National Aeronautics and Space Administration

NASA

EXPLORE SCIENCE

Lunar Discovery and Exploration Program Update

Joel Kearns
Deputy Associate Administrator for Exploration
Science Mission Directorate

Planetary Advisory Committee
March 1, 2023

Lunar Discovery & Exploration Program Elements

- **Commercial Lunar Payload Services (CLPS)**
  - Two landings per year
  - Enabling community-driven science
  - VIPER Delivery in 11/2024
- **Science Instrument Development for CLPS Delivery**
  - Instruments deployed by CLPS (NPLP, LSITP, PRISM)
  - Maturation of instrument concepts (DALI)
- **VIPER Rover**
  - Project
  - VIPER Review Team (VRT)
- **Lunar Reconnaissance Orbiter (LRO) mission operations**
- **Lunar Trailblazer**
  - Project; IM-2 rideshare launch
- **Lunar International Mission Collaborations**
- **Science Instrument Development for Artemis Human Missions (includes LTV, HLS deployed, Astronaut hand-held instruments)**
- **Lunar Science Research – Competed Geology Teams, Internal Science Team, Curation, Data Infrastructure/Tools, Increased Lunar R&A, Apollo Next Generation Sample Analysis (ANGSA)**
- **Mission Concept Studies for Endurance-A, LGN, LRO successor, etc.**
- **Future Missions/Projects**

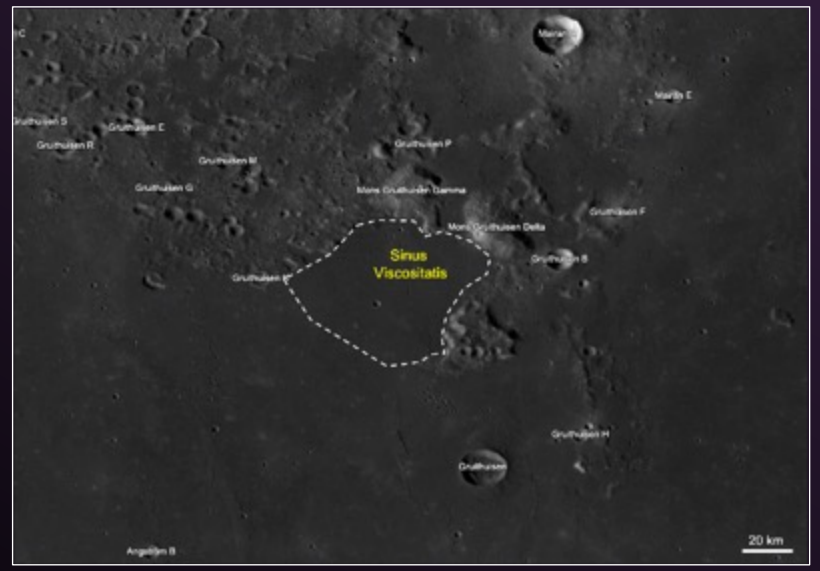
Lunar Discovery and Exploration

Updates from December 2022 Ongoing Activities

- Solicitations:
  - PRISM3 step 2 proposals received December 20 2022; selections in summer 2023
  - Artemis III Geology Team call released January 24, 2023; step 2 proposals due April 25, 2023
- CLPS Deliveries in Q1 2023:
  - Intuitive Machines' Nova-C (IM-1) in I&T
  - Astrobotic's lander for Peregrine Mission-1 (PM-1) completed environmental testing January 2023
    - PM-1 landing site officially named by IAU. The lunar feature is now called **Sinus Viscositatis** "Bay of Stickiness" (homage to viscous magmas that formed nearby Gruithuisen Domes)

What to Expect in 2023

- NASA payloads to be delivered to the lunar surface on the first three CLPS deliveries by Intuitive Machines (x2) and Astrobotic
  - AB's PM-1 launch target: May 2023
  - IM's IM-1 launch target: June 2023
  - IM's IM-2 launch target: November 2023
- Upcoming solicitations: Artemis III Deployed Instruments, Lunar Terrain Vehicle Instruments, and PRISM4
- Plan to define science objectives for Endurance A Mission (South Pole Aitken Basin sample return)



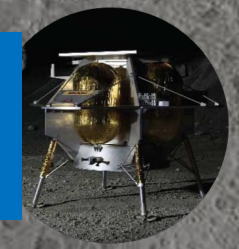
Sinus Viscositatis – a newly named region of the Moon near Gruithuisen Domes

Astrobotic PM-1 lander, ready for TVAC

CLPS Deliveries
2023-2026

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

Delivery Site:
Sinus Viscositatis
Provider: Astrobotic
TO2-AB | Q1 2023

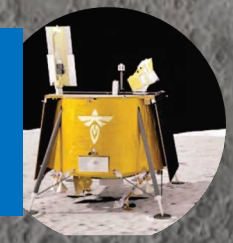


Delivery Site:
Lunar Far Side &
Orbit Insertion
Provider TBD
CS-3 | 2025

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

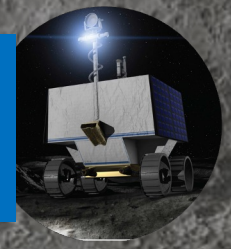
Delivery Site: Malapert A
Provider: Intuitive Machines (IM)
TO2-IM | Q2 2023

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

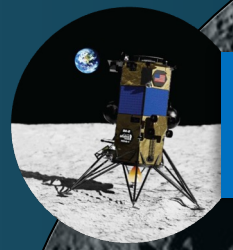
Delivery Site:
South Pole Region
Provider TBD
CP-22 | 2026

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

Updated 2/8/2023

CLPS Deliveries to South Pole

2023-2026

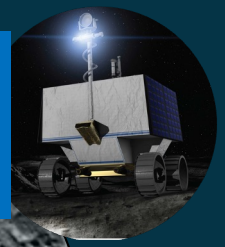


Delivery Site: Malapert A
Provider: Intuitive Machines (IM)
TO2-IM | Q2 2023

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

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

Delivery Site:
Nobile Crater
Provider: Astrobotic
VIPER | Q4 2024



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

Status of Calls

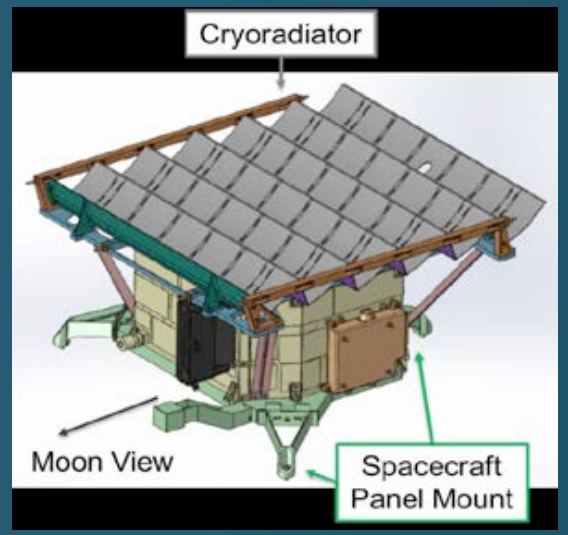
ARTEMIS

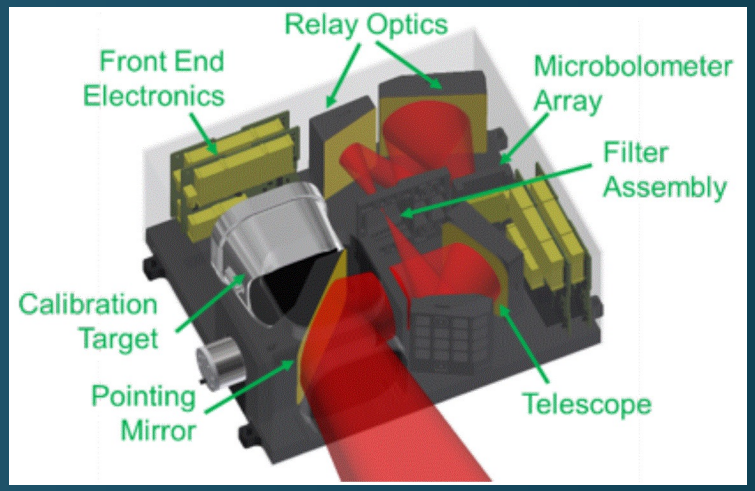
- Artemis III Geology Team
  - Step 1s received, Step 2 due April 25
  - Selection announced in the Fall
- Deployed Instruments for Artemis
  - AIII – Draft out soon
  - AIV – Draft expected this fall
- Instruments for the Artemis Lunar Terrain Vehicle
  - Draft out this summer

