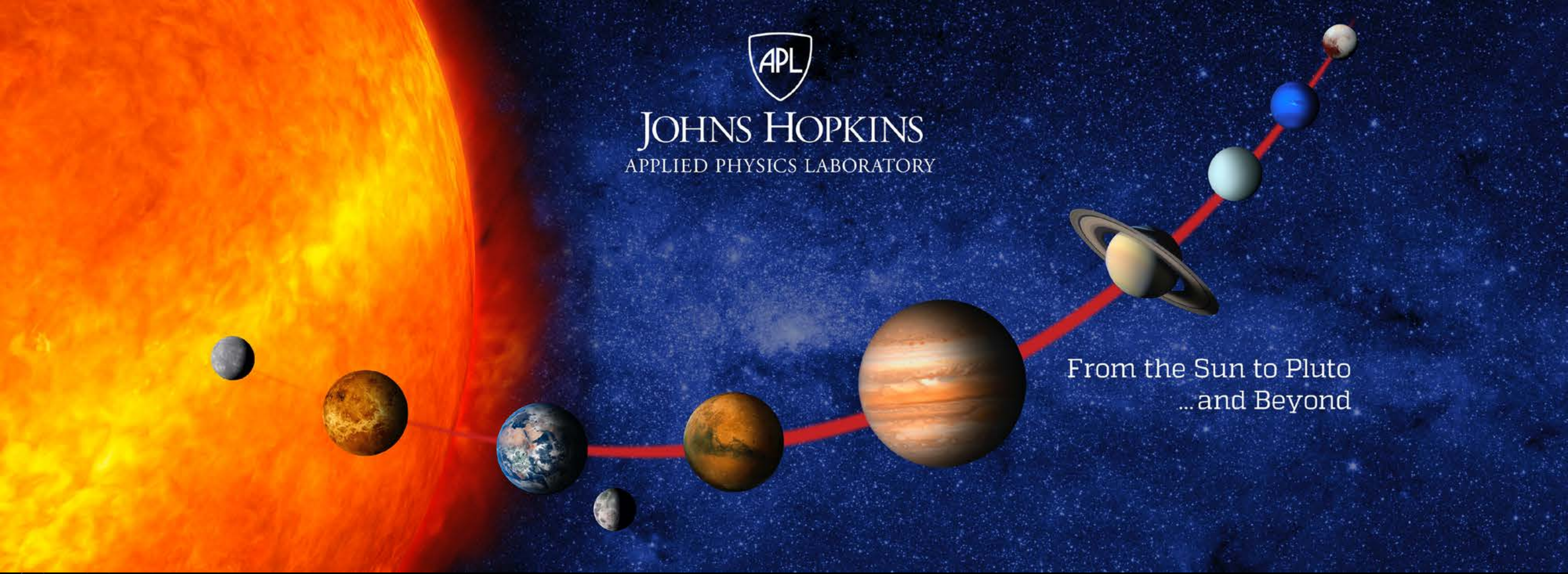

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Mission to Characterize Volatiles in the Old, Cold, Permanently Shadowed Regions on the Moon

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Lunar Permanently Shadowed Regions (PSR)

NASA SVS

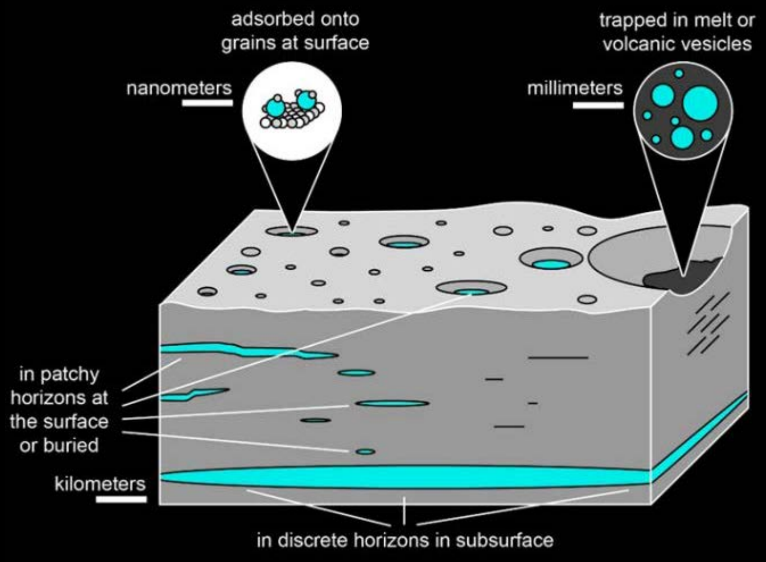
- Low obliquity
- At high latitudes, topography creates permanently shadowed regions
- $>10^4$ km^2 area of PSR
- These exist on size scales ranging from sub-mm to 10 km

