Lunar Poles

Status of Understanding a Potential Resource

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“The Most Valuable Real Estate in the Solar System”

Overarching Polar Issues

- High visibility
  - Public and professionals are aware of various claims about the value of the poles
- Polar relevance as a resource cannot be resolved using remote sensing
  - Most claims cannot be refuted or confirmed with remote sensing
- *In situ* measurements require an approach unlike current crop of Mars landers and rovers.
  - Engineering challenges of operating Mars-type rovers and landers are extreme and irrelevant to Mars exploration
  - Capabilities of MPF/MPL/MER are largely overkill or irrelevant to the problem--this is not geology
- *In situ* measurements require supporting remote sensing measurements to select analysis sites

Status

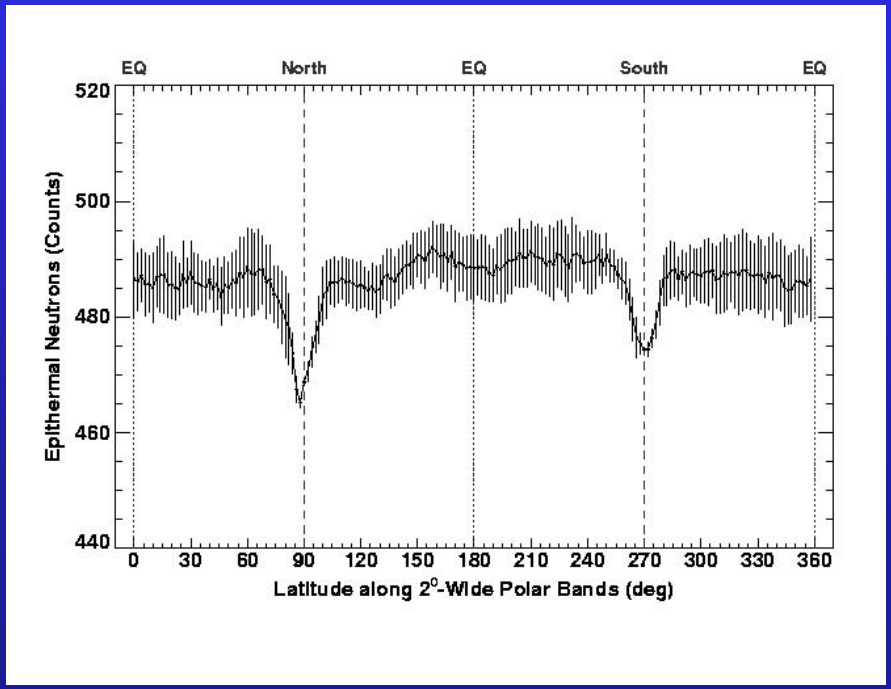
Neutron results

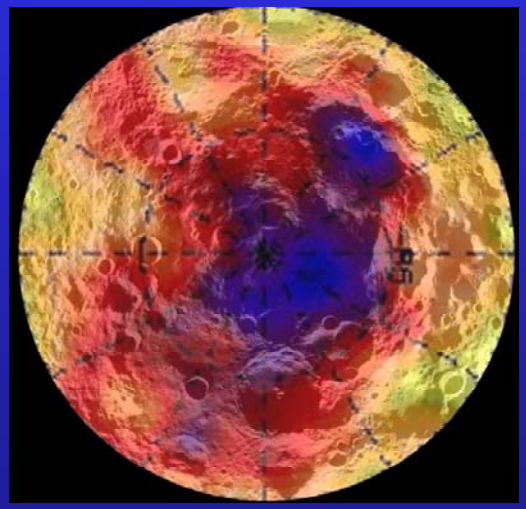
Radar results

Neutron Results

THE LUNAR POLES EXHIBIT A DEFICIT OF EPITHERMAL NEUTRONS

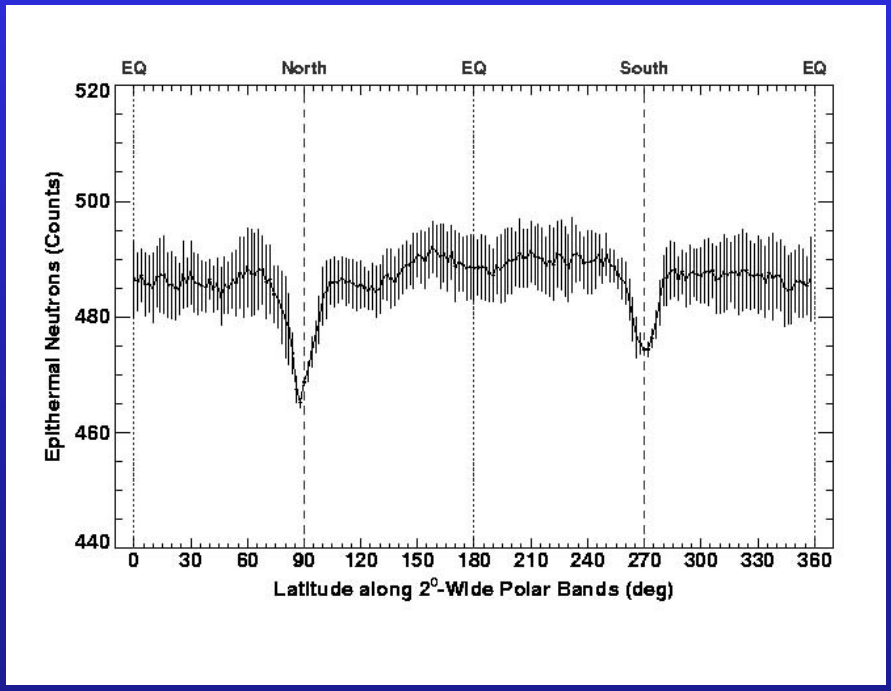
The only geologically reasonable explanation is an anomalous concentration of hydrogen

