National Aeronautics and Space Administration

NASA

EXPLORE SPACE TECH

Ground Systems Architectures Workshop

Dr. Prasun Desai, Deputy Associate Administrator
NASA Space Technology Mission Directorate (STMD) | March 4, 2020

STMD Mission and Guiding Principles

Space Technology develops critical technologies to enable:

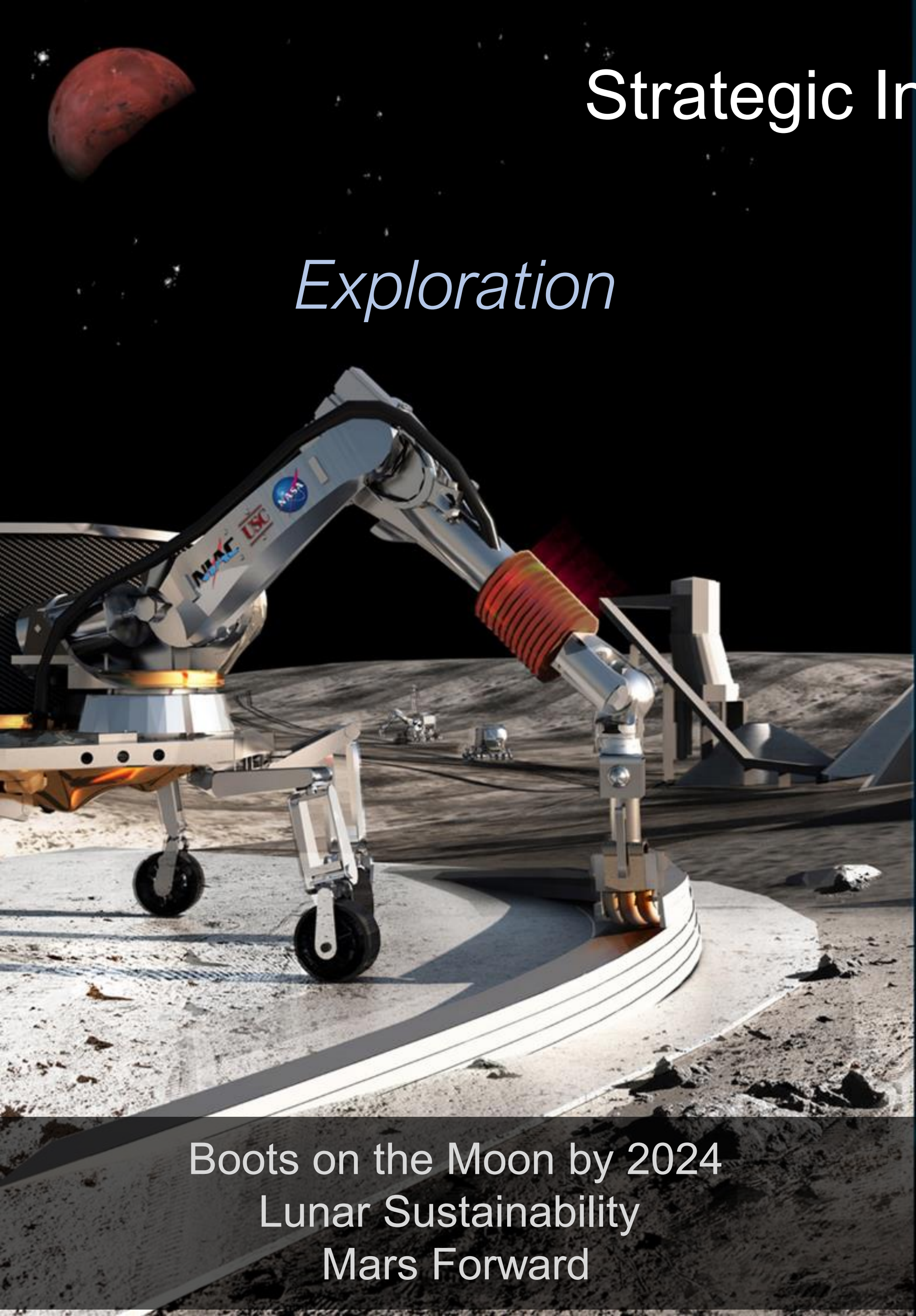
- A sustainable Lunar surface presence,
- The future goal of sending humans to Mars, and
- Critical technologies to enable future science and commercial missions.

We accomplish this mission by:

- Funding critical technology gaps
- Keeping NASA's space technology pipeline growing with emerging, innovative technologies that promise to drive the future of exploration, science and commercialization.

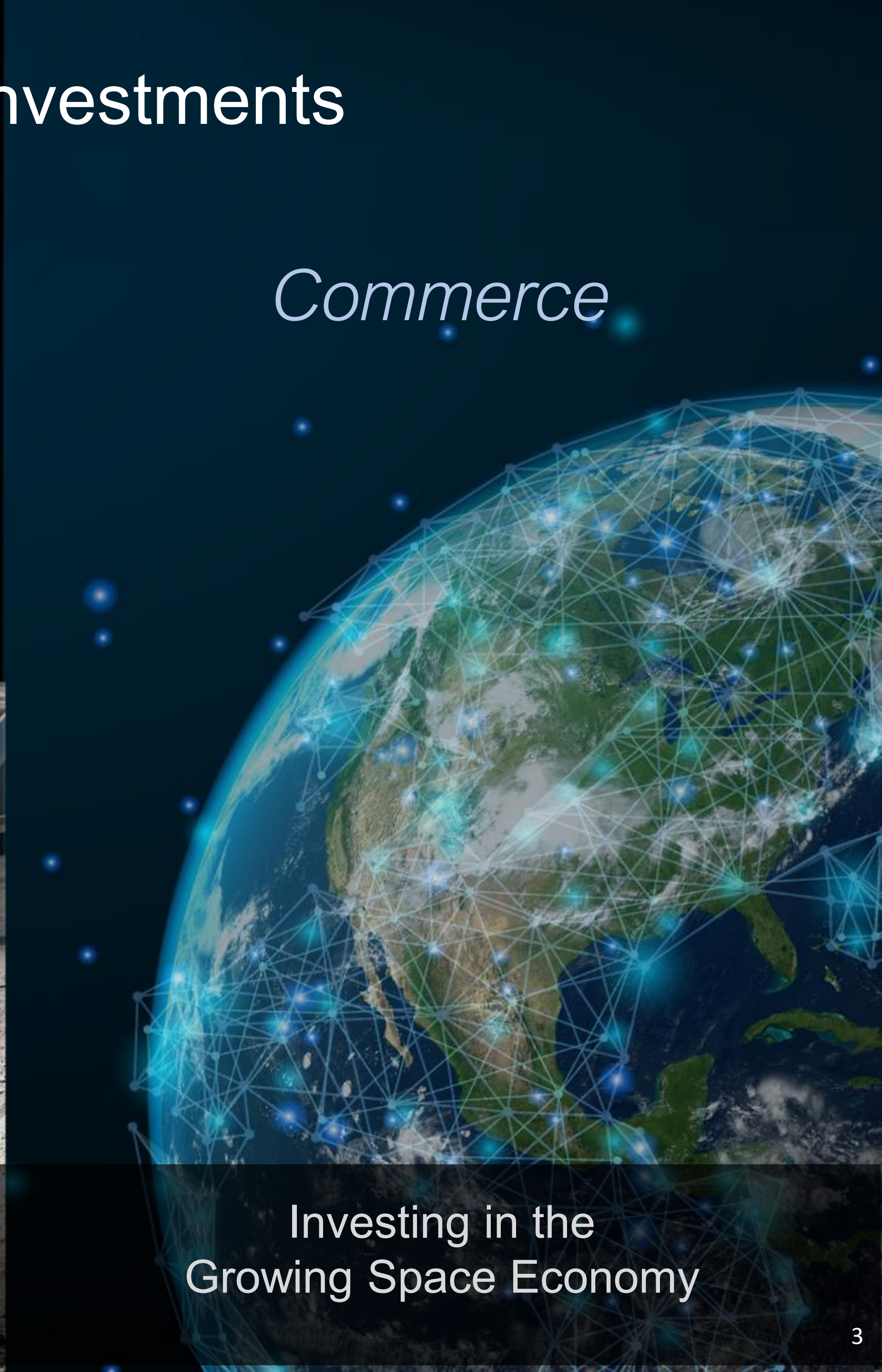
✓ Spark Innovation
✓ Engage The Brightest Minds
✓ Enable Exploration and Discovery
✓ Embrace Competition and Public-Private Partnerships
✓ Invest in America

Strategic Investments



Exploration

Boots on the Moon by 2024
Lunar Sustainability
Mars Forward



Commerce

Investing in the
Growing Space Economy

SBIR/STTR

Partnerships & Technology Transfer

- Technology Transfer
- Prizes and Challenges
- iTech

Early Stage Innovation

- NASA Innovative Advanced Concepts
- Space Tech Research Grants
- Center Innovation Fund/Early Career Initiative

Technology Demonstrations

- Technology Demonstration Missions
- Small Spacecraft Technology
- Flight Opportunities

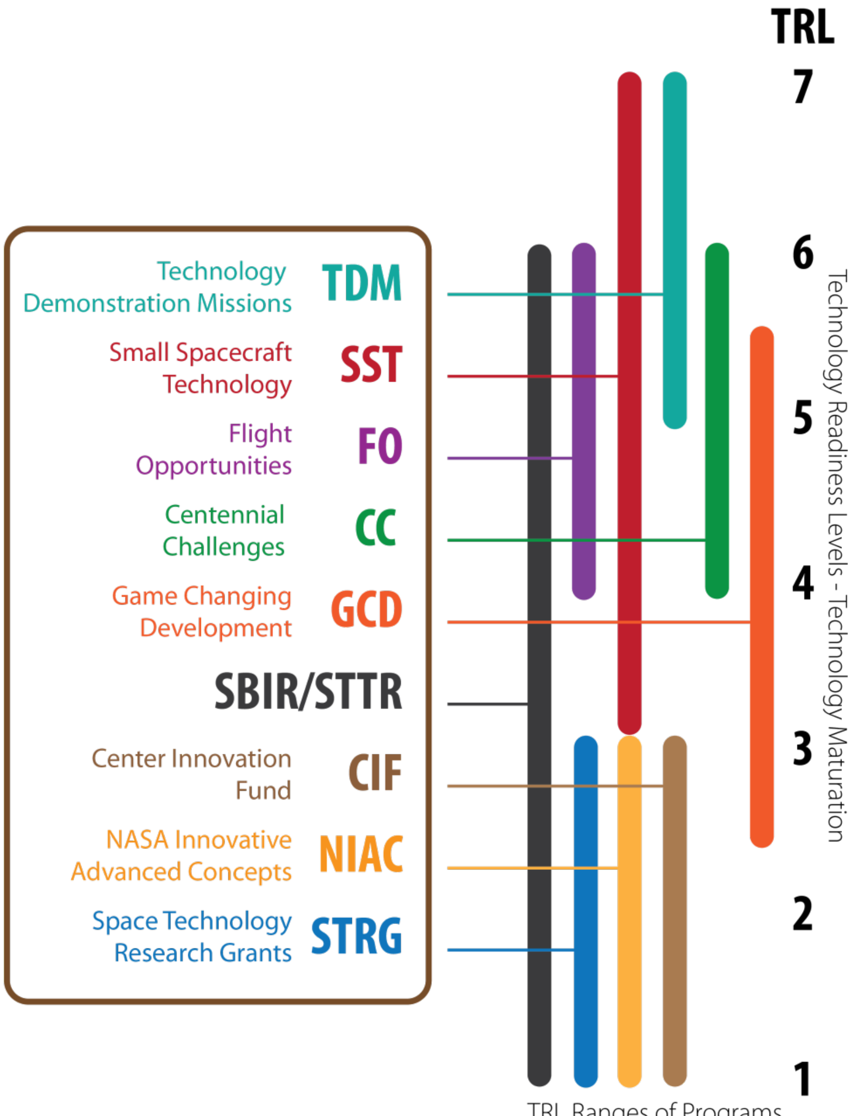
Technology Maturation

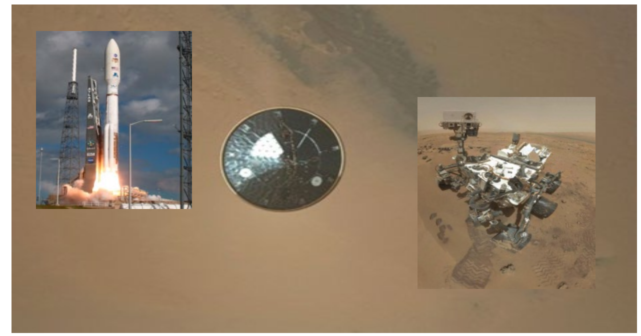
- Game Changing Development

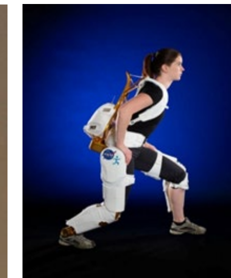
TECHNOLOGY PIPELINE

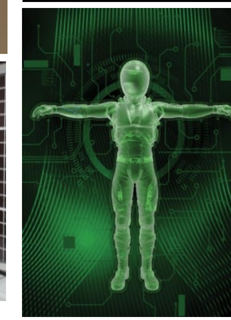
STMD Utilizes a Portfolio Approach

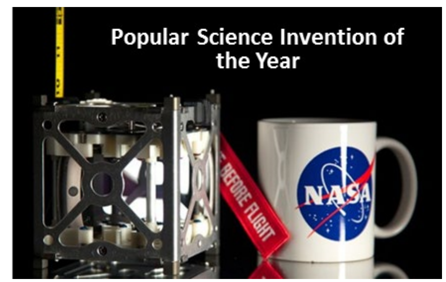
Programs cover broad range of Technology Readiness Level (TRL)

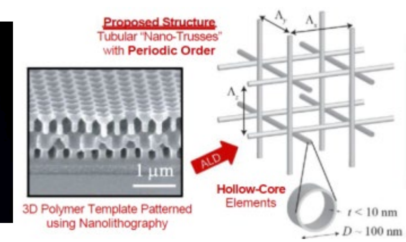


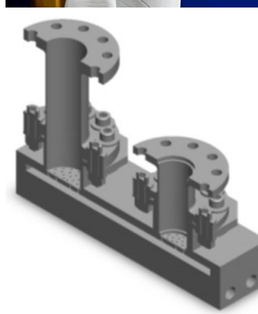












STMD Technology Strategy (*in development*): Three Phases

Guidance

NASA Strategic Plan Objective 3.1:

Develop and Transfer Revolutionary Technologies to Enable Exploration Capabilities for NASA and the Nation

(Agency level guidance)

Regular discussions at various levels with:

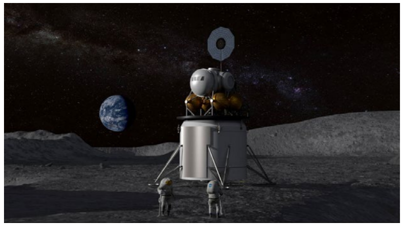
NASA Technical Leadership

(Mission Directorates, System Capability Leads, STMD Principal Technologists, Center Chief Technologists, etc.)

+

External Partners & Customers

(Industry, Academia, Other Agencies, etc.)



Planning

STMD Strategic Framework

4 Strategic Thrusts:

Go

Rapid, Safe, & Efficient Space Transportation

Land

Expanded Access to Diverse Surface Destinations

Live

Sustainable Living and Working Farther from Earth

Explore

Transformative Missions and Discoveries

Strategic Outcomes

Example: STMD makes investments to enable **Reusable Transportation Between the Earth and the Moon**

Capabilities

Example: **Cryogenic Fluid Management**

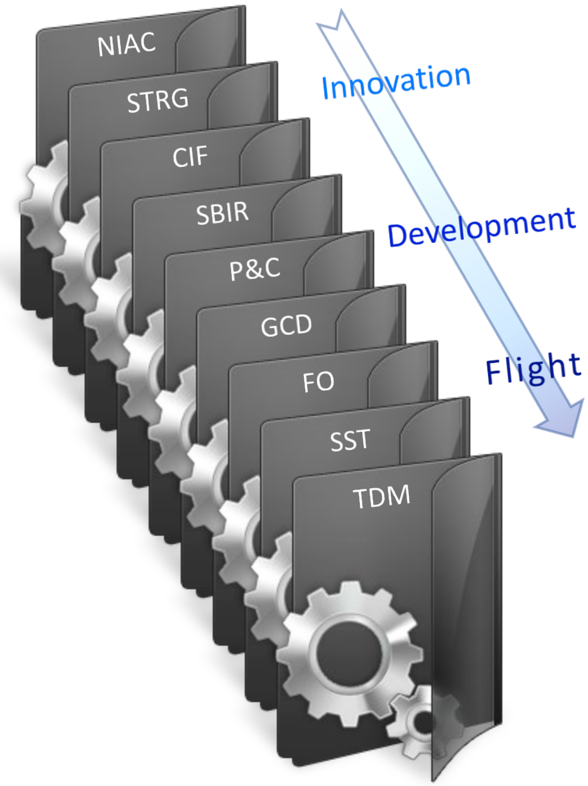
Technical Challenges

Example: **Store liquid hydrogen in space for at least 1 year**

Execution

Technology Projects

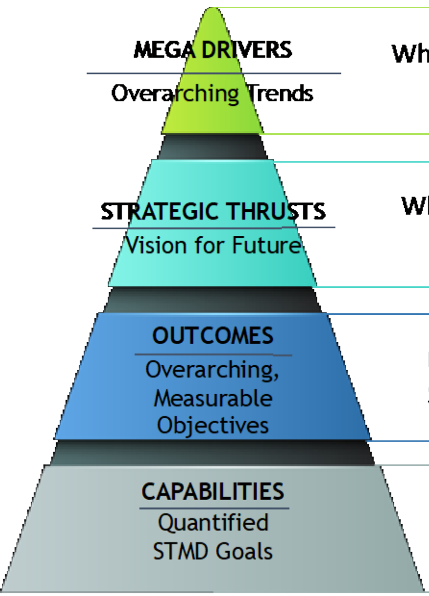
Examples: **GCD Cryocooler**
TDM eCryo
Tipping Point CELSIUS



Technology Development Strategic Flow

NASA Strategic Plan – Objective 3.1:
Develop and Transfer Revolutionary Technologies to Enable Exploration Capabilities for NASA and the Nation

STMD Technology Development Strategic Framework



- What is shaping the global space sector?
- Where can STMD make the greatest impacts?
- Under each Thrust, what is STMD working to achieve?
- Which investments will enable the Outcomes?