Understanding the lunar water system from source to sink

SOURCES

Comets
Meteoroids
Outgassing/internal
Solar wind

Needham and Kring (2018)



SINKS

Sublimation/thermal desorption
Photodissociation
Impact
Sputtering
Chemistry

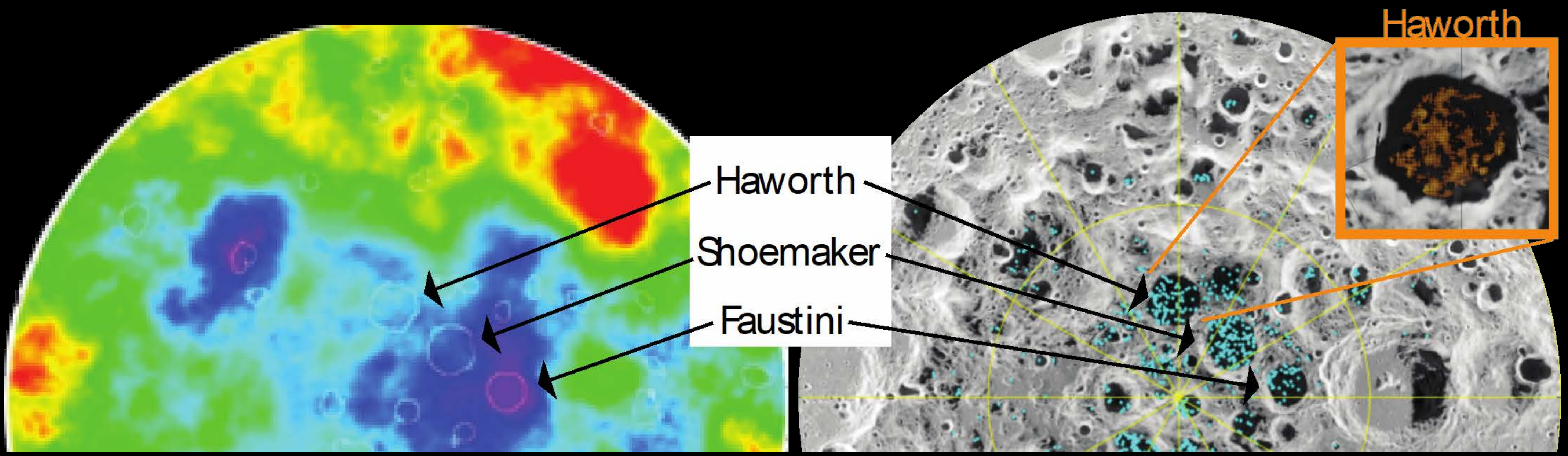
Migration/hopping
Migration/thermal vertical
Impact gardening

REDISTRIBUTION

The Moon's PSRs are the most accessible reservoir of volatile history in the solar system.