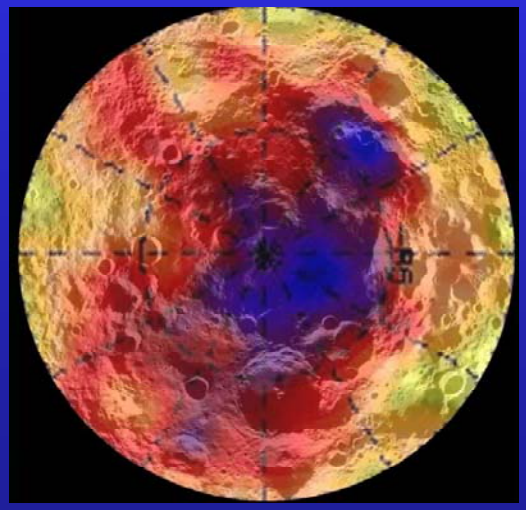




Neutron Results

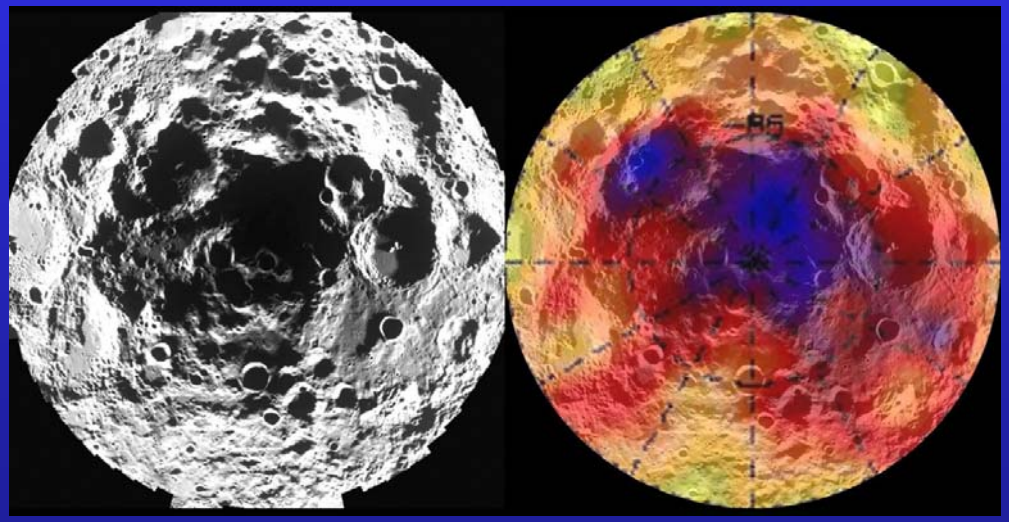
The abundance of H is about 200 ppm at the resolution of LP (~50 km), about 2x that in high Ti mare soils





Neutron Results

If the H is confined to permanent shadow and **if** it is in the form of water ice, then the average abundance in the shadow is 1-2 wt% within the most anomalous LP pixels

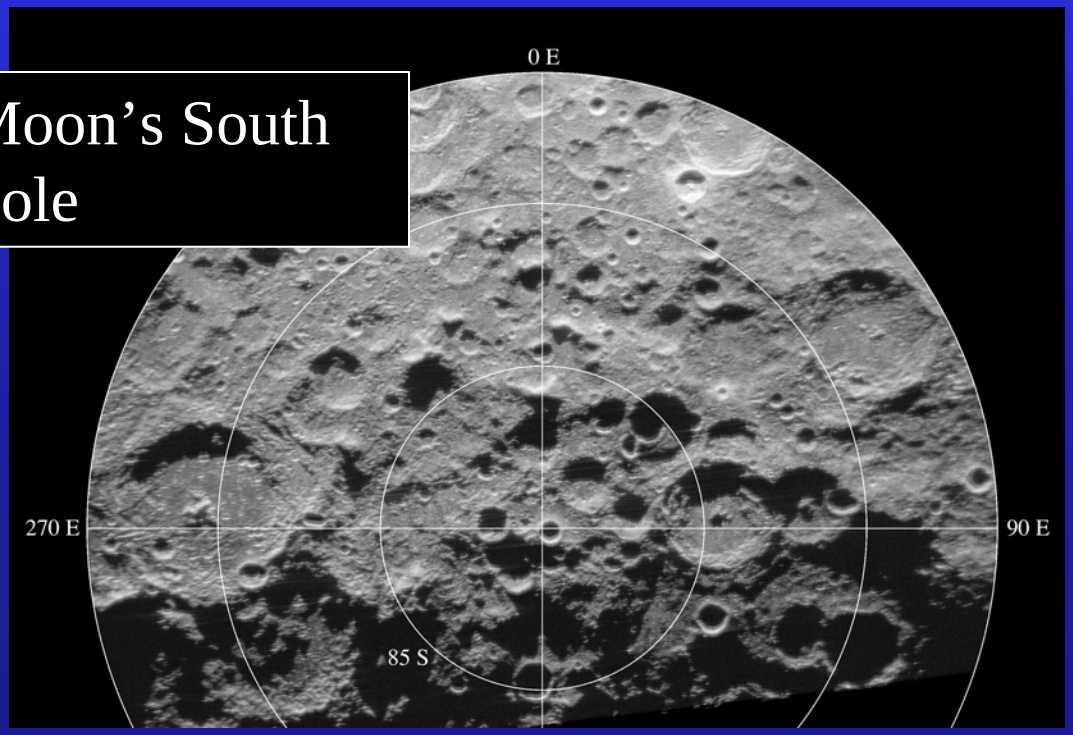


Radar Results

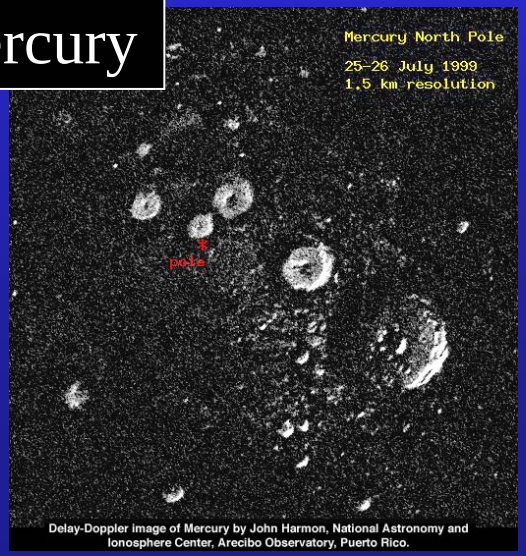
Earth-based radar has imaged several areas believed to be in permanent shade. **No anomalous radar properties are observed in the polar region or shaded regions.**

But, radar is only sensitive to very pure ice, or pure ice with overlain with a thin layer of ice-free soil.

