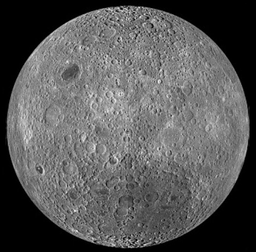
Progress with the International Lunar Resource Prospecting Campaign (ILRPC).



Steering Committee

Clive R. Neal: University of Notre Dame, Notre Dame, IN 46556, U.S.A. cneal@nd.edu
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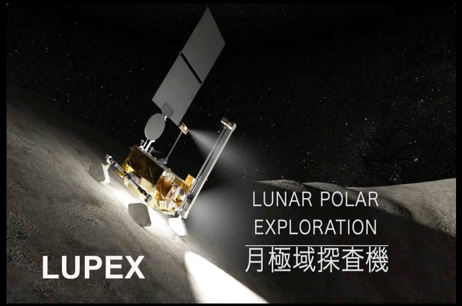
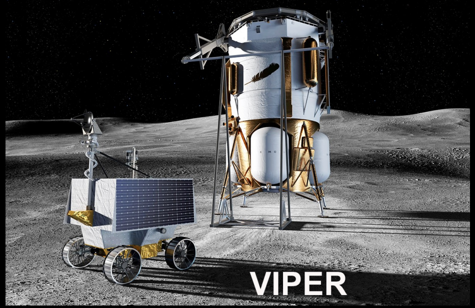
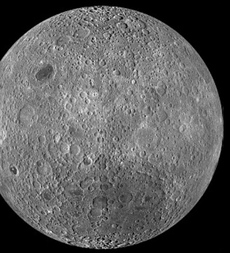




Presentation to the 26th Space Resources Roundtable, 2 June 2026

A permanent Moon Base requires access to reserves of local resources



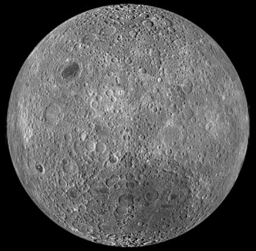
Lunar Resources: What do we know?

TYPE	RESOURCE	LOCATION	USE	
			In-Situ	Export
POLAR VOLATILES	Water	PSRs	X	X
	Helium-3 (?)			X
REGOLITH	Building Materials	GLOBAL	X	
	Metals		X	
	Oxygen		X	X
	Solar Wind Implanted:			
	Hydrogen		X	X
	Helium-3			X
	Carbon		X	
	Nitrogen		X	
	Platinum Group Metals			X
	Rare Earth Metals			X
	Th, U		X	
PYROCLASTICS	Metals	MARE	X	
	Oxygen		X	X
	Water		X	X
STRUCTURES	Lava Tubes	Mostly MARE	X	
	Impact Craters	GLOBAL	X	

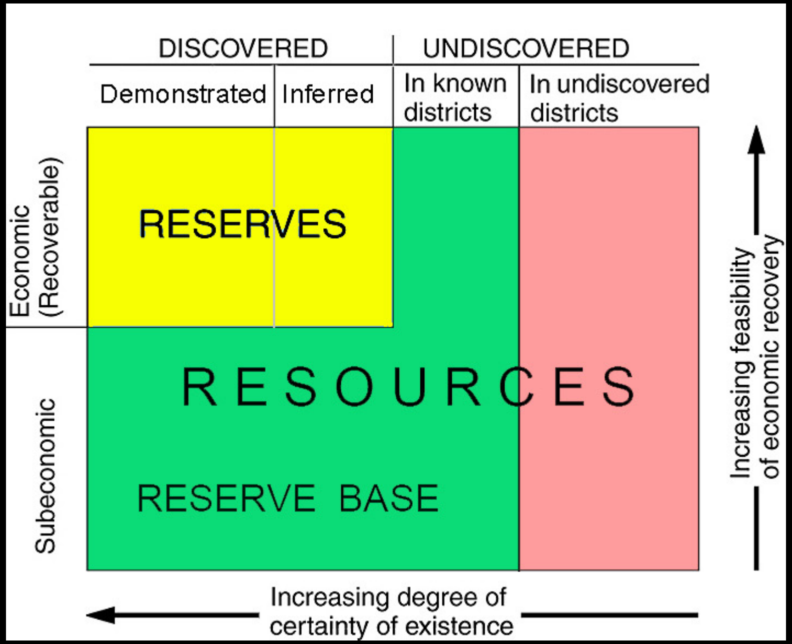
Polar water ice: What data do we have?

MISSION	INSTRUMENT	Pixel Size (m)
Lunar Prospector	Neutron Spectrometer – LPNS	15,000 – 45,000
Lunar Reconnaissance Orbiter (LRO)	Lyman Alpha Mapping Project – LAMP	240
	LRO Camera Narrow Angle Camera – LROC-NAC	PSR imaging = 10-40
	Lunar Exploration Neutron Detector – LEND	10,000
	Miniature Radio Frequency - Mini-RF Synthetic Aperture Radar	150 and 30
	Diviner - thermal infrared radiometer	240
	Lunar Orbiter Laser Altimeter – LOLA	500
Chandrayaan-1	Moon Mineralogy Mapper (M3)	280
	Hyperspectral Imager	80
	Mini-SAR Radar	150
SELENE/Kaguya	X-ray Spectrometer	20,000
	Spectral Profiler	500
	Multi-band Imager	20
	Terrain Camera	10
	Laser Altimeter	800
Chandrayaan-2 Orbiter	DF Synthetic Aperture Radar – DF-SAR (L & S band)	2-75
	Imaging Infra-Red Spectrometer – IIRS	80
	Terrain Mapping Camera - TMC 2	5
	Orbiter High Resolution Camera – OHRC	0.32
Korean Pathfinder Lunar Orbiter - Danuri	ShadowCam	1.7
	Wide-Angle Polarimetric Camera – PolCam	80
	Lunar Terrain Imager – LUTI	2.5
	KPLO Gamma Ray Spectrometer – KGRS	TBD
Lunar Crater Observation & Sensing Satellite (LCROSS)	Geochemical data (5.6±3.3 wt.% H_2O)	~25
	Cratering data (~25 m diameter)	
GRAIL	Ka band Lunar Gravity Ranging System (LGRS)	3-6 km/pixel depending on model and data used