No two lunar PSRs are the same

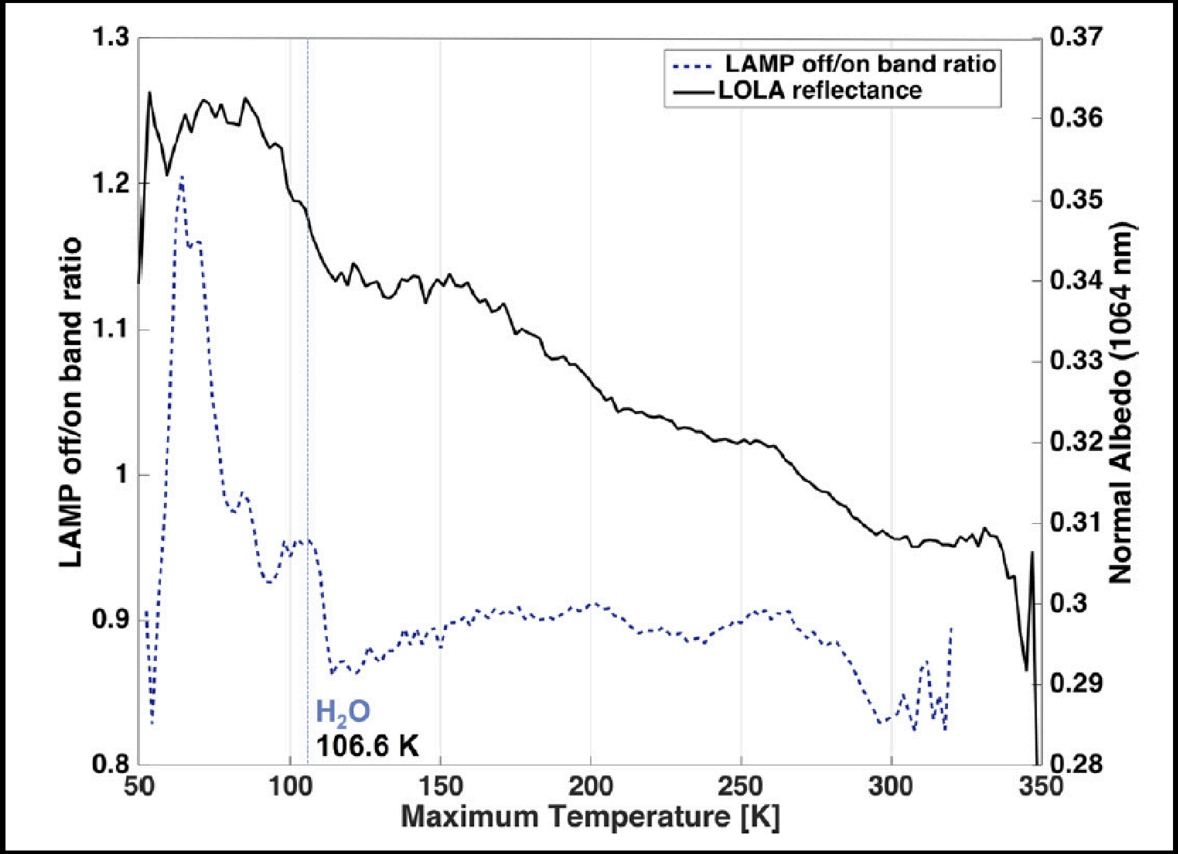
Hydrogen values from depth-integrated measurements differ from surface frost measurements, especially in Shoemaker, Haworth, and Cabeus.



