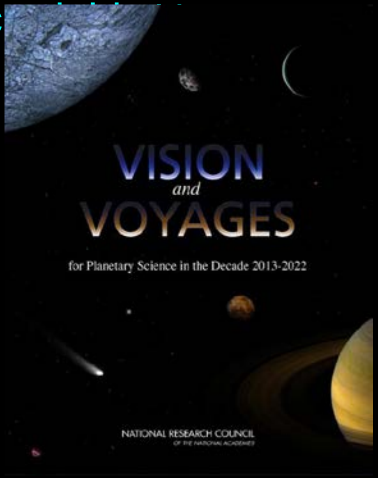
Future (Lunar) Projects: USA

Mars geophysics already discussed (InSight mission).
Asteroid geophysics missions are still being formulated: implementation in microgravity is a major issue.
Focus on lunar activities in this talk.

Guiding Documents

Lunar Exploration Roadmap
Lunar Exploration Analysis Group
www.lpi.usra.edu/leag/roadmap/

Scientific Context for the Exploration of the Moon.
National Academy of Sciences
www.nap.edu/openbook.php?rec
954

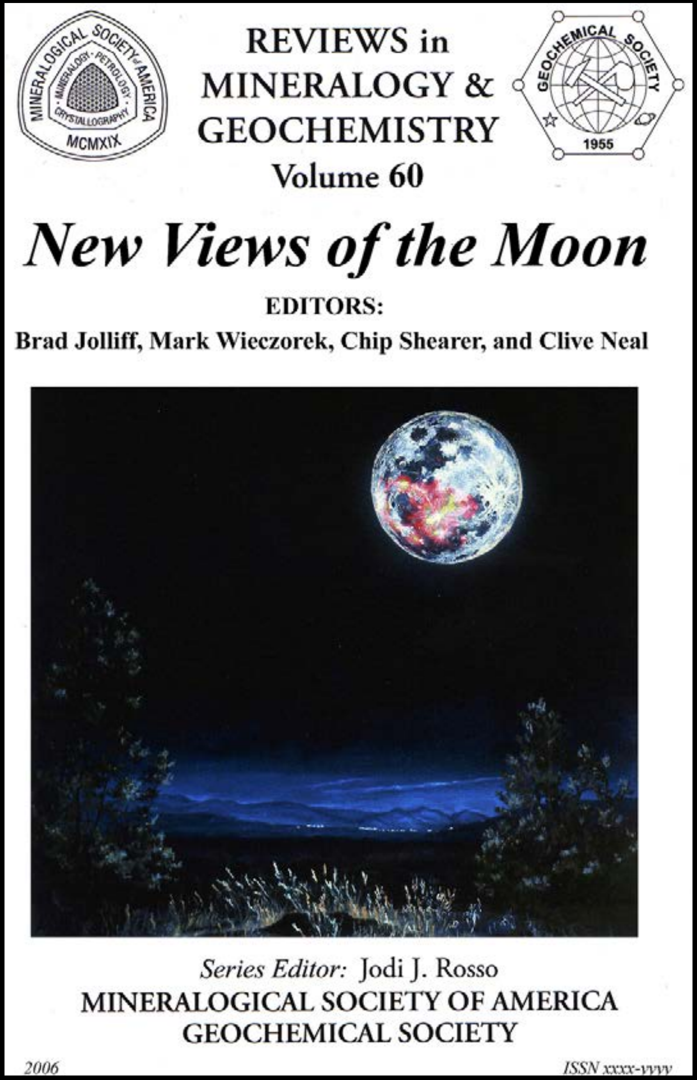


Vision & Voyages 2013-2022.
www.nap.edu/catalog/13117.html

New Views of the Moon (2006) [NVM-2 in progress]
Mineralogical Society of America volume 60
www.minsocam.org/msa/rim/Rim60.html

Global Exploration Roadmap.
International Space Exploration Coordination Group
www.globalspaceexploration.org/wordpress/wp-content/uploads/2013/10/GER_2013.pdf

New Views of the Moon (2006)



- Synthesized datasets from pre-Apollo through 2000.
- Did NOT include data from missions since 2000, so:
  - Moon was still “dry”.
  - Volcanism was older than 3 billion years.
  - Apollo sample collection was representative.

New Views of the Moon 2 is being formulated to include the new discoveries this century.

http://www3.nd.edu/~cneal/NVM-2/

www.minsocam.org/msa/rim/Rim60.html

Scientific Context for Exploration of the Moon (SCEM)

National Research Council, 2007

Prioritized Science Concepts for Lunar Exploration:

1. The bombardment history of the inner Solar System is uniquely revealed on the Moon.
2. The structure and composition of the lunar interior provide fundamental information on the evolution of a differentiated body.
3. Key planetary processes are manifested in the diversity of lunar crustal rocks.
4. The lunar poles are special environments that may bear witness to the volatile flux over the latter part of solar system history.
5. Lunar volcanism provides a window into the thermal and compositional evolution of the Moon.
6. The Moon is laboratory for studying the impact process on planetary scales.
7. The Moon is a natural laboratory for regolith processes and weathering on anhydrous airless bodies.
8. Processes involved with the atmosphere & dust environment are accessible for scientific study while the environment remains in a pristine state.

SCEM was effectively a US study.

www.nap.edu/openbook.php?record_id=11954

Lunar Exploration Roadmap

Developed by the Lunar Exploration Analysis Group (LEAG)

Why should we go back to the Moon?

Science (Sci) Theme: Pursue scientific activities to address fundamental questions about the solar system, the universe, and our place in them

Feed Forward (FF) Theme: Use the Moon to Prepare for Future Missions to Mars and Other Destinations

Sustainability (Sust) Theme: Extend Sustained Human Presence to the Moon to Enable Eventual Settlement

Lunar Exploration Roadmap

Developed by the Lunar Exploration Analysis Group (LEAG)

http://www.lpi.usra.edu/leag/ler_draft.shtml

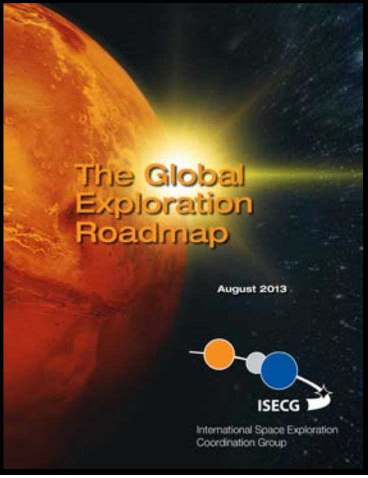
THEMES → **GOALS** → **OBJECTIVES** → **INVESTIGATIONS/ INITIATIVES**

Science Theme: Four Goals;

- Understand the formation, evolution, and current state of the Moon;
- Use the Moon as a “witness plate” for solar system evolution;
- Use the Moon as a platform for Astrophysical, Heliophysical, and Earth-Observing studies;
- Use the unique lunar environment as research tool.