STMD Strategic Framework

4 Strategic Thrusts:

Go
Rapid, Safe, & Efficient Space Transportation

Land
Expanded Access to Diverse Surface Destinations

Live
Sustainable Living and Working Farther from Earth

Explore
Transformative Missions and Discoveries

Example flow

Strategic Outcomes

Example: STMD makes investments to enable **Reusable Transportation Between the Earth and the Moon**

Capabilities

Example: **Cryogenic Fluid Management**

Technical Challenges

Example: **Store liquid hydrogen in space or on the surface of the Moon for at least 1 year**

Technology Projects

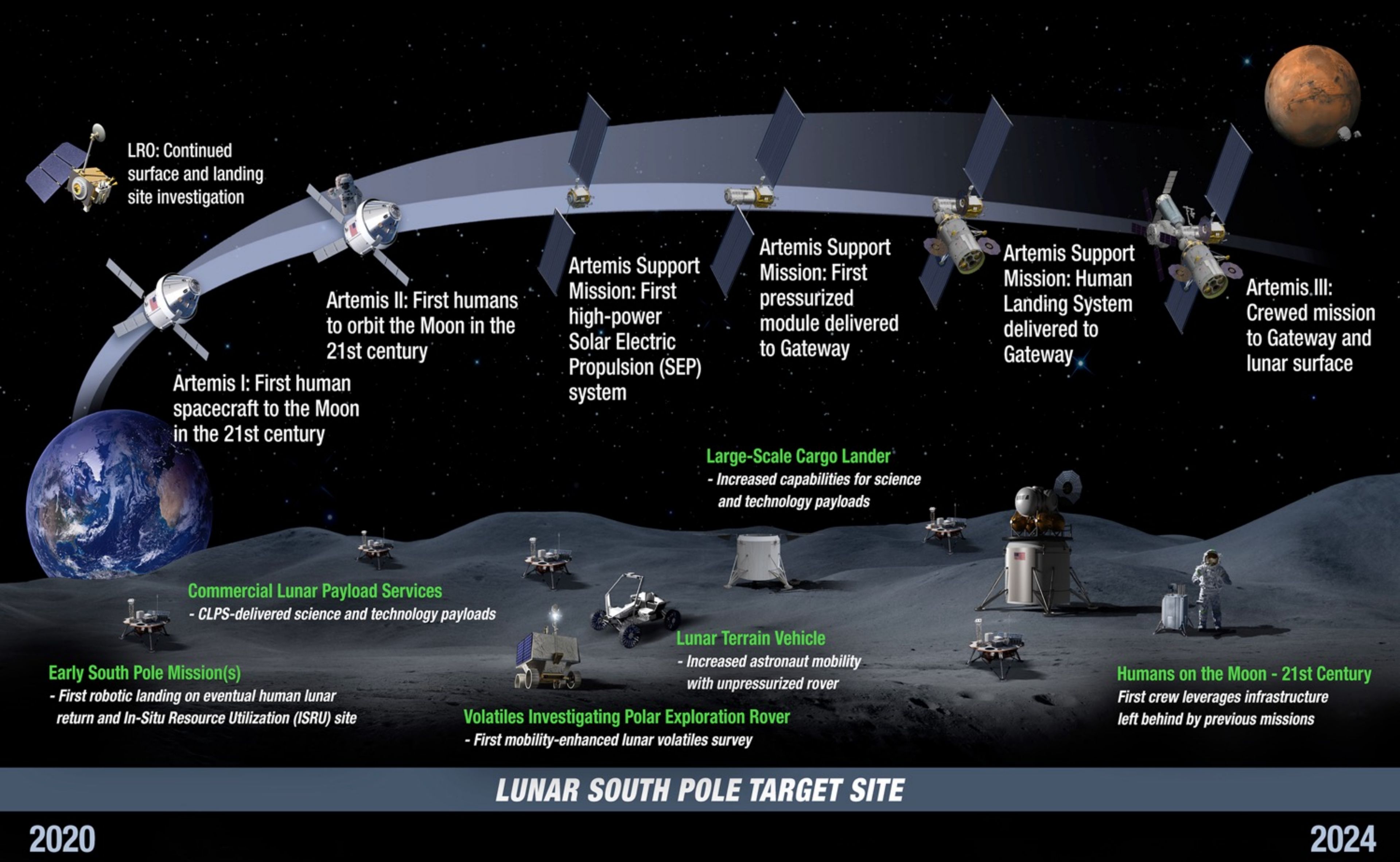
Examples: **GCD Cryocooler**
TDM eCryo
Tipping Point CELSIUS

STMD Strategic Framework

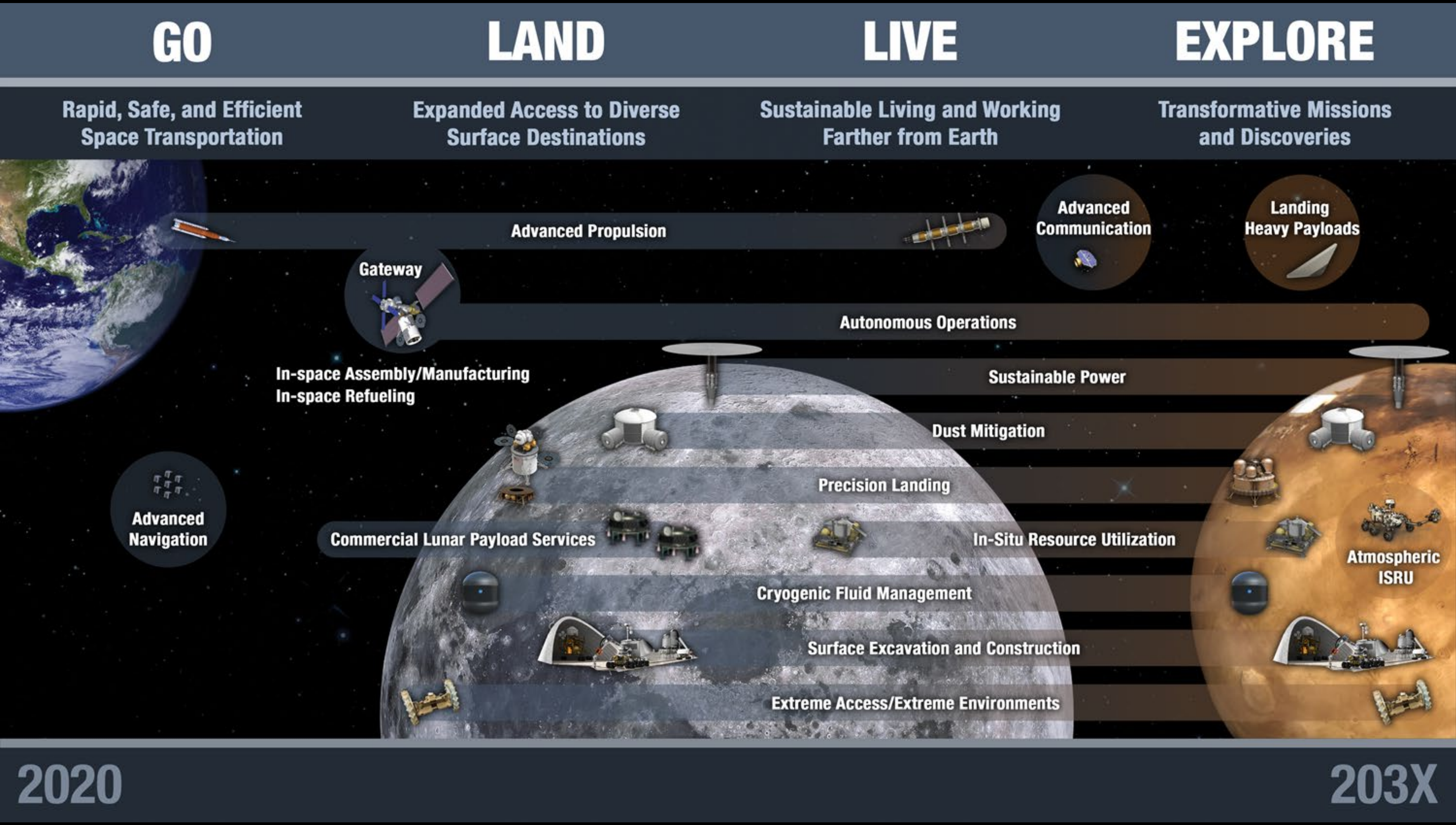
LEAD	THRUSTS	OUTCOMES	CAPABILITIES
Ensuring American global leadership in Space Technology • **Lunar Exploration building to Mars** • **Robust national space technology engine to meet national needs** • **U.S. economic growth for space industry** • **Expanded commercial enterprise in space**	***Go*** ***Rapid, Safe, & Efficient Space Transportation***	• Enable Human Earth-to-Mars Round Trip mission durations less than 750 days. • Enable rapid, low cost delivery of robotic payloads to Moon, Mars and beyond. • Enable reusable, safe launch and in-space propulsion systems that reduce launch and operational costs/complexity and leverage potential destination based ISRU for propellants.	• Cryogenic Fluid Management & Propulsion • Advanced Propulsion
	Land ***Expanded Access to Diverse Surface Destinations***	• Enable Lunar and Mars Global Access with ~20t payloads to support human missions. • Land Payloads within 50 meters accuracy while also avoiding local landing hazards.	• Human & Robotic Entry, Descent and Landing • Precision Landing
	Live ***Sustainable Living and Working Farther from Earth***	• Conduct Human/Robotic Lunar Surface Missions in excess of 28 days without resupply. • Conduct Human Mars Surface Missions in excess of 365 days without resupply. • Provide greater than 90% of propellant and water/air consumables from local resources for Lunar and Mars missions. • Enable Surface habitats that utilize local construction resources. • Enable Intelligent robotic systems augmenting operations during crewed and uncrewed mission segments.	• Sustained human life support systems • Operate in Extreme Environments • Sustainable Power • In-situ Propellant and Consumable Production • Intelligent/Resilient Systems & Advanced Robotics • Advanced Materials and Structures
	Explore ***Transformative Missions and Discoveries***	• Enable new discoveries in Lunar/Mars surface and other extreme locations. • Enable next generation space data processing with higher performance computing, communications and navigation in harsh deep space environments. • Enable potential new architectures and approaches for in-space servicing, assembly and manufacturing and other missions.	• Extreme Access • Small Spacecraft Technologies • Advanced Avionics • Advanced Communications and Navigation • Servicing, Assembly and Manufacturing

Note: Multiple Capabilities are cross cutting and support multiple Thrusts. Primary emphasis is shown

Artemis Phase 1: To The Lunar Surface by 2024

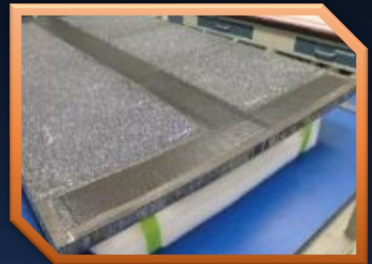


Technology Drives Exploration



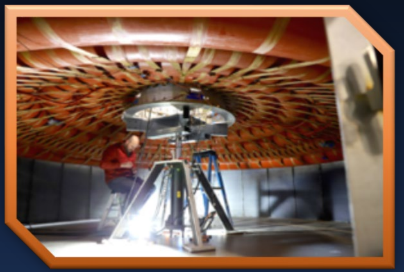
FY 2020-2021: Technology Drives Exploration

Blue Origin Demo of Deorbit, Descent and Landing Lasers
June and December 2020
SPLICE DLC and NDL will be integrated and flown on BO New Shepard suborbital rocket



Composite Technology for Exploration
August 2020
Complete testing of composite joint technology that will reduce launch dry mass

MEDLI 2
February 2021
Mars 2020 enters Mars atmosphere



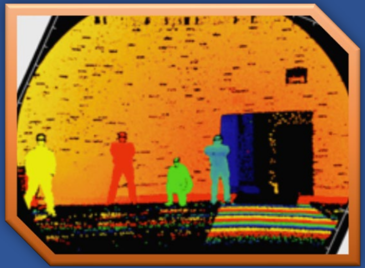
LOFTID
July 2021
Complete Systems Test with Reentry Vehicle Delivery in **December 2021**

SynBio
January 2020
Sample pack returned from ISS for analysis

Nuclear Thermal Propulsion
September 2020
System feasibility assessment review

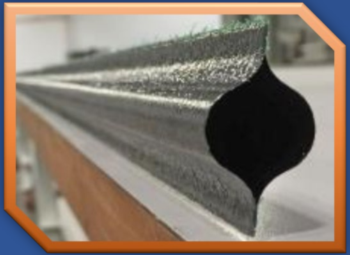
RAMPT
Sept 2021
Full Scale Multi-material Thrust Chamber Hot-fire Test

Navigation Doppler Lidar
June 2021
Lunar Demonstration via CLPS



SPLICE
September 2020
HDL EDU suborbital flight test

Nuclear Fission Power
Mission Concept Review and Systems Req. Review and Industry Trade Studies **FY 20-21**

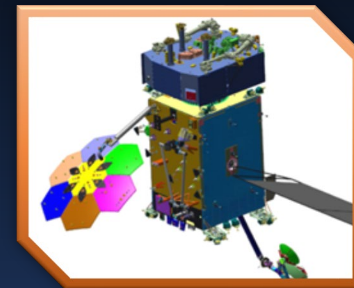


Deployable Composite Boom
November 2020
Zero-gravity flight test of DCB technology

FY 2020-2021: Technology Drives Exploration

Lunar Precursor CubeSat Demos
Conduct three Lunar precursor CubeSat Demos including CAPSTONE mission in **FY21**

Archinaut (OSAM – 2)
Critical Design Review in **FY21**

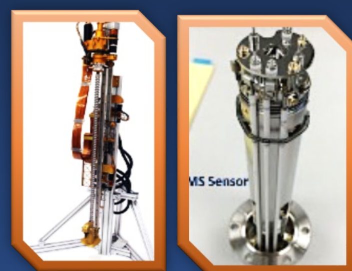


OSAM-1
Sept. 2020 Mission Critical Design Review **FY21:** SPIDER Critical Design Review and Integration and Test

Blue Origin Tipping Point- December 2020
BlueNav-L EDL Sensor Suite Demo

Flight Opportunities Campaigns
FY21 Award of opportunities to industry and academia.