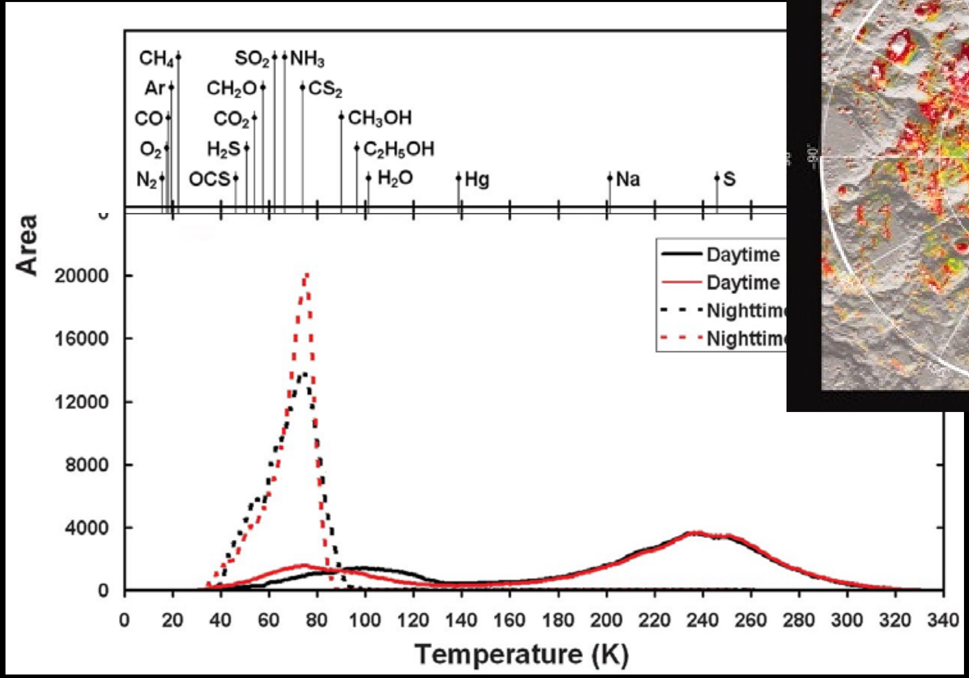
- Neutron spectroscopy senses through the top 1 m of regolith. (McClanahan et al., 2018)
- IR spectroscopy senses the top 1 mm of the surface. (Li et al., 2018)

