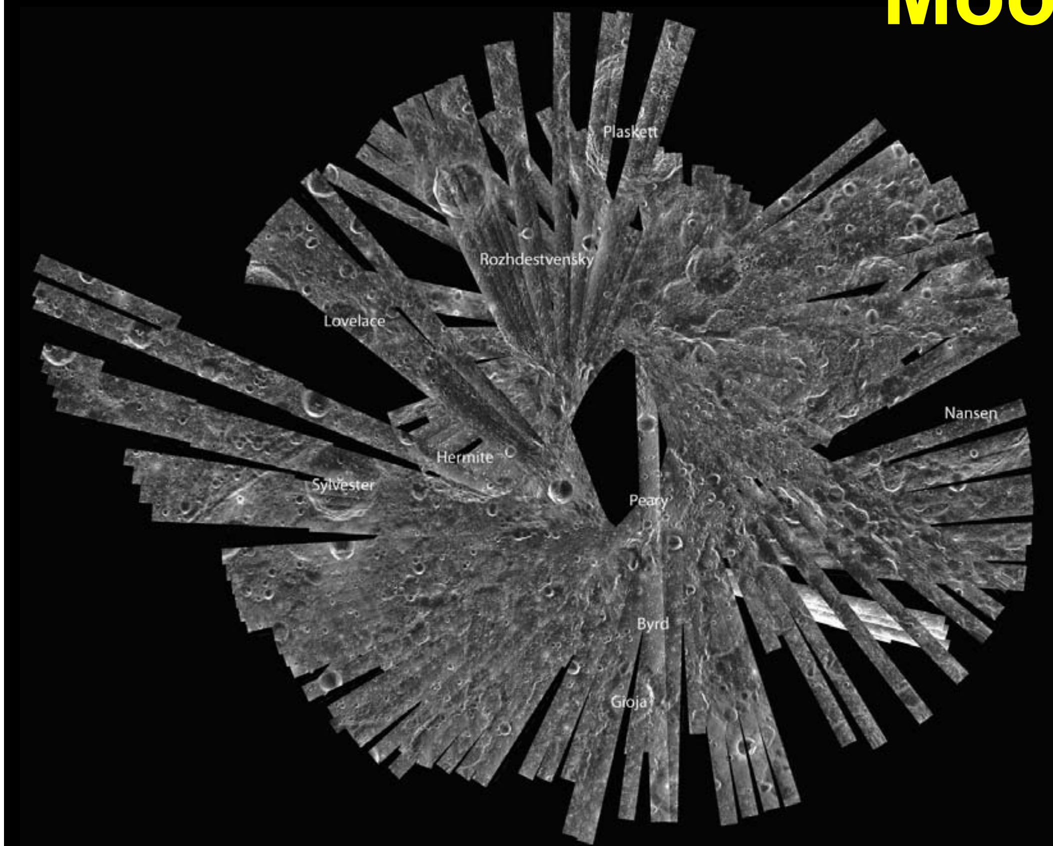
Mini-RF Mapping of the Poles of the Moon



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blogs.airspacemag.com/moon/

Space Resources Roundtable, Golden CO
9 June, 2010

Lunar Polar Environment

Low Lunar Obliquity (1° 32’)

- Geometry stable for ~2 billion years
- Grazing Sunlight
- Extended shadows
- Terminator always nearby

Areas of Quasi-Permanent Light

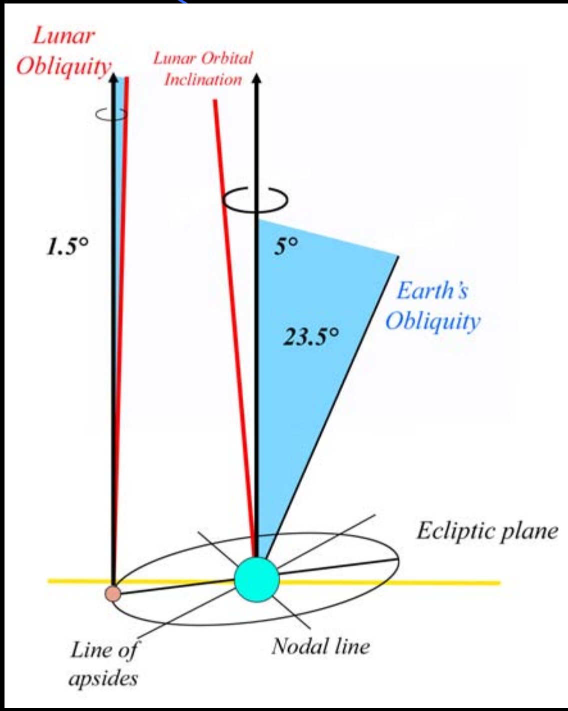
- Prominences stand above the local horizon
- Low, constant surface temperatures (~220K)
- High flux on vertical surfaces
- Serves as solar power source

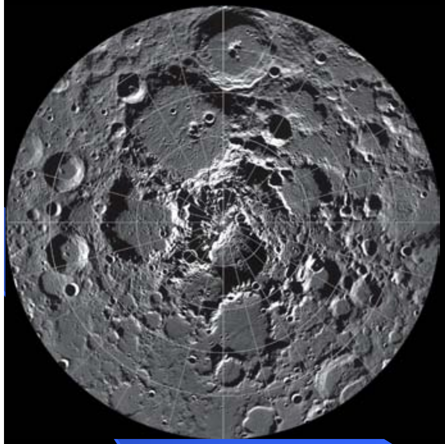
Areas of Permanent Darkness

- Only scattered light or starlight
- No direct solar illumination
- Very low temperatures (~50-70K)
- Serves as cold trap for volatiles

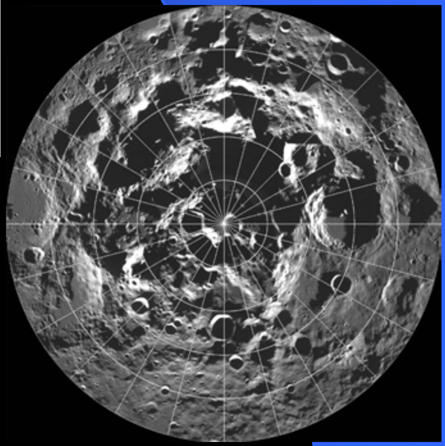
View from the Earth

- Lighted Areas
  - Two weeks of visibility / two weeks obscured
- Shadowed Areas
  - Permanently obscured





