National Aeronautics and Space Administration

EXPLORESCIENCE

Human Exploration, Artemis, Moon & Mars

Decadal Survey Supplemental Presentation

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Science Mission Directorate

Introduction

This input to the Decadal Survey presents high-level information on the current state of Artemis, as applicable to NASA. The intent of these slides is to assist the Committee in the beginning of their deliberations, and NASA welcomes the opportunity to speak further to the Committee on this topic.

The final slide of this presentation includes specific requests from NASA for the Decadal Survey Committee.

<u>Decadal Survey Statement of Task, Study Approach</u>

NASA invites input on where its research and mission programs can support and leverage Agency human exploration and lunar exploration activities (including but not limited to the Artemis program). Recommendations on the research strategy should explicitly reference those opportunities, where appropriate. Documents describing these activities will be delivered to the Survey Committee before or at the first meeting.

Overview

- Artemis, Human Spaceflight
  - Artemis Architecture
  - Artemis Science Objectives
  - Human Spaceflight
- Lunar Activities
  - Lunar infrastructure
  - Lunar Science
  - Gateway, HERMES
- Mars Exploration Mission Concept (for analysis purposes only)
- Request for the Decadal Survey
  - Additional information to inform discussions

Artemis: An Overview

Artemis: A Foundation for Deep Space Exploration


Space Launch System


Orion spacecraft


Human Landing System


Surface Operations

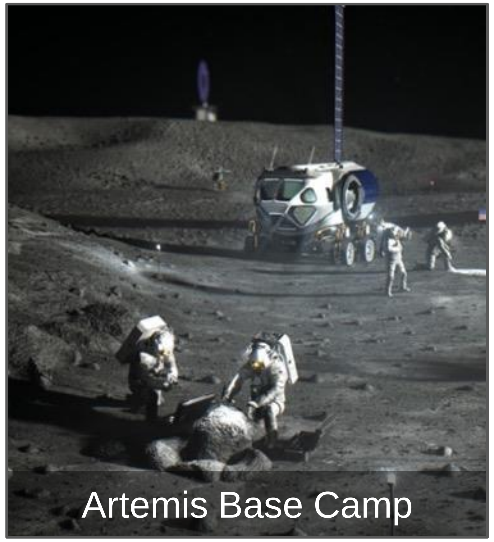

Gateway

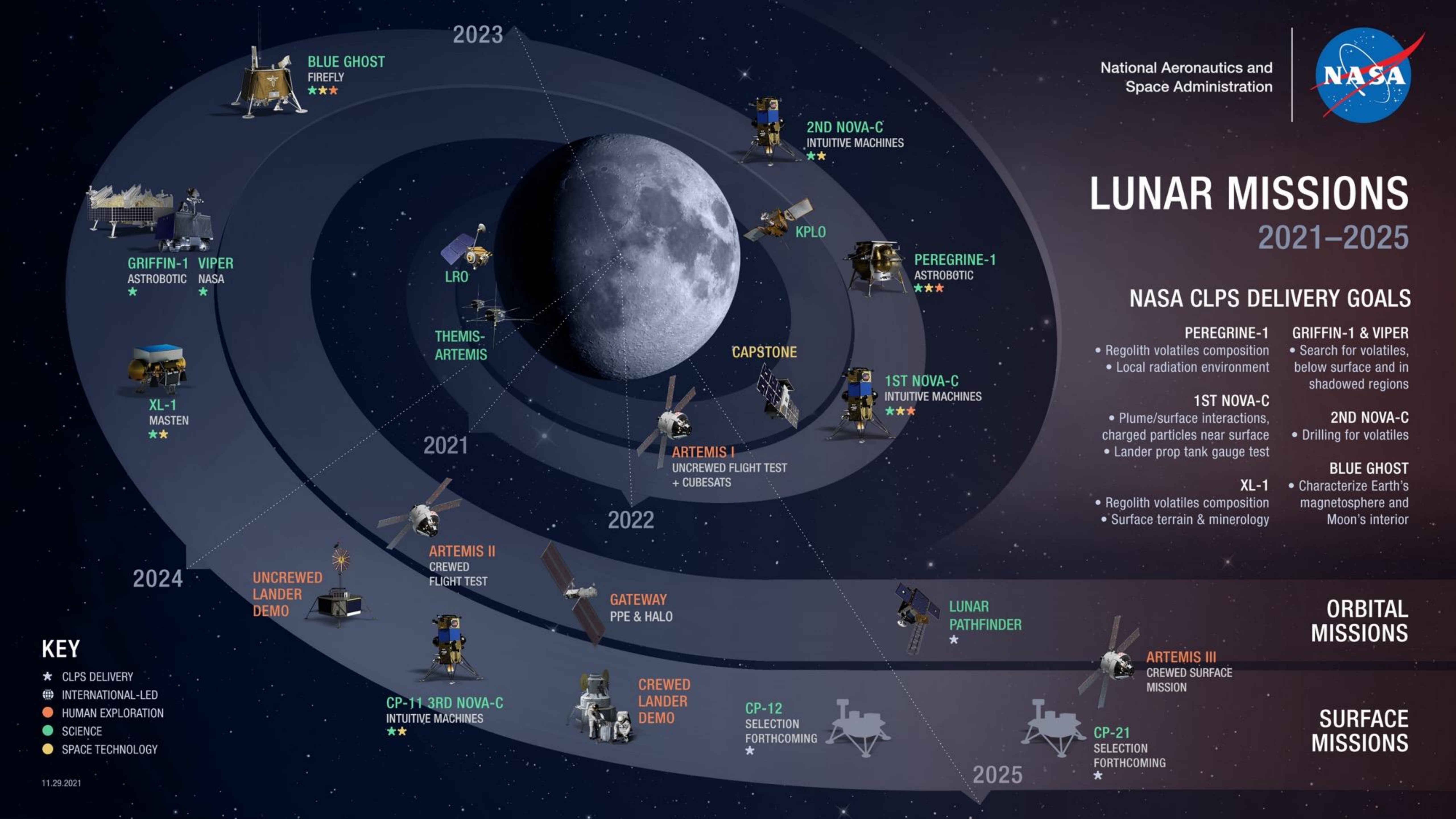

Exploration Ground Systems


Space Communications & Navigation


Surface Mobility


Space Suits


Artemis Base Camp


National Aeronautics and Space Administration
NASA
LUNAR MISSIONS
2021–2025
NASA CLPS DELIVERY GOALS
PEREGRINE-1
• Regolith volatiles composition
• Local radiation environment
1ST NOVA-C
• Plume/surface interactions, charged particles near surface
• Lander prop tank gauge test
XL-1
• Regolith volatiles composition
• Surface terrain & minerology
GRIFFIN-1 & VIPER
• Search for volatiles, below surface and in shadowed regions
2ND NOVA-C
• Drilling for volatiles
BLUE GHOST
• Characterize Earth's magnetosphere and Moon's interior
ORBITAL MISSIONS
SURFACE MISSIONS
2021
2022
2023
2024
2025
BLUE GHOST
FIREFLY
2ND NOVA-C
INTUITIVE MACHINES
KPLO
LRO
PEREGRINE-1
ASTROBOTIC
GRIFFIN-1
ASTROBOTIC
VIPER
NASA
THEMIS-ARTEMIS
CAPSTONE
1ST NOVA-C
INTUITIVE MACHINES
XL-1
MASTEN
ARTEMIS I
UNCREWED FLIGHT TEST + CUBESATS
ARTEMIS II
CREWED FLIGHT TEST
UNCREWED LANDER DEMO
GATEWAY
PPE & HALO
LUNAR PATHFINDER
ARTEMIS III
CREWED SURFACE MISSION
CP-11 3RD NOVA-C
INTUITIVE MACHINES
CREWED LANDER DEMO
CP-12
SELECTION FORTHCOMING
CP-21
SELECTION FORTHCOMING
KEY
CLPS DELIVERY
INTERNATIONAL-LED
HUMAN EXPLORATION
SCIENCE
SPACE TECHNOLOGY
11.29.2021

Artemis Science Objectives and Traceability to Science Priorities

NASA's Artemis Plan laid out seven Science Objectives:

- **Objective 1**: Understanding Planetary Processes
- **Objective 2**: Understanding the Character and Origin of Lunar Volatiles