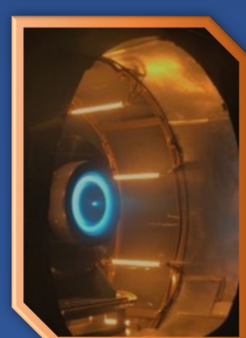
Laser Comm Relay Demo
Launch aboard STPSat-6 in **FY21**



PRIME–Lunar Ice to Water
FY21 Regolith with Ice Characterization demo complete testing and delivery of spaceflight hardware for CLPS Mission

Astrobotics Tipping Point- January 2021
Terrain Relative Navigation Critical Design Review

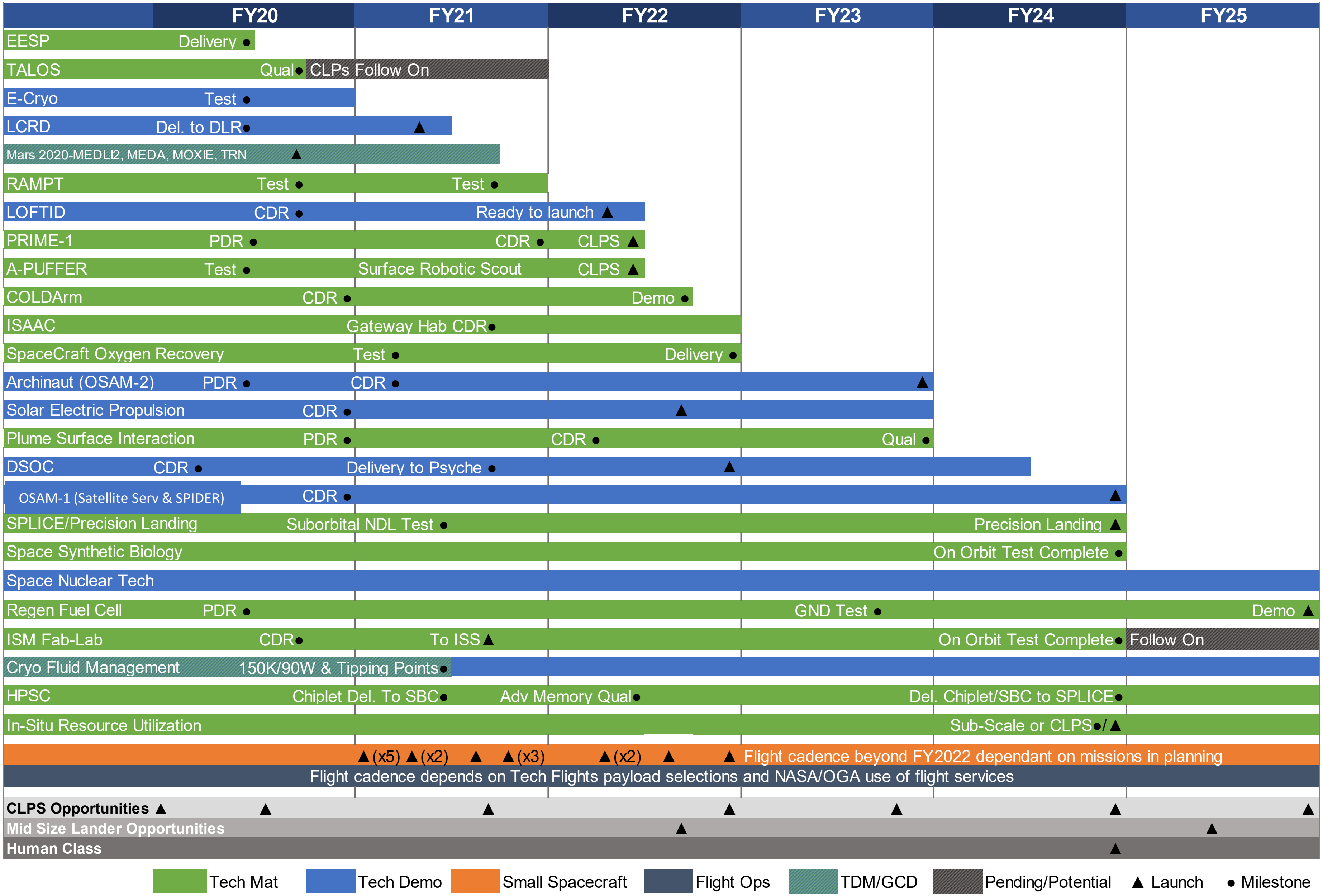
Deep Space Optical Communication
Deliver flight hardware to Psyche for mission



Solar Electric Propulsion
Complete Thruster Qualification String Integration

TALOS
Five thrusters will be used on Astrobotic's first Peregrine Lander **2021**

Exploration Technology Milestones at a Glance

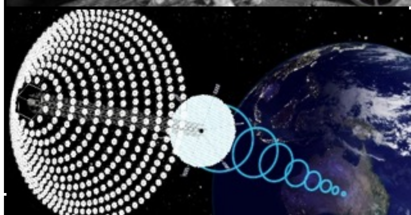


Early Stage Innovation Programs
(Low-TRL)

NASA Innovative Advanced Concepts

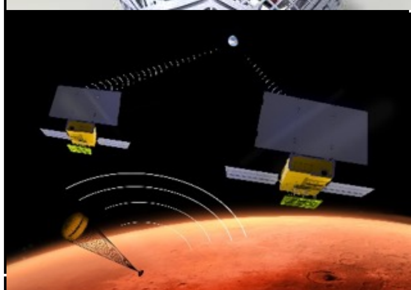
Current and Future Milestones:

Phase III studies added to advance two NIAC Technologies from low to mid-TRL.



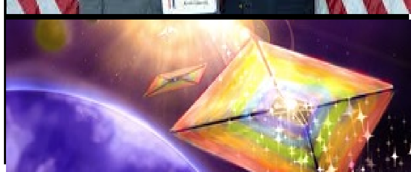
The U.S. Air Force Research Lab began a $100M program to develop hardware for a solar power satellite based on John Mankins' study.

Ali Aghamohommadi- In 2021 Shapeshifter will deploy on the DARPA Challenge in partnership with Stanford, Cornell University.



*MarCO Mission: The first interplanetary CubeSats were recognized by the engineering community with the **2019 Small Satellite Mission of the Year Award**, provided real-time communications link to Earth for InSight during its entry, descent, and landing (EDL) on Mars. First image of Mars from a CubeSat.*

***Presidential Early Career Award for Scientists and Engineers (PECASE)** awarded to Jonathan Sauder for demonstrating innovative technologies to enable a new class of space missions.*



Beam Rider: The "beam-rider" technology could guide light sails and probes to faraway stars or to closer targets in our own Solar System instead of chemically powered rockets.

Objectives:

- Advance NIAC Technologies from low to mid-TRL
- Develop follow-on paths for current studies and assess for NASA missions
- Attract and engage new and diverse researchers to NASA
- Support early-stage advanced spin off technologies and new businesses to build the U.S. economy

Deliverables/Schedule:

FY19: Fund 12 Phase I Fellows, 6 Phase II Fellows, 2 Phase III Fellows

FY20: Fund 15 Phase I Fellows, 7 Phase II Fellows, 1 Phase III Fellow

Additional Milestones:

- Mel Ulmer (IL)- magnetic smart materials to build large in-space telescope received $450K add-on funding from another government agency
- Stephanie Thomas (NJ)- fusion energy study, $1.25M ARPA-E award, two patent applications and an invention for magnetic dipole cancellation, and direct conversion of thermal energy to DC power
- John Slough/David Kirtley (WA)- $20M VC investment, $8M DoE ARPA-E, start-up Helion Energy, fusion as potential commercial energy source, 30 employees

Space Technology Research Grants Program

Awards: 710 States: 43 Territories: 1 *(PR)* Universities: 112

88 new awards in FY20

ESI: 14 NSTGRO: 65 ECF: 9 (selected)

- ✓ **2 STRI18 grants** awarded
- ✓ ***300+ active awards***
- ✓ ***165+ graduate researcher visits to NASA Centers***

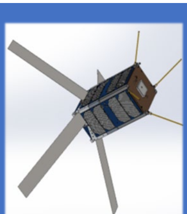
Engage Academia

Tap into spectrum of academic researchers, from graduate researchers to senior faculty members, to examine the theoretical feasibility of ideas and approaches that are critical to making science, space travel, and exploration more effective, affordable, and sustainable

- **NASA Space Technology Graduate Research Opportunities (NSTGRO)**
- **Early Career Faculty (ECF)**
- **Early Stage Innovations (ESI)**
- **Space Technology Research Institutes (STRI)**

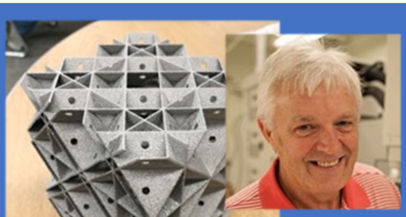
Accelerate development of ground-breaking high-risk/high-payoff low-TRL space technologies

Over 40% of completed STRG grants receive follow-on funding from other sources to directly use or further develop their technologies



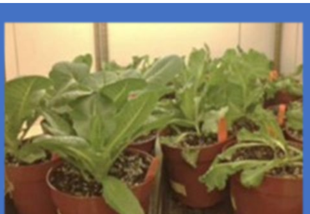
NSTRF17 Sanny Omar/University of Florida - Built a new type of cubesat drag device to safely deorbit these satellites and minimize space junk. His invention will fly this year.

ECF18 - Burcu Gurkan/Case Western Reserve University – Named 2019 influential researcher by the I&EC Journal for her work on ionic liquid based CO_2 scrubber technology.



ESI17 - Haydn Wadley/University of Virginia - Created new structural lattice materials with double the strength of currently used honeycomb sandwich structures.

CUBES



STRI16 - CUBES – The institutes Food and Pharmaceutical Synthesis Division has already grown and extracted a bone regeneration therapeutic compound from lettuce plants and is working on synthesizing other medicines.

Space Technology Research Institutes (STRI)

The goal of the Space Technology Research Institutes (STRI) is to strengthen NASA's ties to the academic community through long-term, sustained investment in research and technology development critical to NASA's future

Computationally Accelerated Materials Development for Ultra High Strength Lightweight Structures

- Institute Title: The Institute for Ultra-Strong Composites by Computational Design (US-COMP)
- Organizations: **Michigan Technological Univ**, Univ of Utah, Florida A&M, Univ of Minnesota, John Hopkins Univ, MIT, Georgia Tech, Univ of Florida, Nanocomp Technologies Inc., AFRL, Virginia Commonwealth Univ, Solvay

Bio-Manufacturing for Deep Space Exploration

- Institute Title: The Center for the Utilization of Biological Engineering in Space (CUBES)
- Organizations: **Univ of California - Berkeley**, Univ of Florida, Utah State Univ, Univ of California - Davis, Stanford Univ, Autodesk

- Institute Title: Resilient ExtraTerrestrial Habitats research institute (RETHi)
- Organizations: **Purdue Univ**, Univ of Connecticut, Harvard College, Univ of Texas - San Antonio, ILC Dover, Collins Aerospace
- RETHi seeks to design and operate resilient deep space habitats that can operate in both crewed and uncrewed configurations.

- Institute Title: Habitats Optimized for Missions of Exploration (HOME)
- Organizations: **Univ of California – Davis**, Univ of Colorado – Boulder, Georgia Tech Applied Research Corporation, Carnegie Mellon Univ; Howard Univ, Texas A&M Engineering Experiment Station, US, Blue Origin, Hamilton Sundstrand Space Systems
- The HOME institute seeks to enable resilient, autonomous and self-maintained habitats for human explorers through

Center Innovation Fund

CIF stimulates and encourages creativity and innovation from within the NASA Centers to transform NASA missions and advance the Nation's capabilities. There is a new slate of projects each year.

- Solicitations at all 10 Centers are run by each Center Chief Technologist with final selection/approval made by STMD.
- **127 FY 2019** CIF projects at all 10 Centers covering **all 15 Technology Areas.**

FY 2020 Highlighted Projects:

- Lunar Autonomous Position System – for autonomous navigation on and around the moon;
- Enabling Exploration of Permanently Shadowed Craters using RF power/comm;
- Novelty-Driven Onboard Targeting for MSL and Mars 2020 Rovers to aid exploration;
- Onboard Autonomous Trajectory Planner- supports off-nominal safe operations;
- 3D Printed Cryogenic Strut – improves cryogenic fluid capabilities

Electrodynamic Dust Shield Coating Pattern for Solar Cells

Electrodynamic dust shield before and after (left and right respectively) clearing JSC-1A lunar dust simulant in a vacuum.

Early Career Initiative (under the CIF Program)

Goal: Invigorate NASA's technological base and best practices by partnering early career NASA leaders with world class external innovators.

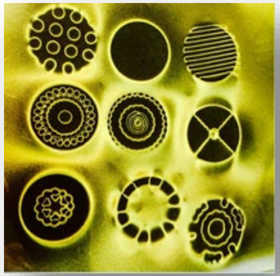
- NASA needs top-notch employees to fill gaps that are growing as people retire.
  - **Initiative to accelerate some early career Civil Servants' capabilities with in an exciting and challenging fashion.**
- STMD is looking for effective management approaches for technology development projects.
  - **Initiative requires alternative management approach (not NPR 7120-based)**
- NASA should work with appropriate partners when possible, to gain access to knowledge, technology, and/or expertise.
  - **Initiative requires partnering with a non-NASA entity (University, other government Agency, business, non-profit).**

Solicitations every year; 2 year projects that start on October 1; $2.5M maximum budget

MSFC LISA-T (Lightweight Integrated Solar Array and Transceiver) self-unfolding system worked well. Investigating flight system for cubesat. Flying various elements on MISSE 10.

KSC IDEAS (Integrated Display and Environmental Awareness System) is continuing development with GSDO funds; still partnered with small business. Collaborating with JSC.

SSC HiDyRS-X (High Dynamic Range Stereo-X) is advancing with other funds and commercial partnerships. Currently working to integrate it onto a single mask/imager system.

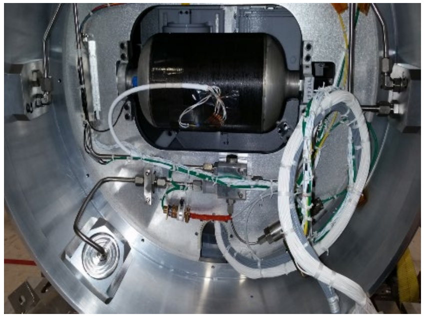


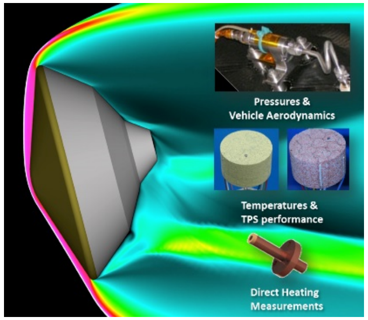
Patterned Magnetic Hold-Separate Techniques

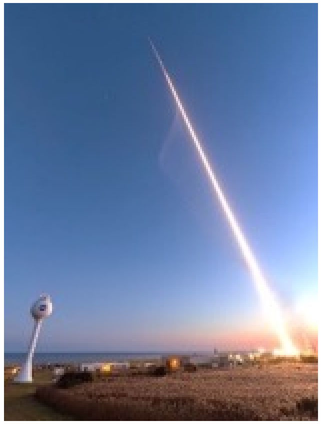
Technology Maturation Program
(Mid-TRL)

Game Changing Development Program

- Game Changing Development (GCD) aims to advance exploratory concepts and deliver infusion-ready technology solutions that enable new capabilities or radically alter current approaches
    - ***Lead, motivate, and inspire*** technology development and innovation through collaborative relationships between government, academia, and commercial entities
    - Focus on ***high-risk, high-reward technologies***
    - Target ***rapid maturation of technologies*** to be infused into NASA missions and advance commercial technologies and markets







Game Changing Development Projects

FY 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027-28

Power and Propulsion Technology

Thruster for the Advancement of Low-temperature Operation in Space (TALOS)

- *Lunar Thruster Validation* (FY 2018–2020)
- Commercial Lander (2020)
- *Lunar Thruster Qualification* (FY 2020–2022)

High Power Electric Propulsion

- *100kW Electric Propulsion Test* (FY 2018–2019)

Nuclear Thermal Propulsion

- *Nuclear Propulsion Ground Development and Flight Study* (FY 2018–2020)
- *Transition to TDM* (FY 2021–2022)

Cryocooler

- *20W/20K Cryocooler* (FY 2018–2021) →
- *150W/90K Cryocooler* (FY 2019–2022) →
- Commercial Lander (2025)

Nuclear Fission Power

- *1kW Demo* (FY 2018–2019)
- *Concept Study* (FY 2020–2021)
- *Transition to TDM* (FY 2022–2027-28)
- Commercial Lander (2027-28)

Regenerative Fuel Cell

- *Fuel Cell/Electrolyzer Development and Testing* (FY 2018–2023)
- *RFC will transition to a lunar demonstration for surface power* (FY 2024–2025)
- *Adaptable Solar Array Study* (FY 2019)
- *Adaptable Solar Array Prototype Development* (FY 2020–2023)

Legend:
- Solicitation
- Launch
- Commercial Lander

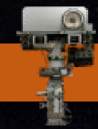
Game Changing Development Projects

FY 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027-28

Advanced Environmental Control, Life Support Systems, and In-Situ Resource Utilization (ISRU)

Mars Environmental Dynamic Analyzer (MEDA)

- *Sensor Development & Integration*
- *Transition to Mars 2020*



SpaceCraft Oxygen Recovery

- *Oxygen Recovery from CO_2 Experiment*
- *Transition to Long Duration Demo on ISS*

