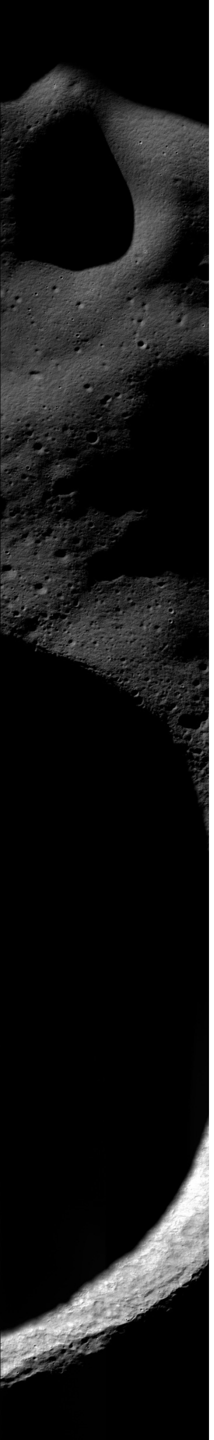


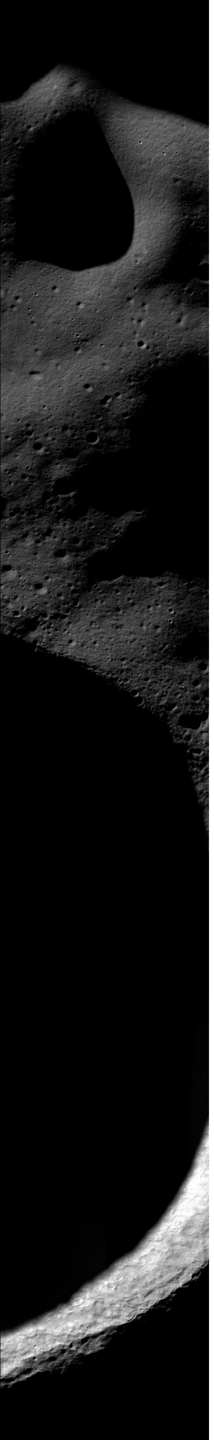
Human Exploration of the Moon:
Decadal Survey on Planetary Science and Astrobiology-Human Exploration Working Group

Dr. Amy L. Fagan
Western Carolina University
Chair, Lunar Exploration Analysis Group

Friday, 23 July 2021

The Moon is an enabling asset that unites our exploration goals across different destinations and the foundation to humanity's understanding of our place in space and time.

Sustainable human presence <u>on</u> the Moon is critical for sustainable human exploration <u>beyond</u> the Moon



Takeaway Points:
Infusing High-Priority Science into Human Exploration

- We have planned, we are prepared, and we are ready. Let's go exploring!
- Open Communication
- Human Exploration benefits from robotics
- Utilize the Moon as a test-bed for exploring beyond

LUNAR EXPLORATION ANALYSIS GROUP

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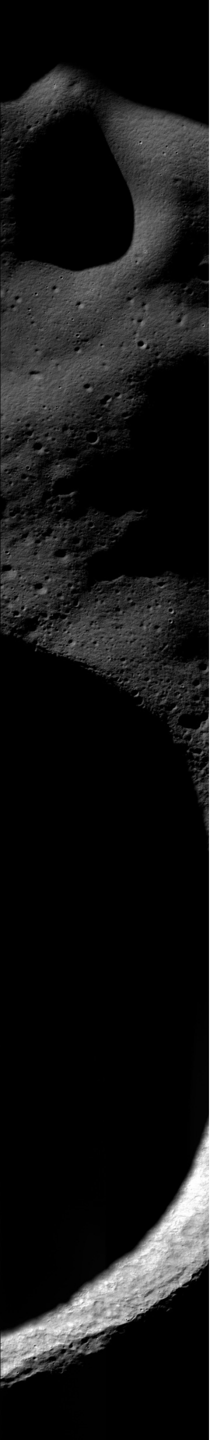
Presented To: Decadal Survey on Planetary Science and Astrobiology-Human Exploration Writing Group

July 23, 2021



We are ready. Let's go exploring!

- **Eager and willing community to participate**
- **Wealth of community documents (1) demonstrate the importance of exploring the Moon and (2) prioritize goals and investigations**
  - Some examples:
    - US Lunar Exploration Roadmap
    - 2007, National Research Council Report, Scientific Context for Exploration of the Moon
    - 2017, Advancing Science of the Moon Specific Action Team
    - 2017, Next Steps on the Moon Specific Action Team
    - 2020, Artemis III Science Definition Team Report ←Relied heavily on community documents
    - 2020, White papers for the Decadal Survey
      - E.g., The Importance of Human Exploration in Accomplishing High Priority Lunar Science Objectives (Lead Author: Dr. Kelsey Young, GSFC)

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White Paper: The Importance of Human Exploration in Accomplishing High Priority Lunar Science Objectives

Slides from Dr. Young's presentation to the Mercury and Moon Panel

https://www.lpi.usra.edu/leag/reports/HumanExplorationDecadalWhitePaper_Final.pdf

Recommendation #1: Integrate the lunar science community with the human spaceflight community to ensure adequate understanding of lunar science objectives and criteria for success

- How is science currently being integrated across Artemis?
  - Lunar Surface Science Workshop: broad community engagement
  - NASA HQ cross-directorate Science & Technology Utilization and Utilization Coordination Integration Group
  - Artemis 3 Science Definition Team: relied on all available community documents
- Other efforts to integrate science into human spaceflight
  - LSIC: Lunar Surface Innovation Consortium, advancing suite of technology areas to support lunar exploration
  - Astronaut training: coordinated by NASA scientists with instructors pulled from academic community
  - Science integrated within tools, technology, and architecture teams across Artemis

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Recommendation #1: Integrate the lunar science community with the human spaceflight community to ensure adequate understanding of lunar science objectives and criteria for success

- LEAG: advocacy and engagement both within the community and up-and-out
  - Key documentation, vetted by LEAG and CAPTEM, are critical resources for Artemis (Lunar Exploration Roadmap, 2010 CAPTEM-LEAG Report)
- NASA SMD-funded and HEO-funded analog missions
  - Increase number of scientists with operational experience
  - High-fidelity analog projects create an integrated exploration workforce in between human spaceflight missions
  - PSTAR and SSERVI provide some of this funding but more is needed to adequately prepare the community
  - Joint funding opportunities between SMD and HEOMD would show greatest flexibility and commitment to exploration science

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White Paper: The Importance of Human Exploration in Accomplishing High Priority Lunar Science Objectives

Slides from Dr. Young's presentation to the Mercury and Moon Panel

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Recommendation #2: Include a strategy in the 2023-2032 Decadal Survey for maximizing lunar science through human exploration, not just through the more traditional orbital and landed missions

- Legacy of successful Participating Scientist Programs
- Lessons learned from Apollo, Mars exploration, International Space Station, etc.
- SMD R&A programs have been shown to bridge the gap, but would benefit from increased funding for analog testing
- Opportunity to find synergies between 'traditional' SMD payloads and the capabilities of human deployed/tended science payloads
  - Human exploration can leverage SMD investments (smaller, low-powered, very capable instruments on rovers/landers) while also increasing possible payload complexity due to astronaut capability
- Conference participation: premier science conferences tend to minimize the importance of analog science and missions as well as the importance of human exploration in accomplishing high-priority science objectives