Global Exploration Roadmap

2013

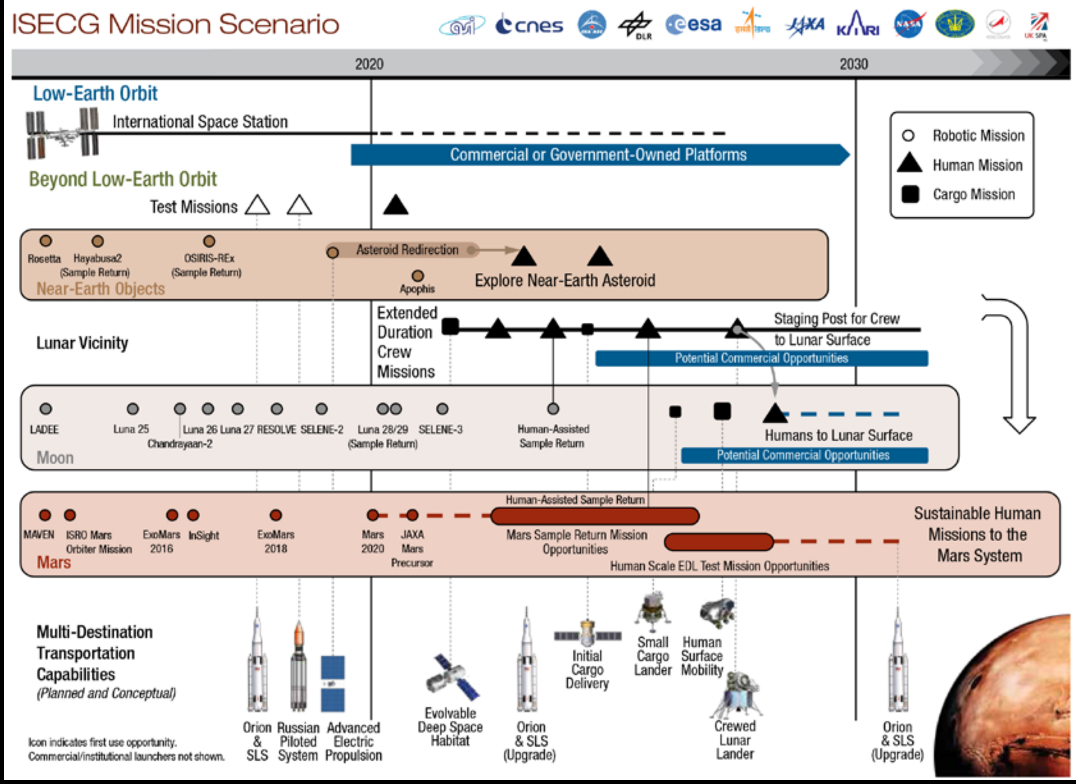


ISECG Mission Themes:

- NEA Exploration;
- Extended Duration Crew Missions;
- Humans to the Lunar Surface

Principles Driving the Mission Scenario:

- Affordability;
- Exploration Value;
- International Partnerships;
- Capability Evolution;
- Human/Robotic Partnership;
- Robustness (learn from Apollo).



Developing the GER

- **Map existing science and exploration documents to GER goals.**

- **Develop the Humans to the Lunar Surface Mission based on the MIT study finding of 2011** (Szajnfarber et al. *Space Policy 27*, 131-145):

    - "We find that when international partners are considered endogenously, the argument for a **"**flexible path**"** approach is weakened substantially. This is because international contributions can make **"**Moon first**"** economically feasible".

See Neal et al. (2014) Developing the global exploration roadmap: An example using the humans to the lunar surface theme. *Journal of Space Policy* **30**, 156-162

Vision & Voyages 2013-2022

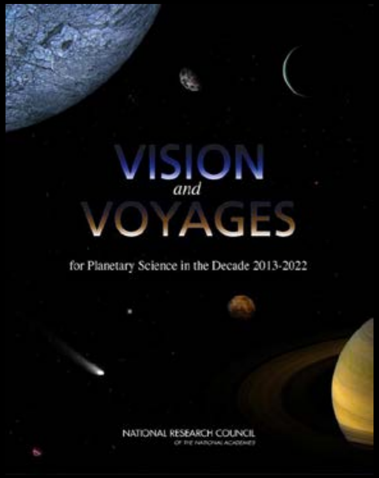
Planetary Science Decadal Survey

Priority Lunar mission goals (New Frontiers Program):

- Sample return from the South Pole-Aitken Basin region;
- A Lunar Geophysical Network.

Page 5-24: Other important science to be addressed by future missions include (Discovery Program):

- The nature of polar volatiles;
- The significance of recent lunar activity at potential surface vent sites;
- The reconstruction of both the thermal-tectonic-magmatic evolution of the Moon;
- The impact history of the inner solar system through the exploration of better characterized and newly revealed lunar terrains.

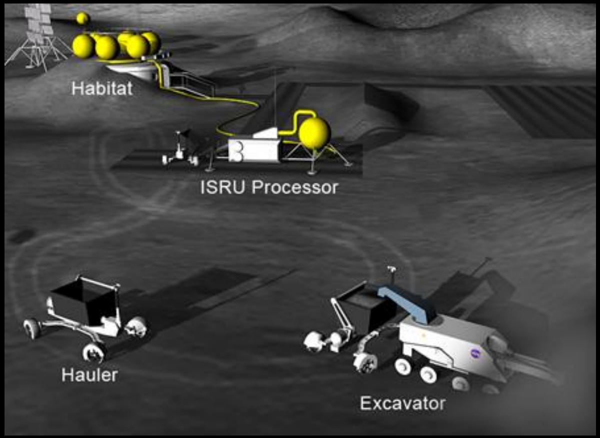


Such missions may include orbiters, landers & sample return.

LEAG Initiatives

- Continue to update the Lunar Exploration Roadmap.
- Published a second “New Views of the Moon” that summarizes the results from 2000 onward.
- Sponsor an international workshop to promote buy-in to the lunar science priorities posed in the 2007 SCEM document and better define the scorecard for addressing these priorities.
- Promote and support collaborative lunar mission concepts.
- Developing the Global Exploration Roadmap.

Moon as an Enabling Asset



Proximity:

- “Ease” of access;
- Risk reduction.

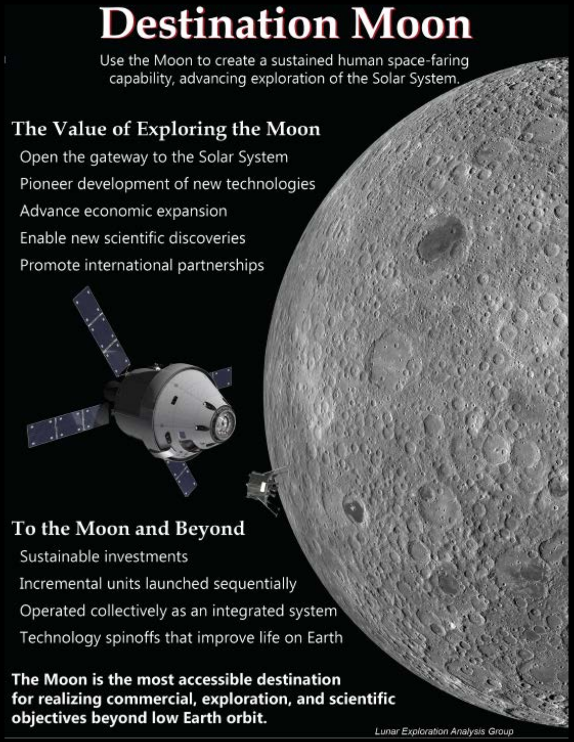
Harsh Environment:

- Test radiation shielding technologies;
- Reduced gravity (not microgravity);
- Dust.