- *Carbon Vapor Deposition*
- *Transition to Long Duration Demo on ISS*

Solicitation

Launch

Commercial Lander

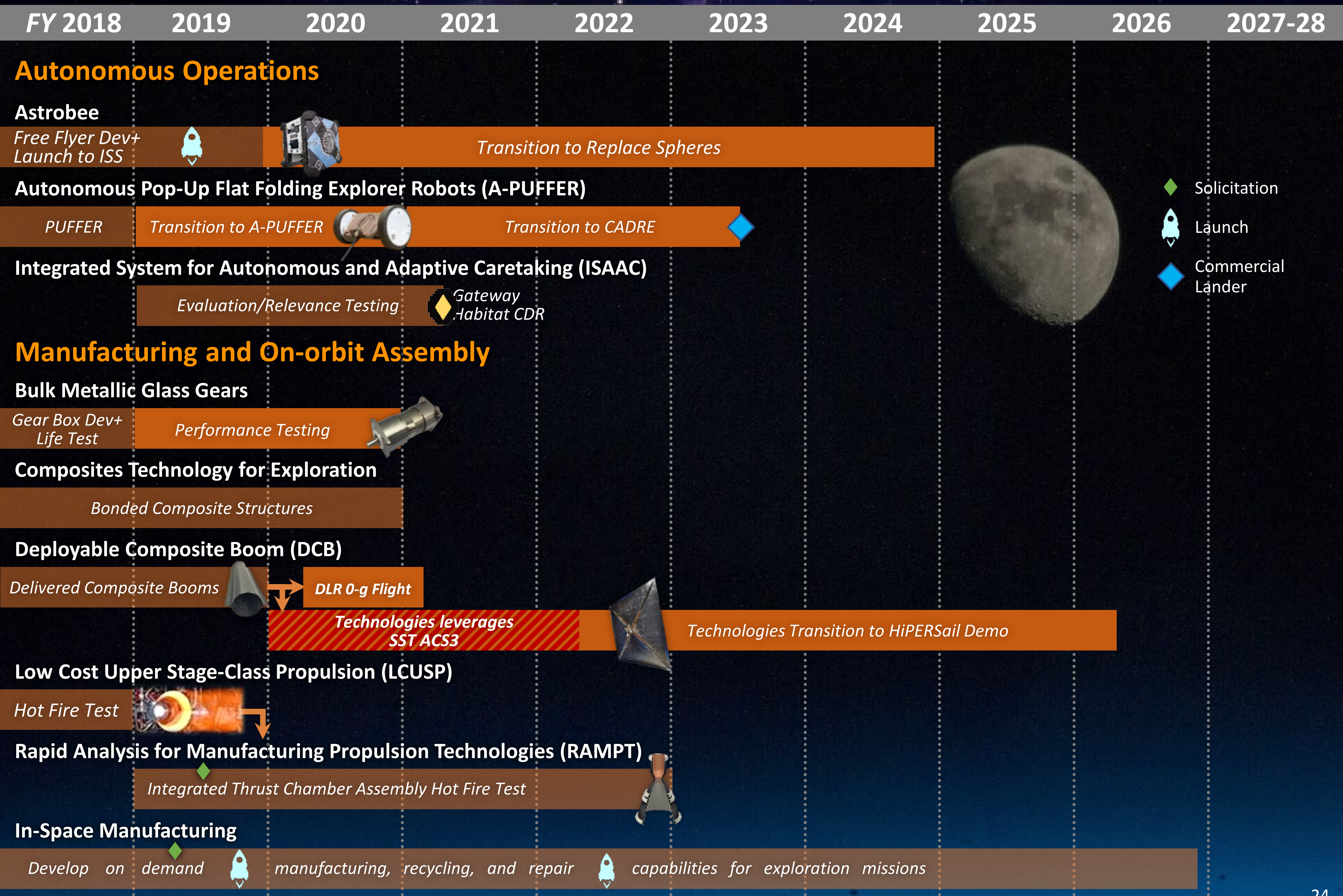
ISRU Technologies

- *ISRU BAA Selection and Awards*
- *Transition to ISRU Commercial Development*
- *Polar Ice Drill Ground Test*
- *Polar Ice Drill Lunar Demonstration*
- *Lunar Regolith Utilization including Simulant Development*
- *Transition Technologies to TDM for future Demos*
- *Lunar Dust Mitigation*
- *Ionic Liquid Recovery from Oxygen Regolith (RRILE)*
- *Laser Spectrometers for Impurity Analysis*
- *Blue Origin Propellant Production Tipping Point*
- *Skyre/Meta Vista Propellant Production Tipping Point*

Space Synthetic Biology

- *BioNutrient ISS Storage*
- *Reactivation Demonstration*
- *CO_2-Based Manufacturing Progress*

Game Changing Development Projects



Game Changing Development Projects

FY 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027-28

Entry, Descent, and Landing

Mars Entry, Descent and Landing Instrumentation 2 (MEDLI 2)

Flight SSE Integration → *Transition to Mars 2020*

Precision Landing and Hazard Avoidance Technologies

Navigation Doplar Lidar

- *GEN 3-unit Astrobotic In-line Ground Test*
- TP—*Blue Origin Deorbit Descent and Landing*
- *SPLICE Closed-Loop Flight Test w/HPSC Emulator*

Draper Terrain Relative Navigation (Masten Xodiac Flight)

TP—*Astrobotic TRN and Visual Velocimetry Sensor*

Descent Landing Computer

Hazard Detection Lidar

Transition to Technologies to Commercial Users/ Integrated Lunar Demo by CLPS

Solicitation

Launch

Commercial Lander

Advanced Communications, Navigation, and Avionics

High Performance Space Computing (HPSC)

Chiplet Award Contracts → *Development Testing*

Advanced Memory Development (AFRL)

Single Board Computing

Transition to commercial lunar landers/SMD , HEOMD, DoD and industry for space applications

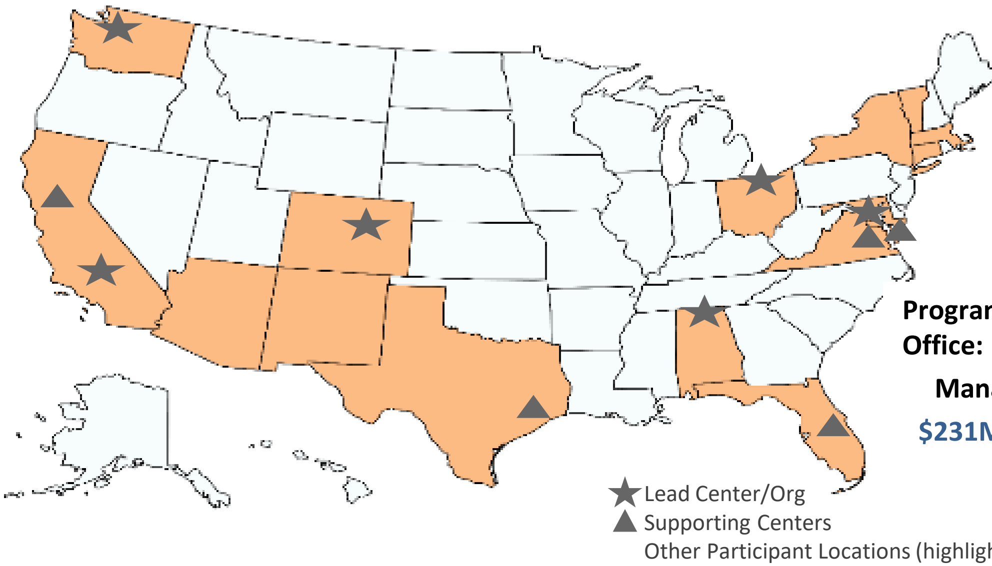
Technology Demonstration Programs
(Higher-TRL)

Technology Demonstration Missions Program

Technology Demonstrations

- **Spaceflight-based** to mature new technologies that have been successfully demonstrated to a high-fidelity prototype that is then tested in a space environment

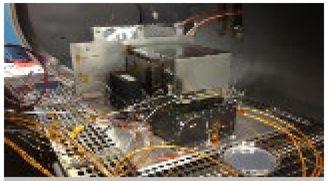
- **Ground-based & atmospheric demonstrations** to mature new technologies to the point of a high-fidelity prototype that may subsequently be integrated into a demonstrational or operational flight mission



Program Office: MSFC

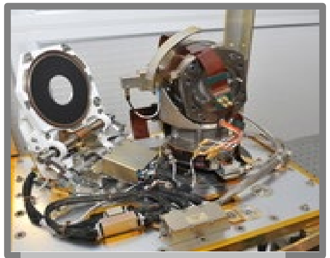
Manages:

$231M FY17



DSAC in TVAC

GPIM SV



LCRD Payload

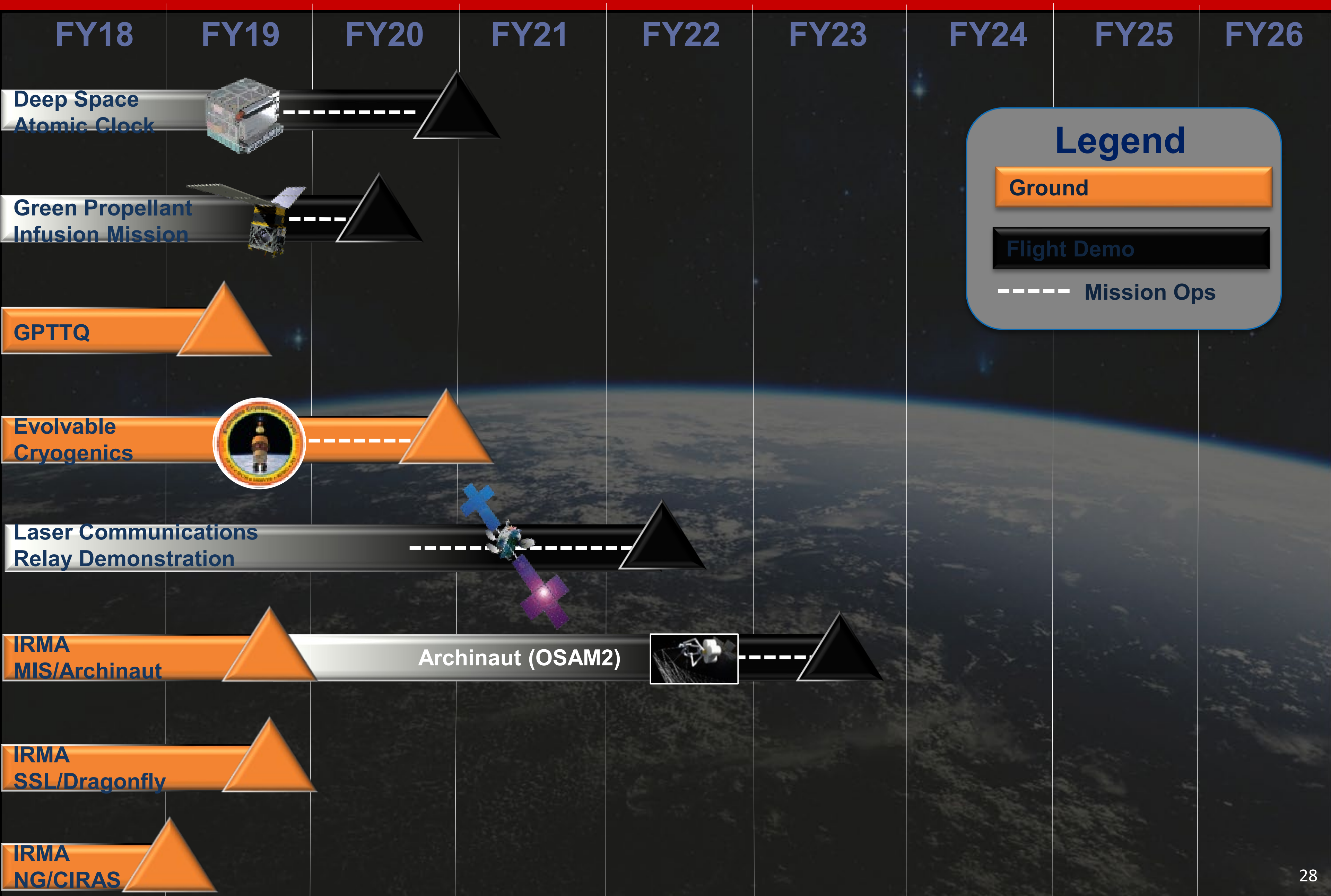
Goal

- Bridge the gap between development and mission infusion by maturing crosscutting and system-level technologies through demonstration in relevant operational environments. (TRL 5-7)

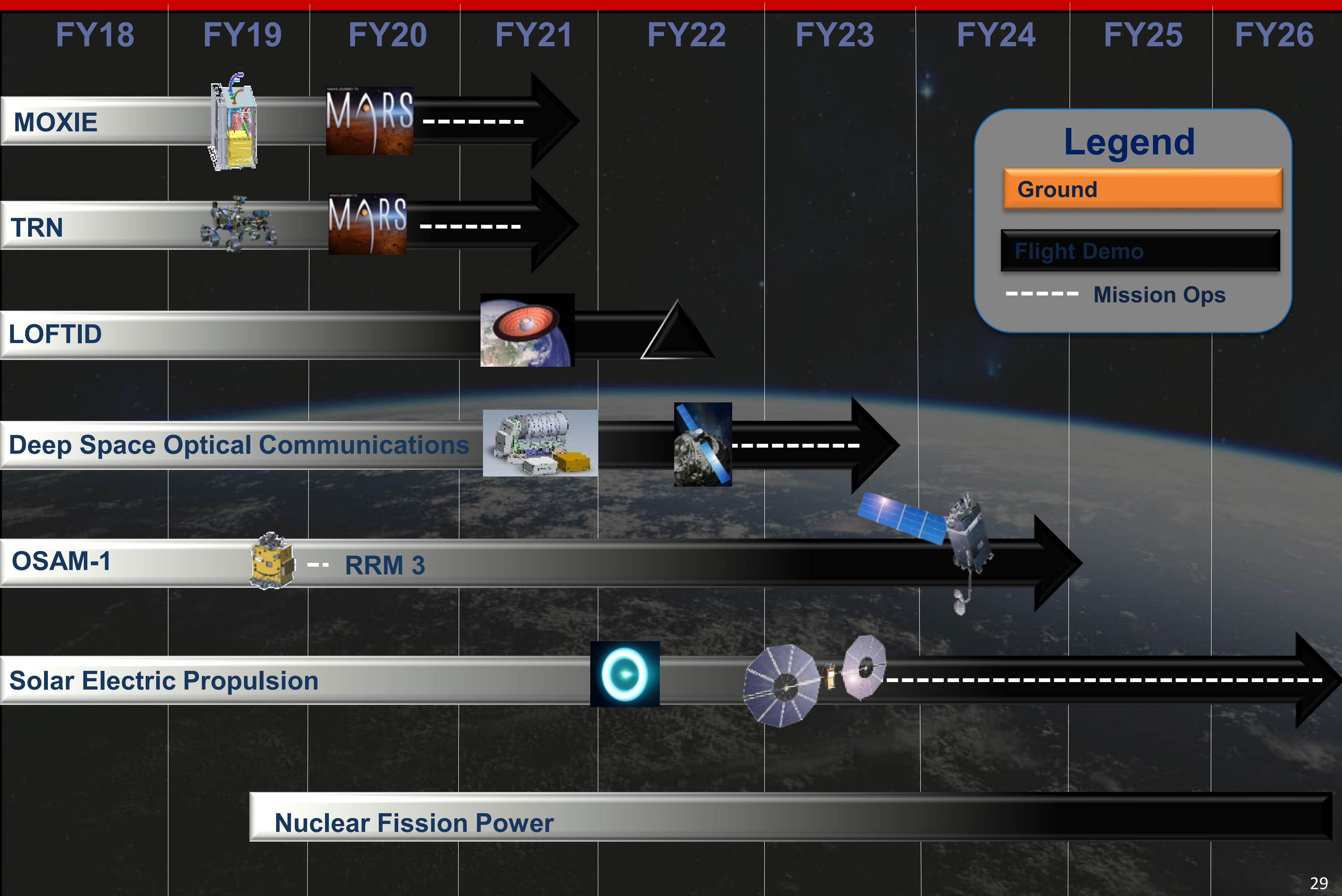
Objectives

- Maintain a portfolio of projects that support STMD's Strategic Investment Plan developed from the Agency's future mission needs
- Partner with organizations that provide cost sharing and technology transition or infusion opportunities
- Conduct system-level demonstrations that reduce risk and/or achieve flight readiness of new cross cutting technologies and capabilities for exploration missions, science missions, or industry use
- Enable transition and/or infusion of technologies or capabilities into NASA missions and the Nation's space enterprise

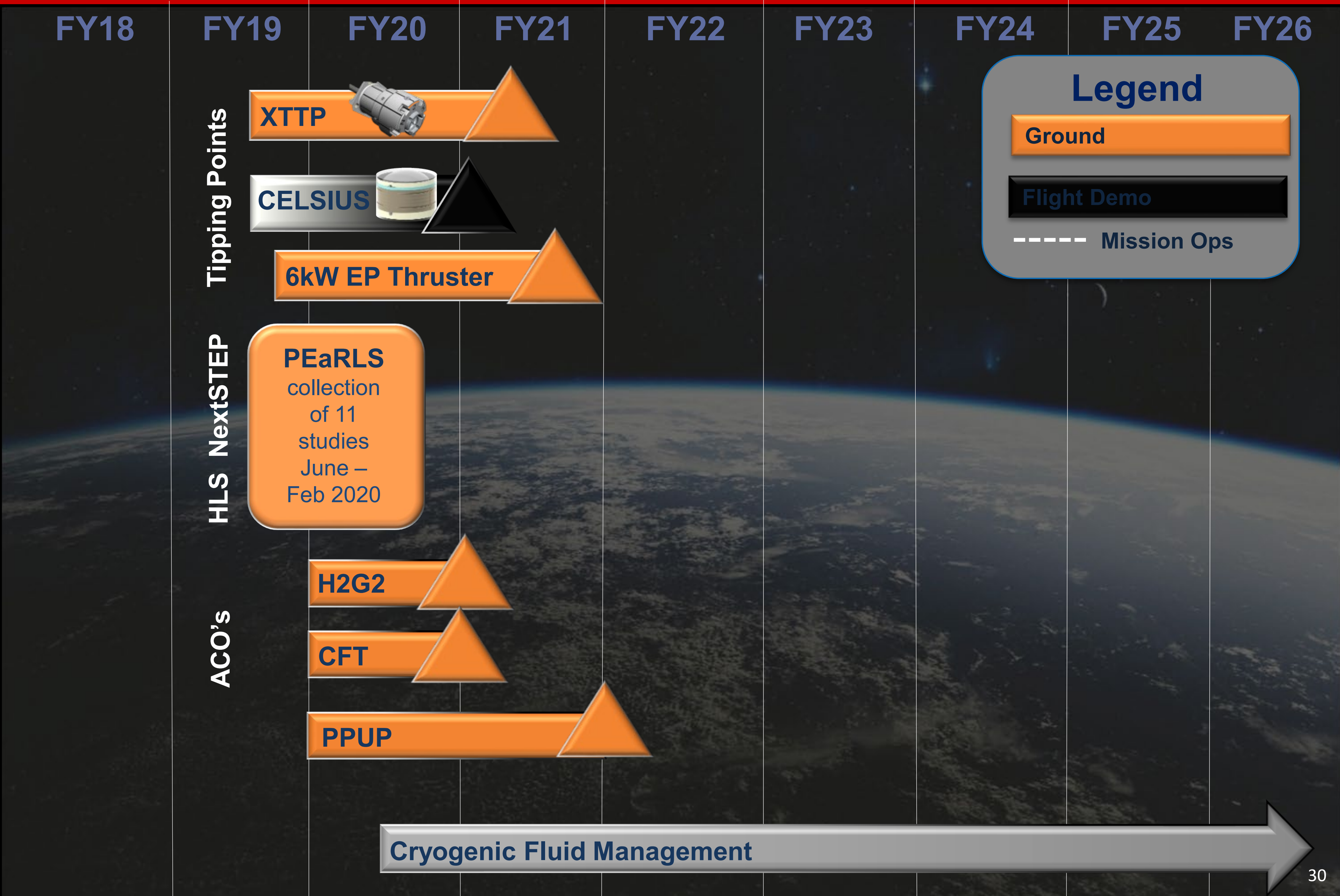
Technology Demonstration Missions Projects