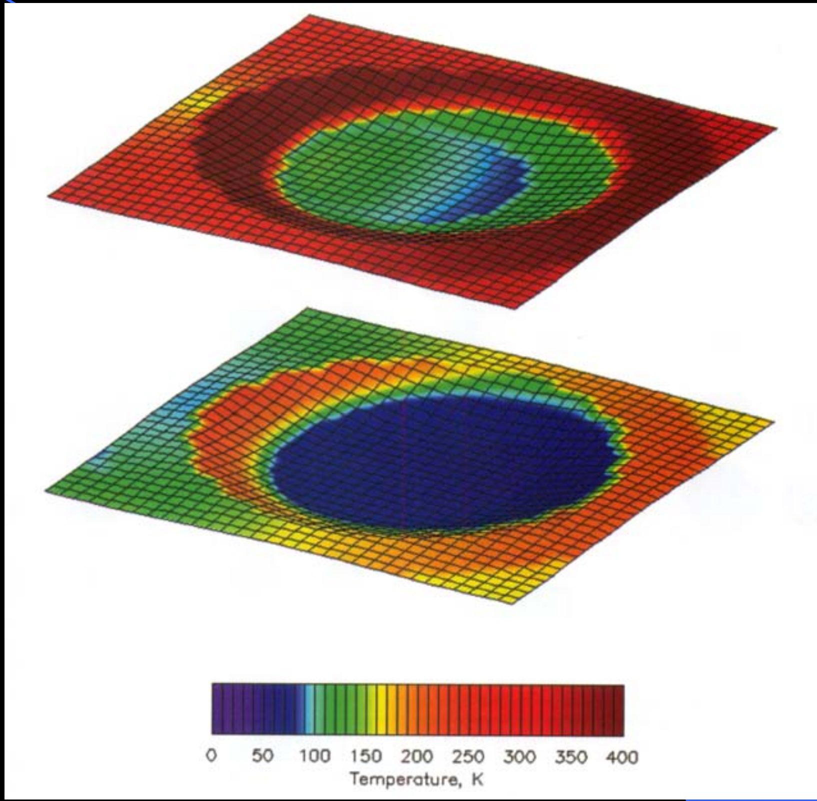
North pole



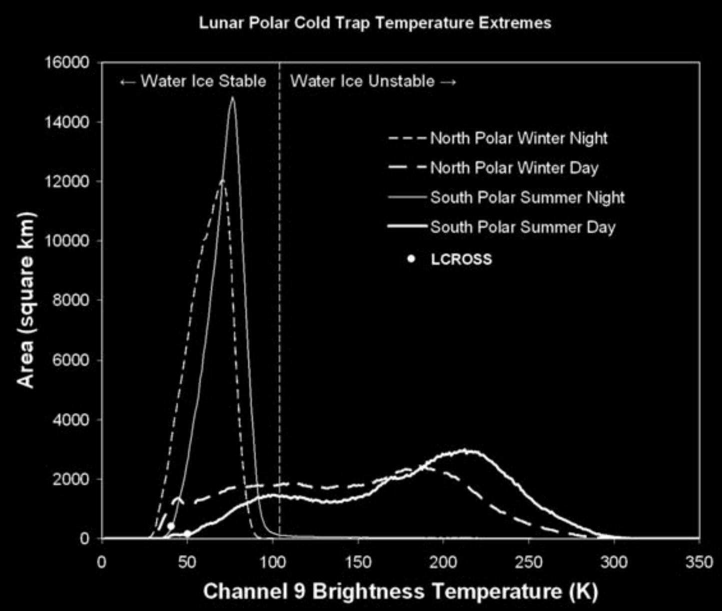
South pole

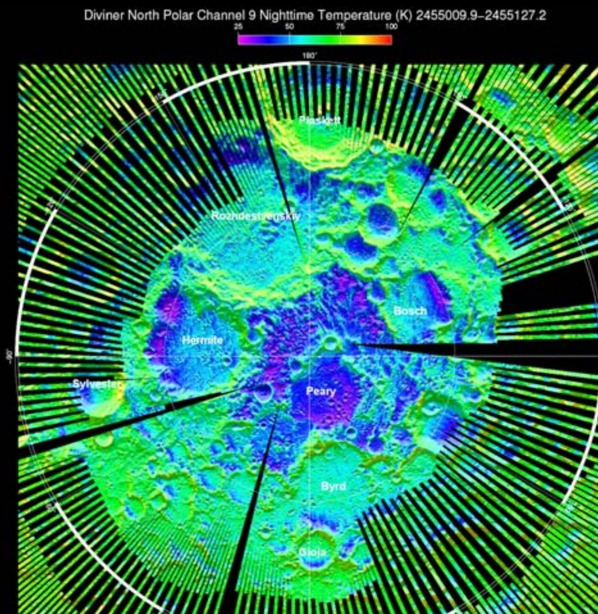
Polar Cold Trap Temperatures

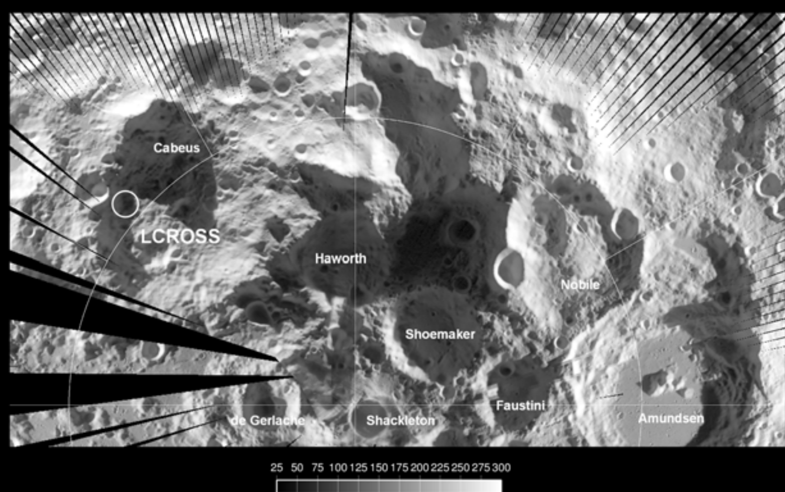
- Permanently shadowed areas have very low model temperatures (~ 50-70 K) and act as cold traps (e.g., Vasavada *et al.* 1999)
- Uncertainty largely a reflection of unknown value for heat flow of Moon (14 - 22 mW m^{-2})
- Temperatures may vary substantially in the shallow subsurface
- At these temperatures, atoms and molecules of volatile species cannot escape
- New DIVINER thermal maps from LRO show that cold traps are even ***colder*** than thought! (as low as 30 K)