Proving the reserve potential of lunar resources is the fundamental goal of the ILRPC



Finding *resources* is not sufficient to start space resource extraction and use



For extraction:

- Demand is required (markets created)
- *Reserve potential* needs to be proven
- Integration of diverse datasets required
- More detailed data sets will be needed

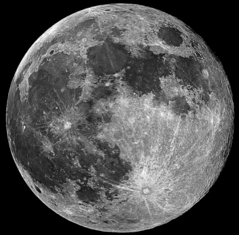
Architecture Component: ISRU Systems (page 43)

ISRU starts with resource identification, characterization, & mapping.

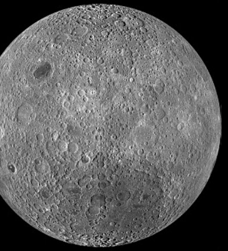
NASA Artemis Architecture Definition Document 2025

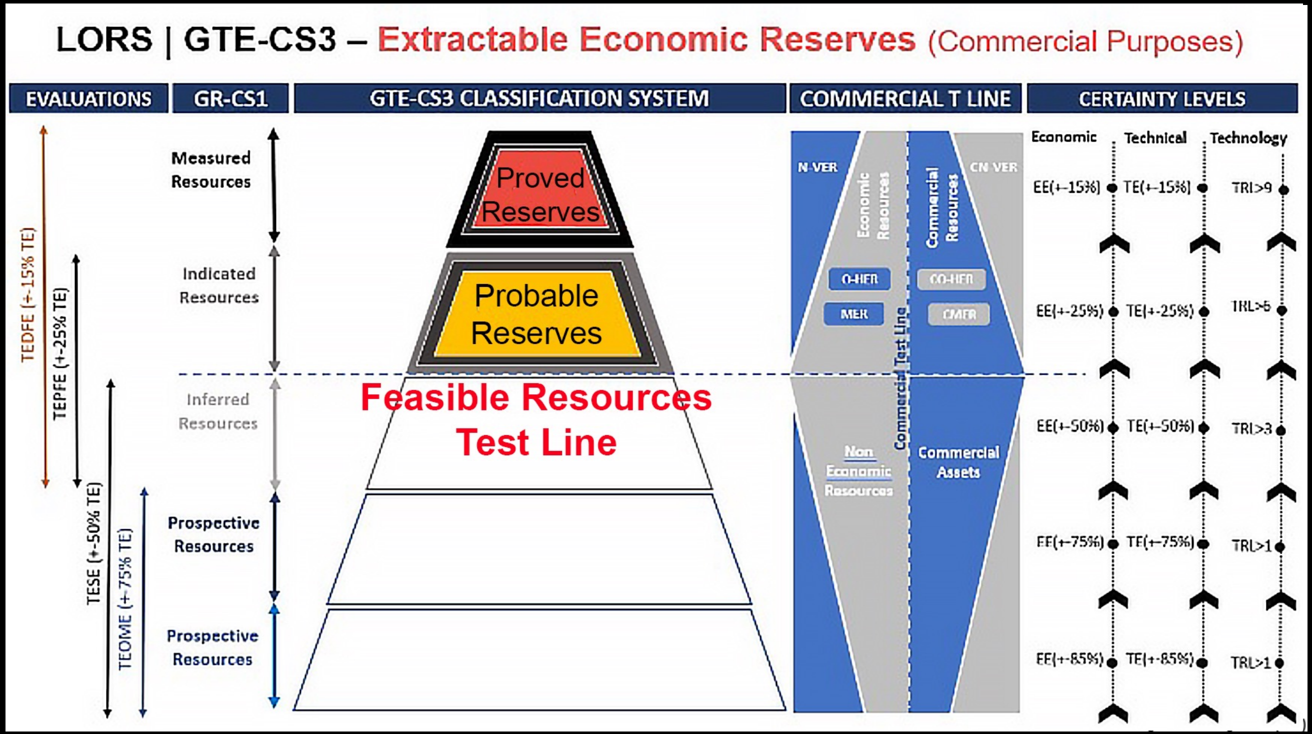
Six "Prospecting" Data Gaps Identified (p. 270-271):

DN-006 L through **DN-011 L**: Orbital & Surface water ice; Regolith Geotechnical & Electrostatic Properties; Regolith Composition; In-Situ Plasma Environment

