National Aeronautics and Space Administration

Moon to Mars: Mission Considerations for Future BPS Science Research

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Program Scientist for Exploration

BPS

Biological & **P**hysical **S**ciences

Agenda

1. Organization
2. Moon to Mars Architecture
3. Artemis Missions and BPS Science Opportunities
4. Upcoming Science Opportunities and Community Involvement

Organization

- Exploration Systems Development Mission Directorate
- Science Mission Directorate Exploration Science Strategy and Integration Office

Exploration Systems Development Mission Directorate (ESDMD) Moon to Mars Program Office

NASA has established the Moon to Mars Program Office within Exploration Systems Development Mission Directorate to focus on hardware development, mission integration, and risk management functions for programs critical to the agency's exploration approach

Lakiesha Hawkins
Deputy to the Deputy Associate Administrator

Amit Kshatriya
Deputy Associate Administrator

Steve Creech
Assistant Deputy Associate Administrator for Technical

NASA Science Mission Directorate (SMD)

Exploration Science Strategy and Integration Office (ESSIO)

Responsible for SMD Moon to Mars Exploration

Dr. Joel Kearns
Deputy Associate Administrator for Exploration

Assistant DAAX
Dr. Brad Bailey

Resource Analyst: Renee Leck
Program Support: Mackenzie Howard
Program Support: Elizabeth Tate
Admin. Assistant: Amy Treat

Program Executives

Jay Jenkins

Angela Melito

Dr. Zachary Pirtle

Program Scientists

--*Vacant*--

Dr. Debra Needham

Dr. Ryan Watkins

Dr. Sarah Noble

Dr. Amanda Nahm

Joint with PSD

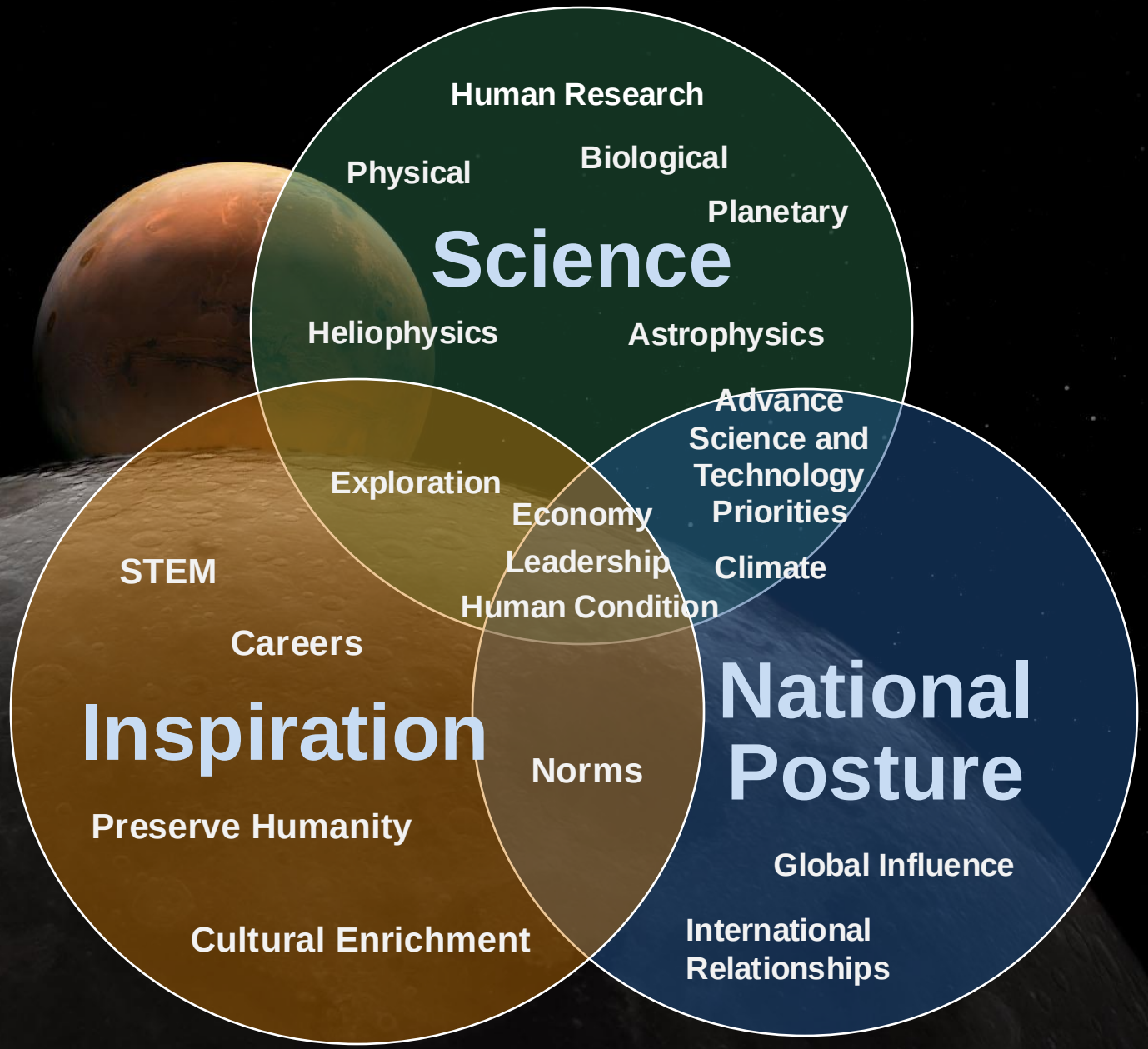
PSD
- PESTO (NPLP & DALI):
  - Ryan Stephan
- PMPO (LRO & LSITP)