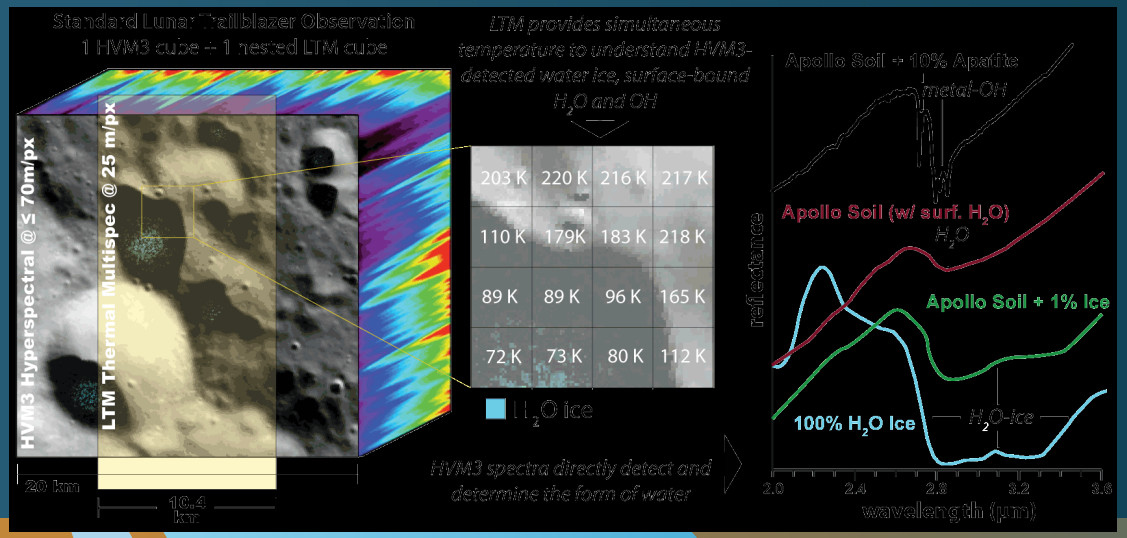
PRISM

- PRISM-3 – proposals in review, selections expected this summer
- PRISM-4 – draft to be released in summer

Lunar Trailblazer







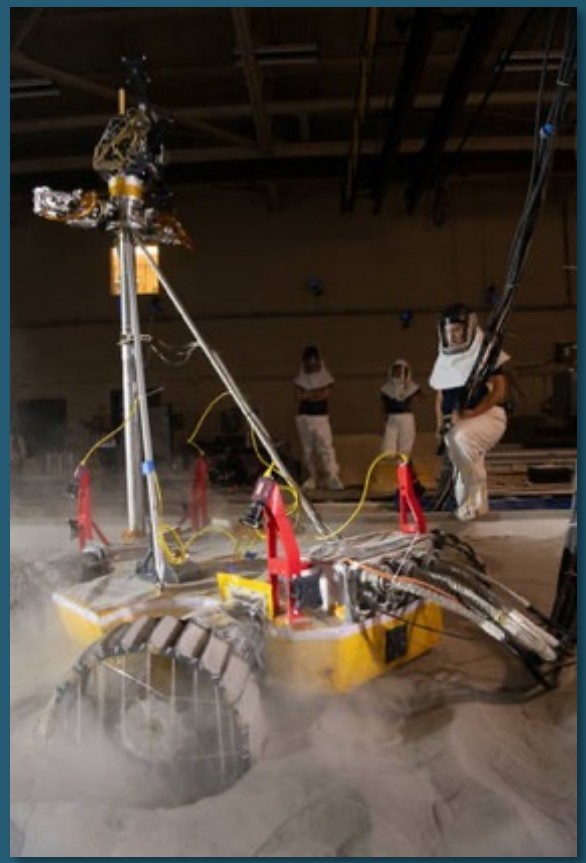
Science Objectives:

- Determine the form, abundance, and distribution of H2O and OH across targeted areas in sunlit portions of the Moon, including variability by latitude, soil maturity, lithology
- Test for and measure the possible temporal variations and mobility of H2O and OH
- Determine the form and abundance of ice, bound H2O, and OH in permanently shadowed regions (PSRs) using terrain scattered light
- Exploration zone reconnaissance for landed missions

Project Status:

- Lunar Thermal Mapper and High-resolution Volatlies and Minerals Mapper (2/2) instruments complete and delivered for integration on the spacecraft
- TVAC beginning this week with delivery into storage expected in May ’23
- Launch with IM-2 in November 2023

Volatiles Investigating Polar Exploration Rover (VIPER)



Science Objectives:

- Characterize distribution and physical state of lunar polar water and other volatiles in lunar cold traps and regolith, to understand their origin
- Provide data and resource maps necessary for NASA to evaluate ISRU potential from lunar polar regions

Key Mission Info:

- Will utilize CLPS (Commercial Lunar Payload Services) for delivery, using the Astrobotic Griffin Lander
- 100+ Earth-day for 3 Lunar day/night cycles
- Instruments: Neutron, Near-IR, and Mass spectrometers; and a 1m drill

Project Status:

- Now targeting Nov 2024 for delivery to Moon
- Systems Integration Review (SIR) conducted in December at JSC

VIPER’s landing region was officially named “Mons Mouton” after Melba Mouton, a mathematician and computer programmer who worked in NASA’s Trajectory and Geodynamics Division at NASA's Goddard Space Flight Center during the Apollo era.

VIPER science team proposed the name to the International Astronomical Union (IAU). The flat-topped mountain is adjacent to the western rim of the Nobile Crater, on which VIPER will land.

LDEP Website is Live!

The LDEP website will be released in stages

Stage 1: Focused on near-term missions/CLPS deliveries, instrument definitions, and setting up a science data distribution protocol (links to external databases where LDEP-managed data is stored)

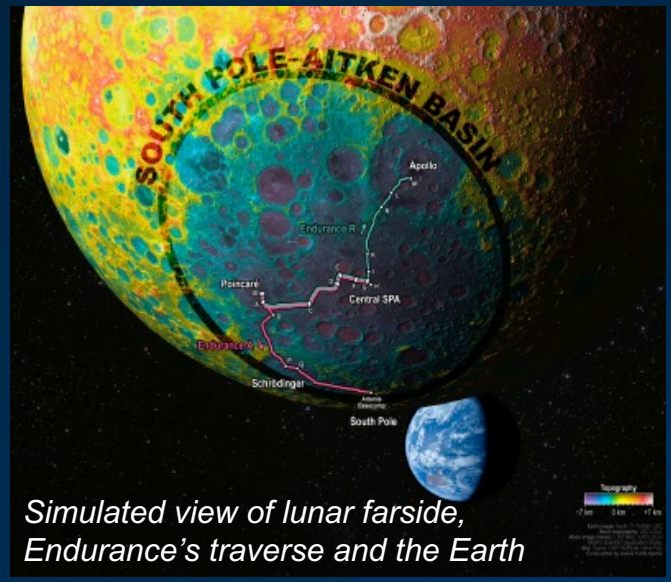
Stage 2: Inclusion of LDEP guiding principles and long-term lunar science strategies, information on solicitation planning, and Artemis science plan forward.

https://science.nasa.gov/lunar-discovery

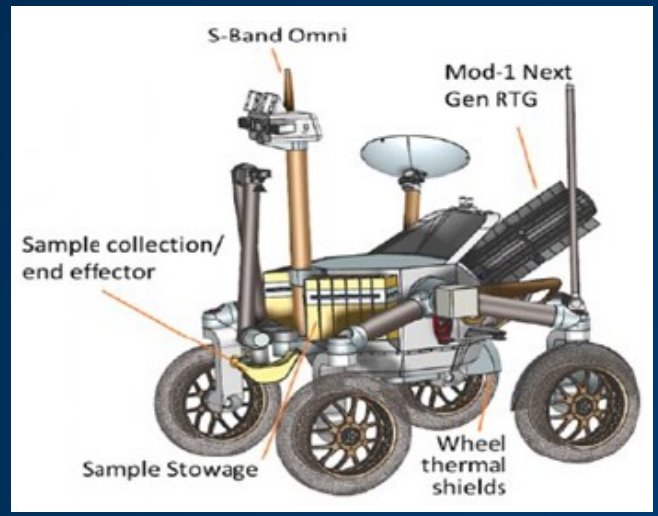
Planetary Science Decadal Survey
Endurance A:
South Pole-Aitken Sampling Campaign