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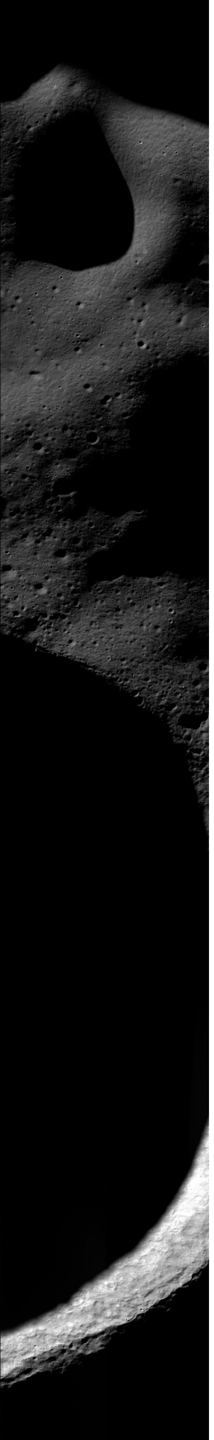

Open Communication:
The non-NASA community should be involved more

- **A long time ago and not that long ago…**
  - Non-NASA scientists worked together with NASA civil servants with a goal of getting humans to the Moon
    - Apollo Examples
      - Geology training (e.g., Dave McKay, Farouk El-Baz, Gene Shoemaker)
    - Constellation Examples
      - 2007 NRC Report, Scientific Context for Exploration of the Moon
      - Mission simulations with Apollo era civil servants and new non-civil

      →See "Training for Lunar Surface Operations" by Kring, Looper, Ney and Janoiko (2020)

      https://www.lpi.usra.edu/lunar/strategies/Artemis-Major-Skills-Training_DV1_2_w_appendix.pdf
- **Now, the non-NASA community is not leveraged to the extent it could be**
  - Artemis III Science Definition Team: 10 NASA CS, 1 USGS CS, 3 non-CS
  - Contamination and Research Integrity (CaRI): 7 NASA CS, 0 non-NASA

https://www.lpi.usra.edu/Artemis/

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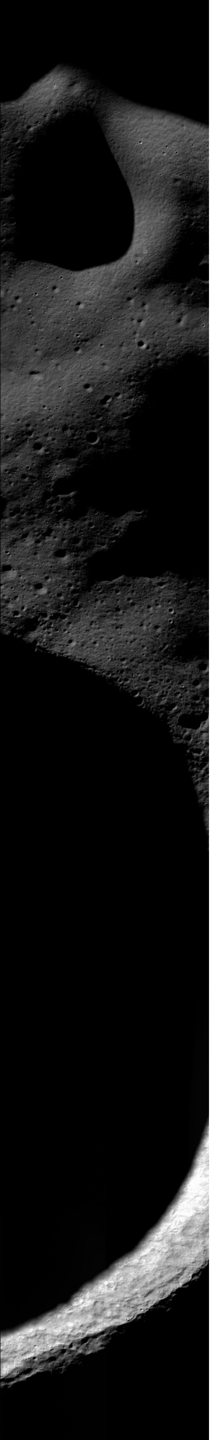

Open Communication:
The non-NASA community should be involved more

- **To be fair, LEAG and the lunar exploration community is utilized, but could provide more**
  - Recent example: Request for joint Specific Action Team with Mapping and Planetary Spatial Infrastructure Team (MAPSIT)
    - Lunar Critical Data Products (Co-chairs: Julie Stopar, Angela Stickle)
  - Lunar Surface Science Workshops https://www.hou.usra.edu/meetings/lunarsurface2020/
    - Wide participation, but how reports are used is nebulous to most
  - Other LEAG Specific Action Teams https://www.lpi.usra.edu/leag/reports/
- **Diversity of thought is important**
  - All members of the community from different sectors should be involved
- **Leverage hard-won “institutional memory”**
  - Apollo and Constellation veterans
  - Increase productivity, avoid earlier mistakes, don’t invent the wheel

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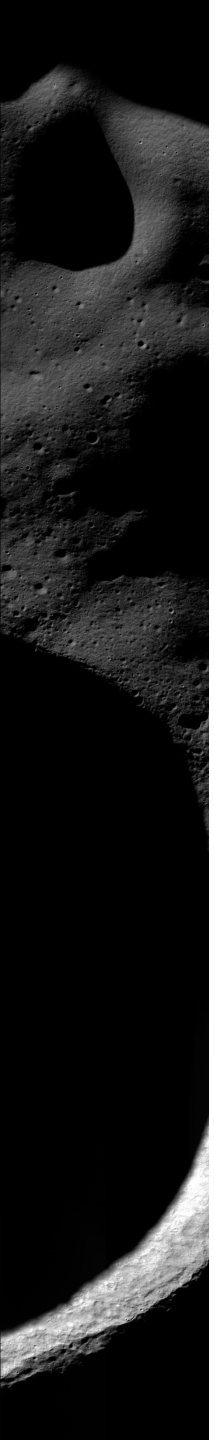

Open Communication: Nurture activities between HEOMD and SMD

- **Somewhat unclear to the community how these groups are working together, but looking forward to hearing more as plans progress**
  - Recommendation by Artemis III SDT Report: Standing working group of Artemis program science leadership (SMD) coordinate with STMD and HEOMD →communication and facilitation
    - Utilization Coordination Integration Group
  - NASA Federated Board (est. 2019; Greg Chavers, Joel Kearns, Walt Engelund)
    - *"…technical integration and coordination activities around the goals of a long-term lunar surface presence beyond the 2024 mission and the first human mission to the surface of Mars"* https://spacepolicyonline.com/news/bridenstine-establishes-federated-board-for-strategic-alignment/
  - 2021 LEAG Annual Meeting Panel to Inform the Community
    - "Bringing the lunar community together" panel
    - Representatives from LSSW, LSII, LSIC, HEO, ESSIO, LEAG, Artemis III SDT

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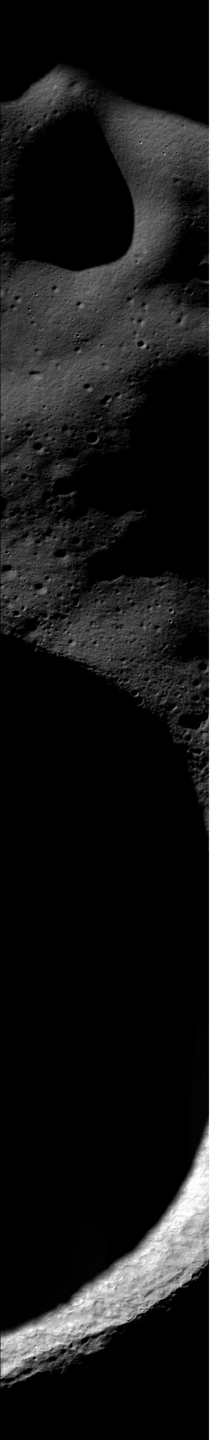

Open Communication: Transparency with decisions and timeline updates

- ****Updated Information Regarding <u>PROCESS</u> for Selections of:**
  - Landing site selections;
    - Who selects the landing sites and when/how can community feedback be included beyond the initial RFIs?
  - Science team selections;
    - What will the science team be doing? For example, will there be a specific "backroom" team and a field training team?
    - What is envisioned for a competed science team? For example, will it be competed as a team or as individuals, who are then combined into a team?
  - Instrumentation selection;
    - How and when will instruments be selected for Artemis?

