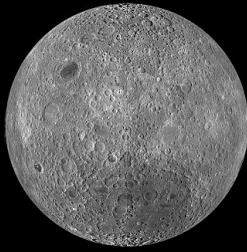


Making In Situ Resource Utilization (ISRU) a Reality on the Moon with the ILRPC: Prospecting, Science, and Planetary Protection



C.R. Neal¹, A. Abbud-Madrid², J.D. Carpenter³, C. Espejel⁴, K. Hadler⁵, C.A. Hibbitts⁶, A. Salmeri⁷

“If God wanted humans to become a space-faring species, He would have given them a Moon”

Paraphrased from Krafft Ehrlicke (1986) [Lunar Industrialization & Settlement](#). In, Lunar Bases & Space Activities of the 21st Century, Mendell W.W., editor, 827-855. Lunar & Planetary Institute, Houston.

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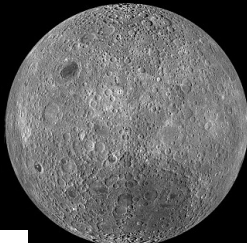
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⁷Lunar Policy Platform, 22 Calle De Valdesangil, Spain (antonino@lunarpolicyplatform.org).



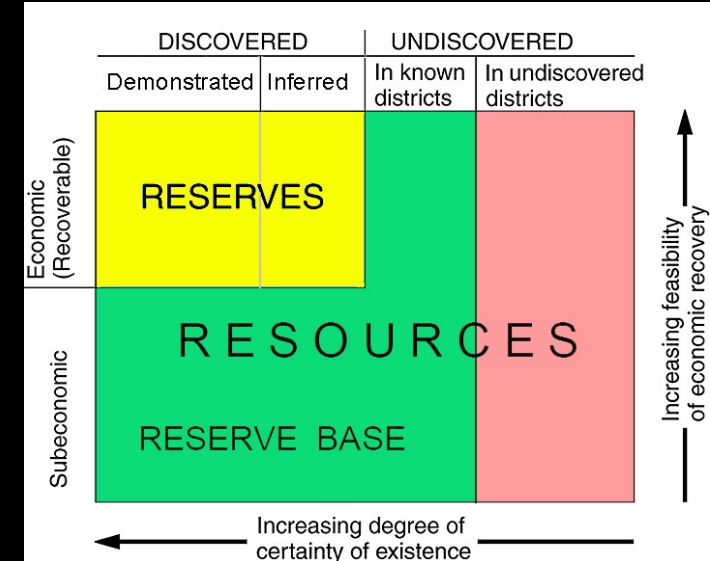
Lunar resources are not ready for extraction/use as their **reserve potential** is unknown



- Finding **resources** is not sufficient to start space resource extraction and use
- For extraction to be considered, the existence of **reserves** needs to be proven

Table 1: Datasets for lunar volatile resource evaluation

Dataset	Specific Data	Use	Measurement
Composition	Concentration of the resource; Concentration & composition of impurities	Evaluate potential investment needed for refining the product	100 µg/g
Form	Cement in pore space; Layers; Irregular blocks; Loose ice grains with regolith	Develop efficient extraction techniques	Image: 0.5 mm/pixel
Distribution	Horizontal; Vertical	Variability needs to be documented to understand the volume of the resource	10 cm
Geotechnical	Torque and power required for any machinery to penetrate the deposit; Energy required to move loose regolith; Hardness of the deposit	Understand the effort required to mine the deposit and investment needed in developing extraction capabilities.	TBD
Near-surface Regolith Stratigraphy	Buried and surface rock populations Ice block/layer distribution	Will impact the extractability of the regolith resource	10 cm
Accessibility	Safe traverse paths	Ease of accessibility has an impact on cost of developing robotic miners.	TBD

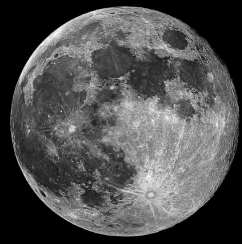


The **reserve potential** of any resource on the Moon cannot be evaluated – **more granular data sets are needed** (Table 1)

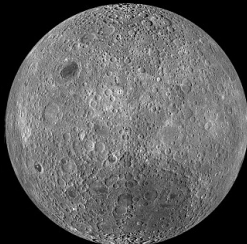
- These new data types would need to be obtained via mobile surface assets via a **lunar resource prospecting campaign**