- **Objective 3**: Interpreting the Impact History of the Earth-Moon system
- **Objective 4**: Revealing the Record of the Ancient Sun and Our Astronomical Environment
- **Objective 5**: Observing the Universe and the Local Space Environment from a Unique Location
- **Objective 6**: Conducting Experimental Science in the Lunar Environment
- **Objective 7**: Investigating and Mitigating Exploration Risks

The Artemis III Science Definition Team was charged with expanding upon these Objectives using community documents, such as the Lunar Exploration Roadmap, Science Context for Exploration of the Moon, and 2013-2022 Planetary Decadal Survey to guide them.

Moon to Mars Science Objectives: Heliophysics Science

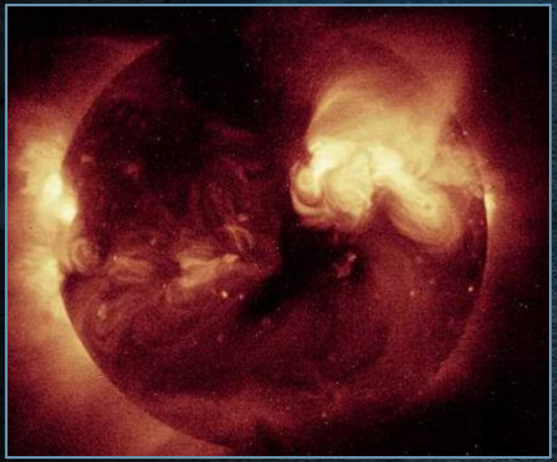
NASA's Moon to Mars strategy identifies goals for each Agency capability.

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

- **Objective HS-1**: 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
- **Objective HS-2:** Determine the history of the Sun and Solar System as recorded in the lunar and martian regolith
- **Objective HS-3:** Investigate and characterize fundamental plasma processes, including dust-plasma interactions, using the cislunar/cis-martian and near-surface environment as a laboratory
- **Objective HS-4:** Compare magnetotail and pristine solar wind dynamics in the vicinity of the Moon and around Mars

These draft Goal and Objectives were released in May 2022 for public comment. Internal review of received comments is underway.

Record of the Ancient Sun



EXPLORATION REQUIREMENTS

- *Collection of core tube samples to capture ancient solar wind trapped in regolith layers*
- *Understanding regolith stratigraphy*

- The Moon's surface has been bathed in solar wind, cosmic rays throughout its history
- Dust grains retain these particles

- Buried regolith and regolith trapped between lava flows retains the historical record of these fluxes
- Detailed excavation and study by humans can retrieve this record to understand how the Sun has changed through time

Human Spaceflight

Hazards of Human Spaceflight

1 Space Radiation

Invisible to the human eye, radiation increases cancer risk, damages the central nervous system, and can alter cognitive function, reduce motor function and prompt behavioral changes.

2 Isolation and Confinement

Sleep loss, circadian desynchronization, and work overload may lead to performance reductions, adverse health outcomes, and compromised mission objectives.

3 Distance from Earth

Planning and self-sufficiency are essential keys to a successful mission. Communication delays, the possibility of equipment failures and medical emergencies are some situations the astronauts must be capable of confronting.

4 Gravity (or lack thereof)

Astronauts encounter a variance of gravity during missions. On Mars, astronauts would need to live and work in three-eighths of Earth's gravitational pull for up to two years.

5 Hostile/Closed Environments

The ecosystem inside a vehicle plays a big role in everyday astronaut life. Important habitability factors include temperature, pressure, lighting, noise, and quantity of space. It's essential that astronauts stay healthy and happy in such an environment.