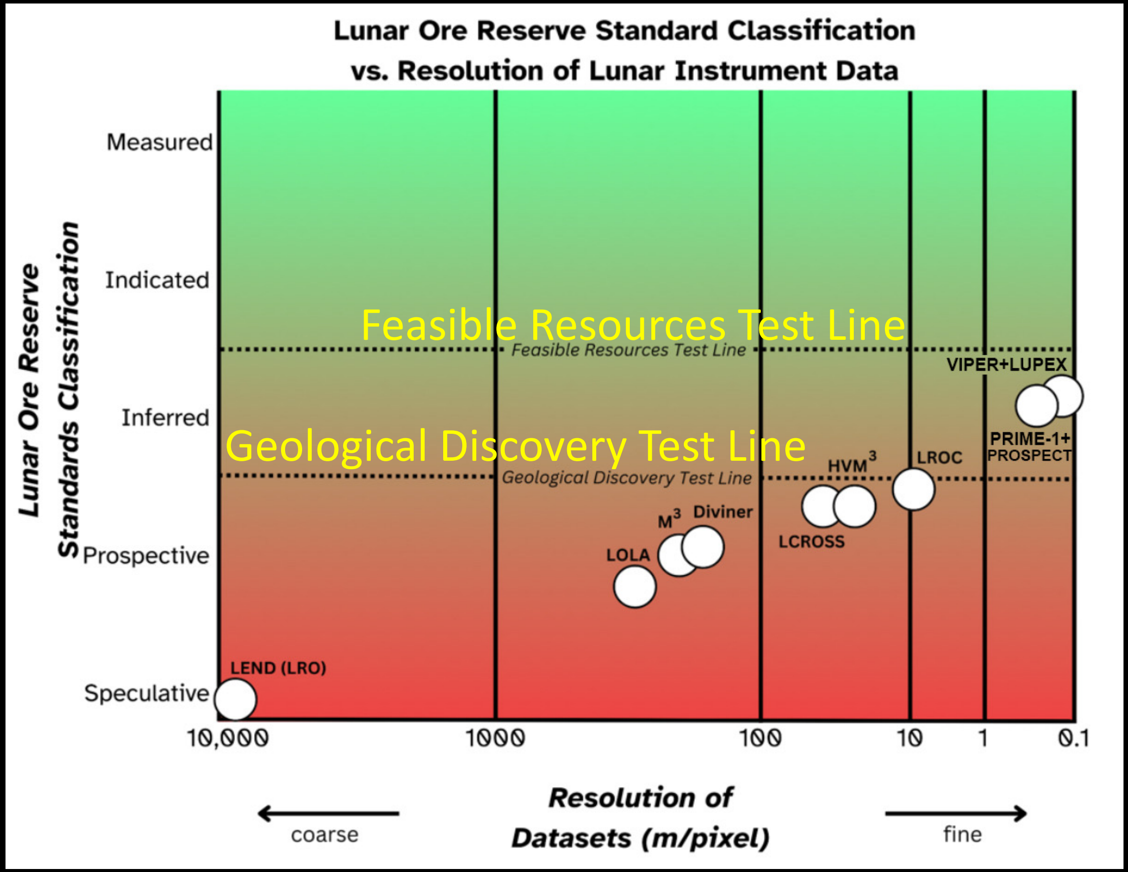


Proving the reserve potential of lunar resources is the fundamental goal of the ILRPC



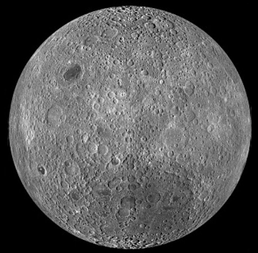


Espejel C.D., Casanova, S. Saydam, Lammy J.-A. (2023) Lunar Ore reserves standards 101 (LORS-101), in: V. Badescu, et al. (Eds.), Handbook of Space Resources, Springer, pp. 999–1022.

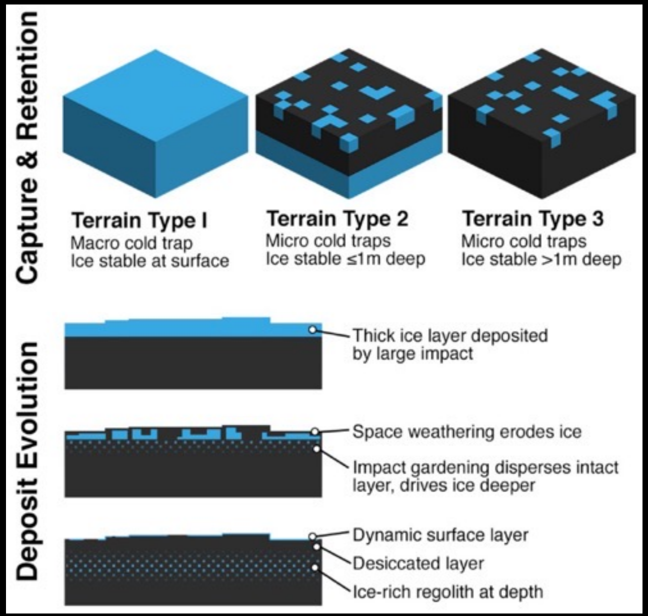


Patterson et al. (2024) Examining the Reserve Potential of Lunar Polar Volatiles. Space Resources Roundtable, Colorado School of Mines; 4-7 June 2024