JSC
- CLPS Office:
  - Chris Culbert

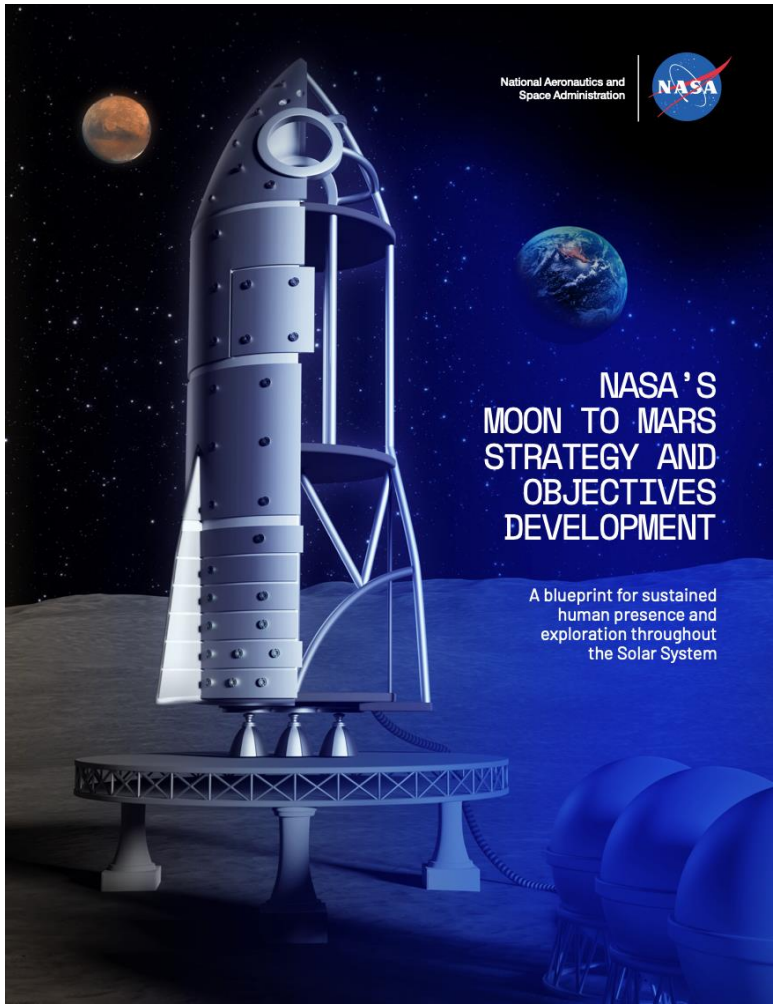

Moon to Mars Architecture
NASA's Moon to Mars architecture represents the hardware and operations needed for human missions to the Moon and Mars, and how they function together as a system.

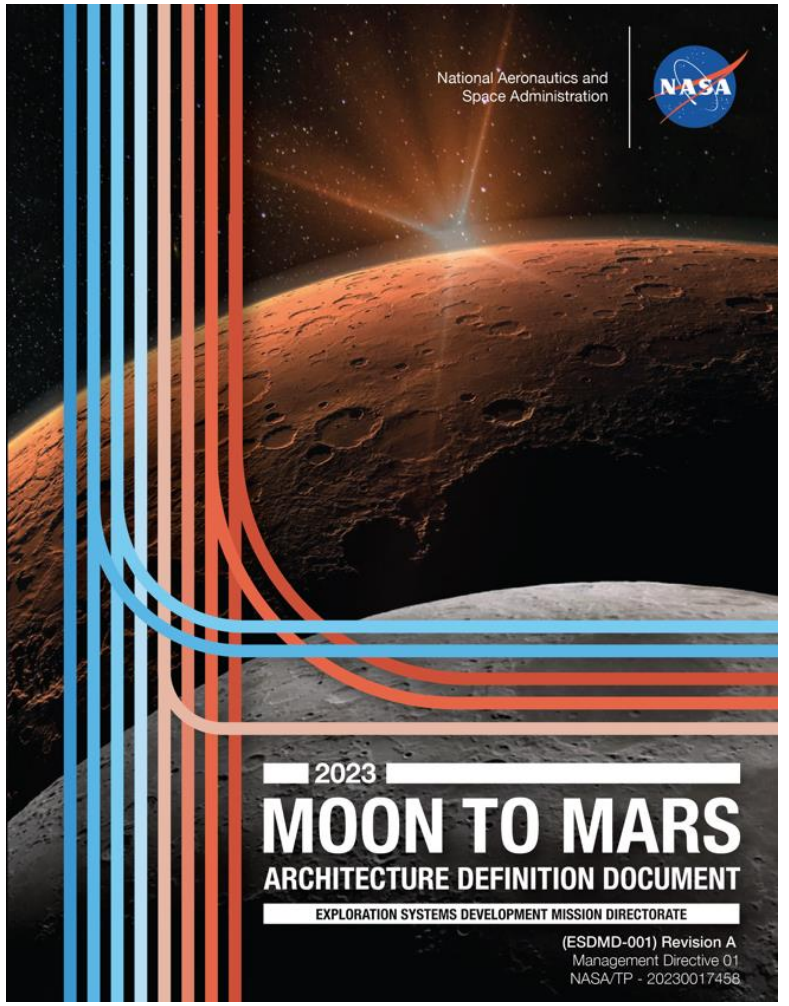
NASA Moon to Mars (M2M) Three Pillars of Exploration

Science Inspiration National Posture



Leading NASA Moon to Mars Documents





Moon to Mars Architecture Website

M2M Objectives – 26 Science Objectives

Lunar/Planetary Science (LPS)

Goal: Address high priority planetary science questions that are best accomplished by on-site human explorers on and around the Moon and Mars, aided by surface and orbiting robotic systems.