Human Landing System

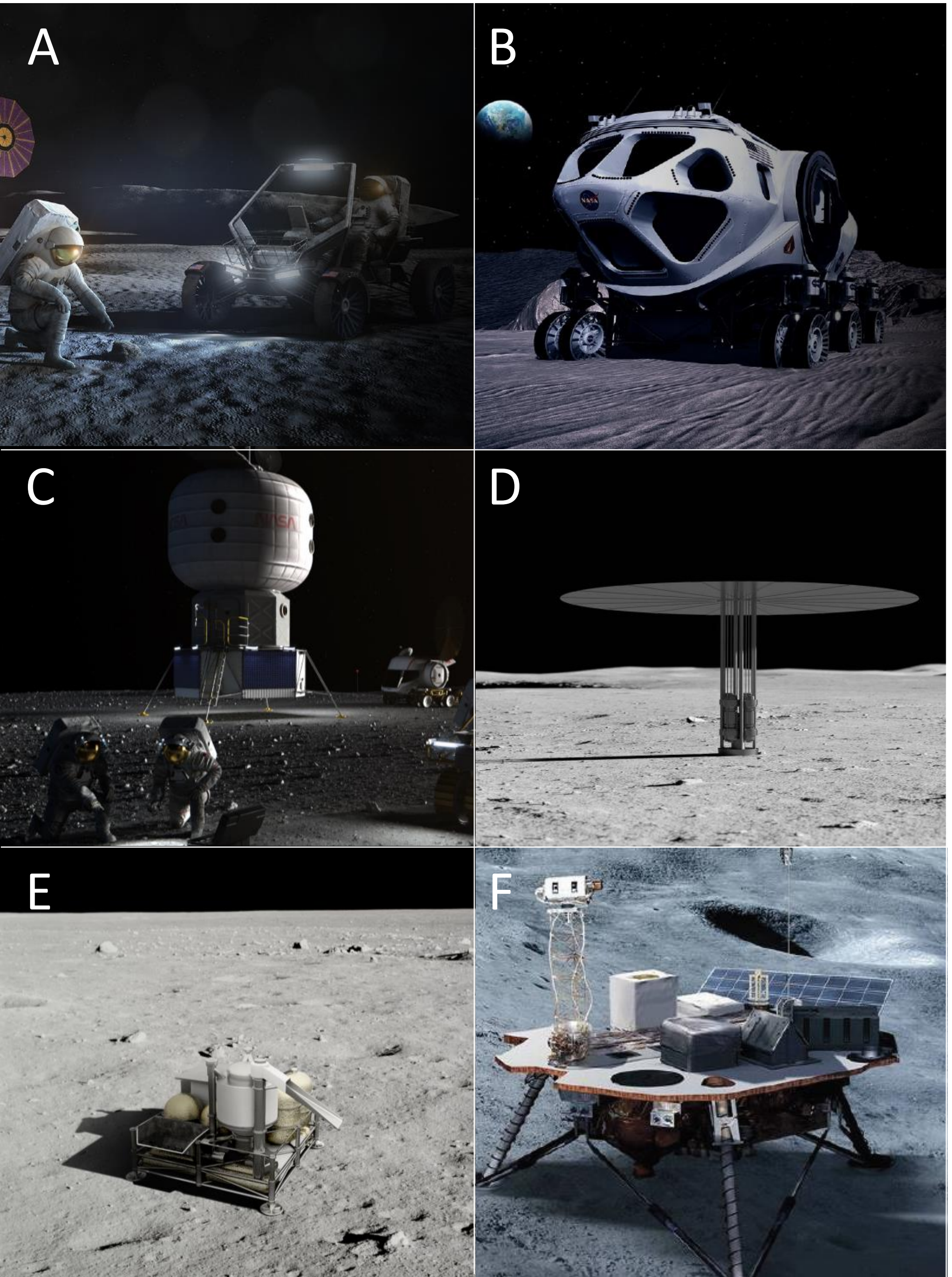
HLS

The first human landing systems in history to be developed by U.S. industry will take astronauts from lunar orbit to the surface and back again.

- Carries crew to the lunar surface and returns them to lunar orbit
- Serves as a habitat on the lunar surface for early Artemis missions
- Houses equipment for surface activities including moonwalks, sample collection, and scientific experiments

Image Credit: SpaceX

Lunar Infrastructure



Lunar Infrastructure allows for a long-duration, sustainable, human presence on the Moon

A) The Lunar Terrain Vehicle (LTV) provides local mobility for crew to expand the reach of geological science investigations

B) The Pressurized Rover significantly broadens the accessible area for crewed and uncrewed exploration and science investigations

C) The Surface Habitat will provide living quarters, laboratory space, and a stable home base from which we can explore and conduct science

D) Fission Surface Power provides reliable power to human landers, deployed science instruments, and ISRU systems

E) In Situ Resource Utilization means we can “live off the land” and utilize the resources available on the lunar surface, including water, power, oxygen, and construction materials

F) The **Commercial Lunar Payloads Services (CLPS)** initiative leverages US industry to deliver payloads to the lunar surface that include scientific investigations, technology demonstrations, and supplies for crewed missions

Lunar Discovery and Exploration Program (LDEP)

SMD's Lunar Discovery and Exploration Program (LDEP):

- Develops lunar surface science instruments that address Decadal and other community document science priorities
  - NASA-internal payloads, Community-developed payloads, PRISM, DALI
- Uses commercial companies to deliver payloads to the Moon (CLPS)
- Develops mobility systems to expand and enhance science investigations on the lunar surface
- Leverages international partnerships for additional opportunities (e.g., instruments, rovers)
- Defines, integrates and leads Artemis science efforts across SMD, other NASA mission directorates, and with other US and international agencies

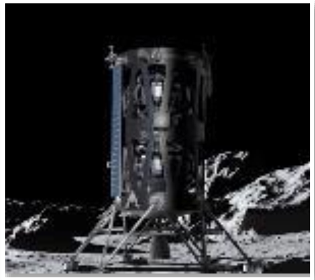
"… infusing decadal-level science goals into both the Lunar Discovery and Exploration Program in general, and into the Artemis program in particular, is viewed by the committee as an essential priority for the next decade." - Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032