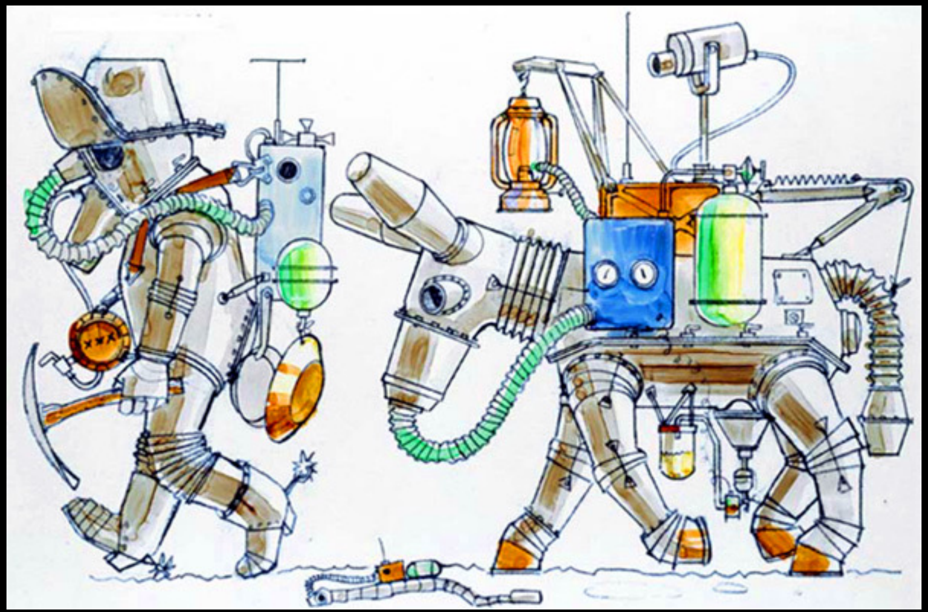
The outcomes from the 2025 ILRPC workshops have given the ILRPC clear direction, starting with water ice

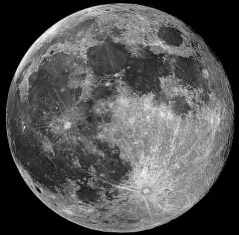


- **Data mining and analysis**: Identify relevant orbital datasets
- **Hot prospect definition & identification**: Direct mobile surface assets for ground truth
- **Prospecting campaign surface measurements**: Accessibility & extractability are key
- **Define standards** for dataset integration
- **Integrate ground truth data** to improve the predictive capability of the orbital models



Cannon & Britt (2020) *Icarus* **347**, Article 113778





Evaluating the reserve potential of any resource on the Moon requires more granular data sets

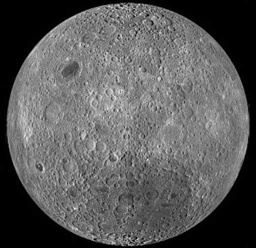


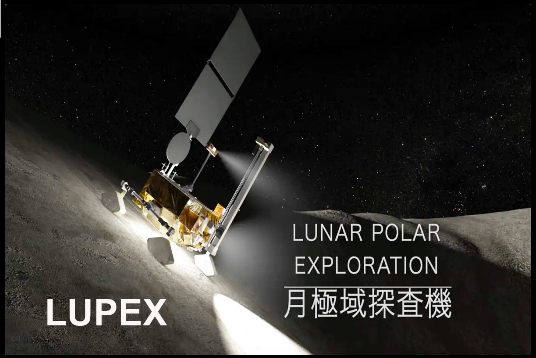
Table 1: Datasets for lunar volatile resource evaluation			
Dataset	**Specific Data**	**Use**	**Measurement**
Composition	Concentration of the resource; Concentration & composition of impurities	Evaluate potential investment needed for refining the product	100 μg/g
Form	Cement in pore space; Layers; 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

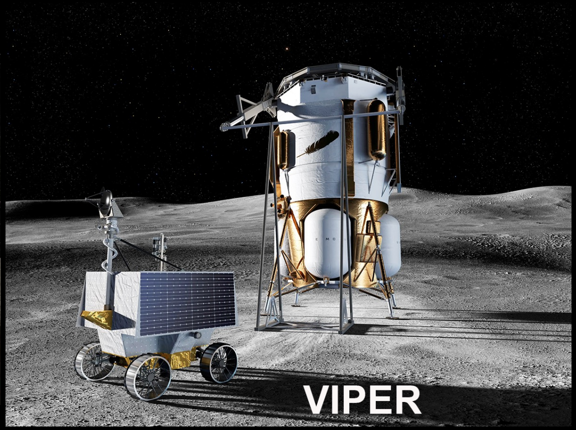
These new data types would need to be obtained via mobile surface assets via a lunar resource prospecting campaign

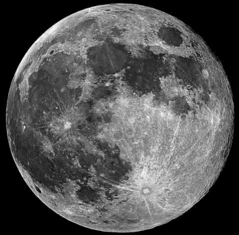
Illustrates why international cooperation is needed:

- 10 most promising sites for polar volatiles cover over 5,900 km^2
  Brown et al., 2022, *Icarus* ***377***, 114874.
  https://doi.org/10.1016/j.icarus.2021.114874

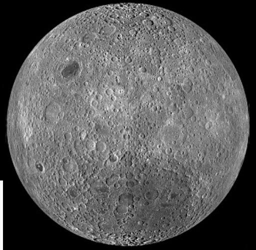
But *exactly* where do we send the mobile surface assets?



