Lunar Exploration Analysis Group
Volatiles Specific Action Team

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Full Report at:

http://www.lpi.usra.edu/leag/reports/vsat_report_123114x.pdf

Motivation and Execution

NASA HEOMD request to Lunar Exploration Analysis Group form a Specific Action Team

- Support international coordination of lunar activities associated with the Global Exploration Roadmap
  - Especially non-traditional participants
    - Emerging space-faring nations and commercial and academic entities that may field lunar missions specifically aimed at poles
- Lunar Polar Volatiles SAT to considered two principal tasks:
  - To assess if additional orbital remote sensing measurements are required to support landed missions
  - To conduct an assessment of the current state of knowledge, select and prioritize regions of interest with the potential of accessible volatiles that may support a synergistic approach of multiple missions, including measurements needed on the surface
- VSAT team membership: Government, national laboratories, universities and industry, included levels of experience from graduate students though senior members of the lunar science and engineering communities
- The SAT conducted multiple telecons with briefings from relevant groups, a face to face meeting coincident with the LEAG annual meeting, and closeout telecons prior to submission of the report on December 31 2014
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"There are sufficient data to support near-term landing site selections"

- LCROSS strategy of regional high hydrogen and low temperatures was successful
- This finding is critically dependent on mission goals and risk tolerance
  - Likely that water ice present is patchy, "dry holes" may be common
    - LCROSS ice abundances above average abundances derived from neutron measurements
    - Cratering of an initially continuous ice deposit will result in a patch distribution
  - Patchiness is a critical issue
    - Immobile landers should have goals resilient against low volatile abundance
    - There are important very low volatile measurements

"Testable hypotheses for volatile distribution should be formulated with the goal of developing a model [for predicting volatile distribution] that exceeds the attainable spatial resolution of orbital neutron measurements"

- Relationship between the lunar environment and volatile distribution is not understood
- In contrast to Mercury where volatile distribution can be predicted from temperature
- Most available data sets are high resolution
- Can a model link high resolution measurements to quality high resolution volatile distribution?
  - Validation

Early Surface Measurements

Zero-order “infrastructure”, ISRU focus, small mission capable

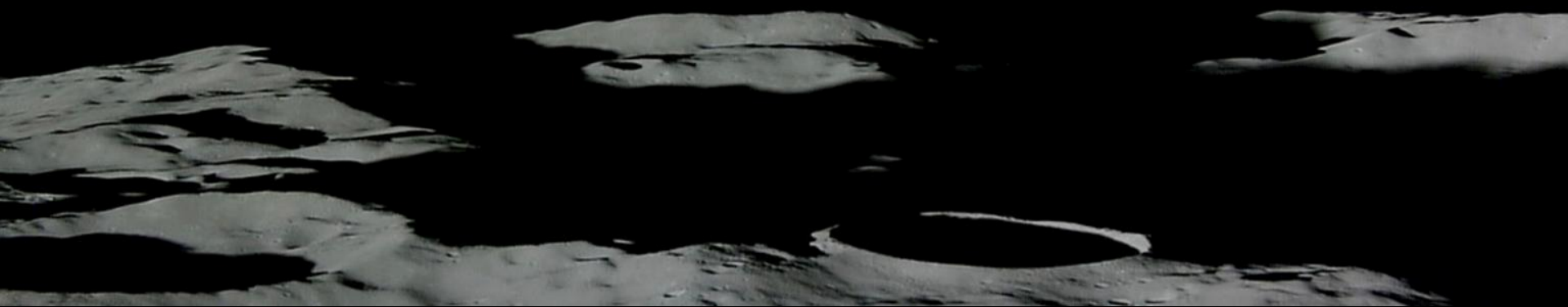
- Horizontal volatile distribution with scale, small rover
  - 1-m to 1-km
  - Supports landing planning, possible enabling of stationary landers
  - Input to resource recovery
  - Payloads might include: NS, GRS, GPR
- Thermal and mechanical properties of polar soils, static lander
  - ISRU process selection dependent on thermal properties
  - Payloads may include: DSC, TGA (Phoenix-like)
- Chemical phases that host volatiles, small rover with sampling
  - E.g. H is...water, hydrogen, organics, water-bearing mineral?
  - Payload: Various IR/optical spectroscopic, GC/MS of evolved gas
- Vertical distribution, small rover with drill
  - NS: 10 cm surface may be desiccated (but CRATER: surface may be wet)
  - Subsurface layering
  - Caution: Apollo
- Atmospheric volatile flux, static lander in, adjacent to, PSR