Moon's South Pole



Mercury

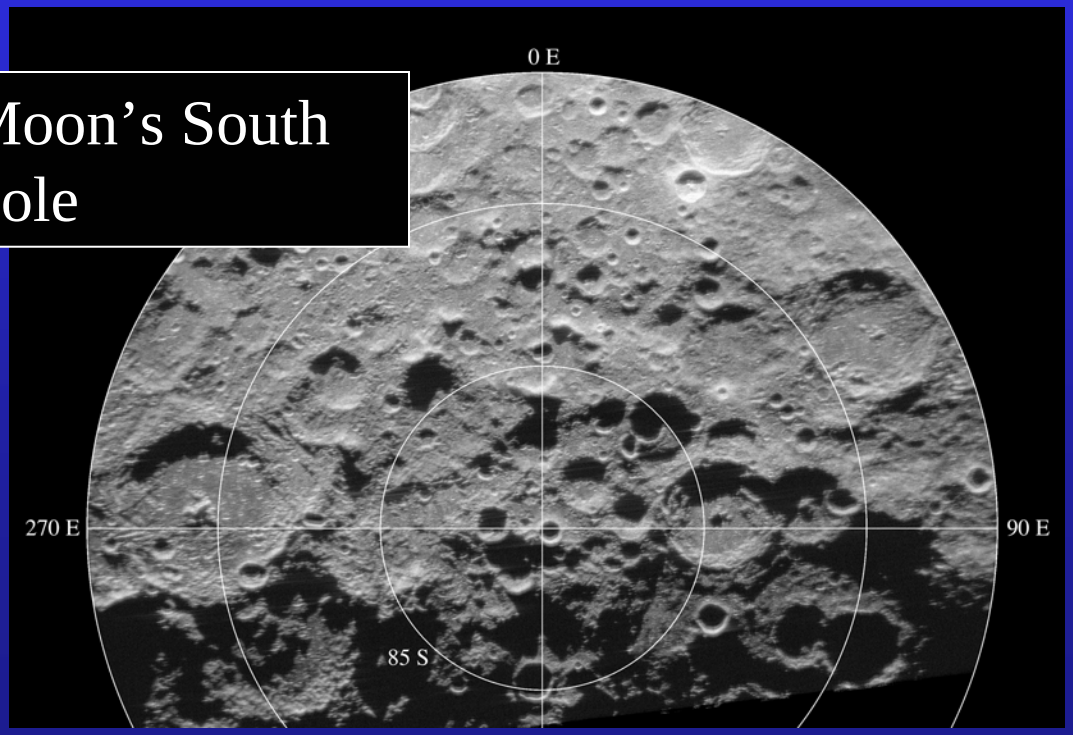


Radar Results

No unusual morphologies are apparent within regions of permanent shade

Current or ancient ice deposits did not leave an obvious geologic overprint

Moon's South Pole



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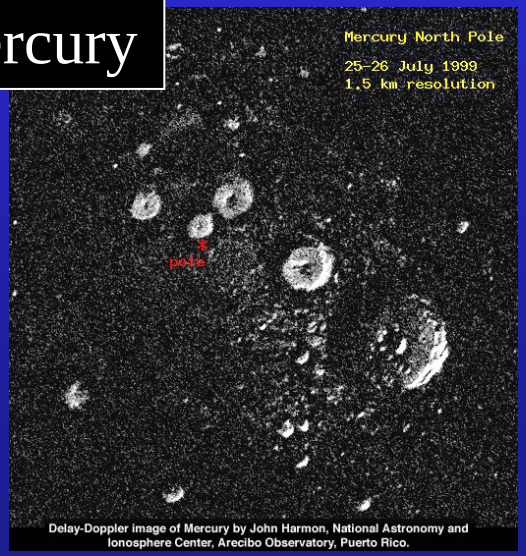
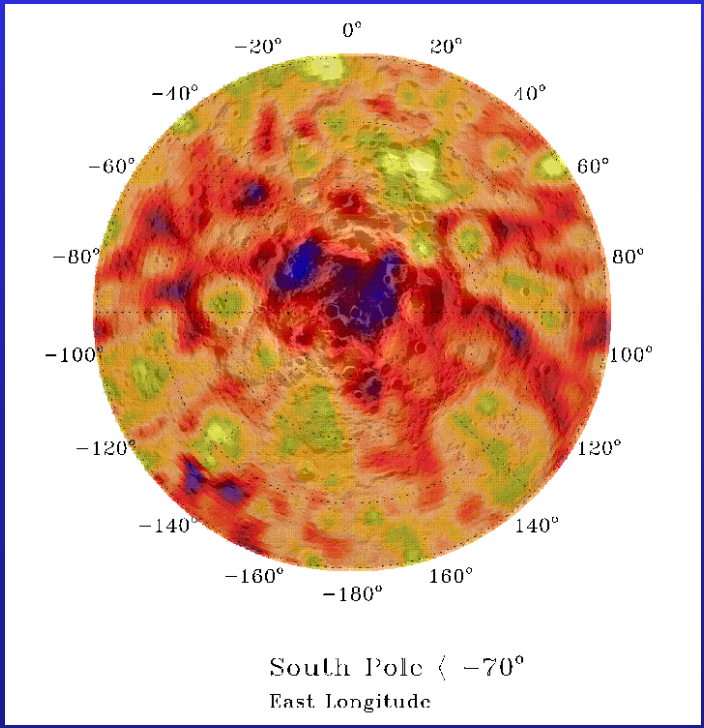
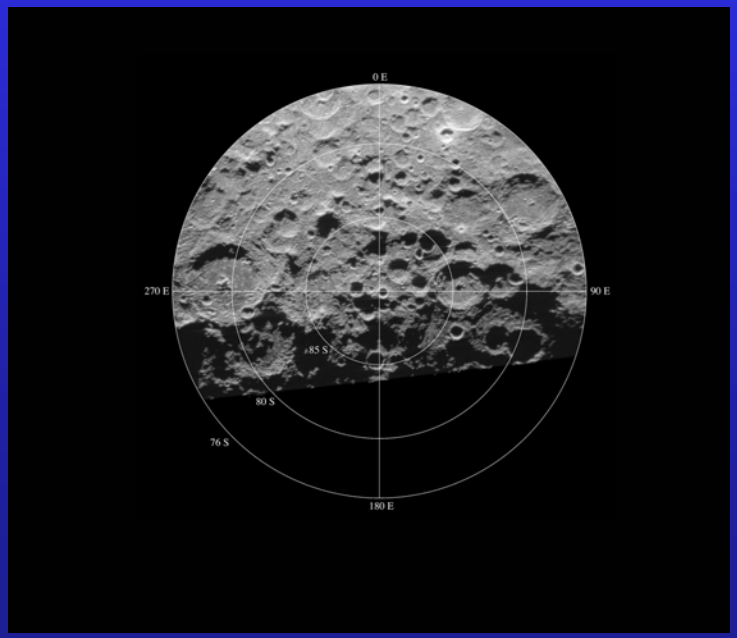


Radar observations and Lunar Prospector neutron measurements are entirely consistent

H in some form must be present at hundreds of ppm in some locations

But, if ice is present it is impure everywhere in the imaged regions to the ~500-m resolution of the data





“A pox on both your houses”

What about Clementine?

- Clementine bistatic radar data was used to detect a weak signal consistent with coherent backscatter in a low-loss medium associated with the south polar crater Shackleton (Nozette, Lichtenberg)
- Others in the radar community disputed the methodology and results based on an attempted reproduction of the original analysis (principally Simpson)
- The Clementine team disputes the navigation used by Simpson
- Earth based data for portions of Shackleton in common show high values, but not clearly anomalous
- Roughness is a plausible explanation for the Clementine bistatic radar results

What about Clementine?

- Despite the spirited exchange, the Clementine detection has not been definitively refuted. However, ubiquitous Mercury-like deposits do not exist in the imaged regions
- The controversial interpretation of the controversial bistatic detection as ice has not been ruled out by new earthbased data. Mercury-like deposits cannot be ruled out in the unimaged regions because the imaged regions may not be representative of the unimaged areas. The areas accessible to Arecibo may be blow-torched by the Earth's magnetotail; Clementine may have glimpsed a deposit shielded from this influence.
- Conclusion: Regardless of the controversy surrounding the detection, its inherent weakness and the existence of plausible alternatives to the ice hypothesis render the contribution of Clementine experiment largely ineffective with respect to the understanding of the lunar poles.

“The garbage dump of the solar system”

Outstanding Questions Remain

- What is the physical and chemical state of the hydrogen?
- Are other volatile elements or compounds present?
- What is the concentration of volatiles at spatial scales relevant to resource recovery?
- Does temperature reliably predict the distribution of volatiles?