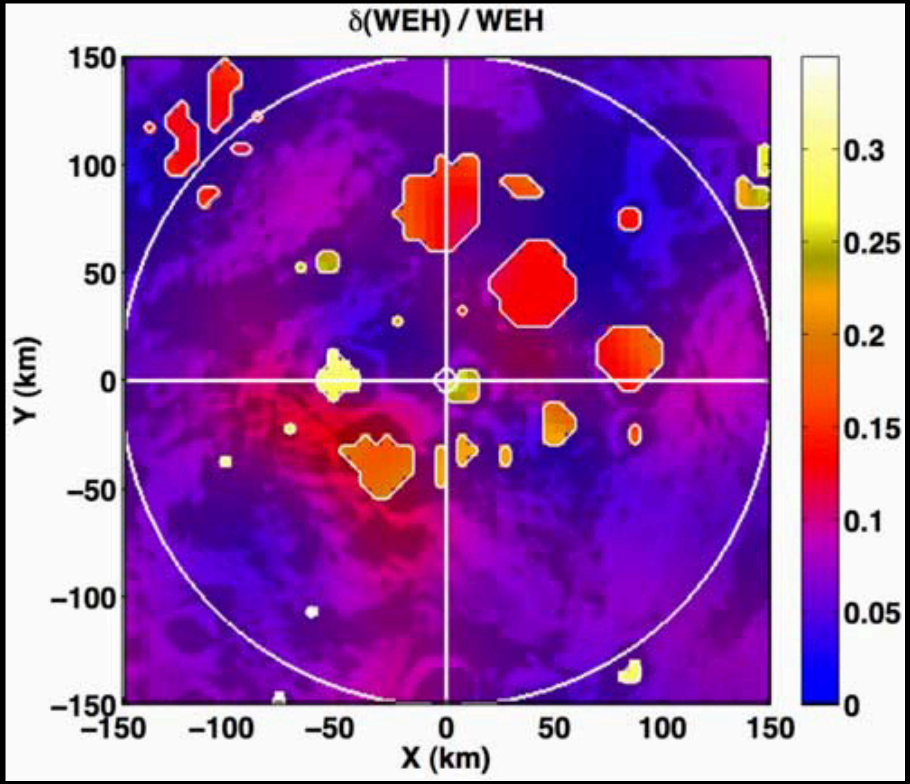




Integration of diverse orbital datasets is necessary to locate hot prospects of lunar water ice



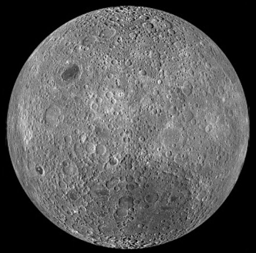
A lunar hot prospect is a location where an enrichment in a resource has been detected in independent datasets, AND is accessible by rovers, hoppers, landers, or other viable technology. Subordinate criteria include availability of sunlight and communications (bandwidth, direct to Earth, orbital comm, etc.), financial, and strategic parameters of interest.



Fractional uncertainty, δ(WEH)/WEH, based on 200 mock deconvolutions with different Poisson noise realizations.

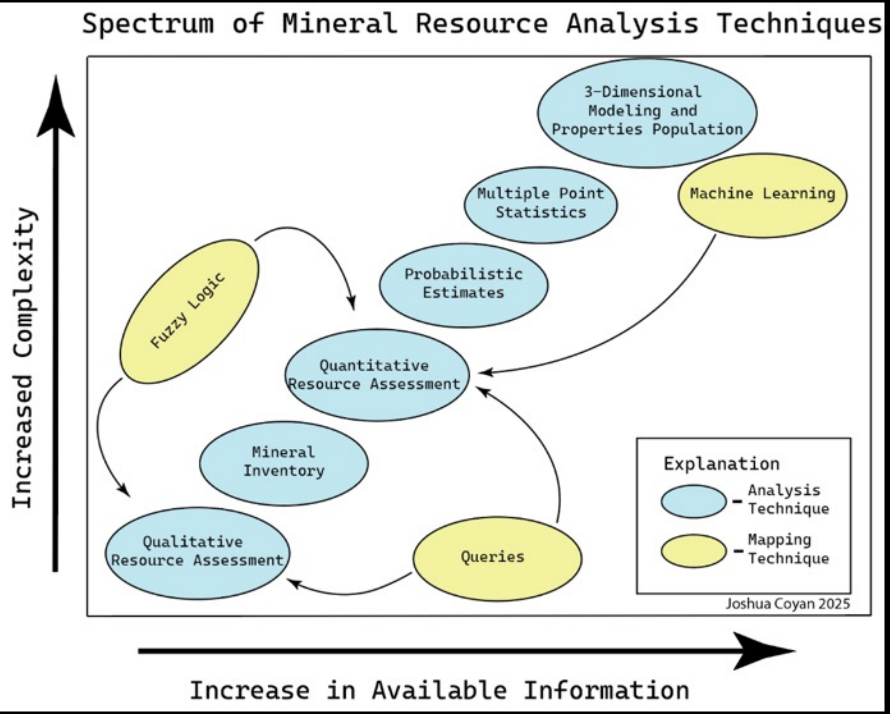
Elphic et al. (2007) Geophys. Res. Lett., 34, L13204, doi:10.1029/2007GL029954.