LPS-1^{LM}:	Uncover the record of solar system origin and early history, by determining how and when planetary bodies formed and differentiated, characterizing the impact chronology of the inner solar system as recorded on the Moon and Mars, and characterize how impact rates in the inner solar system have changed over time as recorded on the Moo
LPS-2^{LM}:	Advance understandi structures, characteri exospheres, and inve
LPS-3^{LM}:	Reveal inner solar sy abundance, composit
LPS-4^{M}:	Advance understandi habitable environmen habitable conditions h solar system beyond

Human and Biological Science (HBS)

Goal: Advance understanding of how biology responds to the environments of the Moon, Mars, and deep space to advance fundamental knowledge, to support safe, productive human space missions, and to reduce risks for future exploration.

HBS-1^{LM}:	Understand the effects of short- and long-duration exposure to the environments of the Moon, Mars, and deep space on biological systems and health, using humans, model organisms, systems of human physiology, and plants.
HBS-2^{LM}:	Evaluate and validate progressively Earth-independent crew health and performance systems and operations with mission durations representative of Mars-class missions.
HBS-3^{LM}:	Characterize an human health, p

Science-Enabling (SE)

Goal: Develop integrated human and robotic methods and advanced techniques that enable high-priority scientific questions to be addressed around and on the Moon and Mars.

SE-1^{LM}:	Provide in-depth, mission-specific science training for astronauts to enable crew to perform high-priority or transformational science on the surface of the Moon, and Mars, and in deep space.
SE-2^{LM}:	Enable Earth-based scientists advanced techniques and tools
SE-3^{LM}:	Develop the capability to retrie on the Moon and volatile-beari facilities on Earth.
SE-4^{LM}:	Return representative samples sample mass commensurate w
SE-5^{LM}:	Use robotic techniques to sur in advance of and concurrent surface and maximize science r
SE-6^{LM}:	Enable long-term, planet-wide r and surface locations at the Mo
SE-7^{LM}:	Preserve and protect represen regions and the radio quiet far science investigations.

Heliophysics Science (HS)

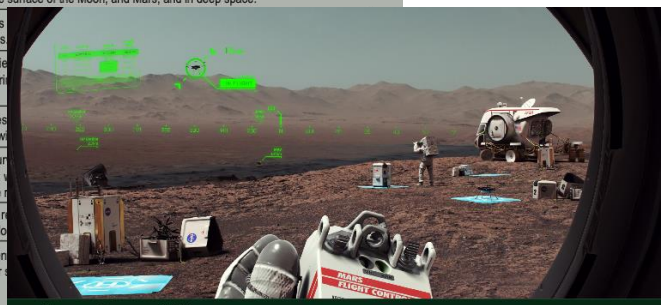
Goal: Address high-priority heliophysics science and space weather questions that are best accomplished using a combination of human explorers and robotic systems at the Moon, at Mars, and in deep space.

HS-1^{LM}:	Improve understanding of space weather phenomena to enable enhanced observation and prediction of the dynamic environment from space to the surface at the Moon and Mars.
HS-2^{LM}:	Determine the history of the Sun and solar system as recorded in the lunar and Martian regolith.
HS-3^{LM}:	Investigate and characterize fundamental plasma processes, including dust-plasma interactions, using the cislunar, near-Mars, and surface environments as laboratories.
HS-4^{LM}:	Improve understanding of magnetotail and pristine solar wind dynamics in the vicinity of the Moon and around Mars.

Physics and Physical Science (PPS)

Goal: Address high-priority physics and physical science questions that are best accomplished by using unique attributes of the lunar environment.

PPS-1^{L}:	Conduct astrophysics and fundamental physics investigations of space and time from the radio quiet environment of the lunar far side.
PPS-2^{LM}:	Advance understanding of physical systems and fundamental physics by utilizing the unique environments of the Moon, Mars, and deep space.



Applied Science (AS)

Goal: Conduct science on the Moon, in cislunar space, and around and on Mars using integrated human and robotic methods and advanced techniques, to inform design and development of exploration systems and enable safe operations.

AS-1^{LM}:	Characterize and monitor the contemporary environments of the lunar and Martian surfaces and orbits, including investigations of micrometeorite flux, atmospheric weather, space weather, space weathering, and dust, to plan, support, and monitor safety of crewed operations in these locations.
AS-2^{LM}:	Coordinate on-going and future science measurements from orbital and surface platforms to optimize human-led science campaigns on the Moon and Mars.
AS-3^{LM}:	Characterize accessible lunar and Martian resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable In-Situ Resource Utilization (ISRU) on successive missions.
AS-4^{LM}:	Conduct applied scientific investigations essential for the development of bioregenerative-based, ecological life support systems.
AS-5^{LM}:	Define crop plant species, including methods for their productive growth, capable of providing sustainable and nutritious food sources for lunar, Deep Space transit, and Mars habitation.
AS-6^{LM}:	Advance understanding of how physical systems and fundamental physical phenomena are affected by partial gravity, microgravity, and general environment of the Moon, Mars, and deep space transit.

