Science Questions and How They Might Be Addressed by the Presence of Humans/Human Support Infrastructure

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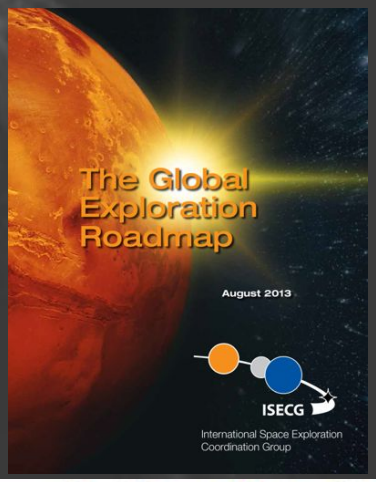
Global Exploration Roadmap

2013

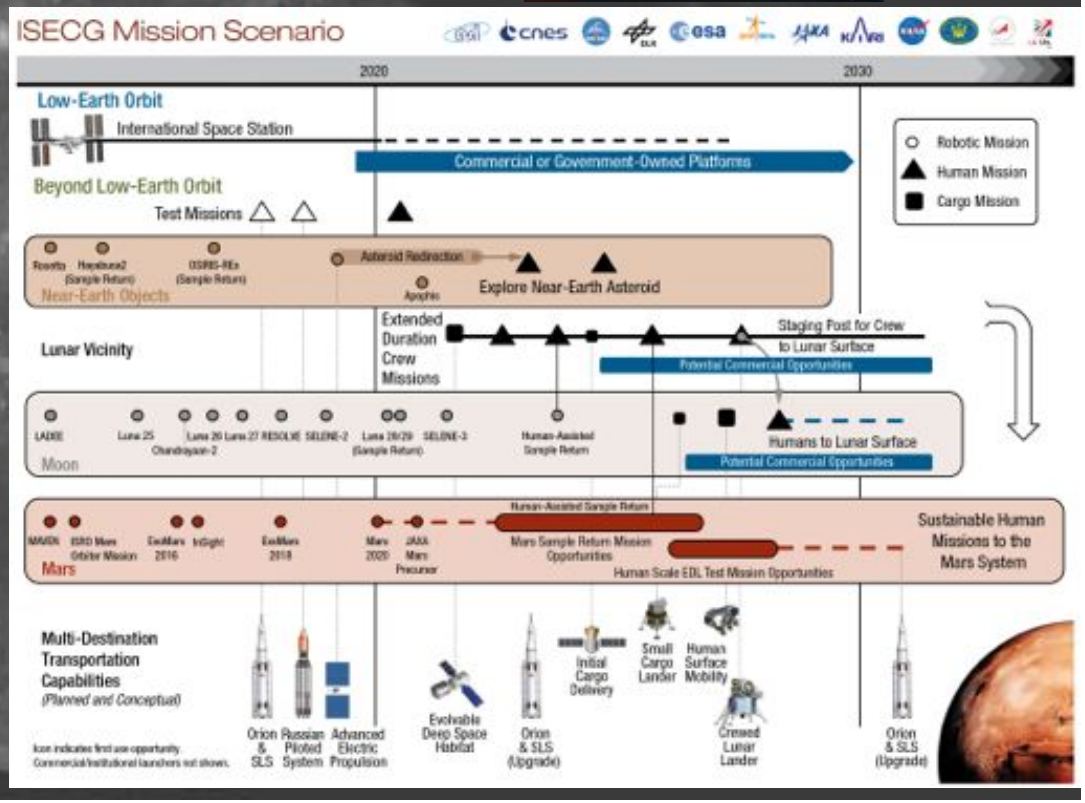


Mission Themes:

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

Principles Driving the Mission Scenario:

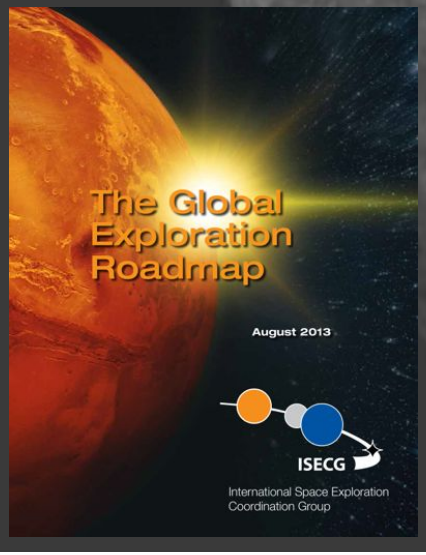
- Affordability;
- Exploration Value;
- International Partnerships;
- Capability Evolution;
- Human/Robotic Partnership;
- Robustness (learn from Apollo).



Contributions to Mars Mission Readiness

NEA Mission

- Space Launch System;
- Solar Electric Propulsion System;
- Spacewalk, rendez-vous, proximity operations, deep space navigation and communications.



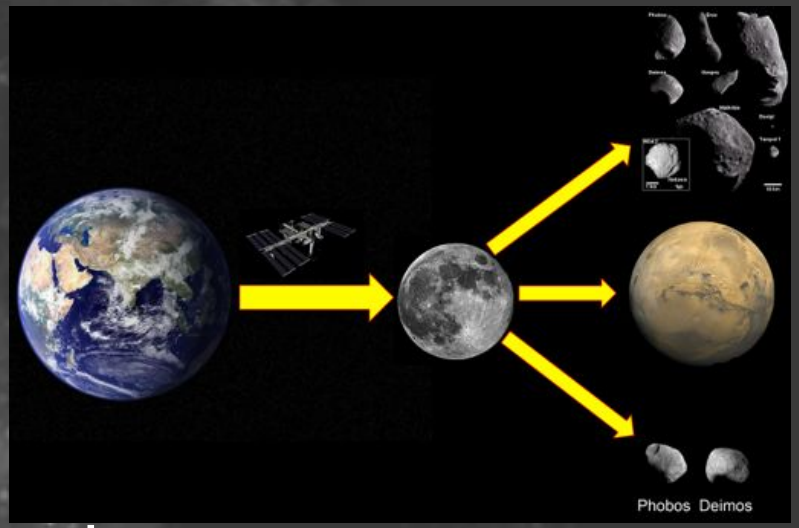
Extended (Lunar Vicinity)

- Deep space exploration capabilities (crew transporta-tion capabilities, life support systems) to reduce risk;
- Autonomous crew operation;
- Operations with reduced supply chain;
- Experience with complex deep space staging operations;
- Advance core technologies & radiation protection strategies for long duration missions;
- Interactive human and robotic operations;
- Solar electric propulsion on a crewed spacecraft.

Lunar Surface

- Staging operations with an Earth-return vehicle;
- Extended crew mobility and habitation systems;
- Advanced power systems;
- Characterize human health and performance, combining deep space and partial gravity environment exposure;
- Operations concepts and enhanced crew autonomy for surface exploration;
- Provide the opportunity for advancing concepts related to use of local resources.

The Moon



Proximity:

- "Ease" of access;
- Risk reduction.

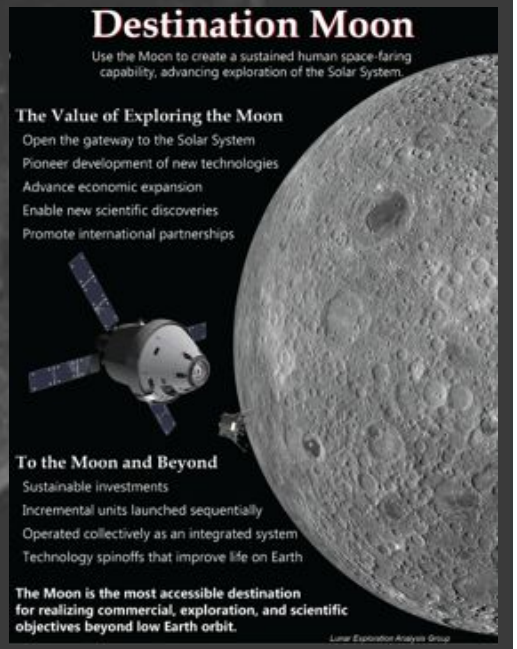
Harsh Environment:

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

Long-duration testbed.