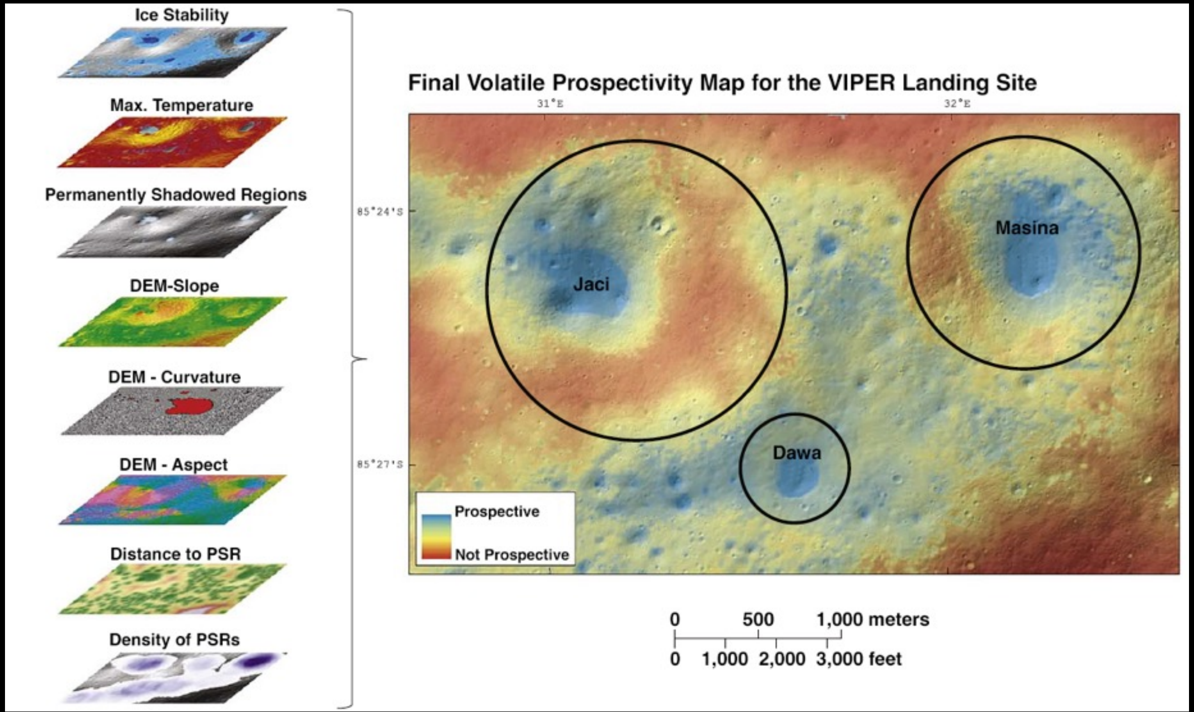
Prospectivity modeling & mapping by integration of orbital data sets will guide surface exploration



Methodology has been described – needs to be standardized

Important for reconciling different geodetic reference frames and weighting criteria for prospectivity mapping

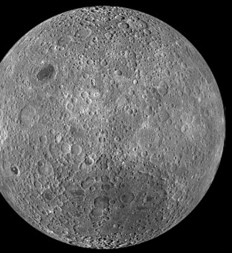




Coyan et al. (2025) Prospectivity Modeling of the NASA VIPER Landing Site at Mons Mouton near the Lunar South Pole. *The Planetary Science Journal* **6**, 205 (9 pp.). https://doi.org/10.3847/PSJ/adbc6c

Coyan (2026) A Framework for Lunar Resource Exploration and Volatile Prospectivity. Lunar Planet. Sci. Conf. 57, #1031

The available orbital data typify the international nature of the lunar resource prospecting campaign



Surface and subsurface indicators

Surface:
- Reflectance (UV-Vis-IR)
- Temperature

Subsurface:
- Neutrons (≤ 1 m)
- Radar (> 1 m)