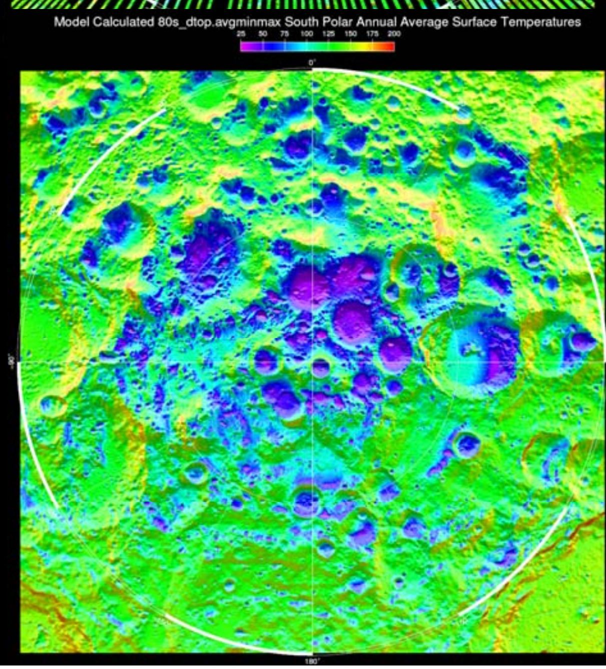
DIVINER thermal data



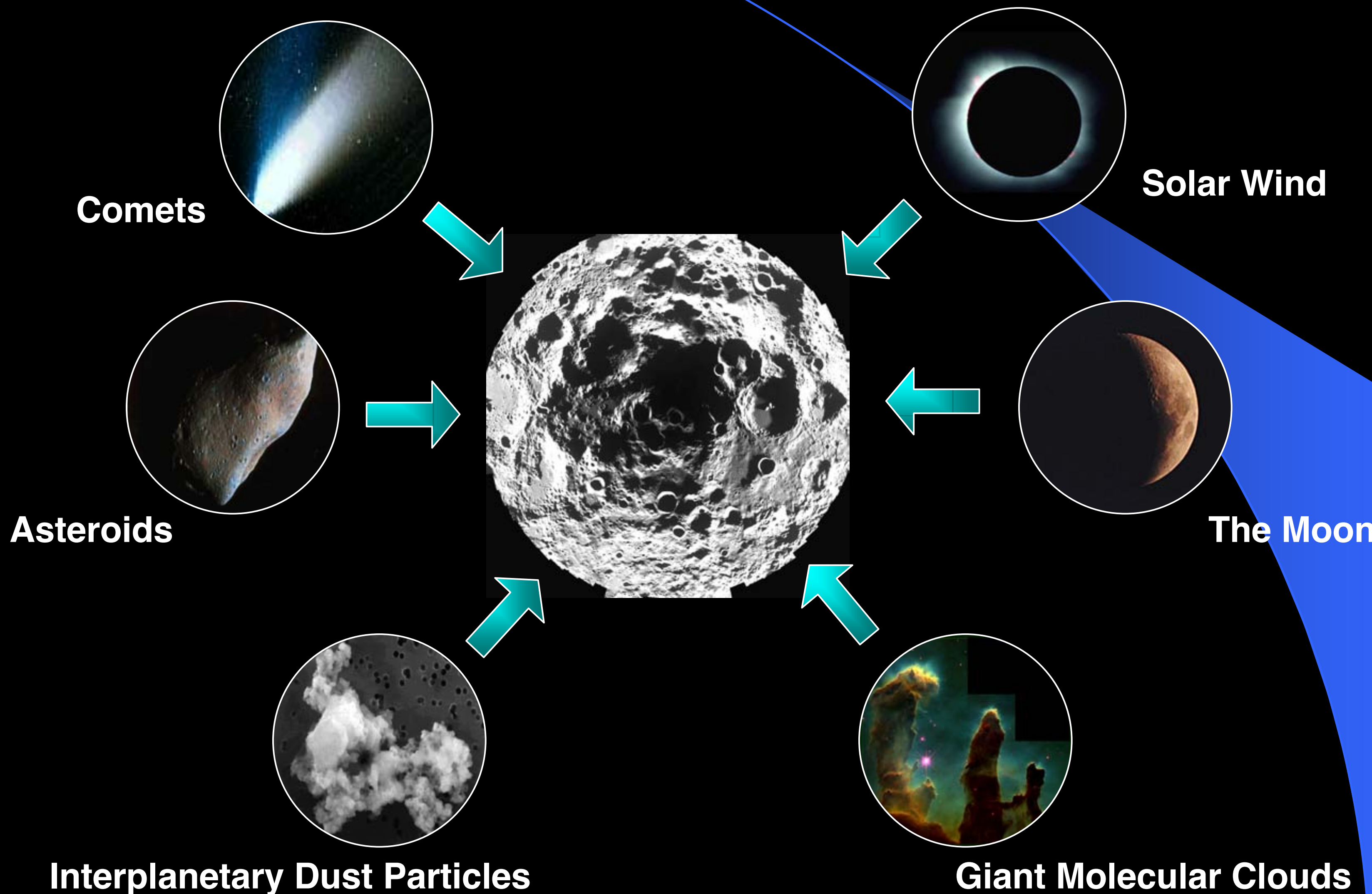




Diviner Channel 8 Brightness Temperature Map (K)



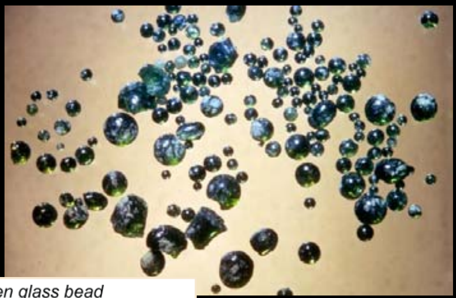
Possible Sources of Lunar Polar Volatiles

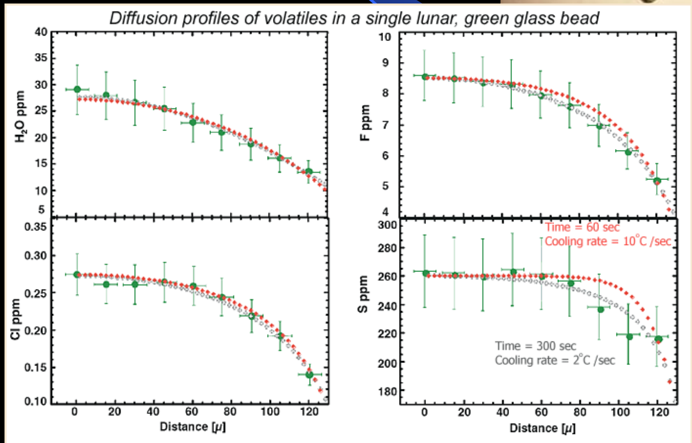


From P. Lucey, 2001

Indigenous lunar water?

- Apollo 15 green glass pyroclastics (volcanic ash) contain up to 50 ppm inside
- Diffusion profiles imply much higher magma concentrations of water
- Implies water concentrations of 260-700 ppm in mantle
- Most water in magma lost during eruption when magma was sprayed into space during “fire fountaining”
- Original Moon was not completely devolatilized; could have degassed cold-trapped water



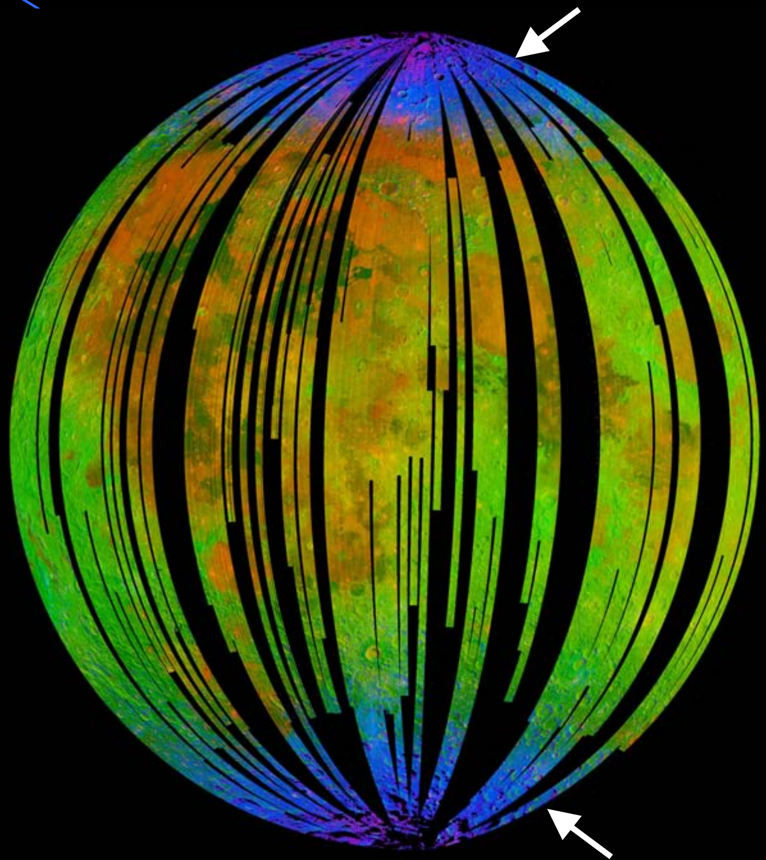


(From Saal et al., 2008, Nature, v. 454, p. 192-196. doi:10.1038/nature07047.)