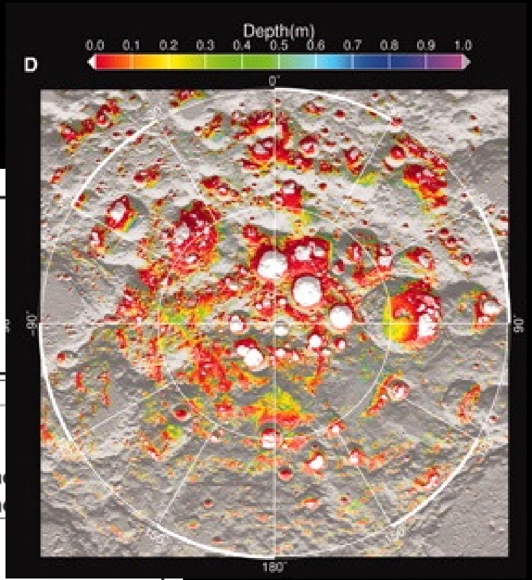
What processes are important in determining the contents of PSRs?

Greatest assortment will be found in coldest PSRs



Fisher et al. (2017) Icarus

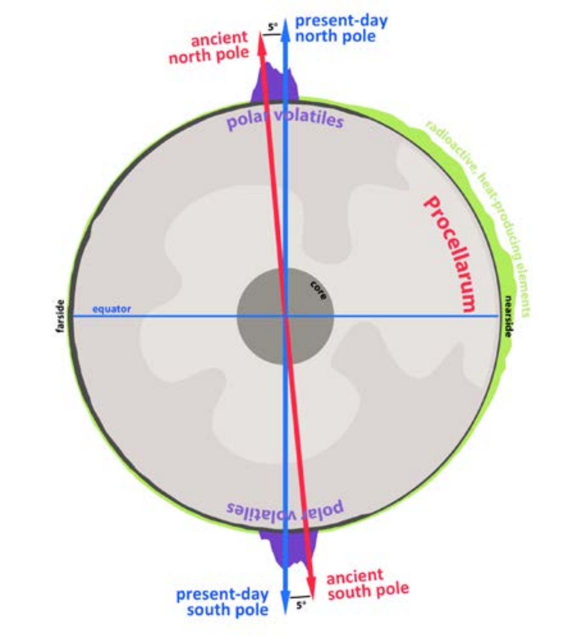




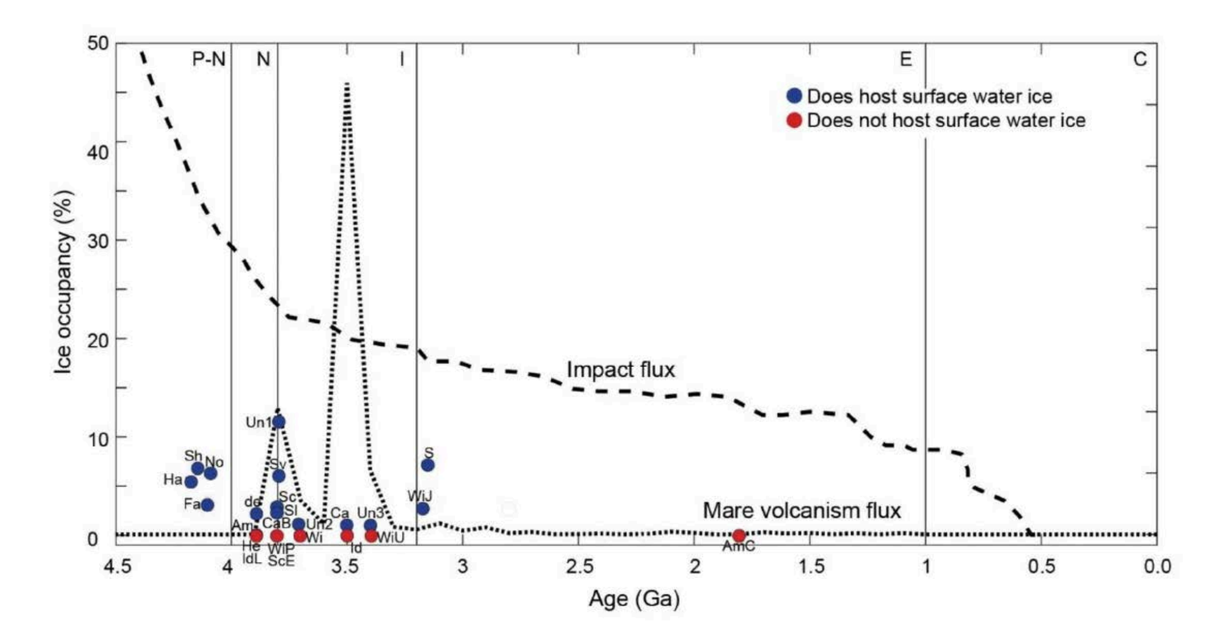
Paige et al. (2010) Science

What are the sources of volatiles and relative importance?