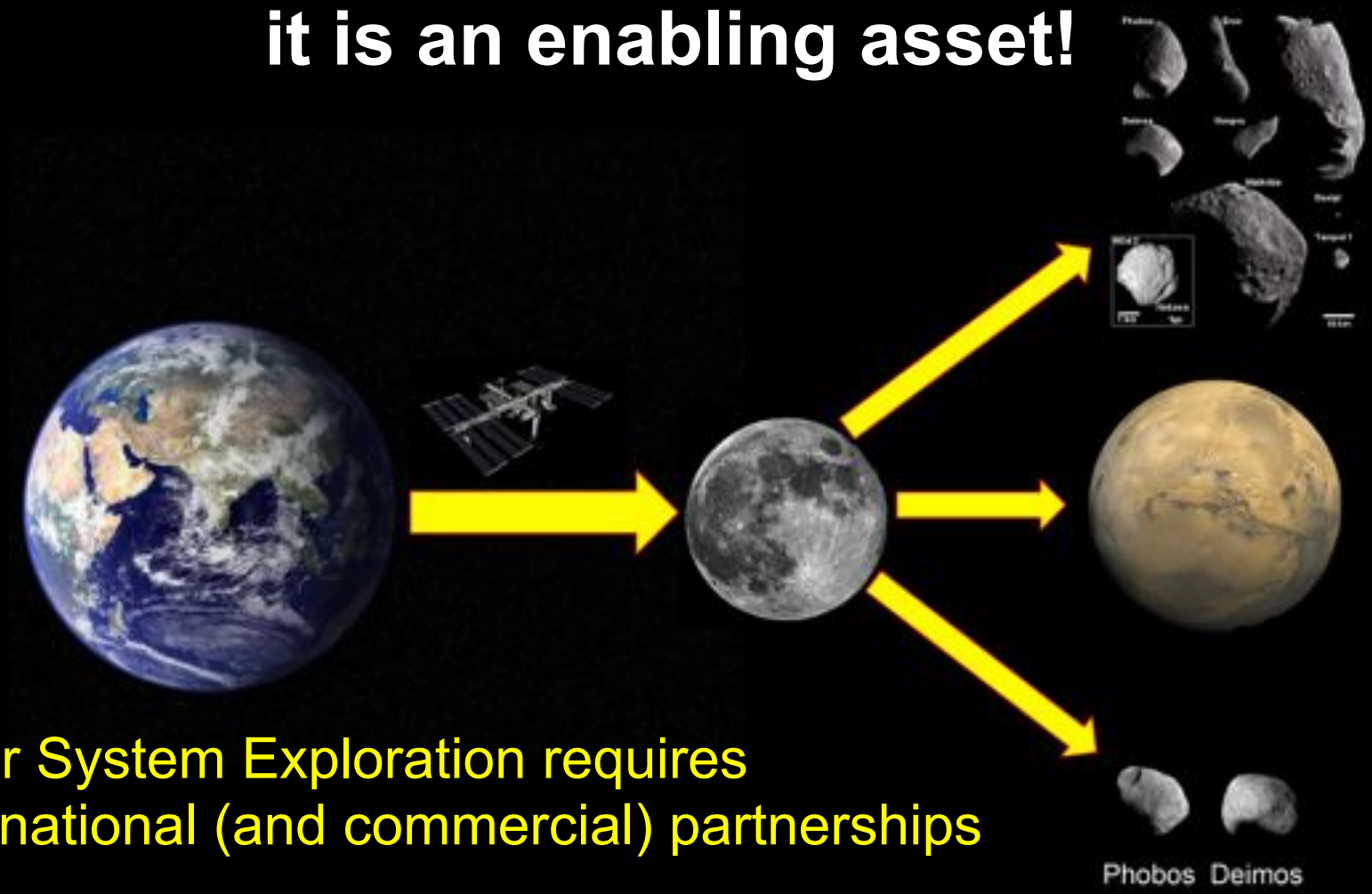
ISRU:

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



Important

The Moon is not a distraction – it is an enabling asset!



Solar System Exploration requires international (and commercial) partnerships

www.lpi.usra.edu/leag

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 Pol. 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".

Humans to the Lunar Surface

GER Goals:

- Technology test bed (surface power systems, long distance mobility concepts, human-robotic partnerships, precision landing).
- Characterizing human health and performance outside Earth's magnetosphere and in a reduced gravity environment.
- Conducting high priority science benefiting from human presence, including human-assisted lunar sample return.
- Advance knowledge base related to use of lunar resources.
- Explore landing sites of interest for extended durations.

Humans to the Lunar Surface

Examples of International Documents used

[1] Ehrenfreund et al. (2012) Toward a global space exploration program: A stepping stone approach. *Adv. Space Res. 49*, 2-48.

[2] LEAG (2012) Strategic Knowledge Gaps for the Moon First Human Exploration Scenario http:// www.lpi.usra.edu/leag/ GAP_SAT_03_09_12.pdf

[3] LEAG (2013) Lunar Exploration Roadmap http://www.lpi.usra.edu/leag/ ler_ draft.shtml

[4] NRC (2007) Scientific Context for the Exploration of the Moon http://www.nap.edu/ catalog/11954.html;

[5] Crawford et al. (2012) Back to the Moon: The scientific rationale for resuming lunar surface exploration. *Planet. Space Sci. 74*, 3-14.

[6] Crawford (2010) Lunar Palaeoregolith Deposits as Recorders of the Galactic Environment of the Solar System and Implications for Astrobiology *Astrobiology 10*, 577-587.

Lunar Exploration Roadmap

2007: LEAG tasked to develop a comprehensive Lunar Exploration Roadmap (LER).

