National Aeronautics and
Space Administration

EXPLORE SCIENCE

Exploration Science Strategy and Integration Office

Brad Bailey, PhD
Assistant Deputy Associate Administrator for Exploration
Science Mission Directorate, NASA HQ

Commercial Lunar Payload Services (CLPS)

- CLPS is an innovative, service-based, competitive acquisition approach that enables rapid, affordable, and frequent access to the Lunar surface via a growing market of American commercial providers
  - To the greatest legal and practical extent CLPS attempts to model common terrestrial deliveries such as FedEx, UPS, etc.
- Service task orders are Firm Fixed Price (FFP) for the full scope of payload delivery: from payload hand-over to delivery (and often operation) on the lunar surface or in CIS lunar space.
- NASA wants to be one of many customers for CLPS services
  - Ideally, CLPS contractors will eventually deliver manifests that include no NASA payloads.
- CLPS deliveries are CLPS Contractor missions (not NASA missions); NASA imposes no NASA policies that would normally apply to a NASA mission.
- CLPS providers secure all necessary hardware, systems, facilities and services to perform the delivery; including launch vehicle and comm/nav systems.
  - NASA has no oversight and limited insight into CLPS vehicle/mission designs and processes.
  - NASA LSP (Launch Services Program) is not engaged in launch vehicle acquisition
- CLPS launches are commercial launches acquired/provided by CLPS provider and approved/licensed by the U.S. Gov't FAA , FCC, and other agencies (not NASA)

A CLPS contractor's business model and regulatory obligation should be the same whether NASA is a customer or not.

CLPS IDIQ Contract and Portfolio

- 14 domestic companies eligible to compete for Lunar surface delivery task orders
- 9 awarded lunar surface deliveries actively in work with initial deliveries as soon as this year.
- NASA expects to continue cadence of ~2 flights per year subject to funding availability.
- CLPS contractors are encouraged to sell lunar delivery services outside of the CLPS IDIQ to non-NASA and non-USG customers.

Initial CLPS companies (Nov 2018):

- *Astrobotic*
- *Deep Space Systems*
- *Draper*
- *Firefly Aerospace*
- *Intuitive Machines*
- *Lockheed Martin Space*
- *Masten Space Systems*
- *Moon Express*
- *Orbit Beyond*

First On-Ramp (Nov 2019):

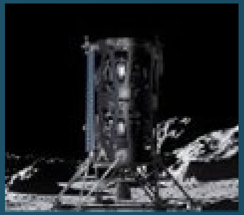
- *Blue Origin*
- *Ceres Robotics*
- *Sierra Nevada Corporation*
- *SpaceX*
- *Tyvak Nano-Satellite Systems, Inc.*

Awarded Deliveries:

TO2 2023
Astrobotic
Peregrine

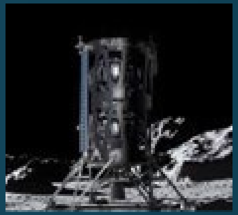
TO2/20C 2023
Intuitive Machines
NOVA-C

TO PRIME-1 2023
Intuitive Machines
NOVA-C



TO19C 2023
Masten
XL-1

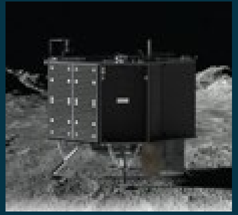
CP-11 2024
Intuitive Machines
NOVA-C



TO19D 2024
Firefly Aerospace
Blue Ghost

TO20A 2024
Astrobotic
Griffin

CP-12 2025
Draper
Series-2



TOCS3 2026
Firefly Aerospace
Blue Ghost

CLPS Deliveries

2023-2026

Delivery Site:
Gruithuisen Domes
Provider TBD
CP-21 | 2026

Delivery Site:
Sinus Viscositatis
Provider: Astrobotic
TO2-AB | May 2023

Delivery Site:
Lunar Far Side & Orbit Insertion
Provider: Firefly
CS-3 | 2026

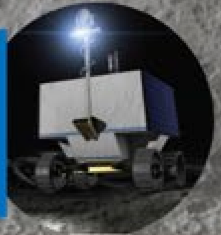
Delivery Site:
Reiner Gamma
Provider: IM
CP-11 | 2024