Remaining Orbital Contributions

- Improved direct measurements of volatiles
- Support understanding of science of volatiles aimed at a predictive model
  - More neutron measurements
  - Laser reflectance in key volatile spectral bands
    - E.g. Lunar Flashlight
    - Future experiments
      - Measure surface organic abundance for CHON (e.g. 3.4 micron, fluorescence)
      - Water abundance and mobility to equatorial lunar background abundances (e.g. 3 micron region)
  - Very high resolution low light passive imaging and spectroscopy (bespoke PSR designs)

Criteria For Site Identification

- Temperature
  - Average, minimum and maximum surface temperatures
- H concentration
  - LRO/LEND and Lunar Prospector
- Slope
- Lighting conditions
  - Duration of illumination
  - Permanent shadow
- Direct to Earth communication potential

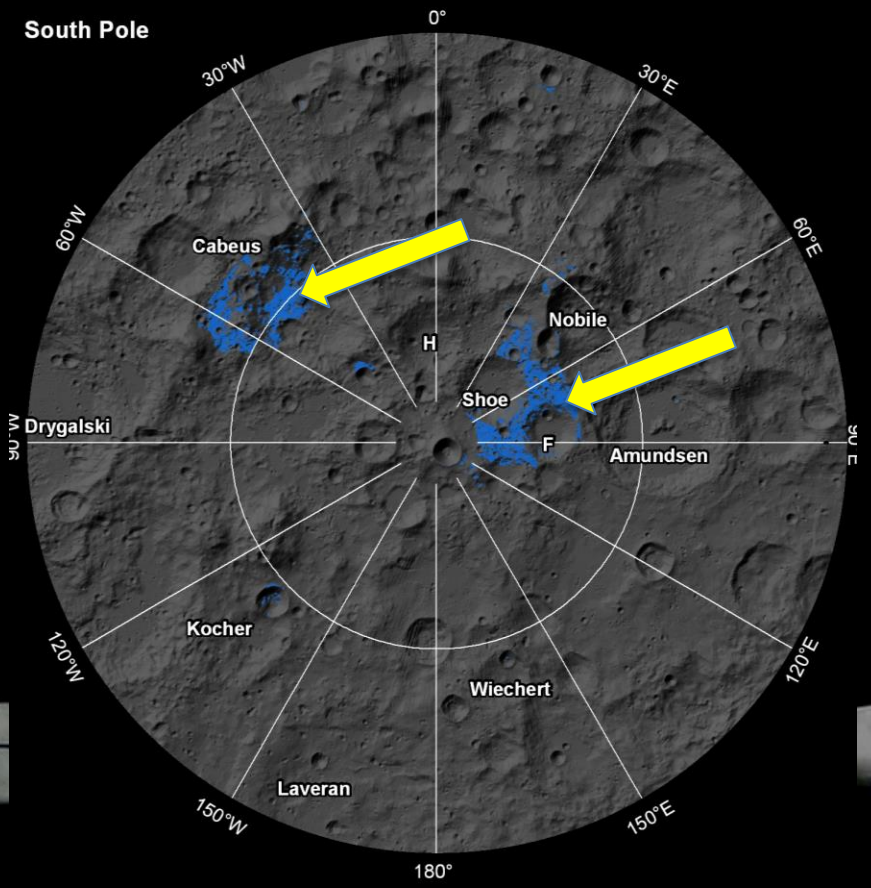


Regions of Interest: Multi-parameter analysis

South Pole

- H>150 ppm
- Average T < 110K
  - Preserves subsurface ice for geologic time
- Slope < 10 degrees
  - Navigable by current rovers
- Outside and adjacent to PSR
  - Lighting available