- One of the top lunar priorities of the Planetary Decadal is Endurance A, a long-duration rover capable of traversing ~2000km and returning ~100kg of samples taken at strategic sites throughout the South Pole-Aitken basin to investigate several lunar science objectives:
  - Solar System Chronology: Anchors the earliest impact history of the Solar System, tests the giant planet instability, impact cataclysm, and late heavy bombardment hypotheses, and anchors the “middle ages” of solar system chronology
  - Planetary Evolution: Tests the lunar magma ocean hypothesis, characterizes the thermochemical evolution of terrestrial planets, and explores the geologic diversity of a giant impact basin from floor to rim

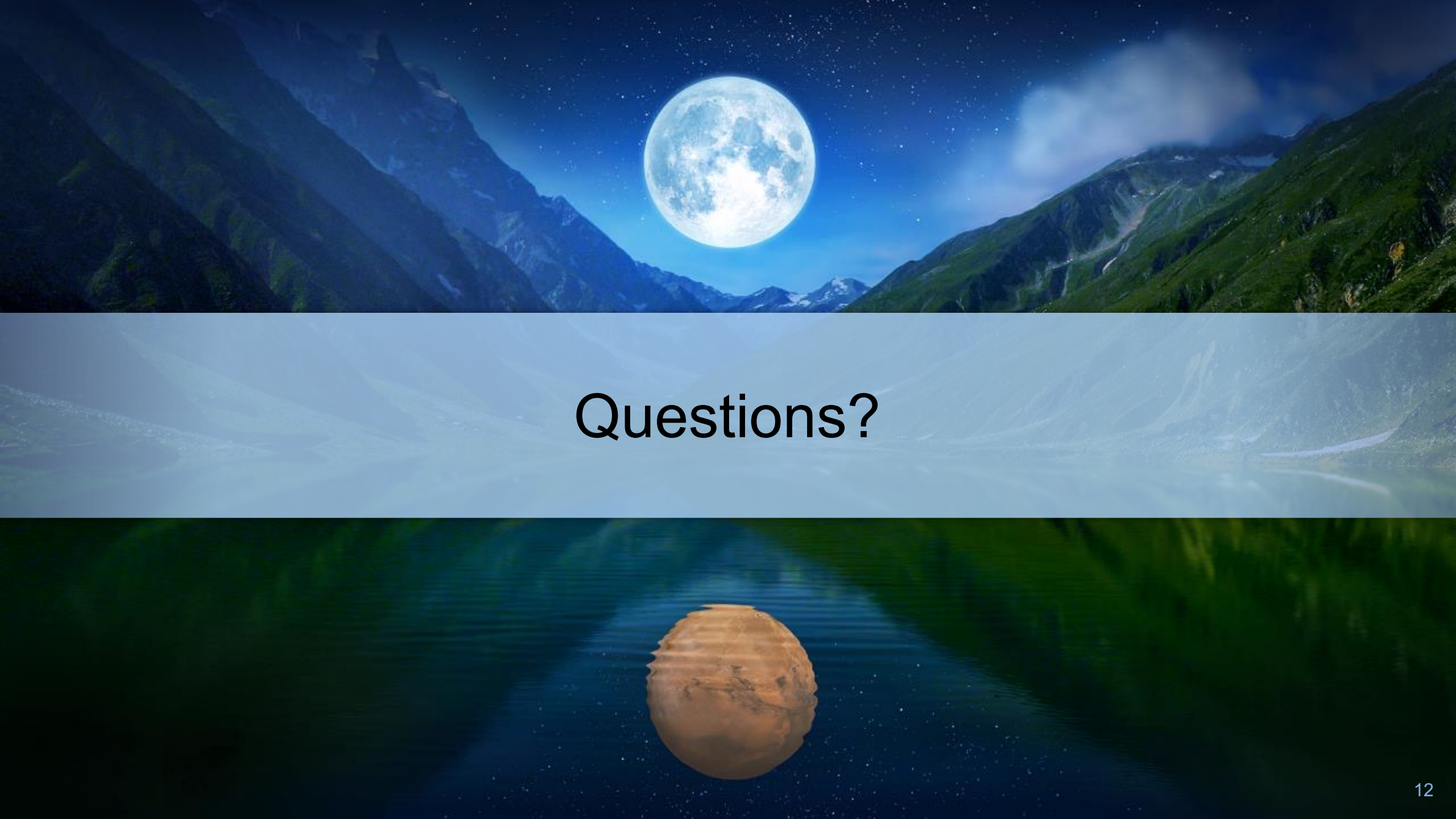
***Recommendation*: Endurance-A should be implemented as a strategic medium-class mission as the highest priority of the Lunar Discovery and Exploration Program. Endurance-A would utilize CLPS to deliver the rover to the Moon, a long-range traverse to collect a substantial mass of high-value samples, and astronauts to return them to Earth.** *– Origins, Worlds, and Life (Planetary Decadal), 22-17*



Simulated view of lunar farside, Endurance’s traverse and the Earth



The full Endurance Report is available at https://tinyurl.com/2p88fx4f



Questions?

Lunar Science Update

Sarah Noble
PSD lunar science lead

Integrated Lunar Science Strategy

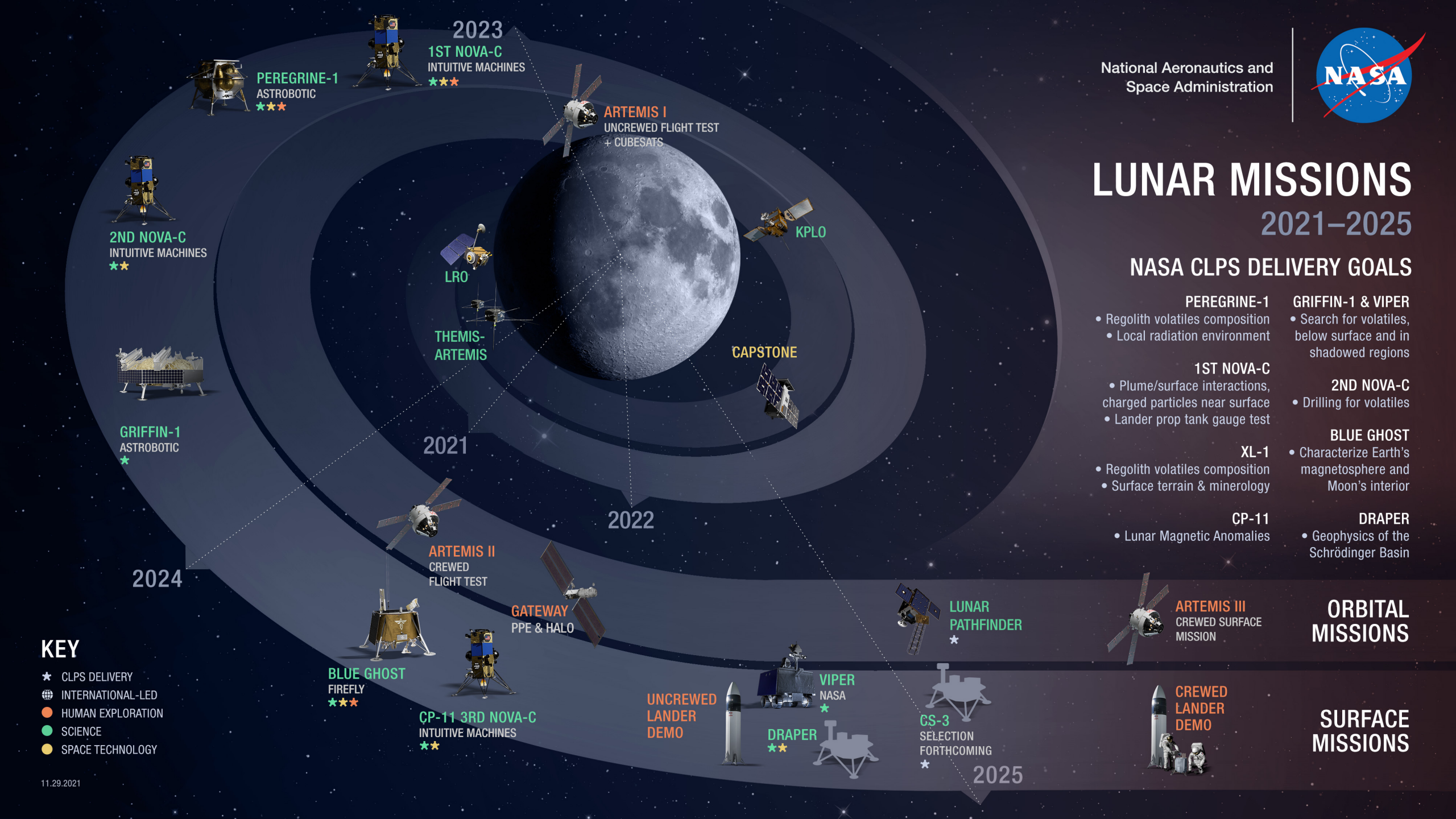
- PSD/ESSIO are continuing to build our integrated lunar science strategy
- Near-term activities:
  - Developing statement of task for NAS study on potential non-polar human destinations
  - JPL conducting study to better define Endurance concept
  - Considering options for Endurance SDT
  - GSFC conducting pre-phase A study on “LExSO” (Lunar Exploration Science Orbiter) using the LEAG CLOC-SAT report as a guide
  - Instigating a joint LEAG/ExMag study on Artemis Samples
- The draft strategy will be posted for community comment, followed by a workshop/townhall to answer questions and discuss, then changes will be incorporated.