Delivery Site: Malapert A
Provider: Intuitive Machines (IM)
TO2-IM | June 2023

Delivery Site:
Mare Crisium
Provider: Firefly
TO19D | 2024

Delivery Site:
Shackleton Connecting Ridge **Provider:** IM
TO PRIME-1 | Q4 2023

Delivery Site:
Nobile Crater
Provider : Astrobotic
VIPER | Nov 2024



Delivery Site:
Schrödinger Basin
Provider: Draper
CP-12 | 2025

Delivery Site:
South Pole Region
Provider TBD
CP-22 | 2026

Delivery Site:
Haworth Crater
Provider: Masten
TO19C | Nov 2023

Updated 3/17/2023

CLPS Lessons Learned

Recommendation: NASA should continue to support commercial innovation in lunar exploration. Following demonstrated success in reaching the lunar surface, NASA should develop a plan to maximize science return from CLPS by, for example, allowing investigators to propose instrument suites coupled to specific landing sites. NASA should evaluate the future prospects for commercial delivery systems within other mission programs and consider extending approaches and lessons learned from CLPS to other destinations, e.g., Mars and asteroids. (Ch 22, CLPS Rec.)

- Origins, Worlds and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032

Lessons Learned (Thus far)

- Cost is not linear with any particular metric
- Augmented Insight
- Establishment of lunar economy and international contributions
- Cost does not go down as we continue to add new desired capabilities

A Keck Institute for Space Studies (KISS) Workshop

A study on how to substantially reduce the cost associated with landed missions to Mars

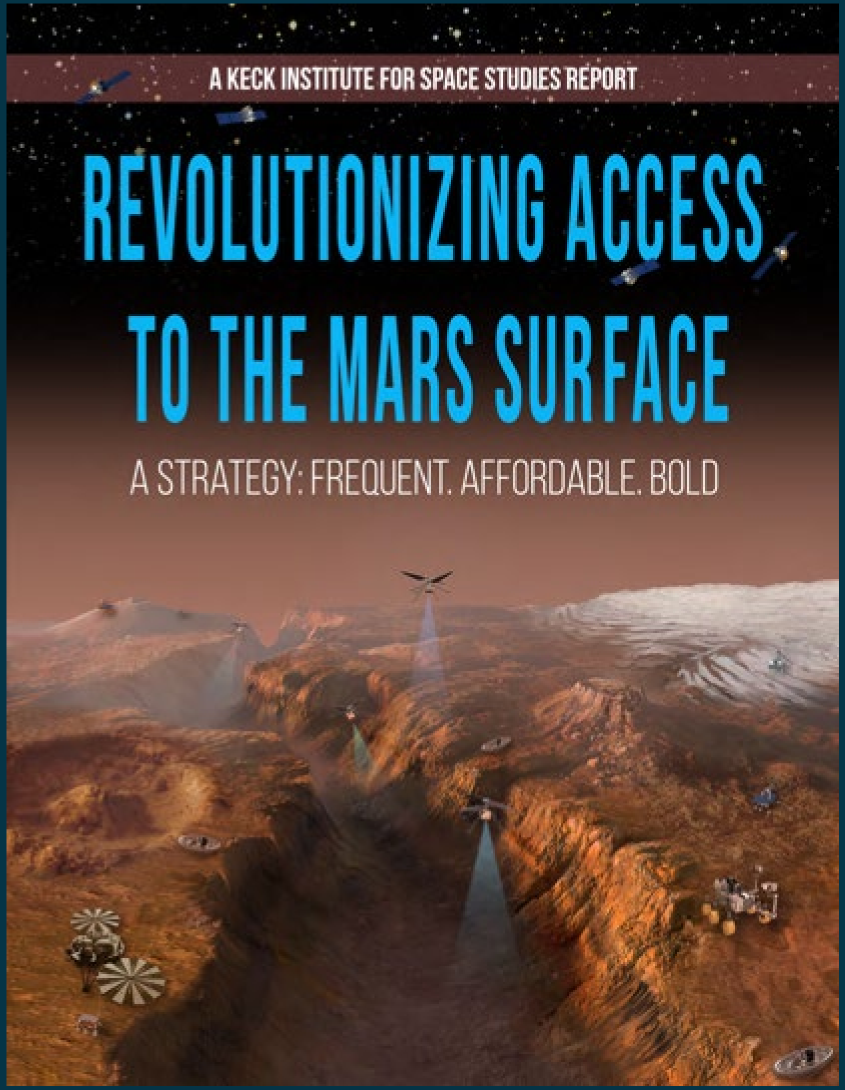
Workshop 1: April 2021, incl. recorded half-day short course

