The Scientific & Exploration Benefits of Humans to the Lunar Surface

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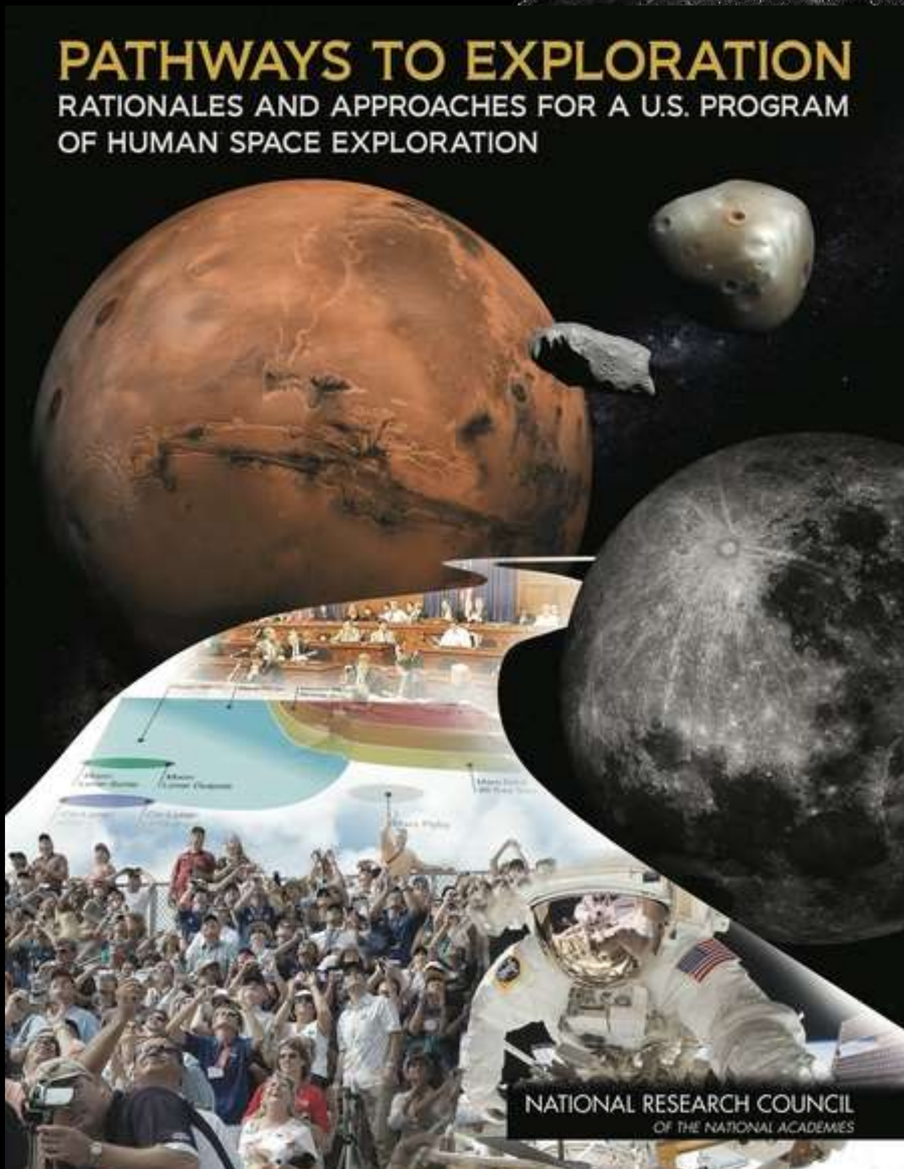
Why Humans?



The current capabilities of robotic planetary explorers are such that although they can go farther, go sooner, and be much less expensive than human missions to the same locations, they cannot match the flexibility of humans to function in complex environments, to improvise, and to respond quickly to new discoveries. Such constraints may change some day.

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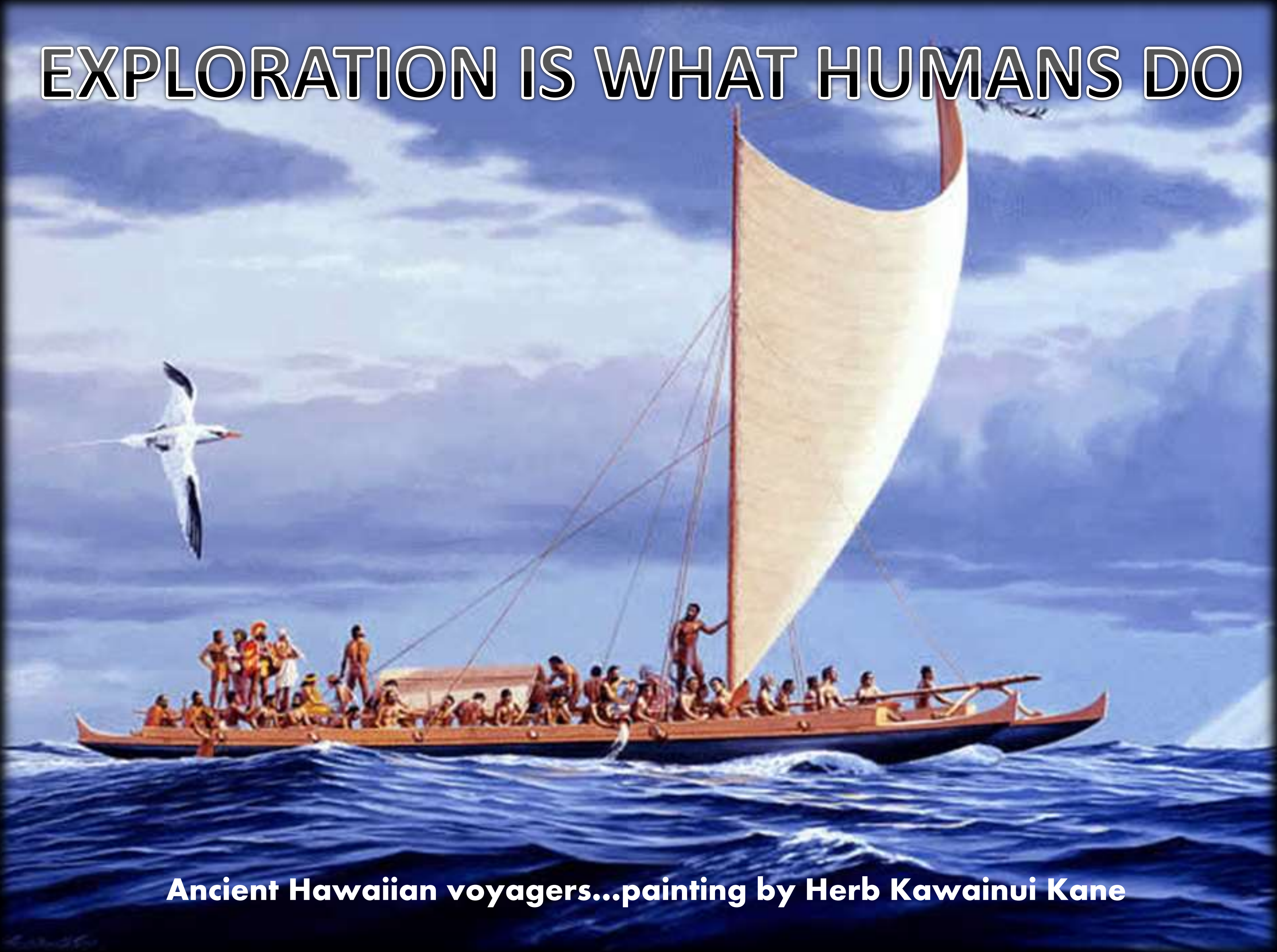
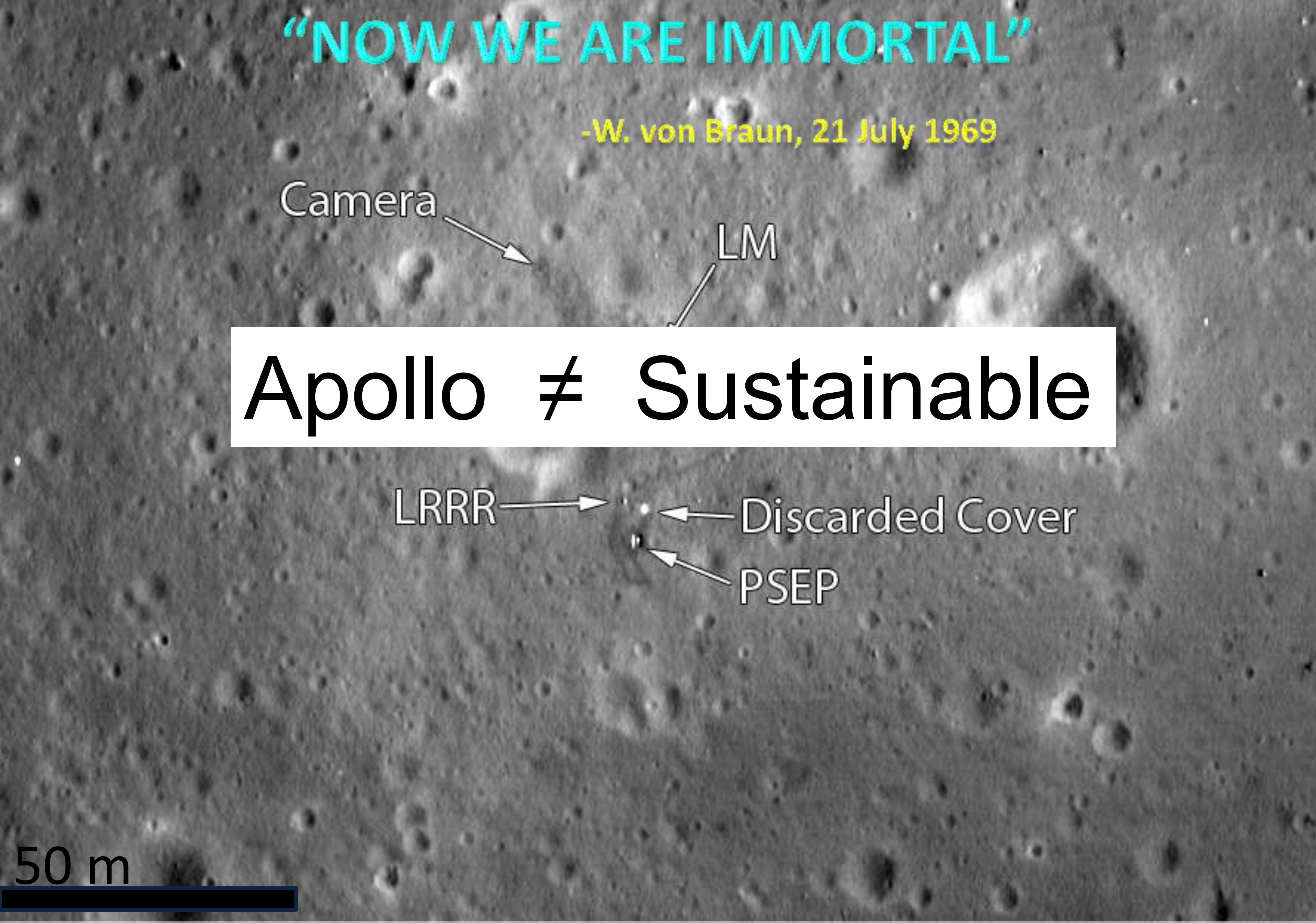
EXPLORATION IS WHAT HUMANS DO



