

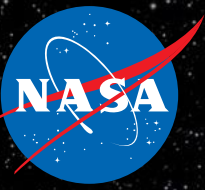


Technology and Science for NASA's Journey to Mars



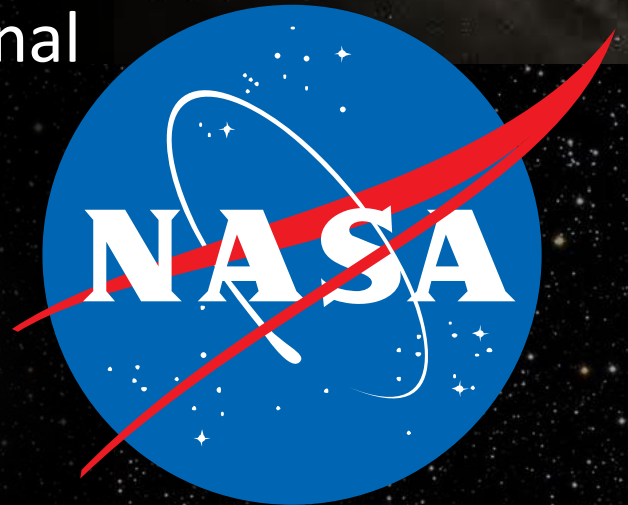
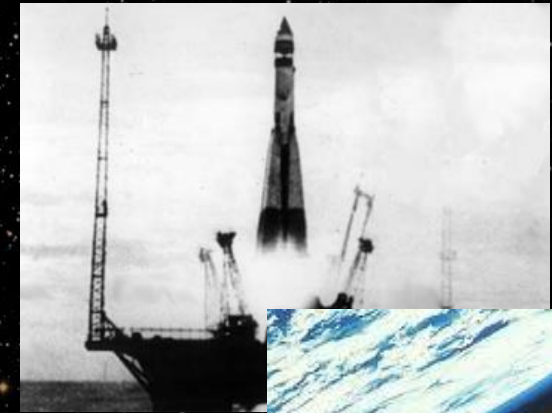
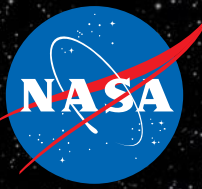
Andrew S. Keys, Ph.D.
NASA Marshall Space Flight Center
21 March 2016
University of Tennessee at Martin

Presentation Outline

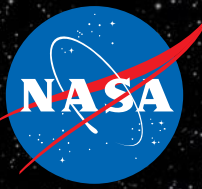


- Introduction
- Brief NASA History
- NASA Today
- Journey to Mars
 - Evolvable Mars Campaign
 - Technologies Required
- NASA Technology Transfer
- How Can YOU to Get Involved

NASA History: Established in 1958



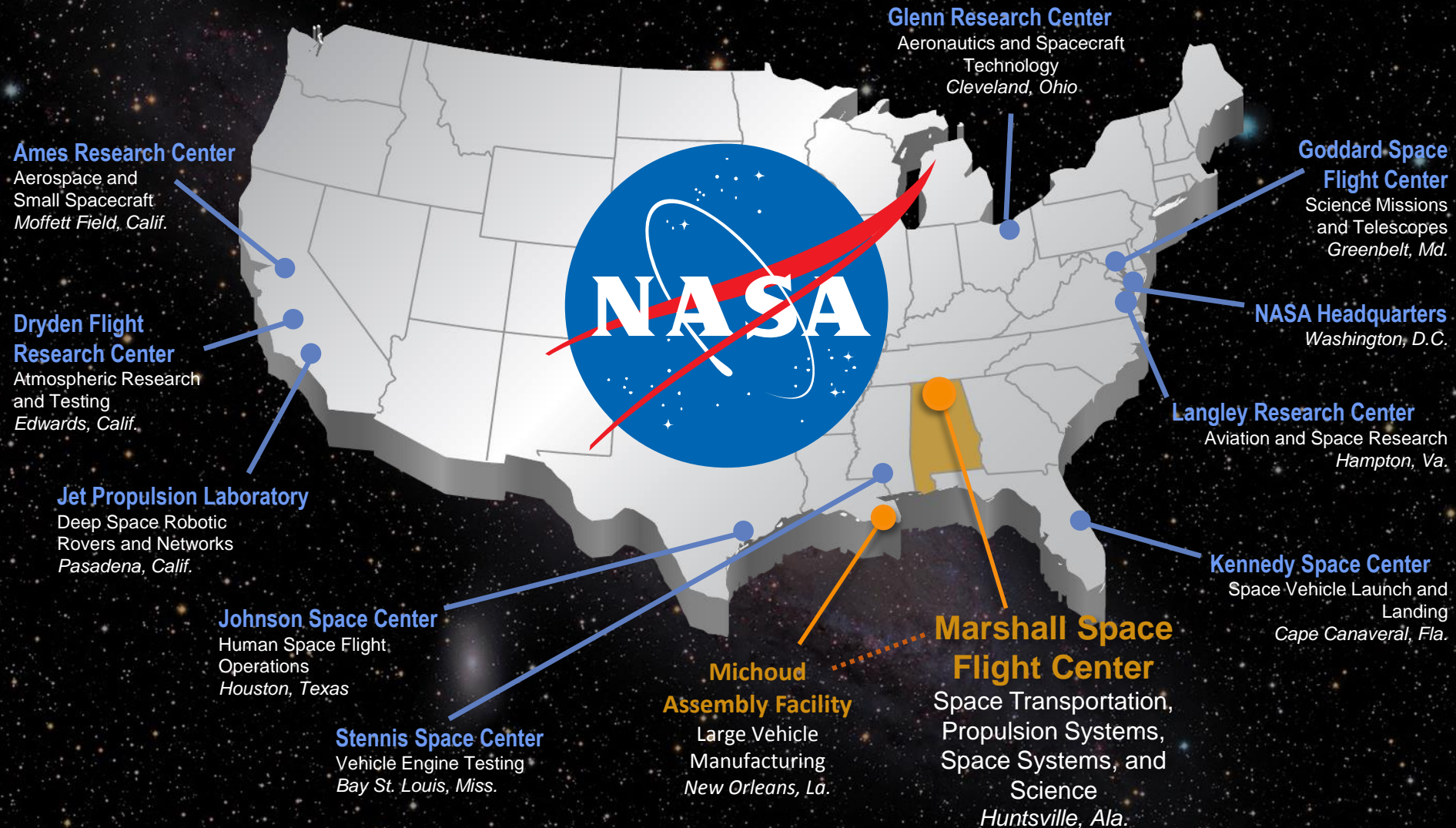
E Pluribus Unim NASA



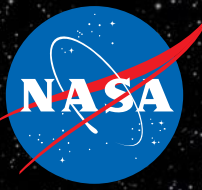
- NASA was established to comprise several existing agencies and commands.
 - **NASA Headquarters** (Washington, DC)
 - Four centers from the National Advisory Committee on Aeronautics (NACA), which had been researching flight technology for more than 40 years prior.
 - **Langley Research Center** (Hampton, VA)
 - **Ames Research Center** (Moffit Field, Mountain View, CA)
 - Lewis Research Center (Renamed **Glenn Research Center**, Cleveland, OH)
 - Dryden High Speed Flight Test (Renamed **Armstrong Flight Research Center**, Mojave, CA)
 - One Department of Defense Agency.
 - Army Ballistic Missile Agency (Renamed to **Marshall Space Flight Center**, Huntsville, AL)
 - One academic institute.
 - **Jet Propulsion Laboratory** (California Institute of Technology, Pasadena, CA)
 - Four Centers established to fulfill functions:
 - **Goddard Space Flight Center** (Greenbelt, MD)
 - Manned Space Center (Renamed **Johnson Space Center**, Houston, TX)
 - **Kennedy Space Center** (Cape Canaveral, FL)
 - **Stennis Space Center** (Southern MS)

As a federal agency, NASA has been considered to operate as a
“loose confederation of semi-autonomous fiefdoms.”

NASA Today: Field Center Locations



NASA History: Support of Aeronautics and Research



- NASA continued the aeronautics research pioneered by NACA as a theme of research.
- It also conducted purely scientific research and worked on developing applications for space technology, combining both pursuits in developing the first weather and communications satellites.



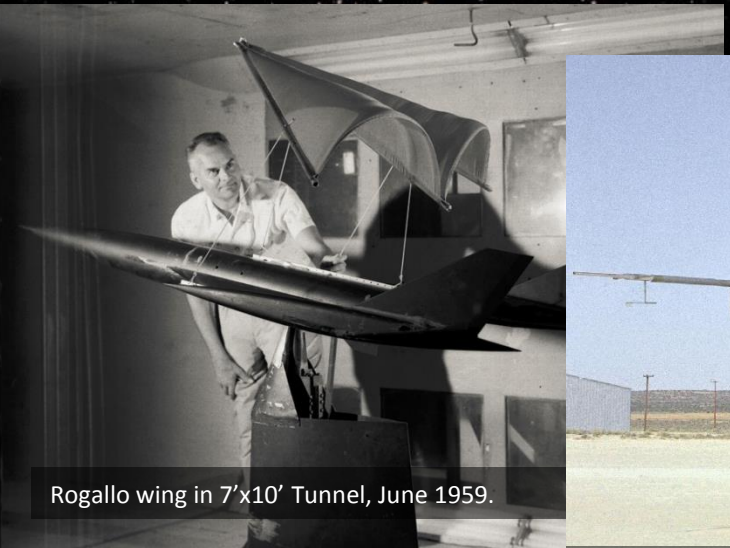
Echo II: 135' balloon satellite launched 25 Jan. 1964



Telstar – First Communication Satellite



Syncom: First Geosynchronous Satellite



Rogallo wing in 7'x10' Tunnel, June 1959.



X-24A lifting body, circa 1969

NASA History: Early Manned Space Missions

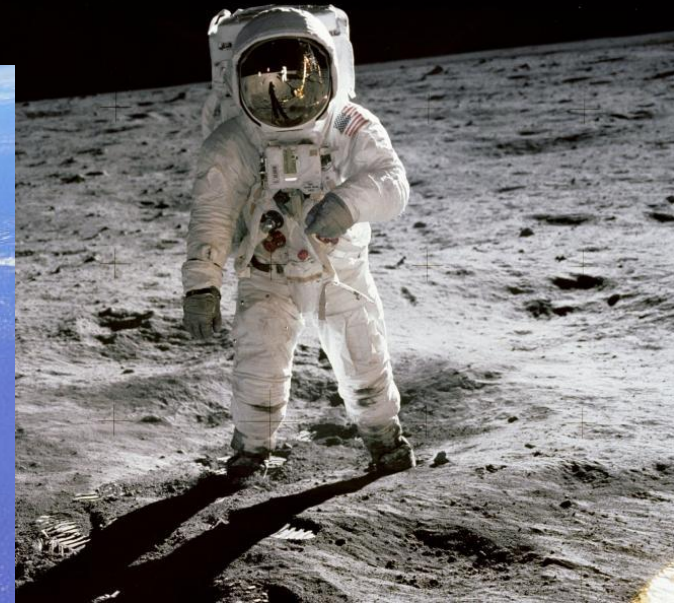


- President John F. Kennedy focused NASA and the nation on sending astronauts to the moon by the end of the 1960s.
- Through the Mercury and Gemini projects, NASA developed the technology and skills it needed for the journey.
- On July 20, 1969, Neil Armstrong and Buzz Aldrin became the first of 12 men to walk on the moon, meeting Kennedy's challenge.

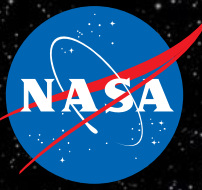
"Mercury 7" Announced by NASA on 09 April 1959