*****These items were presented to the Planetary Advisory Council on 14 June 2021***

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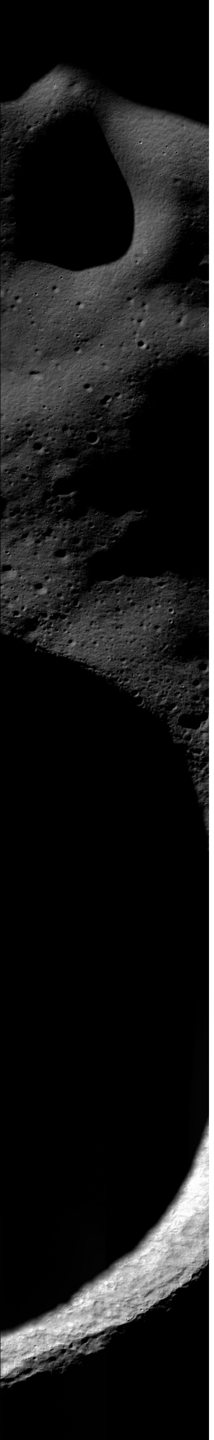

Open Communication:
Transparency with decisions and timeline updates

- ****Updated <u>TIMELINES</u> (including est. dates) for:**
  - Artemis III landing;
  - Artemis Base Camp development and execution;
  - Selection of: landing site(s); astronauts; science team; instrument calls
- ****Suggestion for more stream-lined communication:**
  - Updates be made available at a centralized website (e.g., ESSIO)
    - Access recent charts of updates provided at workshops and meetings
    - Increases the accessibility of information for the community
  - Research Proposal Analogy→ make it easy for the reviewer to find it

*****These items were presented to the Planetary Advisory Council on 14 June 2021***

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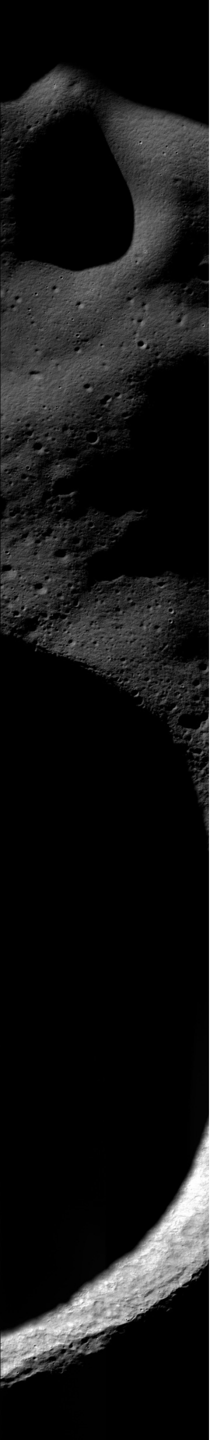
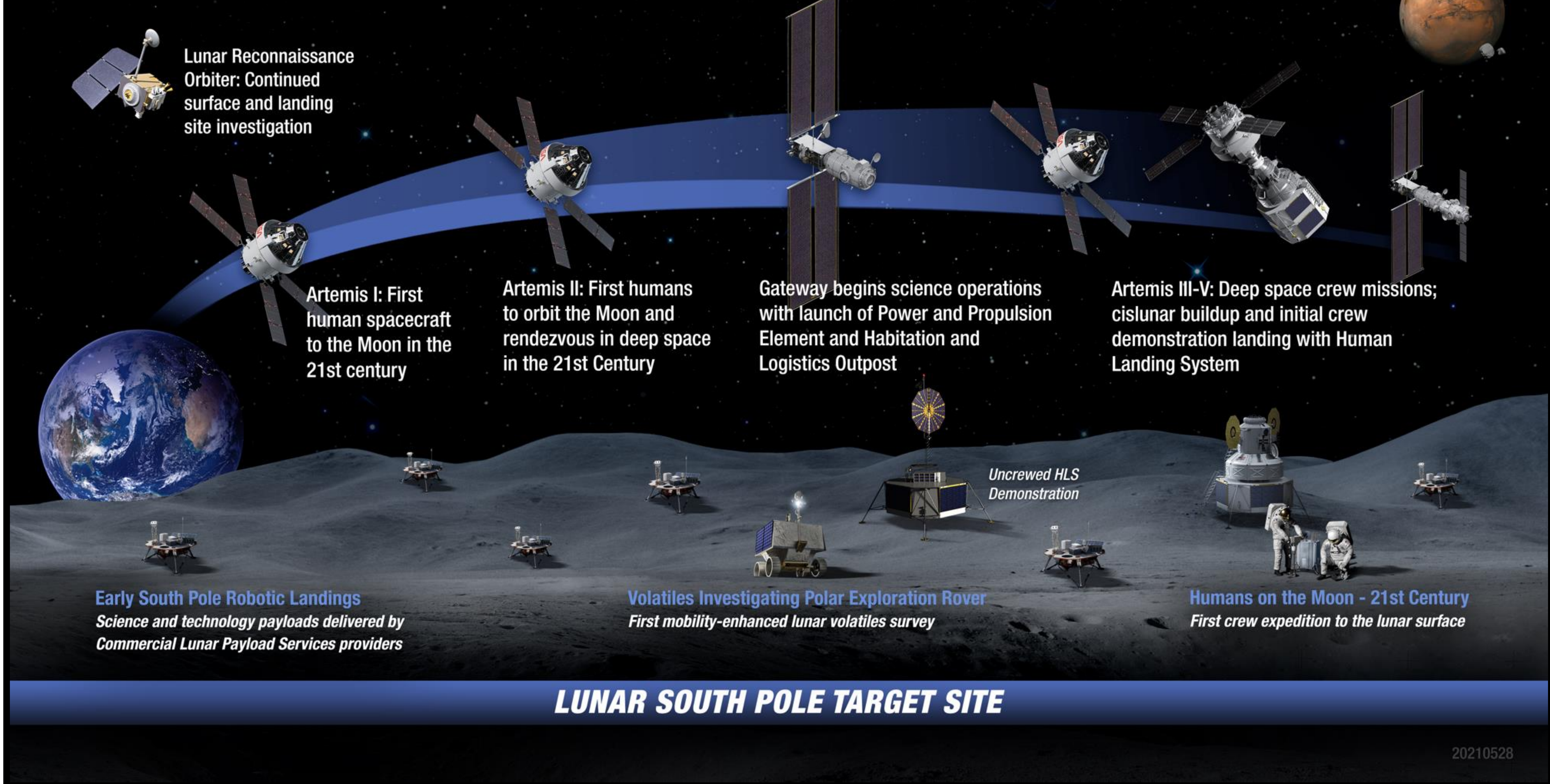
Artemis: Landing Humans On the Moon