Technology Demonstration Missions Projects



Technology Demonstration Missions Projects

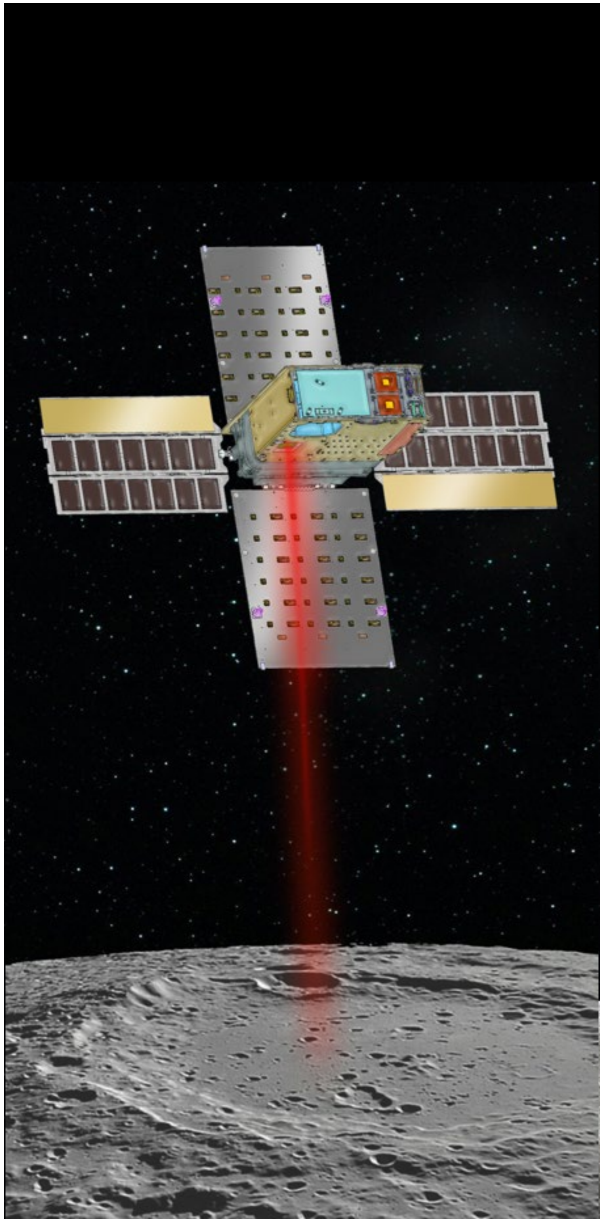


Small Spacecraft Technology Program

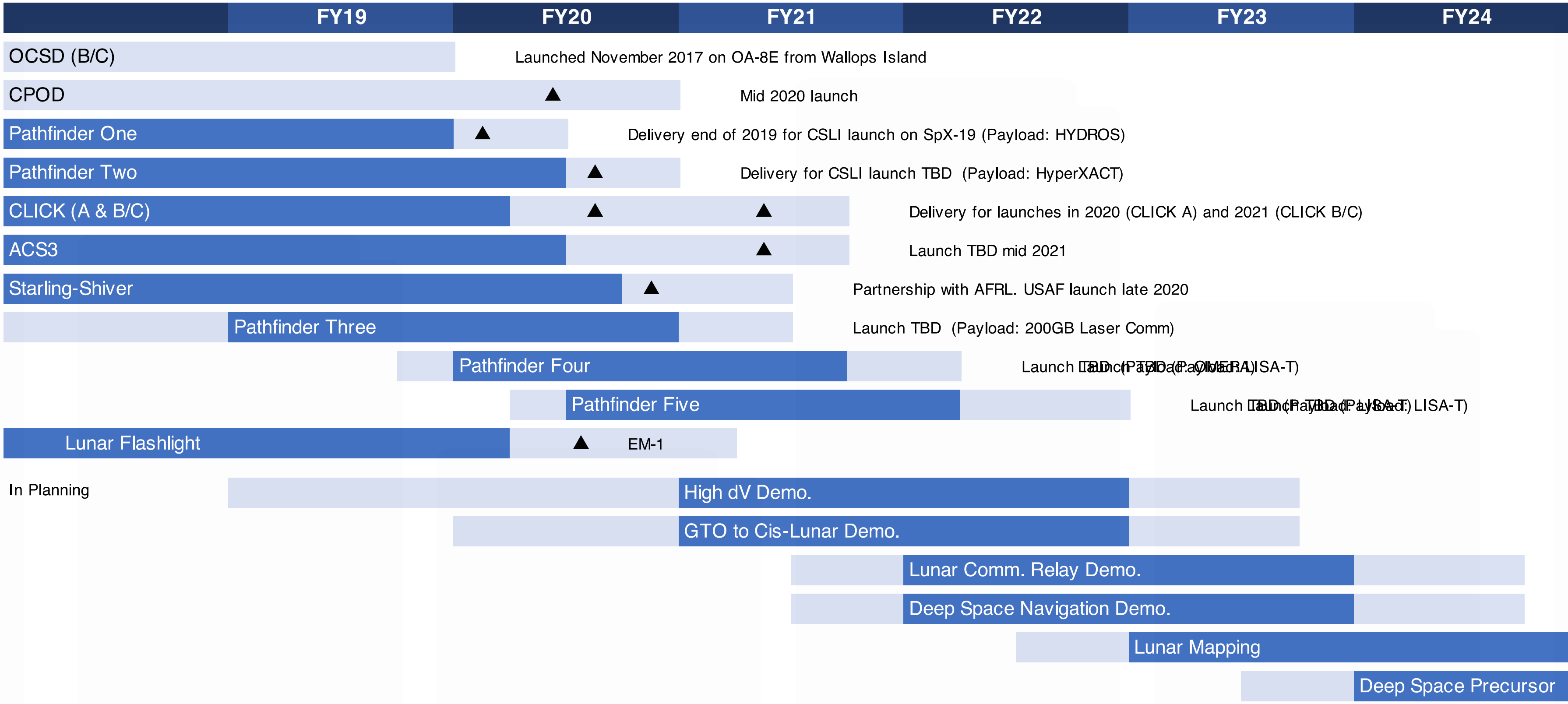
Objectives:
- Enable execution of missions at much lower cost than previously possible
- Substantially reduce time required for development of spacecraft
- Enable and demonstrate new mission architectures
- Expand the capability of small spacecraft to execute missions at new destinations and in challenging new environments
- Enable the augmentation of existing assets and future missions with supporting small spacecraft

Current Status:
- 19 Spacecraft currently in development across 15 missions, including two missions to the moon in 2021
- Engaged in 8 technology partnerships with academia and testing of multiple new technologies from industry

Deliverables/Schedule
- FY20: Launch of PTD-1 and PTD-2. Design/Integration reviews on 9 additional missions. Selection of 9 new technology partnerships
- FY21: Launch of CAPSTONE. Anticipated delivery of Lunar Flashlight, CLICK-A, PTD-3 and ACS3 for launch
- FY22: Anticipated delivery of CLICK-B/C and PTD-4 for launch



Current and Upcoming Small Spacecraft Missions



Project Phase: Pre Phase A / Post Initial Launch Capability & Operations | Authority To Proceed to Initial Launch Capability | ▲ Launch

Mission Key

OCSD: Optical Communications and Sensor Demonstration
CPOD: CubeSat Proximity Operations Demonstration
PTD: Pathfinder Technology Demonstrator
CLICK: CubeSat Laser Intersatellite Crosslink
ACS3: Advanced Composites Based Solar Sail
Starling-Shiver: Distributed spacecraft mission demo.
Lunar Flashlight: Map water and volatiles at the lunar south pole

High dV: CubeSat Propulsion for Deep Space Missions
GTO to Cis-Lunar: CubeSat to the moon from commercal rideshare
Lunar Comm. Relay: Interoperable communications for lunar missions
Deep Space Nav.: CubeSat in-situ navigation for deep space
Lunar Mapping: Map surface / subsurface volatiles and voids
Deep Space Precursor: Demo. of CubeSat precursor mission to Mars

Flight Opportunities Program

Objective:
Facilitate rapid demonstration of technologies for space exploration and expansion of space commerce through suborbital flight testing with industry partners.

In FY2019
- **47 payloads flown**
- **15 successful flights**
- **9 commercial flight providers active**
- **25 technologies selected via Tech Flights 2019 solicitation**

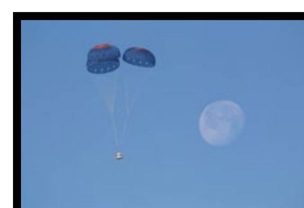
- ***184*** Flights facilitated by Flight Opportunities (FO) through **the end of FY2019**
- **A total of 651** payloads flown as of the end of FY2019 through FO

Highlights of recent milestone in the Flight Opportunities program:
- On **Dec. 6, 2019, 8** FO-supported payloads were tested aboard Blue Origin's New Shepard, including an experiment to study the impact of gravity transitions on gene expression and a system to manage trash and waste in space
- On **Nov. 21, 2019, 6** tests were performed abroad UP Aerospace's SpaceLoft rocket, with a focus on testing guidance and control systems and other system to enable small launch capabilities
- On **Sep 11, 2019** testing of a terrain relative navigation system was tested on Masten Space Systems Xodiac rocket, demonstrating critical landing capabilities for the Moon and Mars
- **On January 2020,** Draft of Tech Flights 2020 solicitation released allowing human tended payloads and adding dedicated funding for educational opportunities.

FY20-21: Award of suborbital opportunities to industry and academia. Integration of commercial suborbital testing opportunities into Small Spacecraft Technology and other NASA solicitations.

Commercial Flight Providers

Blue Origin, Masten, Zero G, Exos Aerospace, Virgin, World View, UP Aerospace, NSC, Raven



Partnerships & Technology Transfer Program

SBIR/STTR Program

Objectives:

- Leverage the Nation's innovative small business community to support research and development in support of NASA's mission in human exploration, science and aeronautics.
- Provide the small business sector with an opportunity to develop technology for NASA, and to commercialize that technology to spur economic growth.

Current Status (FY19)

- The 2019 Phase I solicitation, released in February, emphasizes topics on long-term human exploration and space utilization consistent with the Moon to Mars Campaign.
- NASA continues to seek small business feedback to increase collaboration with small businesses through an annual Request for Information and an innovative public private partnership to conduct an Innovation and Opportunity Forum.
- NASA will begin a pilot with the NSF SBIR program later this year to support growth-oriented commercial space entrepreneurs.
- NASA is in the third year of an I-Corps training grants pilot for Phase I awardees to encourage commercialization of technology funded through awards.
- NASA is offering a robust set of Post-Phase II award opportunities to encourage increase technology transitions and commercialization including:

Deliverables/Schedule (FY 19/20)

- FY19: NASA plans to announce new Phase I selections in June, and Phase II SBIR and STTR selections (from the 2018 solicitation) in May and October, respectively.
- FY20: Conduct Industry day in fall 2019. Release 2020 solicitation in January 2021.

Sustainable Bioproducts, a NASA STTR company, has spun out it's research done deep inside Yellowstone's volcanic hot springs, where organisms must adapt to a barren environment, to develop a new source of food protein. They received $33 million in funds from venture capital firm 1955 Capital and the venture arms of two leading global food suppliers — grain company Archer Daniels Midland and multinational food producer Danone.

Prizes and Challenges: Centennial Challenges

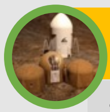
Goal: Stimulate research and technology solutions to support NASA missions and inspire new national aerospace capabilities through public prize competitions.

307 Teams

From **42** States

$10M Awarded

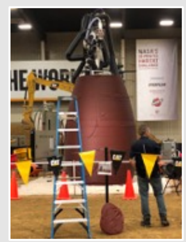
RECENT HIGHLIGHTED SUCCESSES



3D-Printed Habitat Challenge (Completed)

State-of-the-art in autonomous vertical 3D printing construction technology for space and Earth.

- Completed May 2019; $2.06M awarded
- Over $10M in investments from commercial entities.
- Sparked commercialization of technology for Earth applications including affordable housing solutions.



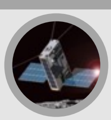
CO_2 Conversion Challenge (Active)

Convert CO_2 into sugar molecules that can be used to produce mission critical supplies.

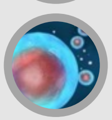
- Awarded $250K in Phase 1; $750K purse for Phase 2 (in progress).
- Solutions from this competition could create game-changing technologies for life support for the Moon and Mars.
- Create potential on-demand bio-farms to provide medicines, food and building materials.

FY2020–2021 PLANS

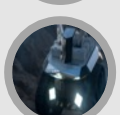
ADDITIONAL ACTIVE CHALLENGES



Cube Quest $5M
CubeSats to be launched on Artemis I, advancing deep space propulsion and communications. $460K awarded to date.



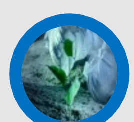
Vascular Tissue $500K
Printing viable thick organ tissue that can advance research and medicine in space and on Earth.



Space Robotics $1.9M
Advancing robotic software and autonomous capabilities. $570K awarded in phase 1; $1M purse for Phase 2 (in progress)

IN DEVELOPMENT

Lunar Power $5M
Energy storage and distribution for future Moon missions.



Lunar Nutrition $3M
Improve access to fresh, healthy and tasty food for long duration missions.

IN FORMULATION

Lunar Excavation, Manufacturing & Construction $5M
Game-changing autonomous operations targeting a large scale, end-to-end demonstration.

Prizes and Challenges: NASA Tournament Lab

Since 2011, the NASA Tournament Lab has enabled NASA researchers, scientists, and engineers to conduct public and internal challenges and other crowdsourcing projects to acquire novel ideas or solutions to accelerate R&D efforts in support of the NASA mission.

344
NASA crowdsourcing projects launched

72M
People accessed worldwide thru 17 crowdsourcing communities

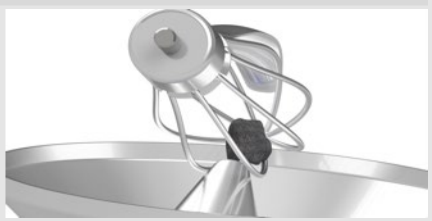
$18M
Savings estimated v. using traditional innovation methods

RECENT HIGHLIGHTED SUCCESSES

Sample Return Regolith Sorter Challenge

5 innovative designs were selected from 200+ submissions as starting point for lunar sample mission designs.

A challenge to design a sampling system for acquiring a defined amount of regolith within specific size ranges while operating under the lunar environmental constraints.



NASA Earth & Space Air Prize

Accurate and affordable aerosol sensor

Public/private partnership with Robert Wood Johnson Foundation to advance the state of the art on aerosol sensors needed for spacecraft and cities on Earth.

FY2020–2021 PLANS

Complete 31 NASA challenges currently in progress

Develop and execute 25+ candidate challenges including: Exploring Hell: Venus Rover Obstacle Avoidance, Mini-Payloads for Small Lunar Rovers, Artemis Camera, Gateway Frozen Sample, EVA Parametric Mass Modeling, Drone AR Visualization, Food Safety Imaging, Advance Thermal Coatings, OCT Seedling

Develop & launch at least $400K in challenges resulting from NASA's "Crowdsourcing Contenders" solicitation

Award the NOIS2 (NASA Open Innovation Services 2) multi-vendor crowdsourcing contract
Supporting a pilot for internally finding needed skills
(Part of Agency Digital Transformation)

Facilitate challenges for other agencies including DHS, NIST, USBR, NGA, CDC, USDA, USAID, DIA, FAA, NOAA, NIH, IARPA (11 challenges in progress)

iTech

Goal: Infusion of a robust spin-in technology pipeline aligned with NASA mission needs identifying advancements in technologies that are solving problems on Earth and have the potential to address existing space challenges to enable NASA missions.

Provides an open platform for the technologies to present their innovations and invite the public to engage.

Innovators

Two hundred and thirty one entrepreneurs had their technologies evaluated and qualified at Ignite the Night Presenters, Cycle Semifinalists and/or Cycle Finalists.

Investors

Investors are a key part of the NASA iTech program. **Ninety two (92)** investors have been involved in evaluations and events.

Industry

From aerospace to biotech, electronics manufacturers and more, industry participants have sourced new partnerships and investments.

Technology Transfer

Finding NASA technology is easy through our online portal, technology.nasa.gov. Licensing fast and straightforward through an online application system. We also offer programs for emerging entrepreneurs like Startup NASA and a university program, T2U (Tech Transfer University).

NASA's software inventory is available—without cost—to industry, academia and other government agencies on software.nasa.gov, the Federal Government's first and only comprehensive software inventory.

Our commercialization success stories are published annually in our Spinoff report and online at spinoff.nasa.gov.