3 Themes: Science, Feed Forward, and Sustainability.

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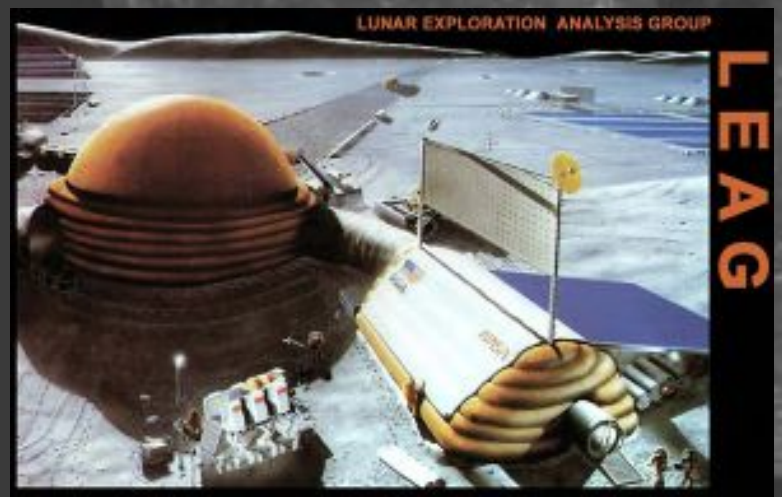
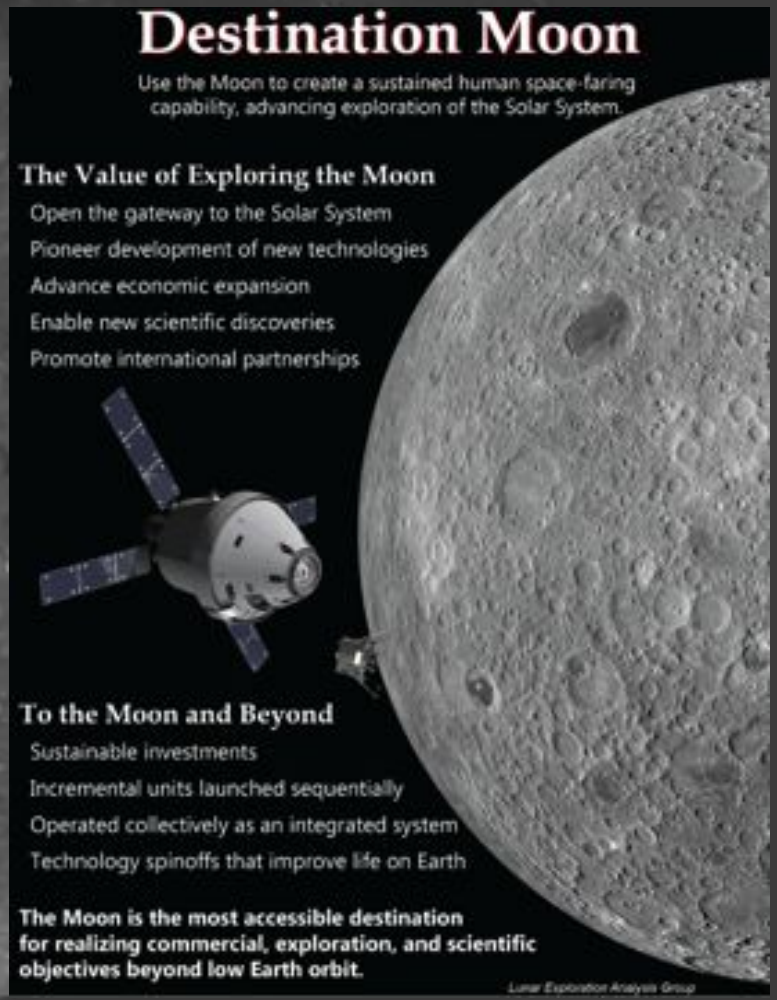




Lunar Volatiles

Global Exploration Roadmap Priority:

- Advance knowledge base related to use of lunar resources.

LEAG Strategic Knowledge Gaps [2]:

- Composition/quantity/distribution/form of water/H species and other volatiles associated with lunar cold traps:
  - Map & characterize broad features of polar cold traps;
  - Determine lateral and vertical extent of polar volatiles;
  - Processes and history of water and other polar volatiles;

SCEM Report [4]:

- Priority 4 - The lunar poles are special environments that may bear witness to the volatile flux over the latter part of solar system history.

LEAG Lunar Exploration Roadmap [3]

- **Objective Sci-A-3**: Characterize the environment and processes in lunar polar regions and in the lunar exosphere (4 Investigations).

COSPAR (Ehrenfreund et al., 2012 **[1])**

- Support studies and precursor activities toward "International human bases"**;**
- Sample return missions to the Moon, near-Earth asteroids and Mars.

Lunar Volatiles

Scientific Rationale (Crawford, 2010 [5]):

- The Moon is the type locality to study volatile loss, transport, and retention on airless bodies;
- The polar deposits represent targets for in situ resource applications.

Astrobiology (Crawford et al., 2012 [6]):

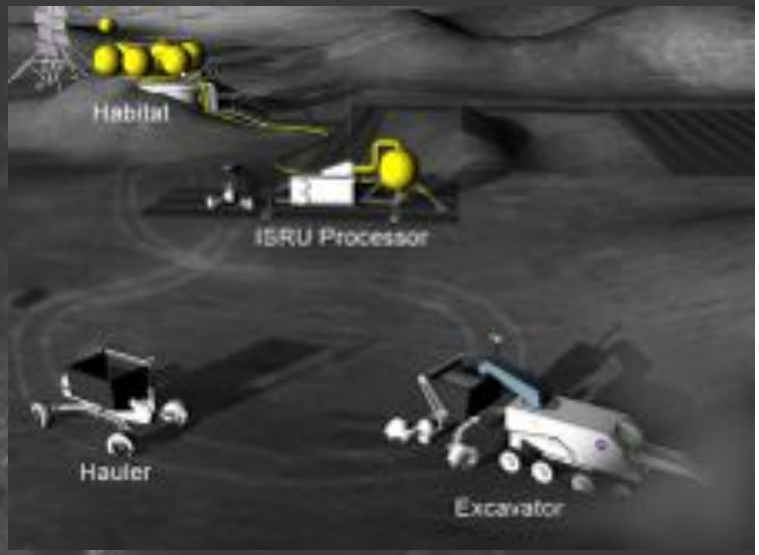
- Information concerning the importance of comets in "seeding" the terrestrial planets with volatiles and prebiotic organic materials can be found in polar volatiles.
- Lunar polar ice deposits will have been continuously subject to irradiation by cosmic rays and may have played host to organic synthesis reactions of the kind thought to occur in the outer Solar System and on interstellar dust grains.

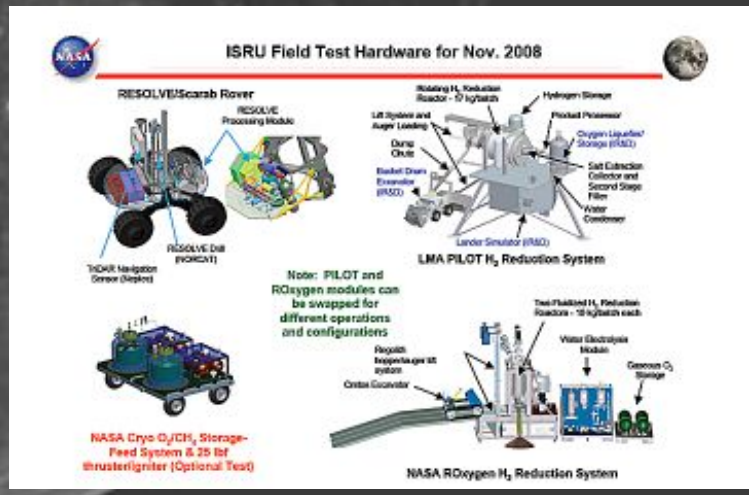
Current Planned Missions:

- Resource Prospector – USA
- Luna 27 - Russia.
- Others….?

Solar System Exploration

- In Situ Resource Utilization (ISRU) is the *game changer* – produce fuel and consumables on the lunar surface to enable human exploration of other airless bodies and Mars.
- Use the Moon to explore the Solar System due to the much reduced "gravity well" and presence of resources.
- Enables international cooperation and commercial participation (i.e., jobs!) in space exploration by starting at the Moon with the goal to go much further.