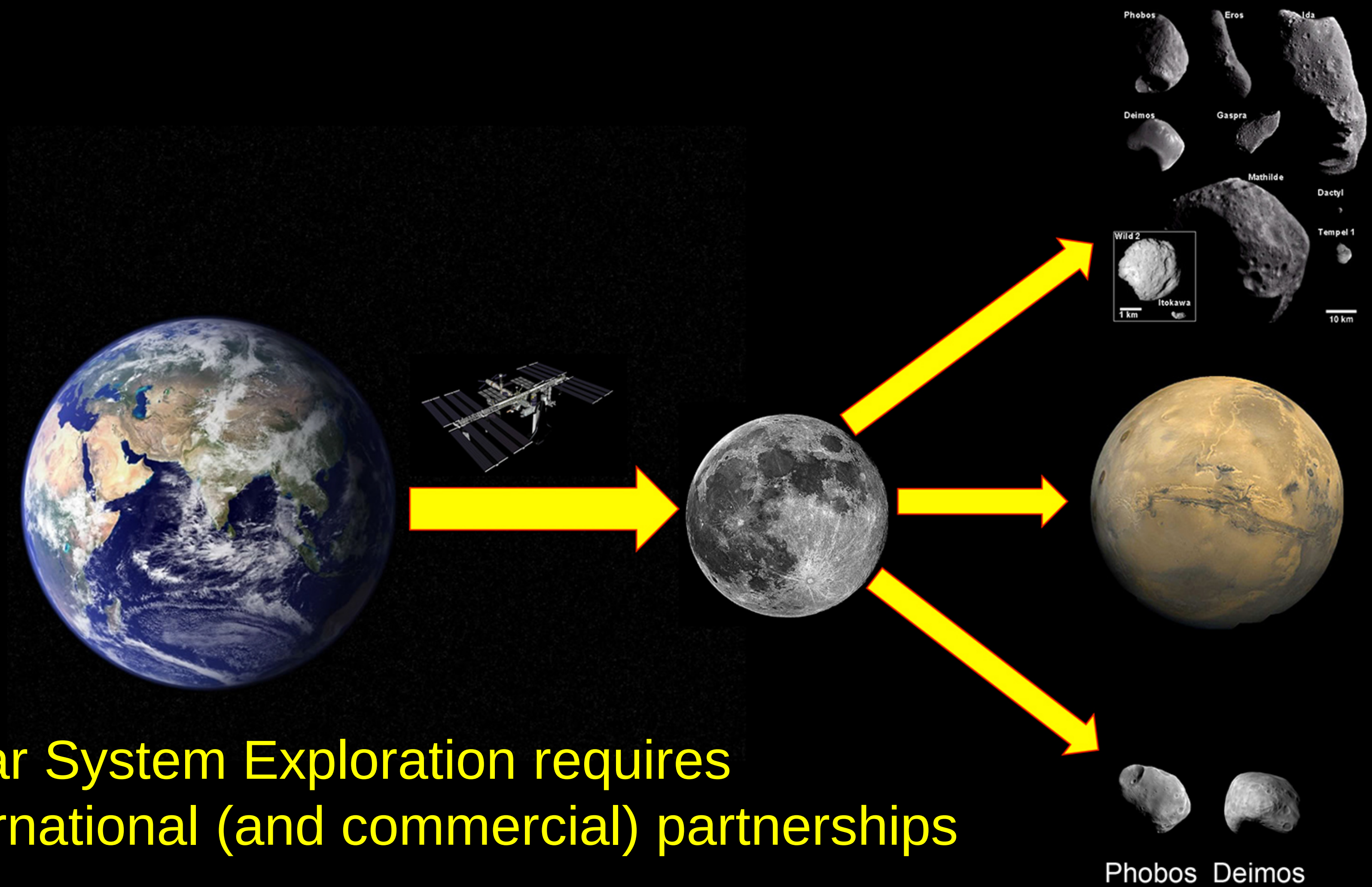
Long-duration testbed.

ISRU:

- Learning to live off the land, off-planet.



LER: Using the Moon to enable Solar System



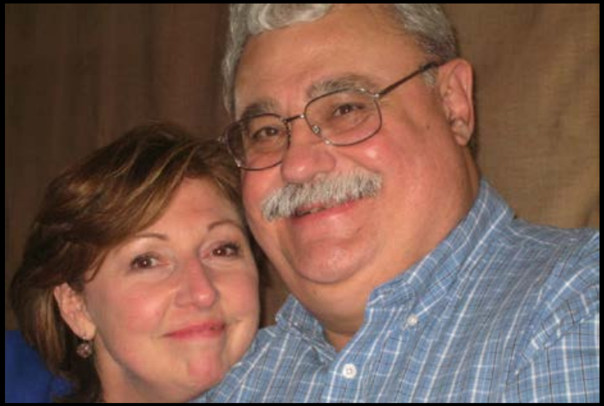
Solar System Exploration requires international (and commercial) partnerships

www.lpi.usra.edu/leag

What's Left to Learn?

"Science Enables Exploration and Exploration Enables Science"

Michael J. Wargo, 1951-2013



- The Polar Environment – e.g., radiation, electrostatic environment, potential resources.
- Volatiles – surface, cold traps, interior (endogenous), potential resources.
- Potential habitats – e.g., lava tubes, "permanent" sunlit areas, potential resource.
- Regolith mechanical properties – mining challenges, trafficability, space weathering, etc.
- Nature of the lunar interior.
- New terranes/rock types.

Science Questions

Neal C.R. (2009) The Moon 35 Years After Apollo: What's Left to Learn? *Chemie de Erde* 69, 3-43

Science Questions*:

Lunar Interior;

Lunar Magmatism;

Regolith.

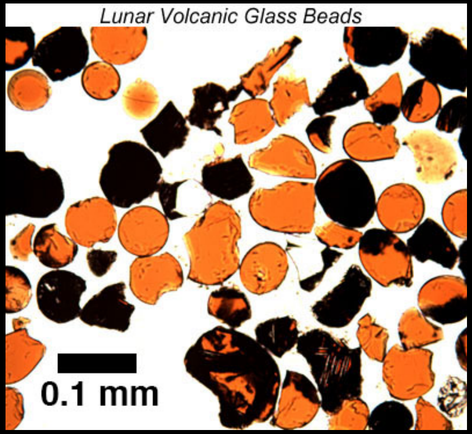
Impact Processes;

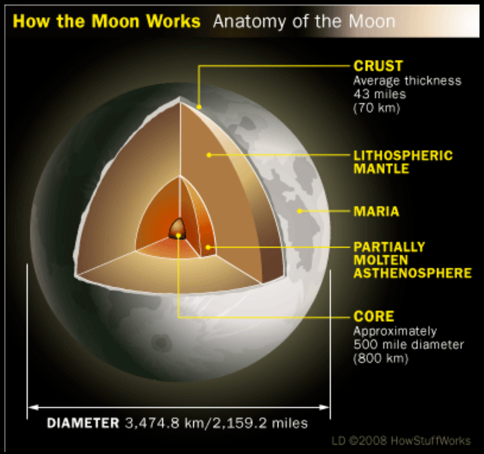
Volatiles;