Architecting from the Right

ARMD

ESDMD

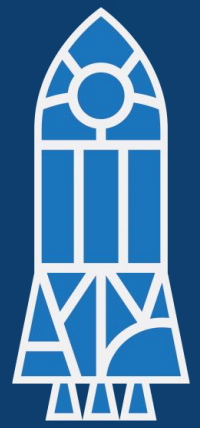
SMD

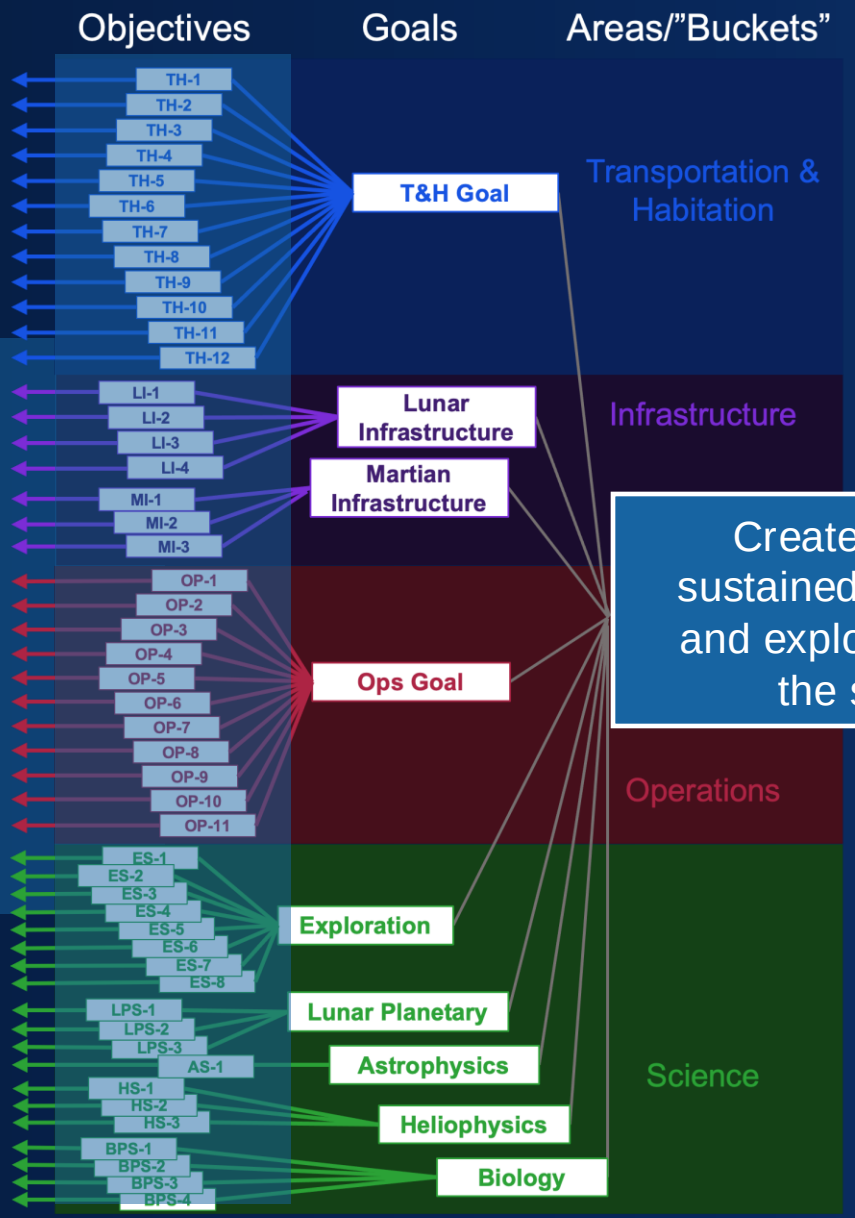
SOMD

STMD

Qualifiers and requirements

Objectives to ESDMD

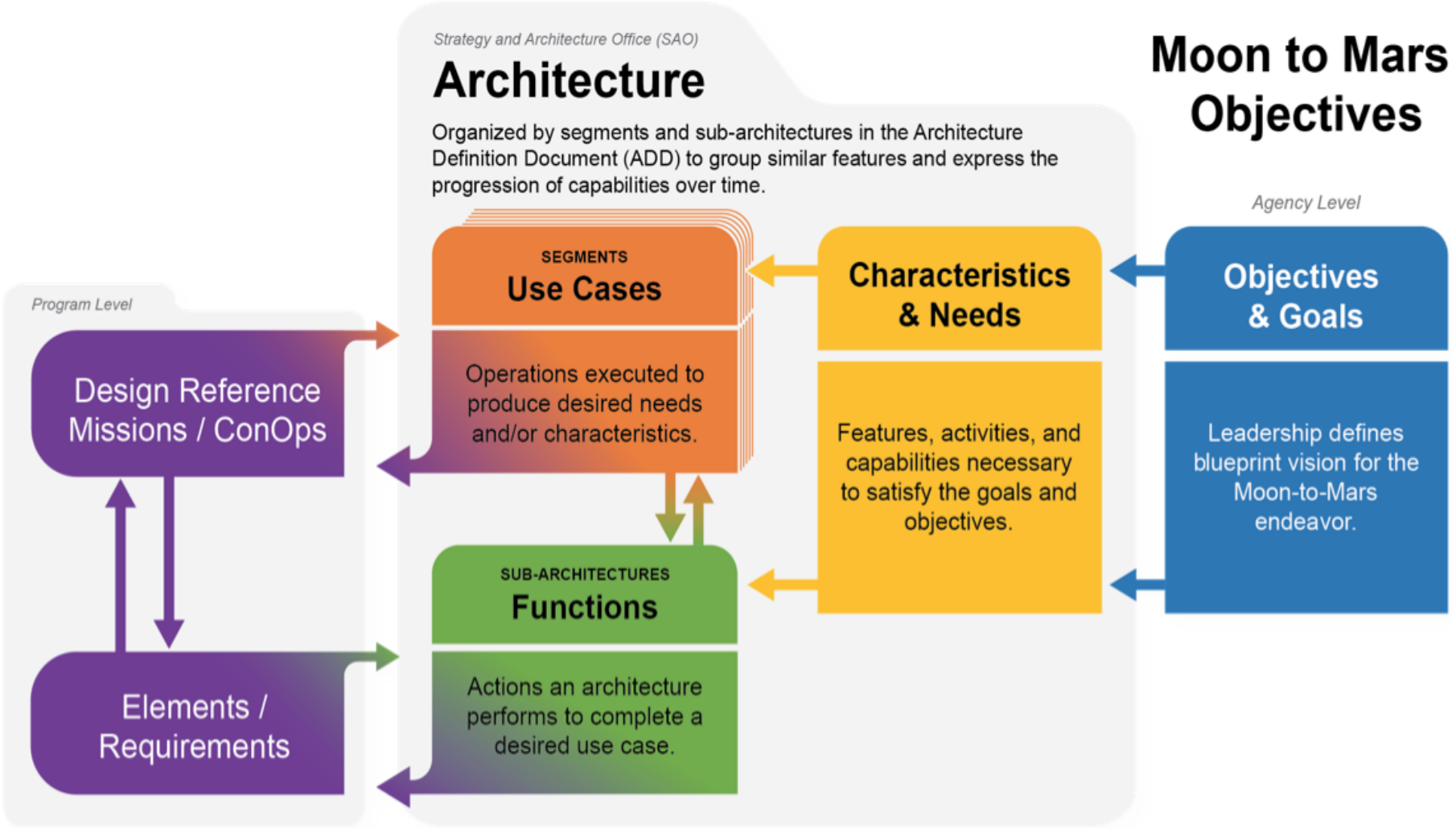




Create a blueprint for sustained human presence and exploration throughout the solar system

Moon to Mars Strategy Industry Workshop 28 July 2022, J. Free and K. Vogel

Moon to Mars Architecture Definition Document Decomposition From Objectives to Requirements



Moon to Mars Program Strategy, Objectives, and Architecture

Science, Industry, and International Space Agencies Getting Involved

January

- Release ADD topics for community comment

February

- By invitation only to those who submitted comments
- Status presentation
- Panel Q&A sessions

November

- Review and closure of previous year's ACR Actions
- Follow-on actions
- Identification of new actions based on current year's workshop findings

Moon to Mars Architecture Website

Strategic Analysis Cycle Task 24: Science Drivers for a Surface Habitat

NASA Lead: Kevin Sato

- Near-term need to define science drivers for Multi-Purpose Habitat
- Identify what long-term habitat capabilities are needed to address relevant science objectives
- Delineate between Intravehicular Activities and Extravehicular Activities needs
- Include the temporal priority of each science need
- Motivating use cases, functions, features that would significantly affect habitat design, mass, volume, power, etc
- Identify science enabling capabilities