Cabeus and Shoemaker/Nobile vicinities meet general criteria and have some Earth visibility



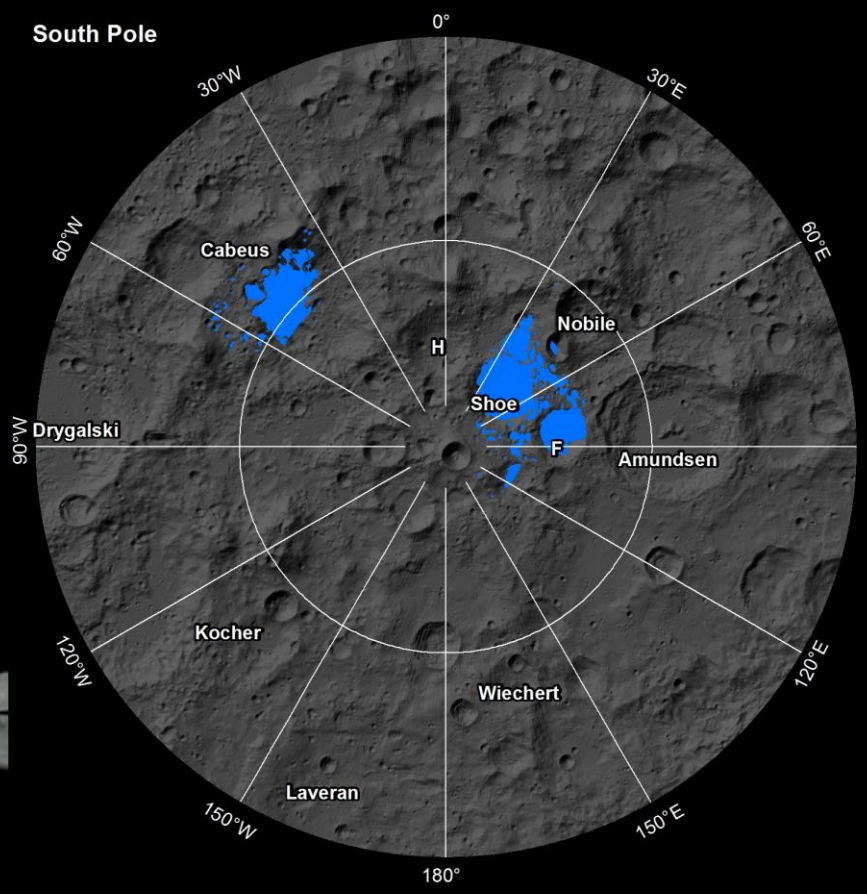
Regions of Interest: Similarity to LCROSS site

South Pole

- Regions similar to LCROSS Cabeus site in H and annual average temperature
  - "Likeness" is Euclidean distance from Cabeus H and T value