Commercial Lunar Payload Services (CLPS)

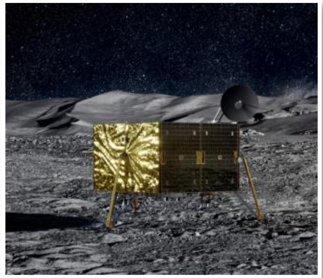
- CLPS is an innovative, service-based model designed to utilize commercial landers to quickly, and affordably, deliver payloads to the lunar surface
- 14 American companies are currently included as CLPS vendors and can bid on deliveries of prescribed payloads to specified locations on the lunar surface
- CLPS payloads are customer-owned, delivered items, but the missions are vendor missions, not NASA missions
- Services provided by CLPS vendors include landing, power, communications, data, operations, and may evolve to include other services as required by the customers
- 7 deliveries with 44 NASA instruments have thus far been awarded to be delivered through 2025, with an expected cadence of two deliveries per year sponsored by SMD

TO2 2022
Astrobotic
Peregrine

TO2/20C 2022
Intuitive Machines
NOVA-C



TO19C 2023
Masten
XL-1



TO PRIME-1 2023
Intuitive Machines
NOVA-C

TO20A 2023
Astrobotic
Griffin

TO19D 2024
Firefly Aerospace
Blue Ghost

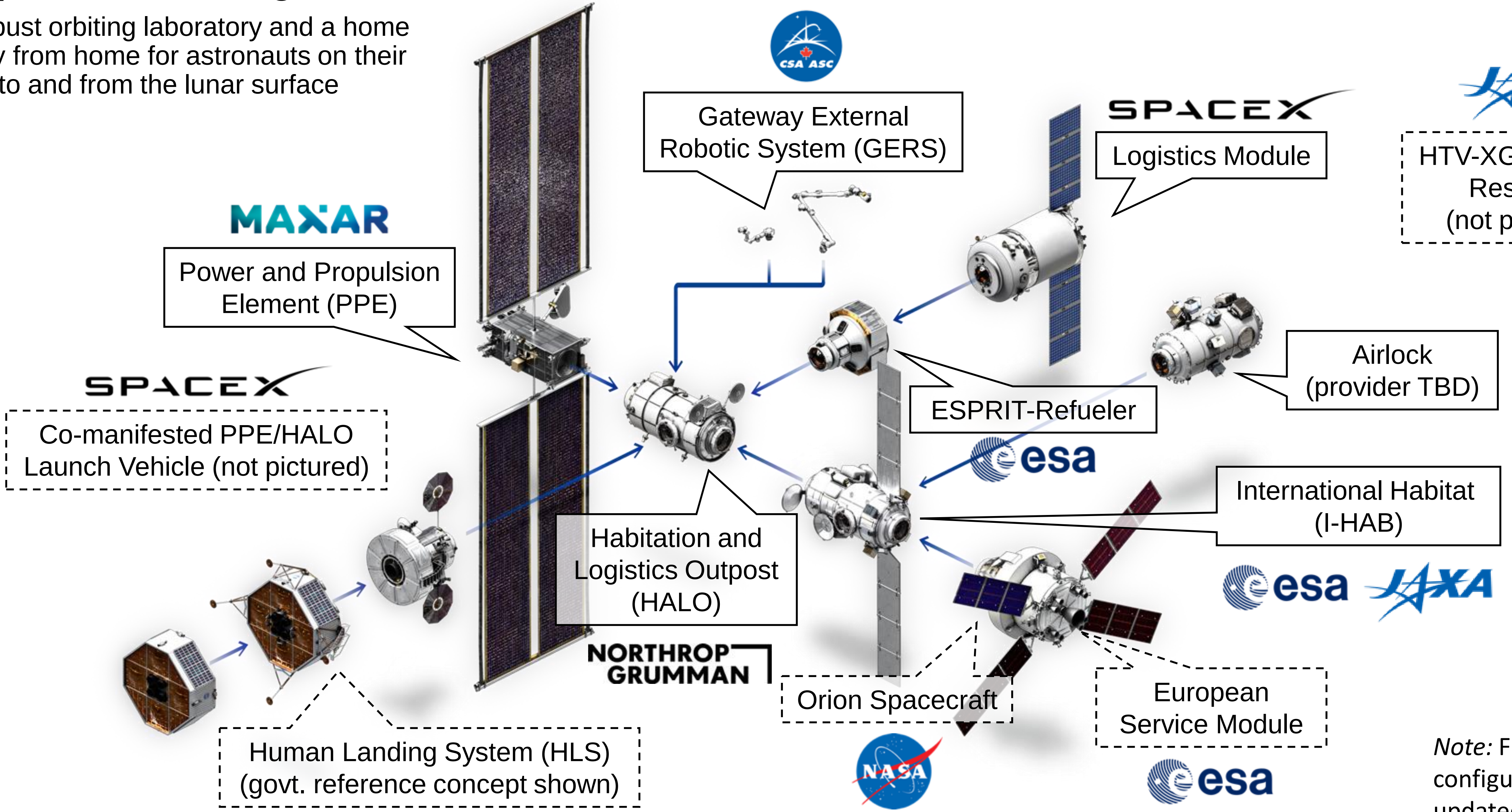
CP-11 2024
Intuitive Machines
NOVA-C

Gateway and HERMES

Gateway

Expanded Configuration

A robust orbiting laboratory and a home away from home for astronauts on their way to and from the lunar surface



Note: Final Gateway configuration may be updated from what is shown here

GATEWAY ORBIT

Cislunar space offers innumerable orbits for consideration, each with merit for a variety of operations. The Gateway will support missions to the lunar surface and serve as a staging area for exploration farther into the solar system, including Mars.

ORBIT TYPES

LOW LUNAR ORBITS

Circular or elliptical orbits close to the surface; excellent for remote sensing, difficult to maintain in gravity well.