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Open Communication:
Transparency with decisions and timeline updates

- **What is the long-term strategy for the Moon? How does it all fit together between humans, CLPS, PRISM, VIPER, etc?**

Artemis Science Implementation Strategy

- Develop a pipeline of science and technology payloads to be delivered to the lunar surface by commercial companies
- Develop mobility systems to expand and enhance science investigations on the lunar surface
- Leverage International Partnerships for additional opportunities (e.g., instruments, rovers)
- Obtain new scientific data from lunar orbit pertinent to planetary, solar system, and cosmological observations using SmallSats
- Use of new human exploration systems, such as Gateway and the Human Landing System, to enable science
- Lead the science mission planning for Artemis crews on the lunar surface including developing the capabilities they will need to conduct effective scientific exploration. These capabilities relate to
  - Field geology
  - Sample collection and return
  - Instrumentation for surface and near-surface environment characterization (e.g. electromagnetic interference, charged particle, neutral particulates)
  - Access to cold regions
  - Access to lunar far side
- Create a pathway for component/sensor/technology development that enables science (e.g., TRL enhancement)

ARTEMIS PLAN

NASA's Lunar Exploration Program Overview

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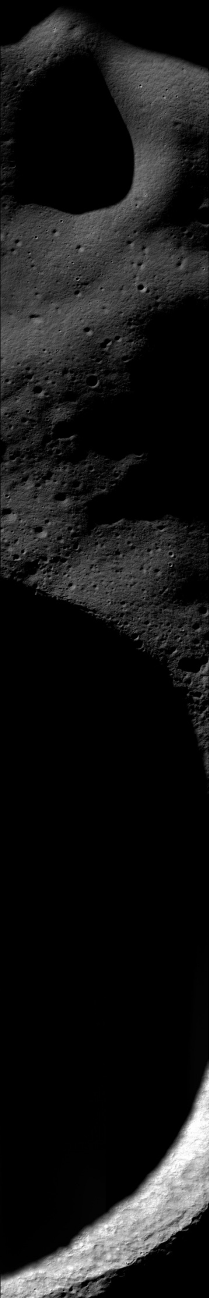

Human Exploration Benefits from Robotics to Achieve Science Goals

- **Pre-cursor robotics**
  - CLPS, PRISM, VIPER
    - Evolution of CLPS and PRISM programs? E.g., delivery of pre-positioned assets?
- **Mobility**
  - Access to greater diversity of terrains
  - Increased carrying capacity (payloads, samples, etc.)
  - Ability to access complex terrains outside of where landers can land (i.e. central peaks)

Mission	Time outside LM (hr)	Distance (km)	Sample Mass (kg)
Apollo 12	7:29	2	34
Apollo 17	22:05	35	110

Data from the Apollo 17 Preliminary Science Report (1973)

- **Complementary missions to achieve big picture science goals**
  - E.g., Lunar Geophysical Network, South Pole Aitken Sample Return, Artemis III
    - not redundant or duplicative→ one mission informs the science outcome from another

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Utilize the Moon as a test-bed for Exploring Beyond

- **Outlined in Lunar Exploration Roadmap** https://www.lpi.usra.edu/leag/roadmap/
  - Themes: Science, Feed Forward, Sustainability
  - **Feed Forward**:
    - ID & test technologies on Moon to enable robotic and human exploration
    - Test-bed for mission operations and exploration techniques
    - Prepare for future missions to airless bodies
- **Artemis Base Camp (2020 Artemis Plan)**
  https://www.nasa.gov/sites/default/files/atoms/files/artemis_plan-20200921.pdf
  - Sustainable presence→ Lunar Terrain Vehicle, Habitable Mobility Platform, habitation module, power systems, ISRU
  - Prepare for Mars
  - Learn more about the Moon and solar system
- **Leverage the Moon as an analog**
  - E.g., Community Workshop for Achievability and Sustainability of Human Exploration of Mars https://www.exploremars.org/affording-mars/

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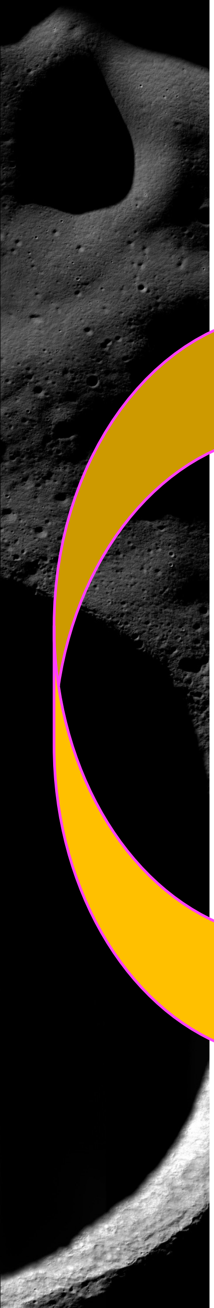

Takeaway Points: Infusing High-Priority Science into Human Exploration

- **We have planned, we are prepared, and we are ready. Let's go exploring!**
- Open Communication
- Human Exploration benefits from robotics
- Utilize the Moon as a test-bed for exploring beyond
  - Use the prioritized goals and investigations from the Lunar Exploration Roadmap
  - Address recommendations from the Artemis III Science Definition Team Report

LUNAR EXPLORATION ANALYSIS GROUP

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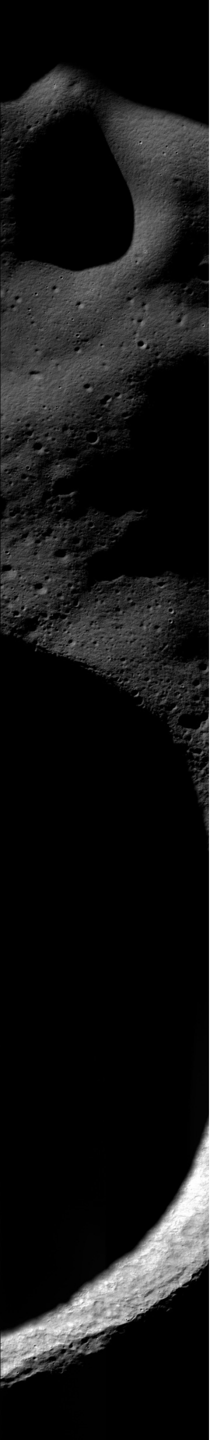
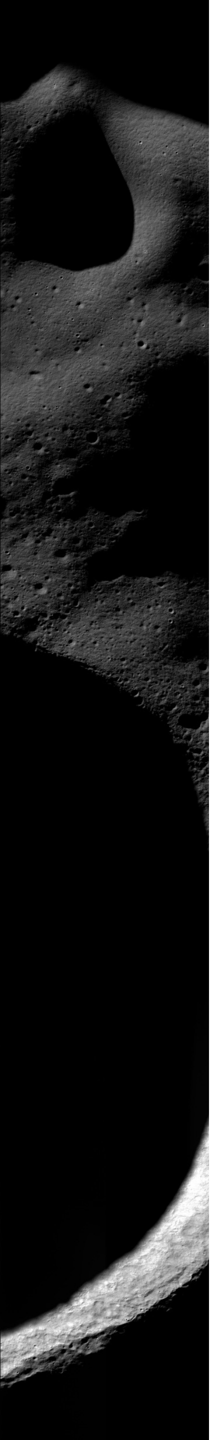