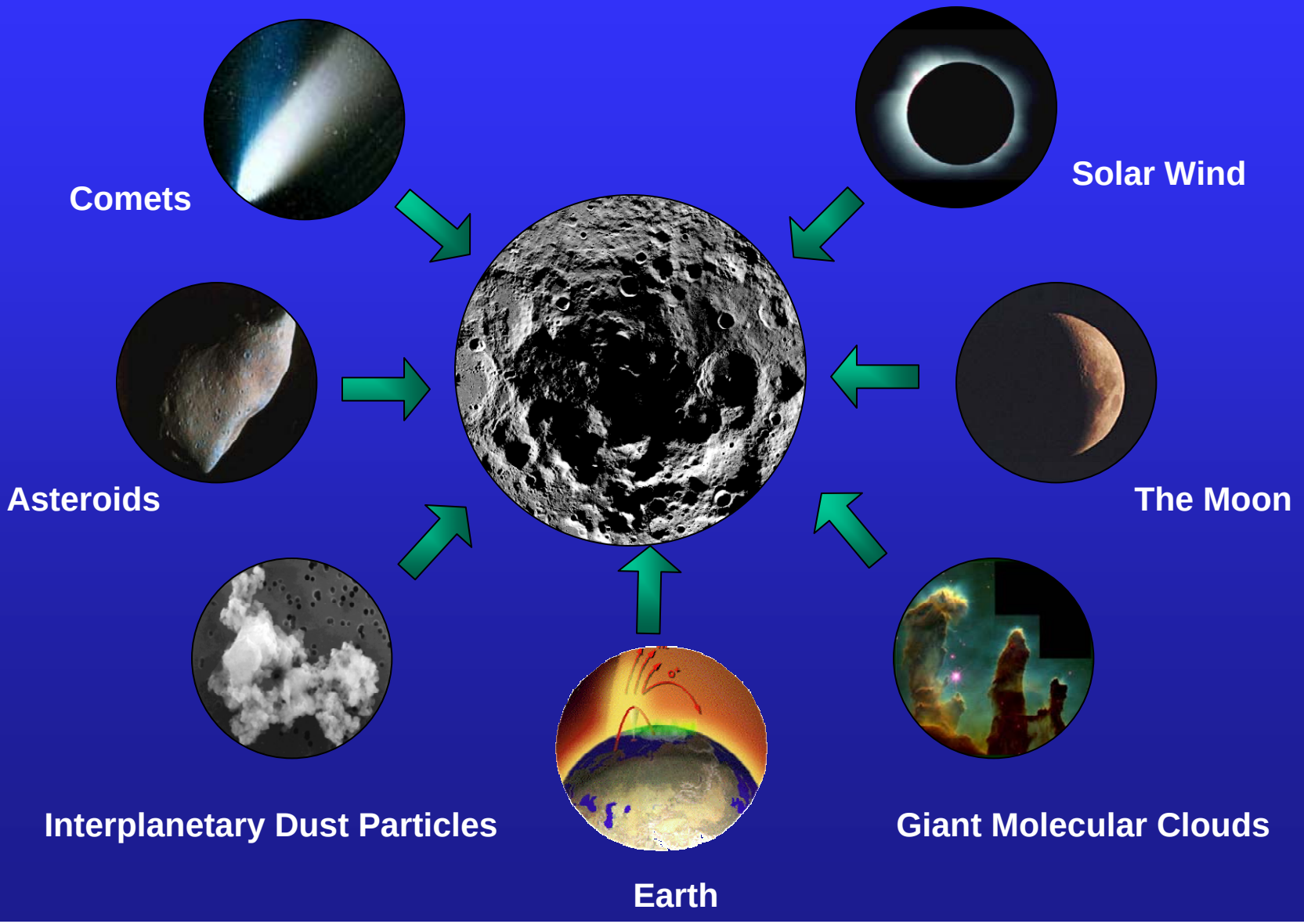
Outstanding Questions Remain

- What is the physical and chemical state of the hydrogen?
- Hydrogen has been proposed to be in the form of:
  - Adsorbed or diffusively trapped H2
  - H2O or methane clathrate
  - Methane ice
- Chemical state is critical to resource utility

Outstanding Questions Remain

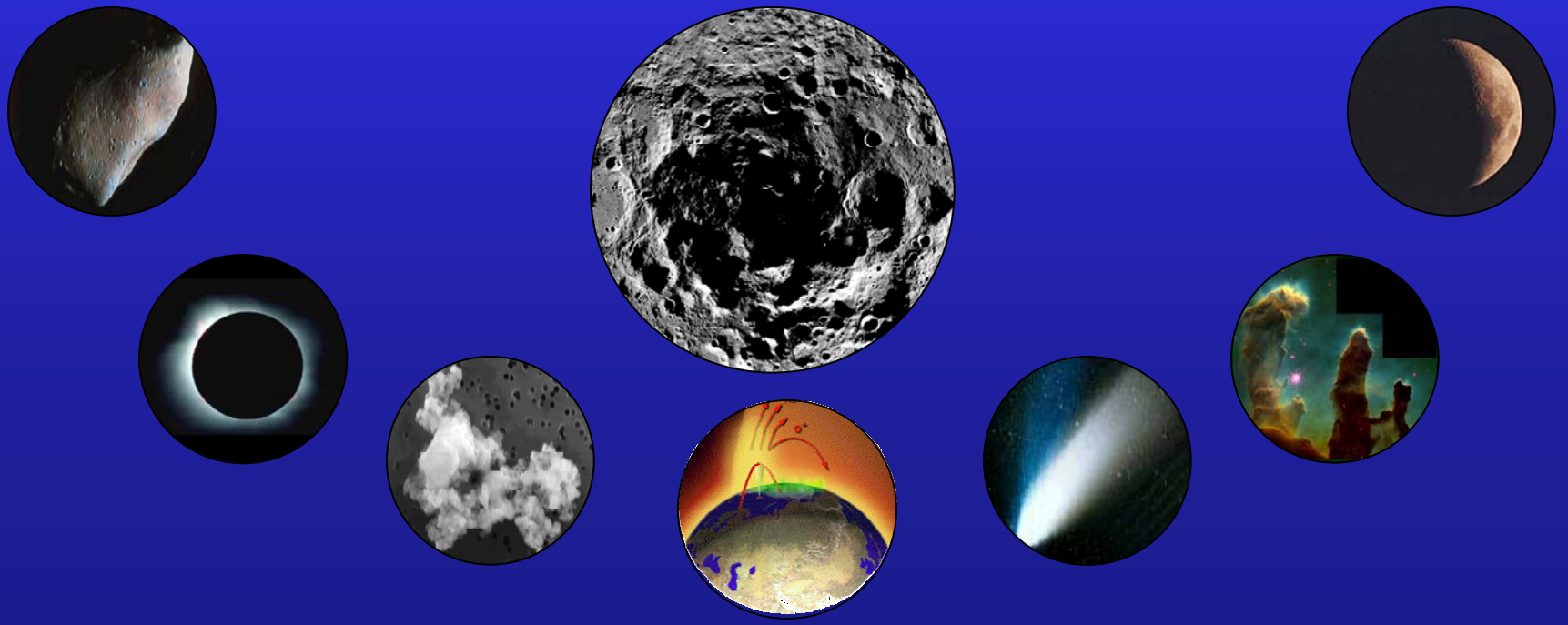
- Are other volatile elements or compounds present?
  - Hydrogen must be an indicator of a more complex volatile deposit