Accessibility:
- Hi-Res Imagery (LROC, OHRC, ShadowCam)
- Topography

MISSION	INSTRUMENT	Pixel Size (m)
Lunar Prospector	Neutron Spectrometer – LPNS	15,000 – 45,000
Lunar Reconnaissance Orbiter (LRO)	Lyman Alpha Mapping Project – LAMP	240
	LRO Camera Narrow Angle Camera – LROC-NAC	PSR imaging = 10-40
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	Spectral Profiler	500
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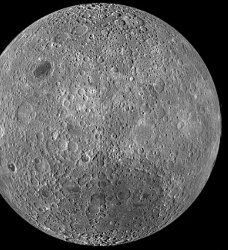
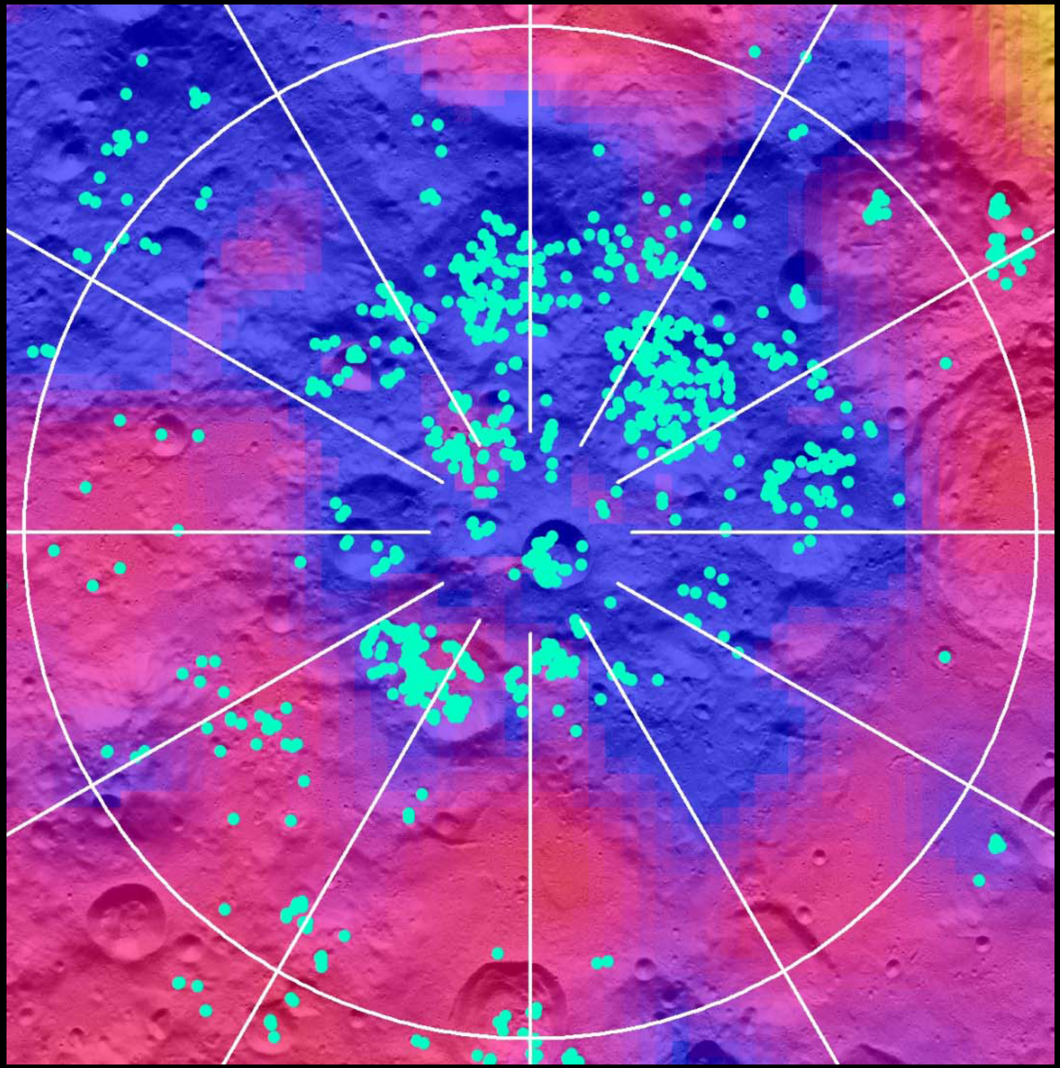
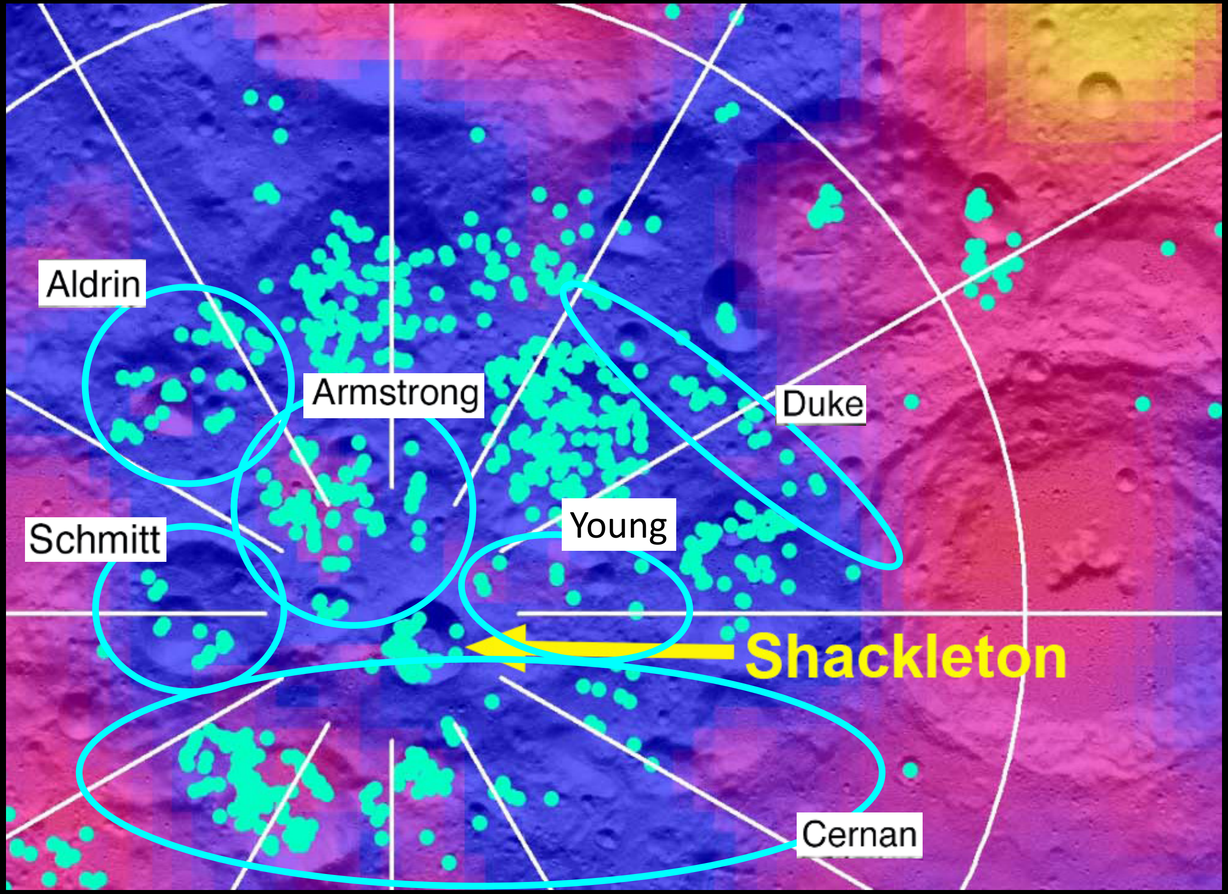
	Cratering data (~25 m diameter)	
GRAIL	Ka band Lunar Gravity Ranging System (LGRS)	3-6 km/pixel depending on model and data used