- Science objectives achievable at a single location or if multiple locations are required

Lunar Surface Science Workshop

1-2 day workshop – in planning for week of August 20 - 21, 2024

Sustained Lunar Exploration

- Fundamental Physics
- Space Biology
- Physical Sciences
- Human Research Program
- Astrobiology
- Astrophysics

Lunar Surface Science Workshop for Planetary Sciences and Heliophysics was conducted April 4, 2024

Artemis Missions and BPS Science Opportunities

ARCHITECTURE SEGMENTS

HUMAN LUNAR RETURN

Initial capabilities, systems, and operations necessary to re-establish human presence and initial utilization (e.g., science) on and around the Moon.

- Orion, SLS, EGS, Gateway, HLS,
- Deep Space Logistics, xEVAS, CPNT
- Science
- Fundamental science research on all platforms
- Foundation and pathfinder investigations
- Fundamental science to close knowledge gaps and develop scientific models

FOUNDATIONAL EXPLORATION

Expansion of lunar capabilities, systems, and operations supporting complex orbital and surface missions to conduct utilization (e.g., science) and Mars-forward precursor missions.

- Lunar Terrain Vehicle, Pressurized Rover, Multi-Purpose Habitat, Large Cargo
- Fundamental science research on all platforms
- Initial expansion of science experiment conducted
- Fundamental science to close knowledge gaps and develop scientific models

SUSTAINED LUNAR EVOLUTION

Enabling capabilities, systems, and operations to support regional and global utilization (e.g., science), economic opportunity, and a steady cadence of human presence on and around the Moon.