Ancient Hawaiian voyagers…painting by Herb Kawainui Kane



STATION TRANQUILLITATIS SEA OF TRANQUILITY 2011

President Obama @ KSC
April 15, 2010

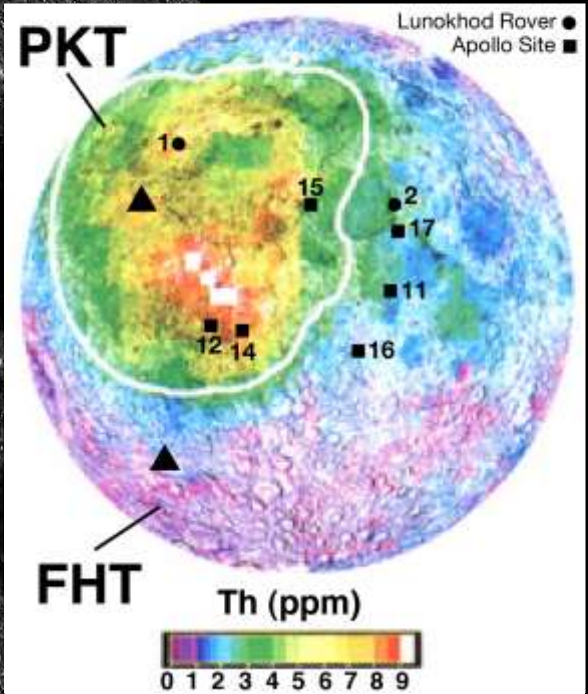
No need to go to the Moon –
“we’ve been there, Buzz has been there”.

We have NOT "been there-done that"!!

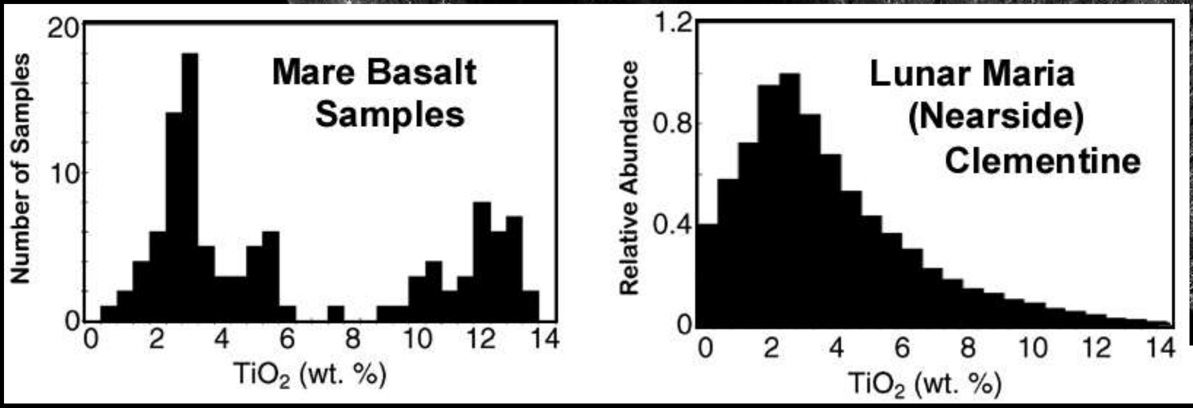
Subsequent mission science has shown that the Apollo landing sites were not ideal for exploring the Moon.

- Apollo sites close to terrane boundaries;
- Samples contain PKT signature;
- Apollo sample collection is not representative of the lunar compositional diversity (Clementine/LP and more recent missions) – sample return needed.
- Some lithologies are not present in the sample collection (Chandrayaan-1 & Kaguya missions).

Ohtake et al. (2009) *Nature* **461**, 236-241
Pieters et al. (2014) *Amer. Miner.* **99**, 1985-1910