President Kennedy at Rice University, 12 Sep. 1962



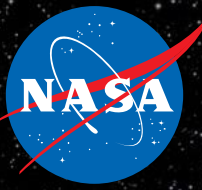
NASA History: The Space Shuttle and ISS



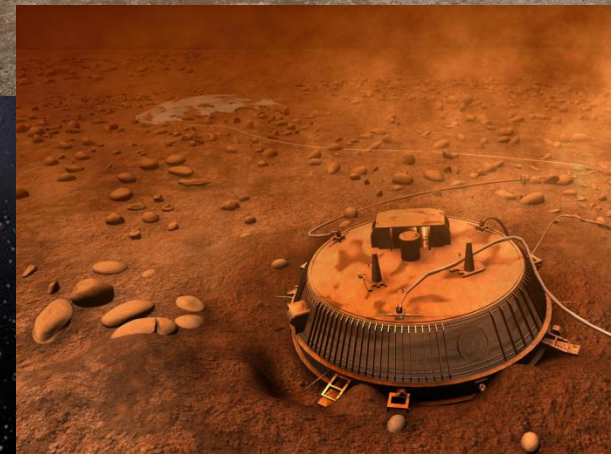
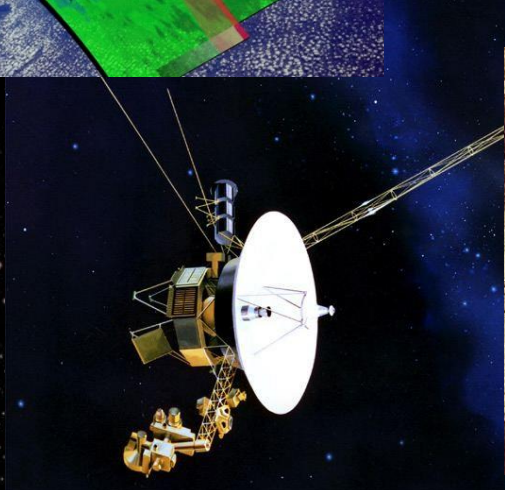
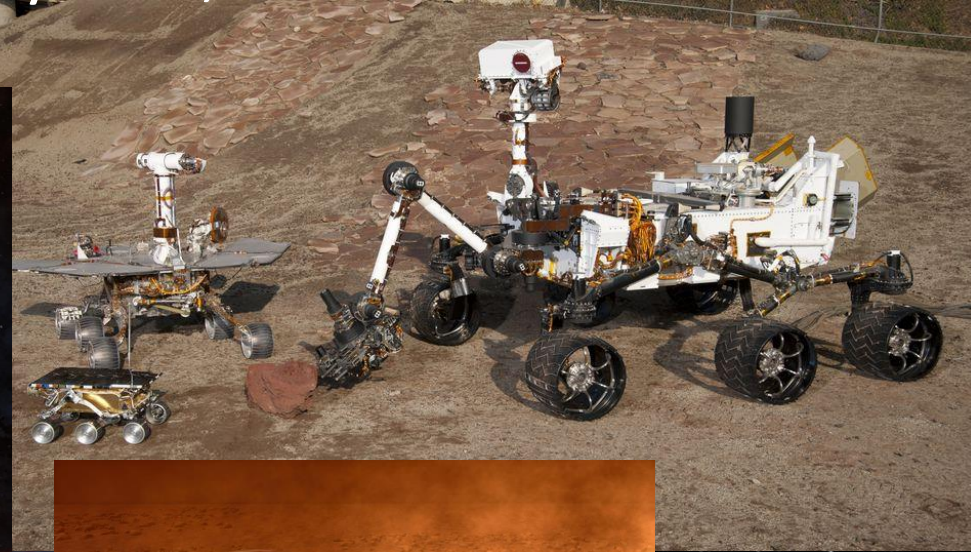
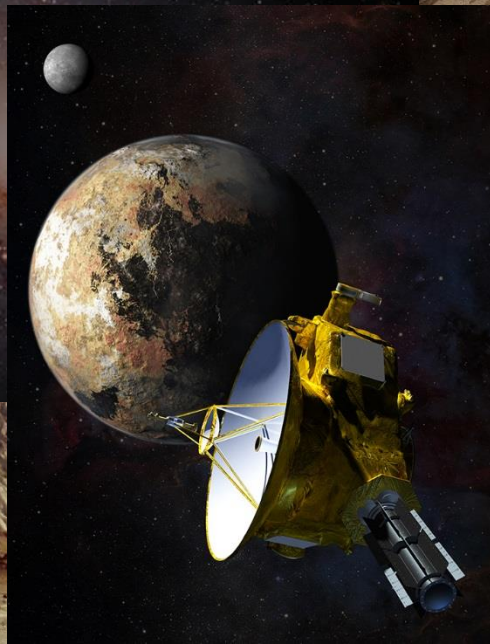
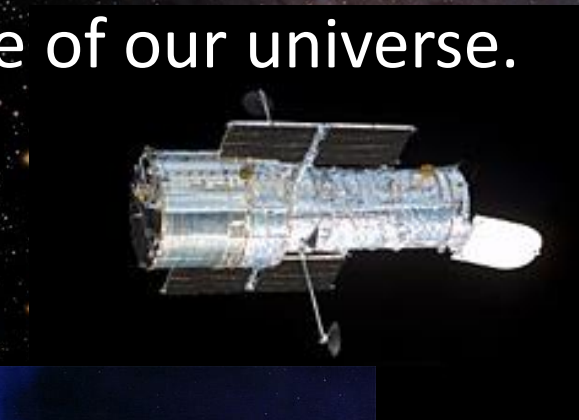
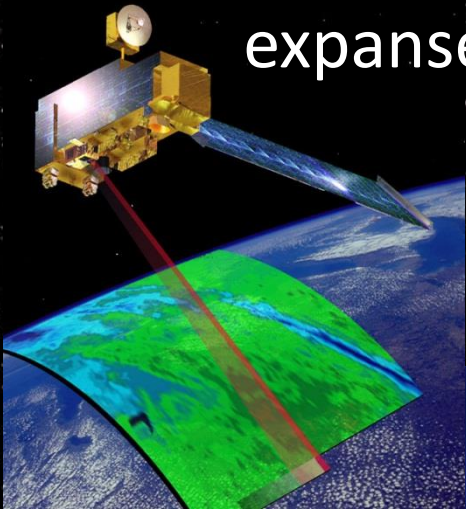
- After Apollo, NASA focused on creating a reusable, man-rated launcher to provide regular access to space: the Space Shuttle.
 - First launched in 1981, the space shuttle flew more than 130 successful flights before retiring in 2011.
- In 2000, the United States and Russia established permanent human presence in space aboard the International Space Station (ISS), a multinational project representing the work of 16 nations.
 - The ISS is still a vital part of NASA's Exploration Program with continuing research conducted on living and working in the space environment.



NASA History: Earth and Space Science Heritage



- NASA also has continued research in Earth and Space Sciences.
- Multiple orbital and deep space missions have observed critical information about Earth, the Sun, our Solar System, and the vast expanse of our universe.



NASA Mission Directorates



Aeronautics Research
Mission Directorate



Space Technology
Mission Directorate



Science Mission
Directorate

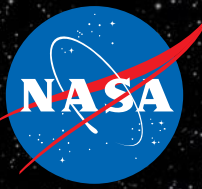


Human Exploration
and Operations
Mission Directorate



*Marshall heavily supports three of four NASA Mission Directorates.*¹¹

NASA Themes and Priorities



Earth Right Now. *Your planet is changing. We're on it.* #EarthRightNow

NASA's fleet of satellites, its airborne missions and researchers address some of the critical challenges facing our planet today and in the future: climate change, sea level rise, freshwater resources, and extreme weather events.



ISS. *Off the Earth, for the Earth.* #ISS

The International Space Station is a blueprint for global cooperation and scientific advancements, a destination for growing a commercial marketplace in low-Earth orbit, and a test bed for demonstrating new technologies. The space station is the springboard to NASA's next great leap in exploration, including future missions to an asteroid and Mars.



Mars. *Join us on the journey.* #JourneytoMars

We are on a journey to Mars. Today our robotic scientific explorers are blazing the trail. Together, humans and robotics will pioneer the next giant leap in exploration.



Technology. *Technology drives exploration.* #NASATech

We develop, test and fly transformative capabilities and cutting edge exploration technologies. Our technology development provides the onramp for new ideas, maturing them from early stage through flight and giving wings to the innovation economy.



Aeronautics. *NASA is with you when you fly.* #FlyNASA

Every U.S. aircraft and air traffic control tower uses NASA-developed technology. We're committed to transforming aviation by reducing its environmental impact, maintaining safety, and revolutionizing aircraft shapes and propulsion.



Solar System and Beyond. *NASA: We're Out There.* #NASABeyond

NASA's exploration spans the universe. Observing the sun and its effects on Earth. Delving deep into our solar system. Looking beyond to worlds around other stars. Probing the mysterious structures and origins of our universe. Everywhere imaginable, NASA is out there.

Science

Exploration

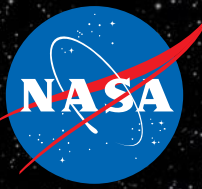
Exploration

Technology

Aeronautics

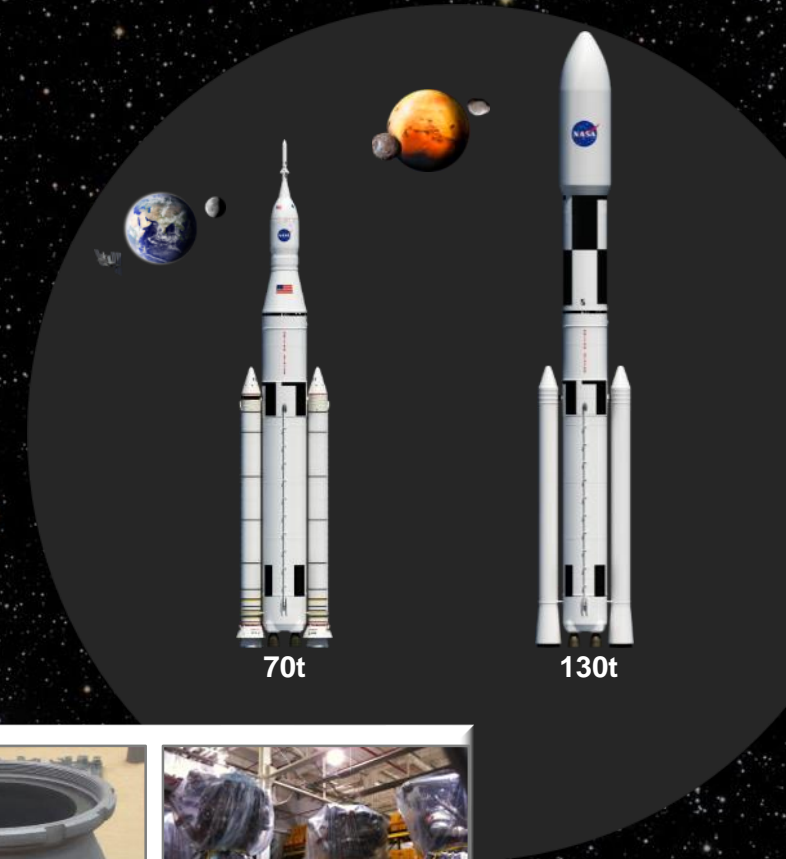
Science

NASA's Space Launch System



SLS – America's Human-Rated Heavy-lift Rocket

- Provides initial lift capacity of 70 metric tons (t), evolving to 130t.
- Initially powered by twin five-segment solid rocket boosters and four RS-25 liquid propellant engines, as well as a modified version of an existing upper stage.
- Carries the Orion Multi-Purpose Crew Vehicle (MPCV) and significant science payloads.
- Supports national and international missions beyond Earth's orbit, such as near-Earth asteroids, cis-lunar operations, and eventually Mars.
- Builds on the proven success of Saturn and Shuttle.



Solid Rocket
Booster Test

Friction Stir
Welding for Core
Stage

Shell Buckling
Structural Test

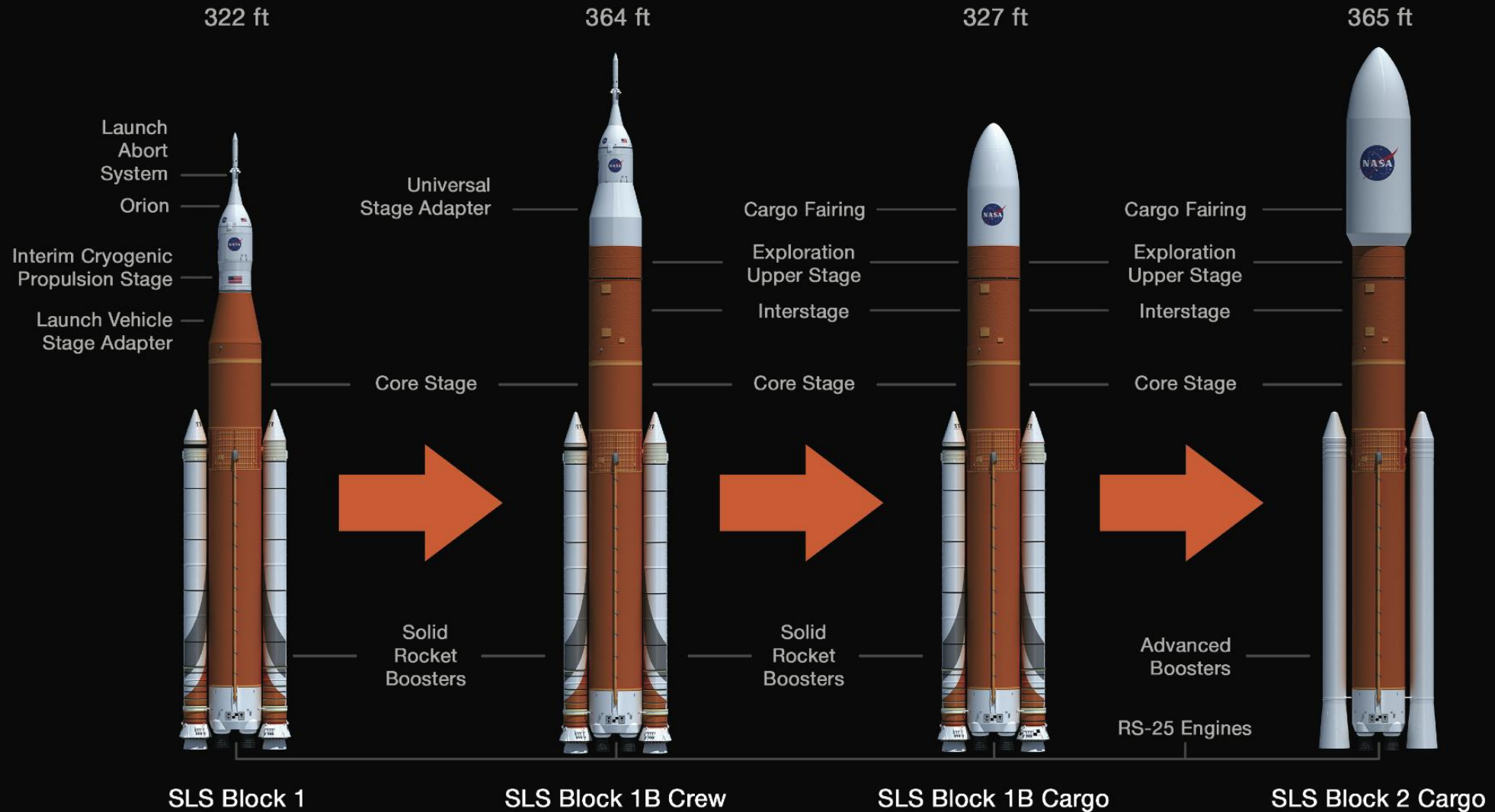
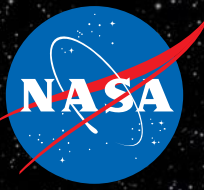
MPCV Stage Adapter
Assembly

Selective Laser
Melting Engine
Parts

RS-25 Core Stage
Engines in Inventory

SLS is essential to the nation's space exploration goals.

Future Evolution Plans for Space Launch System (SLS)



NASA's Orion Multi-Purpose Crew Vehicle



- The Orion Multi-Purpose Crew Vehicle is designed to take humans farther than they've ever gone before.
- Orion will serve as the exploration vehicle that will carry the crew to space, provide emergency abort capability, sustain the crew during the space travel, and provide safe re-entry from deep space return velocities.
- Orion will launch on NASA's new heavy-lift rocket, the Space Launch System.

Commercial Crew Program



- Facilitate the development of U.S. commercial crew space transportation systems to provide safe, reliable, cost-effective access to and from the ISS and low-Earth orbit from America.
- Transport pressurized scientific research and cargo and increase the station crew, enabling twice the amount of scientific research to be conducted.
- By encouraging private companies to provide human transportation services to and from low-Earth orbit, NASA can expand its focus on building spacecraft and rockets for deep space missions on our journey to Mars.

Cost-Effective

Developing safe, reliable crew transportation to ISS that reduces reliance on foreign systems.



SPACE X CREW DRAGON & BOEING CST-100 STARLINER

\$58 MILLION
per seat



RUSSIAN SOYUZ

\$81 MILLION
per seat

After certification, the U.S. will have developed two new, independent, human space transportation systems for less than \$5 billion.