Possible Sources of Lunar Polar Volatiles

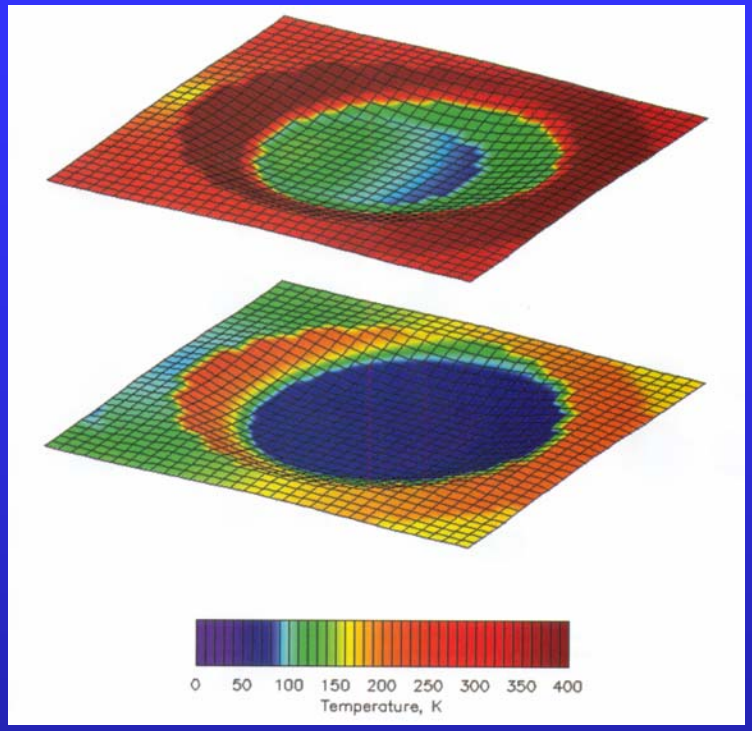


Lunar Polar Volatile Inventory

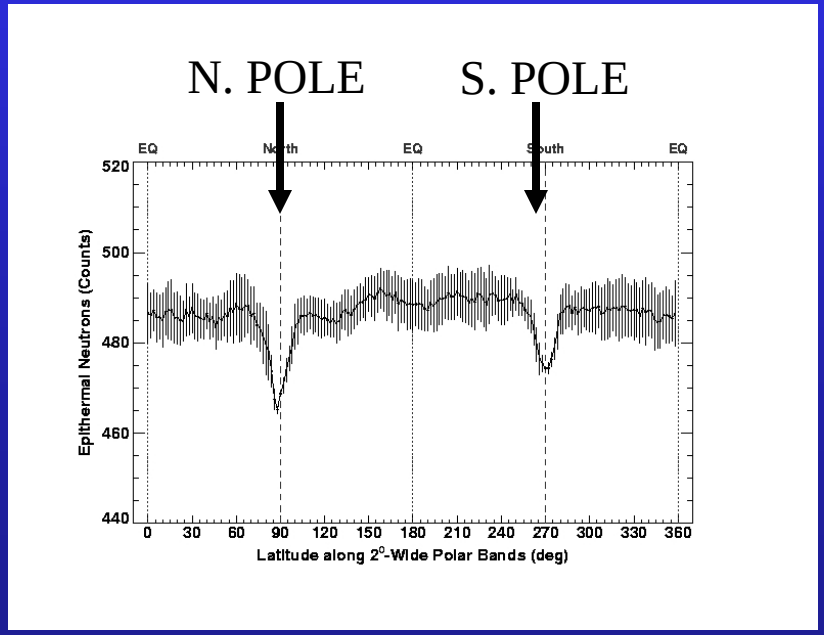
- Each potential source provides a suite of volatile elements and compounds
- No source provides only hydrogen



“Its not the heat, it’s the humidity”

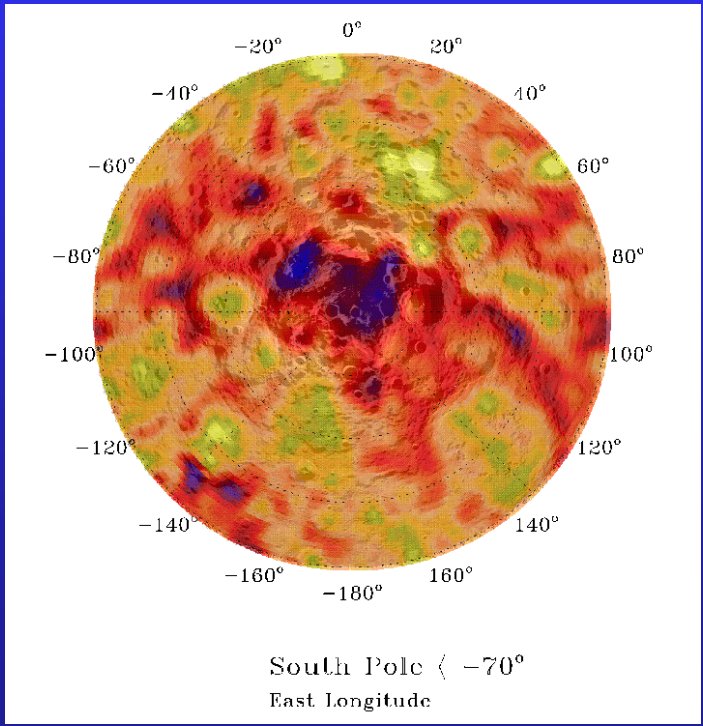


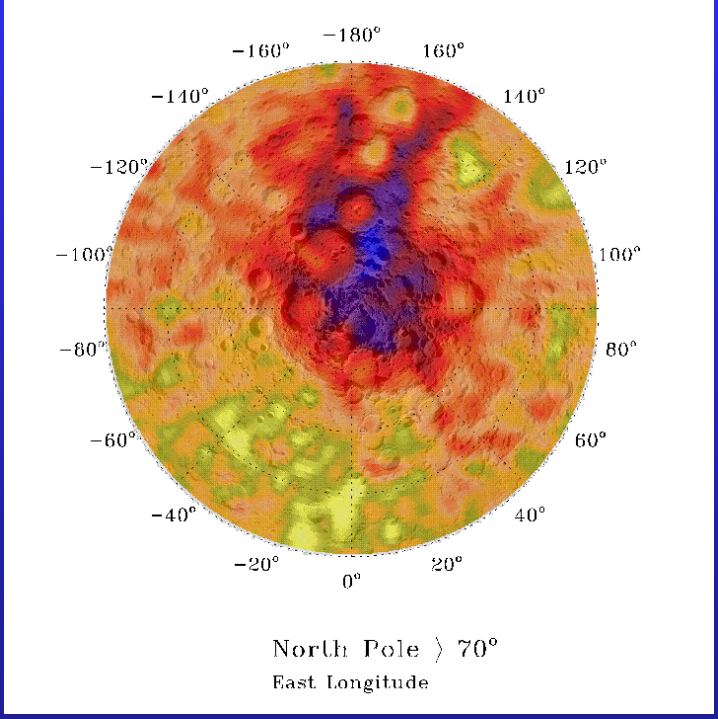
Cold trapping is assumed to control volatile distribution



South Polar deposits seem closely correlated with areas of permanent shade

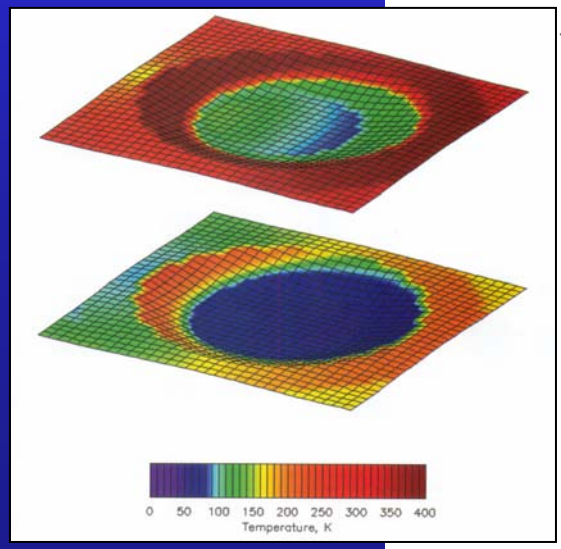
North Polar hydrogen distribution is more enigmatic