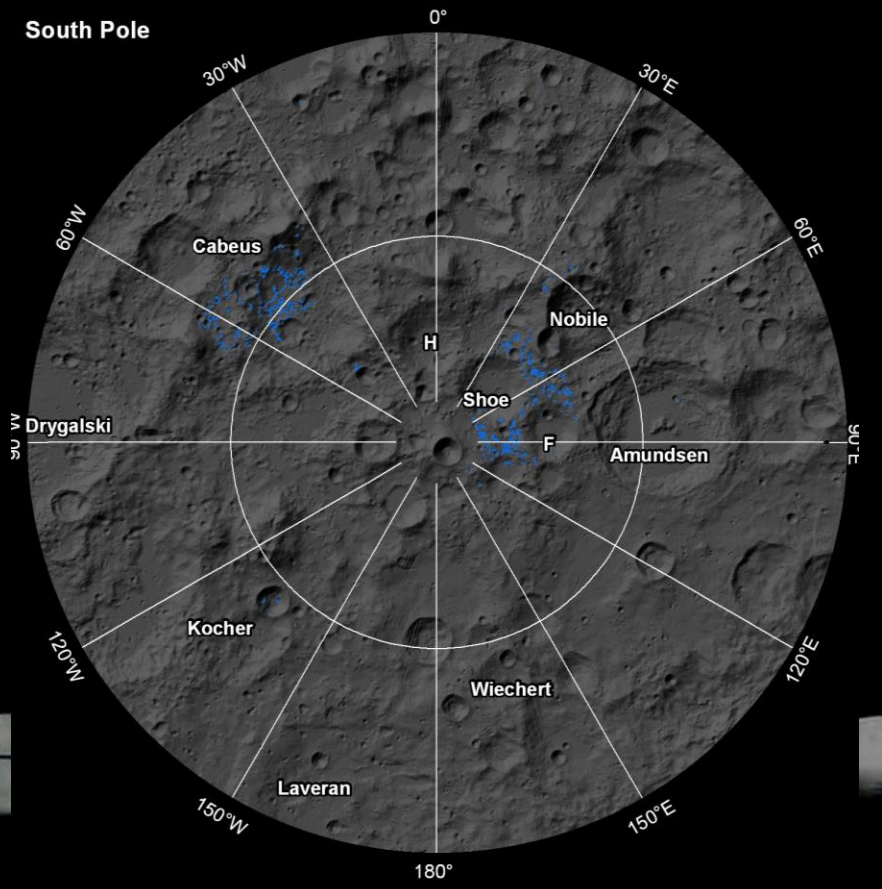
$$"Likeness" = \sqrt{\left(H - H_{Cabeus}\right)^2 + \left(T - T_{Cabeus}\right)^2}$$

Cabeus and Shoemaker/Nobile vicinities contain locations most similar to LCROSS site in H and temperature



Regions of Interest: Proximity to PSR < 1 km

- South Pole
  - Sites meeting multiparameter analysis criteria and having PSR within 1 km
  - Distribution is patchy but shows access to PSR from lit areas is available



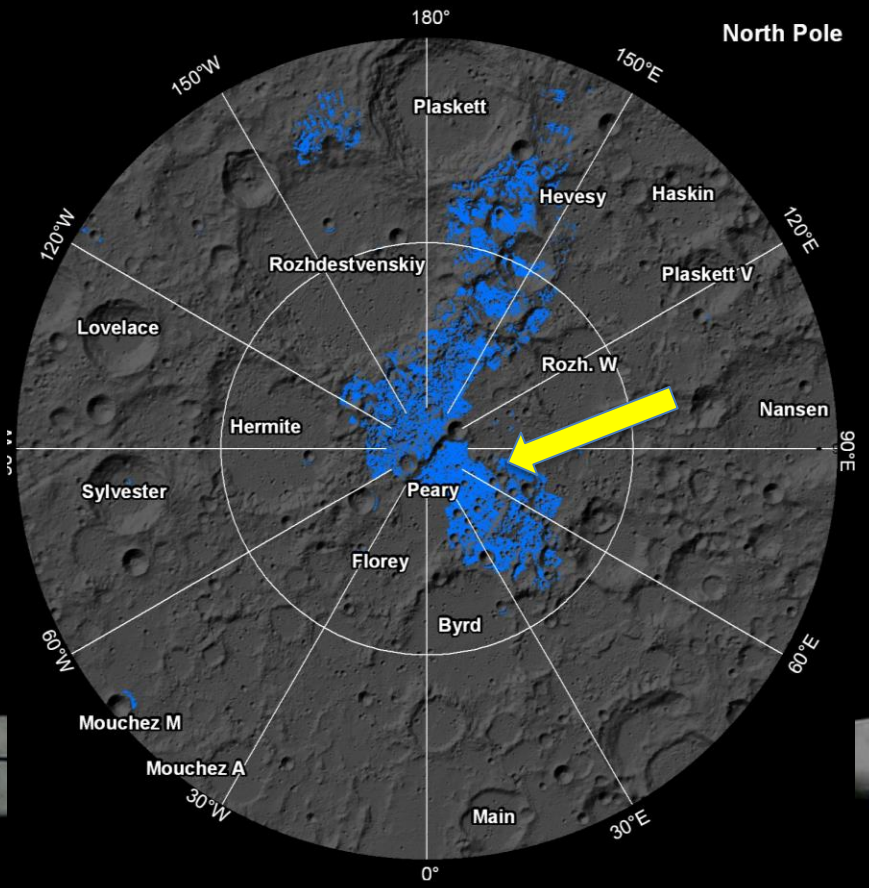
Regions of Interest: Multi-parameter analysis