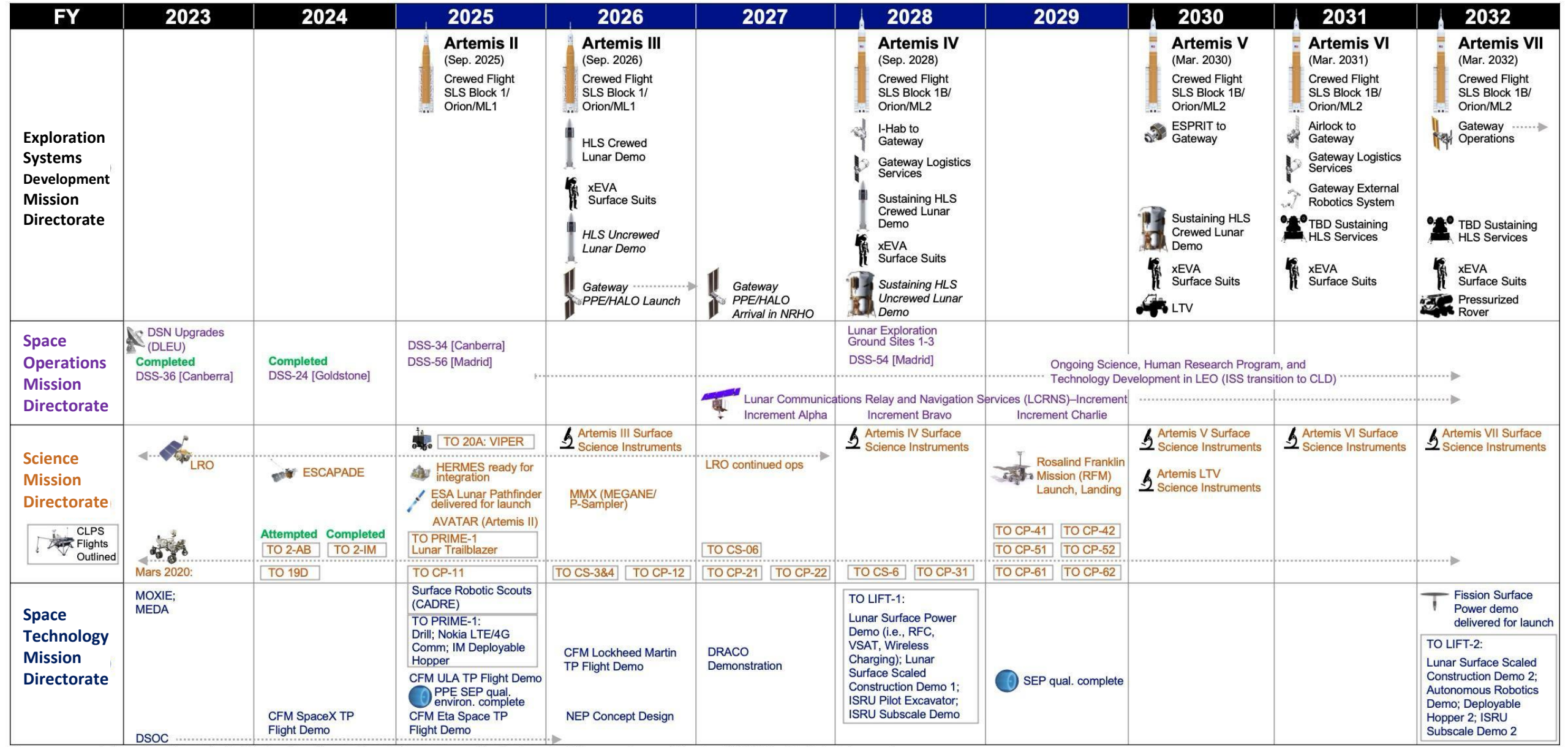
- Power, ISRU, Expanded mobility/habitation
- Further expansion the types of experiments conducted
- Fundamental science to close knowledge gaps and develop scientific models

HUMANS TO MARS

Initial capabilities, systems, and operations necessary to establish human presence and initial utilization (e.g., science) on Mars and continued exploration.

- Transportation, EDL, Ascent, Science Ops,
- Return needs
- New science during transit to and from and on the surface of Mars

FY 2025 President's Budget Request Moon to Mars Manifest



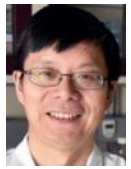
Icons are representative only, and may not reflect final configurations, not to scale | Icons represent the fiscal year in which an event occurs | Based on FY 2025 President's budget request

BioExpt-1

NASA KSC Project Management and Payload Developer

Dr. Federica Brandizzi, Michigan State University
Life Beyond Earth: Effect of Space Flight on Seeds with Improved Nutritional Value
Arabidopsis thaliana (Model Plant)
Grant # 80NSSC19K0707

Dr. Timothy Hammond, Institute for Medical Research, Inc
Fuel To Mars
Chlamydomas reinhardtii (Green Algae)
Grant # 80NSSC19K0706 nt # 80NSSC19K0706



Dr. Zheng Wang, Naval Research Laboratory
Investigating the Roles of Melanin and DNA Repairon Adaptation and Survivability of Fungi in Deep Space
Aspergillus niger (Fungus)
Grant # NNK19OB09A

Dr. Luis Zea, University of Colorado, Boulder
Multi-Generational Genome-Wide Yeast Fitness Profiling Beyond and Below Earth's van Allen Belts
Saccharomyces cerevisiae (Yeast)
Grant # 80NSSC19K07

ARTEMIS I

First mission
(uncrewed flight test)

COMPLETE

September 2025

BPS Pathfinder Tissue Investigation

- Multi-Government Agencies
- NASA Directorates
- Academia
- Commercial Space Company

ARTEMIS II

First crew

CREW SELECTED

2026

Science delivery on Starship with no specimen return

- Physical Sciences and Space Biology Investigations under evaluation
- Tank-to-tank cryogenic fluid transfer data sharing to be assessed by SpaceX