3-month summer study period: working groups addressed specific programmatic, cultural, and engineering factors

Workshop 2: September 2021

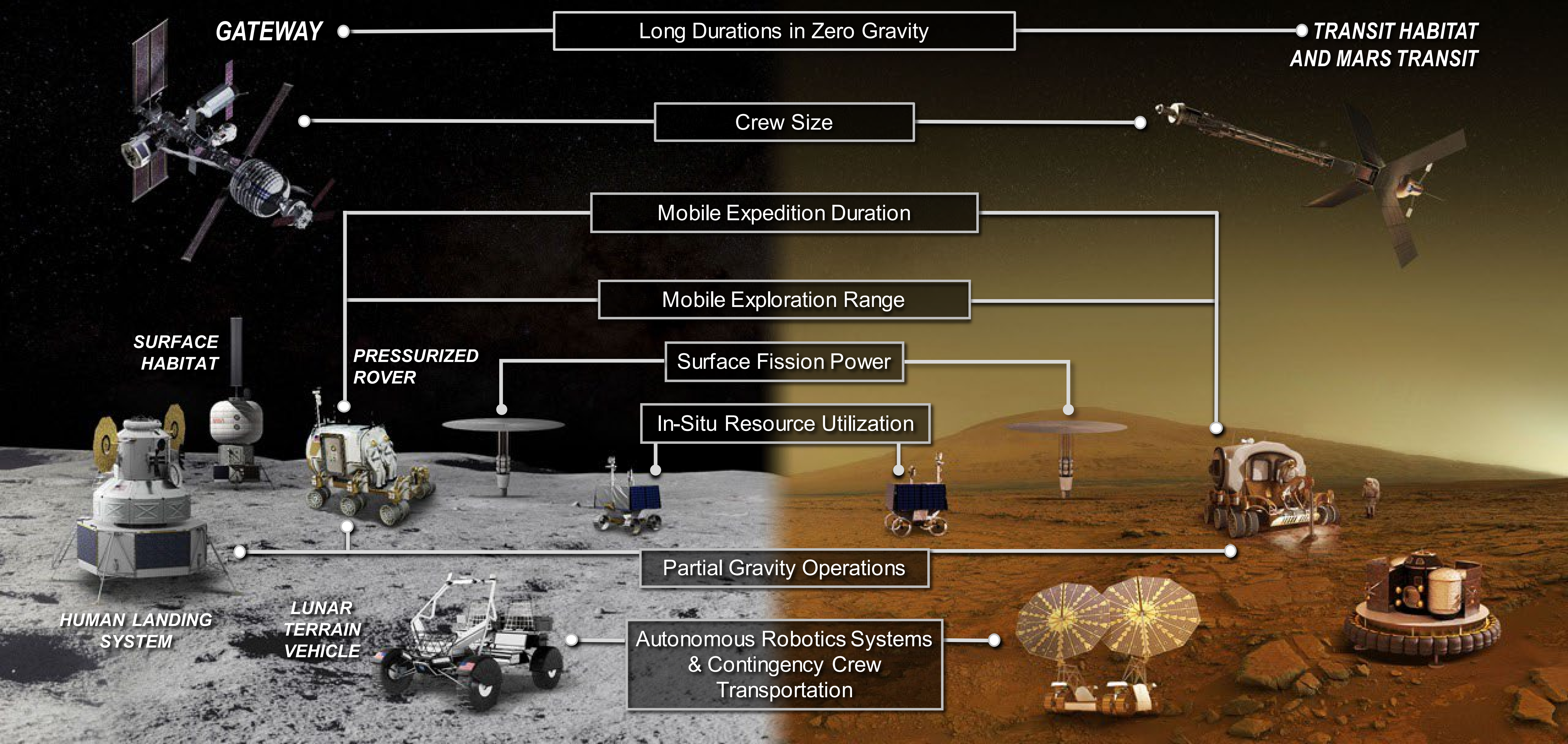
Full report at:

https://kiss.caltech.edu/programs.html#access2mars



MOON AND MARS EXPLORATION

Operations on and around the Moon will help prepare for the first human mission to Mars



The Moon to Mars Architecture is Inherently Common

IN ORBIT

DEEP SPACE AGGREGATION
Assembling a complex ship in deep space

MARS TRANSIT HABITAT
Round the clock, years-long operations of a Mars-class habitat and life support system

ORBIT TO SURFACE OPERATIONS
Operating an orbiting outpost that deploys a lander and its crew to a planetary surface

COMMERCIAL RESUPPLY AND REFUELING
Leveraging the space logistics supply chain for industry provided cargo deliveries

CREW HEALTH & PERFORMANCE
Studying how the human body and mind adapt to deep space hazards

A roundtrip mission to Mars will take about two to three years—and once the ship's course is set, there's no turning back.

As much as is possible, lunar systems will be designed for dual Moon-Mars operations.

Integrated missions in the lunar vicinity prepare us for successful Mars missions.

ON THE SURFACE

SPACESUIT ADVANCEMENTS
Improving spacesuit design across Artemis missions with astronaut input and private sector innovation

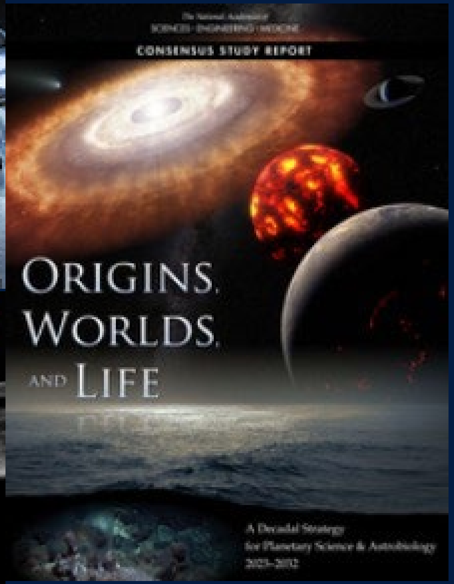
MOBILE OPERATIONS
Living and working 'on the go' inside a mobile habitat for weeks at a time

PLANETARY PROTECTION
Mitigating dust transfer and establishing pristine sample curation protocols

HUMAN ROBOTIC EXPLORATION
Robots pre-positioning surface assets and conducting reconnaissance for astronauts

HUMAN RESILIENCE
Learning how humans can survive and thrive in a partial gravity environment

High Priority Science at the Moon and Mars



NASA SCIENCE MISSION DIRECTORATE (SMD) | 2020

Artemis III Science Definition Team Report

https://www.nasa.gov/sites/default/files/atoms/files/artemis-iii-science-definition-report-12042020c.pdf

NATIONAL ACADEMIES OF SCIENCES, ENGINEERING, AND MEDICINE (NASEM) | 2022

Origins, Worlds, and Life (OWL): A Decadal Strategy for Planetary Science and Astrobiology 2023–2032

https://nap.nationalacademies.org/read/26522/chapter/1

NASA | 2022

Moon to Mars Objectives

https://www.nasa.gov/sites/default/files/atoms/files/m2m-objectives-exec-summary.pdf

NASA'S MOON TO MARS STRATEGY AND OBJECTIVES DEVELOPMENT (2023)

https://www.nasa.gov/sites/default/files/atoms/files/m2m_strategy_and_objectives_development.pdf

Science Objectives (1 of 4)

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 Moon and Mars.