» Orbit period: 2 hours

DISTANT RETROGRADE ORBITS

Very large, circular, stable orbits; easy to reach from Earth, but far from the lunar surface

» Orbit period: 2 weeks

HALO ORBITS

Fuel-efficient orbits revolving around Earth-Moon neutral-gravity points

» Orbit period: 1-2 weeks

NEAR-RECTILINEAR HALO ORBIT (NRHO)

ACCESS

Easy to access from Earth orbit with many current launch vehicles; staging point for both lunar surface and deep space destinations

ENVIRONMENT

The deep space environment is useful for radiation testing and experiments in preparation for missions to the lunar surface and Mars

SCIENCE

Favorable vantage point for Earth, sun and deep space observations

COMMUNICATIONS

Provides continuous view of Earth and communication relay for lunar farside

SURFACE OPERATIONS

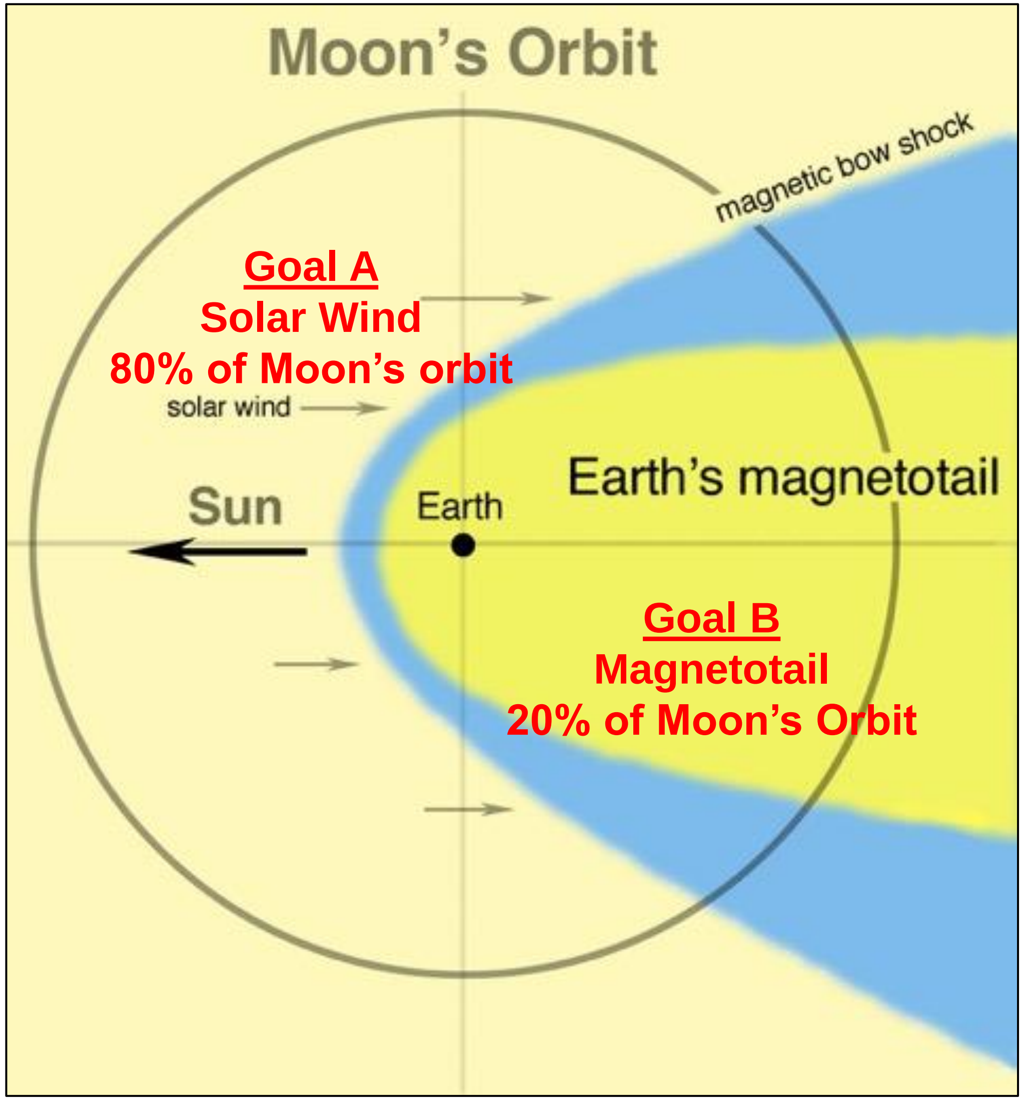
Supports surface telerobotics, including lunar farside; provides a staging point for planetary sample return missions

Early Gateway Science Payloads

Launched with PPE and HALO

- **ERSA:** The European Space Agency's (ESA) radiation instrument package will help provide an understanding of how to keep astronauts safe by monitoring the radiation exposure in Gateway's unique orbit.
- **HERMES:** NASA's space weather instrument suite will observe solar particles and solar wind created by the Sun.
- ESA **Internal Dosimeter Array**, including instruments provided by the Japan Aerospace Exploration Agency. Data provided will allow for the study of radiation shielding effects and improve radiation physics models for cancer, cardiovascular, and central nervous system effects, helping assess crew risk on exploration missions.