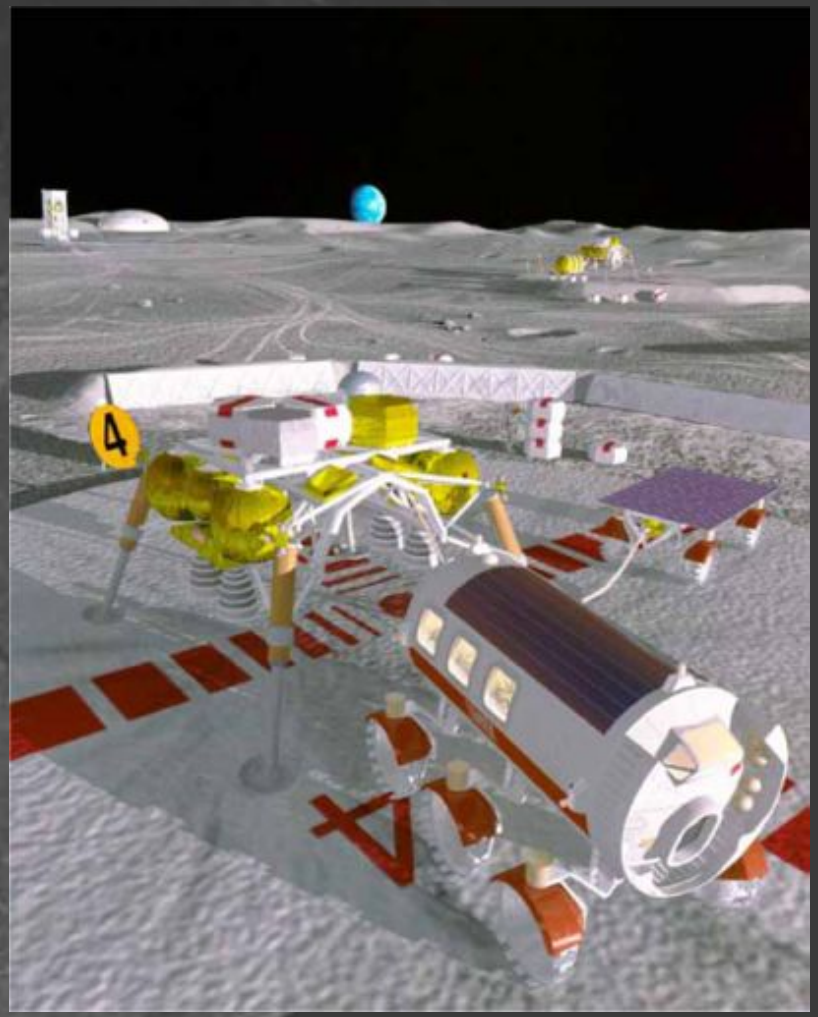




Robotic Precursor Missions

Resource Prospecting and Verification.

- Ground truth is required to validate and characterize the polar and other resources:
  - Determine the form;
  - Measure the amount and location;
  - Characterize the local environment.



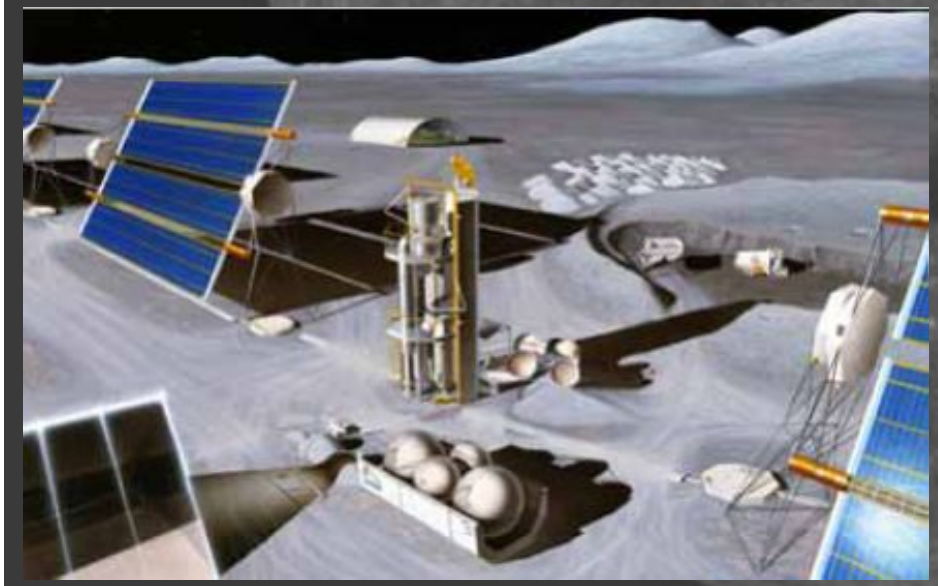
- **Orbital missions are not sufficient.**

See www.lpi.usra.edu/leag for more details

Robotic Precursor Missions

ISRU Technology demonstration on the lunar surface. (NASA Resource Prospector Mission)

- Can regolith be mined on the Moon?
- Can oxygen, water, and propellant be produced from lunar regolith on the lunar surface?
- How long can the products be stored?
- See www.lpi.usra.edu/leag for more details.



Implementing the LEAG LER: Robotic Precursor Missions

Phase I: Lunar Resource Prospecting.

- Defining the composition, form, and extent of the resource:
- Characterizing the environment in which the resources are found;
- Defining the accessibility/extractability of the resources;
- Quantifying the geotechnical properties of the lunar regolith in the areas where resources are found;
- Being able to traverse several km and sample and determine lateral and vertical distribution on meter scales.
- Identifying resource-rich sites for targeting future missions.

Implementing the LEAG LER: Robotic Precursor Missions

Phase II: Lunar Resource Mining.

- Feedstock acquisition and handling;
- Resource extraction, refinement, transport, and storage;
- Usability of resources (e.g., fuel cell, small engine test, propellant depot test);
- Regolith handling and size sorting technologies (only for mineral-based resources);
- Operable life to give information on the longevity of systems and materials in the lunar environment;
- Dust mitigation strategies.

Implementing the LEAG LER: Robotic Precursor Missions

Phase III: Lunar Resource Production.

Based upon the results of Phase II a larger-scale (i.e., more appropriate scale) continuous processing capability would be deployed to the most appropriate site.

Greater quantities of resources will be produced and be used to undertake more extensive demonstrations such as life support, mobility technologies, and fuel for a robotic sample return.

An automated full-scale production capability would be established prior to the first extended human stay on the lunar surface.

Resource Prospector Mission (2018)

Prospecting Mission:

- Characterize the distribution of water and other volatiles at the lunar poles
  - Map the surface and subsurface distribution of hydrogen rich materials
  - Determine the constituents and quantities of the volatiles extracted
  - Quantify important volatiles: H_2, He, CO, CO_2, CH_4, H2O, N_2, NH_3, H_2S, SO_2
  - Measure or provide limits on key isotope ratios,

ISRU Processing Demonstration Mission:

- Demonstrate the Hydrogen Reduction process to extract oxygen from lunar regolith
  - Demonstrate the hardware (e.g., oven, seals, valves) in lunar setting
  - Capture, quantify, and display the water generated.

(Other) Lunar Science

Examples (there are many more!)

- Internal Structure – revitalize the International Lunar Network;
- Lunar magnetic field – origin of “swirls”;
- Moon’s tectonic features – origin and age;
- Current volcanic activity (e.g., IMPs);
- Targeted sample return.

New ILN

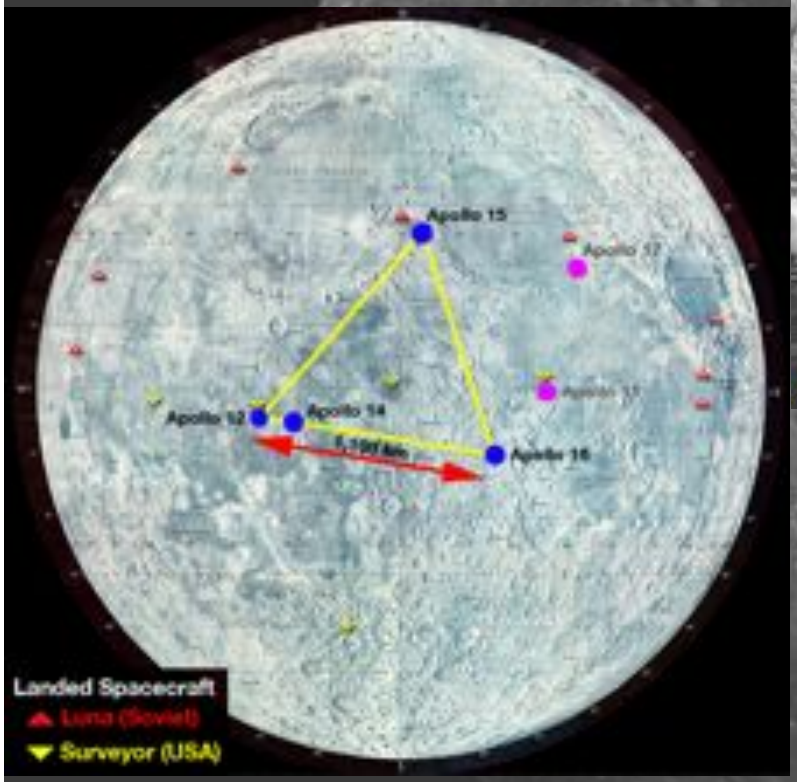
The Moon is the smallest planetary body in the inner solar system with an old planetary surface.