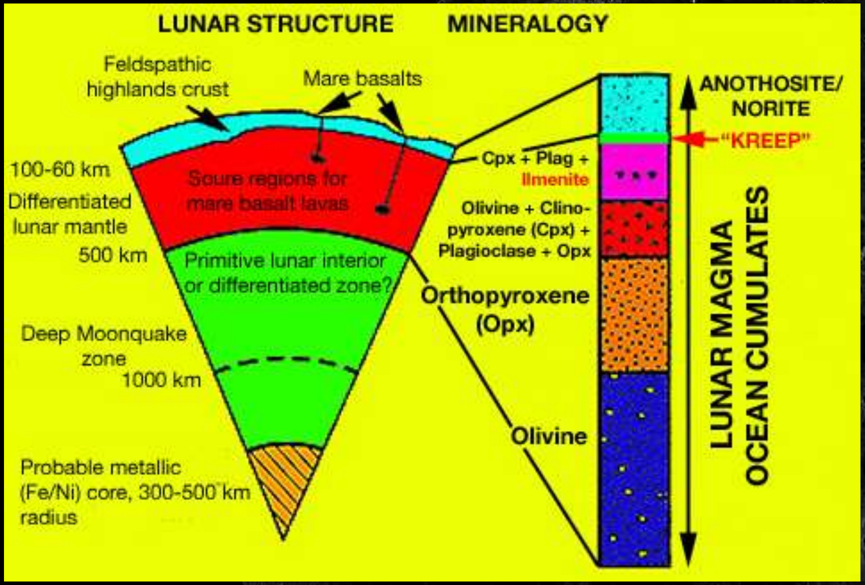


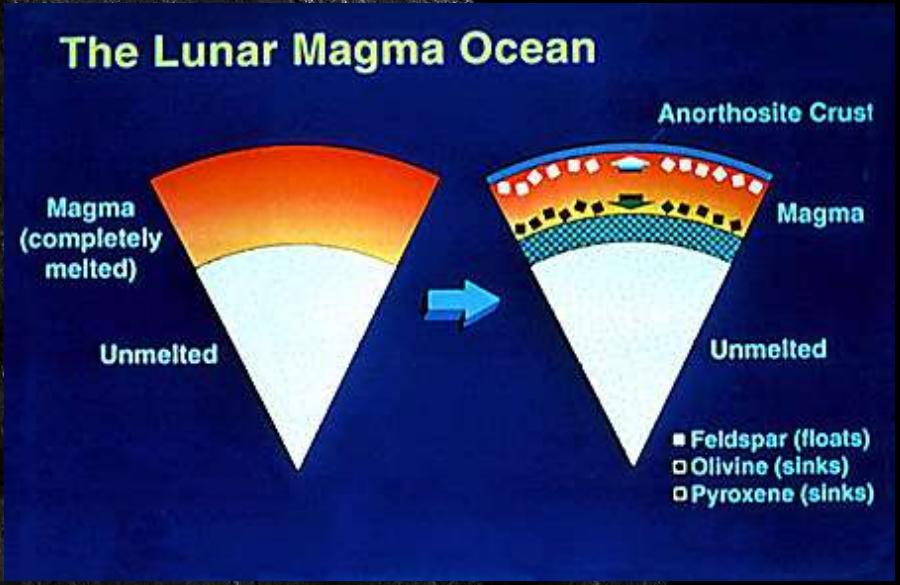
Jolliff et al. (2000) JGR 105, 4197



Giguere et al. (2000) MaPS 35, 193

Lunar Science = Solar System Science





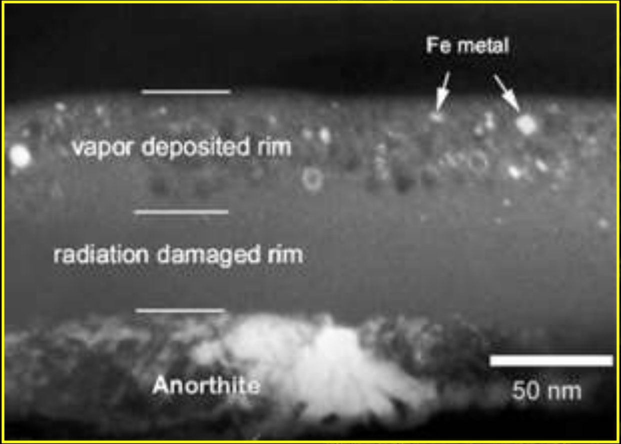
Differentiated source for basalts:

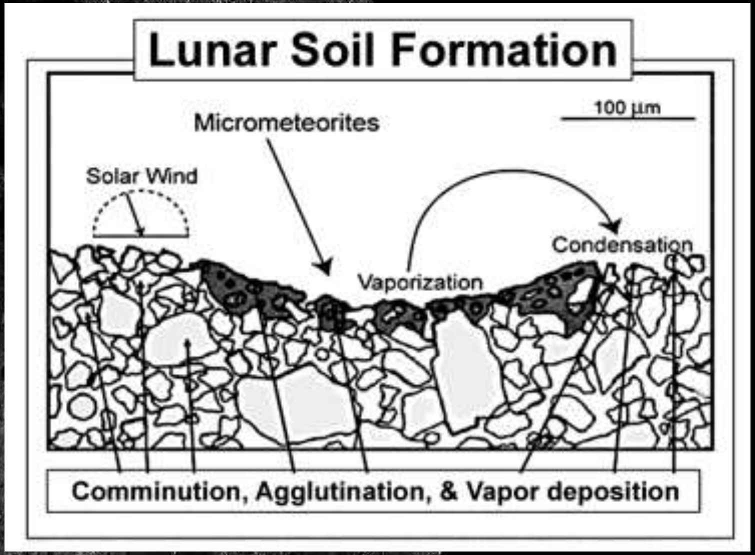
Olivine + Orthopyroxene early; Plag, Cpx & Ilmenite later; "KREEP" = last dregs. Density instability - overturn.

Magma Ocean concept applied to Earth (e.g., McCulloch et al., 1986, *Geol. Soc. Australia Spec Pub*. **14**, 864-876) and Mars (Elkins-Tanton et al., 2003, *Meteorit. Planet. Sci*. **38**, 1753-1771).

Lunar Science =
Solar System Science

Regolith formation on airless bodies;
Space weathering.





Agglutinates form through radiation and meteorite bombardment.

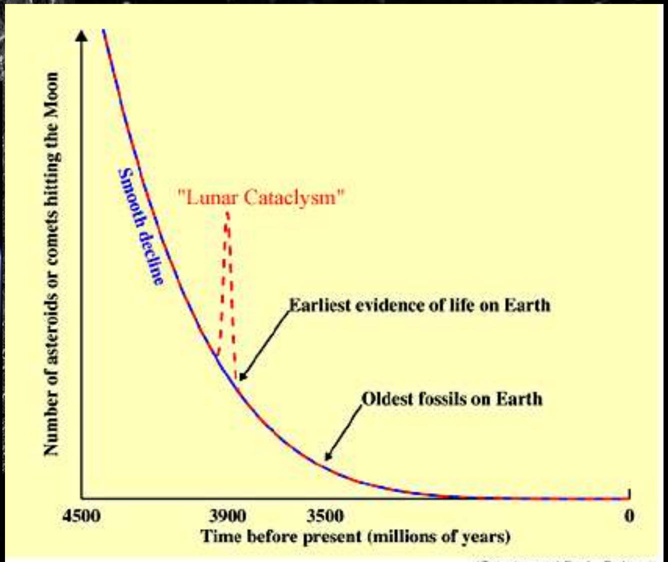
Forms nannophase Fe metal - produces spectral reddening in "mature" surfaces.

Type locality for space weathering of airless bodies.

Lunar Science = Solar System Science

Impact Process & History:

- Use the Moon to better constrain both the ancient and recent impact history of the inner Solar System.
- Critical implications for the origin of life on Earth and possibly beyond.

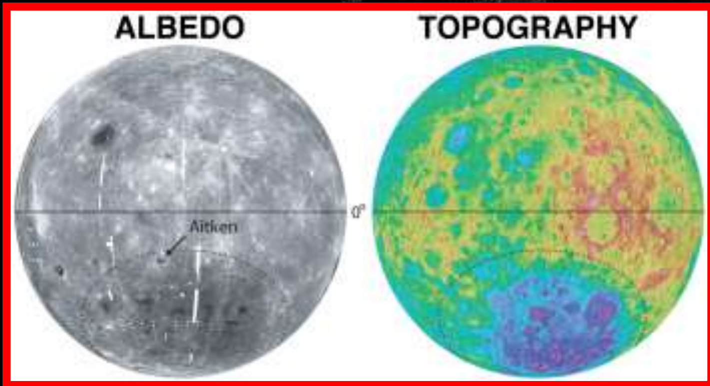


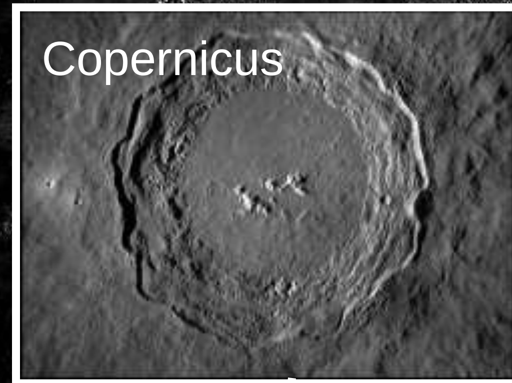
(Courtesy of B. A. Cohen)