Backup Slides For Discussion

- Artemis III Science Definition Team Report Recommendations (short and long-form)
- Examples from Lunar Exploration Roadmap
- Official LEAG White Paper Summaries



Artemis III Science Definition Team Report Recommendations-Short Hand Version

- Geology training for astronauts
- Sample return mass > Apollo
- Careful choreography of sample collection and in situ measurements
- Deploy geophysical and environmental monitoring nodes & geodetic monitoring
- In situ imaging and assessment capability on EVAs
- "real-time transmission of data from *in situ* science instrumentation that provides documentation for site characteristics and enables a science support team (backroom, operations center, etc.) to support EVA operations with (near) real-time feedback to the crew "
- "development of instruments that are capable of addressing more than one measurement need and/or science Investigation"
- Consider pre-positioned assets
- Standing working group of Artemis program science leadership (SMD) coordinate with STMD and HEOMD →communication and facilitation
- Use the analysis groups (e.g., LEAG, ExMAG)
- Long-lived power and communication
- Mobility
- Cryogenic and volatile-bearing sample return
- Standards for lunar geodetic coordinate reference frame and for cartographic and time controls for surface measurements → LCDP-SAT
- New data products (geologic maps, cartography, topographic models)→LCDP-SAT
- Funding for the PDS
- Science should guide site selection

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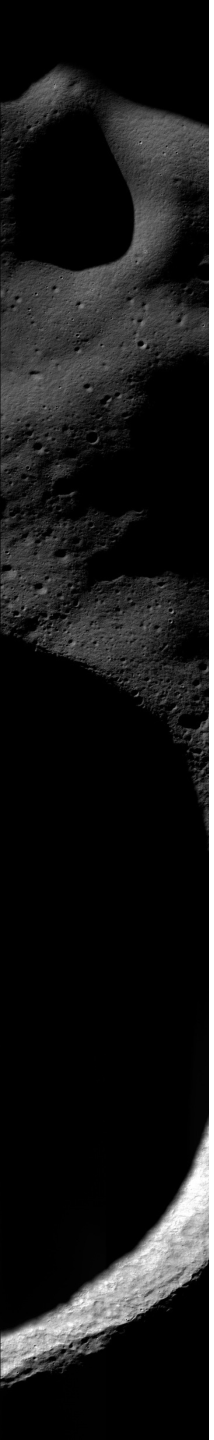


Artemis III Science Definition Team Report Recommendations

- Recommendation 6.1.4-1: Astronauts should participate in an Apollo-style course in geology and planetary science, including both field and classroom components, in order to provide optimal *in situ* geologic characterization of lunar sample collection sites. A dedicated team of scientists should serve in an Earth-based Artemis III Science Mission Center with real-time two-way audio and one-way video between the crew and the Science Mission Center.

- Recommendation 6.1.4-2: Astronauts should be trained and equipped to collect a variety of surface and sub-surface samples. NASA should plan to return total sample masses in excess of previous lunar sample return missions.

- Recommendation 6.1.4-3: NASA should ensure that sample collection and *in situ* measurements are carefully choreographed to maximize science return. Examples of such coordination include the characterization of rock samples with *in situ* instrumentation to aid in prioritization of samples selected for Earth return, and *in situ* volatile measurements made in conjunction with sample collection to characterize volatile losses from sample collection, transport, and/or curation, and efforts to provide “ground truth” for orbital remote sensing datasets.

- Recommendation 6.1.4-4: NASA should focus on the development of lightweight, double-sealed vacuum containers to return volatile bearing lunar samples to Earth. Minimizing the mass penalty for vacuum-sealing any given sample results in increased scientific yield of the mission since more mass can be allocated to the lunar samples instead of the sampling hardware.

- Recommendation 6.2.4-1a: The Artemis III mission is an opportunity lost if the first of a series of geophysical and environmental network nodes is not deployed. While incremental science can be obtained with short-lived experiments, long-lived power and communication capability will be required to fully enable prioritized investigations (see Section 7.1). The Artemis III node can be augmented by both robotic and human future missions, thus building towards a global network.

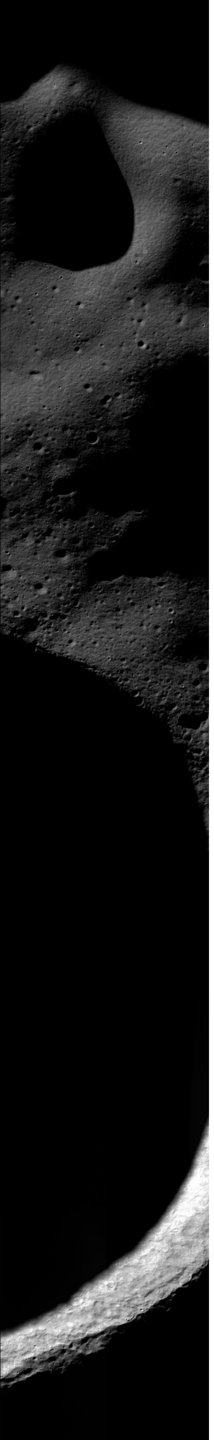
- Recommendation 6.2.4-1b: Geodetic monitoring via Earth-based laser ranging requires no lunar surface power or communication to function and hence will provide science return even in the absence of such capabilities. We advocate for geodetic monitoring capability to be prioritized for Artemis III.

- Recommendation 6.3.7-1a: NASA should ensure that *in situ* imaging and assessment capability is available to crews during extravehicle activity (EVA) to document site characteristics, sampling, and instrument deployment.

- Recommendation 6.3.7-1b: We recommend NASA provides a mission capability of real-time transmission of data from *in situ* science instrumentation that provides documentation for site characteristics and enables a science support team (backroom, operations center, etc.) to support EVA operations with (near) real-time feedback to the crew when necessary on science decision-making, as well as provide processed data when necessary (i.e. helping convert raw data into tactical decision-making). This requires prior establishment of high bandwidth communication that is capable of extensive real-time data transmission to accommodate use of valuable measurements from modern sensors.

- Recommendation 6.4-1: NASA should solicit the development of instruments that are capable of addressing more than one measurement need and/or science Investigation.

- Recommendation 7.2-1: NASA should consider pre-positioning science assets in the vicinity of the Artemis III landing site. This could consist of an inert cache of tools/instruments to be accessed by crew upon arrival, and/or one or more instrumented landers or rovers for environmental monitoring.