Oldest cold traps record lengthy stretch of history



Siegler et al. (2016) Nature

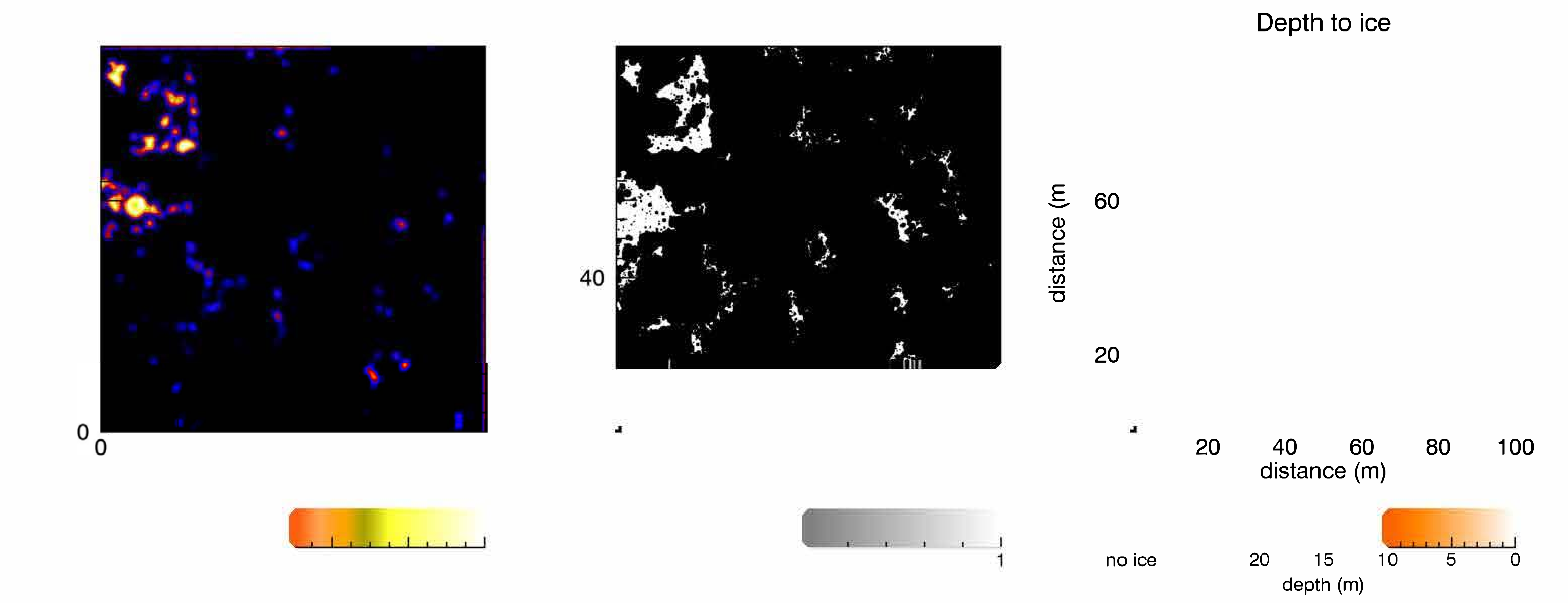


Deutsch et al (2020) Icarus

- Volatiles in a cold trap must be younger than the host cold trap
- Enhancements off of the present day poles line up with potential locations of paleopoles.

What do volatiles tell us about the formation of the Moon and early volatiles in the the inner solar system?

Mobility is required



How do we mine and utilize the volatiles in future missions?

VIPER is the first step of a journey

- A prospecting campaign is required to fully answer fundamental questions about volatiles.
- Ground truthing of orbital remote sensing data will reinvigorate analysis of orbital data.

Following up on big questions uncovered by VIPER is a high priority in the next decade.

Polar Ice Prospecting Explorer for Lunar No-light Environments (PIPELiNE) mission concept

- Go to a cold, old PSR
- Make measurements of volatile composition, abundance, and physical form
- Map the distribution on meter scale
- Relate all measurements to environmental parameters

Science goals

Determine composition, abundance, distribution, and physical form of lunar polar volatiles. DAS

Characterize processes modulating retention and loss of volatiles. DA

Measure the ongoing activity and volatile transport at PSRs. DAS

Determine source(s) and time history of inner Solar System volatiles. DA

Provide ground-truth to remote sensing measurements. AS

Determine the geotechnical properties of cold polar regolith. AS

Characterize the space environment in PSRs. S

Compare contents and processes to Mercury, asteroids. D

KEY

Linkage to community guiding documents

(D)ecadal Goal-V&V;

(A)SM-SAT Goal;