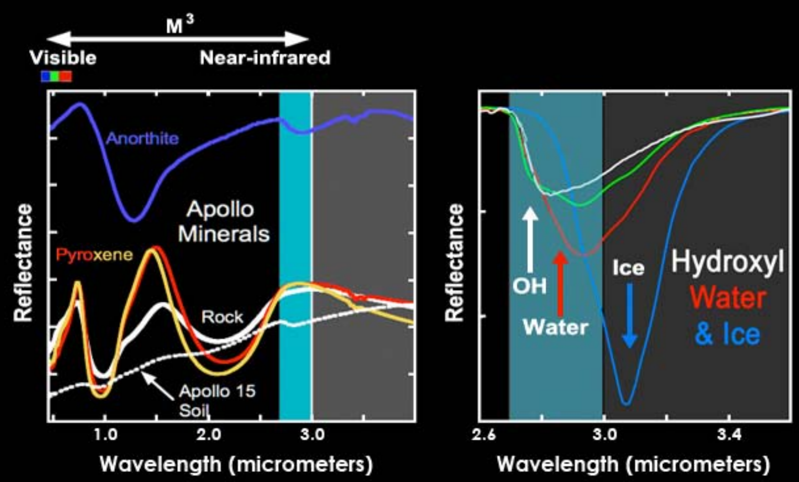
Water on the Moon

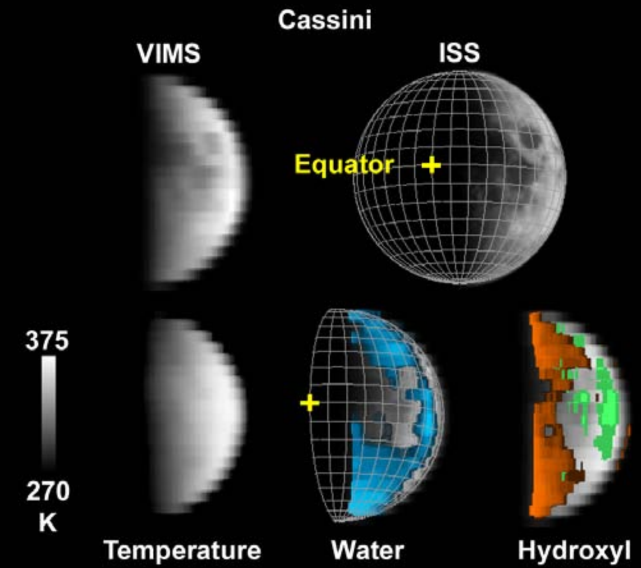
New Evidence from Remote Sensing

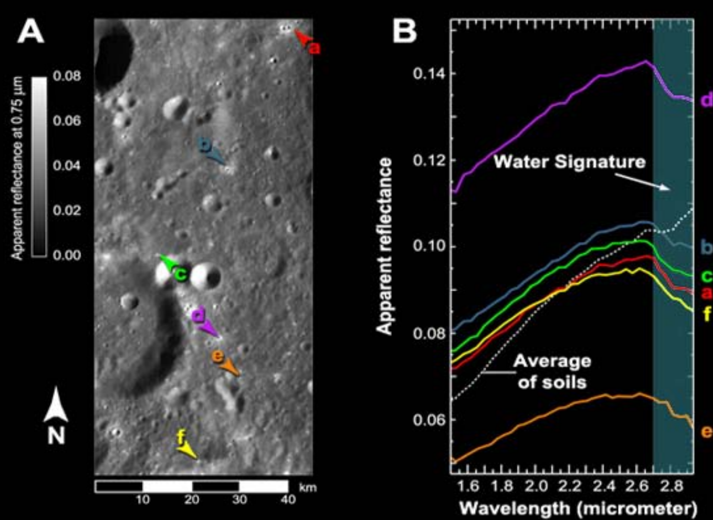
- Spectral evidence for widespread minerals of hydration (2.8 μm absorption band)
- Seems correlated with latitude (most evident at latitudes > 65°)
- Created how?
  - Solar wind reduction of oxides in rock and soil
  - Water residue from comet impacts
  - Outgassed water vapor from lunar interior
- A possible source for polar ice
  - Migration to polar cold traps by ballistic hopping

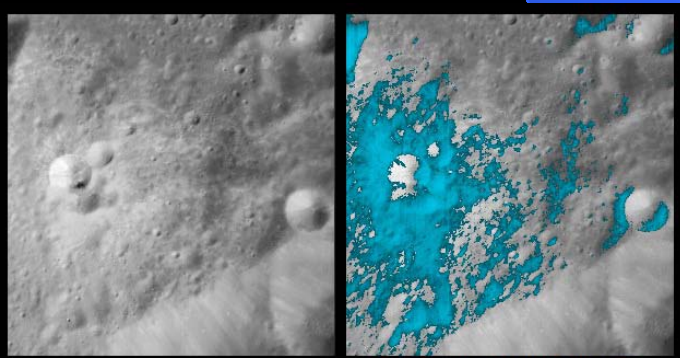


Finding water with spectra







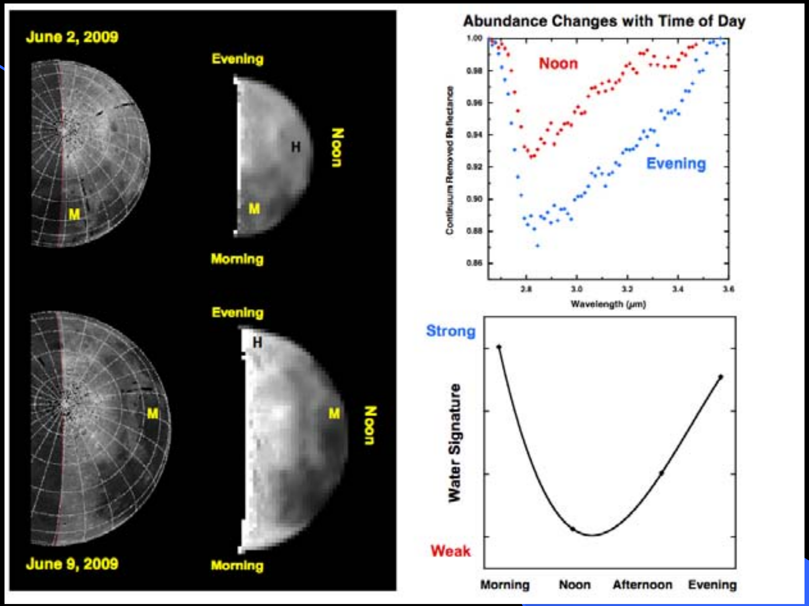


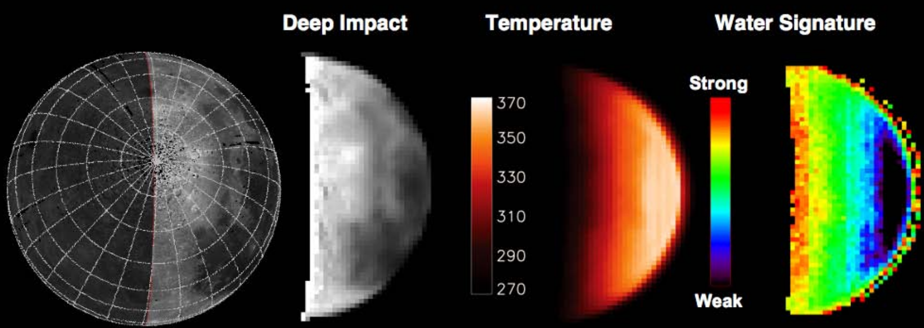
Infrared Reflectance

Blue = water absorption strength on Infrared Reflectance

Chandrayaan-1 Moon Mineralogy Mapper

Water abundance variation
with space, time and temperature

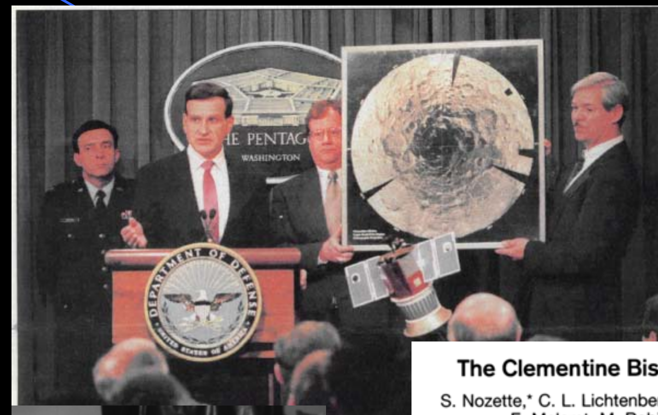




The search for lunar ice

"To be uncertain is uncomfortable but to be certain is ridiculous." – Goethe

- Radar has been used since 1960's to map the lunar surface
- Backscattering properties are different for normal Moon and water ice
- Long recognized that polar areas are dark and cold (Watson, Murray and Brown, 1961)
- Discovery of ice at poles of Mercury in 1992 spurred renewed interest in lunar poles
- Unfavorable viewing geometry of lunar poles complicated the interpretation of results
- Thus, 20 years of controversy