Artemis III Science Definition Team Report Recommendations

- Recommendation 6.5-1a: A standing working group comprising scientific leadership of the Artemis program in SMD should be established and closely coordinate with representatives of STMD and HEOMD to ensure clear lines of communication and facilitate program implementation.
- Recommendation 6.5-1b: NASA's existing Program Analysis Groups, such as the Lunar Exploration Analysis Group (LEAG) and the Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM), serve an important role synthesizing community input across diverse stakeholders in the engineering, science, and commercial communities, and should be leveraged as the program continues to promote external community engagement to the fullest practical extent.
- Recommendation 7.1-1: NASA should pursue solutions for long-lived power and communications to enable networked operation of Apollo Lunar Surface Experiment Package (ALSEP)- like packages at multiple landing sites, as needed, to enable meaningful progress on many of the Goals described in Section 5, and feeding forward to future Artemis missions.
- Recommendation 7.3-1: NASA should include a rover or other mobility solution for crew use on the lunar surface starting as early in the Artemis program as possible, ideally for Artemis III.
- Recommendation 7.4-1: NASA should develop and implement the required hardware and operations to return a subset of the samples at temperatures low enough to preserve water ice and other low temperature volatiles of interest, including non-H_2O volatiles, in the solid state throughout the entire journey from the lunar surface to Earth-based laboratories. Cryogenic sample return will increase the scientific fidelity of sample analyses of volatiles and ices. Minimizing the mass penalty for cryogenic sample return results in increased scientific yield of the mission because more mass can be allocated to the lunar samples instead of the sampling hardware.
- Recommendation 8.2-1: Any needed updates to the standard lunar geodetic coordinate reference frame (e.g., currently used by the Lunar Reconnaissance Orbiter (LRO)) should be identified in 2021, and foundational products should be mapped onto it and/or developed to use it directly. Establishing a standardized coordinate reference frames can significantly improve data reliability and reduce the risk of errors.
- Recommendation 8.2-2: Standards for cartographic and time controls for surface measurements (photographs, video, and surface measurements) should be defined in the near term so that those standards can be implemented in instrument development. This should also include high-fidelity time coding for all surface measurements time-synced with Earth in UTC.
- Recommendation 8.3-1a: We recommend maintaining sufficient funding to the Planetary Data System (PDS) to maintain the online tools needed to search, access, and use lunar data.
- Recommendation 8.3-1b: To support the level of accuracy and precision needed for landing and surface operations, new cartographic products, including mosaics and topographic models, for the south pole should be developed using the highest quality data available (e.g., LRO NAC and LRO WAC frames, SELenological and Engineering Explorer (SELENE) Terrain Camera (TC), SELENE Multi-band Imager (MI), and Chandrayaan-1 Moon Mineralogy Mapper (M3)) and using the standard (possibly updated) lunar geodetic coordinate reference frame.
- Recommendation 8.3-1c: New derivation of higher-order data products from existing missions should also be supported where needed for Artemis III. For example, it is vital that more detailed geologic mapping of candidate landing sites be accomplished at a scale similar to what was done in preparation for Apollo.
- Recommendation 9.1-1a: Science outcomes of this report should be an important consideration during the site selection process for the Artemis III mission.

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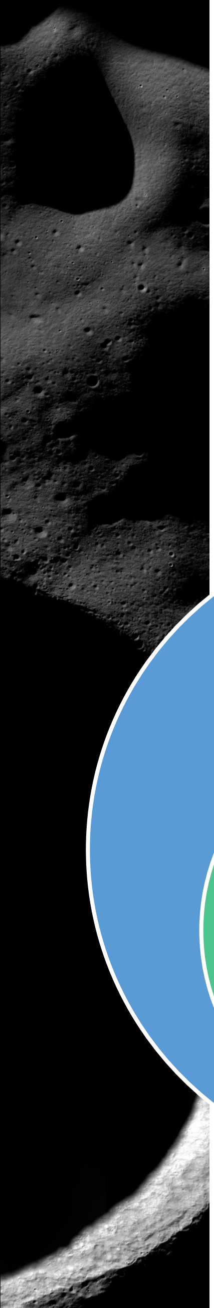

Organized by Theme→ Goals→ Objectives

Why are we going to the Moon?

Themes

- **Science**
- Feed Forward
- Sustainability

Goals (objectives)

- Understand formation, evolution, current state of the Moon
- Witness plate for solar system evolution
- Platform for astrophysical, heliophysical, and Earth-observing studies
- Unique environment as research tool

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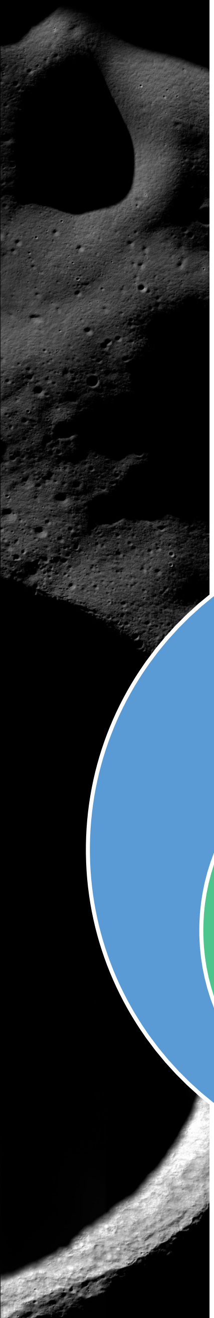
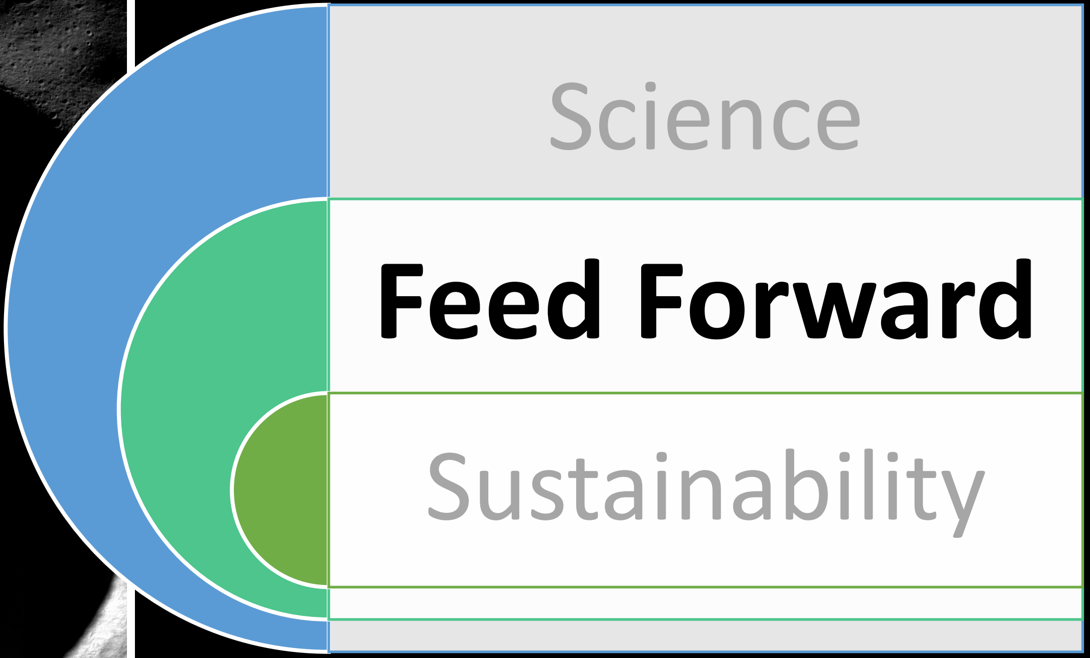


Organized by Theme→ Goals→ Objectives

Why are we going to the Moon?