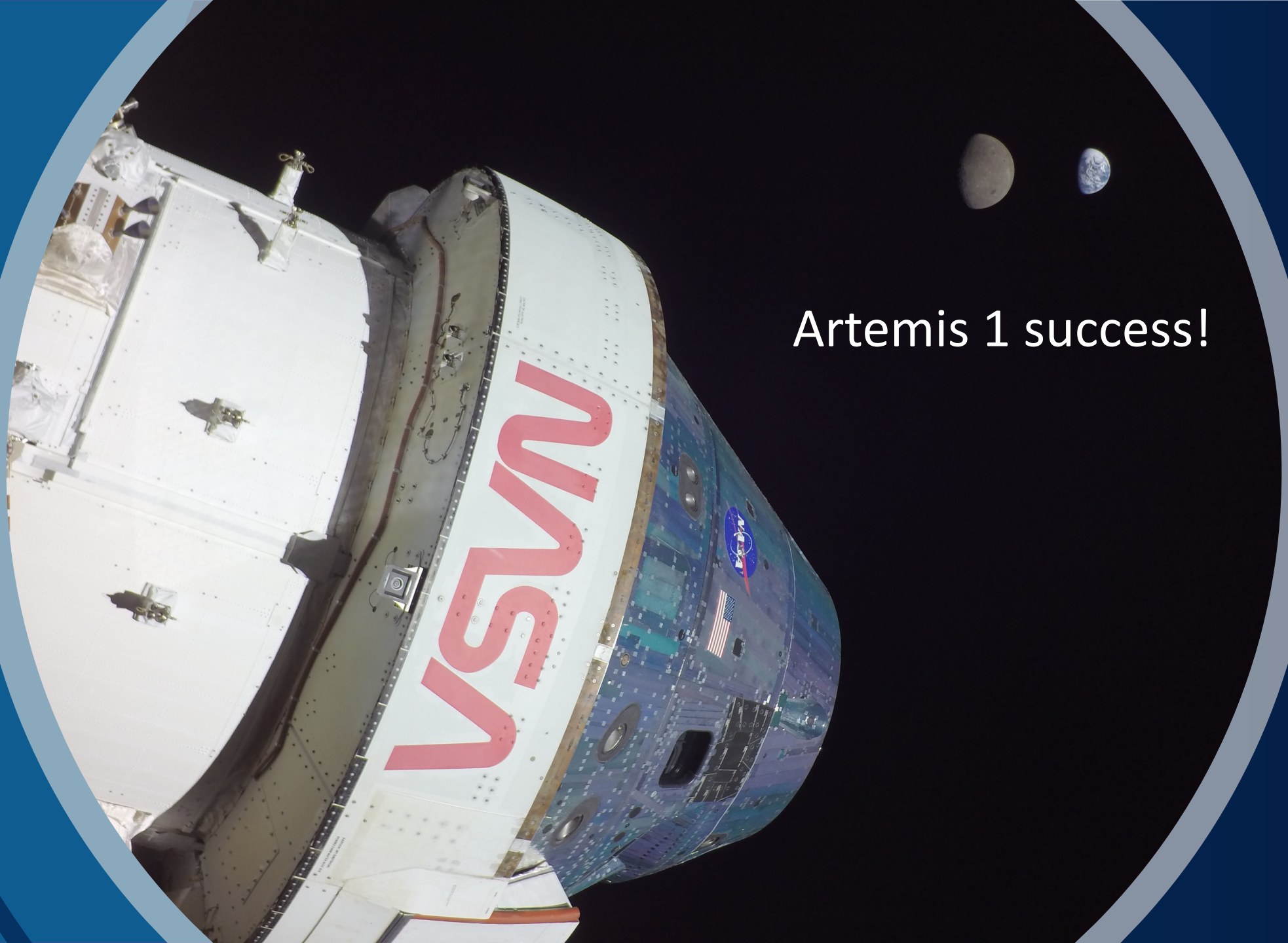
National Aeronautics and Space Administration

NASA

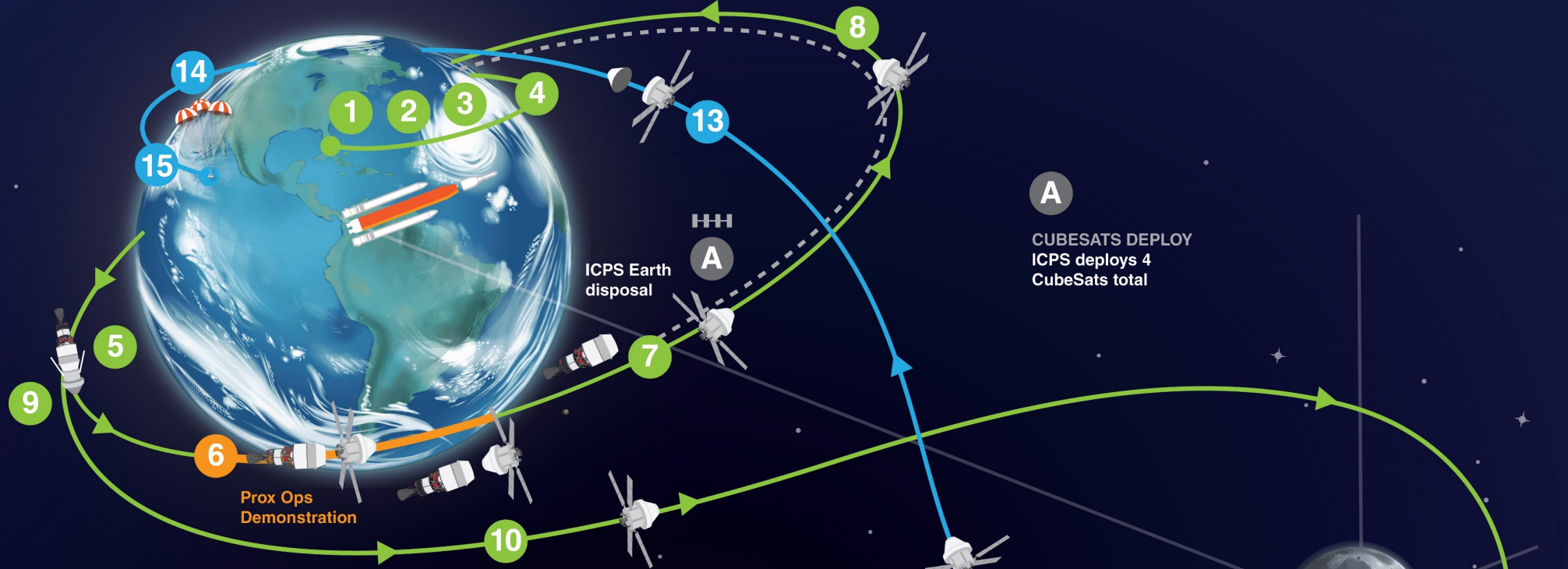
ARTEMIS

Updates


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
CP-11
• Lunar Magnetic Anomalies
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
DRAPER
• Geophysics of the Schrödinger Basin
2023
1ST NOVA-C
INTUITIVE MACHINES
★★★
PEREGRINE-1
ASTROBOTIC
★★★
ARTEMIS I
UNCREWED FLIGHT TEST
+ CUBESATS
2ND NOVA-C
INTUITIVE MACHINES
★★
KPLO
LRO
THEMIS-ARTEMIS
CAPSTONE
GRIFFIN-1
ASTROBOTIC
★
2021
2022
2024
ARTEMIS II
CREWED FLIGHT TEST
GATEWAY
PPE & HALO
LUNAR PATHFINDER
★
ARTEMIS III
CREWED SURFACE MISSION
ORBITAL MISSIONS
BLUE GHOST
FIREFLY
★★★
CP-11 3RD NOVA-C
INTUITIVE MACHINES
★★
UNCREWED LANDER DEMO
VIPER
NASA
★
DRAPER
★★
CS-3
SELECTION FORTHCOMING
★
2025
CREWED LANDER DEMO
SURFACE MISSIONS
KEY
★ CLPS DELIVERY
INTERNATIONAL-LED
HUMAN EXPLORATION
SCIENCE
SPACE TECHNOLOGY
11.29.2021



Artemis 1 success!