Go

Rapid, Safe, & Efficient Space Transportation


Solar Electric Propulsion


Nuclear Propulsion Technologies


Thruster Advancement for Low-temperature Operations in Space

- Enable Human Earth-to-Mars Round Trip mission durations less than 750 days.
- Enable rapid, low cost delivery of robotic payloads to Moon, Mars and beyond.
- Enable reusable, safe launch and in-space propulsion systems that reduce launch and operational costs/complexity and leverage potential destination based ISRU for propellants.

Cryogenic Fluid Management


Green Propellant Infusion Mission


Rapid Analysis and Manufacturing Propulsion Technology


Cryogenic Fluid Management

HLS Refueling Studies

NORTHROP GRUMMAN

Masten

SSL A MAXAR COMPANY

Dynetics

SPACEX

BOEING

LOCKHEED MARTIN

Cryogenic Fluid Transfer Technology Demo Con-ops development with SpaceX

The Evolvable Cryogenics (eCryo) project

ULA United Launch Alliance

ULA H2/O2 Thruster development

Lunar CFM Studies and Cryocooler Development with Lockheed Martin

Creare

BLUE ORIGIN

AEROSPACE

Intuitive Machines: "Utilize NASA's Radio Frequency Mass Gaging System for first flight"

ASTROBOTIC

Cryocooler Development enabling zero boil-off with Creare

MOOG

PARAGON SPACE DEVELOPMENT CORPORATION

Paragon Space Development Corp.: Cryogenic Encapsulating Launch Shroud and Insulated Upper Stage (CELSIUS)

Land

Expanded Access to Diverse Surface Destinations

Mars EDL

Navigation Doppler LIDAR

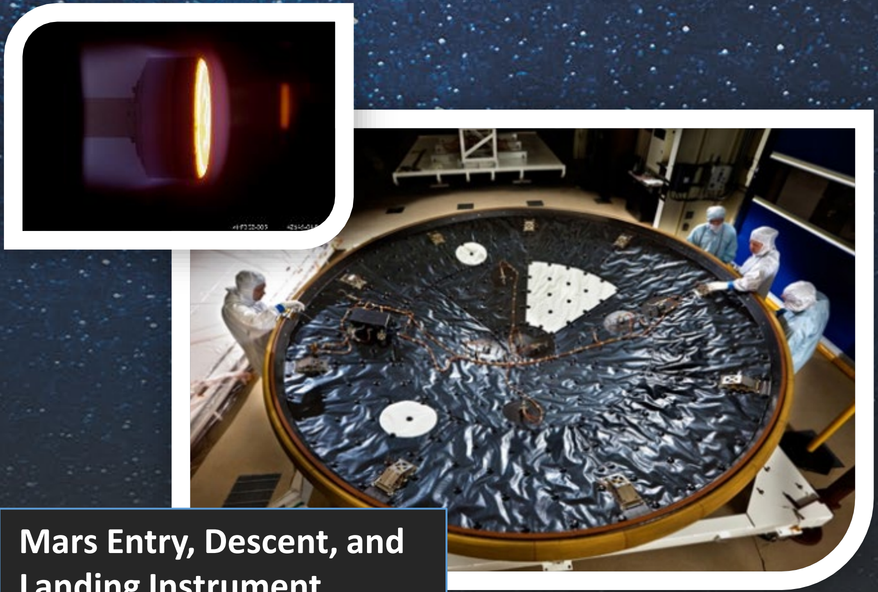
Terrain Relative Navigation

Low-Earth Orbit Flight Test of an Inflatable Decelerator

SPLICE

- **Enable Lunar and Mars Global Access with land large (on the order of 20 ton) payloads to support human missions.**
- **Land Payloads within 50 meters accuracy while also avoiding local landing hazards.**

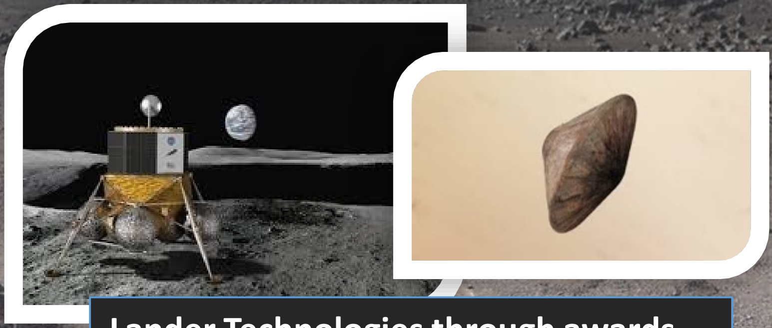
Exploration Technology in Entry, Descent, and Landing



Mars Entry, Descent, and Landing Instrument (MEDLI 2) on Mars 2020

The Safe and Precise Landing Integrated Capabilities Evolution (SPLICE) project; includes high performance spaceflight computing

LeO-based Flight Test Inflatable Decelerator (LOFTID)



Lander Technologies through awards with Astrobotic and Blue Origin

Entry, Descent and Landing (EDL)

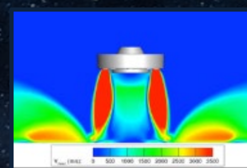
Lunar Capabilities (feeding forward to Mars)

Precision Landing and Hazard Avoidance

Safely and precisely land near science sites or pre-deployed assets

Plume Surface Interaction

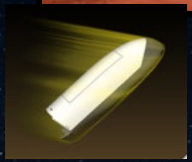
Reduce lander risk by understanding how engine plumes and surfaces behave



Data Return and Model Improvements

Measure entry system performance and update unique, critical simulations for Moon and Mars; modeling for supersonic retro-propulsion

Mars Capabilities



Large Scale Demonstration

Large structures, including deployables, that can deliver high-mass payloads (LOFTID)

- Landing safely within 10 to 100 m of key science and resource sites and pre-deployed assets, to enable sustainable human presence. Capabilities (sensors, computing) demonstrated at the Moon feed directly forward to Mars.
- Understanding the phenomena of Lunar and Martian landing vehicle plumes will reduce risk for all landers and nearby assets. Engine plumes induce environments on the lander that must be considered in design. Modeling and ground test techniques feed forward to Mars.
- Gathering EDL-relevant flight data at every opportunity is critical for validating models, and complements ground tests. EDL relies on simulations for end-to-end capabilities that cannot be fully tested on Earth. Applications: Lunar Deorbit, Descent, Landing, and Ascent (DDL&A), Mars EDL, all planetary entries, and Earth return of crew, assets, or samples.

LOFTID (Low-Earth Orbit Flight Test of an Inflatable Decelerator)

Objective

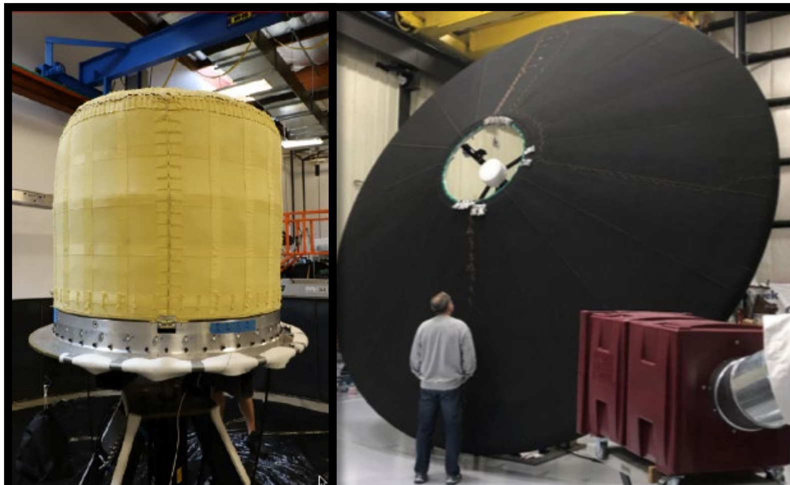
- Demonstrate Hypersonic Inflatable Aerodynamic Decelerator (HIAD) performance at the 6-m scale, at Mars-relevant heating conditions. Collect data to assess thermal and aerodynamic response

Current Status

- Co-Manifest with NOAA satellite JPSS-2 confirmed
- Successful Preliminary Design Review held June 2019
- Aeroshell and Rigid Structures Engineering Development Unit (EDU) testing complete
- Reentry Vehicle (RV) Subsystems EDU testing underway
- RV Subsystems Peer Reviews underway
- Rigid Structures Flight Hardware Build underway
- Partnership with SBIR company to include advanced gas generator

Deliverables/Schedule

- Critical Design Review: July 2020
- Avionics Integration Complete: February 2021
- System Test Complete: July 2021
- Reentry Vehicle Delivery to ULA: December 2021
- **Launch on Atlas V 401 from Vandenberg AFB: March 2022**



March 2022 LOFTID flight will be the largest heatshield ever flown.

Live

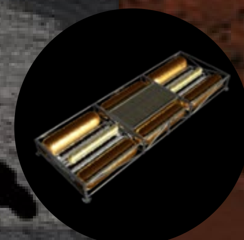
Sustainable Living and Working Farther from Earth

Surface Power

Astrobee

In Space Manufacturing

Regenerative Fuel Cells



Synthetic Biology

ISRU

Integrated Systems for Autonomous Adaptive Caretaking

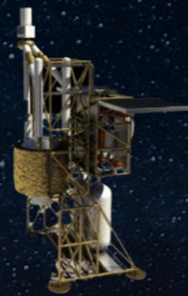
- Conduct Human/Robotic Lunar Surface Missions in excess of 28 days without resupply.
- Conduct Human Mars Surface Missions in excess of 365 days without resupply.
- Provide greater than 90% of propellant and water/air consumables from local resources for Lunar and Mars missions.
- Enable Surface habitats that utilize local construction resources.
- Enable Intelligent robotic systems augmenting operations during crewed and uncrewed mission segments.

Note: Mid TRL and High TRL Technology Development for Life Support and EVA suits are HEOMD Responsibility

Lunar Surface Innovation Initiative (LSII)

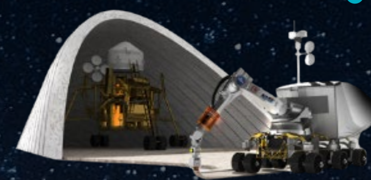
In Situ Resource Utilization

Collection, processing, storing and use of material found or manufactured on other astronomical objects



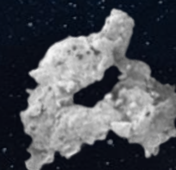
Surface Excavation/Construction

Enable affordable, autonomous manufacturing or construction



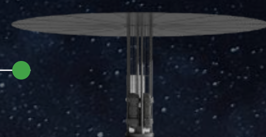
Lunar Dust Mitigation

Mitigate lunar dust hazards



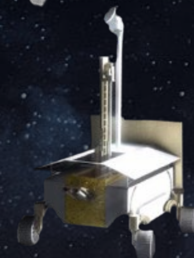
Sustainable Power

Enable continuous power throughout lunar day and night



Extreme Environments

Enable systems to operate through out the full range of lunar surface conditions



Extreme Access

Access, navigate, and explore surface/subsurface areas

- Spurs the creation of novel technologies needed for lunar surface exploration.
- Accelerates technology readiness of key systems and components.
- Addresses technology development needs for lunar surface operations, including surface payloads.
- Implements development through a combination of unique in-house activities, competitive programs, and public-private partnerships.
- Coordinates with SMD and HEOMD to identify priorities.

Lunar ISRU Development and Demonstration Timeline

Reconnaissance, Prospecting, Sampling

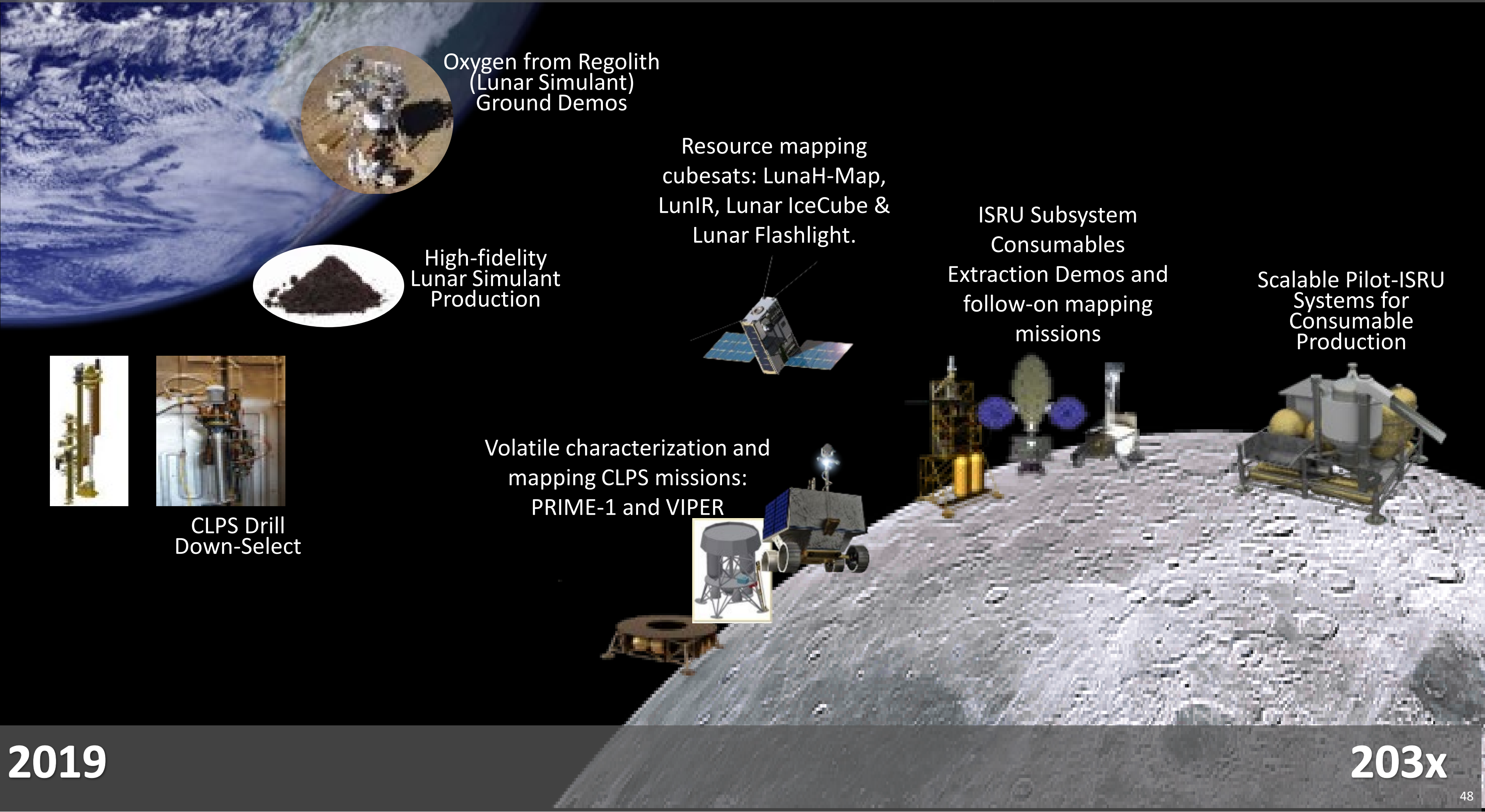
Sub-system Demonstrations: Investigate, sample, and analyze the environment for mining and utilization.

Resource Acquisition & Processing

Follow The Natural Resources: Demonstrations of systems for extraction and processing of raw materials for future mission consumables production and storage.

Pilot Consumable Production

Sustainable Exploration: Scalable Pilot Systems demonstrating production of consumables from in-situ resources in order to better support sustained human presence.



Polar Resources Ice Mining Experiment-1 (PRIME-1)

Objective
Develop a flight ready system that can assess the composition of regolith for water content and other volatiles at a polar lunar landing location.