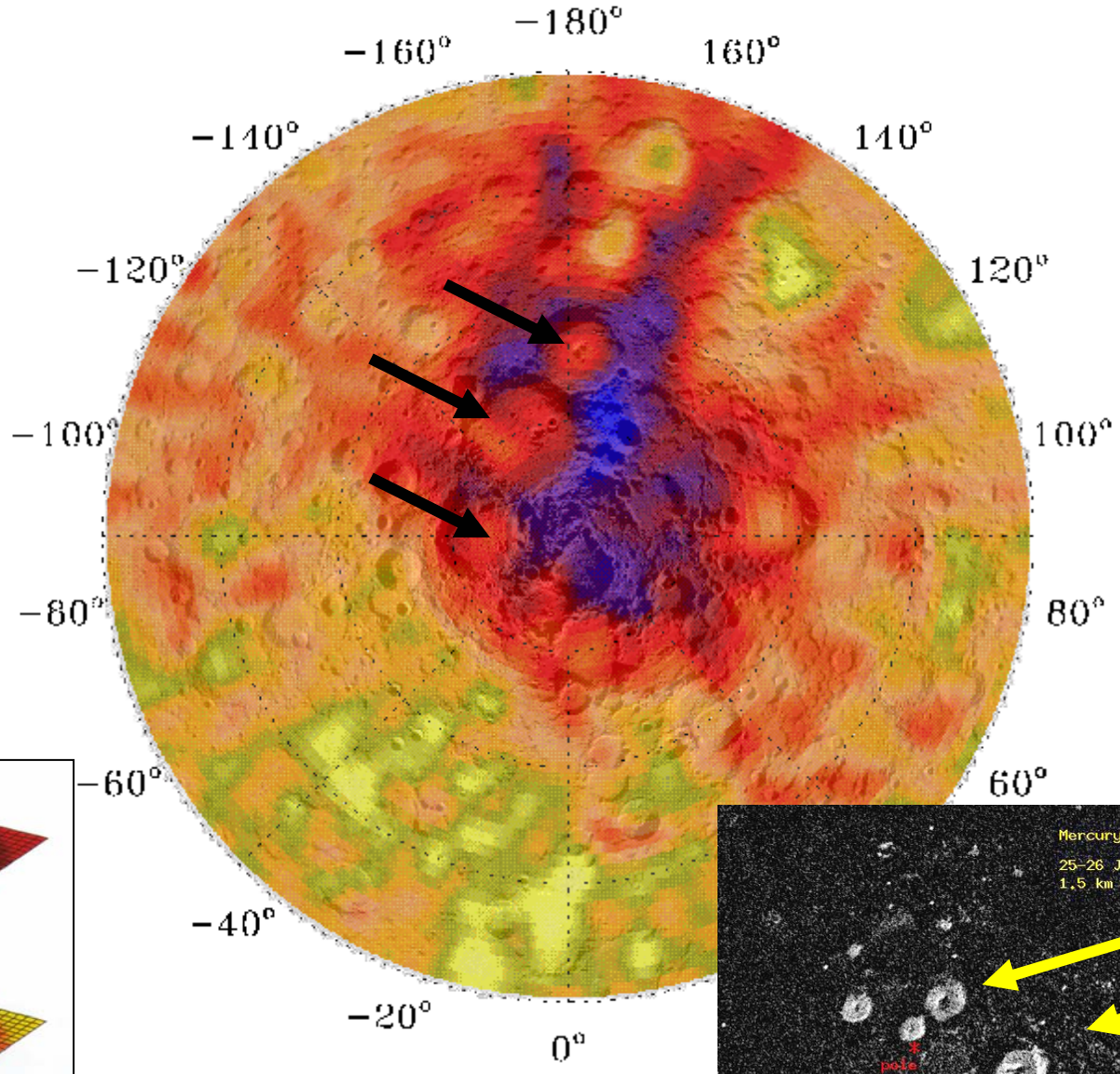


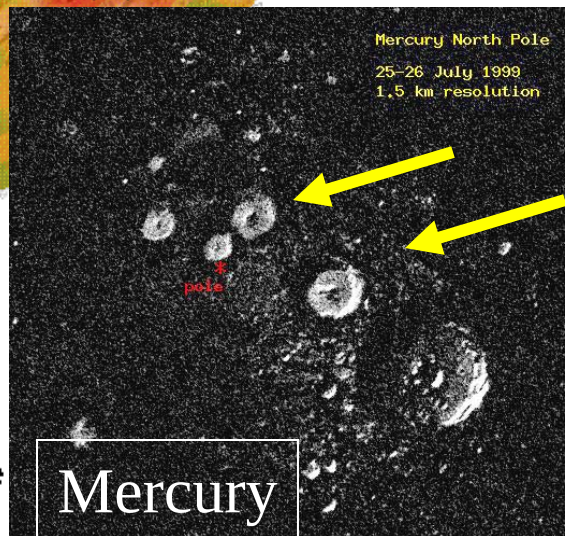


North Pole:

Large flat-floored craters show low hydrogen abundances relative to adjacent terrain.