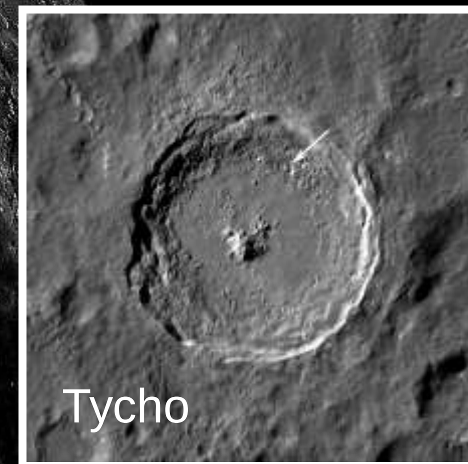
Lunar Science = Solar System Science

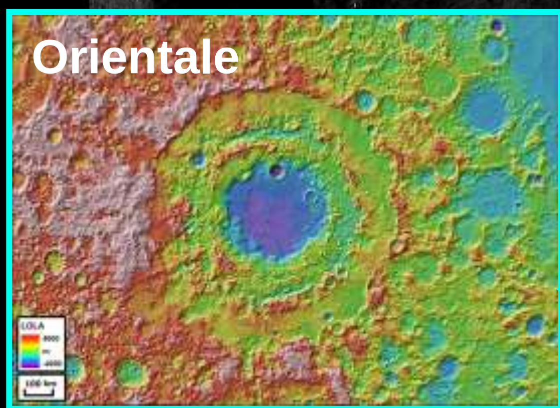
Impact Processes – Calibrating Crater Chronology.

South Pole-Aitken Basin

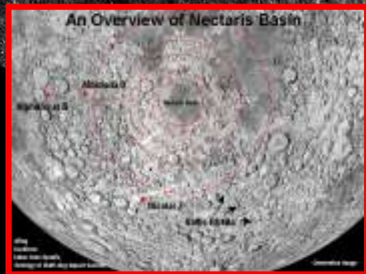


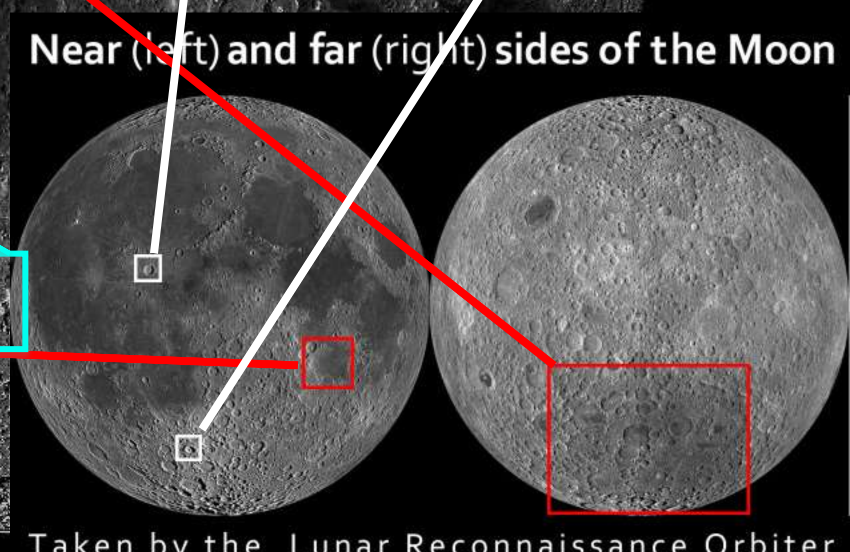






Nectaris





Lunar Science =
Solar System Science

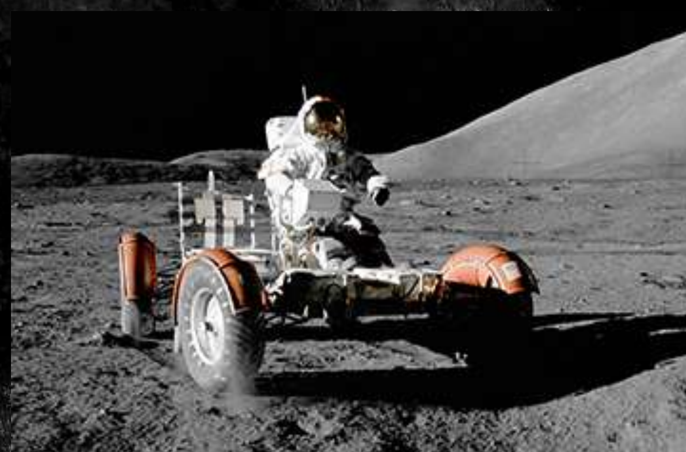
Planetary Evolution:

- The Moon is the small end-member of terrestrial planet evolution;
- Its small size suggests that thermal-tectonic-magmatic evolution occurred early in Solar System history;
- This preserves a stage that has since been obliterated in the larger terrestrial planets.
- The Moon also represents the larger end-member in small body evolution, potentially adding to the understanding of the evolution of asteroids and other stony moons.

Why Humans on the Moon?

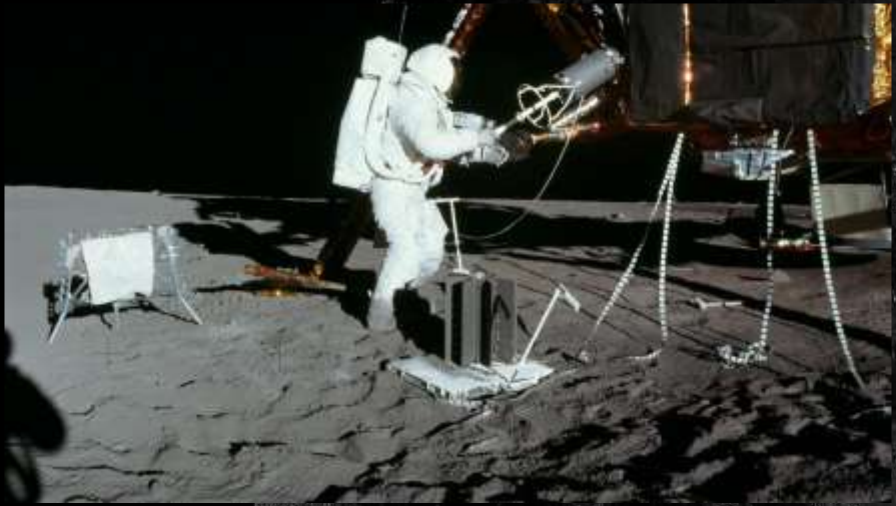
Opportunity (Mars) ~40.5 km……………………………11+ Years
Lunokhod 2 (Moon) ~37 km…………………………….~4 mos.

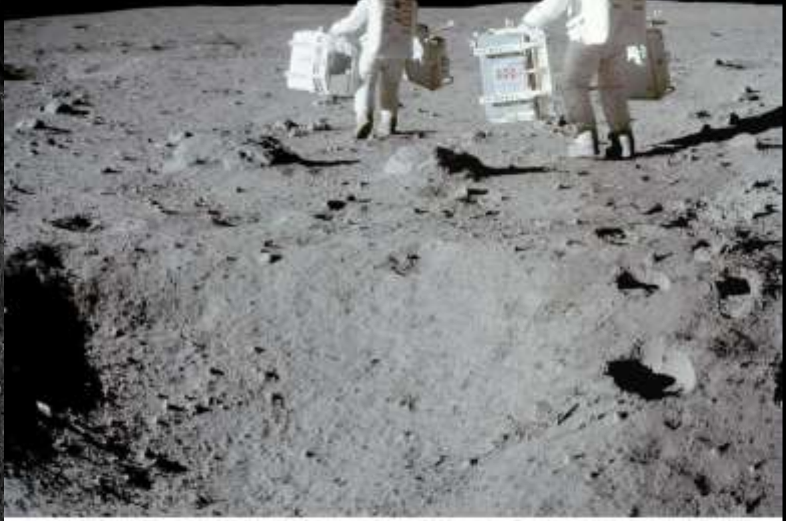
Apollo 17 LRV (Moon) 35.74 km……………………….3 Days
Apollo 15 LRV (Moon) 27.8 km………………………..3 Days
Apollo 16 LRV (Moon) 27.1 km………………………..3 Days