ARTEMIS II

First Crewed Test Flight to the Moon Since Apollo

A CUBESATS DEPLOY
ICPS deploys 4 CubeSats total

1 LAUNCH
Astronauts lift off from pad 39B at Kennedy Space Center.

2 JETTISON SOLID ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM

3 CORE STAGE MAIN ENGINE CUT OFF
With separation.

4 PERIGEE RAISE MANEUVER

5 APOGEE RAISE BURN TO HIGH EARTH ORBIT
Begin 24 hour checkout of spacecraft.

6 ORION SEPARATION FROM INTERIM CRYOGENIC PROPULSION STAGE (ICPS) FOLLOWED BY PROX OPS DEMO
Plus manual handling qualities assessment for up to 2 hours.

7 ORION UPPER STAGE SEPARATION (USS) BURN
Begins high Earth orbit checkout. Life support, exercise, and habitation equipment evaluations.

8 PERIGEE RAISE BURN

9 TRANS-LUNAR INJECTION (TLI) BY ORION'S MAIN ENGINE
Lunar free return trajectory initiated with European service module.

10 OUTBOUND TRANSIT TO MOON
4 days outbound transit along free return trajectory.

11 LUNAR FLYBY
5,630 nmi (mean) lunar farside altitude.

12 TRANS-EARTH RETURN
Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time approximately 4 days.

13 CREW MODULE SEPARATION FROM SERVICE MODULE

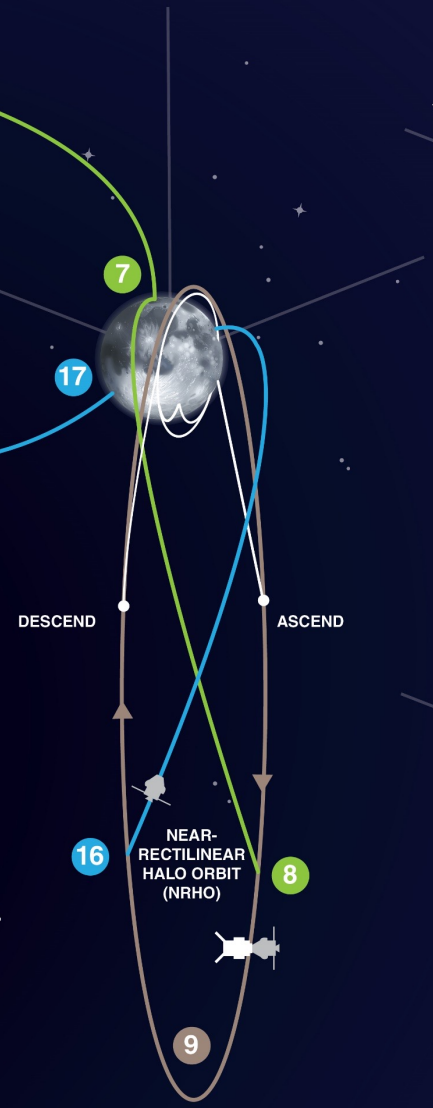
14 ENTRY INTERFACE (EI)
Enter Earth's atmosphere.

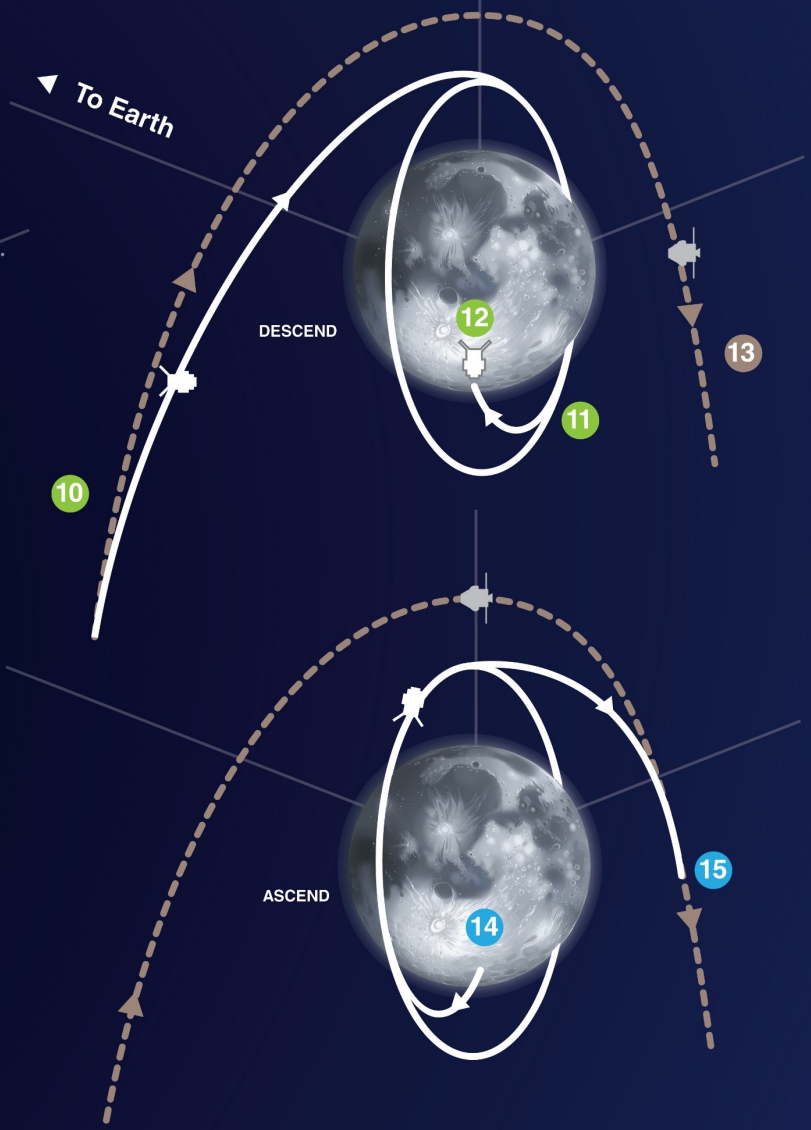
15 SPLASHDOWN
Ship recovers astronauts and capsule.

PROXIMITY OPERATIONS DEMONSTRATION SEQUENCE	
1	10
2	11
3	12
4	13
5	14
6	15
7	16
8	17
9	

ARTEMIS III

Landing on the Moon





1 **LAUNCH**
SLS and Orion lift off from Kennedy Space Center.

2 **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**

3 **CORE STAGE MAIN ENGINE CUT OFF**
With separation.

4 **ENTER EARTH ORBIT**
Perform the perigee raise maneuver. Systems check and solar panel adjustments.

5 **TRANS LUNAR INJECTION BURN**
Astronauts committed to lunar trajectory, followed by ICPS separation and disposal.

6 **ORION OUTBOUND TRANSIT TO MOON**
Requires several outbound trajectory burns.

7 **ORION OUTBOUND POWERED FLYBY**
60 nmi from the Moon.

8 **NRHO INSERTION BURN**
Orion performs burn to establish rendezvous point and executes rendezvous and docking.

9 **LUNAR LANDING PREPARATION**
Crew activates lander and prepares for departure.

10 **LANDER UNDOCKING AND SEPARATION**

11 **LANDER ENTERS LOW LUNAR ORBIT**
Descends to lunar touchdown.

12 **LUNAR SURFACE EXPLORATION**
Astronauts conduct week long surface mission and extra-vehicular activities.

13 **ORION REMAINS IN NRHO ORBIT**
During lunar surface mission.