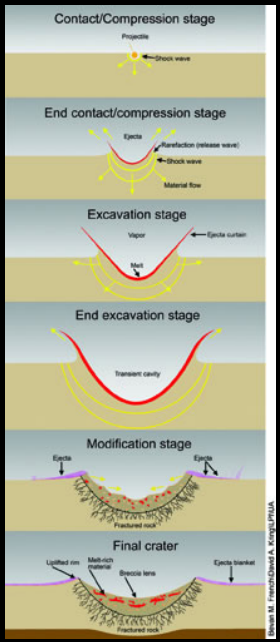
Sample Return Issues;

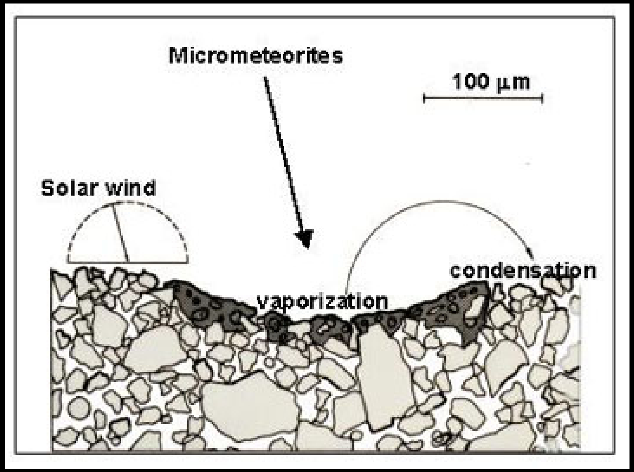
Lunar Environment.

* Extra slides with science questions appended to this presentation.



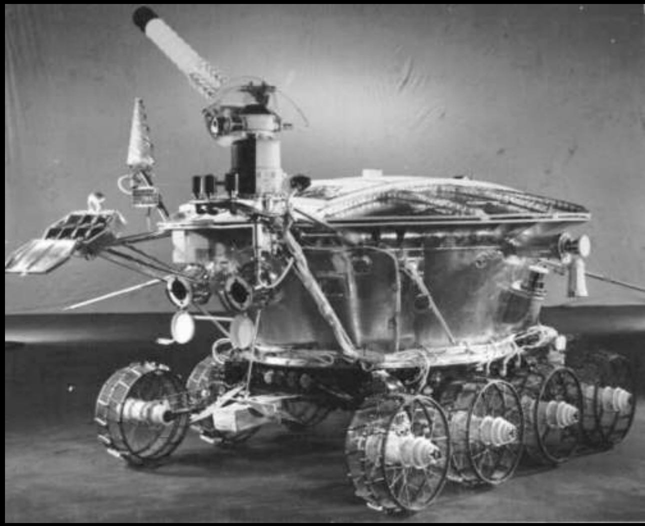






Designing a Mission

Define the mission goals (what needs to be achieved).
 - this includes instruments/experiments

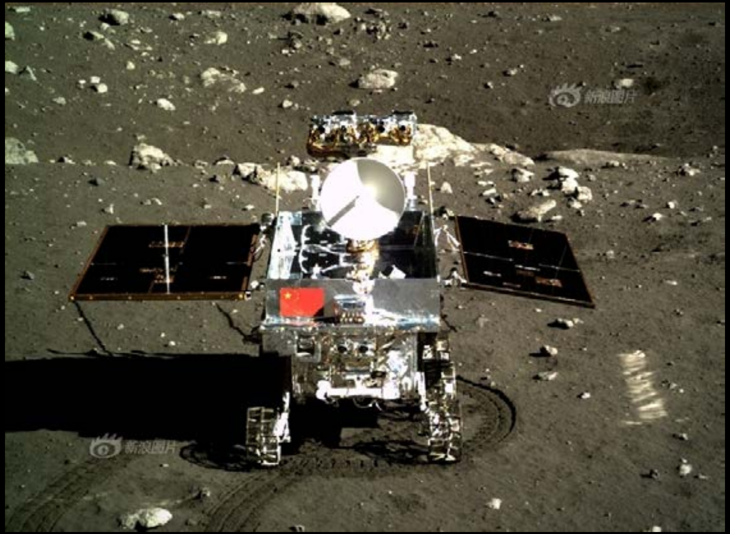


Success Criteria:

- Baseline mission;
- Threshold mission (science floor).

Landing site selection:

- Science;
- Safety;
- Engineering (e.g., ΔV, thermal).

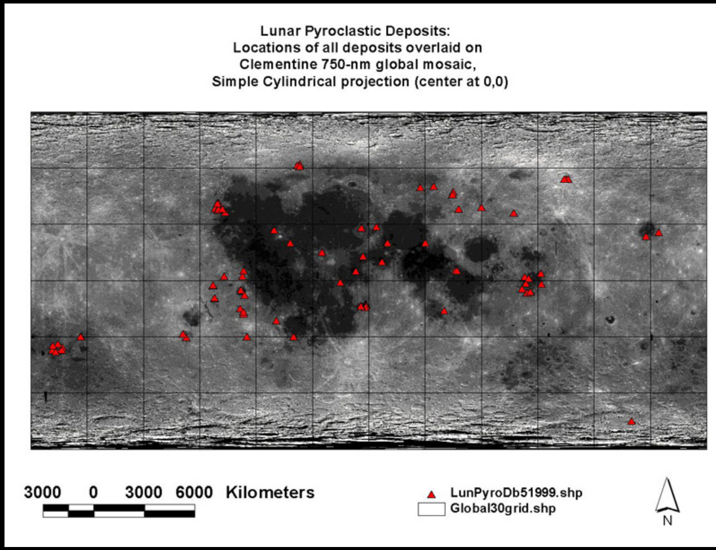


Designing the mission:

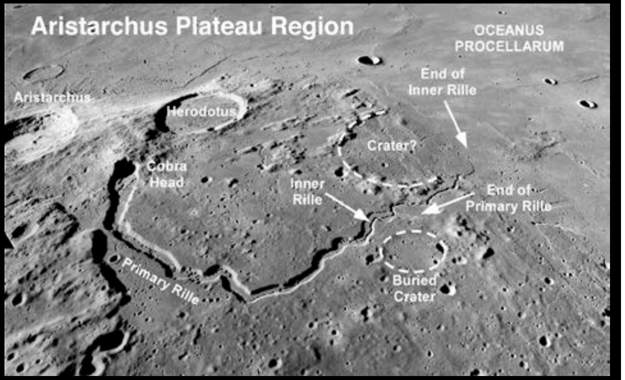
- Power requirements;
- Mass;
- Volume;
- Cost.

Future Mission Examples

Establish a Global Lunar Geophysical Network (through international cooperation/collaboration).



Lunar Magmatic Provinces.

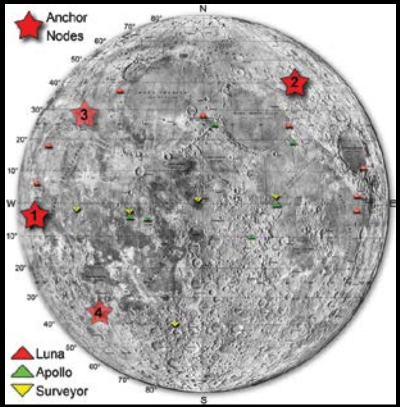


Impact Processes.