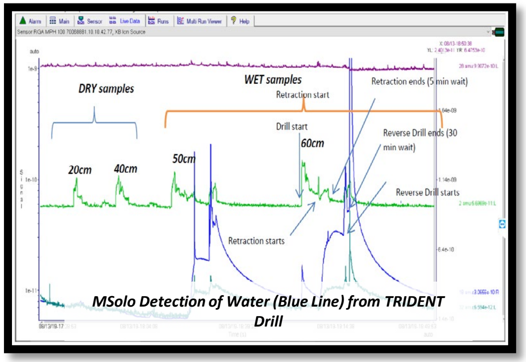
Description
PRIME-1 consists of two high-TRL subsystems; Mass Spectrometer observing lunar operations (MSolo) and The Regolith and Ice Drill for Exploring New Terrain (TRIDENT). These two subsystems will be integrated onto a commercial lunar lander for flight in 2022

Industry Participants
Honeybee Robotics is providing TRIDENT drill and Inficon will provide the mass spectrometer

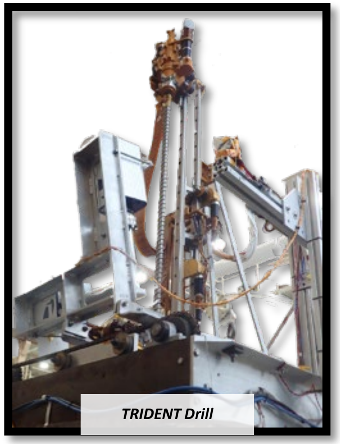
Current Status
- 8/6 – 8/27/2019: TRIDENT and Pvex drill testing at GRC
- 10/30/2019: Project delivered final report with TRIDENT drill selection
- 11/18/2019: Program held independent review and concurred with project’s drill selection
- 4/2020: Preliminary Design Review of TRIDENT drill and Msolo mass spectrometer

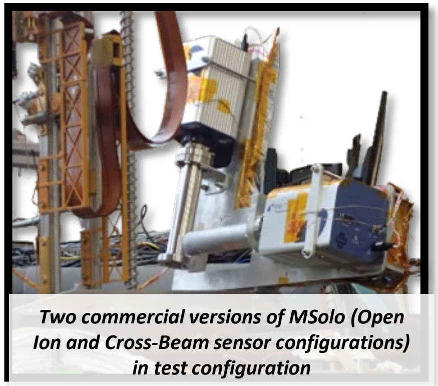
Deliverables/Schedule
- FY 2020: Complete Trident and Msolo Critical Design Reviews.
- FY 2021: Complete testing and delivery of spaceflight qualified hardware

Delivery of spaceflight qualified hardware for CLPS mission in 2023



MSolo Detection of Water (Blue Line) from TRIDENT Drill


TRIDENT Drill

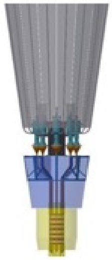
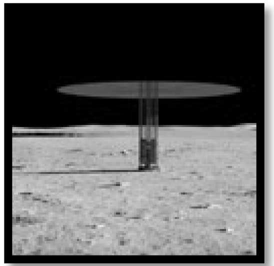
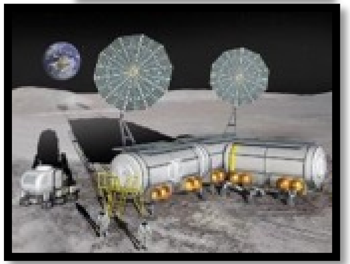

Two commercial versions of MSolo (Open Ion and Cross-Beam sensor configurations) in test configuration

Lunar Surface Power

STMD is developing technologies which can provide the capability for continuous power throughout day and night for lunar and Mars Surface missions.

Technology Developments Underway:

- Power Generation
  - Lunar Surface Fission Power System: Flight reactor demonstration (2027)
  - Adaptable Lunar Lander Solar Array Systems: Requirements definition and concept evaluation leading to a 10kW-class solar array
  - Chemical Heat Integrated Power Source: Develop 100 W-class, 350 hour non-nuclear lunar night power source
- Energy Storage
  - Develop a sub-kW class, integrated Regenerative Fuel Cell (RFC) and conduct lunar relevant ground testing to demonstrate long-duration energy storage & night power generation (~350 hr)
  - Primary Fuel Cell Technology Tipping Point (Blue Origin, September 2019): Demonstrate fuel cell element on early lander using propellant-grade hydrogen and oxygen reactants to extend the lander surface mission duration
- Initiated for surface-to-surface power beaming, advanced rover energy storage technology and power distribution architectures.
- Conducting a phased, system level assessment of power architecture for lunar surface missions with HEOMD

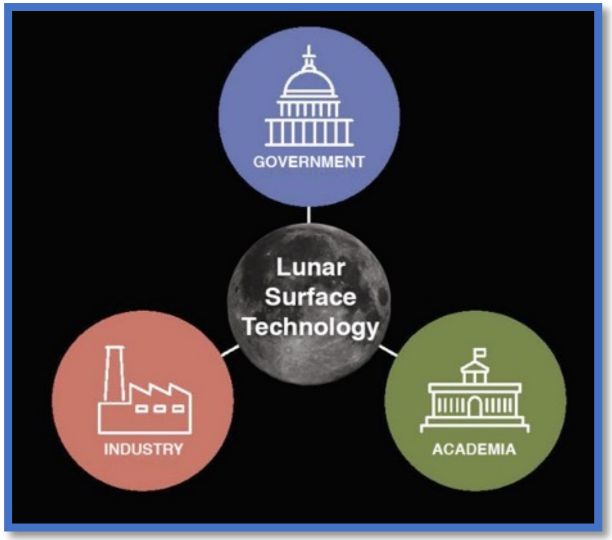




Lunar Surface Innovation
C O N S O R T I U M

The University Affiliated Research Center, Johns Hopkins Applied Physics Lab, has a task with NASA STMD to assess and recommend a model for a LSII technology system integration role. As part of this assessment, APL will convene the Lunar Surface Innovation Consortium composed of industry, academia and NASA with expertise in key lunar surface technology development capability areas.

Key Consortium Tenets

- **Technology** – Develop key lunar infrastructure capabilities
- **Collaboration** – Enable partnerships that leverage common objectives for establishing lunar infrastructure
- **Communication** – Create information paths to best match needs with opportunities
- **Future Workforce** – Ensure the the U.S. maintains the workforce needed for sustained space exploration



The Consortium Will…

- Identify lunar surface technology needs and assess the readiness of relative systems and components
- Make recommendations for a cohesive, executable strategy for development and deployment of the technologies required for successful lunar surface exploration
- Provide a central resource for gathering information, analytical integration of lunar surface technology demonstration interfaces, and sharing of results

Kickoff on 2/28/20 at APL with broad industry, academia, and government participation.

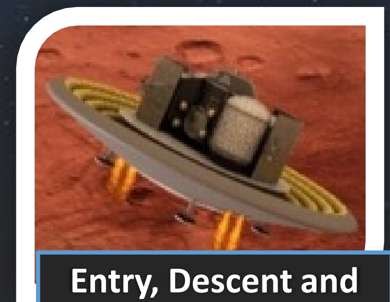
Mars Surface Technologies

Lunar Surface Technologies
- Volatile extraction
- Water electrolysis
- Gas liquefaction
- Cryo fluid management and storage
- LOX-based propulsion
- Entry, Descent & Landing
- Surface Power

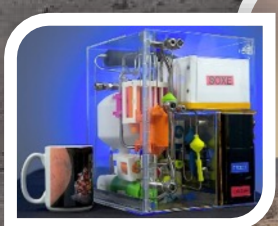
Mars Surface Technologies
- Atmosphere processing
- Solid oxide electrolysis
- Gas liquefaction
- Cryo fluid management and storage
- LOX-based propulsion
- Entry, Descent & Landing
- Surface Power

Regenerative fuel cells are an integral part of surface power

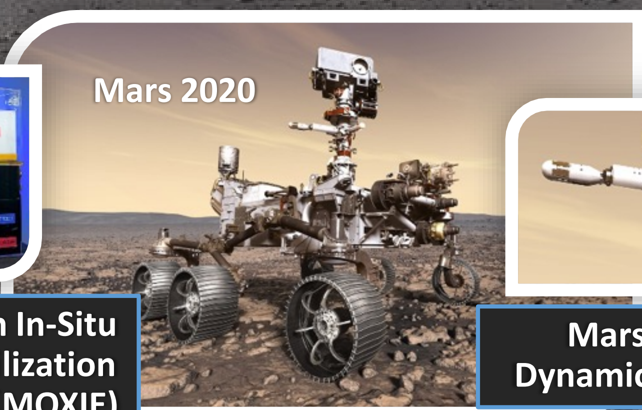
Laser In Situ Resource Analyzer

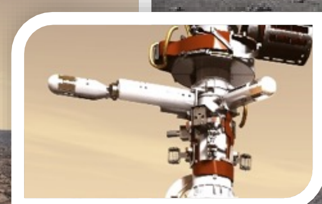


Entry, Descent and Landing



Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE)

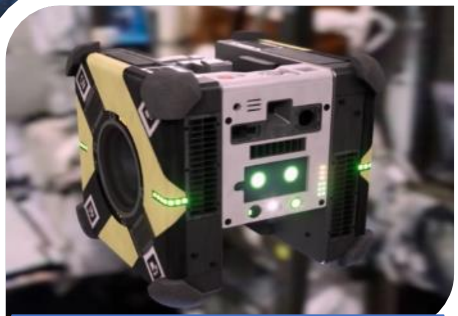


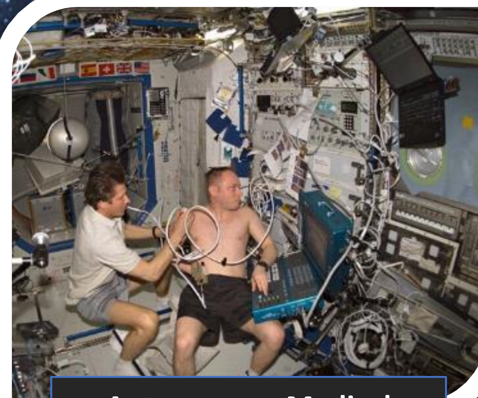


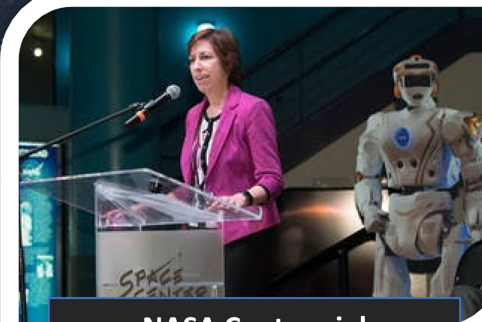
Mars Environmental Dynamics Analyzer (MEDA)

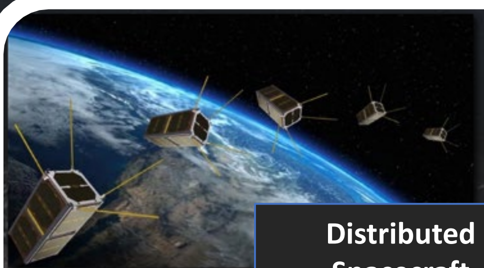
Nuclear Surface Power

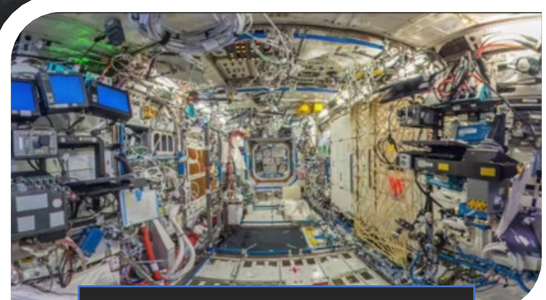
Exploration Technology in Autonomous Systems


Astrobee- A self-flying robot


Autonomous Medical Operations (AMO)


NASA Centennial Challenges Program Space Robotics Challenge Phase III


Distributed Spacecraft Autonomy (DSA)


Integrated Systems for Autonomous Adaptive Caretaking (ISAAC)

PUFFER



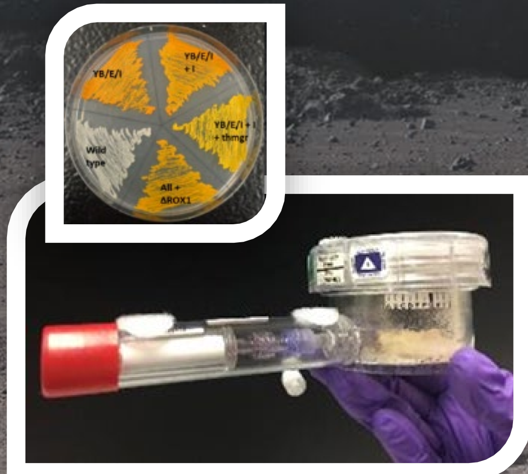
Space Technology Research Institutes (STRI): Smart Deep Space Habitats (SmartHabs) for resilient and autonomous operation.

Exploration Technology in Bio Manufacturing

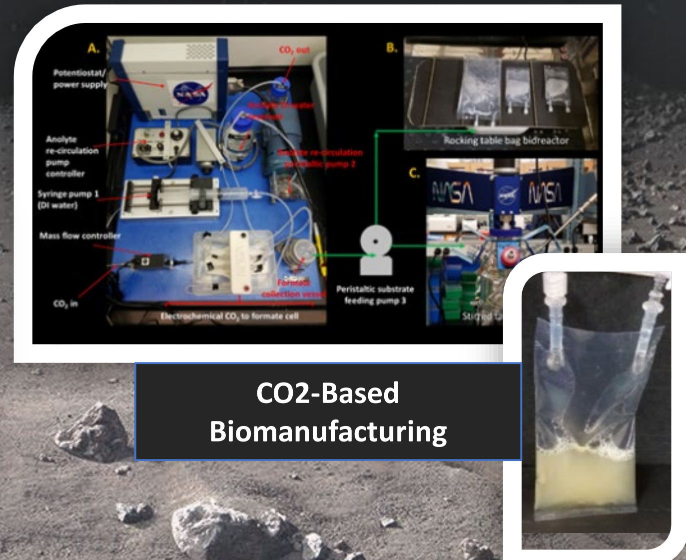
NASA Centennial Challenges Program Vascular Tissue And CO2 Conversion Challenges

Space Technology Research Institute: The Center for the Utilization of Biological Engineering in Space (CUBES)

Biosensors for Radiation Exposure



In-Space Targeted Nutrient Production

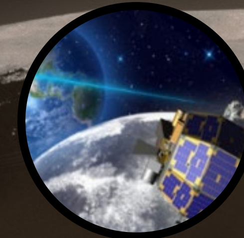


CO2-Based Biomanufacturing

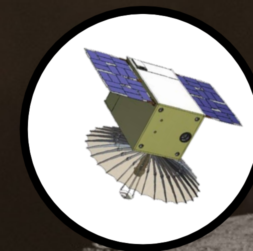
Explore

Transformative Missions and Discoveries

- Enable new discoveries in Lunar/Mars surface and other extreme locations.
- Enable next generation space data processing with higher performance computing, communications and navigation in harsh deep space environments.
- Enable potential new architectures and approaches for in-space servicing, assembly and manufacturing and other missions.



Laser and Optical Communications



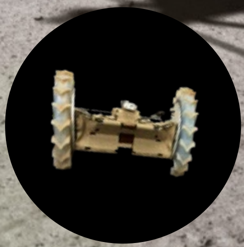
Small Spacecraft Demos

SPIDER

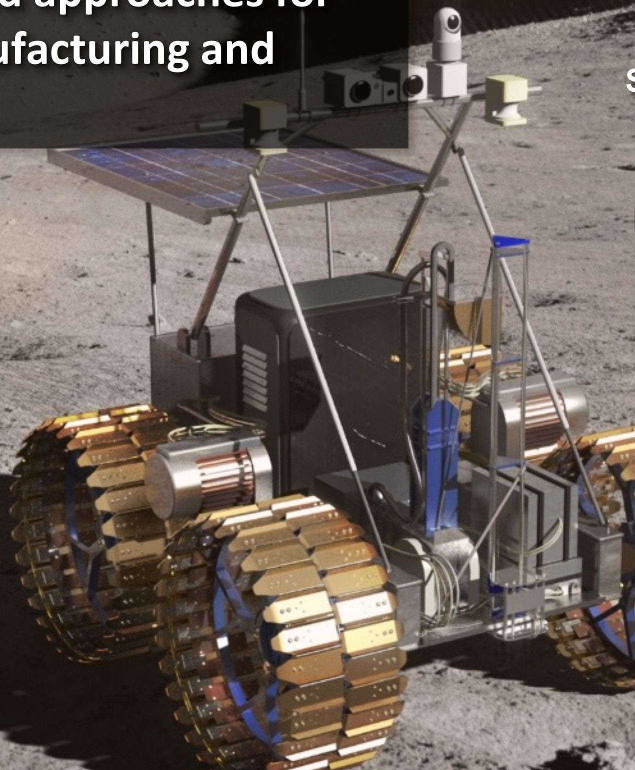
Atomic Clock

Bulk Metallic Glass Gears

Archinaut

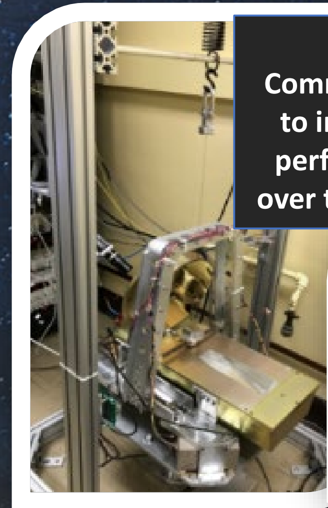


Surface Robotic Scouts

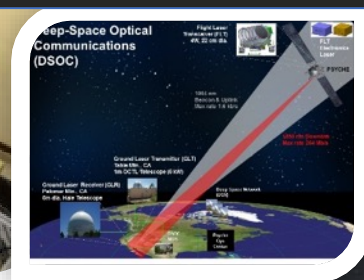


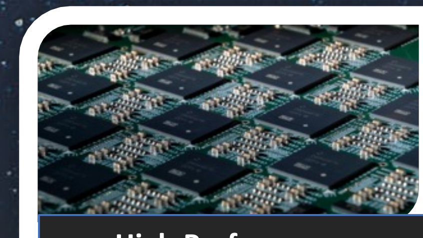
Exploration Technology in Deep Space Communications, Navigation and Advanced Avionics

Deep Space Atomic Clock (DSAC) is a revolutionary smaller space clock design, requires less power, and is more stable than current space-qualified atomic clocks



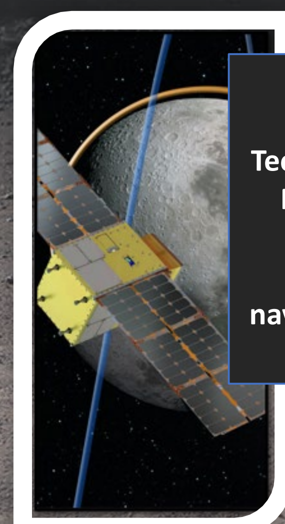
Deep Space Optical Communications (DSOC) seeks to improve communications performance 10 to 100 times over the current state of the art