The Clementine Bistatic Radar Experiment

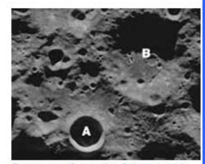
S. Nozette,* C. L. Lichtenberg, P. Spudis, R. Bonner, W. Ort, E. Malaret, M. Robinson, E. M. Shoemaker

During the Clementine 1 mission, a bistatic radar experiment measured the magnitude and polarization of the radar echo versus bistatic angle, β, for selected lunar areas. Observations of the lunar south pole yield a same-sense polarization enhancement around β = 0. Analysis shows that the observed enhancement is localized to the permanently shadowed regions of the lunar south pole. Radar observations of periodically solar-illuminated lunar surfaces, including the north pole, yielded no such enhancement. A probable explanation for these differences is the presence of low-loss volume scatterers, such as water ice, in the permanently shadowed region at the south pole.

Ice Store At Moon's South Pole Is A Myth

by Staff Writers
Paris (AFP) Oct 18, 2006

Hopes that the Moon's South Pole has a vast hoard of ice that could be used to establish a lunar colony are sadly unfounded, a new study says. In 1994, radar echoes sent back in an experiment involving a US orbiter called Clementine appeared to show that a treasure trove of frozen water lay below the dust in craters near the lunar South Pole that were permanently shaded from the Sun.



Because of the tilt of the moon's orbital plane relative to the Earth's equatorial plane, the Earth can rise much higher above the

Water on the Moon? Scientists Await Definitive Answer

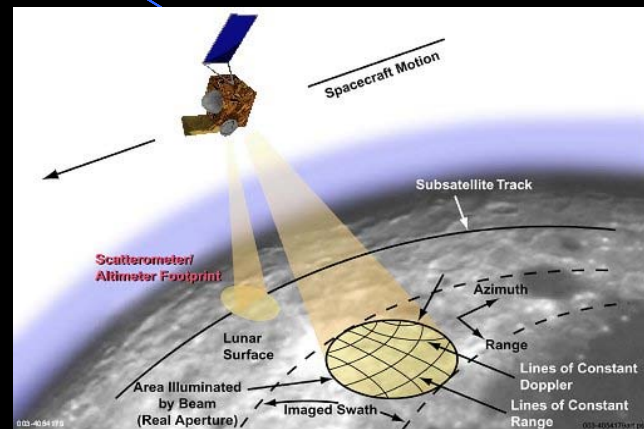
By Rick Callahan
Associated Press
posted: 01:00 pm ET
12 November 2003

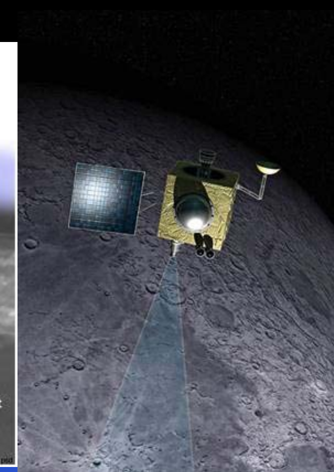
Mini-SAR

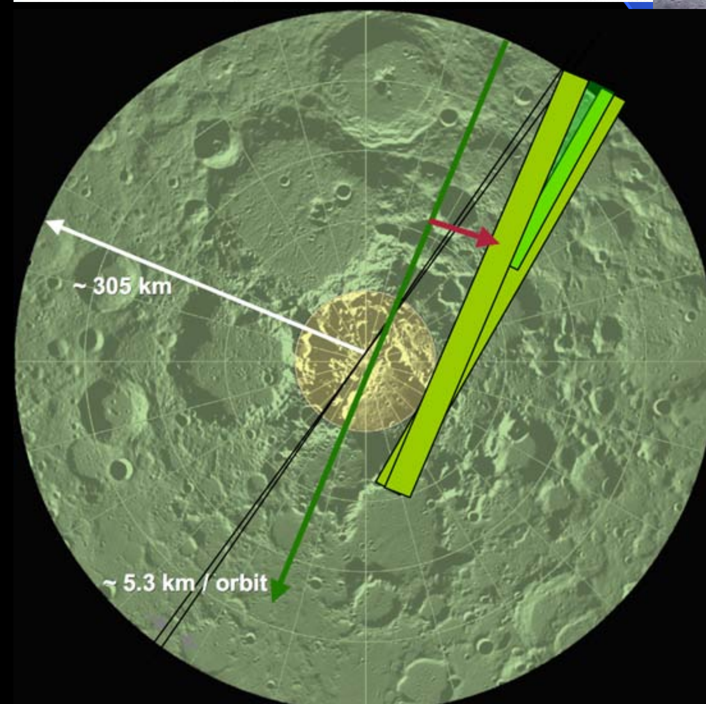
Imaging Radar on the Chandrayaan-1

- Mini-SAR is an S-band (λ = 12.6 cm) imaging radar with hybrid polarity architecture
- Map both polar regions at 75 m/pixel
- Transmit LCP, receive ***H*** and ***V*** linear, coherently
- Use Stokes parameters and derived "daughter" products to describe backscattered field
- Map locations and extent of anomalous radar reflectivity
- See polar dark areas (not visible from Earth)
- Cross-correlate with other data sets (topography, thermal, neutron)

- LRO version (Mini-RF) has two bands (λ=12.6 and 5 cm), high-resolution zoom mode (15 m/pixel)