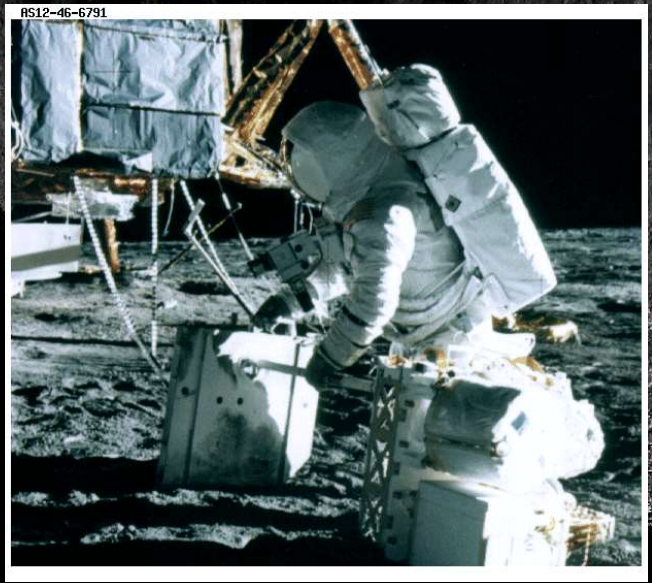
Why Humans on the Moon?

Deployment of Surface Experiments





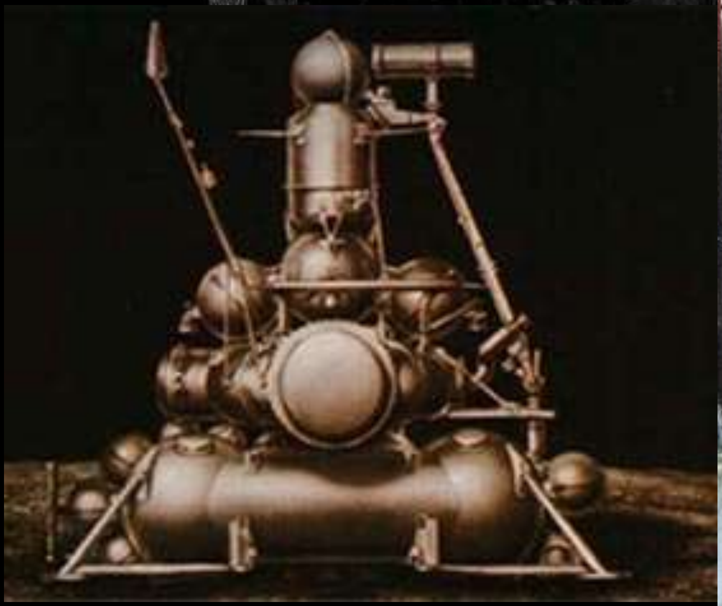
Apollo11, Sea of Tranquility, 20 July 1969, frames A11-40-5943 and 44 : Buzz Aldrin is deploying the EASEP



Why Humans on the Moon?

Sample Return - Robotic

Mission	Country	Date Returned	Mass (kg)
Luna 16	USSR	24 Sept. 1970	0.10
Luna 20	USSR	25 Feb. 1971	0.03
Luna 24	USSR	22 Aug. 1976	0.17
Total			0.30



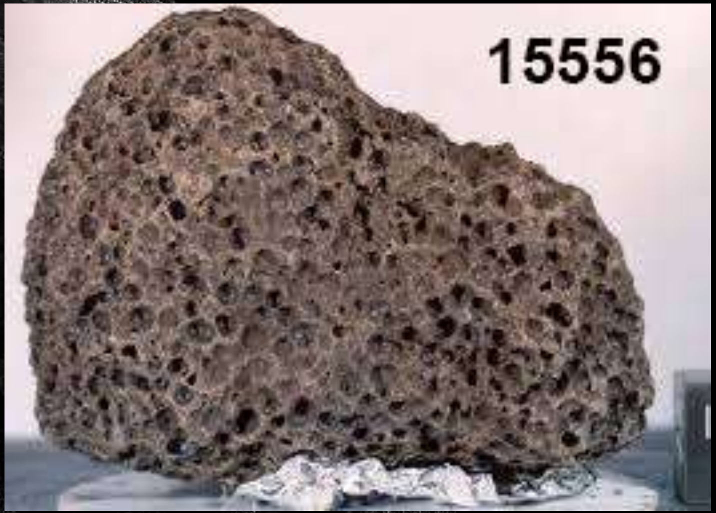
Why Humans on the Moon?

Sample Return - Human

Mission	Country	Date Returned	Mass (kg)
Apollo 11	USA	24 July 1969	21.6
Apollo 12	USA	24 Nov. 1969	34.3
Apollo 14	USA	9 Feb. 1971	42.3
Apollo 15	USA	7 Aug, 1971	77.3
Apollo 16	USA	27 Apr. 1972	95.7
Apollo 17	USA	19 Dec. 1971	110.5
Total			**381.7**

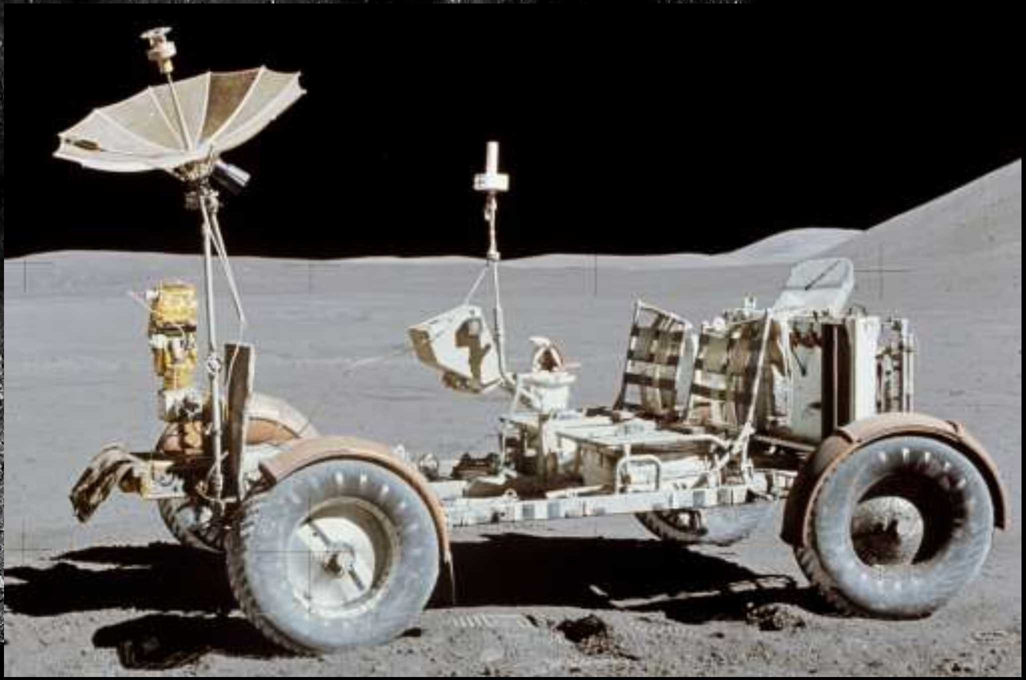
Why Humans on the Moon?