Regolith.

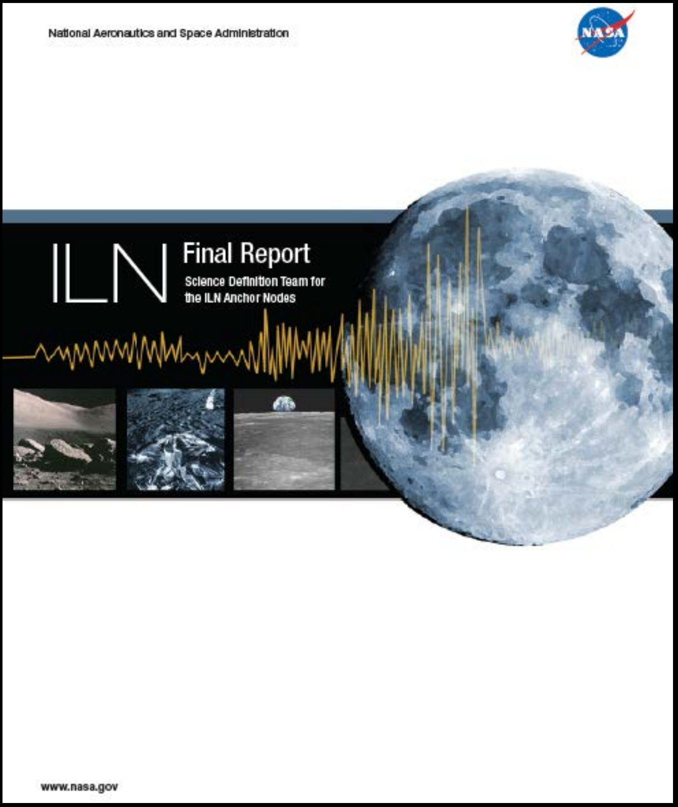
Volatiles.

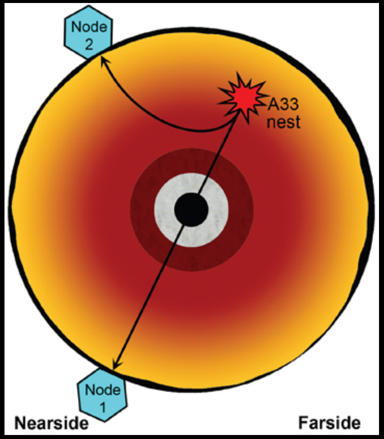
Sample Return.



International Lunar Network

http://sservi.nasa.gov/articles/international-lunar-network-issues-2009-final-report/



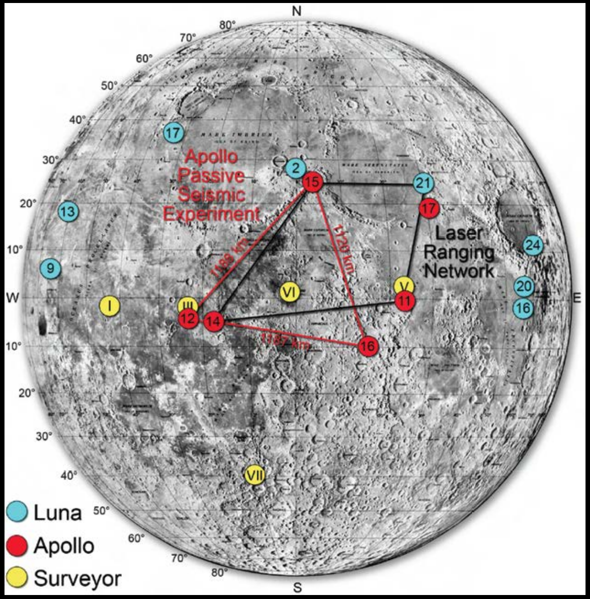


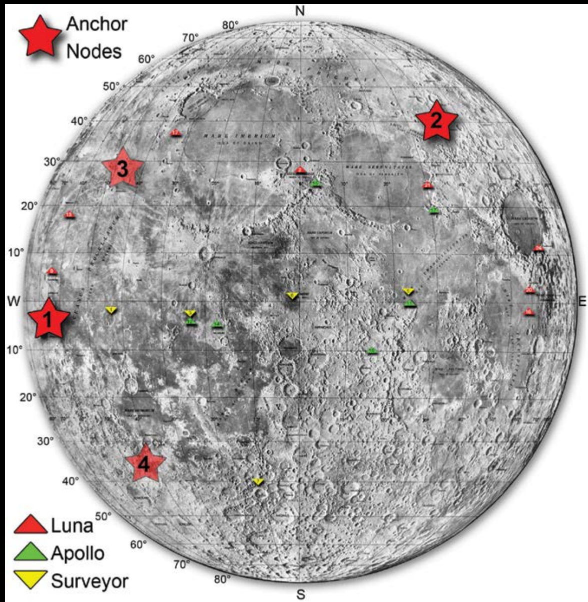
Seismometer.

Magnetomers/ EM Sounding.

LRR (nearside).

Heat Flow Probes.





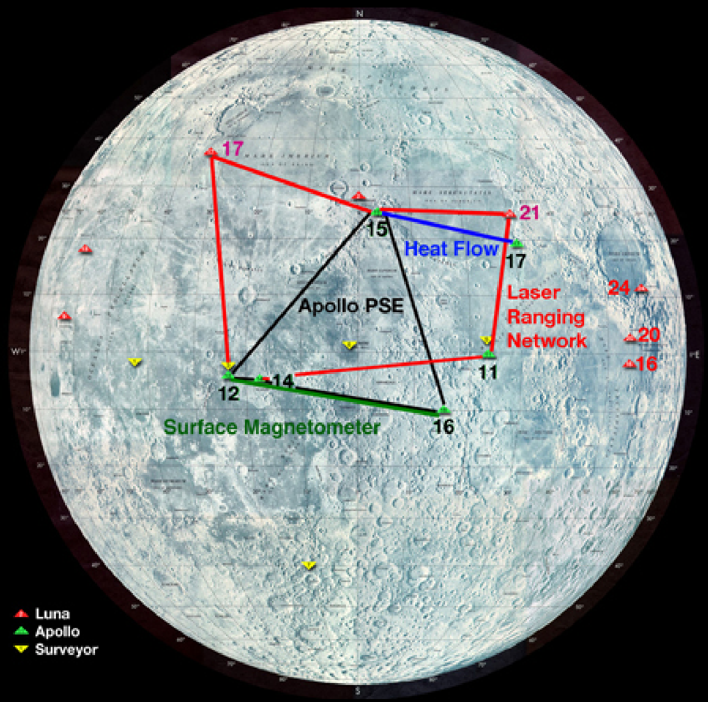
Lunar Geophysical Network

Named New Frontiers mission in the Decadal Survey (US$1 billion cost cap).

Any investigation must be equal to or better than Apollo.

Each node should contain:

- Seismometer;
- ElectroMagnetic Sounding;
- Heat Flow Probe;
- Laser Retroreflector (nearside);
- VLBI (or other radio science);
- Ground Penetrating Radar.