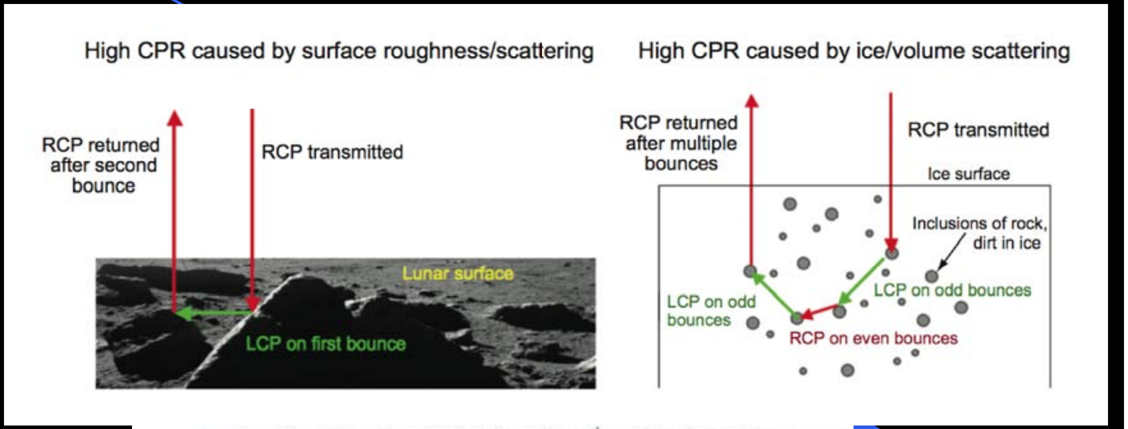


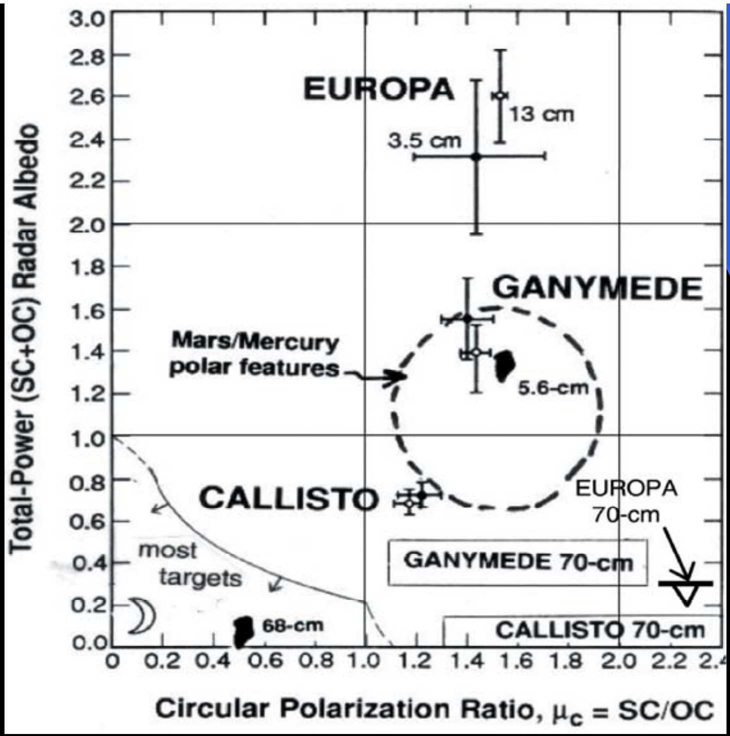




Circular Polarization Ratio (CPR)

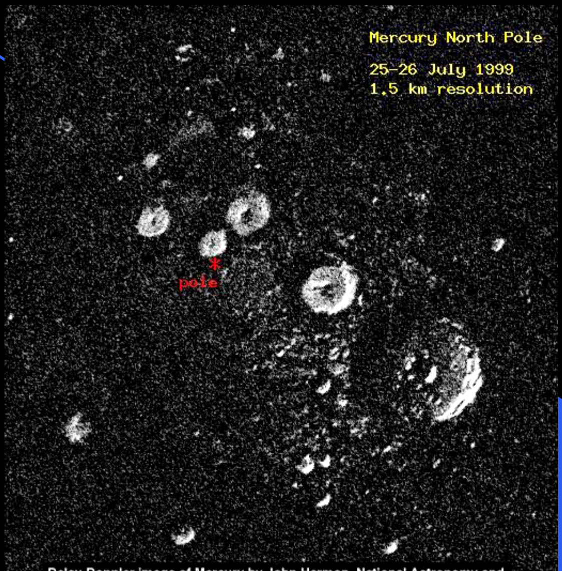
- Ratio of received power in both right and left senses
- Normal rocky planet surfaces = polarization inversion (receive opposite sense from that transmitted)
- "Same sense" received indicates something unusual:
  - double- or even-multiple-bounce reflections
  - Volume scattering from RF-transparent material
- High CPR (enhanced "same sense" reception) is common for fresh, rough (at wavelength scale) targets and water ice



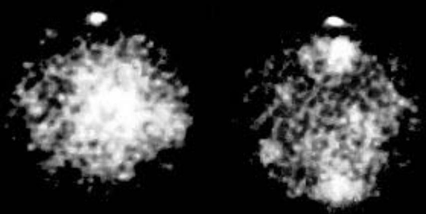


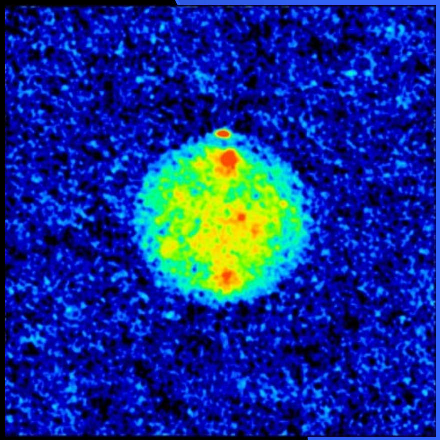
What does high CPR mean?

- Is high CPR diagnostic of surface roughness or composition?
- Mercury shows high CPR within polar crater floors (Harmon et al., 2000)
- Mercury also shows high CPR areas at mid-latitudes (Muhleman, 1992)
- On Mercury, it is accepted that high CPR may have different causes, depending on local geological circumstances
- High CPR on the Moon may likewise have multiple causes

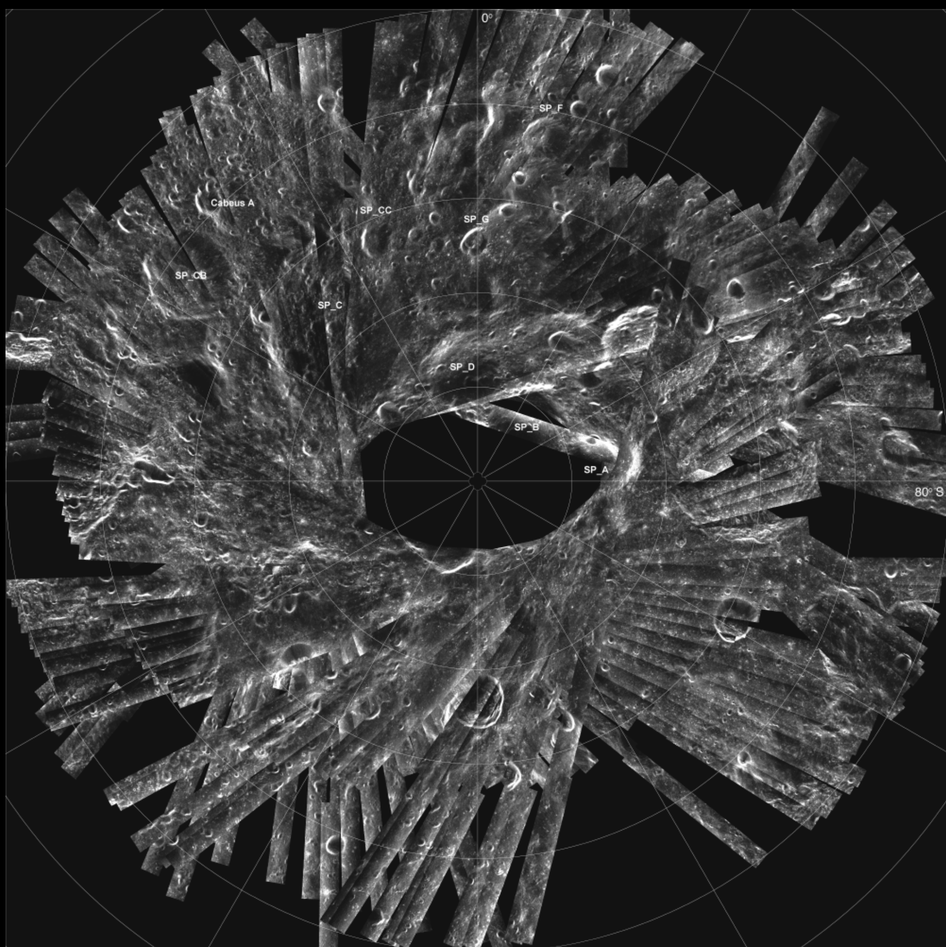


Delay-Doppler image of Mercury by John Harmon, National Astronomy and Ionosphere Center, Arecibo Observatory, Puerto Rico.