Themes



Goals (objectives)

- ID & test technologies on Moon to enable robotic and human exploration
- Test-bed for mission operations and exploration techniques
- Prepare for future missions to airless bodies

Organized by Theme→ Goals→ Objectives

Why are we going to the Moon?

Themes

- Science
- Feed Forward
- **Sustainability**

Goals (objectives)

- Maximize commercial activity
- Collaborative expansion of science and exploration
- Enhance security, peace, safety

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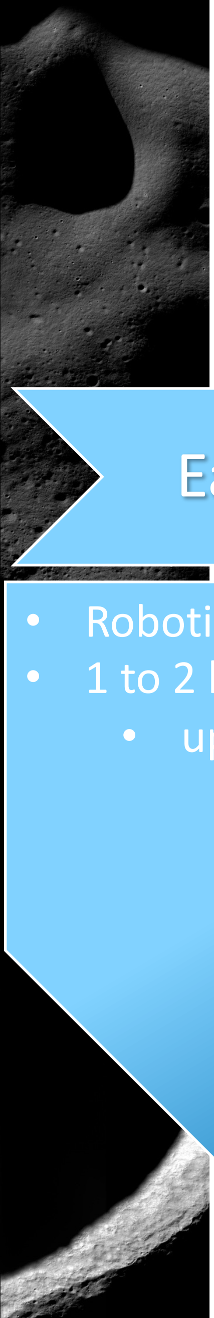

Prioritization in Timing and Science

Time Phasing

Early → **Middle** → **Late**

Early
- Robotic pre-cursors
- 1 to 2 human landings
  - up to 1 lunar day

Middle
- Continue robotics
- Human stays 1 lunar day + part of lunar night
- Initial outpost

Late
- Continue robotics
- Established outpost
- Human presence >30 days at a time

Science Priority

High → **Medium** → **Low**

High
- Essential information and technological developments to:
  - Facilitate habitation on lunar surface
  - Further exploration
  - Facilitate scientific advancements

Low
- Not essential for habitation and exploration
- Incremental science advances
- Still good to do!

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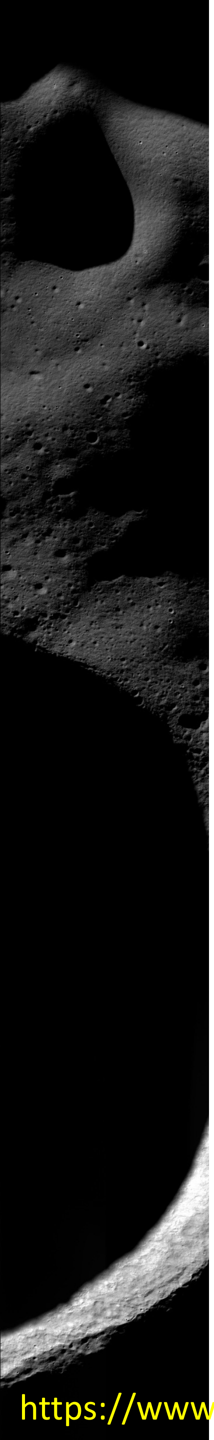

Prioritization in Timing and Science

Time Phasing { Pre-Early | Early | Middle | Late

Science Priority {
- High Priority
- Med Priority
- Low Priority

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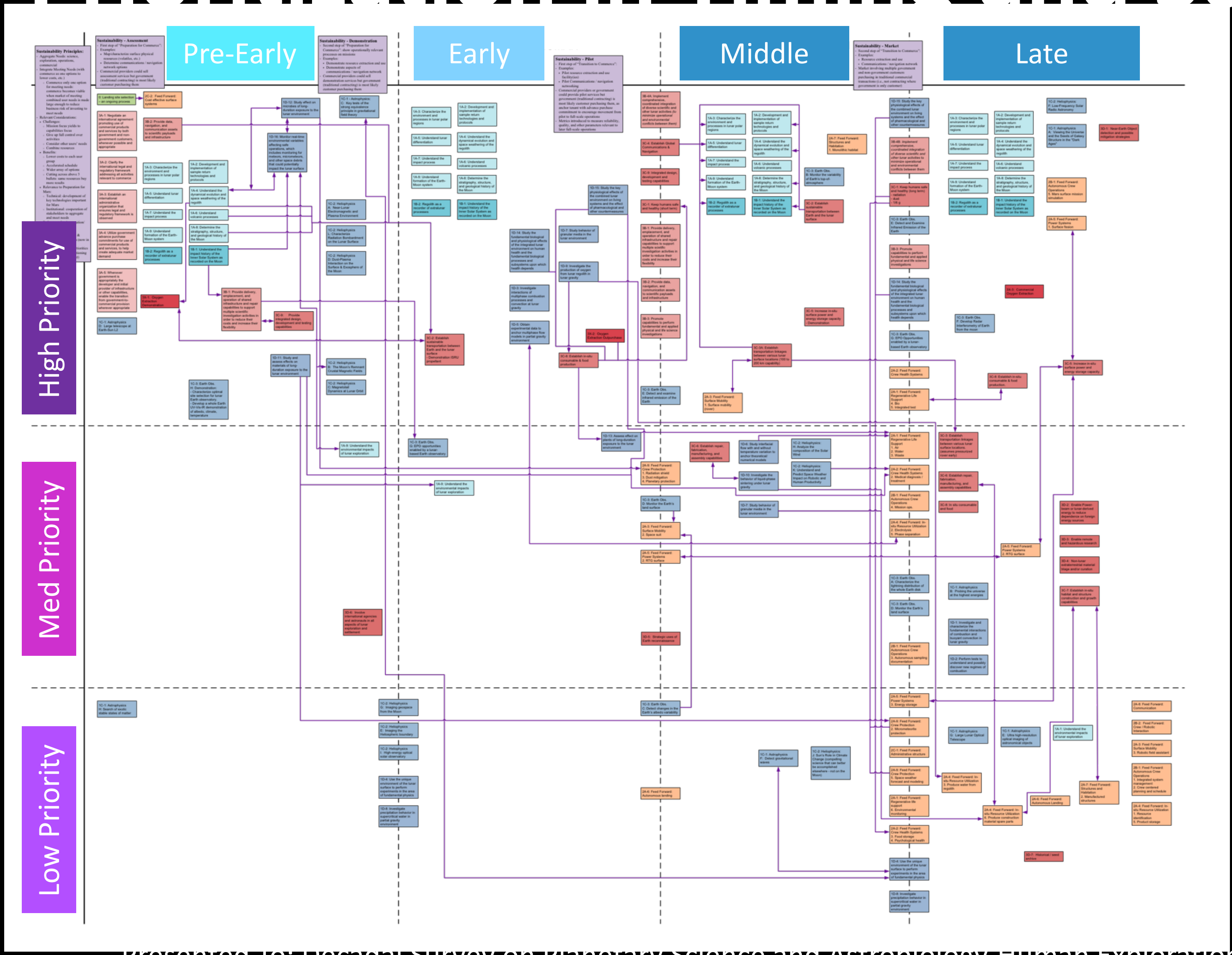
https://www.lpi.usra.edu/leag/roadmap/