It's evolution was halted at an early stage so its structure represents the initial stages of terrestrial planet differentiation.

The Moon therefore represents an end-member.

Apollo Seismic Stations

The *complete* Apollo passive seismic network operated from 20 April, 1972, until 30 September, 1977.




Apollo 16 Seismometer Test


Apollo 11 Geophysics Package deployed on the Moon

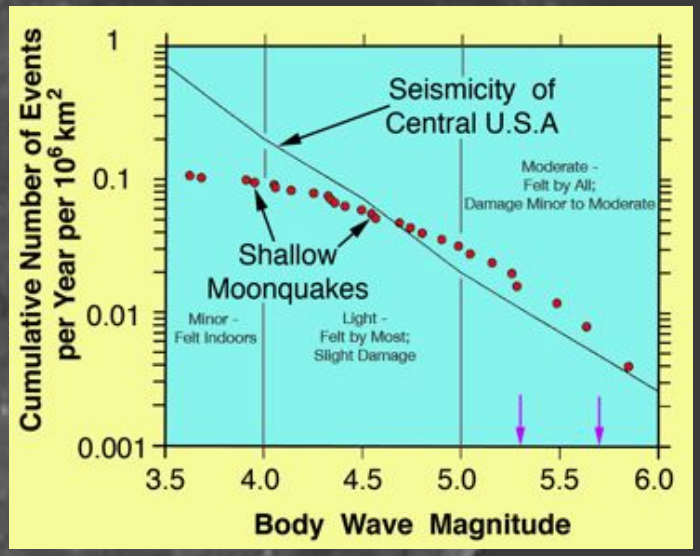
Network too restricted to define global lunar structure

Extended Lunar Presence

The Moon is NOT seismically dead – Thermal, Deep, Impact, Shallow.

Shallow Moonquakes present a potential significant risk to any proposed lunar outpost.

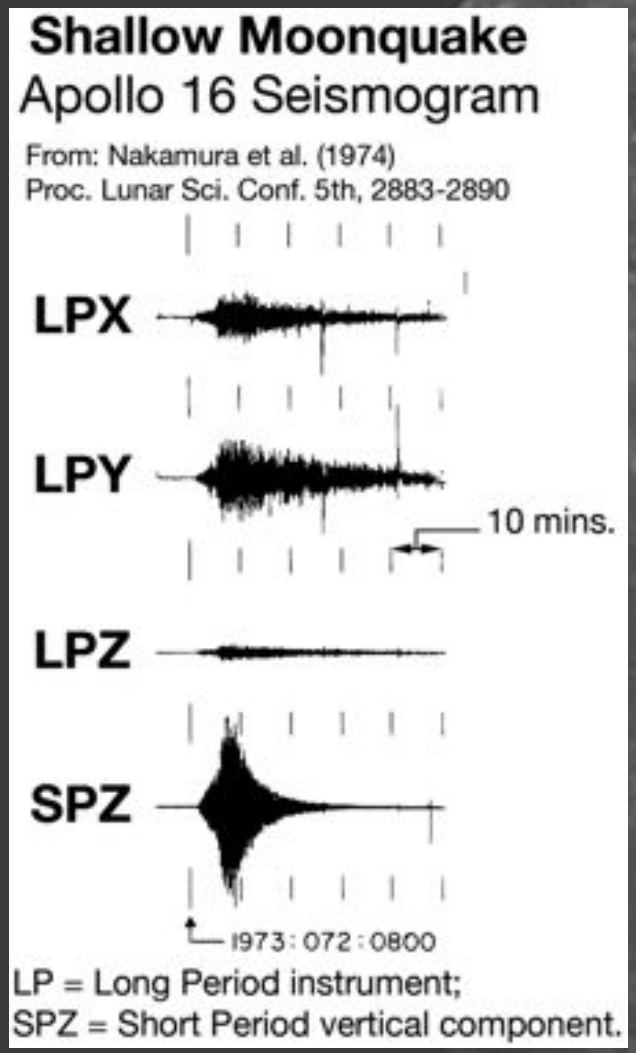
[Oberst & Nakamura, 1992, Lunar Base Workshop, LPI; Oberst & Nakamura (1991) *Icarus* 91, 315-325]

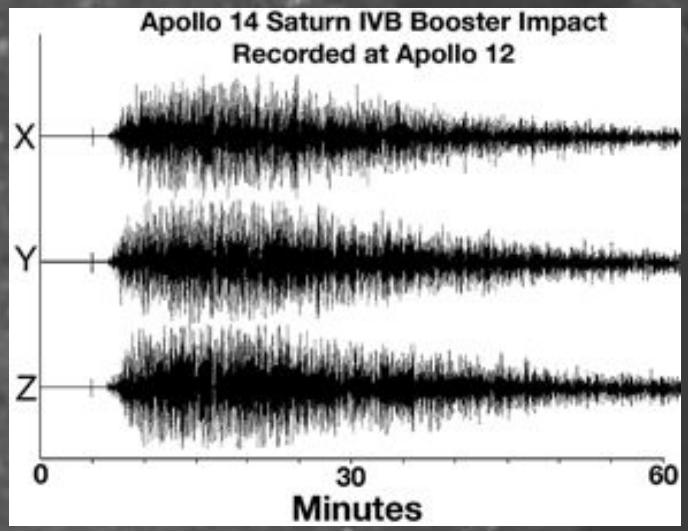


Shallow Moonquake seismicity similar to intraplate seismicity on Earth.

28 Shallow Moonquakes recorded, 7 with magnitude > 5.

Extended Lunar Presence





Dainty et al. (1974)
The Moon 9, 11-29.

Initial build-up phase;

Long duration of energy tail off.

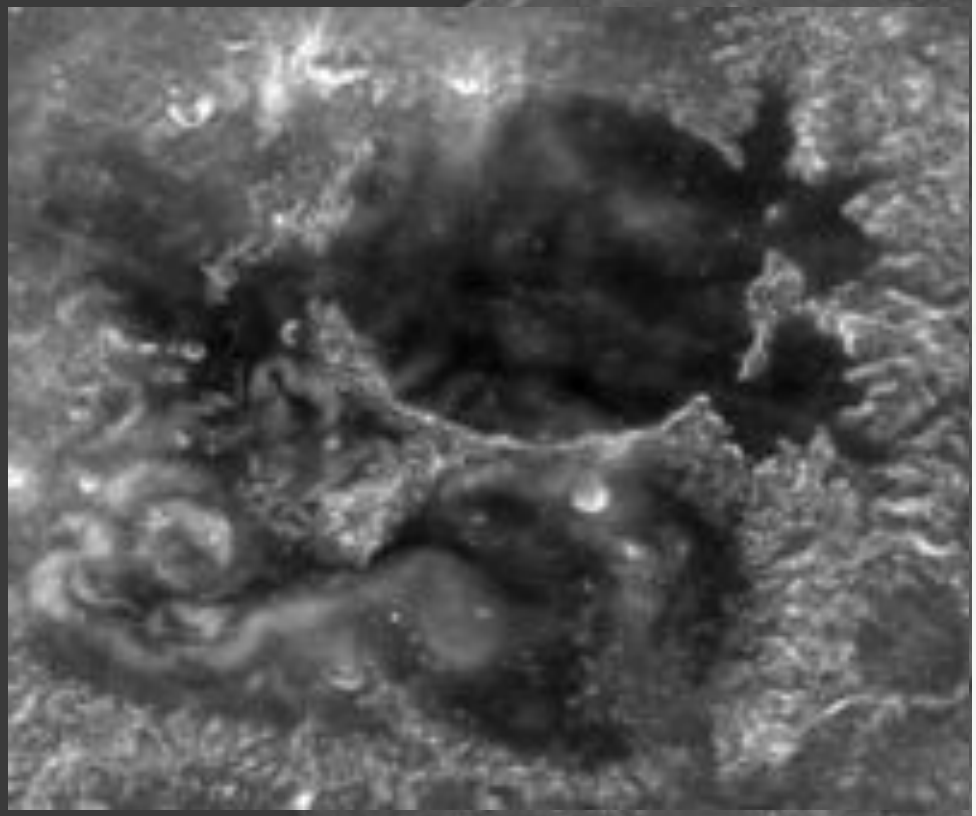
Highest energy release over a period of 10 minutes or longer.