ARTEMIS III

SpaceX Starship
Uncrewed Demonstration

Segment: Human Lunar Return

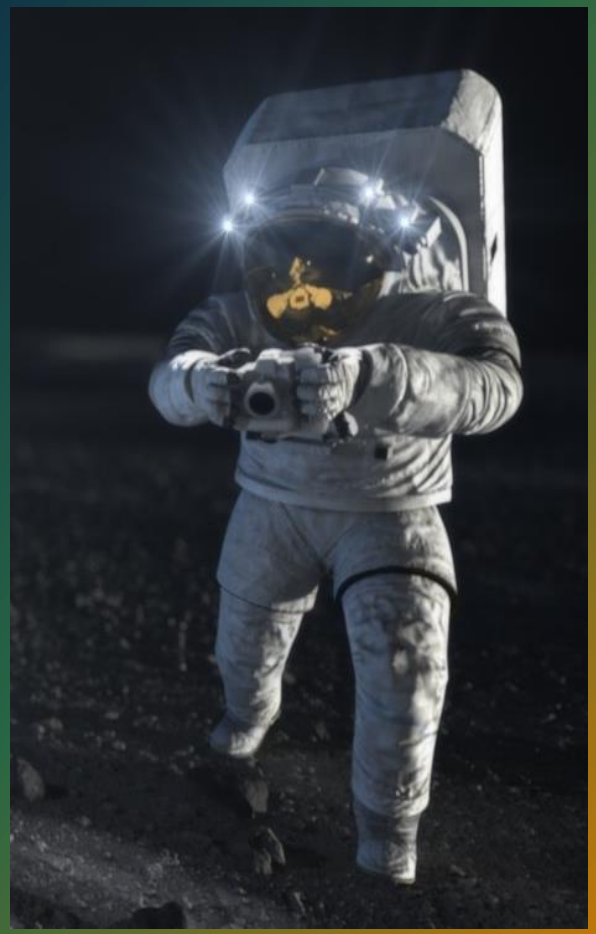
September 2026

Science payloads delivered on SpaceX Starship and Orion; specimen return on Orion

- Artemis III Deployed Instruments (A3DI) – LEAF
  - Co-Sponsorship between NASA Science Mission Directorate Exploration Science Strategy and Integration Office and Biological and Physical Sciences Division
- Tissue physiology investigation under assessment by Artemis

ARTEMIS III

First human surface landing



Artemis III Deployed Instruments (SMD ESSIO)

Lunar Effects on Agriculture Flora (LEAF)
Dr. Christine Escobar, Space Lab Technologies, LLC
Co-Sponsored by ESSIO and BPS Division

Lunar Environment Monitoring Station (LEM)
Dr. Mehdi Benna, University of Maryland

Lunar Dielectric Analyzer
Hideaki Miyamoto, University of Tokyo

LEAF

Lunar Effects on Agricultural Flora

Summary: LEAF will apply system biology and engineering to investigate the effects of the lunar surface environment on the short-term organism-wide physiological responses of model space crops.

Science Goals:

- Grow resilient model space-crops in lunar & Earth environments
- Compare crop phenotypes in lunar and Earth environments:
  1. Seed germination & clonal reproduction rates
  2. Crop morphology (size, orientation, and color) and growth
  3. CO_2 consumption and O_2 production
- Identify genome-wide biomolecular deviations in lunar grown crops
- Define future science hypotheses regarding crop potential for life support via photosynthetic gas exchange & nutrient production

PI: Christine Escobar, Space Lab Technologies LLC

Co-Sponsorship between ESSIO and BPS Division

Segment: Human Lunar Return

September 2028

Science payloads delivered on SpaceX Starship and the Deep Space Logistics Module; specimen return on Orion

- Gateway study in assessment
- Lunar surface study to be assessed
- Selected payloads: Gateway
  - European Radiation Sensor Array (ERSA)
  - European Internal Dosimeter Array (IDA)
  - SMD Heliophysics Environment and Radiation Measurement Experiment Suite (HERMES)
  - Human Research Instruments

ARTEMIS IV

First lunar space station assembly mission

TBD

Science delivery on Starship with no specimen return

- BPS will work with NASA HLS for opportunities to fly science payloads on this uncrewed mission

ARTEMIS V

Blue Orgin Blue Moon
Uncrewed Demonstration

Segment: Foundational Exploration

2030

Science payloads delivered on SpaceX Starship and the Deep Space Logistics Module; specimen return on Orion

- BPS Division has been working with the NASA ESSIO Lunar Traverse Rover (LTV) team on capabilities for supporting science
- BPS will investigation science payload opportunities that can use the capabilities of the LTV
- BPS will investigate science opportunities on the lunar surface and on Gateway

ARTEMIS V

First unpressurized rover

Segment: Foundational Exploration

2031 and Beyond

Science payloads delivered on Blue Moon and the Deep Space Logistics Module; specimen return on Orion

- BPS Division has been working with the NASA ESSIO and the Pressurized Rover team (NASA and JAXA) on capabilities for supporting science
- BPS Division has been working with the NASA ESDMD team studying the capabilities for the Multi-Purpose Habitat
- BPS will investigation science payload opportunities that can use the capabilities of the Pressurized Rover
- BPS will investigate science opportunities on the lunar surface and on Gateway

ARTEMIS VI and Beyond

First pressurized rover

Multi-Purpose Habitat

Segments: Foundational Exploration to Sustained Lunar Evolution

ARTEMIS BEYOND

Longer missions = preparation for human Mars missions

Access to more of the Moon = new scientific discoveries

Where Are We Going?