Should be International:

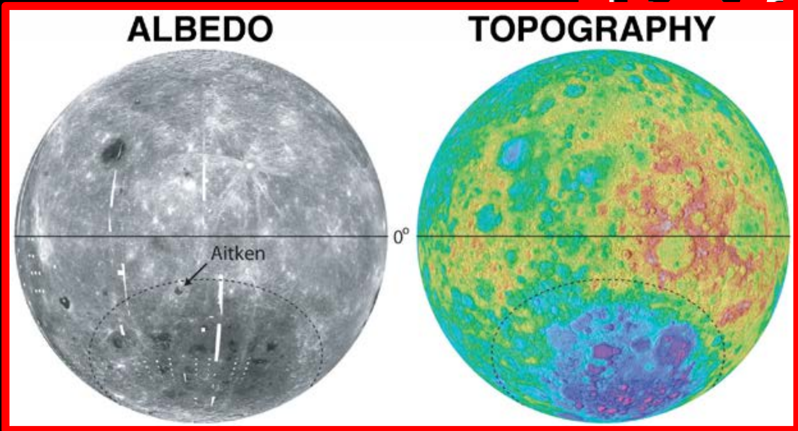
- Common instruments and data products;
- Common interfaces;
- Common downlink;
- Different nations contributing a node and/or instruments.

Farside nodes essential (need orbital Communications Satellite).

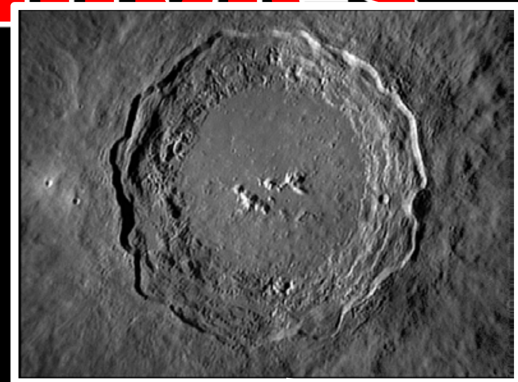
Should last longer than the Apollo network.

Future Mission Examples

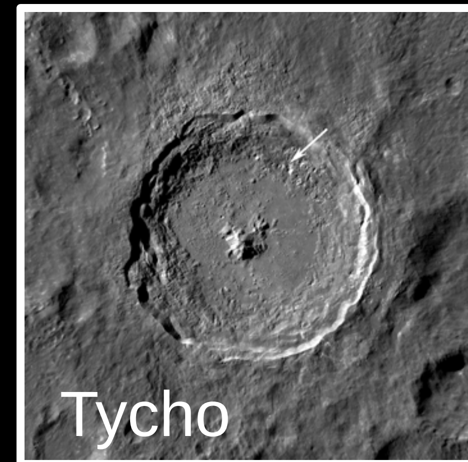
Impact Processes – Calibrating Crater Chronology.

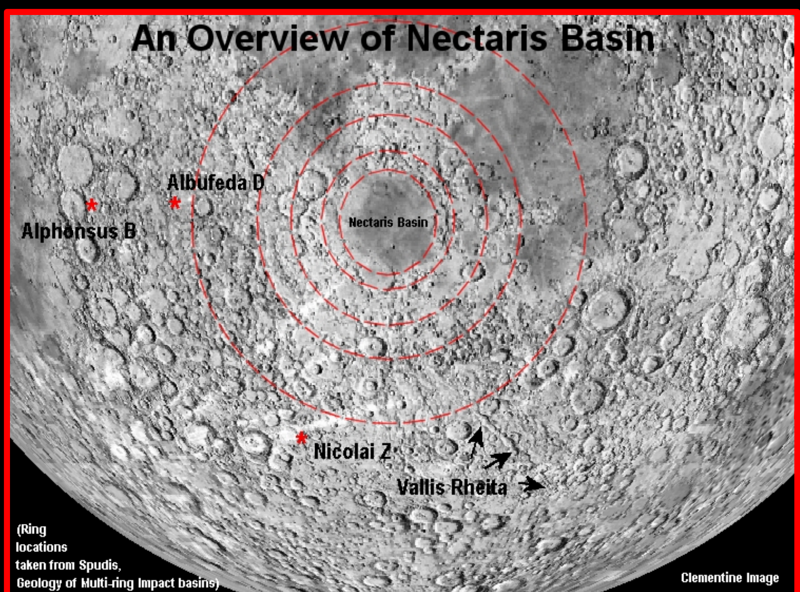


South Pole-Aitken Basin

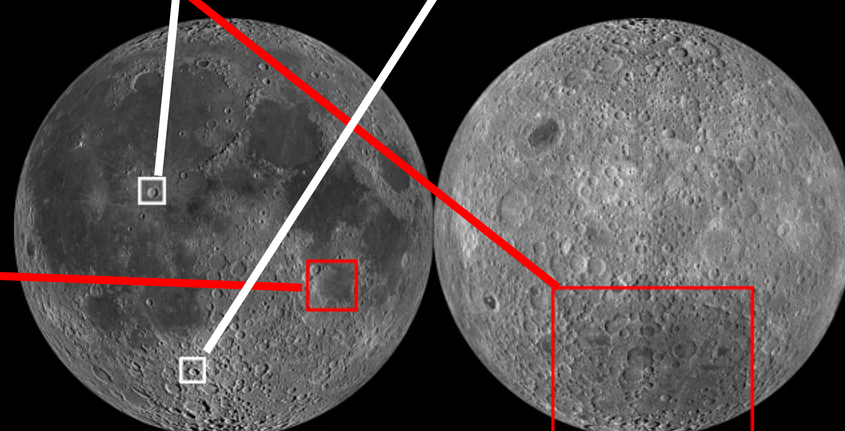


Copernicus





Near (left) and far (right) sides of the Moon

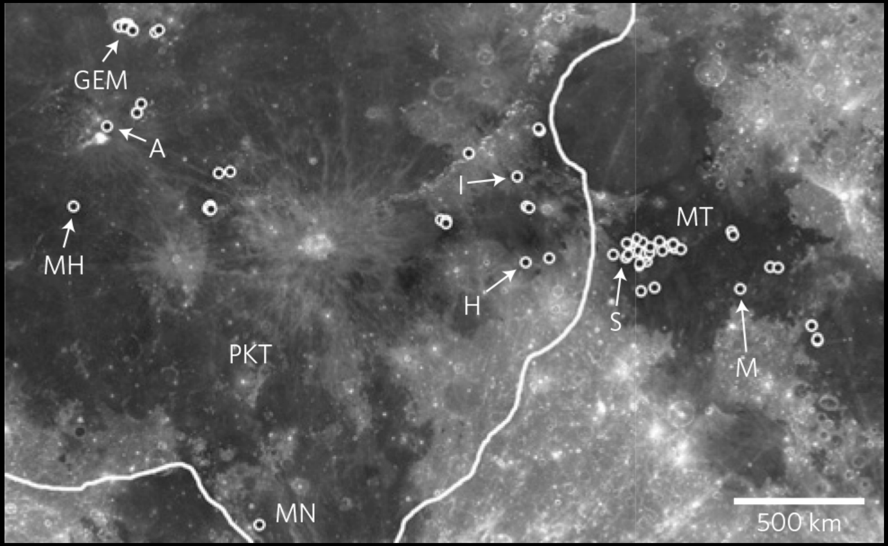


Taken by the Lunar Reconnaissance Orbiter

Lunar Magmatic Provinces

Young Magmatic Provinces.