Astronauts

Veteran NASA astronauts training to fly the first U.S. Commercial Crew test launches.



Bob Behnken



Eric Boe



Doug Hurley



Suni Williams

PROVIDERS



Boeing

Spacecraft:
CST-100 Starliner

Launch Vehicle:
ULA Atlas V

Height:
171 Feet

Launch Pad:
Space Launch Complex 41

Destination:
International Space Station

Maximum potential value:
\$4.2B



SpaceX

Spacecraft:
Crew Dragon

Launch Vehicle:
Falcon 9

Height:
208 Feet

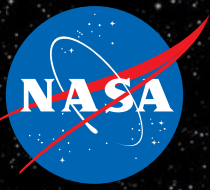
Launch Pad:
Launch Complex 39A

Destination:
International Space Station

Maximum potential value:
\$2.6B



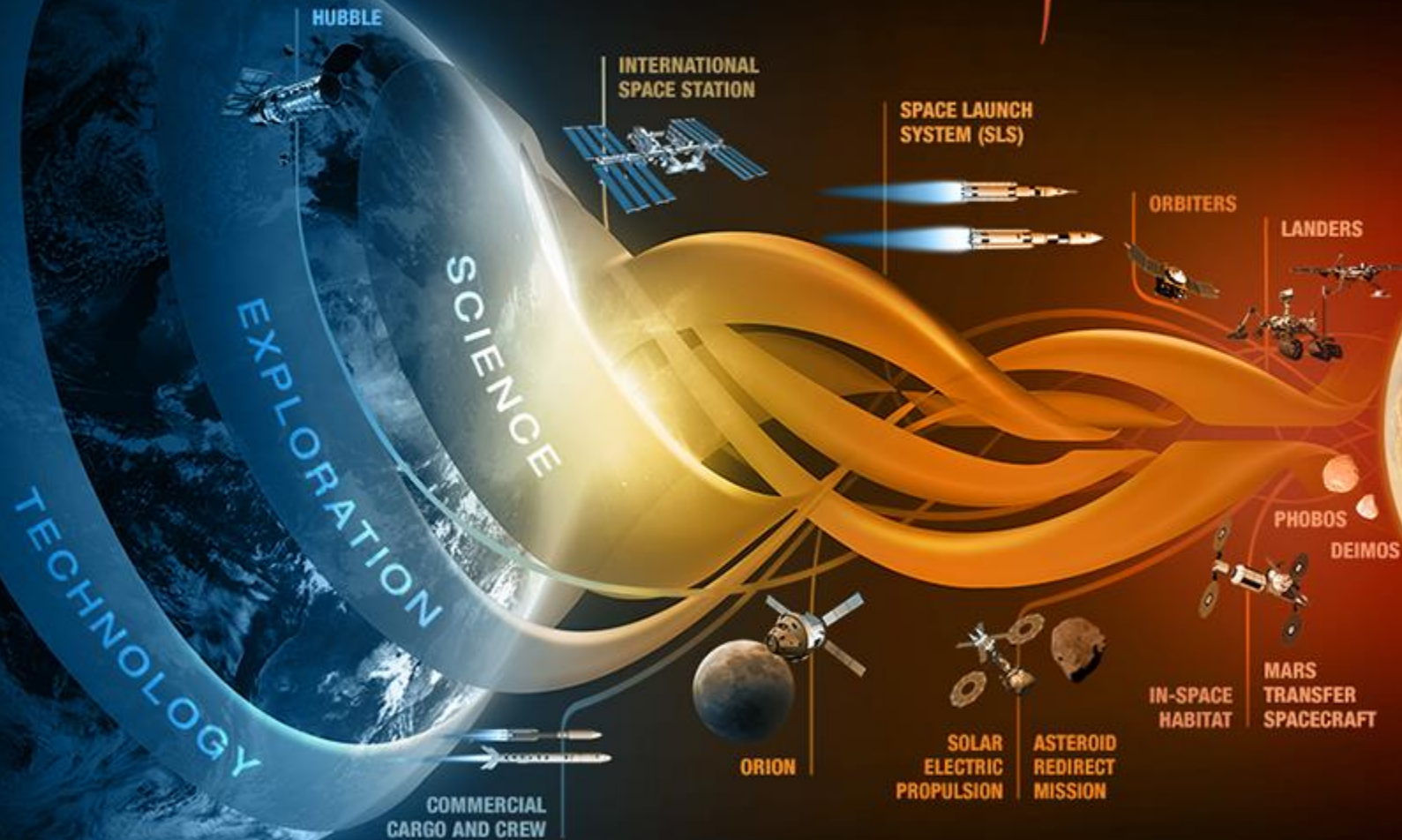
Commercial Launch Services



- A little more than two years after the end of the Space Shuttle Program, SpaceX and Orbital ATK began successfully resupplying the space station with cargo launched from the United States.
- The companies developed the rockets and spacecraft through public-private partnerships under the agency's [Commercial Orbital Transportation Services \(COTS\)](#) program
- NASA then awarded Orbital ATK and SpaceX [commercial resupply services contracts](#) to each deliver at least 20 metric tons of cargo to the orbiting laboratory.
- The companies are successfully resupplying the space station, and more missions to deliver scientific investigations and cargo are planned.
- This partnership is changing the way NASA does business,
 - helping build a strong American commercial space industry, and
 - freeing NASA to focus on developing the next-generation rocket and spacecraft that will allow us to travel farther in space than ever before.



JOURNEY TO MARS



MISSIONS: 6-12 MONTHS
RETURN: HOURS

EARTH RELIANT

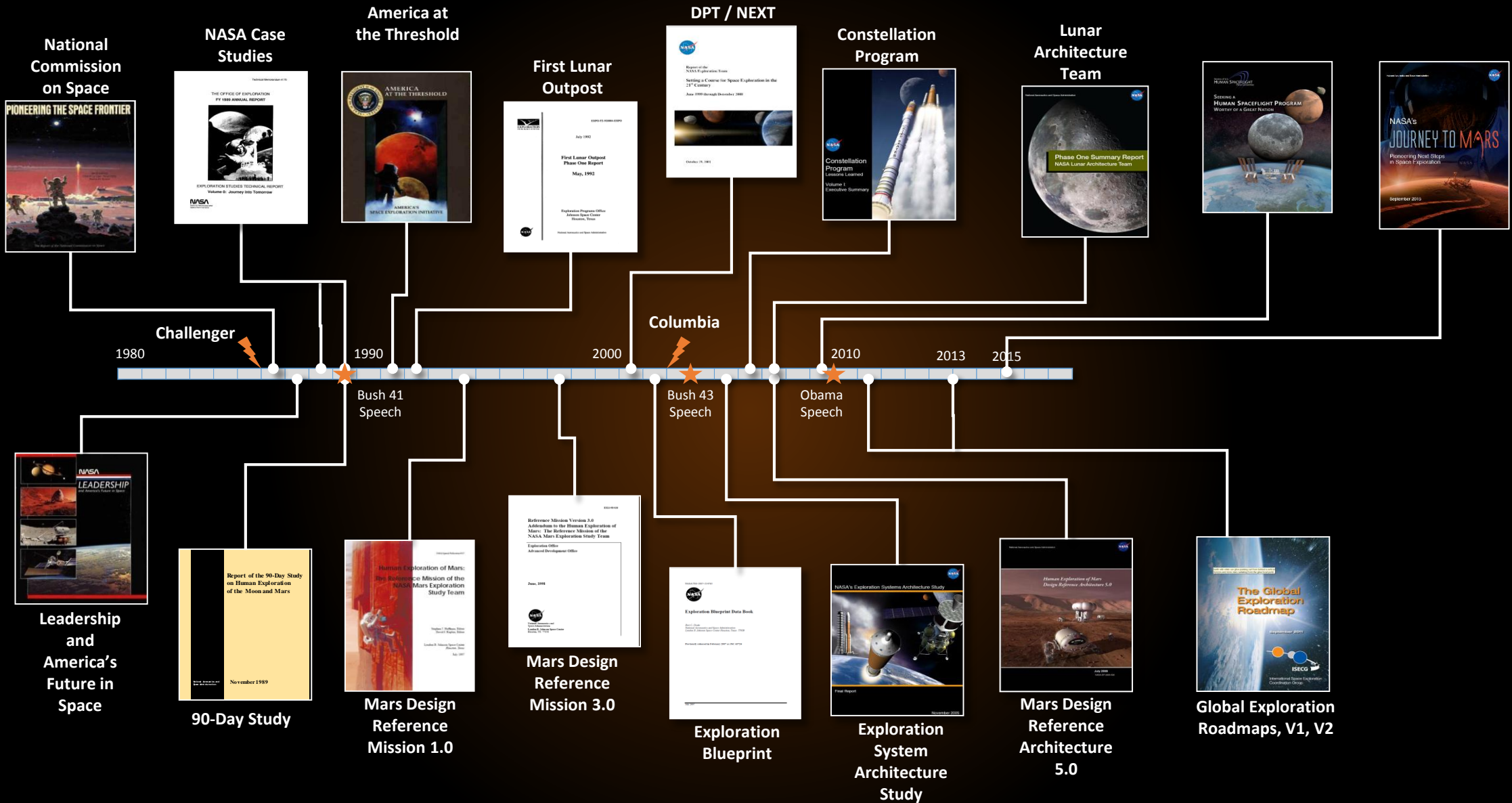
MISSIONS: 1-12 MONTHS
RETURN: DAYS

PROVING GROUND

MISSIONS: 2-3 YEARS
RETURN: MONTHS

EARTH INDEPENDENT

Human Exploration Studies Beyond LEO - Toward Mars



Strategic Principles for Sustainable Exploration Campaign



- **Implementable in the near-term** with the buying power of current budgets and in the longer term with budgets commensurate with economic growth;
- **Exploration enables science and science enables exploration**, leveraging robotic expertise for human exploration of the solar system
- Application of **high Technology Readiness Level (TRL) technologies** for near term missions, while focusing sustained investments on technologies and capabilities to address challenges of future missions;
- **Near-term mission opportunities** with a defined cadence of compelling and integrated human and robotic missions providing for an **incremental buildup of capabilities** for more complex missions over time;
- Opportunities for **U.S. commercial business** to further enhance the experience and business base;
- **Multi-use, evolvable space infrastructure**, minimizing unique major developments, with each mission leaving something behind to support subsequent missions; and
- Substantial new **international and commercial partnerships**, leveraging the current International Space Station partnership while building new cooperative ventures.

Plan Outlining Next Steps in the Journey to Mars

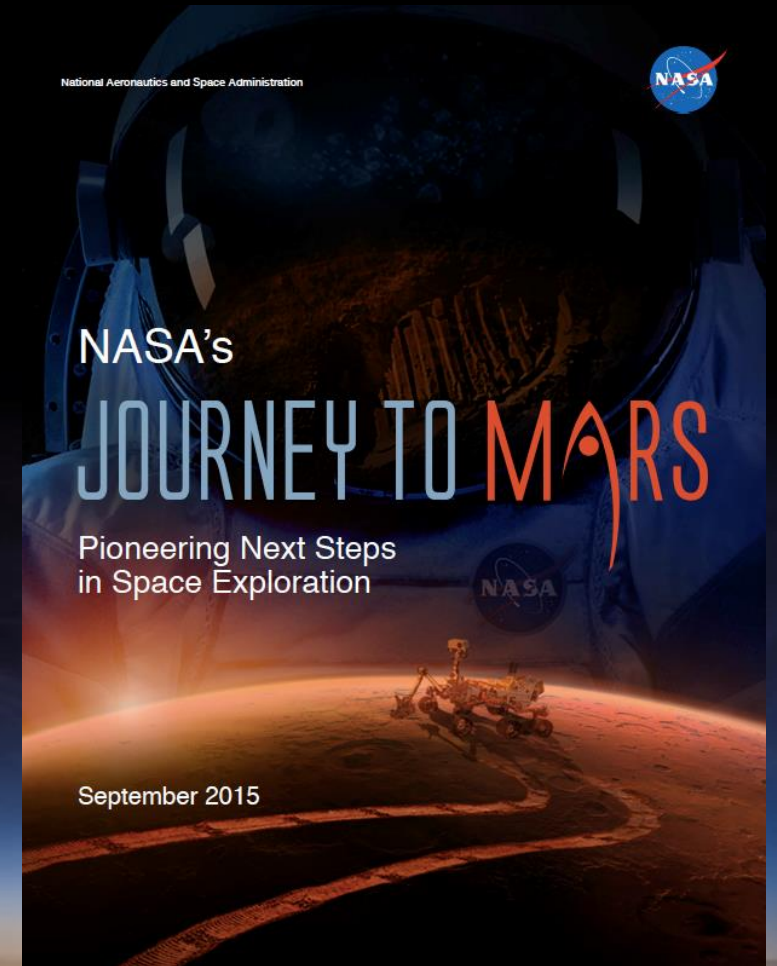


Draft versions – 18 months

- Revised by internal & external stakeholders

Overall Flow

- Introduction and Goals
- Our Approach – Pioneering Principles
- Three Phases for J2M
- Our Strategy for the Journey to Mars
 - Cislunar steps
 - Science and human exploration
- Our Progress and Plans
 - Earth-Reliant – ISS, Commercial Crew/Cargo
 - Proving Ground – SLS, Orion, SEP, habitats
 - Earth-Independent – Robotic missions, evolving architectures
- Pioneering Challenges
 - Transportation
 - Working in Space
 - Staying Healthy
- Summary



<http://go.nasa.gov/1VHDXxg>

#JOURNEYTOMARS

Key Capabilities for the Human Exploration of Mars



- Common Findings from Multiple Studies:

1,100 Days

Total time crew is away from Earth



Maximum surface stay for any given mission

500 Days

12 km/s

Highest Orion Earth entry speed



100 km

Distance for long-range routine exploration



130 t

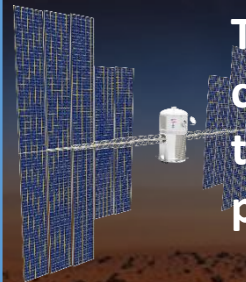
Heavy-Lift Mass

Multiple

Launches per mission

100-200 kWe

Total continuous transportation power



44 min



Maximum two-way communication time delay

20-30 t

Ability to land large payloads



20 t

Oxygen produced for ascent to orbit

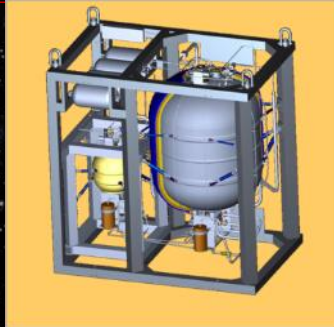


Capabilities and Platforms for Mars Exploration

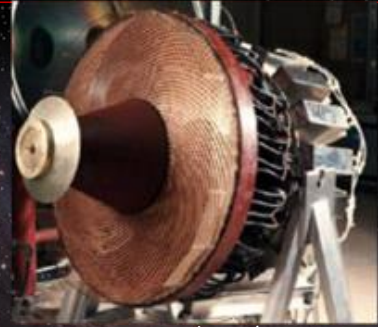


		ISS	Cis-lunar Short Stay (e.g. ARM)	Cis-lunar Long Stay	Mars Orbit	Mars Surface, Short Stay	Mars Surface, Long Stay
Working in Space and On Mars	In Situ Resource Utilization & Surface Power						X
	Surface Habitat & Mobility					X	X
	Human/Robotic & Autonomous Ops		X	X	X	X	X
	Exploration EVA		X	X	X	X	X
Staying Healthy	Crew Health	X	X	X	X	X	X
	Environmental Control & Life Support	X	X	X	X	X	X
	Radiation Safety		X	X	X	X	X
Transportation	Ascent from Planetary Surfaces					X	X
	Entry, Descent & Landing					X	X
	In-space Power & Prop (incl. SEP, Hybrid)		X	X	X	X	X
	Beyond LEO: SLS (w/ EUS) & Orion		X	X	X	X	X
	To LEO: Commercial Cargo & Crew	X					
	Comm & Navigation	X				X	X

MSFC Technology Emphasis Areas



In-Space Propulsion with Emphasis on Cryogenics



In-Space Propulsion (Green Propellants, Electric)



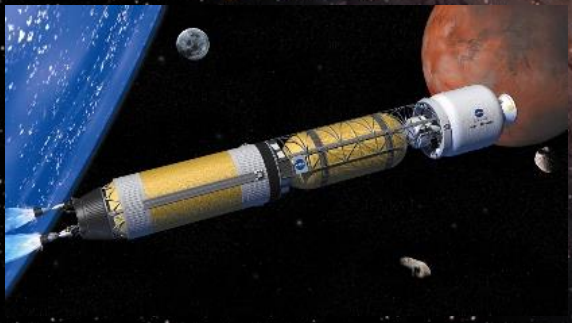
In-Space Propulsion (Nuclear)



In-Space Propulsion (Solar Propulsion Testbeds and Sails, Tethers)



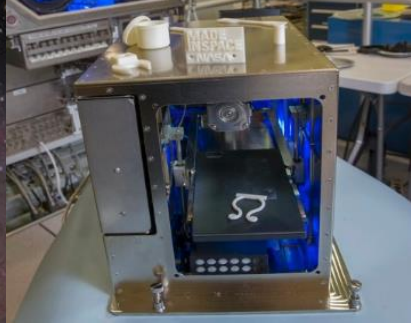
Demonstration Missions



Habitats and Technologies for "Beyond Low Earth Orbit" Exploration



Technologies Supporting Utilization of ISS



Advanced Manufacturing with Emphasis on In-Situ Fabrication and Repair



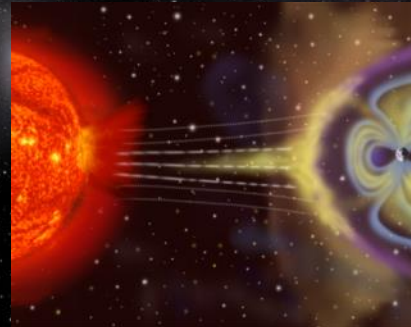
Human Habitation Elements and Life Support Systems



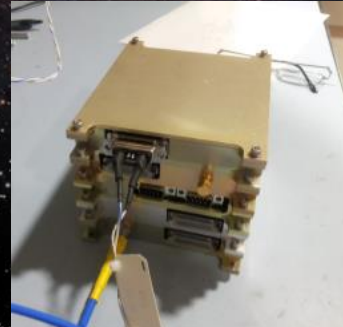
Technologies for Small payload Launch



X-ray Astrophysics; Scientific Instrument Dev.



Space Environments and Space Weather, Research to Operations



Small Spacecraft and Enabling Technologies



Rapid/Affordable Manufacturing with Emphasis on Propulsion Components

EMC Goal: Define a pioneering strategy and operational capabilities that can extend and sustain human presence in the solar system including a human journey to explore the Mars system starting in the mid-2030s.

- Identify a plan that:
 - **Expands human presence into the solar system** to advance exploration, science, innovation, benefits to humanity, and international collaboration.
 - Provides different **future scenario options** for a range of capability needs to be used as guidelines for near term activities and investments
 - In accordance with key strategic principles
 - Takes advantage of capability advancements
 - Leverages new scientific findings
 - Flexible to policy changes
 - Identifies **linkages to and leverage current investments** in ISS, SLS, Orion, ARM, EAM, technology development investments, science activities
 - Emphasizes **prepositioning and reuse/repurposing of systems** when it makes sense
 - Use location(s) in cis-lunar space for aggregation and refurbishment of systems

EVOLVABLE MARS CAMPAIGN

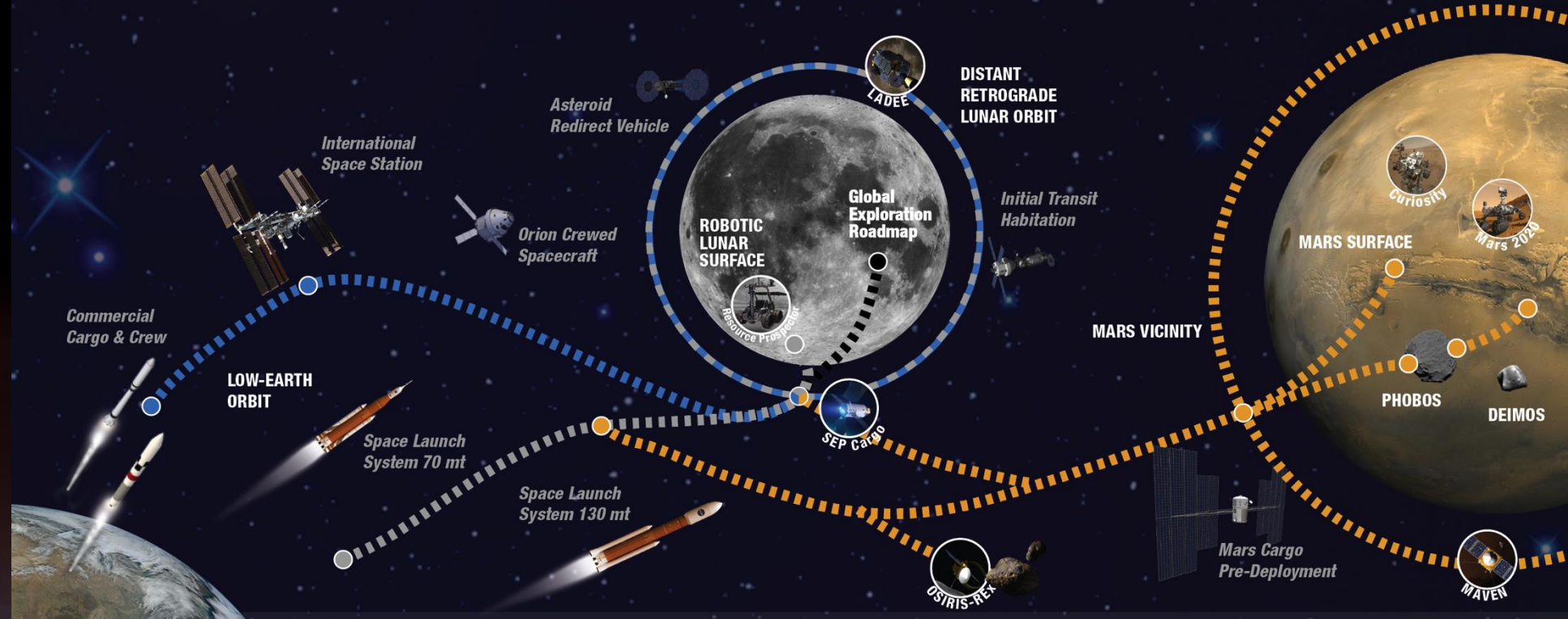
A Pioneering Approach to Exploration



EARTH RELIANT

PROVING GROUND

EARTH INDEPENDENT



THE TRADE SPACE

Across the Board | Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities

Cis-lunar Trades |

- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

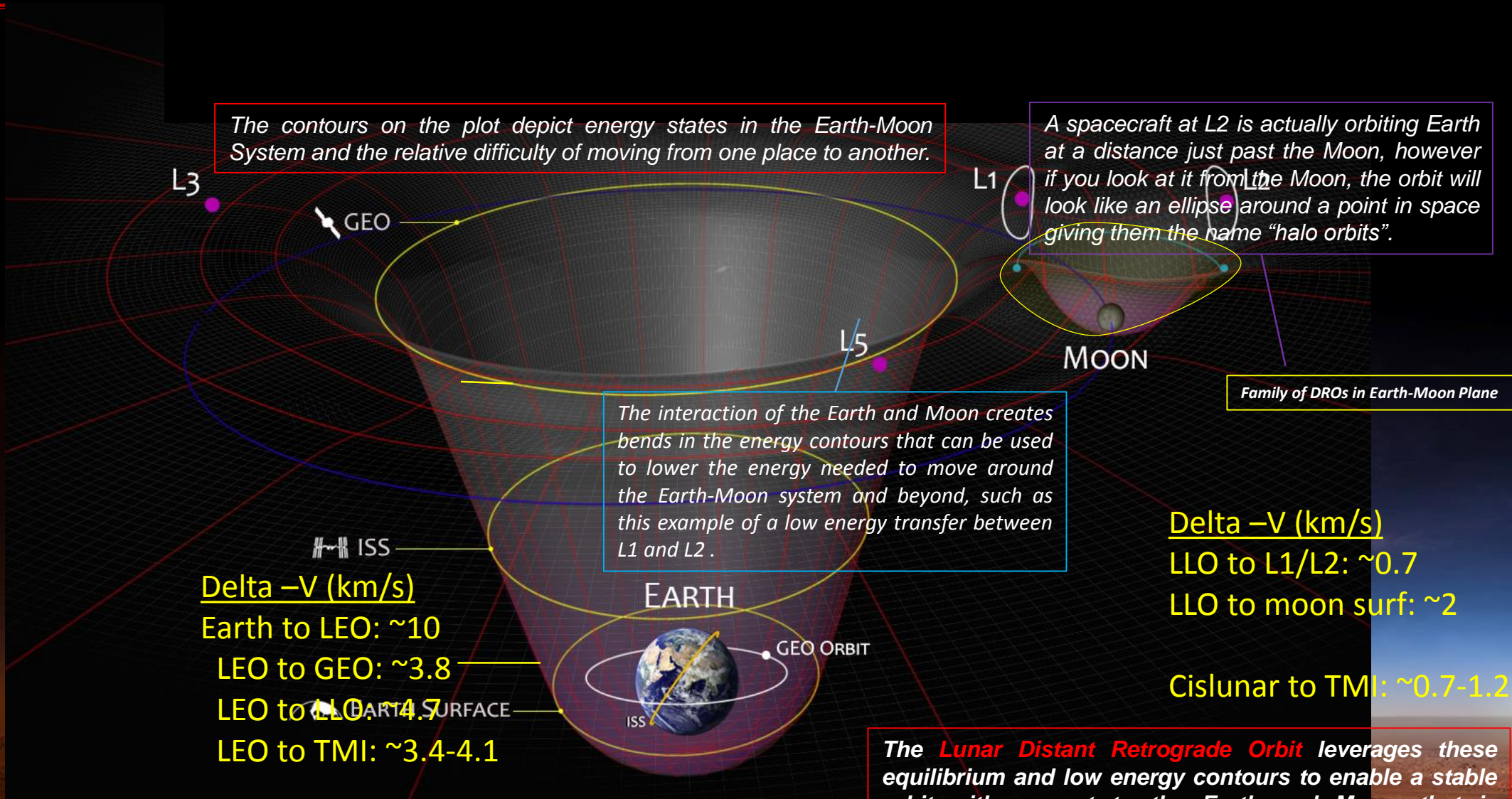
Mars Vicinity Trades |

- Split versus monolithic habitat
- Cargo pre-deployment
- Mars Phobos/Deimos activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses

#JOURNEYTOMARS

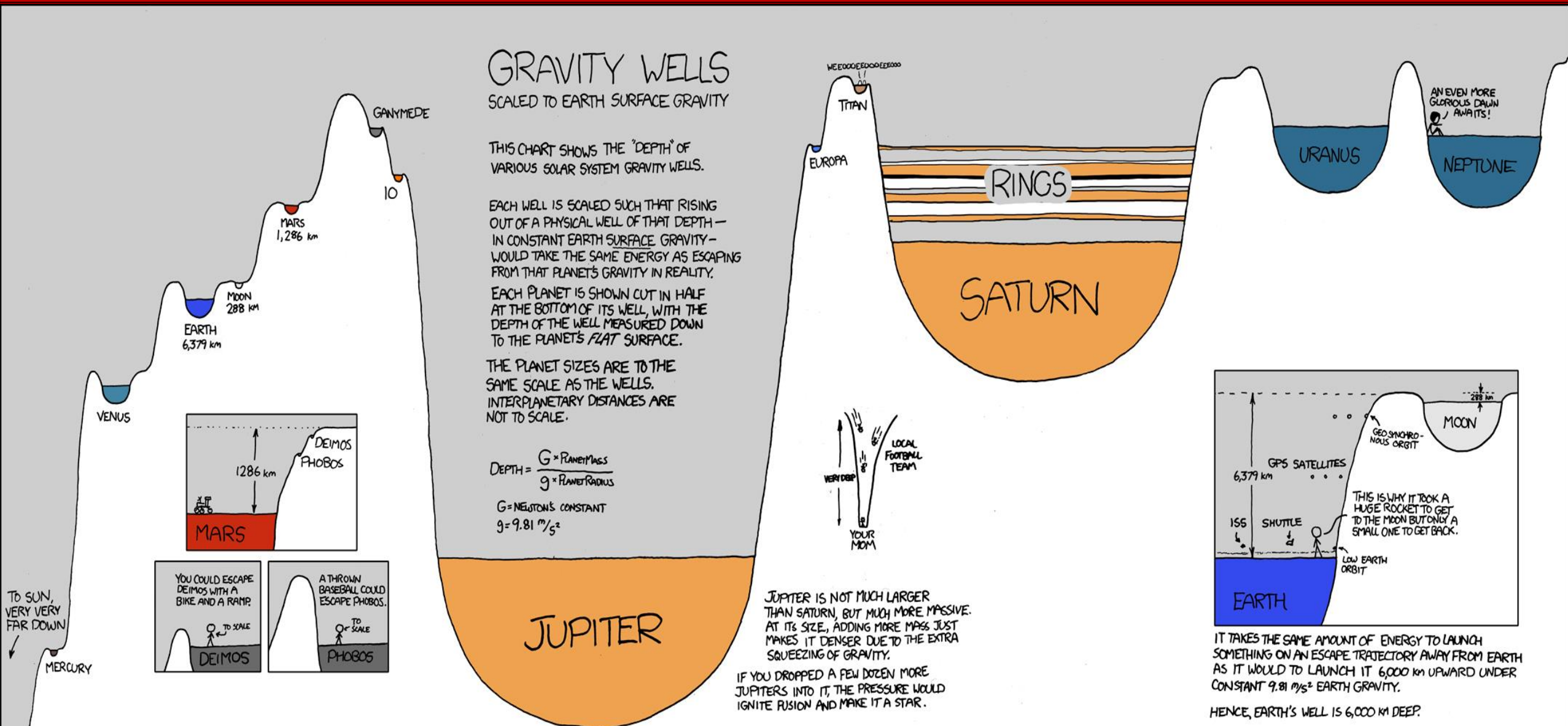
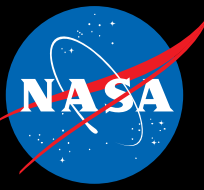
Why Cislunar Space?