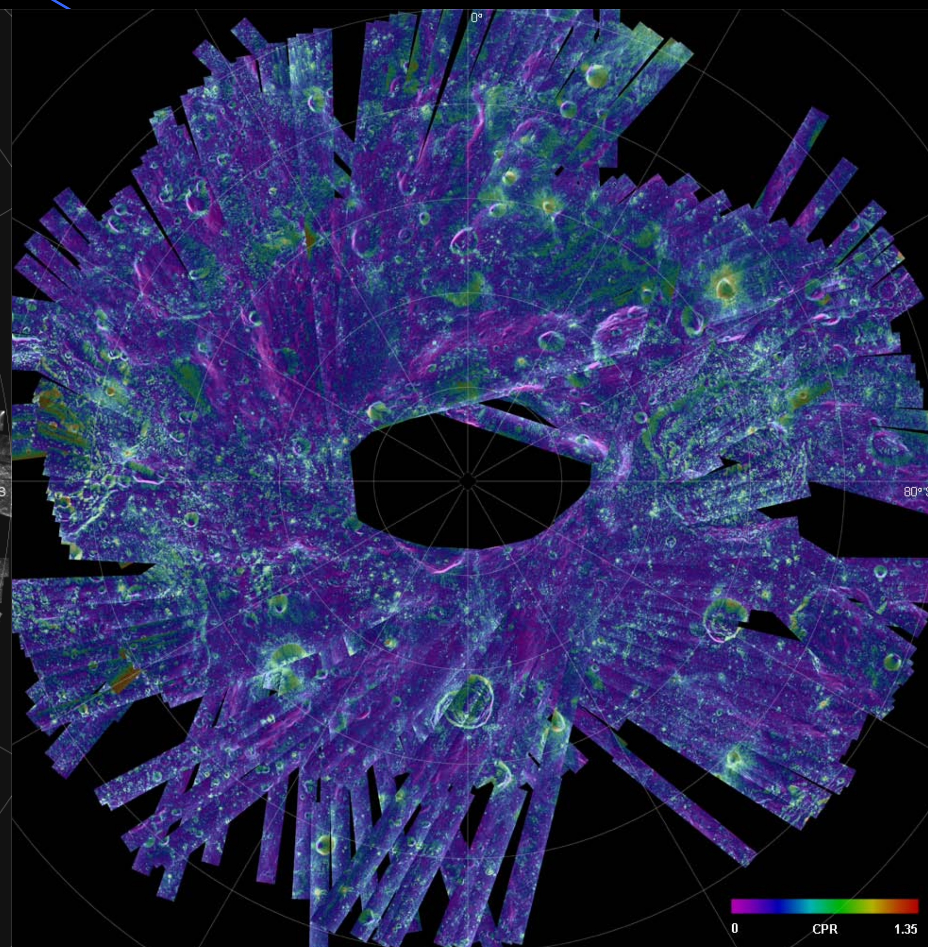




South Polar Mosaics

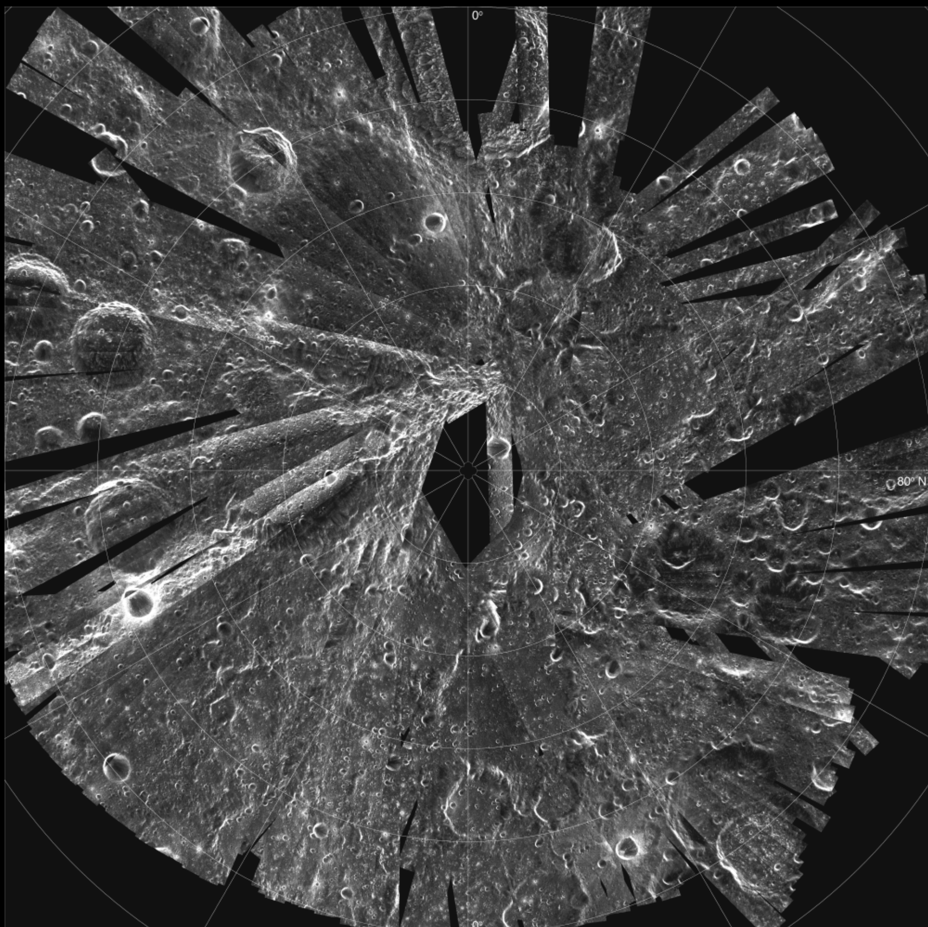


OS SAR image

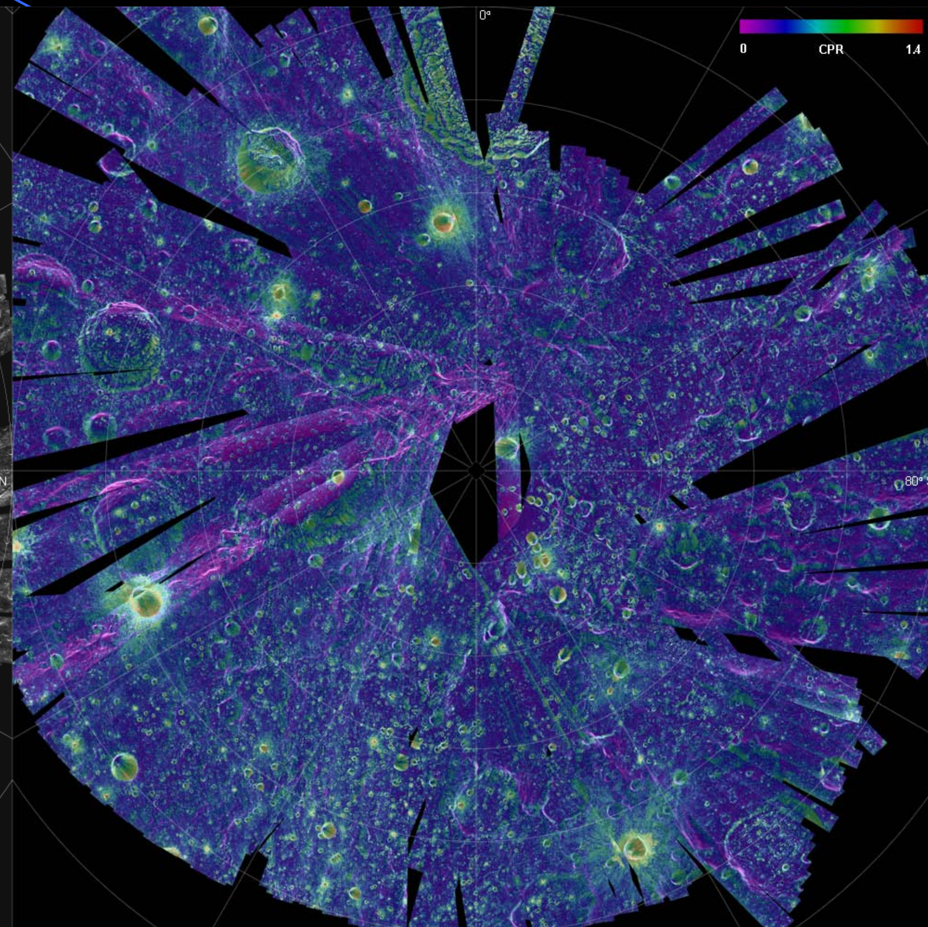


CPR image

North Polar Mosaics