A low resolution water-ice prospectivity map of the lunar south pole is being produced



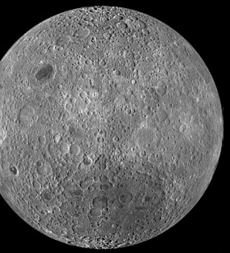


Surface water ice[1] overlain on Lunar Prospector neutron data (cooler colors represent buried H)[2], adapted from Li et al.[3].



1: Li et al. (2018) PNAS 115, 8907-8912; 2: Elphic et al. (2007) GRL 34, L13204; 3: Li et al. (2023) LPSC-55, abstract #2537

The initial product will identify hot prospects for ground truthing surface missions to fill data gaps



ID	TITLE
DN-006 L	Orbital observations of water ice deposits in the south polar region
DN-007 L	In situ measurements of the horizontal and vertical distribution, abundance, and physical makeup of shallow bulk water ice
DN-008 L	Geotechnical properties of highland regolith at the lunar south pole
DN-009 L	Electrostatic properties of highland regolith at the lunar south pole
DN-010 L	South polar lunar regolith elemental and mineral composition
DN-011 L	In situ lunar surface plasma environment characterization

Surface data (Table 1) allow the resource potential of polar water ice to be evaluated

Filling the ADD data gaps allow the resources to be processed

NASA Artemis Architecture Definition Document 2025

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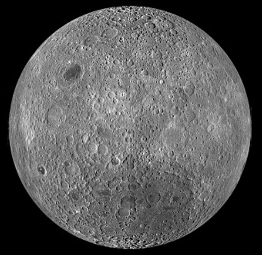
Near-surface Regolith Stratigraphy	Buried and surface rock populations Ice block/layer distribution	Will impact the extractability of the regolith resource	10 cm
Accessibility	Safe traverse paths	Ease of accessibility has an impact on cost of developing robotic miners.	TBD

Enabling regulations for space resource activities requires knowledge and data



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

”*Sites of Extraordinary Scientific Importance*” proposed – potential “Keep Out” areas?

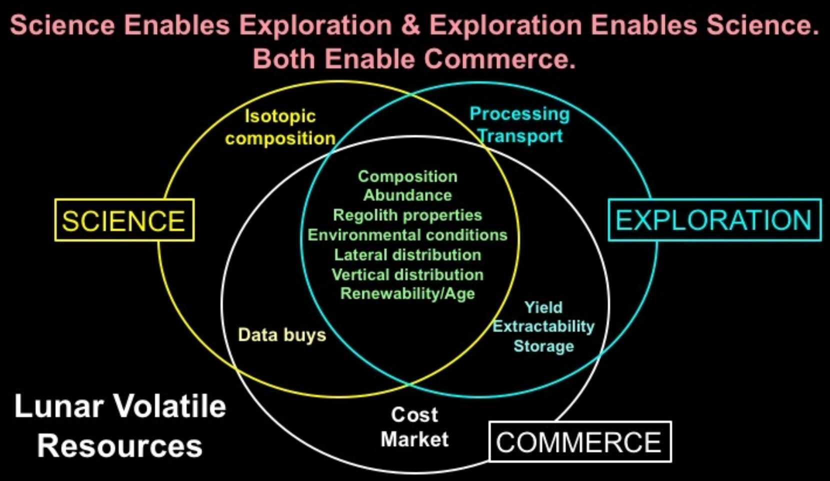
Elvis et al. (2020) *Phil. Trans. R. Soc. A* **379**, 20190563; Krolikowski A. & Elvis M. (2024) *Phil. Trans. R. Soc. A* **382**: 20230078

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

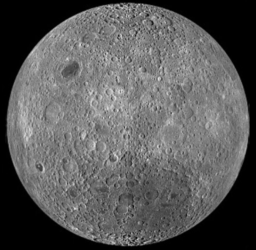
https://www.unoosa.org/oosa/en/ourwork/copuos/lsc/space-resources/index.html

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

Sowers (2018) *Room – The Space Journal,* issue 3, 8-13



The ILRPC is happening and the NASA Ignition and Moon Base announcements highlight its' importance



Take Home Messages

- Site selection for the Moon Base requires knowledge of resource reserve potential
- Indications are the Moon Base will be distributed – regional resource knowledge is needed
- ILRPC needs to expand to inform the Moon Base site(s) selection, and to inform the regulatory framework
- 2026 is going to be a banner year!