The 'Gravity Well' Advantage



Gravity Wells Explained

xkcd.com by Randall Munroe



GRAVITY WELLS SCALED TO EARTH SURFACE GRAVITY

THIS CHART SHOWS THE "DEPTH" OF VARIOUS SOLAR SYSTEM GRAVITY WELLS.

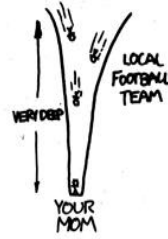
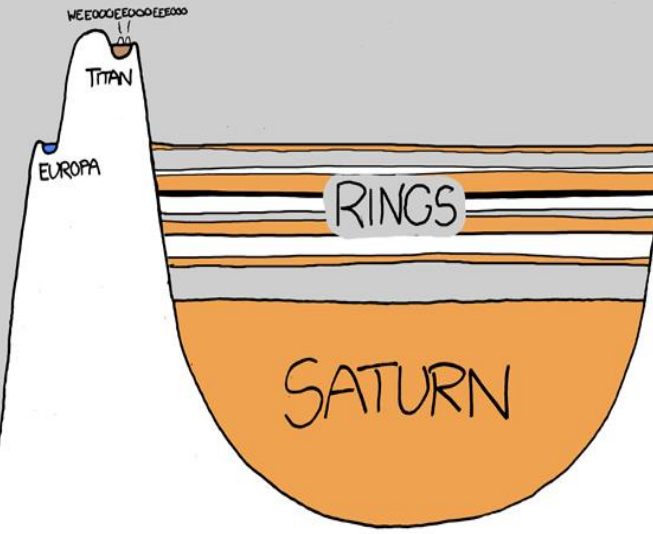
EACH WELL IS SCALED SUCH THAT RISING OUT OF A PHYSICAL WELL OF THAT DEPTH — IN CONSTANT EARTH SURFACE GRAVITY — WOULD TAKE THE SAME ENERGY AS ESCAPING FROM THAT PLANET'S GRAVITY IN REALITY.

EACH PLANET IS SHOWN CUT IN HALF AT THE BOTTOM OF ITS WELL, WITH THE DEPTH OF THE WELL MEASURED DOWN TO THE PLANET'S FLAT SURFACE.

THE PLANET SIZES ARE TO THE SAME SCALE AS THE WELLS. INTERPLANETARY DISTANCES ARE NOT TO SCALE.

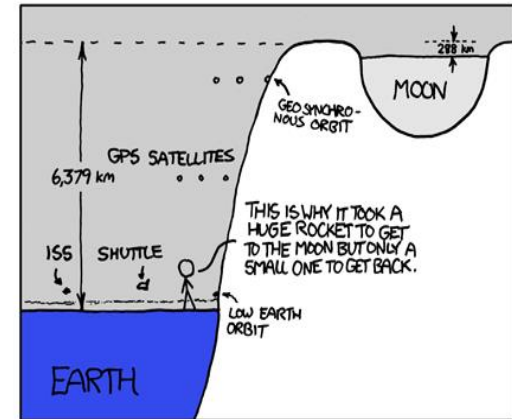
$$\text{DEPTH} = \frac{G \cdot \text{PLANET MASS}}{g \cdot \text{PLANET RADIUS}}$$

$G = \text{NEWTON'S CONSTANT}$
 $g = 9.81 \text{ m/s}^2$



JUPITER IS NOT MUCH LARGER THAN SATURN, BUT MUCH MORE MASSIVE. AT ITS SIZE, ADDING MORE MASS JUST MAKES IT DENSER DUE TO THE EXTRA SQUEEZING OF GRAVITY.

IF YOU DROPPED A FEW DOZEN MORE JUPITERS INTO IT, THE PRESSURE WOULD IGNITE FUSION AND MAKE IT A STAR.



IT TAKES THE SAME AMOUNT OF ENERGY TO LAUNCH SOMETHING ON AN ESCAPE TRAJECTORY AWAY FROM EARTH AS IT WOULD TO LAUNCH IT 6,000 km UPWARD UNDER CONSTANT 9.81 m/s^2 EARTH GRAVITY.

HENCE, EARTH'S WELL IS 6,000 km DEEP.

PROVING GROUND OBJECTIVES



Using Cislunar Resources to Enable Human Missions to Mars



TRANSPORTATION



WORKING IN SPACE



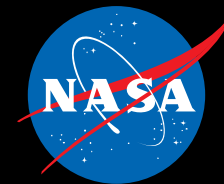
STAYING HEALTHY

- **Heavy Launch Capability**: beyond low-Earth orbit launch capabilities for crew, co-manifested payloads, large cargo
- **Crew**: transport at least four crew to cislunar space
- **In-Space Propulsion**: send crew and cargo on Mars-class mission durations and distances

- **ISRU**: Understand the nature and distribution of volatiles and extraction techniques and decide on their potential use in human exploration architecture.
- **Deep-space operations capabilities**: EVA, Staging, Logistics, Human-robotic integration, Autonomous operations
- **Science**: enable science community objectives

- **Deep-Space Habitation**: beyond low-Earth orbit habitation systems sufficient to support at least four crew on Mars-class mission durations and dormancy
- **Crew Health**: Validate crew health, performance and mitigation protocols for Mars-class missions

Split Mission Concept



DESTINATION
SYSTEMS
SEP pre-deploy to
Mars orbit

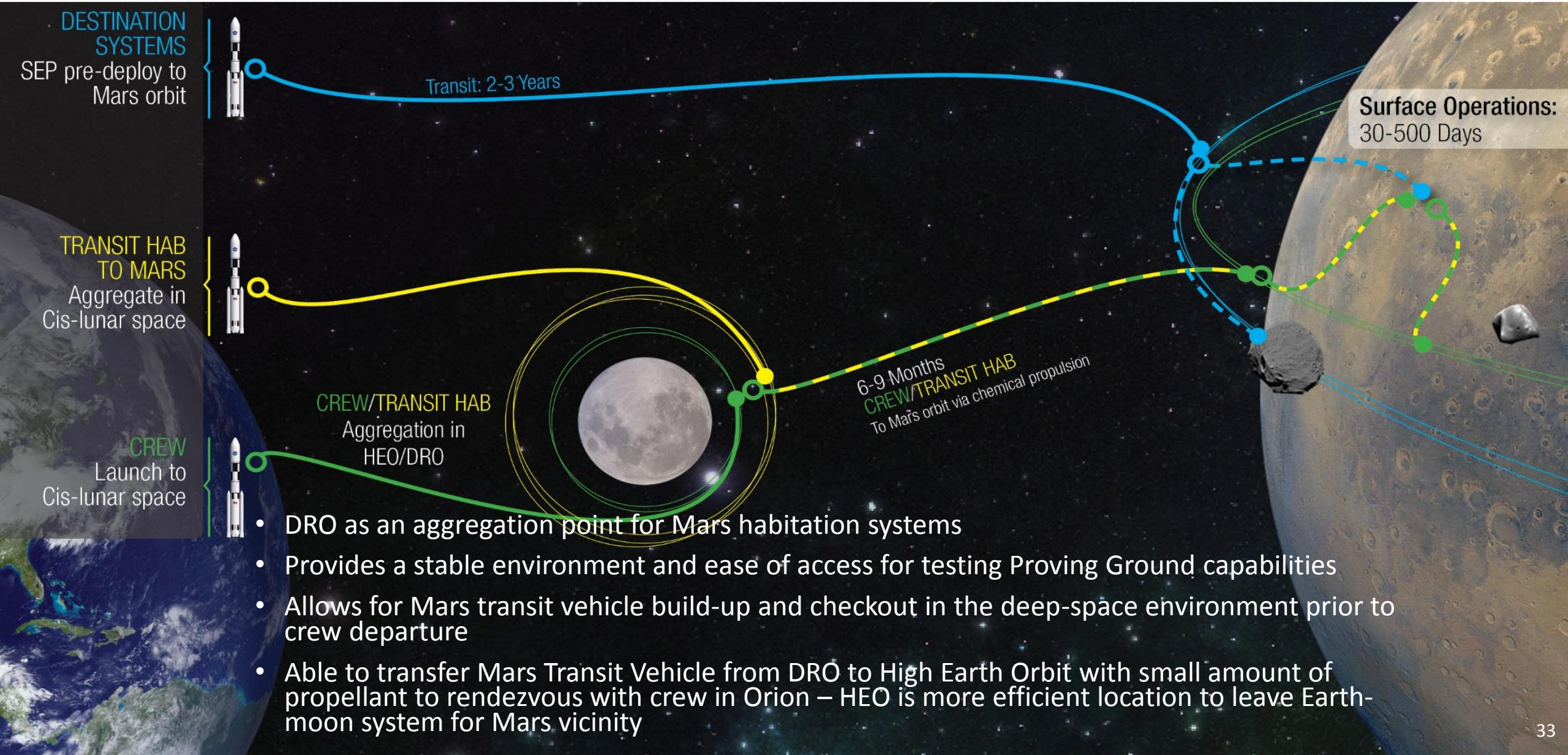
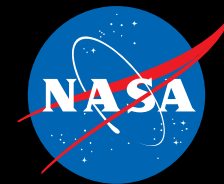


Transit: 2-3 Years

Surface Operations:
30-500 Days

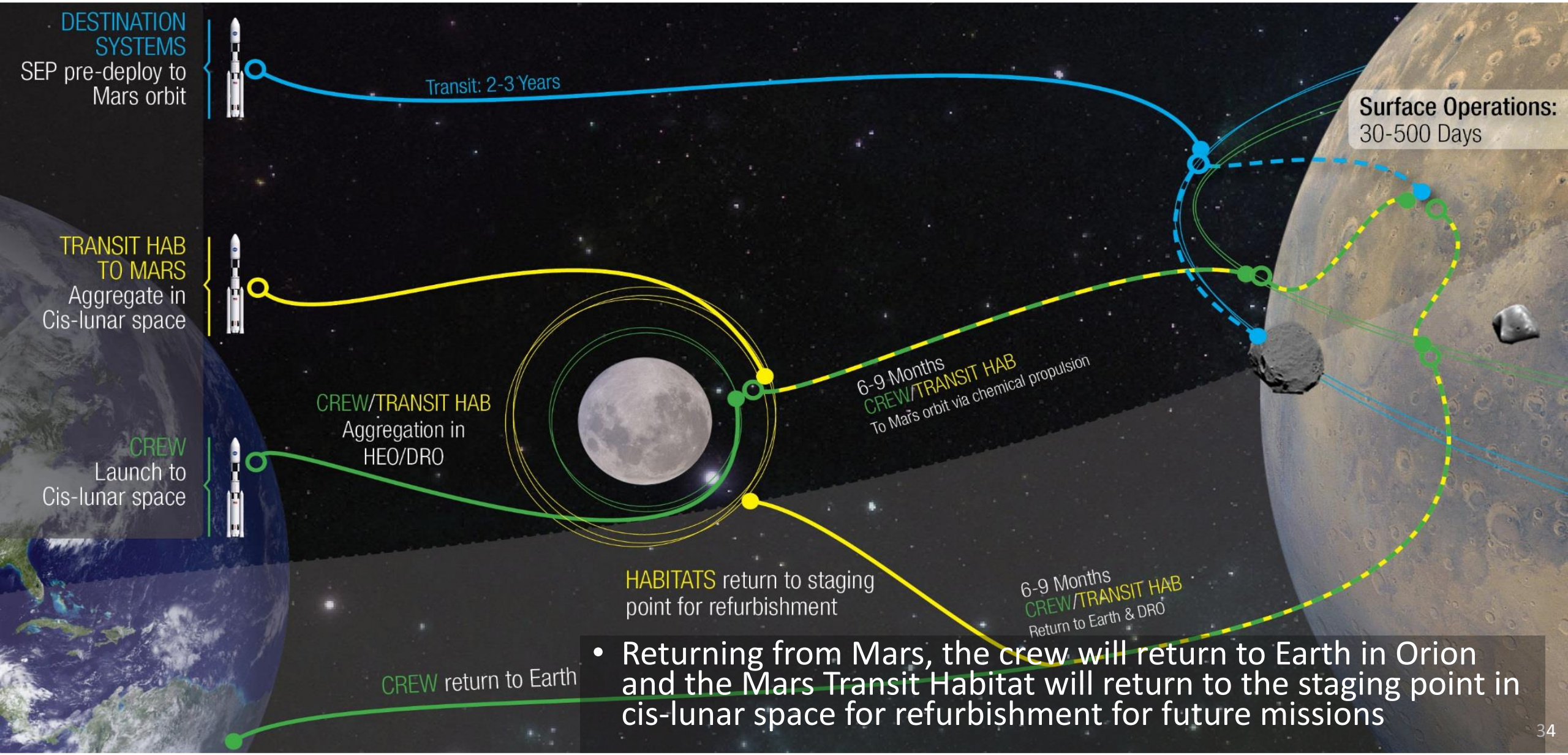
- Using SEP for pre-emplacement of cargo and destination systems enables sustainable Mars campaign
- Minimizes the cargo needed to be transported with the crew on future launches
- Enables a more sustainable launch cadence
- Pre-positions assets for crew missions allows for system checkout in the Mars vicinity prior to committing to crew portion of mission