14 **LANDER ASCENDS TO LOW LUNAR ORBIT**

15 **LANDER PERFORMS RENDEZVOUS AND DOCKING**

16 **CREW RETURNS IN ORION**
Orion undocks, performs orbit departure burn.

17 **ORION PERFORMS RETURN POWERED FLYBY**
60 nmi from the Moon.

18 **FINAL RETURN TRAJECTORY CORRECTION (RTC) BURN**
Precision targeting for Earth entry.

19 **CREW MODULE SEPARATION FROM SERVICE MODULE**

20 **ENTRY INTERFACE (EI)**
Enter Earth's atmosphere.

21 **SPLASHDOWN**
Ship recovers astronauts and capsule

Artemis III Science Team

Artemis Science Lead (Sarah Noble)
Exploration Rep (Jake Bleacher)

Artemis III Project Scientist

Internal Artemis Science Team

- NASA scientists working within Artemis
- SMD funded
- Conflicted from competition

Competitively selected Geology Team

- A3GT call out now
  - Proposals due in April
- Participating scientist call anticipated
  - Call timing TBD

Competitively selected Payload Teams

- Artemis III payloads call draft text to be released soon!

Role of Internal vs. Competed Teams

Internal Team

- Make sure the architecture/systems can support science
  - Embedded on boards and working groups across the agency, reviewing documents
  - Rapid response to requests and queries from across the agency
- Interface between NASA and competed teams to maximize science return
  - Lead classroom, field, and ops training for crew
  - Lead operational training for competed teams
- Program Level Strategic Planning
  - Mission-to-Mission continuity

Competed Geology Team

- Focused on Artemis III sortie
- Develop mission science objectives for that sortie
  - Field science goals
  - Traverse planning
  - Sampling strategy
- Support training as needed
- Real-time operations support
- Preliminary Examination of Samples
- Post Mission Geology Report

Artemis Internal Science Team

Artemis Lunar Science Lead (Sarah)
Exploration Rep (Jake)

Internal Artemis Science Team:

Training and Ops
- Training and Strategic Integration Lead - **Cindy Evans**
- Science Flight Operations Lead - **Kelsey Young**
- EVA Hardware and Testing Integration Lead - **Trevor Graff**

Samples
- Sample Integrity Lead - **Barbara Cohen**
- Contamination Control Scientist - **Andy Needham**
- Artemis Curation Lead - **Ryan Zeigler, Acting**

Planning and Data
- Mission Planning and Science Implementation Lead - **Sam Lawrence**
- Spatial Planning and Data Lead - **Noah Petro**
- Software Systems Lead **- Matthew Miller**

Payloads
- SMD Payload Integration Officer - **Renee Weber**

Artemis Training Update - Progress

- Artemis Training Team is fully integrated with NASA Flight Operations
- Executing basic Earth and planetary science training for new Astronaut class (year 1 complete, year 2 content and field capstone in June)
- Providing annual “Geology 101’ field immersion class for flight operations, hardware, and mission management community
  - 40 flight controllers, flight directors, Artemis mission managers, EVA trainers, spacesuit and tools experts are signed up for class in April
- Basic lunar science “Lunar Fundamentals” for crew content is complete and being tested
  - Roll-out to crew office this spring in advance of crew assignments
- Training requirements for flight controllers are being defined
- Field objectives (integrated science and operations) for each of 5 field locations under development with xEVA training office
- Detailed 24-month training flow plan with integrated lunar science, field science and EVA operations well underway

Geology and Planetary Training Flow

PHASE 1

Initial Training

New Astronaut Classes
Laying the foundation

- Initial Classroom Training
- Basic Field Training
- Expeditionary Components

PHASE 2

Building/Maintaining Skills

Before/Between
Flight Assignment

- Proficiency Training
- Lunar Fundamentals
- Operational Tests

PHASE 3

Assigned Crew Training

Mission Specific
Science Training (L-24 mo)

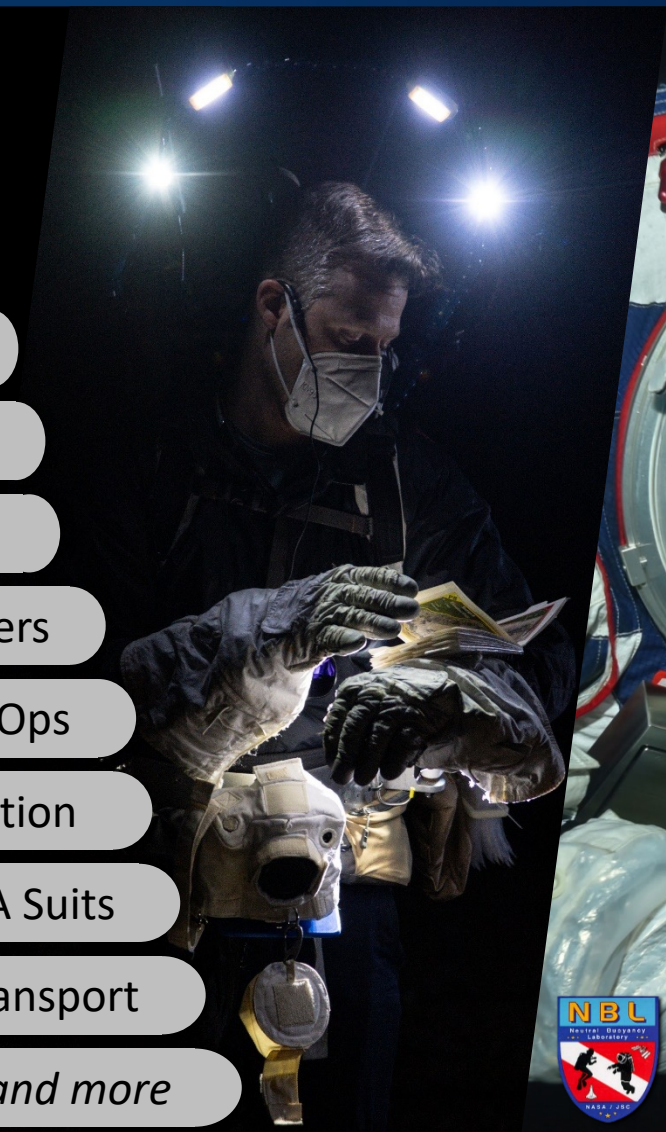
- Advanced Classroom
- Extensive Fieldwork
- Science & Ops Sims

Science Testing Activities

- Science activities continue to be integrated in numerous facility and field-based testing environments.

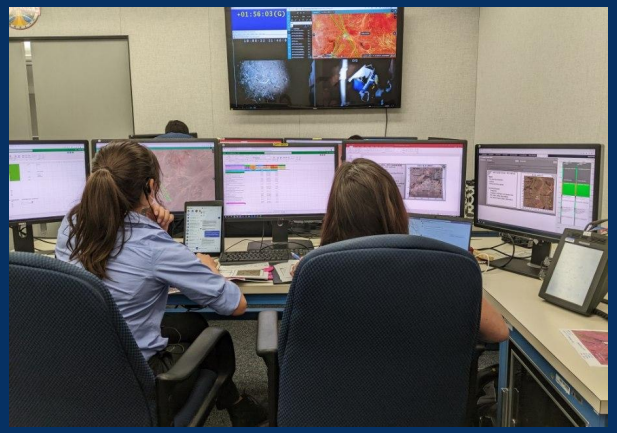
Testing Themes

- Imaging
- Sampling
- Navigation
- EVA Con Ops
- Ops Software
- Geology Tools
- Mobility / Rovers
- Flight Control Ops
- Lunar Illumination
- Reference EVA Suits
- Equipment Transport
- *…. and more*