North Pole

- H>150 ppm
- Average T < 110K
  - Preserves subsurface ice for geologic time
- Slope < 10 degrees
  - Navigable by current rovers
- Outside PSR
  - Lighting available

Peary vicinity meets general criteria and has Earth visibility

Substantial area of farside also meet general criteria

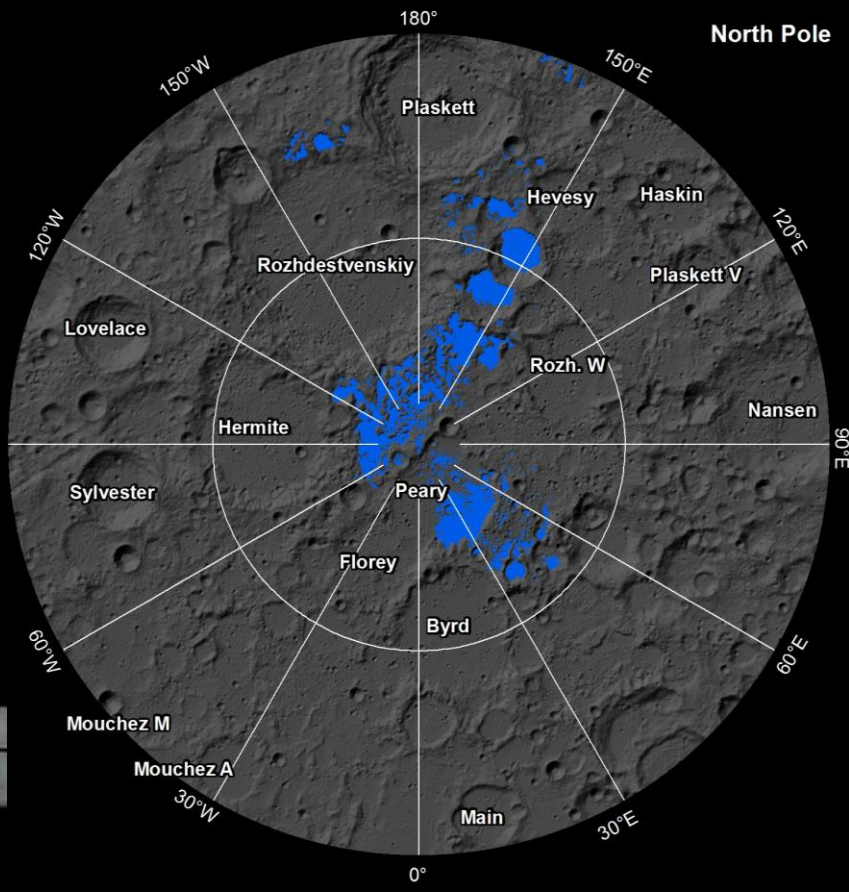


Regions of Interest: Similarity to LCROSS site

North Pole

- Regions similar to LCROSS Cabeus site in H and temperature
  - "Likeness" value threshold at <30