Split Mission Concept

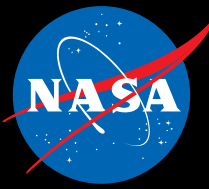


- DRO as an aggregation point for Mars habitation systems
- Provides a stable environment and ease of access for testing Proving Ground capabilities
- Allows for Mars transit vehicle build-up and checkout in the deep-space environment prior to crew departure
- Able to transfer Mars Transit Vehicle from DRO to High Earth Orbit with small amount of propellant to rendezvous with crew in Orion – HEO is more efficient location to leave Earth-moon system for Mars vicinity

Split Mission Concept



- Returning from Mars, the crew will return to Earth in Orion and the Mars Transit Habitat will return to the staging point in cis-lunar space for refurbishment for future missions



EMC – Major Results to Date

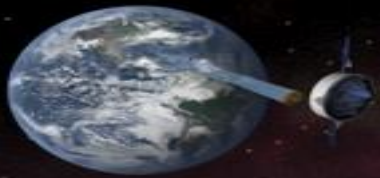
- **Regardless of Mars vicinity destination, common capability developments are required**
- **ISS provides critical Mars mission capability development platform**
- **Lunar DRO is efficient for aggregation and potential refurbishment due to stable environment**
 - Use of gravity assist trajectories enable use of DRO
- **Orion Block 1 is sufficient for Mars architectures with reusable habitats**
- **SLS co-manifested cargo capability increases value of crewed missions and improves cadence**
- **Deep-space habitation serves as initial starting point regardless of destination**
- **ARV derived SEP vehicle can serve as an effective tool for human Mars missions**
 - Reusability can enable follow-on use in cis-lunar space
 - Refuelability under study to enable Mars system follow-on use
 - Current SEP evolvability enables Mars system human missions
- **Mars Phobos /Deimos as initial Mars vicinity mission spread out development costs and meets policy objectives of Mars vicinity in 2030's**
 - Common crew transportation between Mars Phobos / Deimos and Mars Surface staging
 - Phobos provides 35% reduction of radiation exposure compared to other Mars orbit missions
 - Provides ability to address both exploration and science objectives

Mars Technology Video

Technology Needs for Deep Space Exploration



Technology Path to Pioneering Space



Asteroid Retrieval Mission



Hypersonic Inflatable Aerodynamic Decelerator



Low-Density Supersonic Decelerator



Optical Communications



Solar Electric Propulsion

GO

LAND

LIVE

Environmental Control & Life Support System



Surface Power



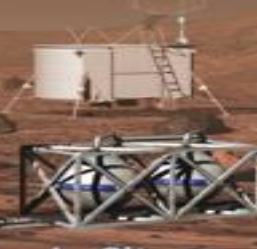
Next Generation Spacesuit



Robotics & Autonomy



In-Situ Resource Utilization



Space Technology Portfolio and Programs



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)

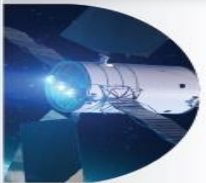
Programs provide an opportunity for small, high technology companies and research institutions to develop key technologies addressing the Agency's needs and developing the Nation's innovation economy.



Enabling Future Exploration Missions



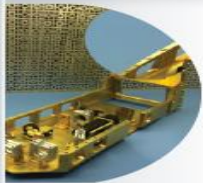
Space Technology focus investments in 8 thrust areas that are key to future NASA missions and enhance national space capabilities.



In- Space Propulsion

Create improvements in thrust levels, specific power, and alternatives to traditional chemical propulsion systems for destination-agnostic, deep space exploration spacecraft systems.

External Application:
Enhanced propulsion capabilities for Commercial and OGA Satellites



High Bandwidth Space Comm

Substantially increase available bandwidth and data rates for near earth and deep space, currently limited by power and frequency allocation limits. Assure robust and reliable interconnected space network.

External Application:
High bandwidth for Commercial and OGA Satellites



Advanced Life Support & Resource Utilization

Human exploration missions beyond low earth orbit will require highly reliable technologies (e.g. reclaiming water reuse of trash, air revitalization) to minimize resupply requirements and increase independence from earth.

External Application:
Mining Industry and other closed environments; OGA



Entry Descent and Landing Systems

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

External Application:
Returning commercial assets from space and research from ISS



Space Robotic Systems

Extends our reach by helping us remotely explore planetary bodies, manage in-space assets and support in-space operations by enhancing the efficacy of our operations.

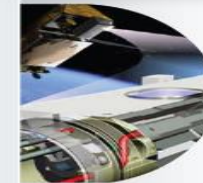
External Application:
Human-safe Robotics for industrial use, disaster response, & overall autonomous operations



Lightweight Space Structures

Targets large decreases in structural mass for launch vehicles and spacecraft materials using nanotech, composites and in space manufacturing capabilities.

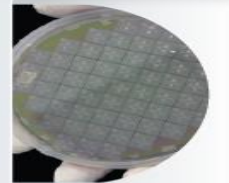
External Application:
Industrial Materials and Composites for large structures (rockets, aircraft)



Deep Space Navigation

Allows for more capable science and human exploration missions; enables more precise entry trajectories for inserting into orbits around planets and bodies like Mars, Europa, and Titan.

External Application:
Next Generation GPS and build new industrial base



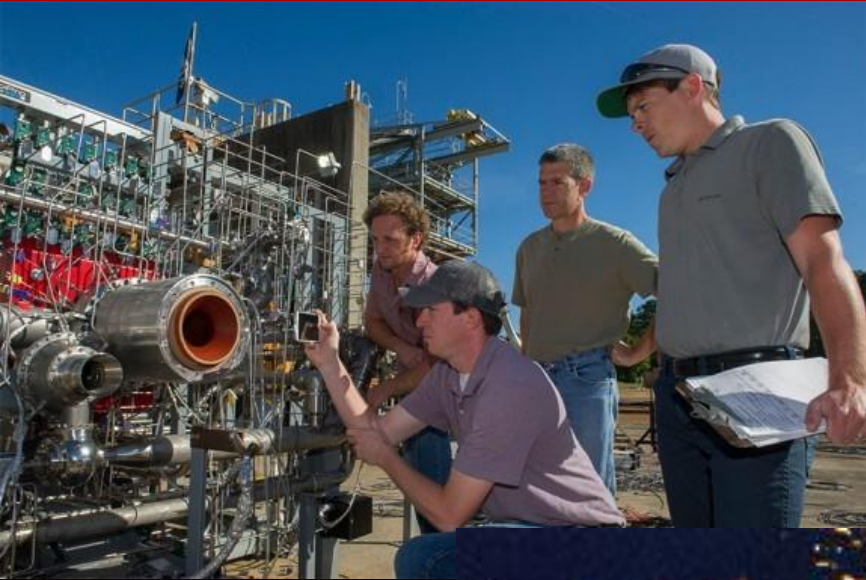
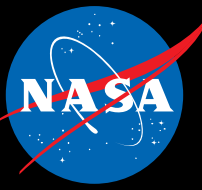
Space Observatory Systems

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.

External Application:
Industrial Materials, Earth Observation

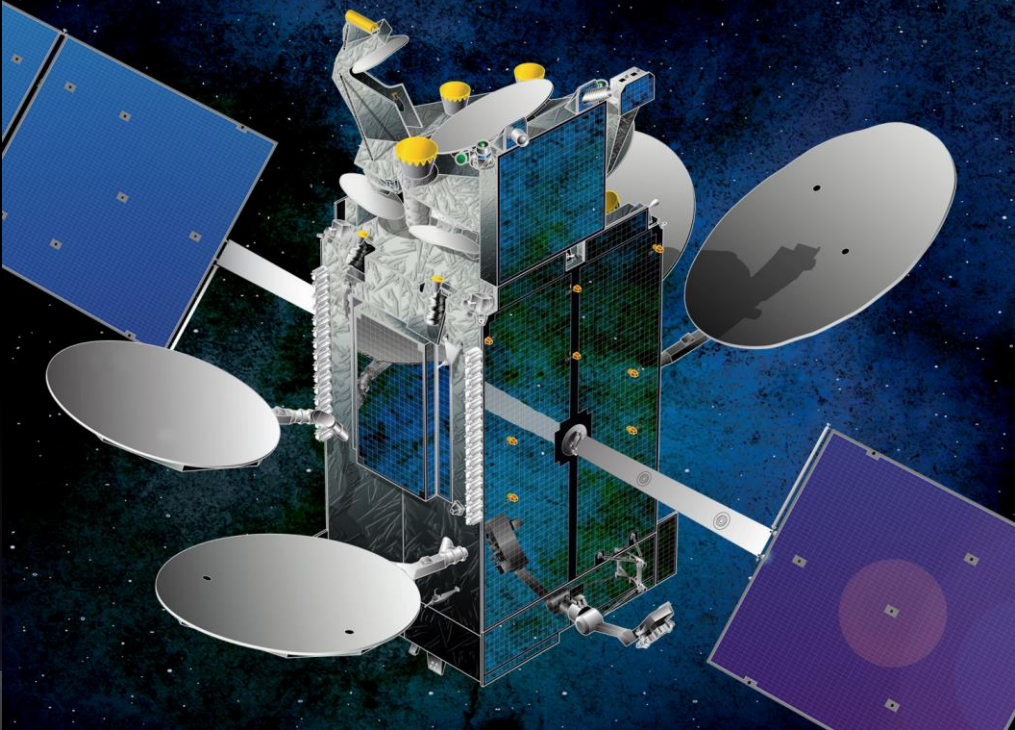
THRUST AREAS

Propulsion Research



#JOURNEYTOMARS

Communications



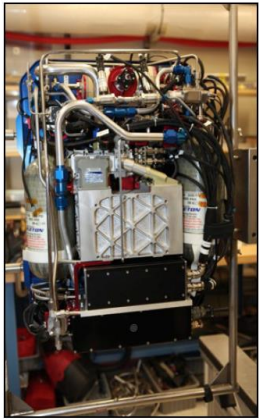
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Next Generation Space Suits



Crew Mobility Systems Domain

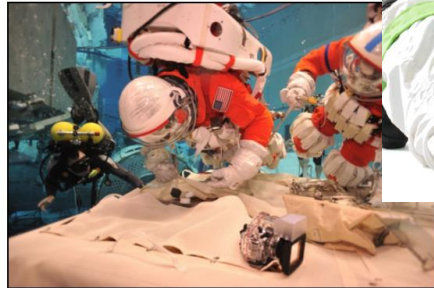
Advanced EVA: Development and testing of next generation space suits and portable life support systems (JSC).



Portable Life Support System 2.0 incorporates new technology components for CO₂ removal, thermal management, pressure regulation, and energy storage.



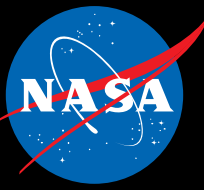
Z-2 Space Suit



Testing Modified Advanced Crew Escape Suit (MACES) in Neutral Buoyancy Lab for Asteroid Redirect Mission.



Growing Plants in space



Scott Kelly ✓
@StationCDRKelly

Follow

#SpaceFlower out in the sun for the first time!
#YearInSpace



#JOURNEYTOMARS

Staying Healthy – Human Research Program (HRP)



BHP

ISS Medical Project



HHC

Human Health and Countermeasures



ExMC

Exploration Medical Capabilities



ISSMP

Behavioral Health And Performance



SHFH

Space Human Factors And Habitability



SRPE

Science Management

Habitat studies



Deep Space Habitat
Concept Demonstrators

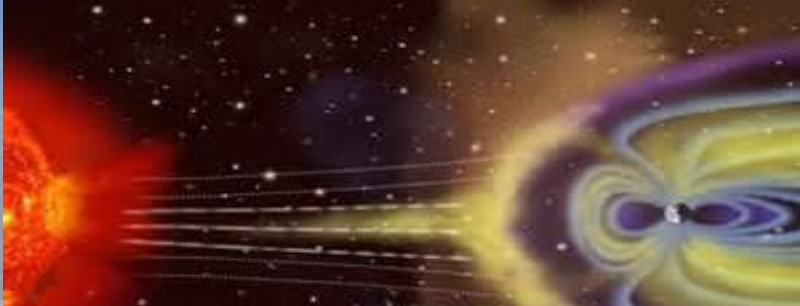
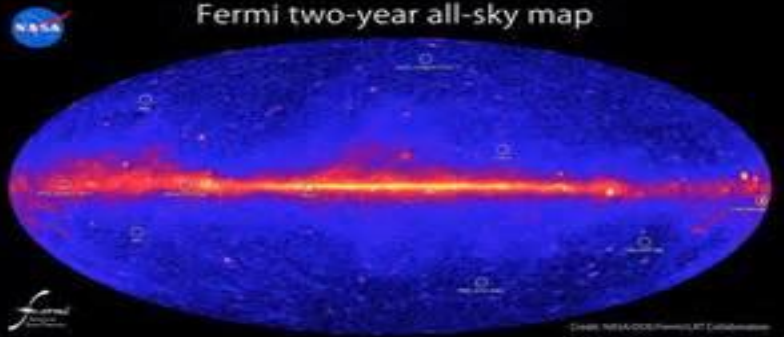
- 300-lb. 20' Diameter (Nesvick Base)
- On-Liner 5.5' 10' Diameter (Nesvick Base)
- External Module (3.5' Diameter)