NOTE: 10 most promising sites for polar volatiles cover over 5,900 km²

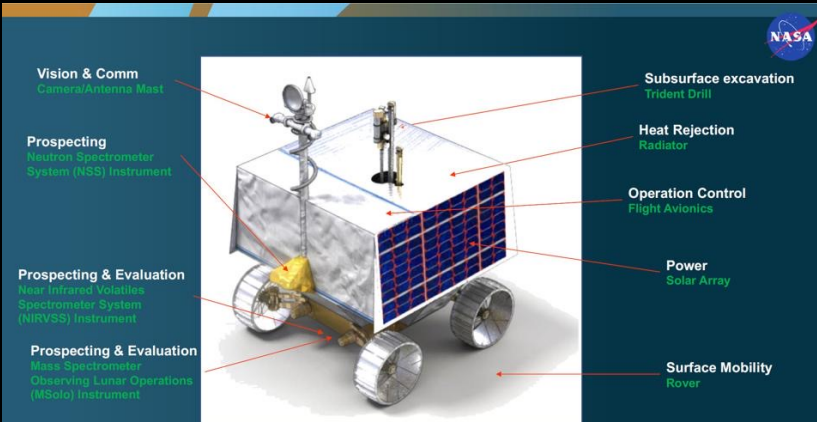
Brown et al., 2022, *Icarus* **377**, 114874. <https://doi.org/10.1016/j.icarus.2021.114874>



Campaigns require cooperation between science, exploration, commerce, and national space agencies



VIPER: Volatiles Investigating Polar Exploration Rover

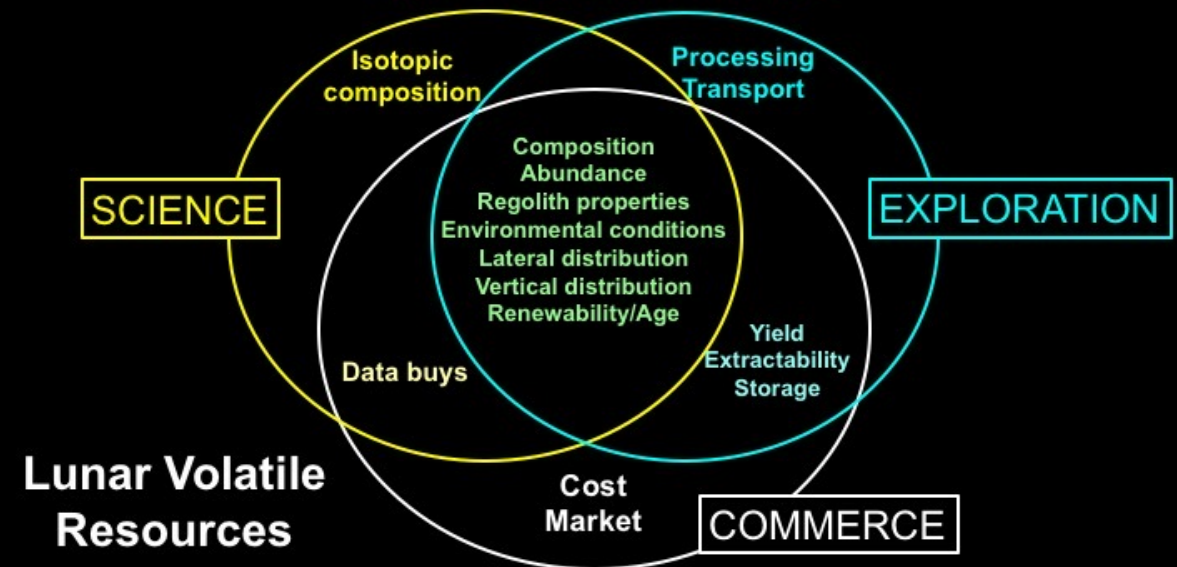


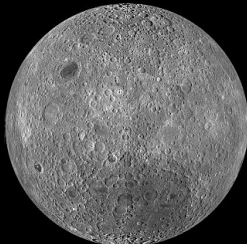
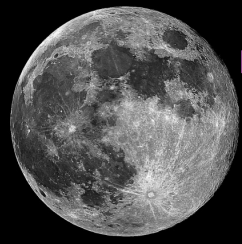
Prospecting campaigns to characterize resources and their environments is the **immediate next step** for the Moon:

- **Partnerships** between lunar science, exploration, commerce
- **Opportunities** for international cooperation, development of interoperability standards, promotion of information sharing protocols

**Science Enables Exploration & Exploration Enables Science.
Both Enable Commerce.**

Resource exploration that documents the reserve potential of lunar resource will inform multiple stakeholders and give a baseline for the environment in which the resources are found