Lack of chemical alteration allows the Moon to "vibrate" for much longer than the Earth (high Seismic "Q").

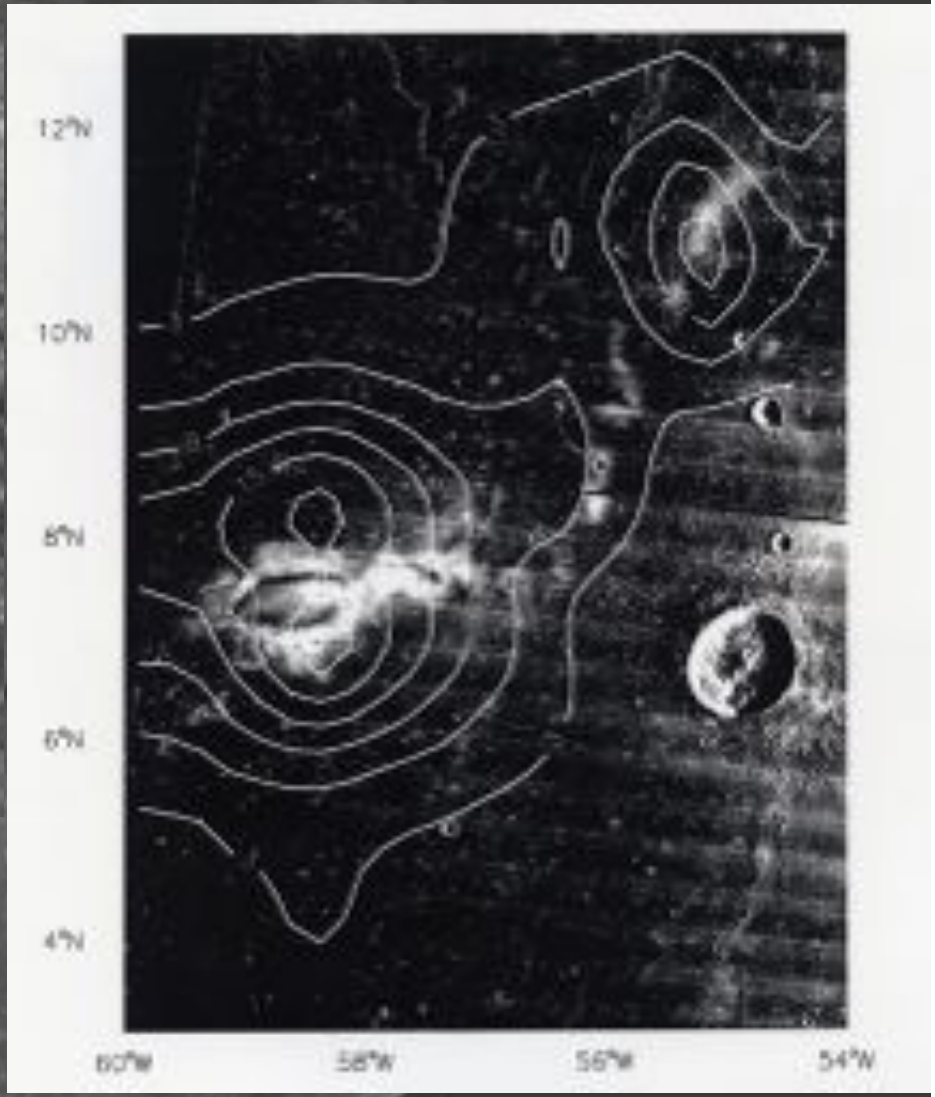
Moon seismic Q is approximately an order of magnitude higher than that of Earth.

Ground shakes for a long time!