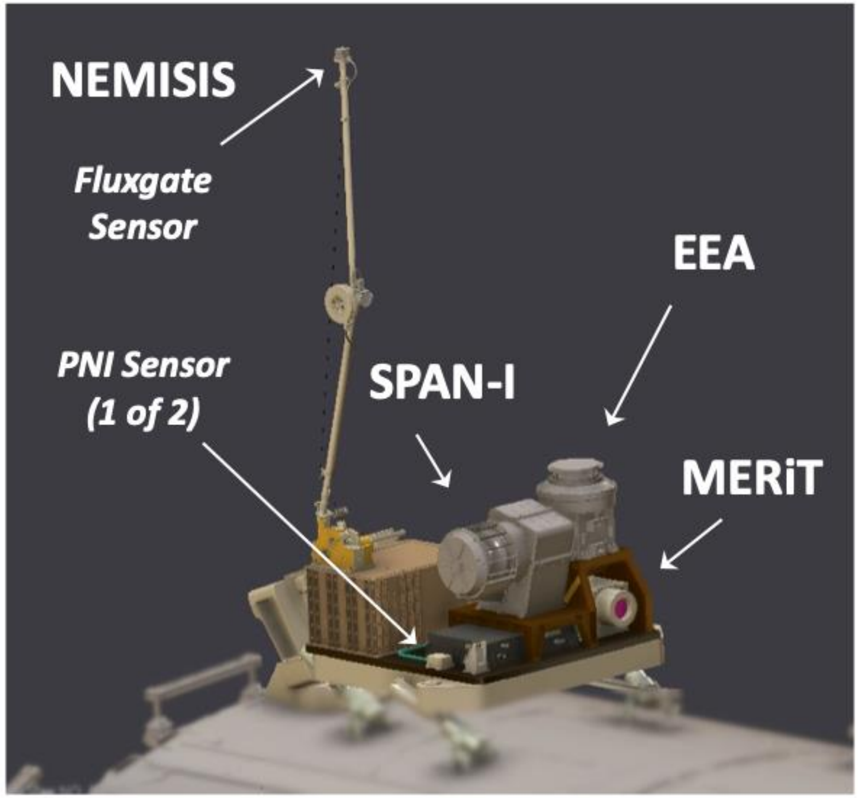
HERMES Science Goals and Objectives



GOAL	OBJECTIVE
A: Determine mechanisms of *solar wind* mass and energy transport	A1: Determine effects of large-scale structures on plasma transport and particle energies within the solar wind.
	A2: Determine effects of small-scale structures on plasma transport and particle energies within the solar wind.
B: Characterize energy, topology, and ion composition in the deep *magnetotail*	B1: Determine structure and dynamics of the magnetotail at lunar orbit.
	B2: Quantify energy content of the magnetotail at lunar orbit.
	B3: Quantify transport of atmospheric ions.
C: Establish observational capabilities of an on-board *pathfinder payload* measuring local *space weather* to support deep-space and long-term human exploration	C1: Assess the effects of field of view limitations associated with accommodation on Gateway.
	C2: Assess interference with measurements due to electric currents and surface charging.

HERMES Instruments

Instrument	Measurement	Cadence	THEMIS EQUIVALENT?	Provider/PI
MERiT: Miniaturized Electron pRoton Telescope	High energy electron flux High energy proton flux (i.e. radiation)	1.0 s	No	NASA GSFC/ Shrikanth Kanekal
NEMISIS: Noise Eliminating Magnetometer In a Small Integrated System	Magnetic field vector (×3) 1 fluxgate sensor 2 pni sensors	0.1 s	Yes	NASA GSFC/ Eftyhia Zesta, U.Mich/Mark Moldwin
SPAN-I: Solar Probe Analyzer - Ions	Low energy ion flux, density, temperature, velocity, Mass/Charge ID	0.218 s	Partial (No Mass/Charge)	U.C. Berkeley/ Roberto Livi
EEA: Electron Electrostatic Analyzer	Low energy electron flux, density, temperature	1.0 s	Yes	NASA GSFC/ Daniel Gershman



HERMES
MASS ~ 33 kg or less
(X,Y,Z) < 0.5 × 0.5 × 0.5 m (Boom Stowed)
Magnetometer Boom Extends ~ 1 m

Mars Exploration Mission Concept

Note: Reference architecture for analysis purposes only. Information does not reflect a finalized plan.

STRATEGIC ANALYSIS CYCLE (SAC) 21:
Reference First Human Mars Mission Concept

WHO

Current analysis includes 4 crew

2 remain in Mars orbit while 2 explore the Mars surface

WHAT

- Nuclear Transportation
- Landers and Surface Systems
- Mars Ascent and Earth Return

WHERE

- Cislunar, Deep Space and 5-sol Mars orbit
- Mars Surface

WHEN

- 2039 opportunity analyzed
- Crew away from Earth ~2.5 years
- ~30 sols on Mars

WHY

Science, Exploration, and U.S. leadership

HOW

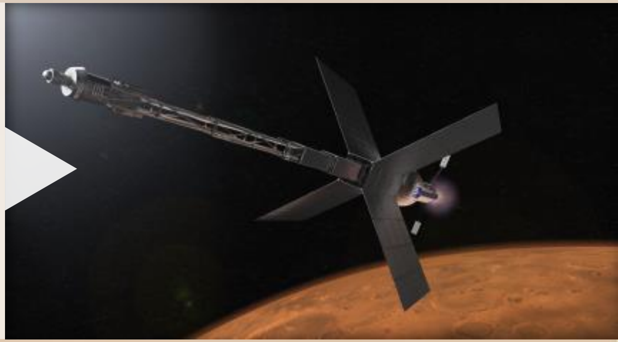
1. *Pre-Deployed Cargo Phase*
2. *Crewed Surface Exploration Phase*
   "Light" Exploration Footprint