Prioritization in Timing and Science

Time Phasing

Science Priority



Color Scheme

Science

Feed Forward

Sustainability

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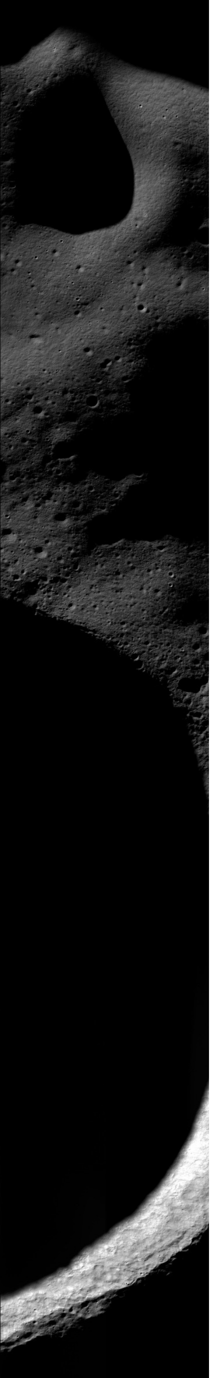

4 Official LEAG White Papers Submitted

- The Importance of Human Exploration in Accomplishing High Priority Lunar Science Objectives
  - Lead Author: Dr. Kelsey Young
- Lunar Missions for the Decade 2023-2033
  - Lead Author: Dr. Barbara Cohen
- Planetary Science Priorities for the Moon in the Decade 2023-2032: Lunar Science is Planetary Science
  - Lead Author: Dr. Erica Jawin
- The Moon is a Special Place
  - Lead Author: Dr. Daniel P. Moriarty III

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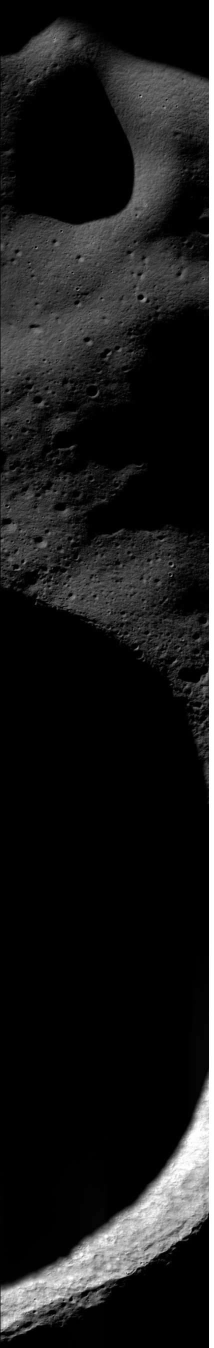

4 Official LEAG White Papers Submitted

- The Importance of Human Exploration in Accomplishing High Priority Lunar Science Objectives (Lead Author: Dr. Kelsey Young)
  - Recommendation: The lunar science community should be integrated with the human spaceflight community to ensure adequate understanding of lunar science objectives and criteria for success.
  - Recommendation: The Planetary Science Decadal Survey should include a strategy for maximizing lunar science through human exploration, not just through the more traditional orbital and landed missions.

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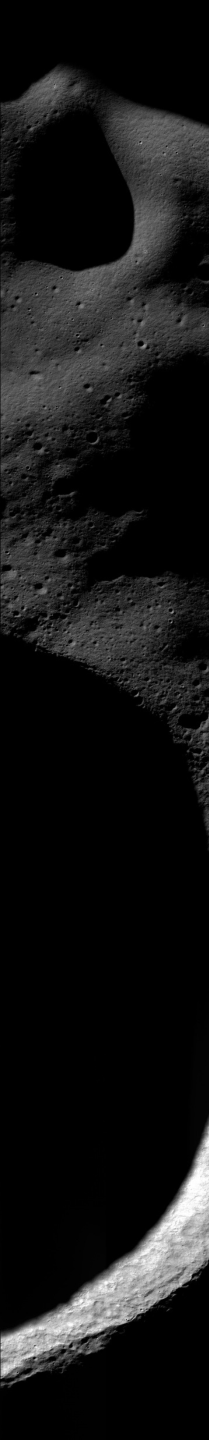

4 Official LEAG White Papers Submitted

- Lunar Missions for the Decade 2023-2033 (Lead Author: Dr. Barbara Cohen)
  - Recommendation: New Frontiers missions include…
    - Lunar Geophysical Network
    - Solar System Chronology (sample return or in situ dating)
    - Long-Range Geologic Explorer
  - Recommendation: Advocate for lunar missions that accomplish Solar System science in the Discovery and SIMPLEX programs.
  - Recommendation: Initiate Studies for…
    - Lunar Permanently-Shadowed Region Volatiles Explorer mission
    - Next Generation Lunar Orbiter mission
  - Recommendation: Investigate potential mission partnerships
  - Recommendation: Highlight enabling technology investments

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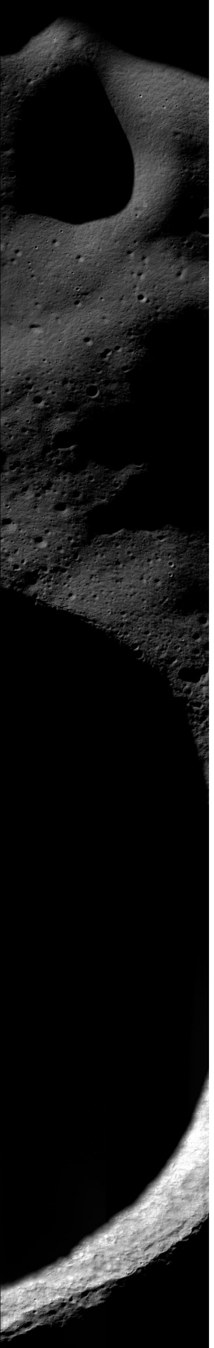

4 Official LEAG White Papers Submitted

- Planetary Science Priorities for the Moon in the Decade 2023-2032: Lunar Science is Planetary Science (Lead Author: Dr. Erica Jawin)
  - Recommendation: Prioritized recommendations in community documents are still valid such as:
    - 2007 NRC Report: Scientific Context for Exploration of the Moon
    - Advancing Science of the Moon Specific Action Team
    - Lunar Exploration Roadmap
  - Consider critical role of team dynamics, equity, diversity, inclusion, and accessibility in planetary science

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4 Official LEAG White Papers Submitted

- The Moon is a Special Place (Lead Author: Dr. Daniel P. Moriarty III)
  - Recommendation: The Moon provides a critical foundation for achieving fundamental planetary science and exploration goals. The Moon remains a target of the highest priority.
  - Recommendation: A robust program of lunar science and exploration, including orbital missions, robotic sample return, in situ analyses, human exploration, numerical modeling, laboratory experiments, terrestrial analog work, sample analyses, and data analysis.
  - Recommendation: The lunar science community will be greatly strengthened through a clear commitment to diversity, inclusion, education, and public outreach.

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