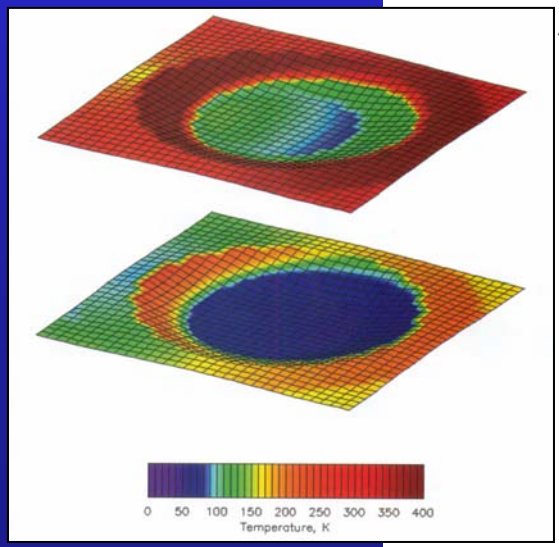


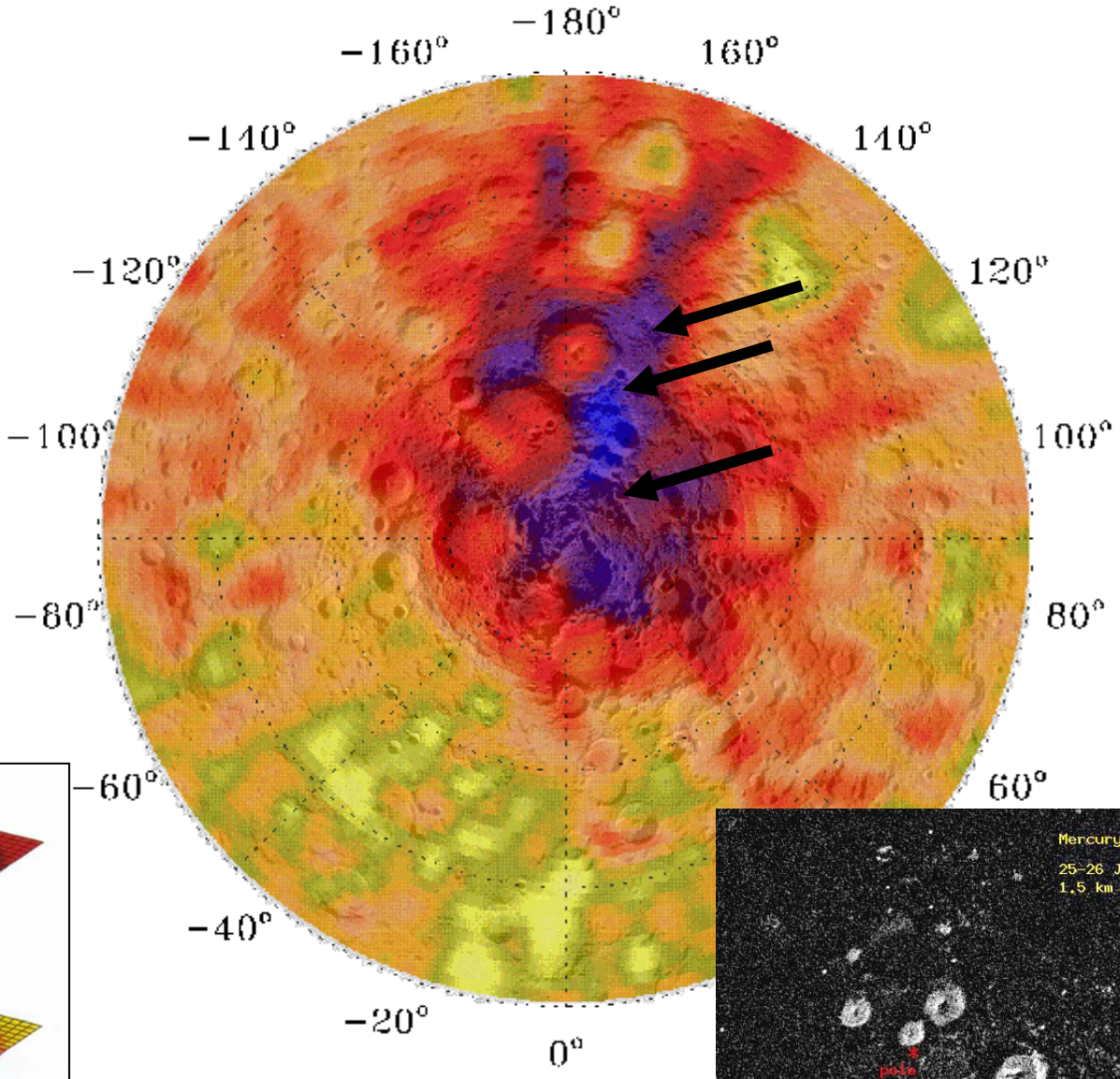


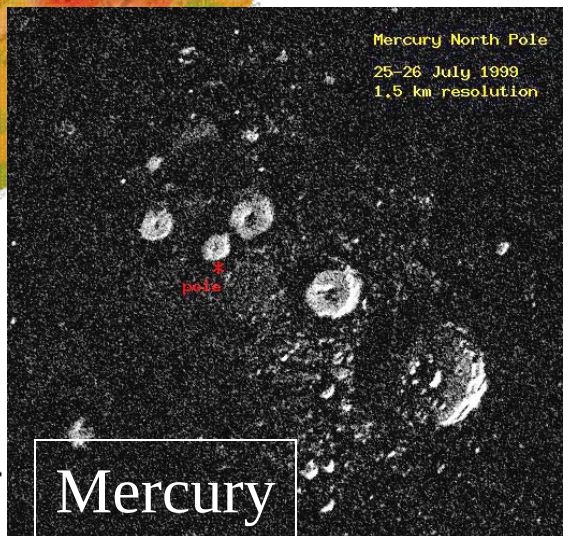


North Pole:

Neutron deficit is largely confined to surrounding rough terrain







North Pole Hypotheses:

1) Rough terrain promotes low temperatures
    - Small declivities better shielded from sunlight
2) Smooth terrain promotes loss mechanisms
    - More susceptible to sputtering, more integrated radiation load
3) Relic deposit embayed by subsequent processes
    - H-bearing material must be refractory
        - Bound water
        - High molecular weight organics
    - Must be very ancient (embayed by light plains)

Natural *in situ* production of "refractory" compounds is plausible

- Production of clay minerals in wet, hot ejecta blankets owing to impacts into ice rich targets during Mercury-like era
- Production of high molecular weight organics from CHON and proton irradiation
  - CHON derived from ices or solar wind ions

“To the Batpoles, Robin”

The Next Step

We know:

- Hydrogen is present in anomalous concentrations at the poles at 50 km resolution
- Thick ice deposits are absent in the imaged areas of permanent shade

We can assume:

- Lyman α and micrometeorites almost certainly have desiccated the uppermost few centimeters

We do not know:

- The volatile inventory
- The concentration of volatiles at resource recoverable scale (~100m)
- The position of any features to 10's of km laterally and 5's of km vertically in the polar regions
- The degree to which temperature controls the distribution

The Next Step

Orbiter Goals:

- Establish the geodetic knowledge necessary to address problems at high resolution
- Determine the morphology at scales relevant to safety of landed experiments
- Refine the knowledge of volatile distribution
- Determine the controls on volatile distribution to allow prediction

Lander Goals:

- Determine the volatile inventory

Potential Orbiter Payloads

Task	Instrument
Establish the geodetic knowledge necessary to address problems at high resolution	LIDAR, LIDAR/Stereo, Radar Interferometry
Determine the morphology at scales relevant to landing safety	SAR, Low light level optical imaging
Refine the knowledge of volatile distribution	Collimated neutron spectroscopy
Determine controls on volatile distribution to enable prediction	IR or microwave radiometry