Peary and the north rim of Hermite vicinities contain locations most similar to LCROSS site in H and temperature with Earth visibility



Regions of Interest: Proximity to PSR < 1 km

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  - Sites meeting multiparameter analysis criteria and with PSR within 1 km
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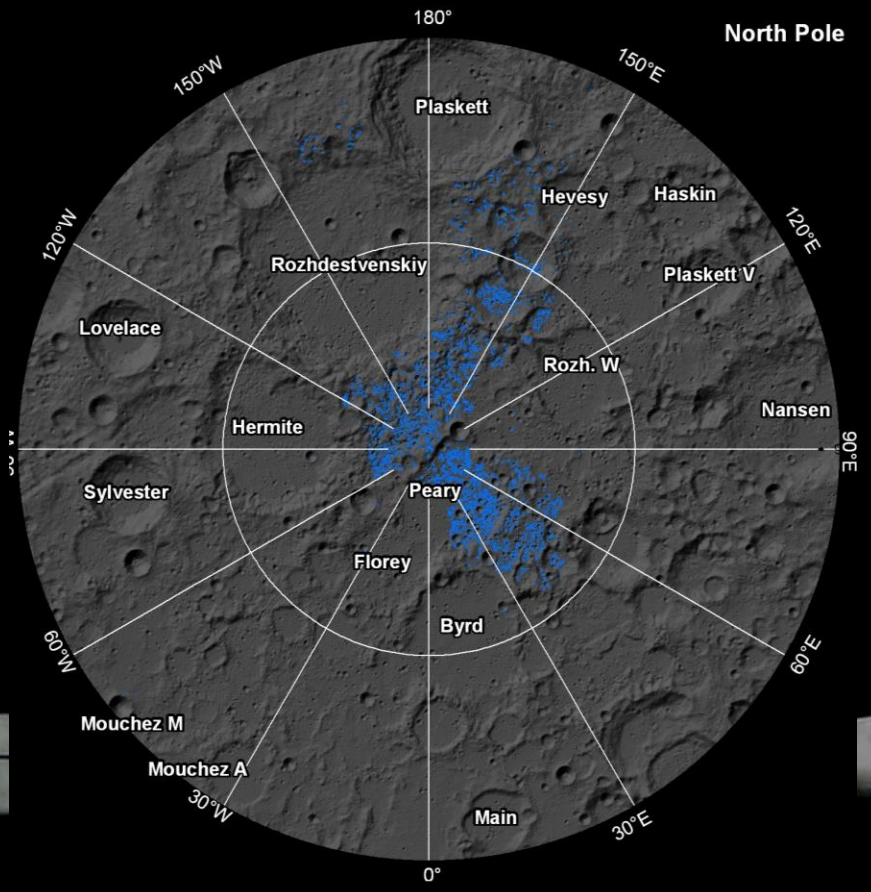
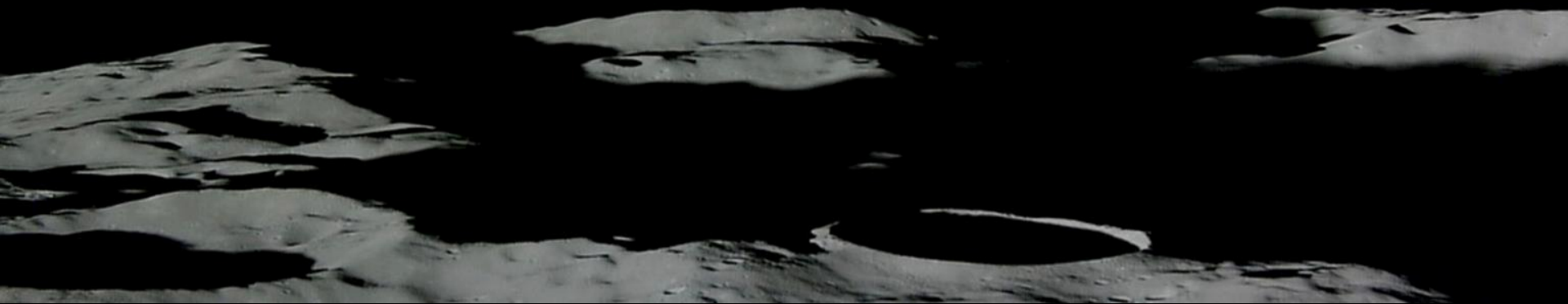