LPS-2^{LM}: Advance understanding of the geologic processes that affect planetary bodies by determining the interior structures, characterizing the magmatic histories, characterizing ancient, modern, and evolution of atmospheres/exospheres, and investigating how active processes modify the surfaces of the Moon and Mars.

LPS-3^{LM}: Reveal inner solar system volatile origin and delivery processes by determining the age, origin, distribution, abundance, composition, transport, and sequestration of lunar and Martian volatiles.

LPS-4^{M}: Advance understanding of the origin of life in the solar system by identifying where and when potentially habitable environments exist(ed), what processes led to their formation, how planetary environments and habitable conditions have co-evolved over time, and whether there is evidence of past or present life in the solar system beyond Earth.

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.

Full M2M Objectives: https://www.nasa.gov/sites/default/files/atoms/files/m2m-objectives-exec-summary.pdf

Superscripts indicate applicability to Lunar (L), Martian (M), or both (LM)

Science Objectives (2 of 4)

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, support safe, productive human space missions and 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 & performance systems and operations with mission durations representative of Mars-class missions.

HBS-3[LM]: Characterize and evaluate how the interaction of exploration systems and the deep space environment affect human health, performance, and space human factors to inform future exploration-class missions.

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.

Full M2M Objectives: https://www.nasa.gov/sites/default/files/atoms/files/m2m-objectives-exec-summary.pdf

Superscripts indicate applicability to Lunar (L), Martian (M), or both (LM)

Science Objectives (3 of 4)

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 to remotely support astronaut surface and deep space activities using advanced techniques and tools.

SE-3^{LM}: Develop the capability to retrieve core samples of frozen volatiles from permanently shadowed regions on the Moon and volatile-bearing sites on Mars and to deliver them in pristine states to modern curation facilities on Earth.

SE-4^{LM}: Return representative samples from multiple locations across the surface of the Moon and Mars, with sample mass commensurate with mission-specific science priorities.

SE-5^{LM}**:** Use robotic techniques to survey sites, conduct in-situ measurements, and identify/stockpile samples in advance of and concurrent with astronaut arrival, to optimize astronaut time on the lunar and Martian surface and maximize science return.

SE-6^{LM}: Enable long-term, planet-wide research by delivering science instruments to multiple science-relevant orbits and surface locations at the Moon and Mars.

SE-7^{LM}**:** Preserve and protect representative features of special interest, including lunar permanently shadowed regions and the radio quiet far side as well as Martian recurring slope lineae, to enable future high-priority science investigations.

Full M2M Objectives: https://www.nasa.gov/sites/default/files/atoms/files/m2m-objectives-exec-summary.pdf

Superscripts indicate applicability to Lunar (L), Martian (M), or both (LM)

Science Objectives (4 of 4)

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.

Full M2M Objectives: https://www.nasa.gov/sites/default/files/atoms/files/m2m-objectives-exec-summary.pdf

Superscripts indicate applicability to Lunar (L), Martian (M), or both (LM)

A NASEM Study: High Priority Science Objectives and Associated Measurements Substantively Enhanced by Human Explorers at Mars

NASA recognizes the importance of defining science goals and objectives as early as possible to inform and drive architecture design.

This Academies study will define and prioritize key science objectives substantially enabled by human explorers enroute to/from and at Mars, as well as to identify the key measurements and associated equipment needed to address those science objectives.

Recommendations would be used during early stages of ESDMD program planning, to guide decisions on human exploration architecture capabilities and requirements

> "NASA should engage with the science community to define scientific goals for its human exploration programs at the early stages of program planning" (Chapter 19 Recommendation #2).
>
> "… conducting decadal-level science should be a central requirement of the overall human exploration program" (Chapter 22, Recommendation #32).
>
> - Origins, Worlds and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032