There is disagreement about lunar resource prospecting and utilization

Arguments against resource prospecting/utilization:

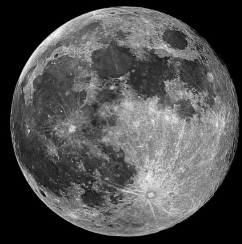
- Compromise the radio-quiet far side & astronomical investigations
Maccone (2019) *Acta Astronautica* **154**, 233-237; Krolikowski (2023), *Nature Astronomy* **7**, 637-639;
Krolikowski A. & Elvis M. (2024) *Phil. Trans. R. Soc. A* **382**: 20230078
- Destroy the PSR environment resulting in calls for “science-only” sites
Elvis et al. (2016) *Space Policy* **38**, 30-38; Prem et al. (2020) *JGR Planets* **125**, e2020JE006464;
Clery (2023) *Science* **382**, 984-985

Protection of areas that contain resources for science is unnecessary; prospecting will deliver science data on these areas & environments that otherwise would likely not be visited.

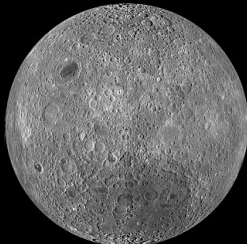
OST Article 1, paragraph 2:

Outer space, including the Moon and other celestial bodies, *shall be free for exploration and use by all States* without discrimination of any kind, on a basis of equality and in accordance with international law, *and there shall be free access to all areas* of celestial bodies.

When we go to the Moon, Mars & beyond, we must go together



The regulation of space resource activities requires knowledge and data to be properly defined



Locations at the poles of limited darkness are premium locations for competing interests

Elvis et al. (2020) *Phil. Trans. R. Soc. A* **379**, 20190563

UN-COPUOS Legal Subcommittee Working Group on the Legal Aspects of Space Resource Activities

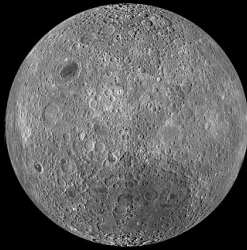
<https://www.unoosa.org/oosa/en/ourwork/copuos/lsc/space-resources/index.html>

Without data from resource prospecting/exploration, regulations may not be enabling for any stakeholder





An International Lunar Resource Prospecting Campaign (ILRPC) is essential for science, exploration & commerce



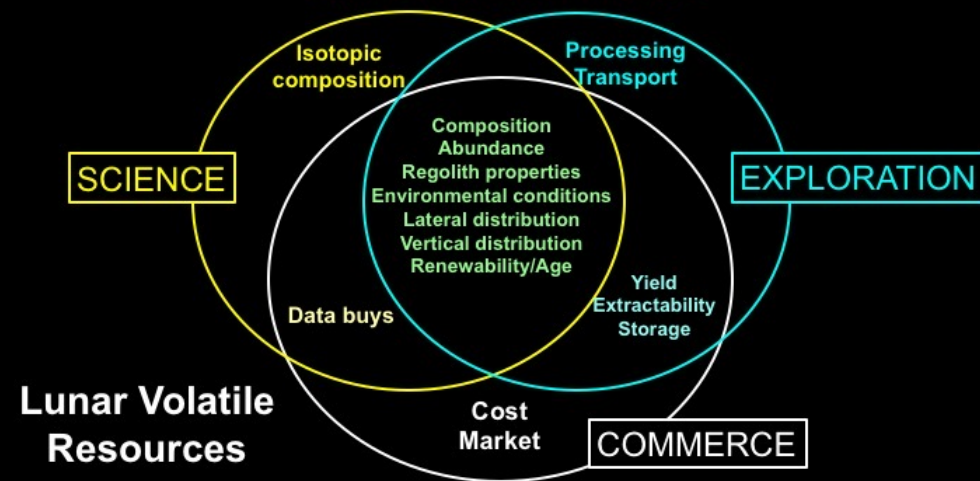
Resource prospecting will:

- Characterize resource environments
- Yield foundational data that will define the origin and evolution of lunar resources
- Allow regulations to be enabling
- Facilitate access to "*sites of extraordinary scientific importance*"* that would probably not be visited without resource prospecting

*Krolikowski A. & Elvis M. (2024) *Phil. Trans. R. Soc. A* **382**: 20230078

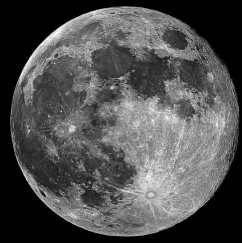


Science Enables Exploration & Exploration Enables Science.
Both Enable Commerce.