"Well, it turned out what had happened was that Dave had been driving along, "Whoa! There it is! There's a rock with all these holes in it. They're not going to let us stop." So they did this seat belt thing to convince Mission Control that they had to stop, and it worked. You know, it worked." Apollo 15 Oral History
http://www.jsc.nasa.gov/history/special_events/Apollo15.htm



Human Cognition

Volatiles in the lunar interior

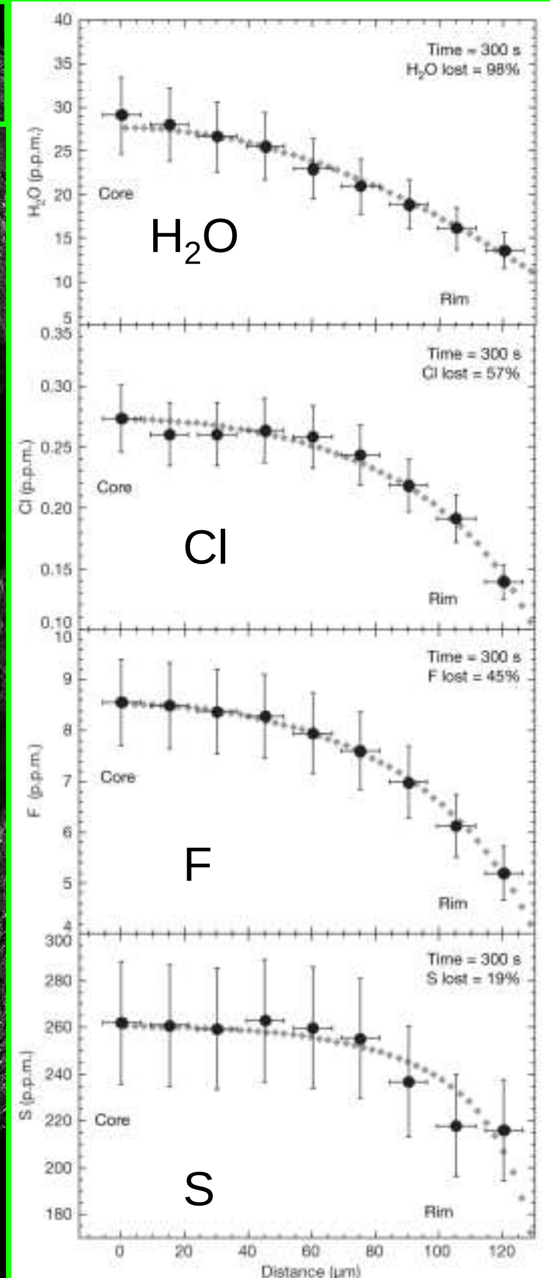


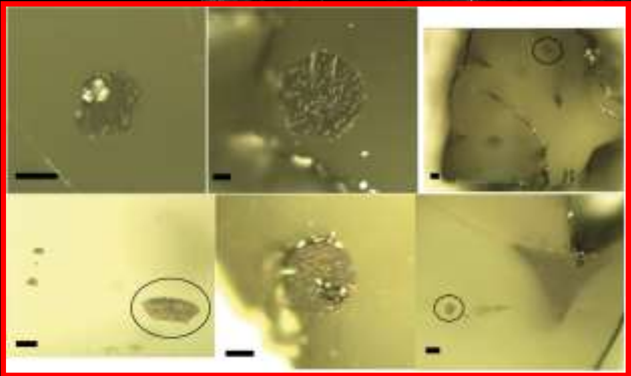
Lunar Endogenous Volatiles

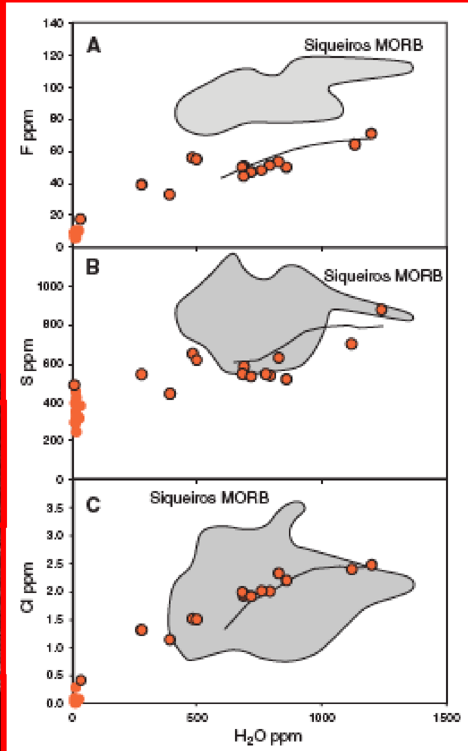
Water in the Glass Parent Magma: 260-745 ppm

Saal et al. (2008 *Nature* **454**, 192-195)

Apollo 15 Green Glass (VLT)







Hauri et al. (2011) *Science* **333**, 213-215

Melt Inclusions in Olivine

Why Humans on the Moon?