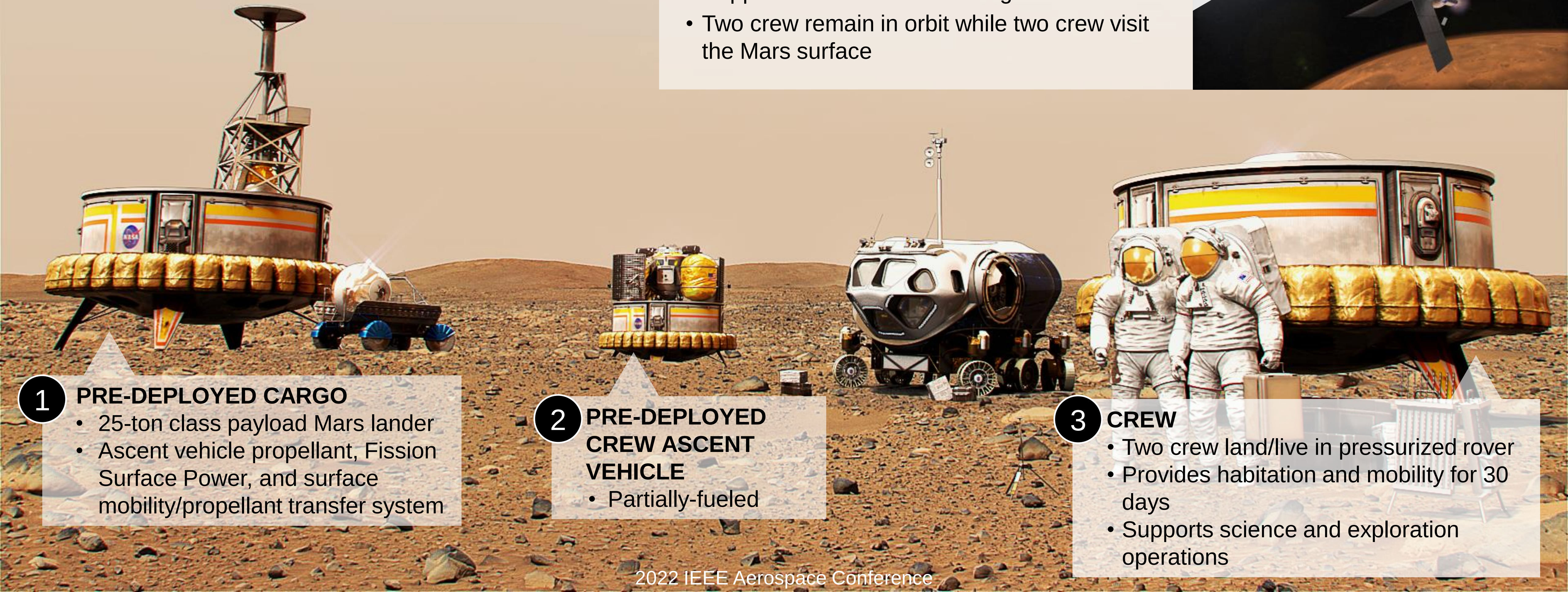
SAC21 First Mars Reference Mission

Reference architecture for *analysis purposes only.* Should not be considered “the plan”

TRANSIT HABITAT (TH) AND HYBRID NUCLEAR ELECTRIC PROPULSION (NEP) / CHEMICAL STAGE

- Supports four crew on the long mission to Mars
- Two crew remain in orbit while two crew visit the Mars surface





1 PRE-DEPLOYED CARGO

- 25-ton class payload Mars lander
- Ascent vehicle propellant, Fission Surface Power, and surface mobility/propellant transfer system