Summary

- Simple landed missions can contribute very significantly to engineering and scientific understanding of the polar environment
- New orbital measurements of surface volatiles are possible and contribute to the scientific understanding of the polar environment
- The distribution of lunar polar volatiles is not understood
  - Testable models to predict volatile distribution may be possible using existing data and the community is encouraged to pursue them.

LEAG VSAT FINDINGS SUMMARIES



Motivation and Execution

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- The LEAG established the Lunar Polar Volatiles SAT to consider two principal tasks:
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Landed Findings

1. **Small near term missions can provide critical data to resolve important unknowns regarding polar volatile science and resource utilization**
2. **Early characterization of the variation in volatile abundance at ISRU and scientifically relevant spatial scales would greatly benefit all future missions**
3. **The physical and chemical forms of abundant volatile elements are critical to understanding the resource and its origins**
4. **Successful exploitation of *in situ* resources requires knowledge of the physical (geotechnical) and thermal properties of polar regolith in addition to the volatile abundance**
5. **On-going development of polar rovers should include the ability to negotiate terrain and environmental conditions defined by measurement requirements (e.g. *LExSWG Lunar Surface Exploration Strategy (1995)*)**
6. **Polar missions should leverage persistent lighting at the lunar poles**
7. **Solar powered roving missions should take advantage of mobility to extend mission lifetime by "chasing the light"**
8. **In addition to ISRU goals, landed experiments should include measurements of current volatile flux to aid understanding volatile transport mechanism**

Orbital Findings

1. **There are sufficient data to support near-term landing site selections**
2. **Mapping of subsurface hydrogen with sufficient precision and resolution to resolve many individual PSRs (<5 km after any required signal averaging) is the most important orbital measurement**
3. **Testable hypotheses for volatile distribution should be formulated with the goal of developing a model that exceeds the attainable spatial resolution of orbital neutron measurements.**
4. **Missions that include early ISRU demonstrations should be aimed at sites with environmental conditions that are consistent with more extensive subsequent surface operations**
5. **LCROSS-like impact experiments should be encouraged**
6. **Restarting the LRO bistatic radar capability should be a priority**
7. **New orbital remote sensing can characterize the distribution of surface volatiles, provide some insight into buried volatiles and aid understanding the cycling of polar volatiles**

Regions of Interest: Finding #1

At both poles there are regions that are generally suitable for a common landing region

1. **Cabeus vicinity (south pole)**
2. **Shoemaker/Nobile vicinities (south pole)**
3. **Peary vicinity (north pole)**

- **These are:**
  - Volatile rich (H > 150 ppm)
  - Can maintain subsurface ice (average annual surface temperature < 110K),
  - Modest slopes (10 degrees)
  - Adjacent to locations similar to the LCROSS impact site in terms of H abundance and temperature
  - Availability of PSR from lit areas
- When including Earth visibility and lighting explicitly, the north polar Peary vicinity is slightly favored owing to somewhat more persistent lighting, with the Cabeus vicinity showing the least persistent lighting

Regions of Interest: Finding #2

Specific landing sites for individual missions are critically dependent on mission goals and capabilities

- However, a study by NASA Ames Research Center in support of the RESOLVE polar resource mission demonstrated that within general regions of interest, many acceptable landing sites were available