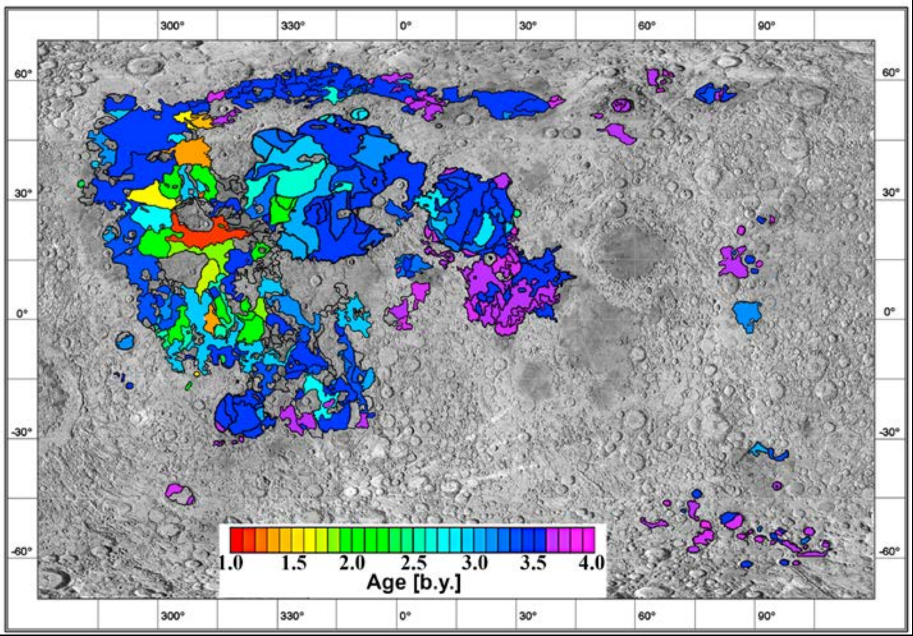
Braden et al. (2014) Nature Geosci. 7, 787-791

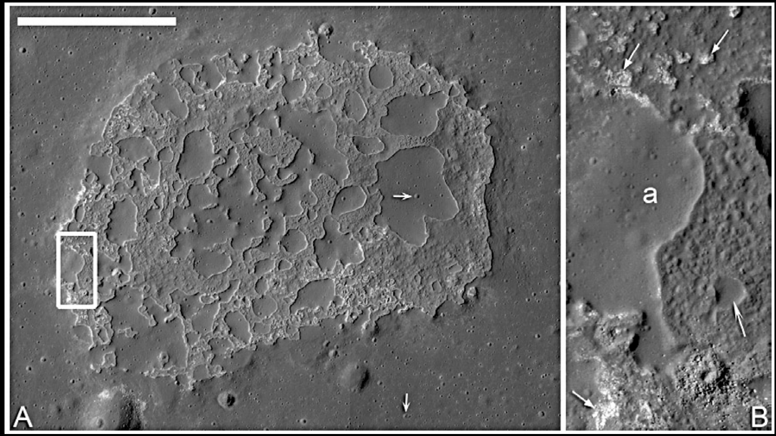


Irregular Mare Patches <100 Ma

Mare Basalts ~1 Ga

Hiesinger et al. (2010) JGR 115, E03003, doi:10.1029/2009JE003380





Ina "IMP"

Schultz et al. (2006) Nature 444, 184-186

Future Mission Examples

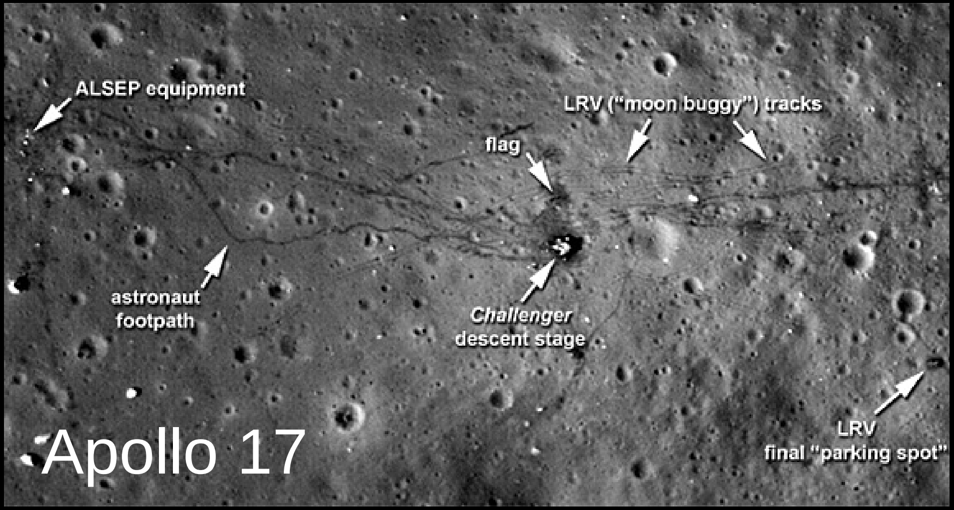
Regolith.

Regolith mechanics: lunar surface experiments and PSRs.

Space weathering mechanisms.

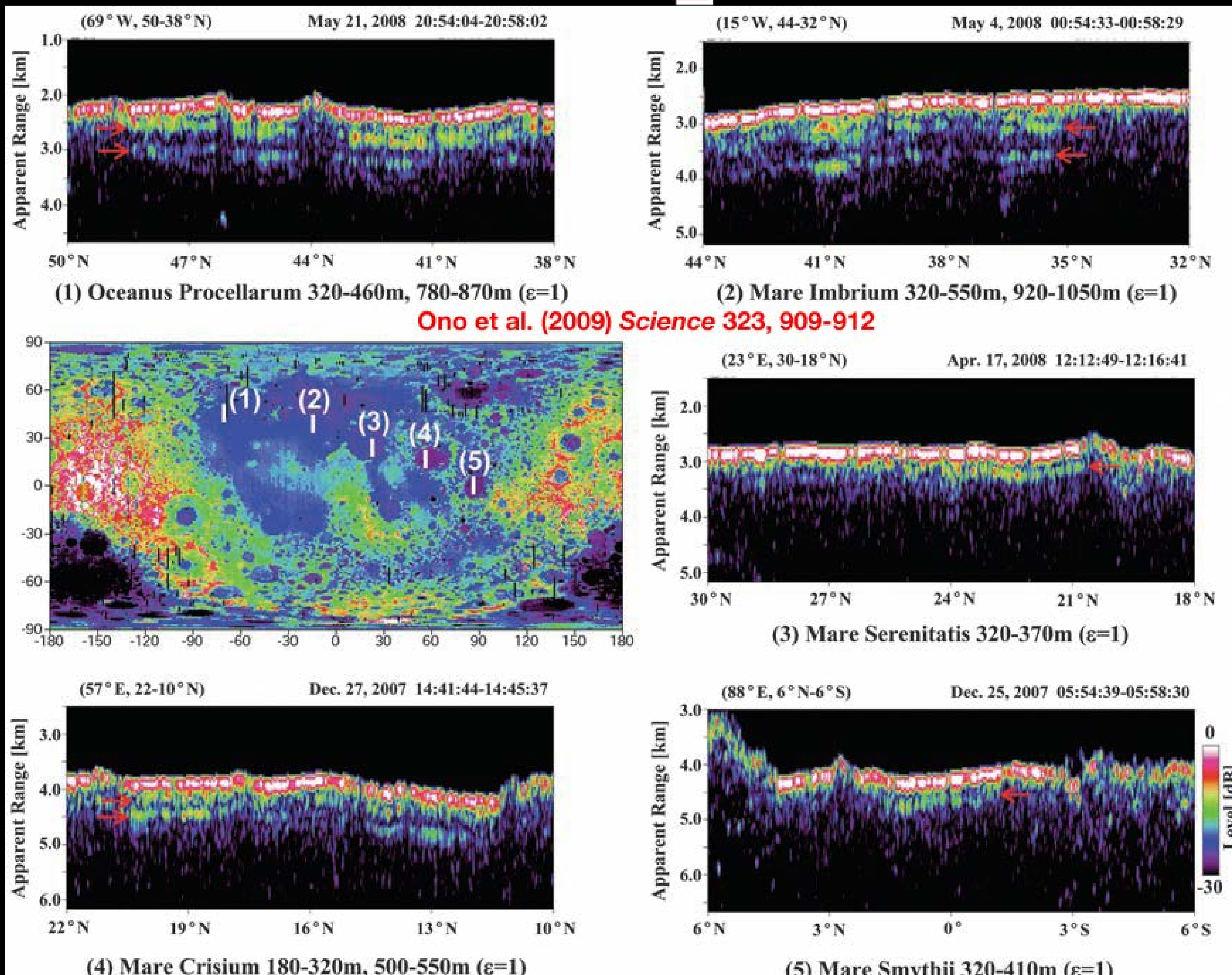
Mining and trafficability.