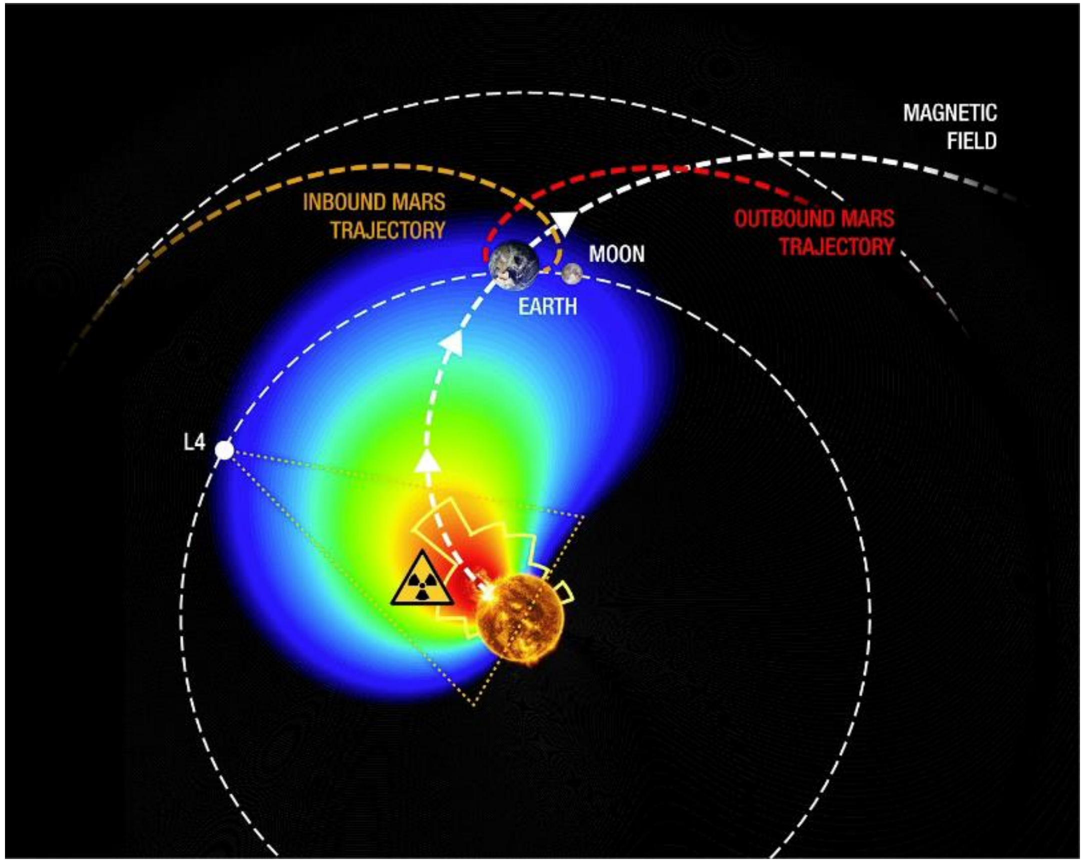
2 PRE-DEPLOYED CREW ASCENT VEHICLE

- Partially-fueled

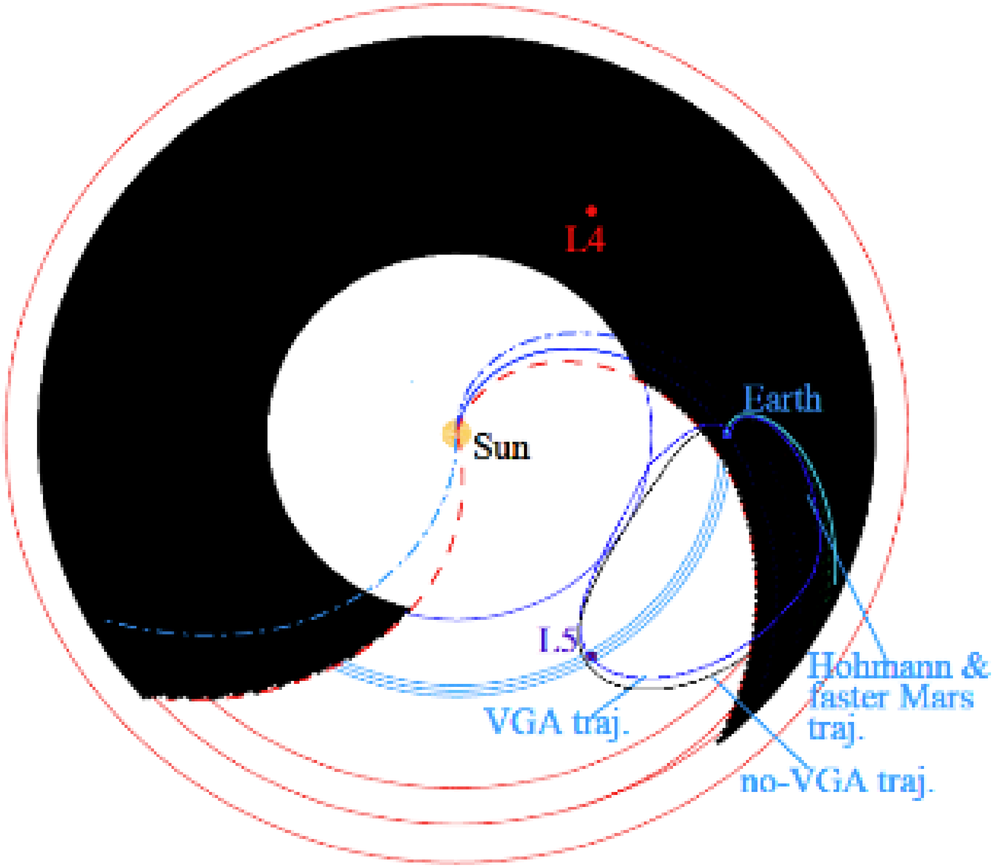
3 CREW

- Two crew land/live in pressurized rover
- Provides habitation and mobility for 30 days
- Supports science and exploration operations

Space Weather Observations for Moon and Mars Exploration



The histogram shows the relative source longitudes of all three-spacecraft SEP events in the STEREO era as described in Richardson et al. [2014]. SEP event modeling is based on Strauss, Dresing & Engelbrecht [2017].



Current (Earth-Sun L1-supported) Space Weather "Safe Zone" (white shaded regions)

Request for the Decadal Survey

Request for the Decadal Survey

Charge to the Decadal Survey Committee: *NASA invites input on where its research and mission programs can support and leverage Agency human exploration and lunar exploration activities (including but not limited to the Artemis Program). Recommendations on the research strategy should explicitly reference those opportunities, where appropriate.*

- Identify heliophysics and space weather science to be conducted in the next decade that is enabled and enhanced by lunar exploration activities (both in lunar orbit and on the lunar surface)
- Identify preparatory space weather activities to be conducted in the next decade that would enable or enhance human exploration of Mars beginning in the 2030s
- Identify where and how heliophysics and space weather science can inform and later integrate into human exploration architecture implementation, including but not limited to the purposes of
    - Providing needed observing, modeling, and support to operational users for human missions to the Moon and later to Mars
    - Providing a technical foundation for human and robotic exploration implementation decisions
    - Enabling and enhancing heliophysics research in the next decade and beyond (e.g. lunar farside radio telescope with solar observation capability, lunar resupply vehicle put into a heliocentric disposal orbit)
- Identify opportunities for cross-disciplinary and -divisional science activities within lunar exploration activities
- Prioritize within the Heliophysics Division programs activities supporting and leveraging robotic and human exploration of the Moon and Mars
- Clearly incorporate budget guidance for recommended activities

Additional Information for the Decadal Survey

- Artemis schedules are dynamic, architecture details are subject to change
  - Including providers for specific architecture components

- HERMES is multi-purposed:
  - Perform heliophysics science from a unique vantage point
  - Support lunar exploration with Artemis
  - Establish an Earth-independent space weather capability for future deep space human exploration

- Decadal Survey discussions and recommendations should be based on five generic platform locations/configurations:
  - Lunar orbit
  - Transiting vehicles between Low Earth Orbit and the Moon
  - Stationary and mobile platforms on the lunar surface
  - Human habitat on the lunar surface
  - 1 AU, heliocentric disposal orbit

References

- Strategic Documents
  - Artemis III Science Definition Report 2020 (link)
  - Heliophysics Science and the Moon: Potential Solar and Space Physics Science for Lunar Exploration 2007 (link)
  - Visions and Voyages for Planetary Science in the Decade 2013-2022 (link)
  - Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032 (link)
  - The Lunar Exploration Roadmap. Exploring the Moon in the 21st Century (link)
  - The Science Context for Exploration of the Moon (link)
  - The Artemis Plan: NASA's Lunar Exploration and Program Overview (link)

- Implementation Studies, Documents
  - Space Weather Architecture Options to Support Human and Robotic Deep Space Exploration 2020 (link)
  - Safe Human Expeditions Beyond Low Earth Orbit 2022 (link)
  - Deep Space Gateway Concept Science Workshop 2018 (link and link)

- NASA SMD Solicitations
  - Payloads and Research Investigations on the Surface of the Moon (PRISM) [link)
  - Development and Advancement of Lunar Implementation (DALI) (link)
  - Commercial Lunar Payloads Services (CLPS) (link)

#HelioRocks