The Lander Problem

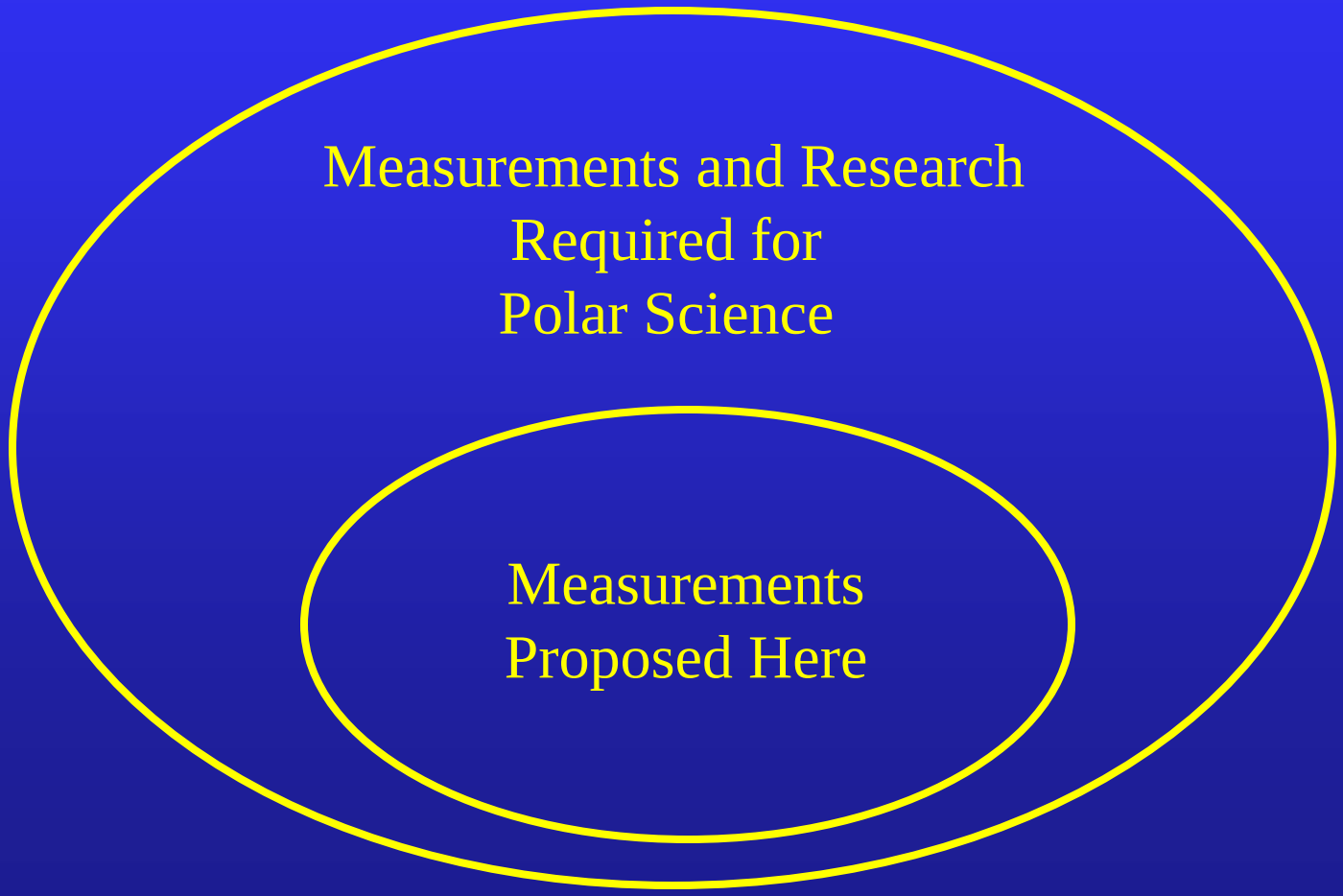
- Lyman α and micrometeorites almost certainly have desiccated the uppermost few centimeters
- Landed science must access the zone between 0.1 (assumed “dry”) and 1 m (depth of LP measurement)
- Trench, drill or mole in the dark at 50 kelvins or,
- Get the depth instantly for free with a penetrator

Potential Lander Payloads

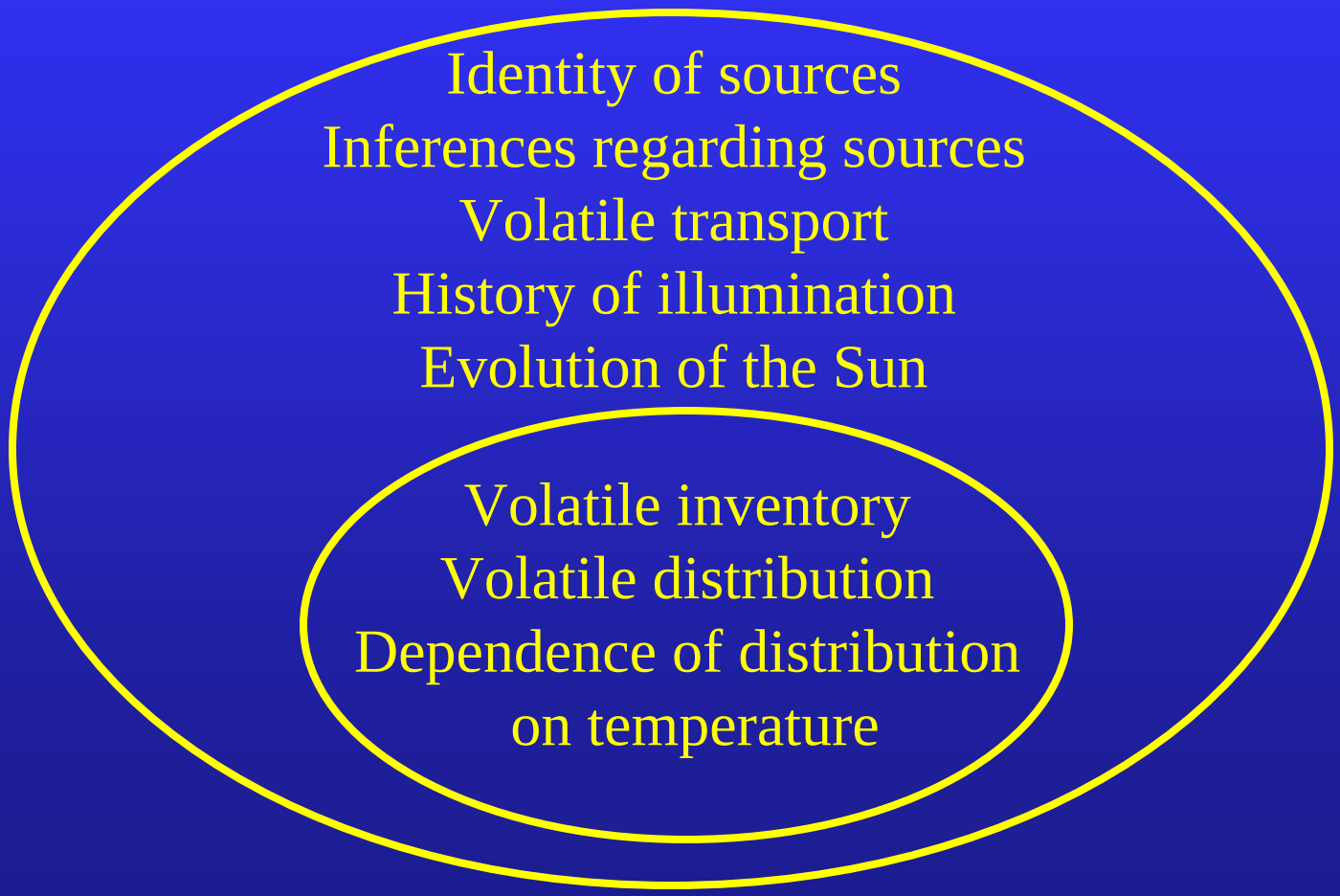
Determine the volatile Inventory	Measurements at multiple sites (if T is a poor predictor of distribution)	Several landers
	Chemical state of hydrogen	Mass spectrometer, IR spectrometer, H gas detector
	Detection of all volatile species to lunar background levels	Mass spectrometer
	Detection of involatile H-bearing and other resource-relevant, polar peculiar, species	DSC/MS

“Perfection is the enemy of good enough”

Polar Science vs. Applied Science



Polar Science vs. Applied Science



“That’s All Folks”