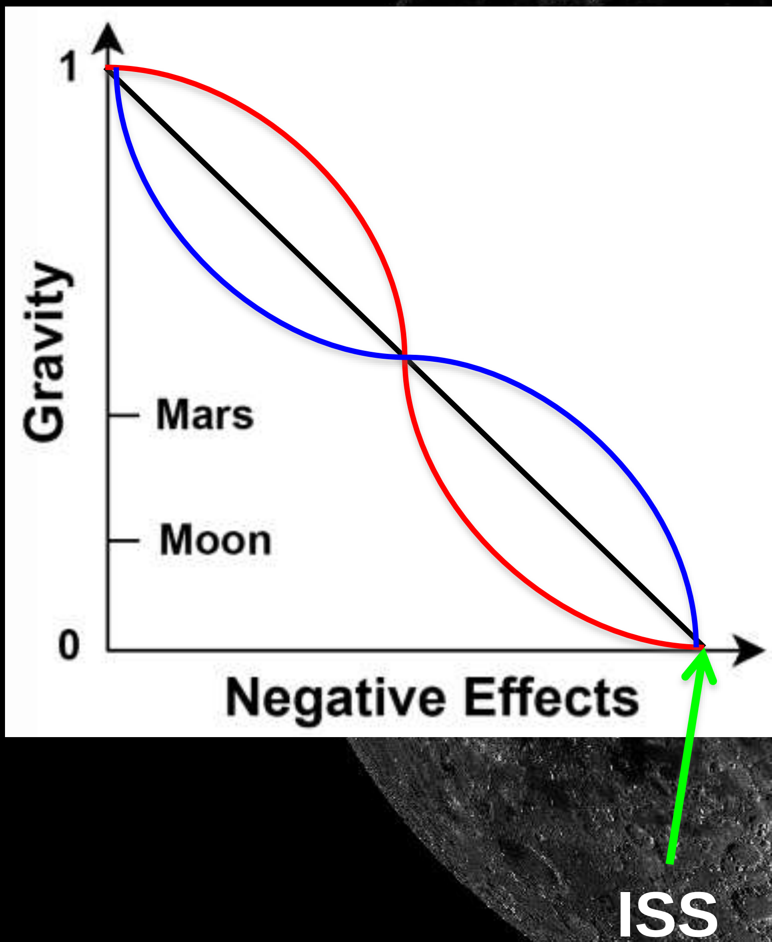
Human Adaptability

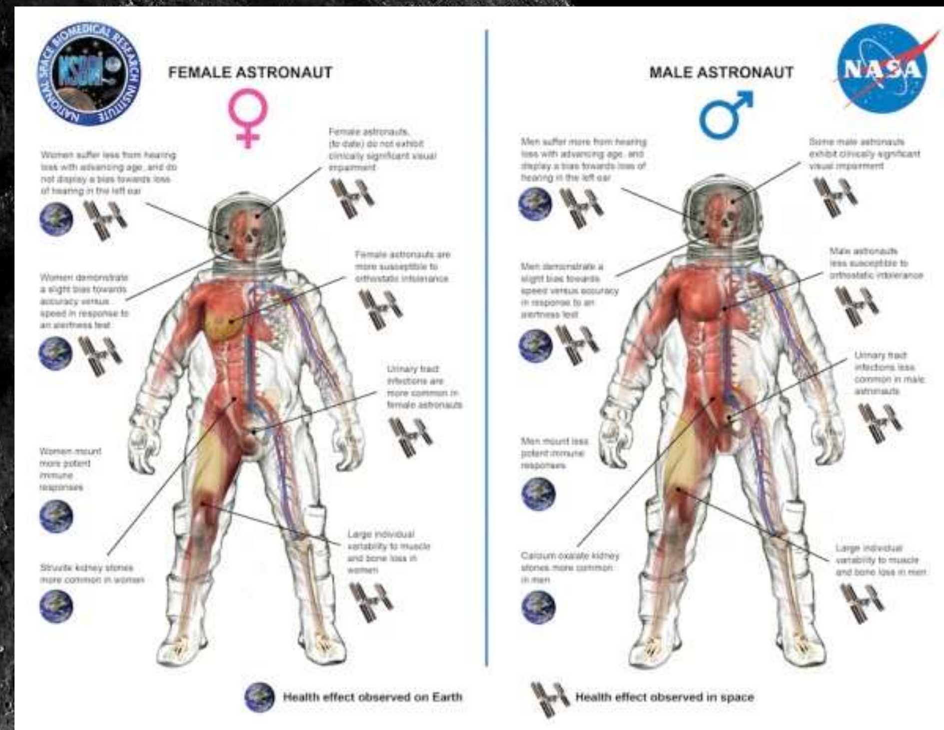
Repairing machinery

Apollo 17 LRV dust guard

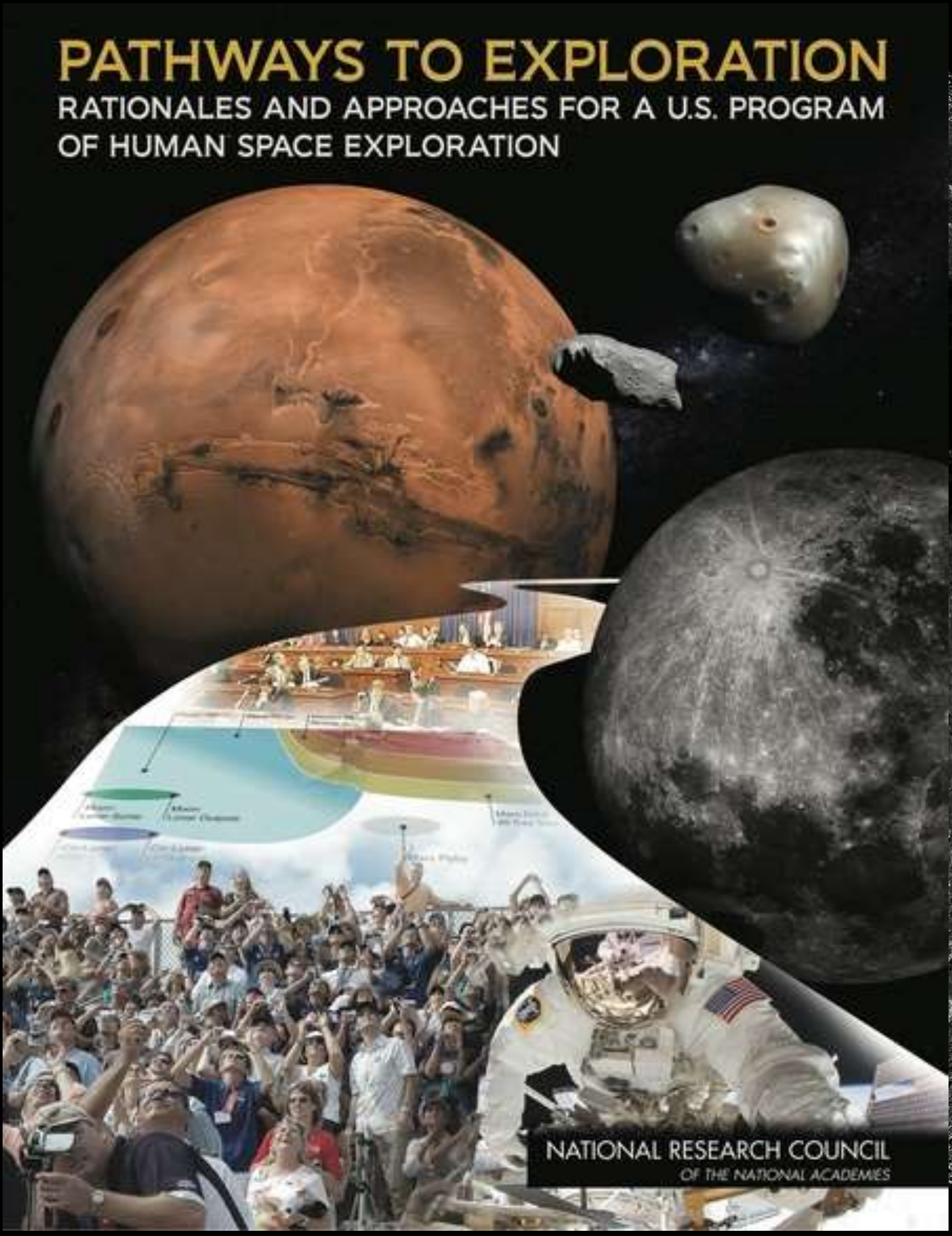
Why Humans on the Moon?

Partial gravity effects on the human body.





Moon is a nearby testbed



Enduring Questions:

How far from Earth can humans go?

What can humans discover and achieve when we get there?

Mars is the "horizon" goal – use a "pathways" approach to get there.

Use a stepping-stone approach along pathways.

~~Stepping Stones~~
Gateways

Stepping Stones: get left behind - abandoned;

Gateways: part of an integrated architecture that does not abandon assets.

- Cis-lunar space, which encompasses missions to the Earth–Moon L-2 point, lunar orbit, and the lunar surface (both lunar sorties with relatively short stays and lunar outposts with extended stays).
- Near-Earth asteroids (NEAs) in their native orbits.
- Mars, which encompasses a Mars flyby mission and missions to the moons of Mars, Mars orbit, and the surface of Mars.

Gateway to the Solar System

Proximity:
- Our closest celestial neighbor – only 2-3 days away
- Risk reduction.

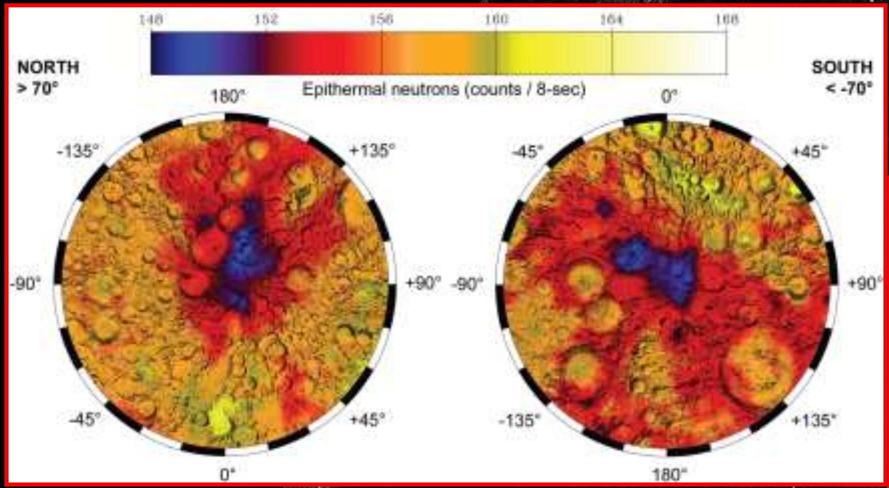
Harsh Environment:
- Test radiation shielding technologies;
- Reduced gravity (not microgravity);
- Dust.

Long-duration testbed.

In Situ Resource Utilization (ISRU):
- Presence of Resources;
- Learning to live off the land, off-planet.