Designing Low Cost
Physical Habitats

Mark's Deep Space
Habitats

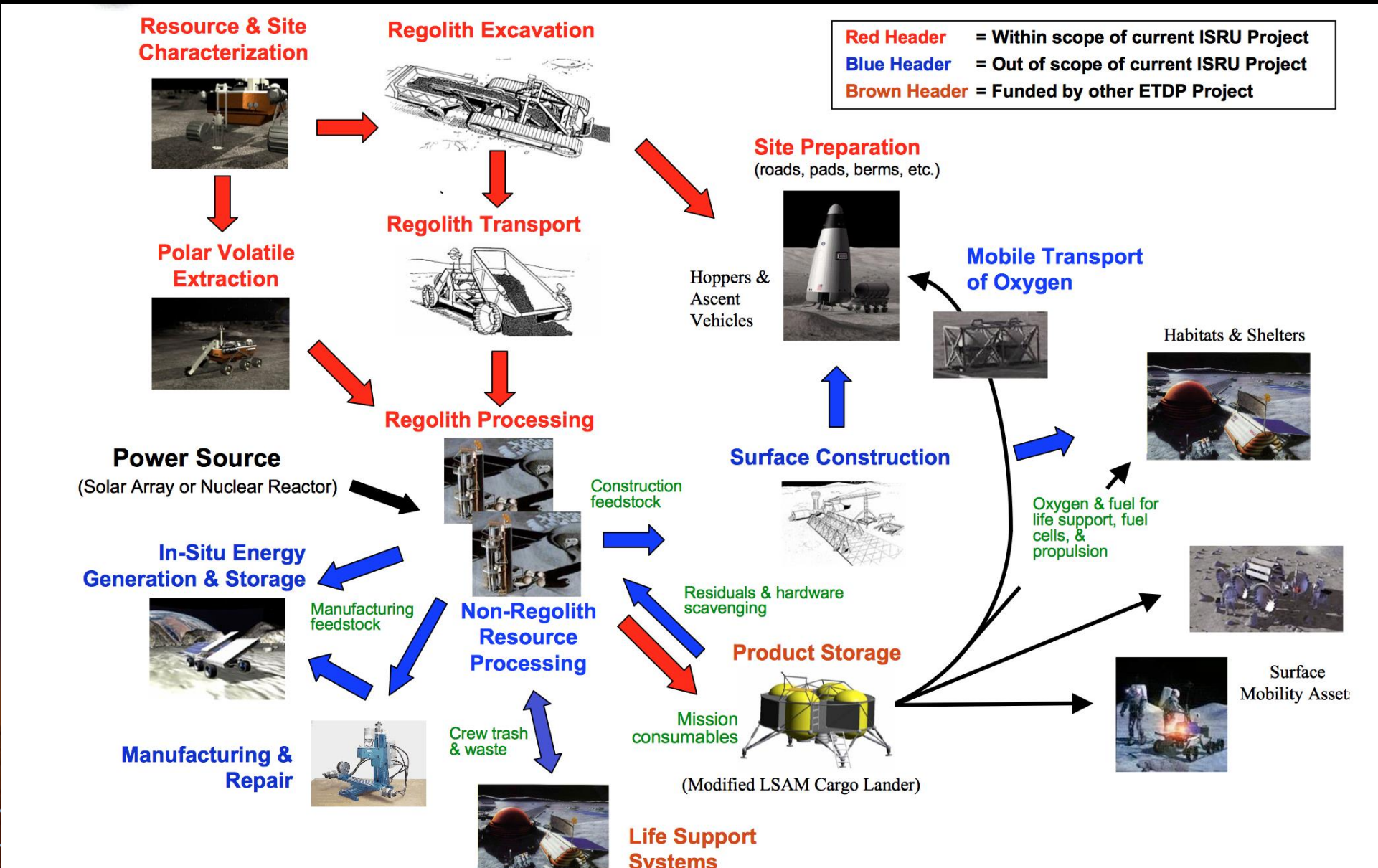
Designing for the
comfort of long and
working in deep space

Radiation studies

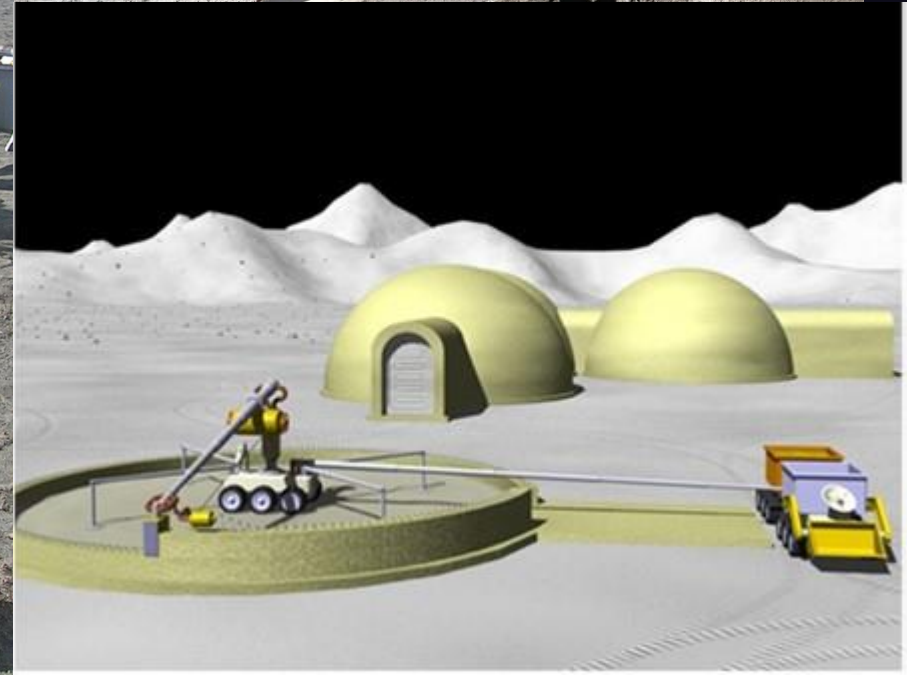
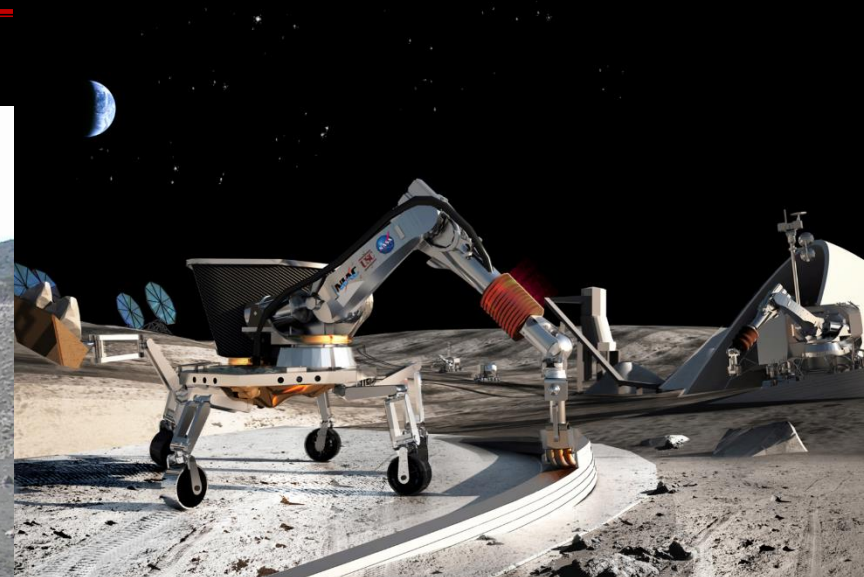
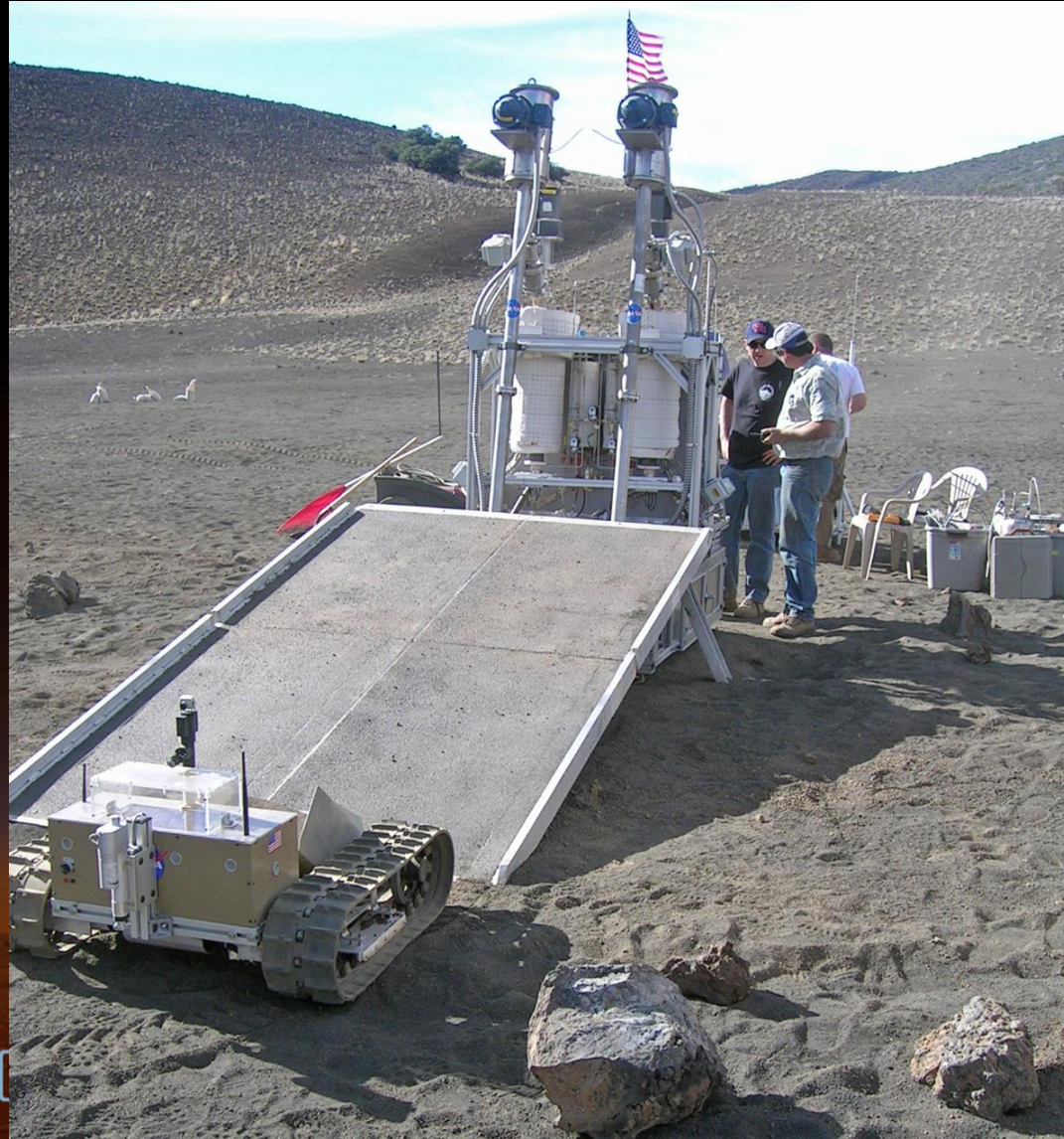


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In Space Resource Utilization

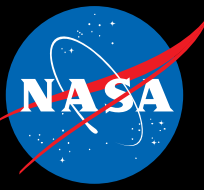


In Space Resource Utilization



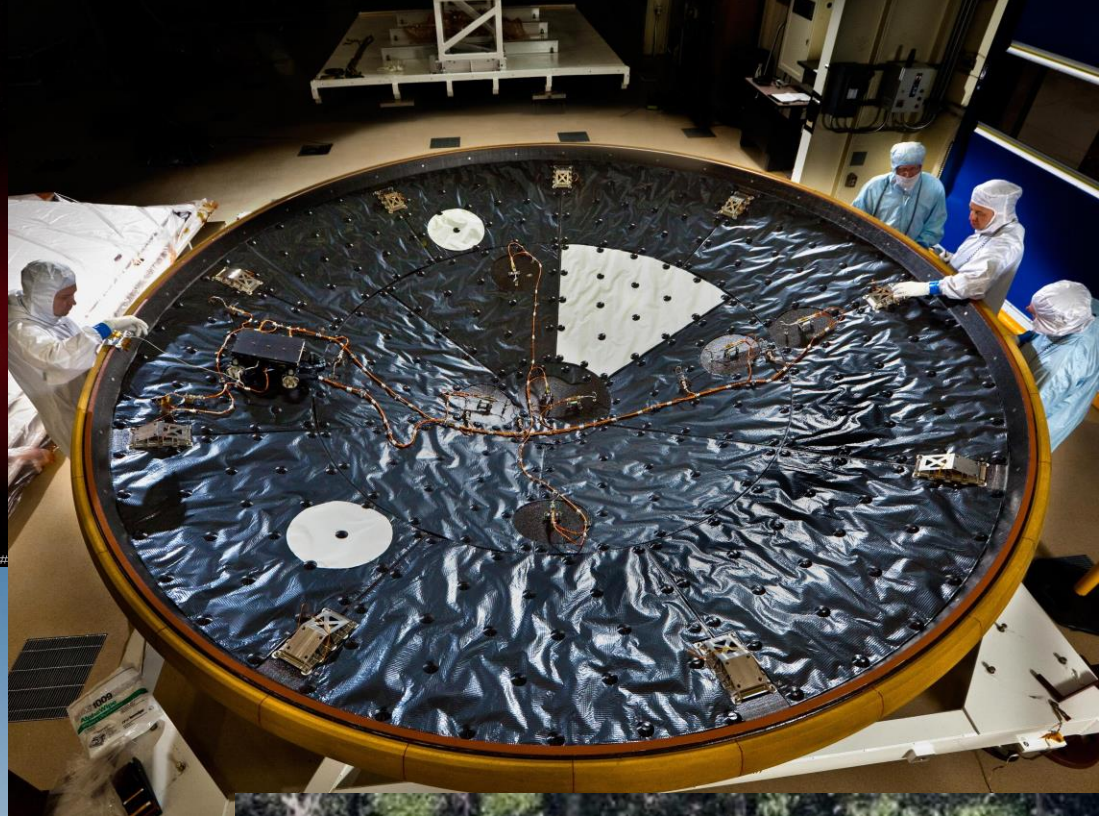
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Surface Power and Mobility



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Ascent and Descent

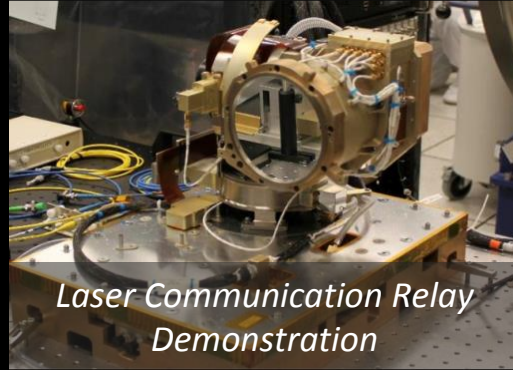


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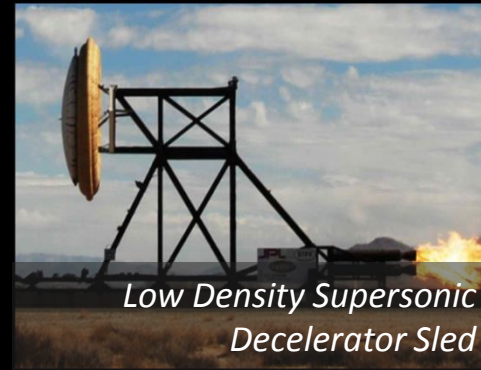
Supporting Exploration & Science