(S)trategic Knowledge Gap

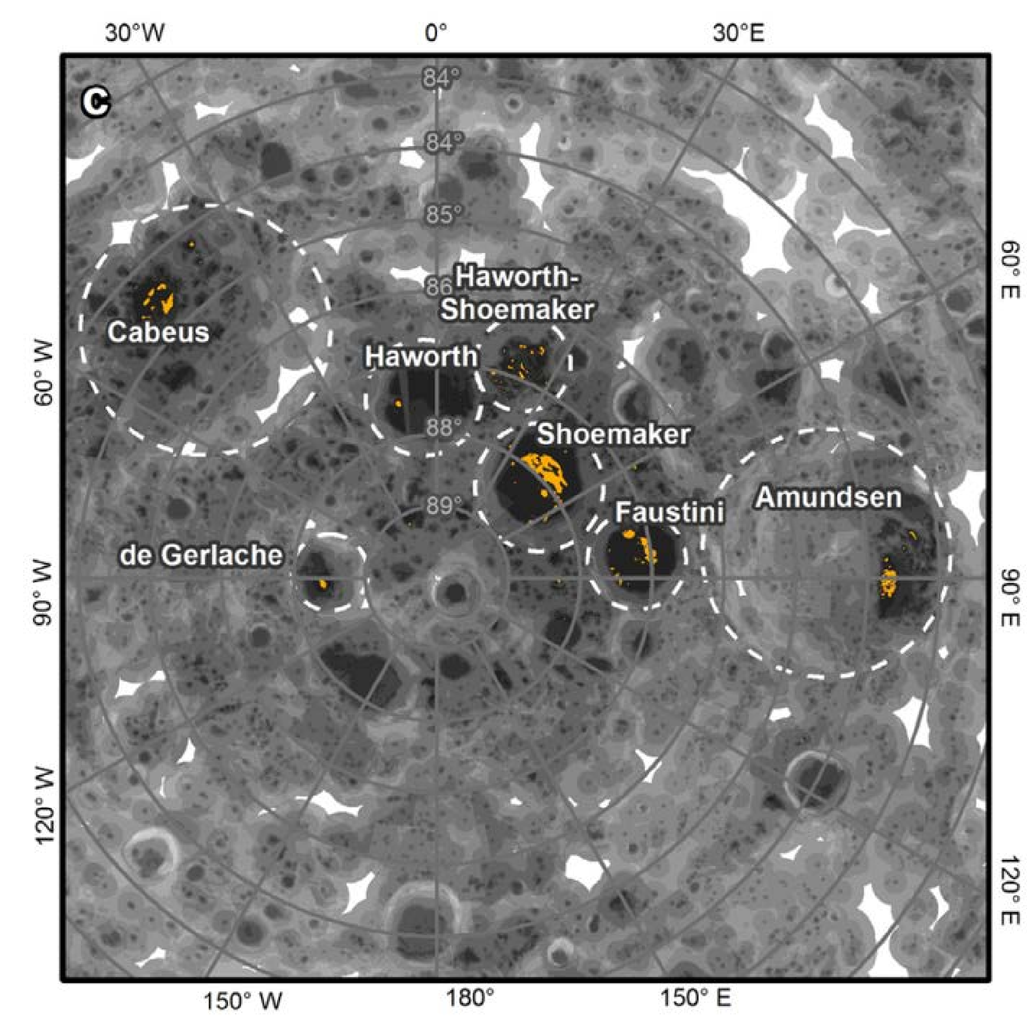
Notional PIPELiNE implementation

Mission Design
Launch/Falcon 9
Direct injection at the Moon/Star-48
Landing using ALHAT directly in PSR

Landing site
Cold PSR (highly volatile compounds)
Positive detection of volatiles by remote sensing
Earth visibility
Traverse-friendly slopes

Rover
Direct to Earth communications
MMRTG plus battery power
Flash illumination for navigation

Concept of Operations
Survey while roving to find location with high subsurface H.
Perform site analysis with drill to sample at 10 cm depth increments:
observe pilings with IR and ingest sample for composition analysis.
Include periods for recharging between traverse and sampling activities.



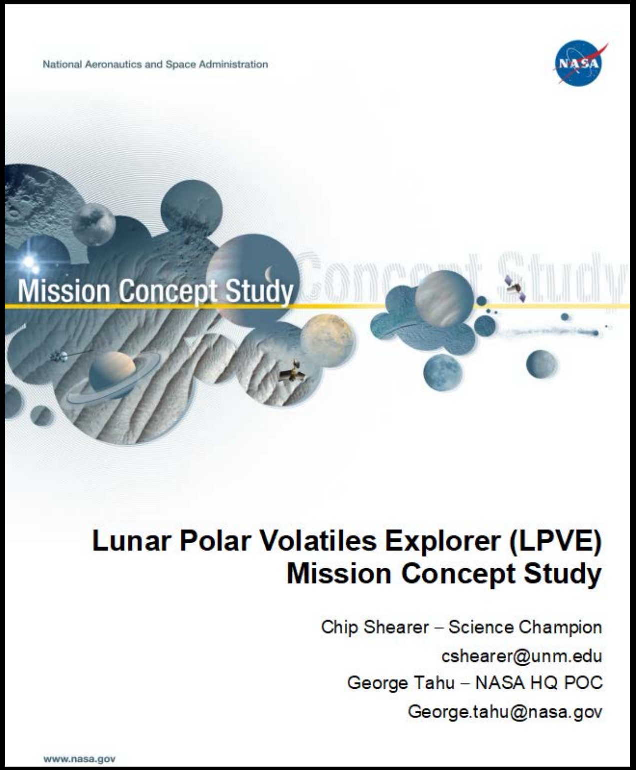
Lemelin et al (2014)