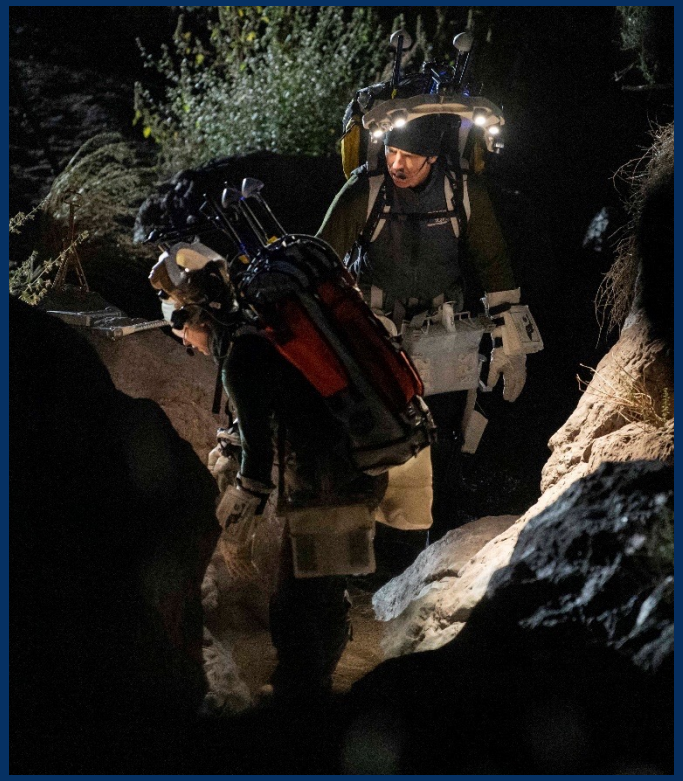
2022 Artemis Field Tests

- JETT1 – New Mexico
- JETT2 – Iceland
- JETT3 - Arizona



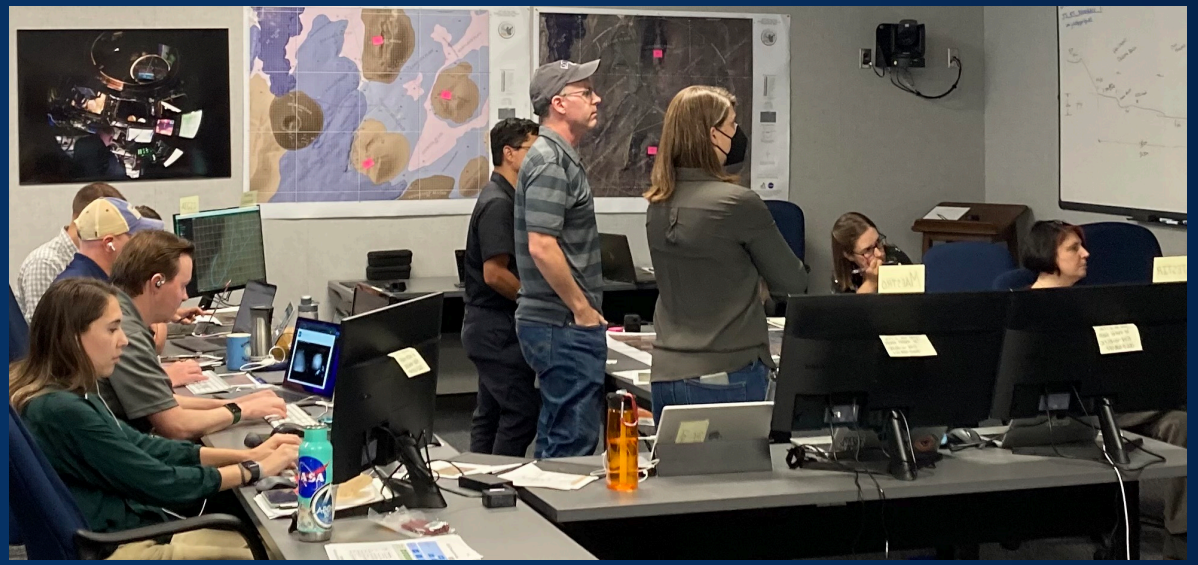
JETT3
EVA/Science Integration Testing

- JETT3 (Joint EVA Test Team) mission simulation (Oct 2022) mimicked relevant Artemis mission constraints
  - 4 EVAs (4-6 hrs) in 5 days, 2km exploration radius
  - Full EVA Flight Control Team (FCT) and Science Team
- SMD Science Team supported pre-mission and mission execution
  - Pre-mission science-focused activities: geologic mapping, Science Traceability Matrix, prioritized science stations
  - Dry Run training week at NASA JSC in Aug 2022
  - Integration of science objectives and priorities with EVA FCT objectives: creation of traverse plans and operations products (e.g., cuff checklists, EVA Map Book)
  - Mission Execution: science reps on field team; full Science Team supported from the SER



JETT3
EVA/Science Integration Testing

- Critical lessons learned:
  - SER facility requirements
  - SER roles & responsibilities
  - Refinement of EVA Science Officer role
  - Science team pre-mission products and workflow
  - Critical science/ops products and tools

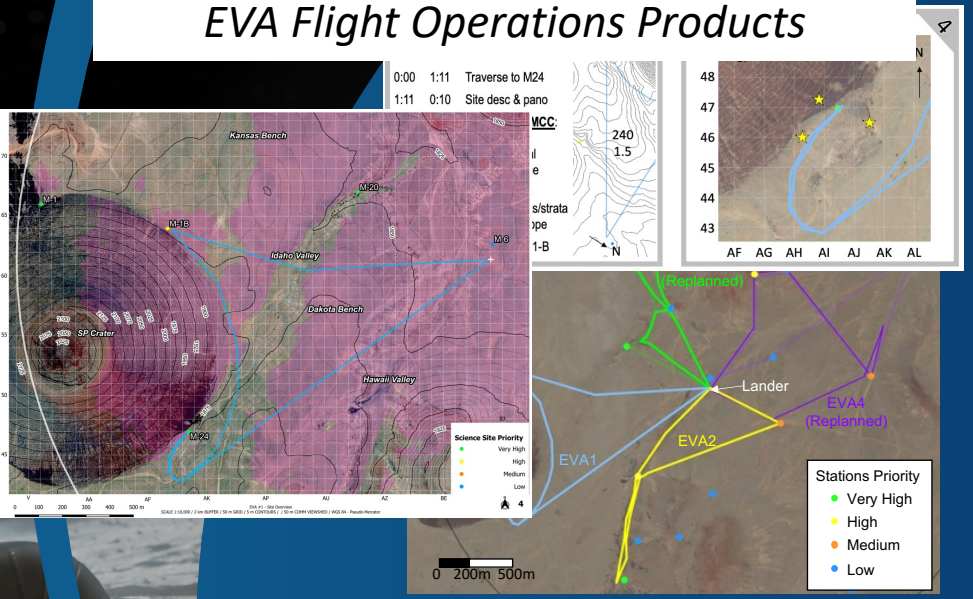


- Checked off many of the top priorities in the LEAG AOA SAT report
- Poster session at LPSC

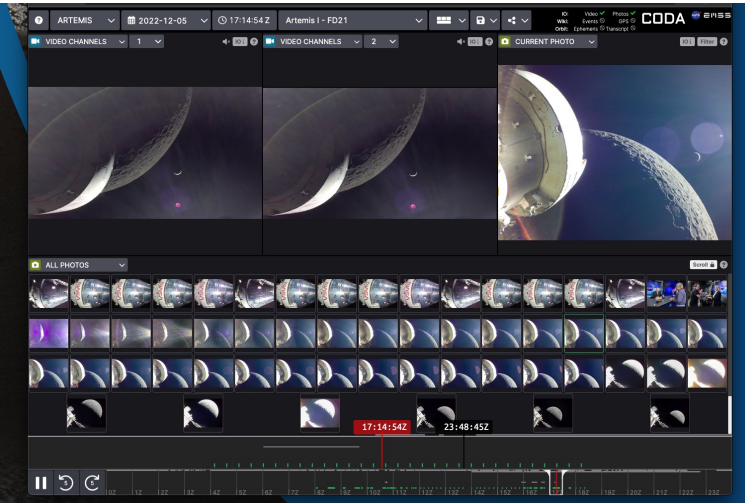
Science Flight Operations Updates

- Progress over the last year has focused on developing the structure and infrastructure for science integration into Mission Control and the EVA Flight Control Team (FCT)
- Development of Science Evaluation Room (SER; science backroom)
  - SER facility requirements definition phase complete
  - Next phase (FY23-FY24): SER design and construction in Mission Control
- Science real-time integration will evolve to fit the mission
  - Ex. New EVA Science Officer position in the EVA FCT
  - Ex. Artemis 2 SER integration
- 2022-2023 Testing included evaluations and refinement of science integration structure
  - JETT3 (October 2022) was highest fidelity Artemis EVA mission simulation ever conducted and included a full SMD Science Team in pre-mission and mission execution phases
  - JETT5 (planned for Fall 2023) will build on JETT3 results and include two daily science shifts (Tactical and Strategic)

