Down to Earth"



Link to new T2 portal:
technology.nasa.gov

- Modern
- Simple
- Searchable
- Streamlined
- Updated Weekly

Marshall Technology Exposition

Join us on the journey

Technology Partnership Opportunities

Moderator: Earl Pendley, Office of Procurement, NASA Marshall

Marshall Technology Exposition

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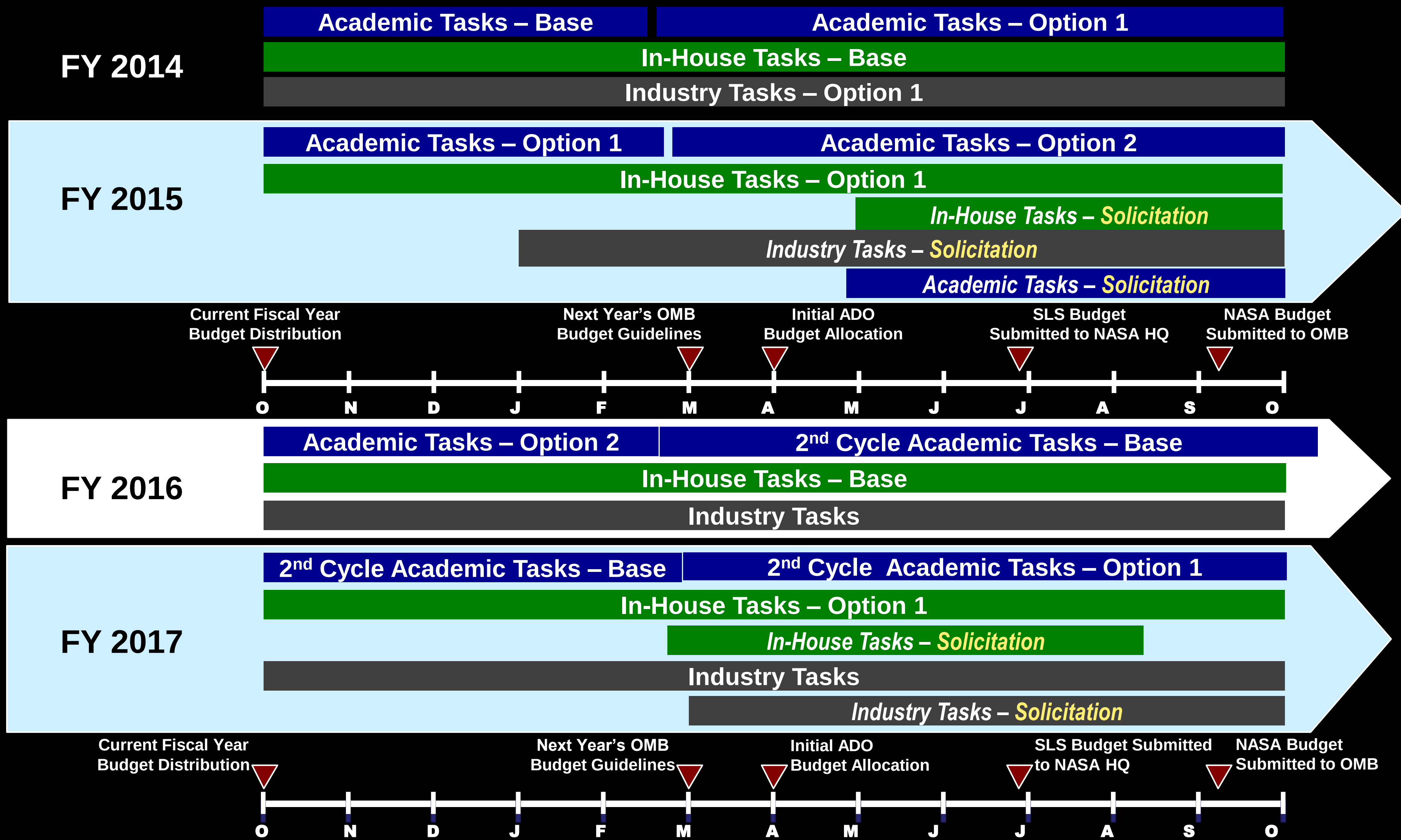
Technology Partnership Opportunities

Chris Crumbly, Manager, Spacecraft/Payload Integration and Evolution Office, SLS Program Office, NASA Marshall

SPIE Advanced Development Group Acquisition



Marshall Technology Exposition

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Technology Partnership Opportunities

Jody Singer, Director, Flight Programs and Partnerships Office, NASA Marshall

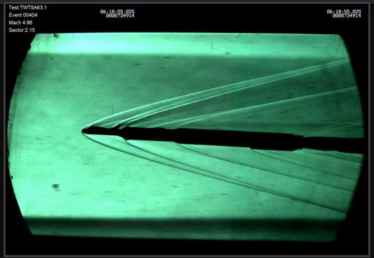
Marshall Partnerships Office

- Entry point/hub for partners not familiar with Marshall
- Connect partners with Marshall technical expertise/capabilities
- Advocate for the partner on special requirements/challenges
- Support partner events
- Maintain commitment to long-term relationship
- Integrate Partnerships office with
  Center Strategic Development,
  Science & Technology, Engineering,
  external community
- Leverage Marshall/partner resources
  for win/win experience
- Focus on business practices and
  collaborative forums that facilitate partnerships

Marshall’s Commitment to Partnerships

- NASA technologies, capabilities, and assets available to support growing commercial space industry
  - Industry focusing on low Earth orbit
  - NASA focusing on deep space exploration
- More than 250 ongoing collaborative agreements
- Partnerships Office created as entry




Marshall is ready for future challenges –
adapting and building mutually beneficial partnerships
to develop new and innovative technologies.

Redstone Arsenal Major Organization Overview

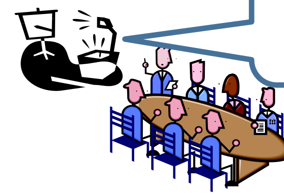
Partnering Process Steps

Opportunity

<u>Identify</u> Opportunity

I wonder if NASA could assist?

Marshall Opportunity <u>Evaluation</u>



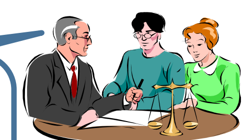
Within NASA's Mission?
Commercially available?
Needed Resource Available?

Agreement

Jointly <u>Develop</u> Agreement

Here is a draft that clearly defines the scope, schedule. I also included the estimated cost. What do you think?

Agreement Review & Approval - <u>Capture</u>



All that pre-coordination produced a quality and rapid review!

Agreement Transition / <u>Execution</u>

I'm glad we worked out the responsibilities in the agreement.

Questions / Discussion

Marshall Technology Exposition

Join us on the journey

Closing Remarks

Johnny Stephenson, Acting Director, Office of Strategic Analysis and Communications, NASA Marshall

Continue the discussion…

Meet the Panelists

Visit the Exhibits

Tell us what you think!

www.nasa.gov/marshallTECHexpo