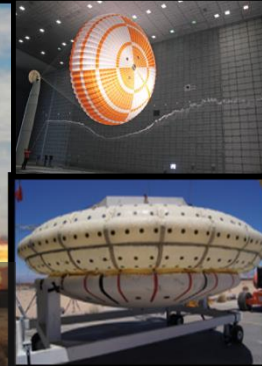
Deep Space Atomic Clock



Laser Communication Relay Demonstration



Low Density Supersonic Decelerator Sled



Solar Electric Propulsion



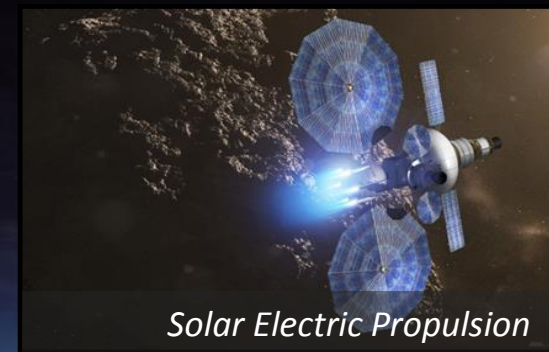
Human Robotics Systems



Hypersonic Inflatable Aerodynamic Decelerator

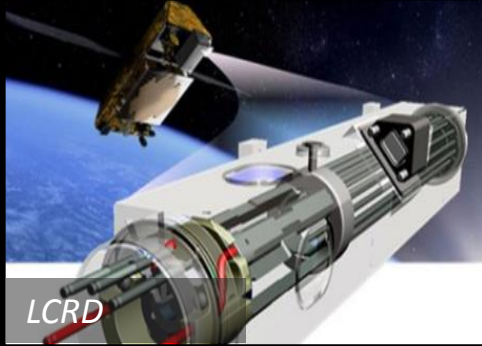


Environmental Control and Life Support System



Composite Cryogenic Propellant Tank

Technology & Enterprise



LCRD



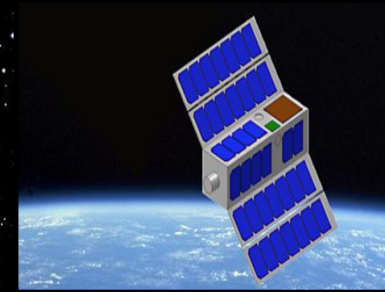
SBIR/STTR



Small Spacecraft Technology



Additive Manufacturing/
3-D Printers



Flight Opportunities



Green Propellant Infusion
Missions



Centennial Challenge

#JOURNEYTO

Technology Transfer

Technology Transfer Examples



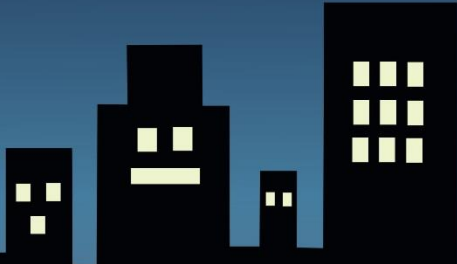
#SUITINGUP IS CHANGING OUR EVERYDAY LIVES

Technology Drives Exploration



Every system is **100%** pressure tested and inspected.

Heat-sealing technology used on spacesuits is used creating these systems.



Beat the Heat



Thermocule technology regulates the temperature between the skin and fabric by as much as:

3°

Cooling undergarments worn by athletes help reduce overheating and sweating.

The technology acts like ice cubes in a drink by absorbing heat and cooling the material.



Medical



These systems allow one-person operation.

Pharmaceutical containment systems enable safe processing of active pharmaceutical ingredients.



UV Protection

Using NASA spacesuit technology, UV-blocking apparel was developed to protect those with severe sun sensitivities.

98%

of UV rays are blocked in the apparel

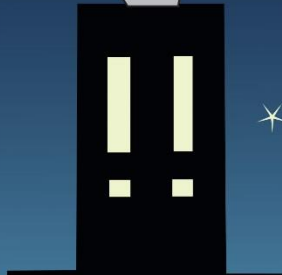
Charcoal, coconut and titanium are used in the fabrics to reflect UV rays.



Masks will operate for **4** hours

1.5M U.S. soldiers are equipped with gas masks

30+ spacesuit spinoffs



Human Safety



Masks can be on and working in

30 seconds

Gas masks and protective suits provide state-of-the-art protection from chemical, biological and nuclear inhalants.



Extreme Exposure

Specialized chemical handlers wear suits that utilize air produced from:

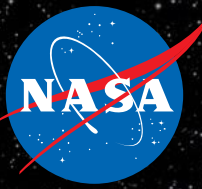
-350°F cryogenic liquid air backpacks



Firefighters use lightweight breathing systems and wear suits made out of heat-protective and fire-resistant materials.



This technology was developed during Apollo and the Space Shuttle Program for the Supercritical Air Mobility Pack.



NASA Today: Federal and NASA Budget

FY16 US Federal Budget

(estimated outlay) = **\$3.919T**



NASA's FY16 Appropriated Budget = **\$19.3B**

Federal Discretionary spending = **\$1.15T**



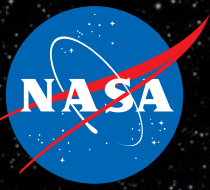
In FY15, NASA's budget is 0.48% of the full federal budget outlay.

From 1958 through 2015 inclusive, NASA's cumulative budget is

0.75%

of cumulative US Federal Budget Spending.

Space Technology Research Grants Program



Engage Academia: tap into spectrum of academic researchers, from graduate students 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 Research Fellowships**

- Graduate student research in space technology; research conducted on campuses and at NASA Centers and not-for-profit R&D labs

- **Early Career Faculty**

- Focused on supporting outstanding faculty researchers early in their careers as they conduct space technology research of high priority to NASA's Mission Directorates

- **Early Stage Innovations**

- University-led, possibly multiple investigator, efforts on early-stage space technology research of high priority to NASA's Mission Directorates
- Paid teaming with other universities, industry and non-profits permitted



NASA SPACE TECHNOLOGY

National Aeronautics and
Space Administration



RESEARCH FELLOWSHIPS 2016

CALL FOR FELLOWSHIP APPLICATIONS

Learn, collaborate, discover, achieve...

The NASA Space Technology Mission Directorate seeks to sponsor graduate student researchers pursuing or planning to pursue master's and doctoral degrees in relevant space technology disciplines who show significant potential to contribute to the strategic goals and missions of NASA in the area of **space technology**.

The fellowship, up to \$74,000 per year, will coincide with the start of the fall 2016 term. In addition to providing a \$36,000 annual stipend, the fellowship provides support for tuition, health insurance and the faculty advisor. The fellowship also provides support for onsite tenure at NASA Centers across the country.

To date, NASA has awarded these prestigious fellowships to 301 students from 83 universities across 36 states and one U.S. territory. Fellowship recipients will collaborate with leading experts in space technology to provide a more robust national capability for aerospace activities and contribute to the Nation's innovation economy.

The solicitation opened on *September 10, 2015*

Student applications will be due by 6:00 p.m. ET on **November 05, 2015**

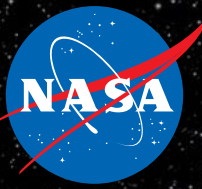
Applications will be accepted via NSPIRES after September 10, 2015:

<http://tinyurl.com/NSTRF2016>



U.S. citizens and permanent residents only.
PS-00885-1012

NASA Space Technology Research Fellowships



Eligibility Requirements for NSTRF16

1. Pursuing or seeking to pursue advanced degrees directly related to space technology.
2. Are U.S. citizens or permanent residents of the U.S.
3. Are or will be enrolled in a full-time master's or doctoral degree program at an accredited U.S. university in fall 2015.
4. Are early in their graduate careers.

NSTRF16: <http://tinyurl.com/NSTRF2016>
NSTRF15: <http://tinyurl.com/NSTRF2015>
NSTRF14: <http://tinyurl.com/NSTRF14>
NSTRF13: <http://tinyurl.com/NSTRF13>
NSTRF12: <http://tinyurl.com/NSTRF12-OCT>
NSTRF11: <http://tinyurl.com/NSTRF11-OCT>

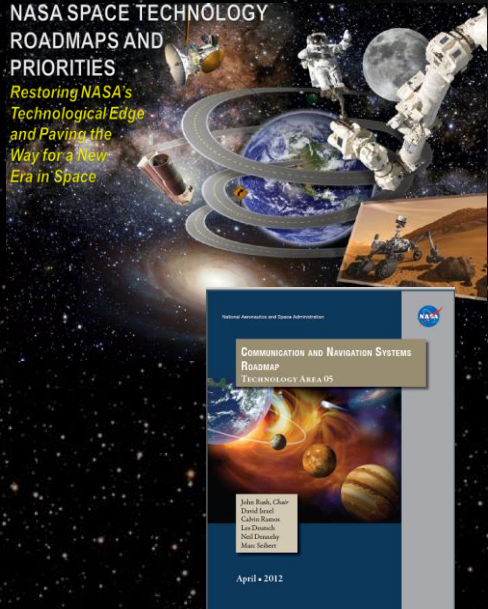
Application Components

- | | |
|--|-----------------------------------|
| 1 Proposal Cover Page
(Program Specific Data Questions) | 5 Curriculum Vitae |
| 2 Personal Statement | 6 Transcripts |
| 3 Project Narrative | 7 GRE General Test Scores |
| 4 Degree Program Schedule | 8 Three Letters of Recommendation |

Award Value

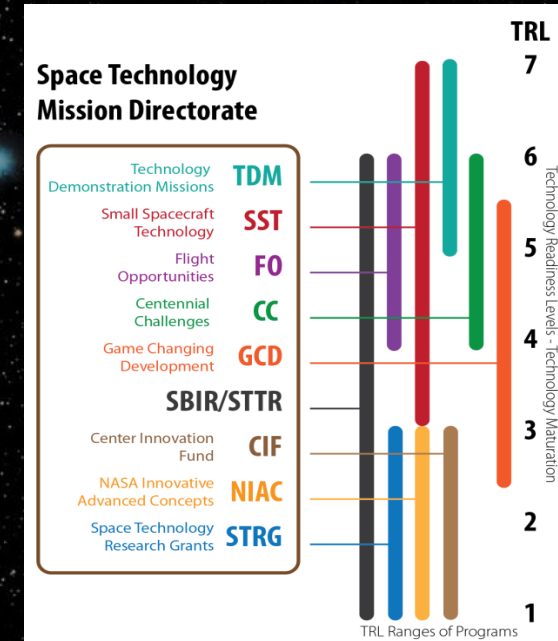
Fellowship Budget Category	Max value
Student Stipend	\$36,000
Faculty Advisor Allowance	\$10,000
Visiting Technologist Experience Allowance	\$10,000
Health Insurance Allowance	\$1,000
Tuition and Fees Allowance	\$17,000
TOTAL	\$74,000

Early Career Faculty and Early Stage Innovations Opportunities



Technical Characteristics:

- Unique, disruptive or transformational space technologies
- Low TRL
- Specific topics tied to Technology Area Roadmaps
- Big impact at the system level: performance, weight, cost, reliability, operational simplicity or other figures of merit associated with space flight hardware or missions



<http://tinyurl.com/NASAECE>
<http://tinyurl.com/NASA-14ECF>
<http://tinyurl.com/NASA-15ECF>
<http://tinyurl.com/NASAESI>
<http://tinyurl.com/NASA-13ESI>
<http://tinyurl.com/NASA-14ESI>
www.tinyurl.com/NASA-15ESI

Eligibility Summary:

Both ECF and ESI proposals must be submitted by accredited U.S. universities

Early Career Faculty

- PI must be recent Ph.D. (last 7 years)
- Untenured assistant professor and on tenure track
- U.S. citizen or permanent resident
- No co-investigators

Early Stage Innovations

- PI must be from proposing university
- Co-investigators are permitted
- ≥ 50% of the proposed budget must go to the proposing university
- ≥ 70% of the proposed budget must go to universities

NSPIRES Solicitation Source (<https://nspires.nasaprs.com/>)



NSPIRES

NASA Solicitation and Proposal Integrated Review and Evaluation System

Home NASA Research Help Login



NSPIRES Time: Mar 13, 2016 03:54PM EDT

NSPIRES Home

► [Solicitations](#)

Getting Started

► [NSPIRES Help](#)

► [Getting an Account](#)

Help Desk

If you need help or have any questions regarding the NSPIRES website, please contact the NSPIRES Help Desk at (202) 479-9376 Monday through Friday, 8:00 AM to 6:00 PM EST/EDT, or by email at nspires-help@nasaprs.com.



NASA Research Opportunities

Supporting research in science and technology is an important part of NASA's overall mission. NASA solicits this research through the release of various research announcements in a wide range of science and technology disciplines. NASA uses a peer review process to evaluate and select research proposals submitted in response to these research announcements. Researchers can help NASA achieve national research objectives by submitting research proposals and conducting awarded research. This site facilitates the search for NASA research opportunities.

NASA Research

► [Solicitations](#)

Search for and view open, closed, past, and future NASA research announcements. The full text of the [solicitation announcements](#) can be viewed and downloaded.

Solicitations and selected proposals for years prior to NSPIRES implementation, January 1, 2005, were posted manually; therefore, some postings for years 2000-2004 may not be as complete as those posted through the NSPIRES system from 2005 to the present.

Research.gov

[Research.gov](#) is a partnership of federal research-oriented grant making agencies. Research.gov is led by the National Science Foundation.

WARNING:

This is a U.S. Government computer. By accessing and using the computer system, you are consenting to the use of system monitoring. Unauthorized use of, or access to, this computer system may subject you to disciplinary action and criminal prosecution.

► [Getting Started](#)

To submit a research proposal to NASA, individuals and the organizations with which they are affiliated must be registered in NSPIRES. Individuals may register at any time.

Organizations are required to have a valid registration with the System for Award Management (SAM) before they can register in NSPIRES. See [Registration Information](#) for more details on user and organization registration.

Member Login:

Username:

Password:

Login

► [Forgot Your Password?](#)

► [Registration Information](#)

Site News

New NASA Grants and Cooperative Agreements Regulations and Guidance

New regulations and guidance has been released.

► [Continue Reading](#)

NRA/CAN Proposer's Guidebook

Available online

► [Continue Reading](#)

Gmail and NSPIRES email

Your Gmail could be flagging NSPIRES emails as Spam.

► [Continue Reading](#)