Uniting Scientific Data and Priority with EVA Flight Operations Products



Building Mission Context to support the Operations and Scientific Enterprise

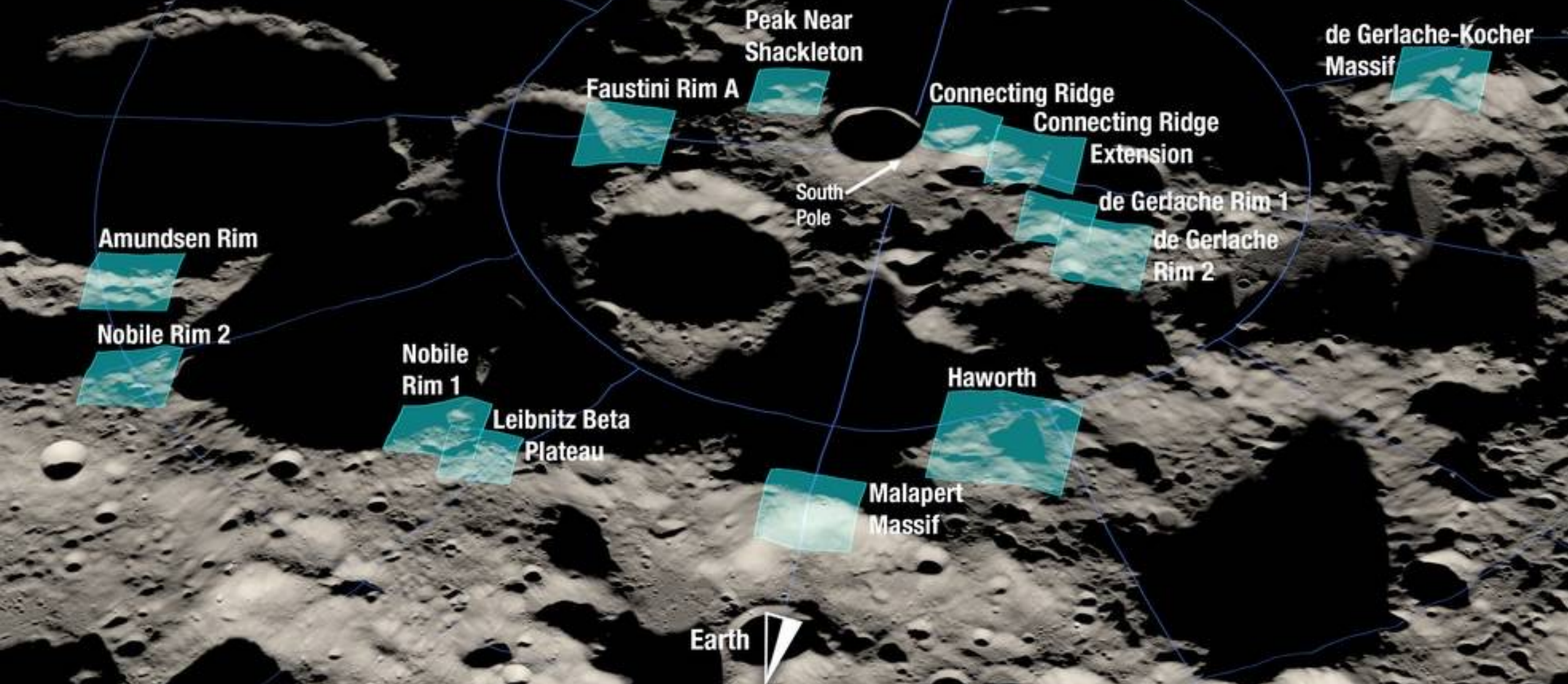


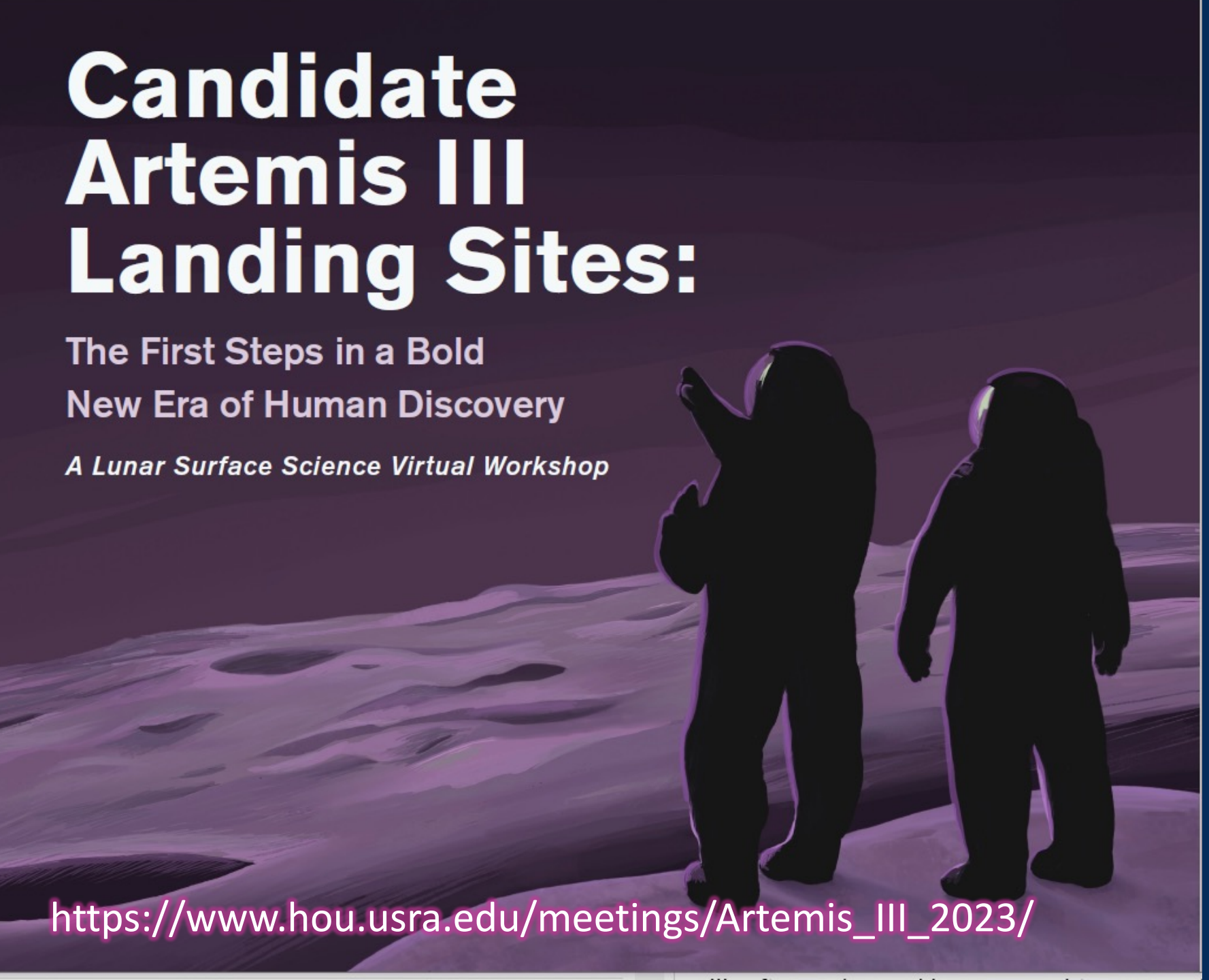
Artemis Data and Software Systems Update

- Developing new software systems for the Artemis era
  - Near-term: Artemis-in-real-time and mission support systems
  - Future: Advanced informatics such as spacesuit augmented reality for crewed EVAs
- Software systems development is integrated with the EVA Human and Surface Mobility Program (EHP) testing program
  - Using analog and testing opportunities, like JETT-3 to refine needs and improve software tools to meet science needs
- Artemis Geospatial Data Team was formulated in 2022 and is directly integrated with site selection, mission planning, and EVA development
  - Developing and verifying products, such as hazard maps, as input to the site selection process

Announced 13 Candidate Landing Regions for Artemis III at 2022 LEAG Annual Meeting

Now subject of ongoing, intense analysis by a cross-Agency team to assess complicated interplay of mission design and architectural implications, as well as science and exploration value of each of the 13 Regions.





Upcoming LSSW to get input from the community on the science value of those 13 regions

Will be held virtually April 4-5

Tremendously important venue for community participation and feedback into the Artemis III mission

Other upcoming LSSWs

- Updates from HQ/Artemis – May date TBD
- Human/Robot interactions – summer date TBD
- Geologic mapping of the lunar South Pole – summer date TBD

https://lunarscience.arc.nasa.gov/lssw/