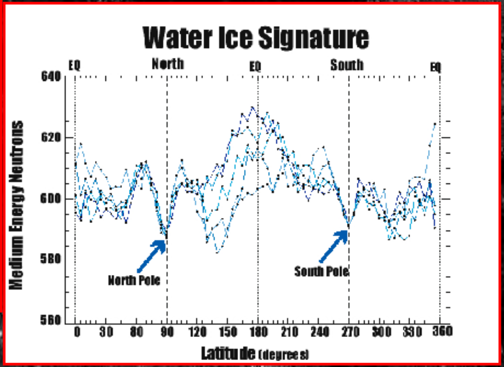
Moon as an Enabling Asset

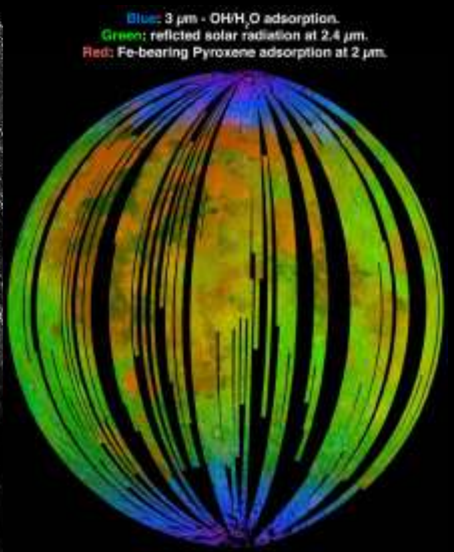
Exogenous Volatiles on the Moon

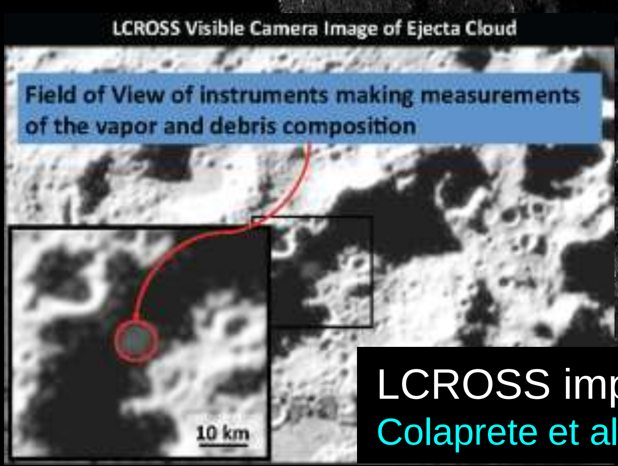


Hydrogen in PSRs – better resolution needed.
Lawrence et al. (2006) JGR 111, E08001, doi:10.1029/2005JE002637

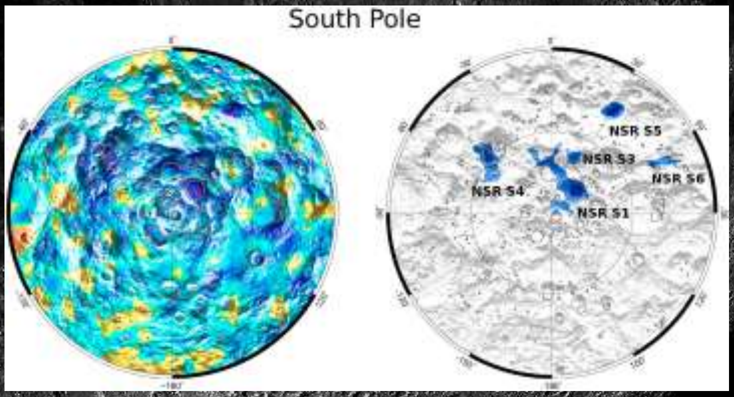
"Moon Frost"
Pieters et al. (2009) Science 326, 568-572







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

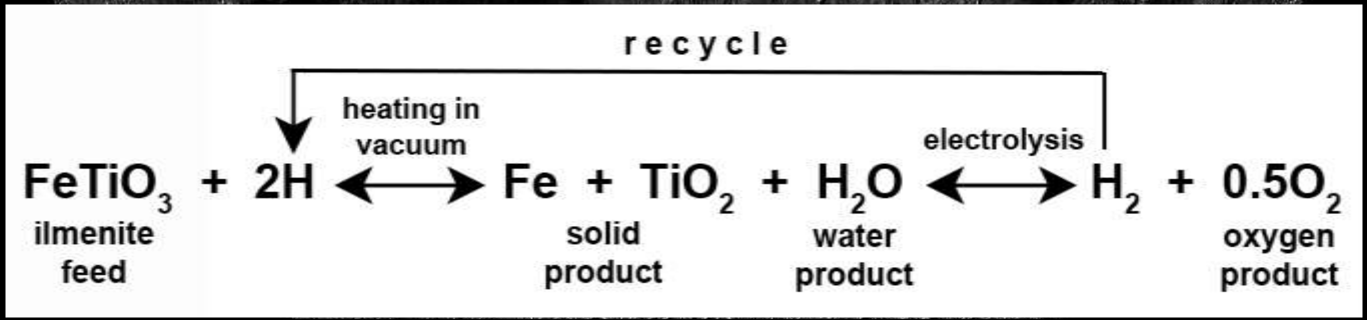


Hydrogen Deposits: Lunar Prospector
Mitrofanov et al. (2012) JGR 117, E00H27, doi:10.1029/2011JE003956

Moon as an Enabling Asset

Science has demonstrated that solar wind proton implantation facilitates formation of water in mature regoliths, especially those containing ilmenite.

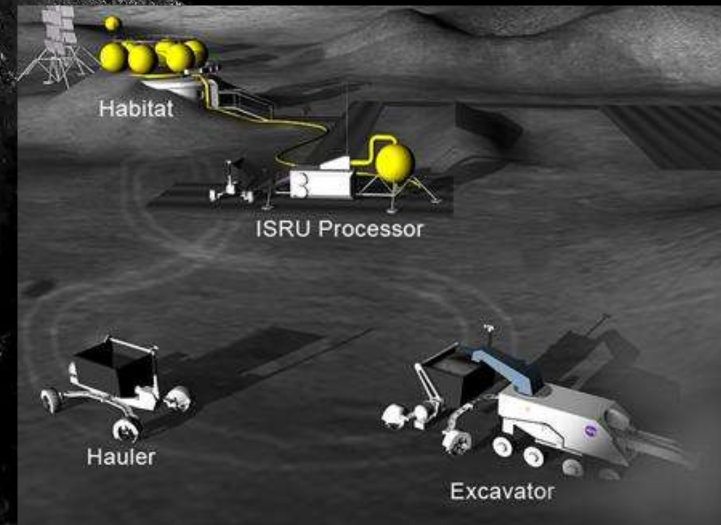
Haskin (1992) *Lunar Bases & Space Activities* **2**, 393-396

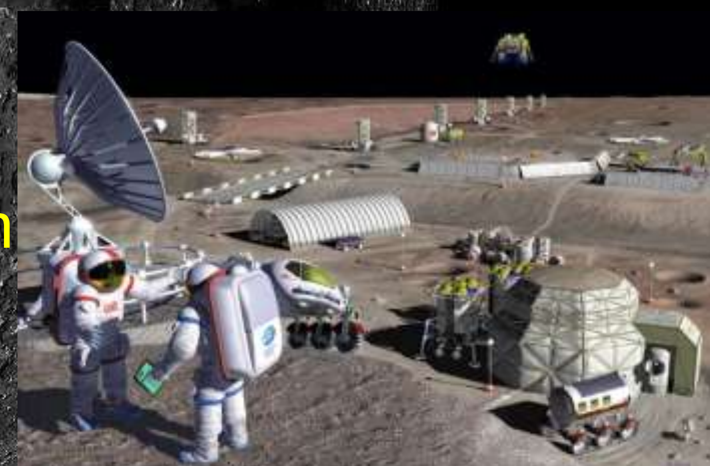


Living off the land! Water and Oxygen can be mined.

Moon as an Enabling Asset

- ISRU is the *game changer* – produce fuel and consumables on the lunar surface to enable human exploration of other airless bodies and Mars, as well as the Moon (IMLEO reduction >40%)
- Enables international cooperation and commercial participation – brings the Moon into our economic sphere of influence.
- ISRU produces science and exploration synergies.





The Moon enables long-term (sustainable) Lunar & Solar System Science & Human Exploration beyond LEO.

Summary

The Moon represents the "Rosetta Stone" for the exploration of the inner Solar System:

- Preserves the earliest stages of planetary differentiation;
- Preserves the early bombardment history;
- It is the type locality for understanding the cratering process and space weathering of airless bodies.

Continued analysis of Apollo samples and Apollo era data yield exciting results allowing more intricate science questions to be asked and addressed by future missions.

From scientific research, we know that the Moon has resources that could enable in-depth lunar and Solar System science & exploration by humans.

The Moon, as an enabling asset, can be the Gateway to the Solar System.

Humans to the Lunar Surface Enable Solar System Science & Exploration

Phobos Deimos

The “*been there, done that*” negativity becomes a positive advantage making the Moon an enabling asset for Solar System science and exploration.

Questions?