Image Credit: NASA/ASU

Artemis III Candidate Landing Regions

KEY LANDING REGION CHARACTERISTICS

Close proximity to the geographic South Pole

Gentle slope for landing and moonwalks

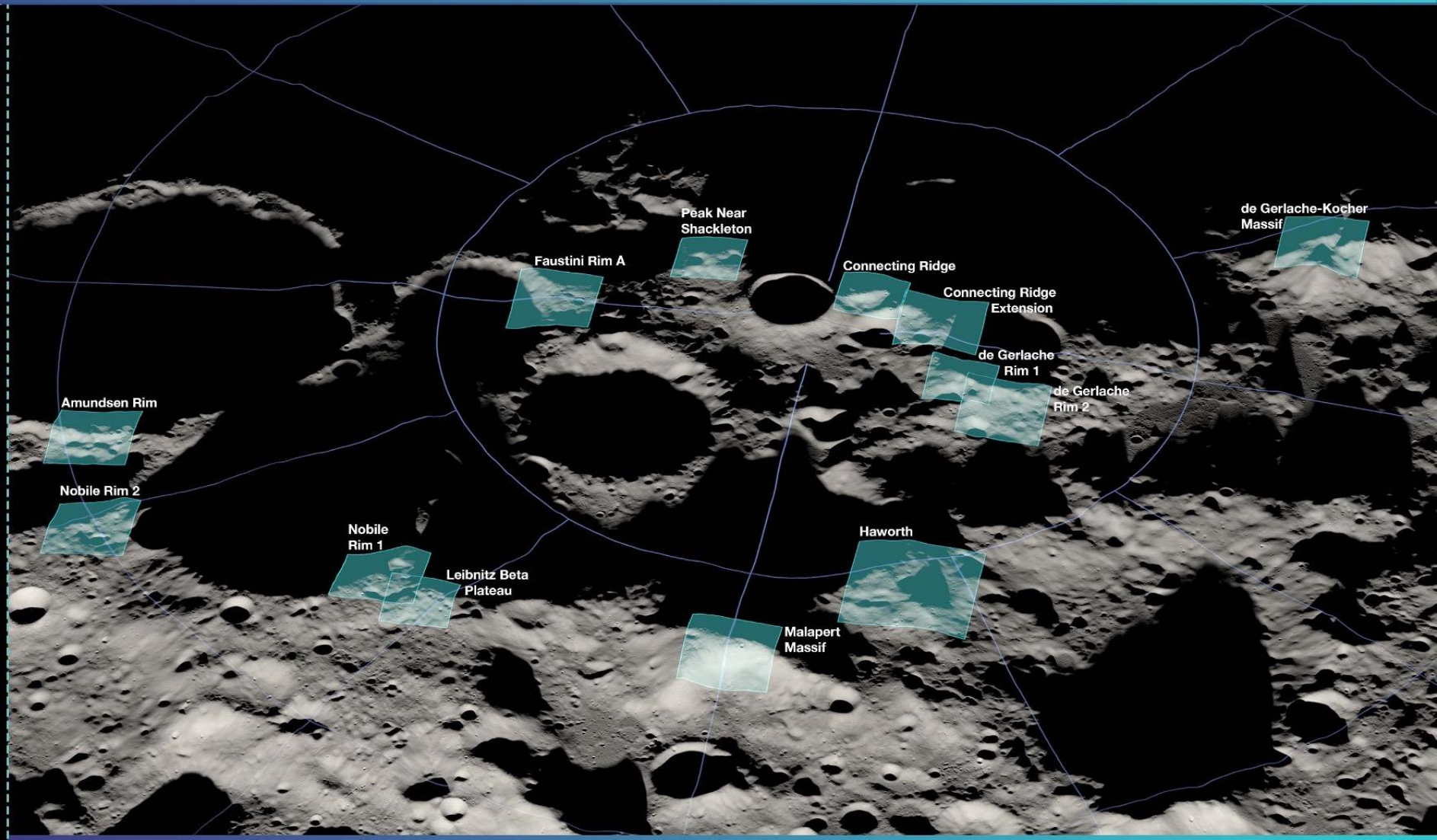
Constant view to Earth for communications

Continuous sunlight throughout the surface expedition of about 6.5 days

Surface data resolution

Combined mission vehicle capabilities: Space Launch System, Orion spacecraft, Starship Human Landing System

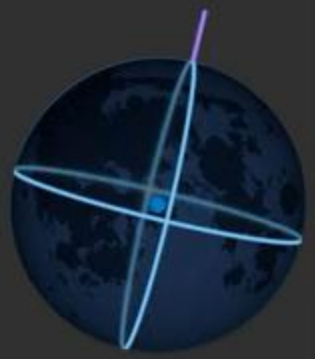
A landing *region* is approximately 15 km^2. Each landing region includes multiple potential landing sites.



Video Credits: NASA Scientific Visualization Center

Sun Path

Looking
EAST



Subsolar
Longitude
179°E

Earth Days

0

Video Credits: NASA Scientific Visualization Ce

9°S
APOLLO 16

26°N
APOLLO 15

60°N

90°S

Video Credits: NASA Scientific Visualization Center

Upcoming Science Opportunities and Community Involvement

Get Involved in Artemis!

- **Upcoming ESSIO Artemis-related calls:**
  - Lunar Mapping Program – proposals due 6/12
  - Analog Activities Program – proposals due 12/6
  - Artemis 3 Participating Scientist Program
  - Artemis 4 Deployed Instruments (2024)
  - Artemis Handheld Instruments
  - Lunar Terrain Vehicle Instruments
  - PRISM-SALSA CLPS Solicitation (2024)
  - PRISM-4 Solicitation (2025)
  - Gateway Solicitations (U.S. and International)
- **Opportunities to provide input:**
  - Lunar Surface Science Workshop
  - Sustained Lunar Exploration (Aug. 20-21)
  - LEAG, ExMAG, MEPAG
  - LEAG is soliciting for a single community representative for biological and physical sciences
  - Upcoming NAS and SDT studies

Thank You!