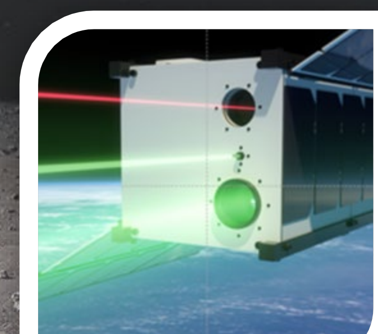


High Performance Spaceflight Computing (HSPC) offers new advanced flight computing architecture

Laser Communications Relay Demonstration (LCRD) will be NASA's first end-to-end optical relay



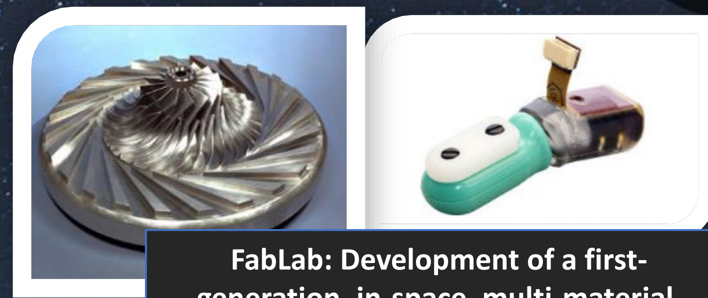
Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) test autonomous relative navigation for Gateway and other lunar missions



CubeSat Laser Infared Crosslink (CLICK) mission that will demonstrate optical crosslink and timing exchange between two small spacecraft in LEO

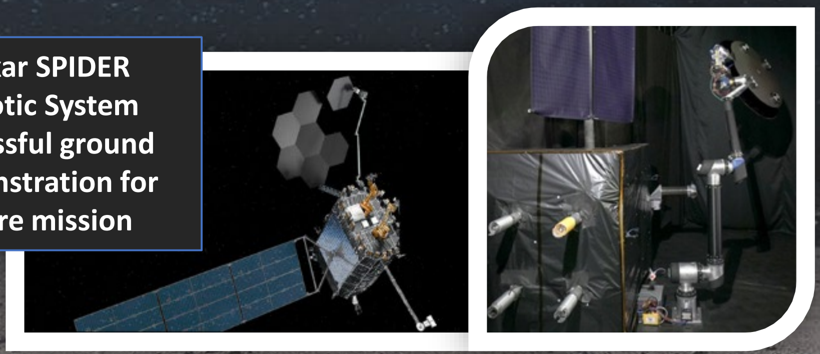
Exploration Technology for On-orbit Servicing, Assembly and Manufacturing

Made In Space validated additive manufacturing and robotic assembly with a future mission, Archinaut



FabLab: Development of a first-generation, in-space, multi-material fabrication laboratory for space missions

Maxar SPIDER Robotic System successful ground demonstration for future mission



Refabricator is the first integrated 3D printer and recycler in space and aboard ISS. However it experienced a failure with the novel recycler filament extrusion bonding system in 2019. Additional bonder testing will be performed prior to decommissioning. The Refabricator was able to successfully manufacture a tensile specimen on the ISS in Feb. 2020 which will be brought back soon for further testing and evaluation aboard SpaceX-20 in April 2020

OSAM-1 (Satellite Serv & SPIDER) approaching CDR

Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE)

CAPSTONE has contracts with Advanced Space LLC, Tyvak Nano-Satellite Systems Inc. and rapid commercial launch procured by HEOMD/AES

Objectives:

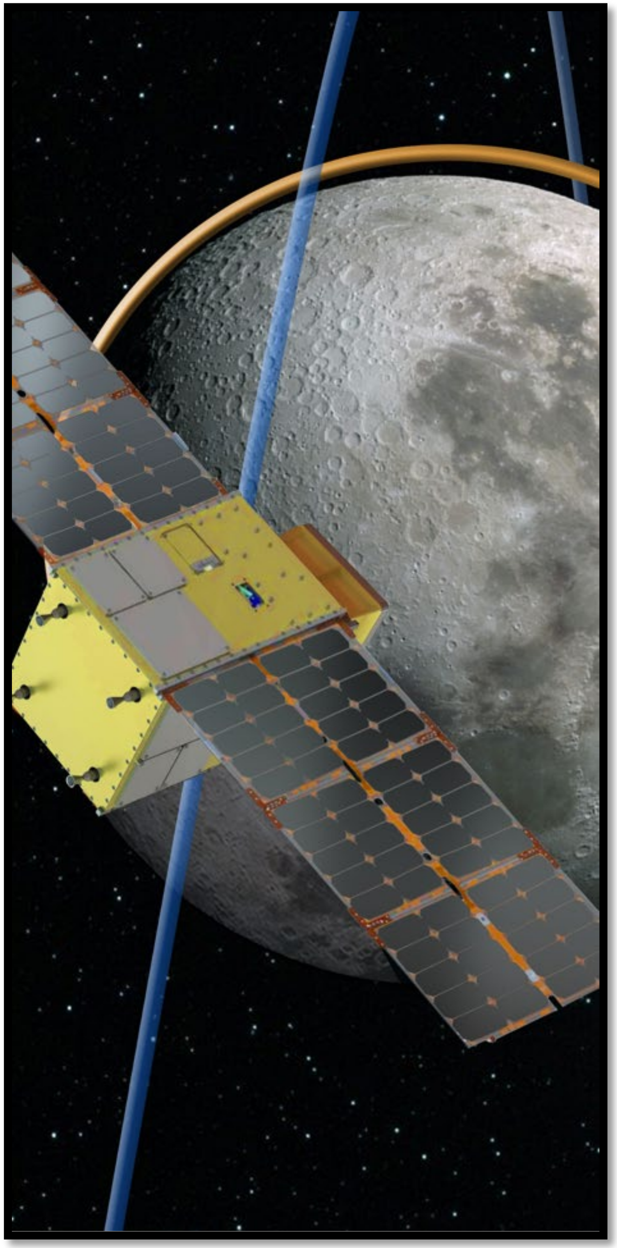
- Rapid demonstration leveraging American small businesses to test autonomous relative navigation for Gateway and other lunar missions, verify NRHO orbital dynamics, and demonstrate novel low energy transfers to cislunar space.
- Execute a cislunar mission in under $30M (including launch) and in under 3 years

Current Status:

- Kick off of SBIR Phase III award in September 2019.
- System Requirements Review and Preliminary Design Review completed in FY20

Deliverables/Schedule:

- FY20: Critical Design Review and Flight Hardware delivery
- FY21: Launch, lunar transfer, and begin demonstration operation in cislunar space
- FY22: Complete demonstration mission

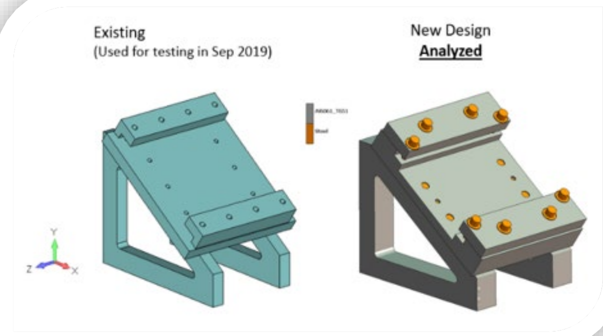


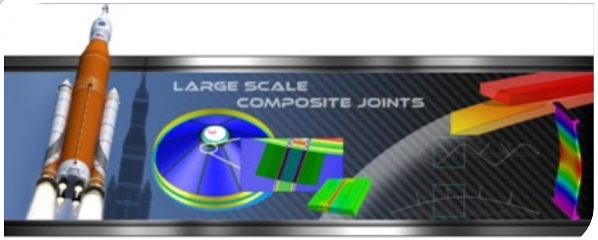
Technology Infusion Successes

Astrobee

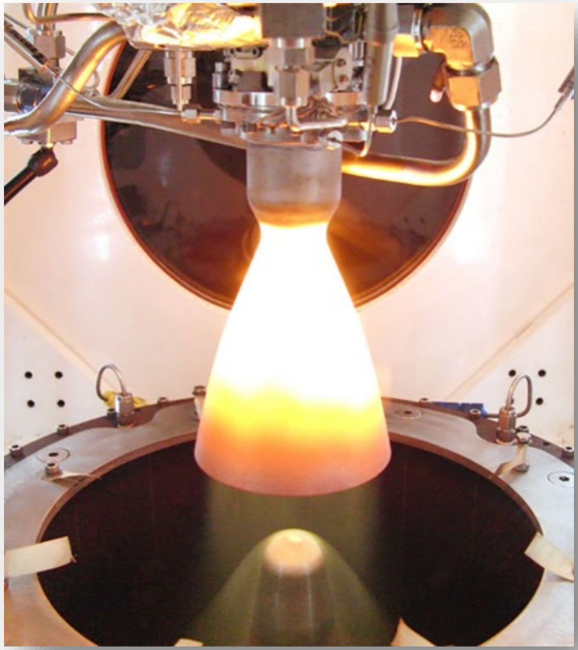
- Astrobee, NASA's next-generation free-flying robotic system on the ISS, will advance the agency's Artemis mission by saving valuable astronaut time and advancing autonomy research.
- Guest scientists will be able to use Astrobee to carry out investigations that will help to develop technology – both hardware and software – for future missions.
- Working autonomously or via remote control by astronauts, flight controllers or researchers, the robots will help complete tasks such as inventory and documenting experiments conducted by astronauts.

- **Composite Technologies for Exploration (CTE)**
- The CTE composite joints technology development benefits include mass and part reduction, which results in significant cost savings and increased payload capability for launch vehicles.
- CTE's longitudinal bonded joints have been baselined for the SLS Payload Adapter to reduce weight and manufacturing time, replacing traditional metallic methods.
- In addition, CTE's circumferential bonded joints will provide lighter weight structures for greater performance and increased payload capability for future SLS block upgrades.
- CTE will enable the technology infusion of lightweight composite joints into future exploration missions.





Technology Infusion Successes



The Thruster for the Advancement of Low-temperature Operation in Space (TALOS)

- Frontier Aerospace Corporation (FAC) contract for the design and development of high-performance, lightweight, and compact spacecraft propulsion systems.
- Astrobotic's (of Pittsburgh, Pa.) Peregrine lander has baselined the TALOS thrusters for both axial and attitude control system propulsion for their lunar mission demonstration scheduled for 2021. Under the TALOS project, the thrusters will be flight qualified to approximately technology readiness level (TRL)-6.
- A Tipping Point contract has been awarded to FAC to provide the first flight set of axial thrusters for the Astrobotic mission. The flight of the Peregrine mission is expected to advance the TRL of the TALOS thruster to TRL-9.

Sampling of Industry and OGA Participants in Exploration Technology

BWXT BWX Technologies, Inc.
MAXAR TECHNOLOGIES
exos Aerospace
ORBITBeyond Delivering to the Moon
CUBIC AEROSPACE
AEROJET ROCKETDYNE
MADE IN SPACE
Los Alamos NATIONAL LABORATORY EST.1943
MOON EXPRESS
FRONTIER AEROSPACE
NEVADA NATIONAL NNSS SECURITY SITE
GeoOptics
FIREFLY AEROSPACE
CUA
WORLD VIEW
Masten
CFD RESEARCH
ASTROBOTIC
SPACEX
FREEDOM PHOTONICS
Cornerstone RESEARCH GROUP
RAVEN AEROSTAR
zero G
Virgin Galactic
air squared
TETHERS UNLIMITED
NORTHROP GRUMMAN
nanocomp TECHNOLOGIES, INC.
Honeywell
PARAGON SPACE DEVELOPMENT CORPORATION
Advanced SPACE
Ball
Space Lab Technologies, LLC
ULA United Launch Alliance
Tyvak
ExoTerra
IC2
LUNA
PIONEER ASTRONAUTICS
OPTERUS RESEARCH AND DEVELOPMENT, INC.
ROBUST ANALYTICS
BOSTON MICROMACHINES CORPORATION
INNOVATION Labs, Inc.
BOEING
CAC
Viasat
CDI
IOS INTELLIGENT OPTICAL SYSTEMS, INC.
BUSEK Space Propulsion and Systems
ATAC
AGNC SINCE 1986
IAI Intelligent Automation, Inc.
BNS
ALPHACORE
DRAPER
Lynntech
Composites Automation LLC.
anasphere
BRM Bally Ribbon Mills
PSI Physical Sciences Inc.
MT
MOSAIC ATM
X-WAVE INNOVATIONS, INC. Make state-of-the-art obsolete
SNC SIERRA NEVADA CORPORATION
QORTEK
TDA RESEARCH
QUEST THERMAL GROUP
UP
AEROGEL technologies
VOXTELOPTO
QSI QUALTECH SYSTEMS INC
LOCKHEED MARTIN
Integrated Spaceflight Services
Creare
ASRC
ROCCOR
CPE
SPIRIT AEROSYSTEMS
USNC ULTRA-SAFE-NUCLEAR
Virgin Orbit
DSS digital surveillance systems
NSC Near Space Corporation
INTUITIVE MACHINES
FIBERTEK, INC.

STMD By The Numbers (FY 2019)

>3,500 Proposals Evaluated

>1,000 Active Technology Projects

>700 Proposals Selected

>2,300 Software Releases

>350 University Partnerships with >100 Universities

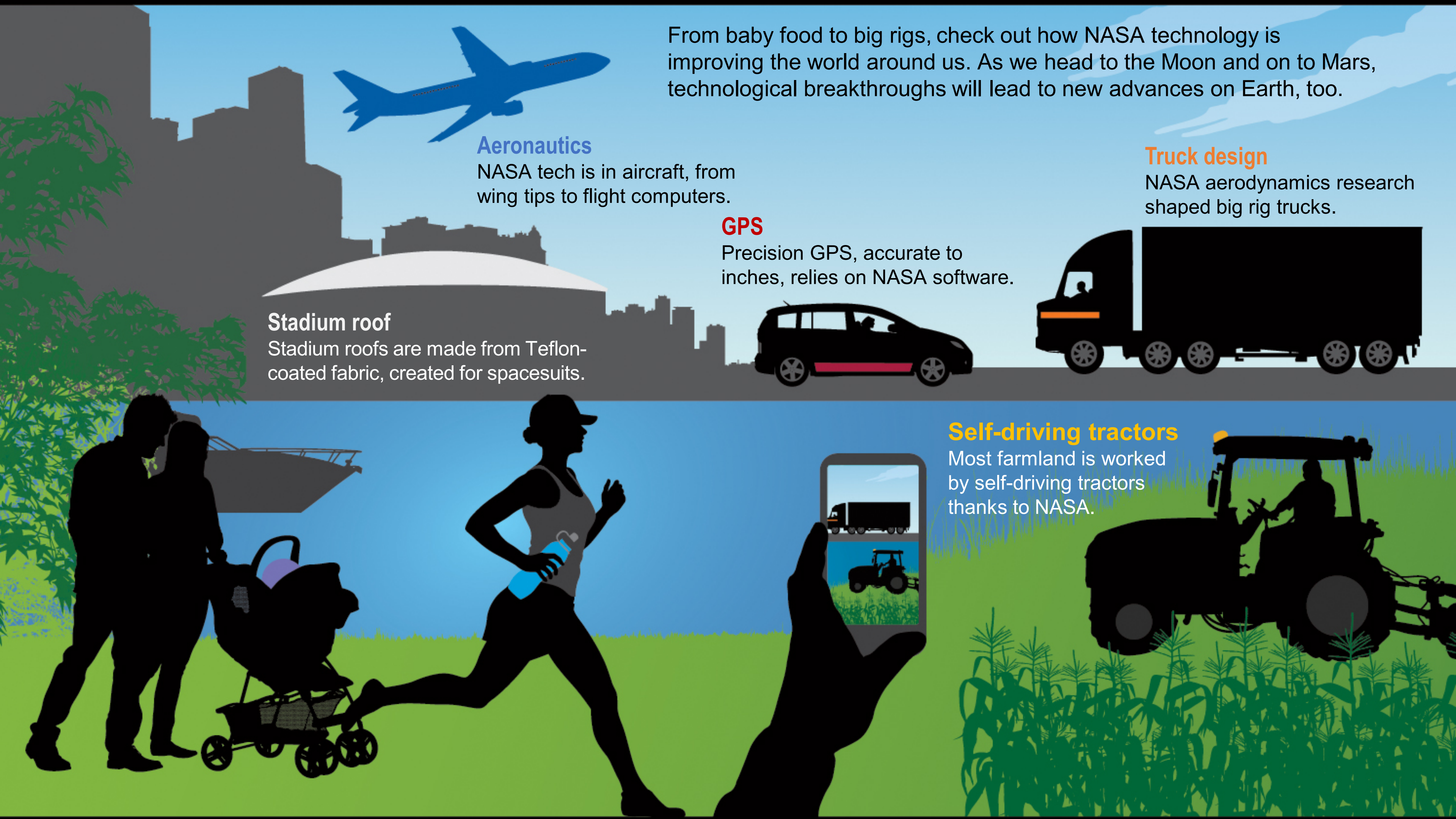
>400 Industry Collaborators

>50 Projects Leading to Flight Demonstrations

>900 Transitions since 2011


NASA
EXPLORESPACE TECH
TECHNOLOGY DRIVES EXPLORATION

There's more Space in your Life than you think!



Baby food
NASA synthesized a nutrient found in breast milk, making formula healthier.

Clean water
Nano-technology filters clean water on the go.

Cell phone cameras
Today's digital image sensors were invented by NASA.

Crop forecasts
Farmers rely on satellite data to monitor crops.

Website of Everyday Technology Developed by NASA

www.nasa.gov/homeandcity