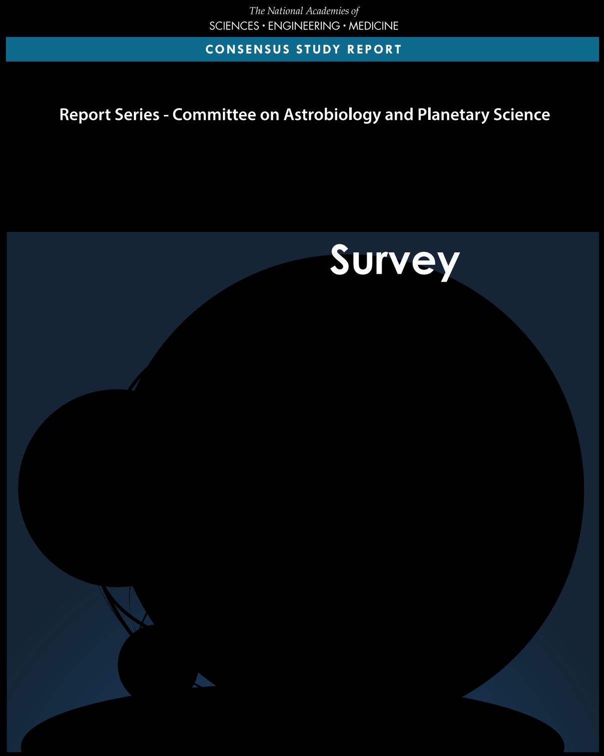
PIPELiNE potential payload

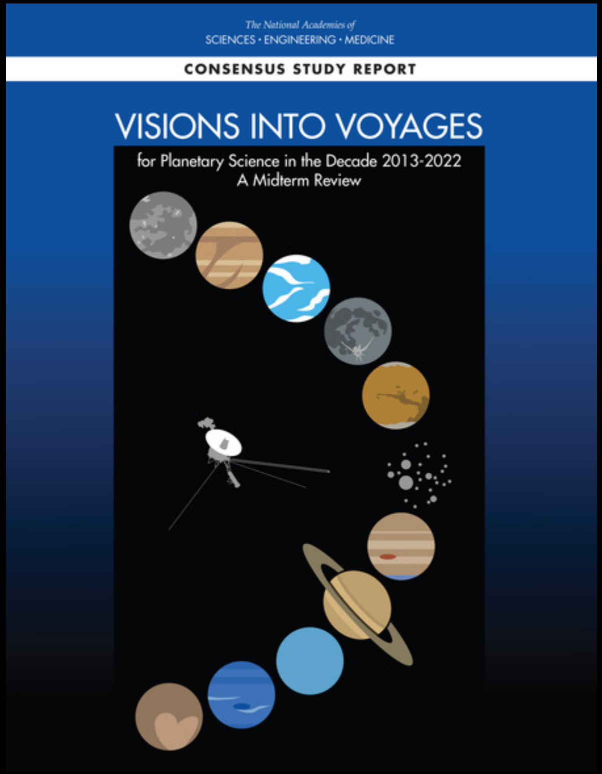
Instrument	Mass (kg)	Peak Power	TRL	Function
NavCams	1	7.5 W	9	Navigation and context
Neutron Spec	1.9	1.5 W	6	Volumetric H content
GasChrom.MassSpec	15	60 W	6	Composition incl. isotopes
IR Spectrometer	4	30 W	6	Composition, abundance, temperature
Drill	18.0	100 W	6	Subsurface access – 1 meter
Spatial Heterodyne Spec	1	6 W	4	Exosphere composition & isotopes
Raman	7.2	15.5 W	4-6	Chemical & isotopic compositions
Ground Penetrating Radar	6	10 W	6	Subsurface context, ice blocks
Ion Spectrometer	5	9 W	9	Charged particle flux

A concept study can define a New Frontiers mission

- A Lunar Polar Volatiles Mission remains a high science priority.
- The concept presents technical challenges that are not insurmountable.
- A reexamination is warranted.







David T. Blewett, Joshua Cahill, Nancy Chabot, Benjamin Greenhagen, Charles Hibbitts, Rachel Klima, David Lawrence, Kathleen Mandt, Jorge Núñez, Wes Patterson, Parvathy Prem, & Angela Stickle, *APL*

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Timothy Livengood *Univ. Maryland*

Measurements Objectives

- Abundance
  - Exploration rationale: assess value and extraction technique
  - Science rationale: tied to abundance of sources
- Composition
  - Exploration: additional resources
  - Science: chemical fingerprint of source
- Distribution
  - Exploration: scale of operations and extraction technique
  - Science: age of deposits; redistribution and retention processes
- Physical State
  - Exploration: extraction technique; operational paradigm
  - Science: interactions between volatiles and regolith
- Environmental Context
  - Geotechnical properties
  - Thermal environment
  - Stratigraphy
  - Geologic context