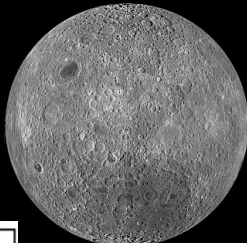


Resource utilization is in the future:

- Science must be involved
- Follow the "*construction model*" in Europe
- Science and exploration enable each other, and both enable commerce



The Moon contains many potential lunar resources that can be used **in situ**, for **export**, or **both**



1) Polar volatile deposits

2) Regolith:

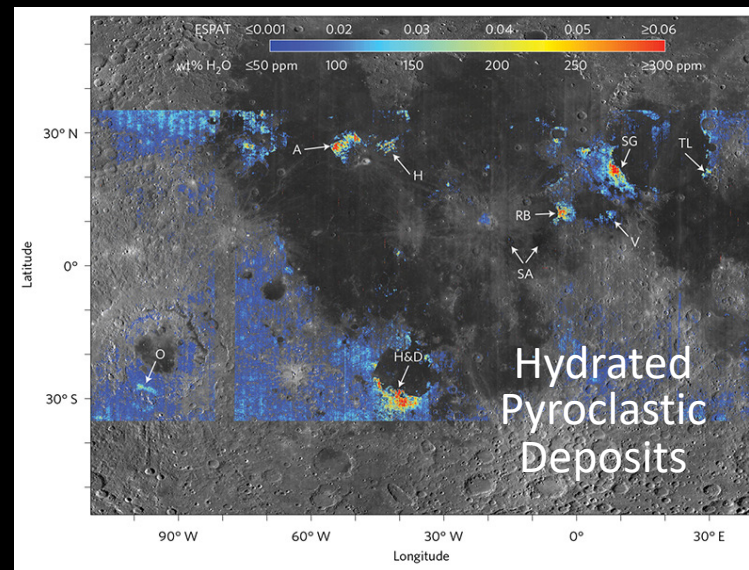
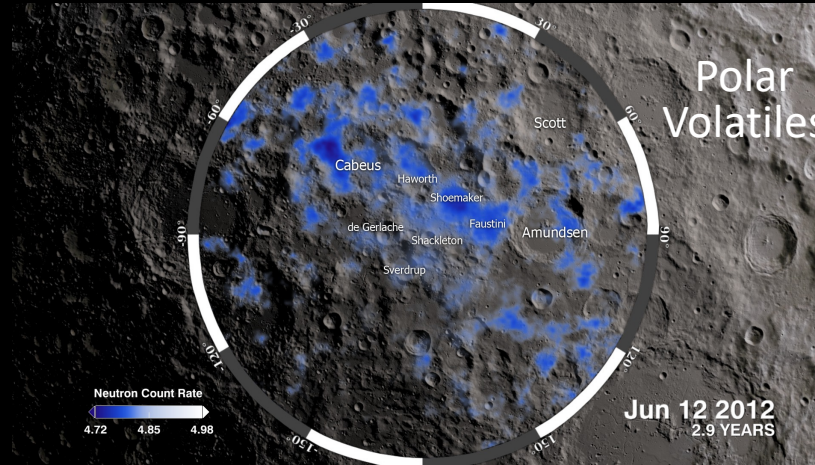
- Building materials (e.g., 3D printing)
- Metals
- Oxygen
- Solar wind implanted volatiles (H, He C, N, etc.)
- Platinum group metals
- Rare earth metals
- Th, U

3) Pyroclastic Deposits:

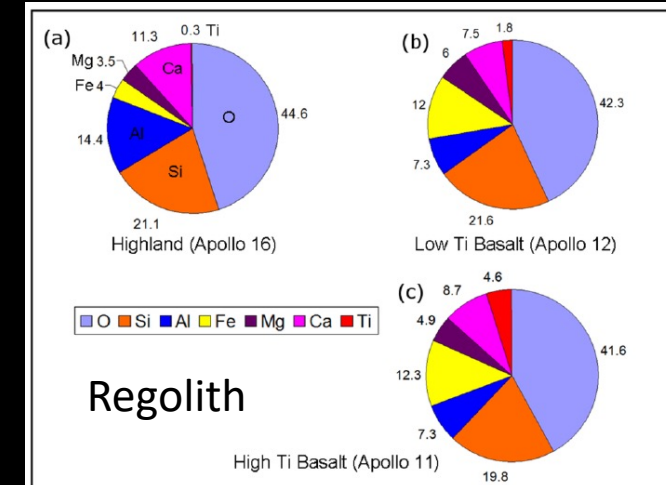
- Volatiles
- Metals

4) Geologic Structures:

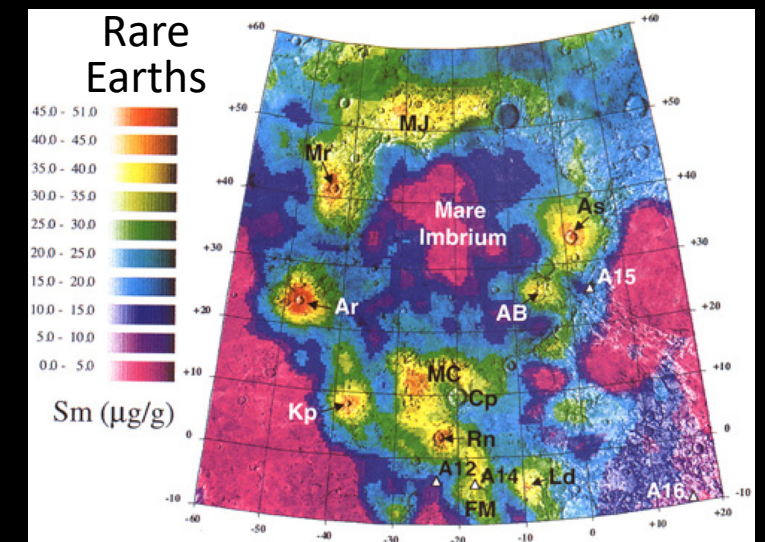
- Lava tubes
- Impact craters



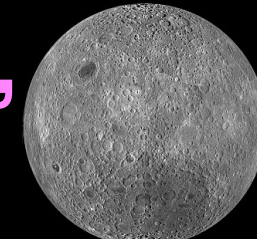
Milliken & Li (2017) *Nat. Geosci.* **10**, 561-565.



Crawford (2015) *Prog. Phys. Geogr.* **39**, 137-167



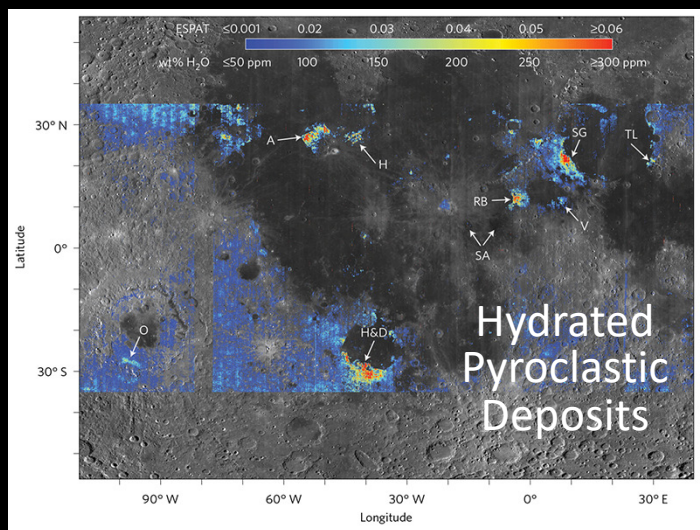
Elphic et al. (2000) *J. Geophys. Res.* **105**, 20,333-20,345



Future lunar prospecting campaigns can benefit science, exploration, & commercial stakeholders