Lunar Swirls

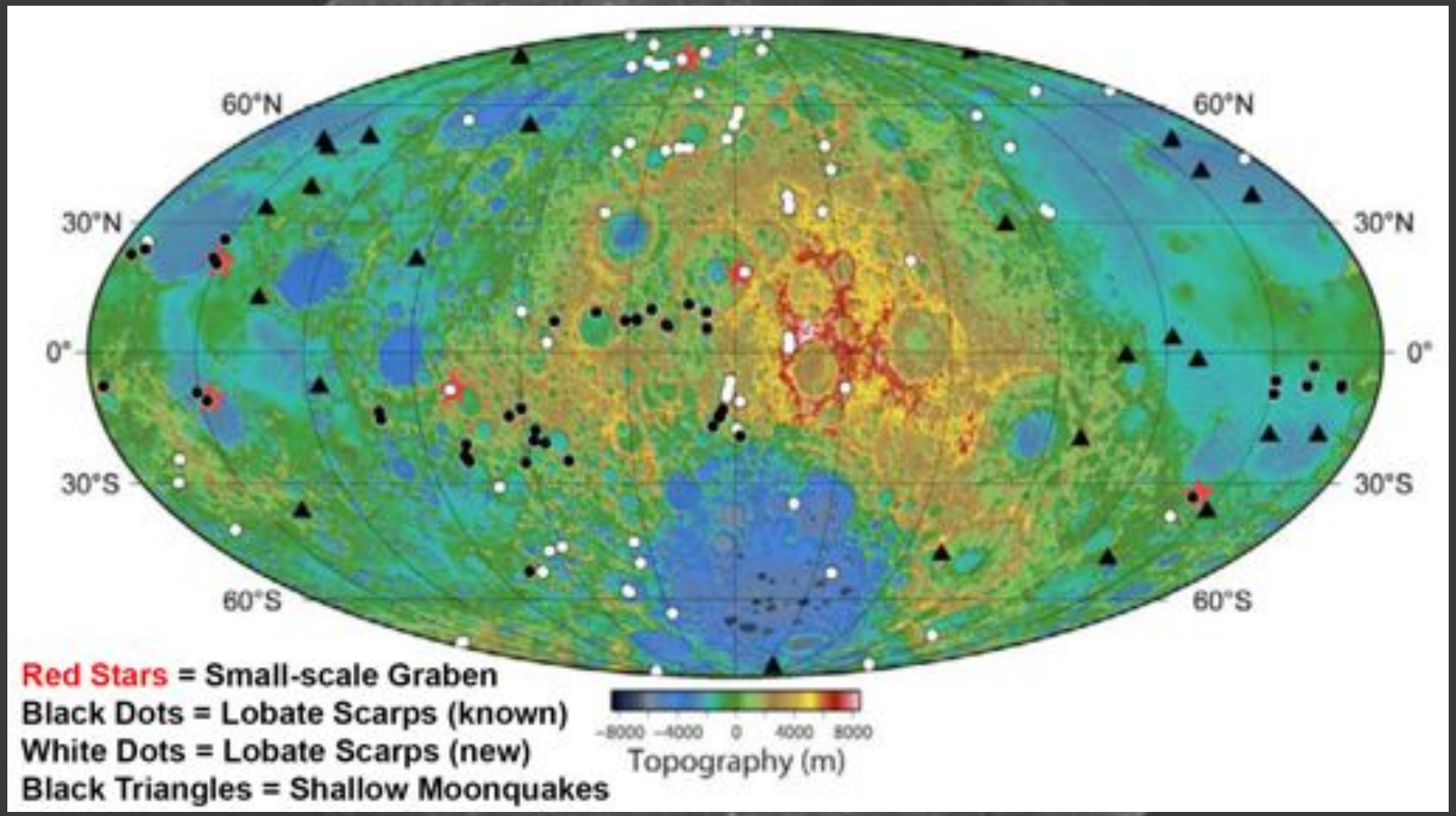


Mare Ingenii



Reiner Gamma

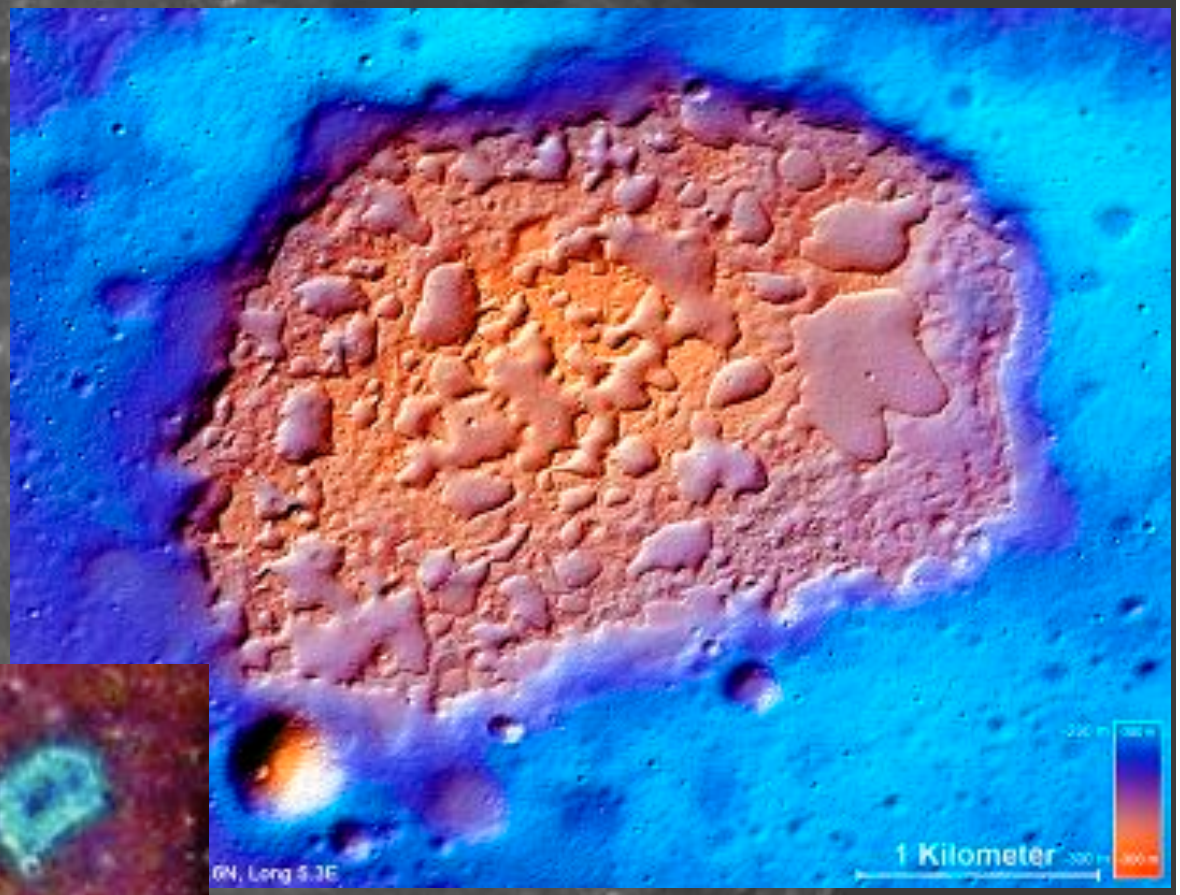
Lunar Tectonic History

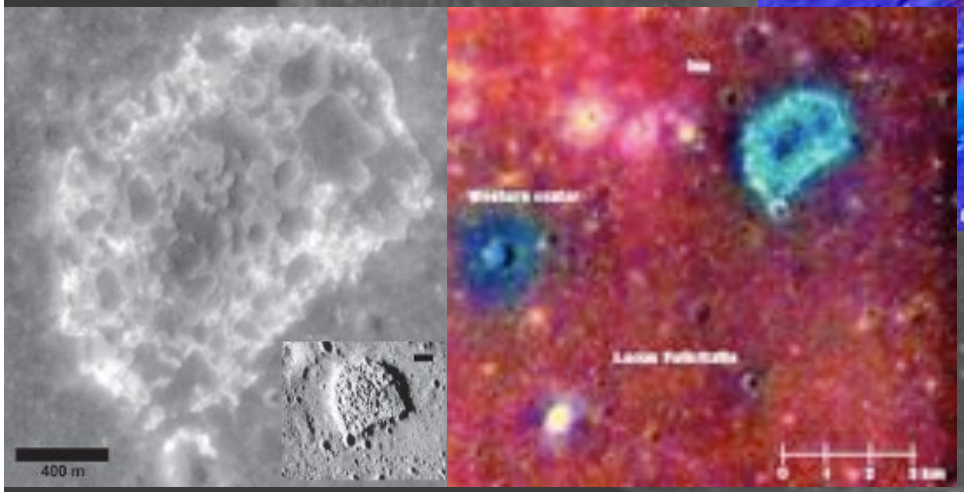


Watters et al. (2012) *Nature Geosci*. doi: 10.1038/NGEO1387

Recent Volcanic Activity

The Ina Structure





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

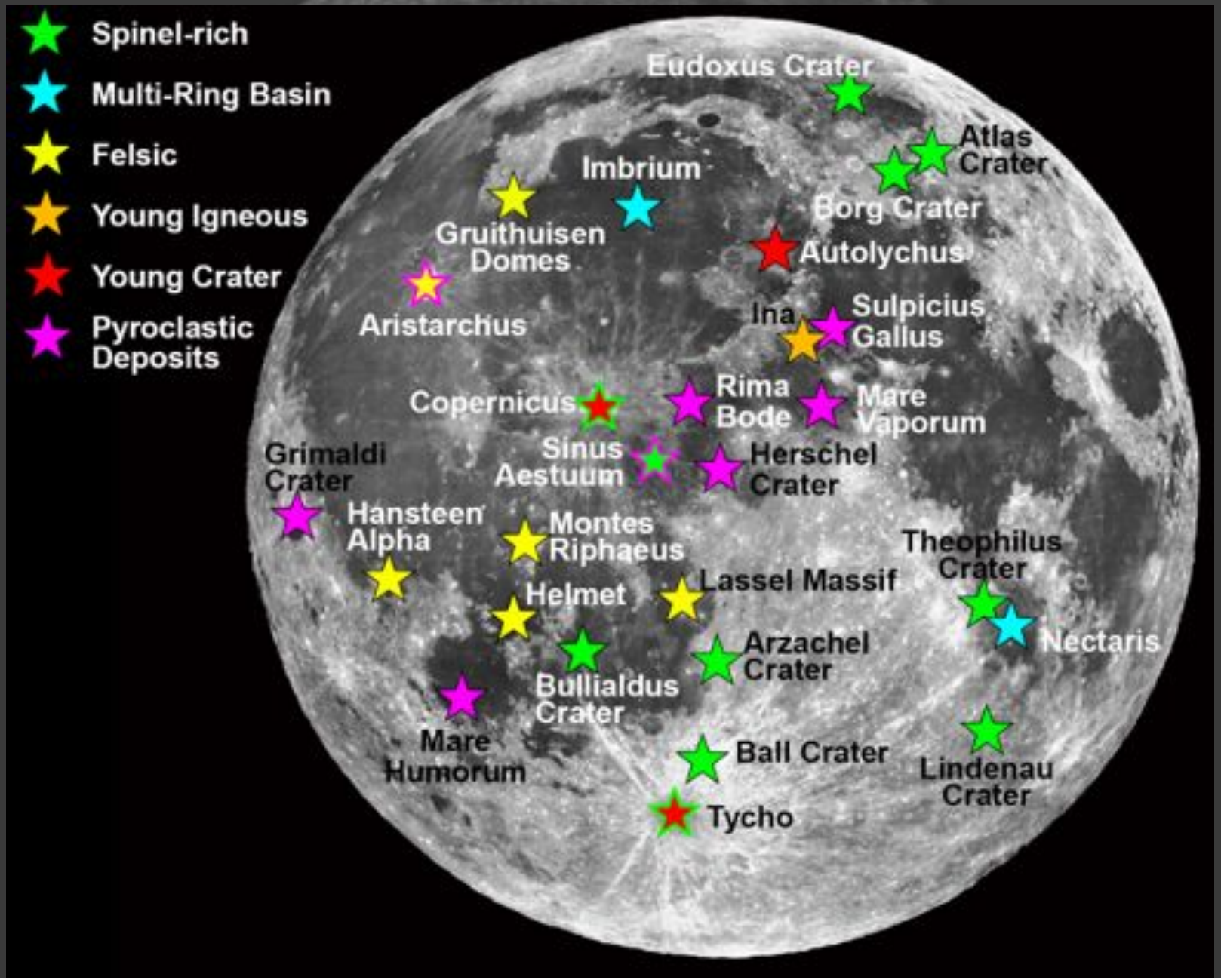
Lacus Felicitatis (north of Mare Vaporum and south of the Apollo 15 landing site) – contains the Ina Structure, which is <10 Ma. Fumarolic activity?

Sample Return

Targeted 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.

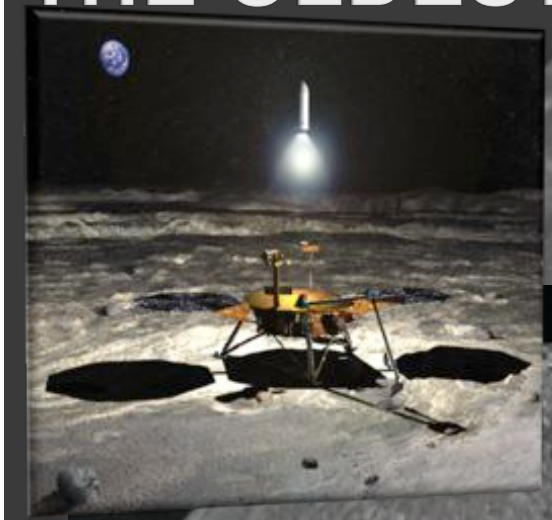
Sample Return - nearside

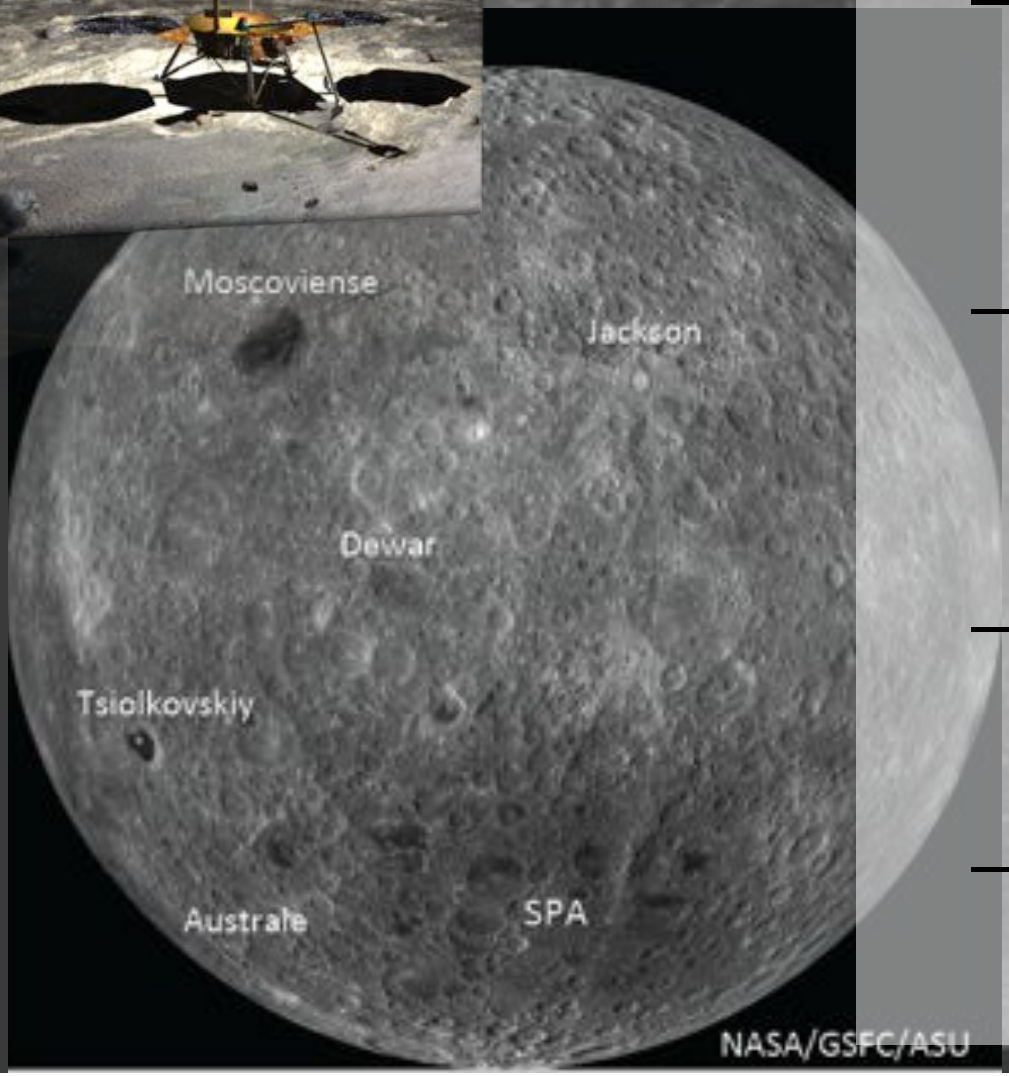


Long-Duration Rover

- Long duration (1000 km, 2 yr), feasible <u>today</u>
- Many possible traverses
  - Telepresence demonstration
  - Discover new resources, assay known resources
  - **Tie remote sensing data to ground**
  - Engineering observations enabling future technology development
- Engage public with NASA exploration in a sustained collaboration
- Workforce development

THE OLDEST BASIN ON THE MOON





- South Pole-Aitken Sample Return
  - Largest and oldest basin
    - When did it form?
    - What are compositions of basalts?
  - *Tests the early cataclysm hypothesis for early bombardment of Earth-Moon System*
  - *Profound implications for our understanding of early Earth and Solar System*
  - *Establish farside operational capability*

WAITING FOR A RETURN VISIT…

APOLLO 17 LM *CHALLENGER* , 25 cm/pixel

2011

Discussion

- Perspectives for gaining international consensus on priorities;
- What types of missions/capabilities are needed to achieve high priority science objectives?
- How does science enable exploration as part of these missions?