Global regolith thickness.



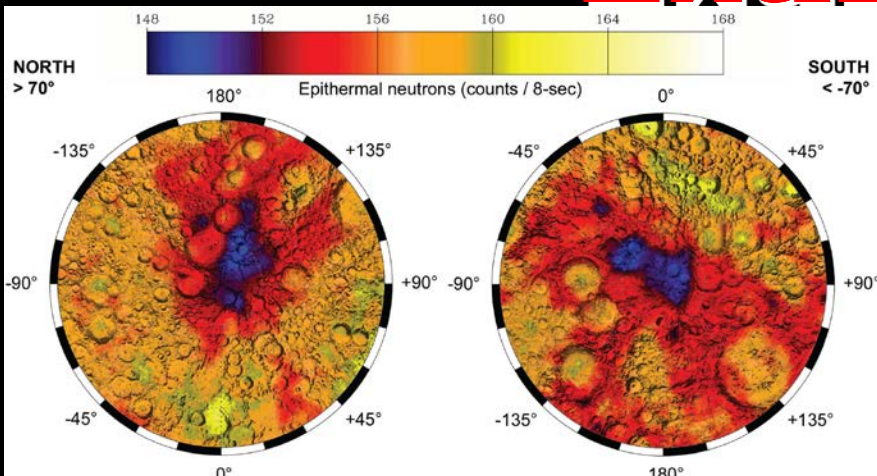
Future Mission Examples

Regolith. Global regolith thickness.

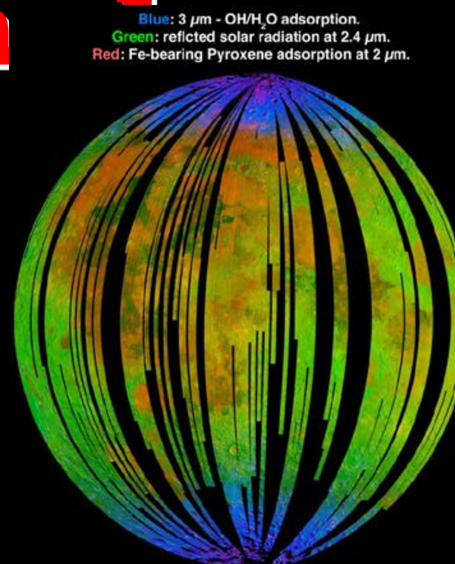


Future Mission Exam

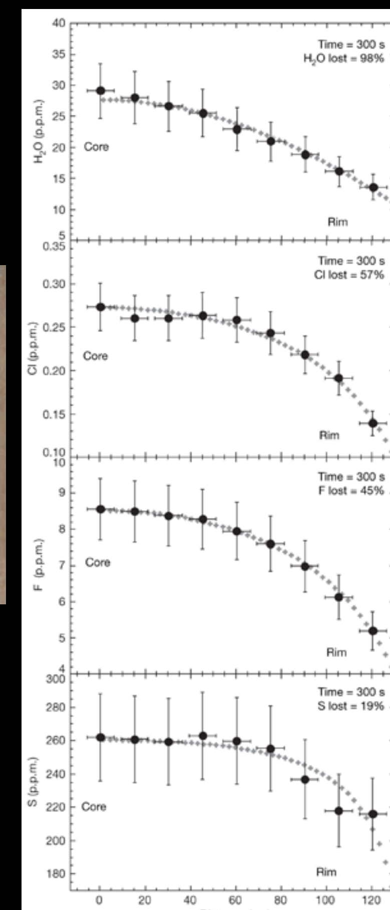
Volatiles.



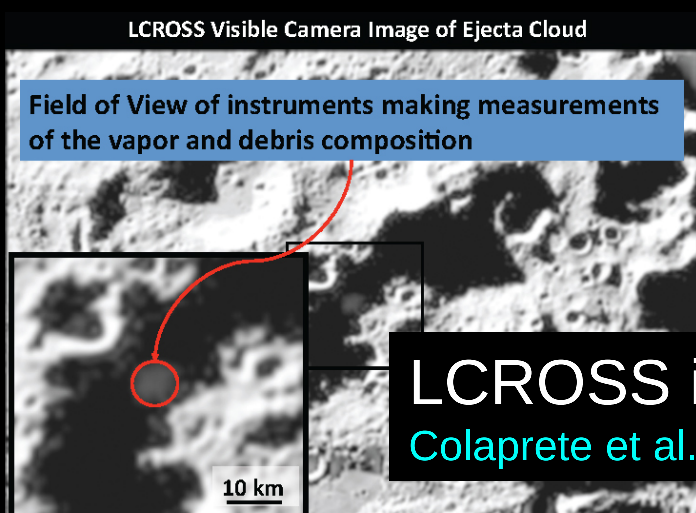
Hydrogen in PSRs – better resolution needed.
Lawrence et al. (2006) JGR 111, E08001, doi:10.1029/2005JE002637



"Moon Frost"
Pieters et al. (2009) Science 326, 568-572



Apollo 15 Green Glass
Saal et al. (2008) Nature 454, 192-195



LCROSS impact into Cabeus
Colaprete et al. (2010) Science 330, 463-468

Future Mission Examples

Sample Return:

New Lunar Terranes/Sample Return:

- New lithologies
- South Pole-Aitken Basin impact melt (“Moonrise”)
- Other younger (e.g., Copernicus, Tycho) impact craters
- Multi-ring basins (Nectaris, Imbrium, and Orientale)
- Young volcanic features (e.g., the Ina Structure)
- Felsic domes (Gruithuisen Domes, Hansteen-Alpha, Compton-Belkovich);
- Large pyroclastic deposits.

Future Mission Examples