Water – North and South Poles
+ hydrated pyroclastic deposits

Milliken & Li (2017) *Nat. Geosci.* **10**, 561-565

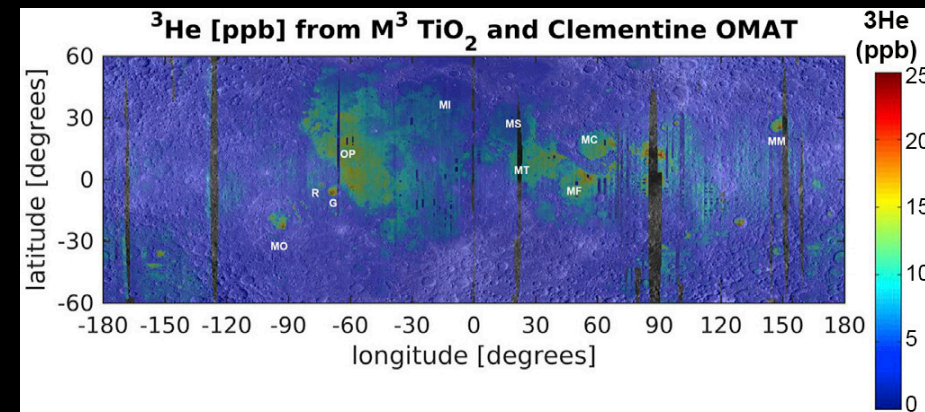
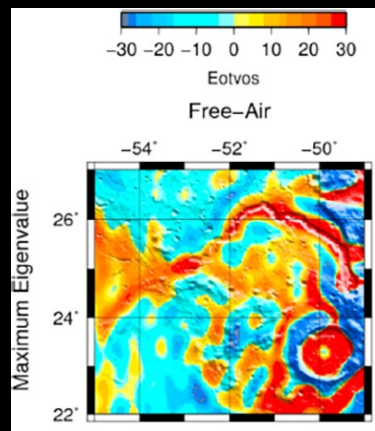
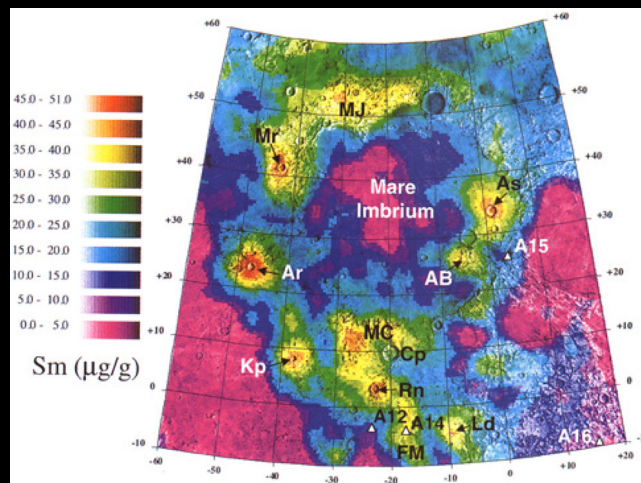


Lava Tubes = safe havens,
Aristarchus: Schröter Rille

Chappaz et al. (2017) *GRL* **44**, 1-5-112

Rare earth metals
+ **Th, U**

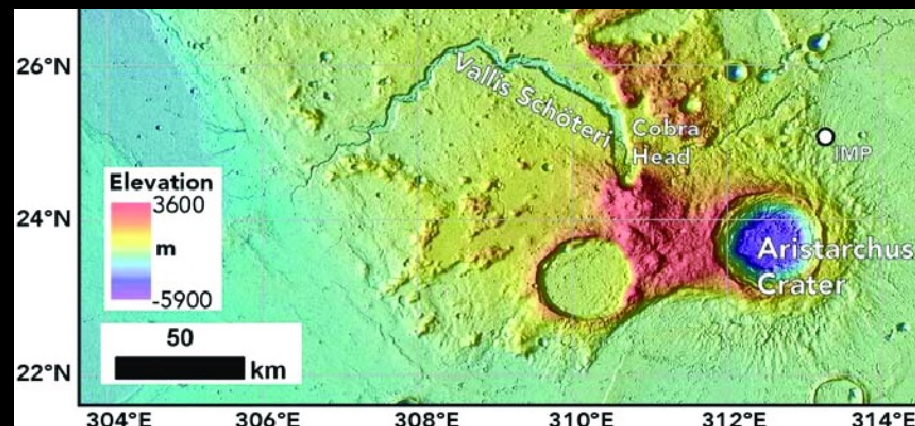
Elphic et al. (2000) *J. Geophys. Res.* **105**, 20,333-20,345

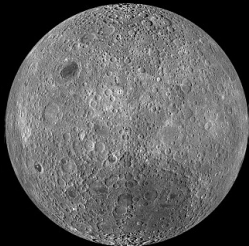


Kim et al. (2019) *Planet. Space Sci* **177**, 104686

Helium

Solar wind implantation mature
ilmenite rich regolith and PSRs(?)





Take Home Messages

When we go to the Moon, we must go together

Formulating an international framework for lunar/space resources activities would benefit from the data returned by an international lunar resource prospecting campaign.

International lunar resource prospecting campaigns would:

- Nurture international cooperation
- Develop information sharing protocols
- Initiate interoperability requirements
- Conduct science, exploration, & commercial activities at the same time
- Understand the resources in order to responsibly utilize them