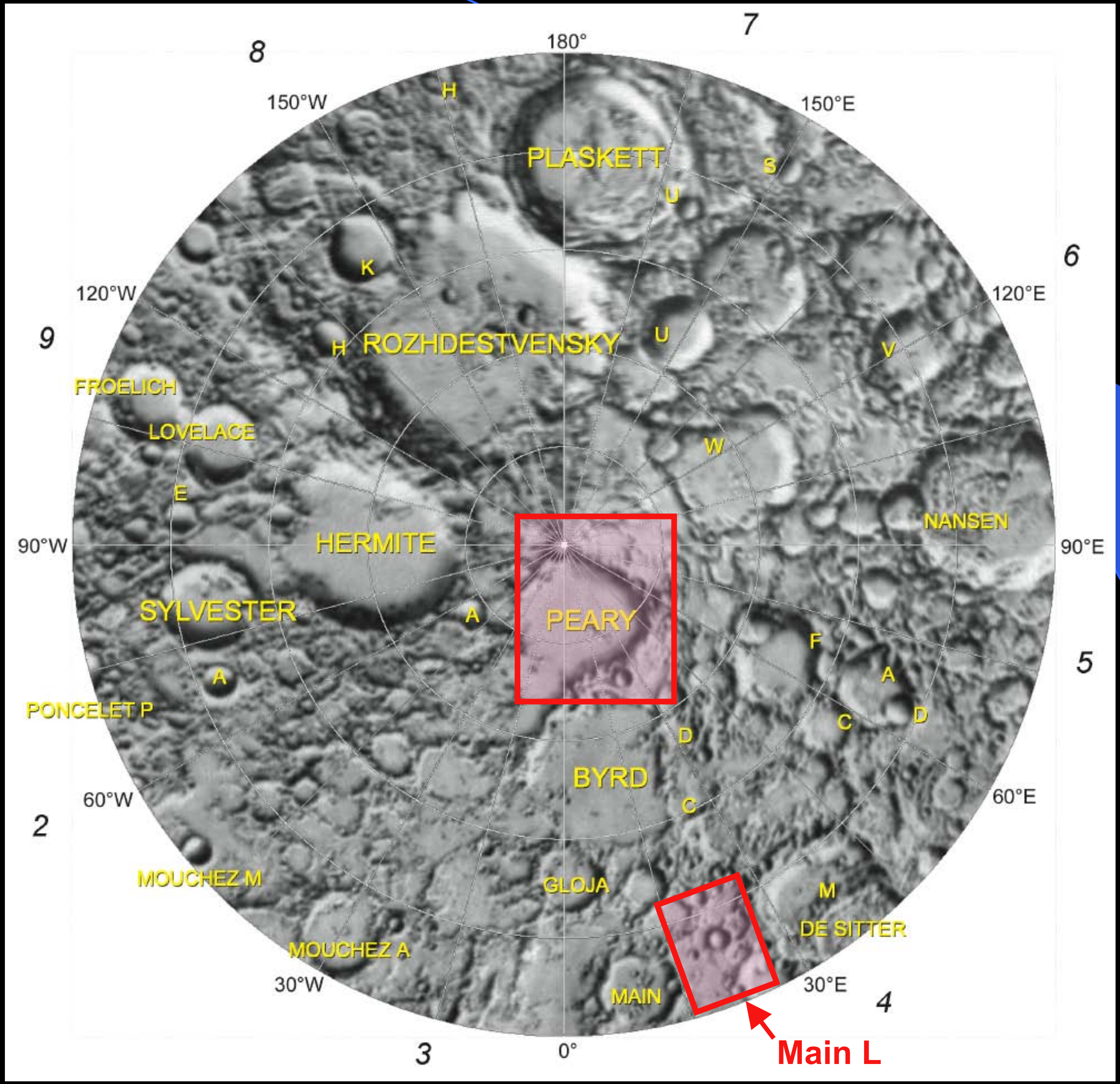


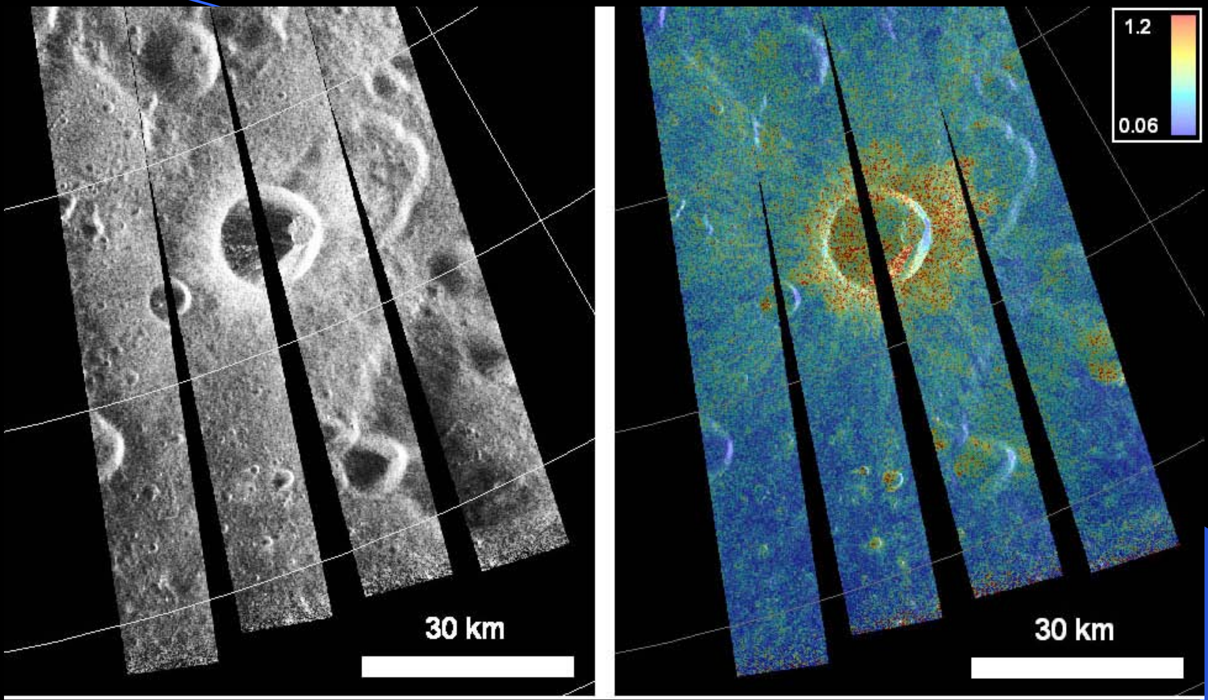
OS SAR image



CPR image

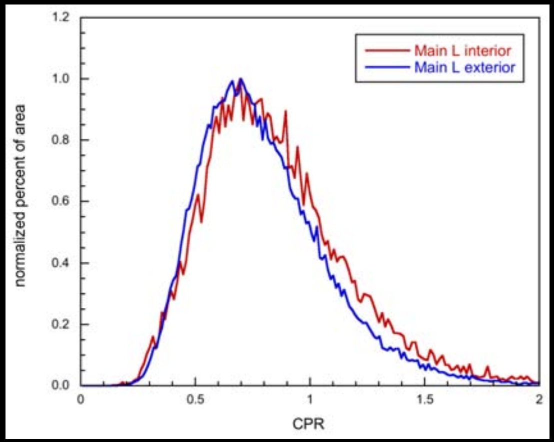
A Tale of Two Scatterers



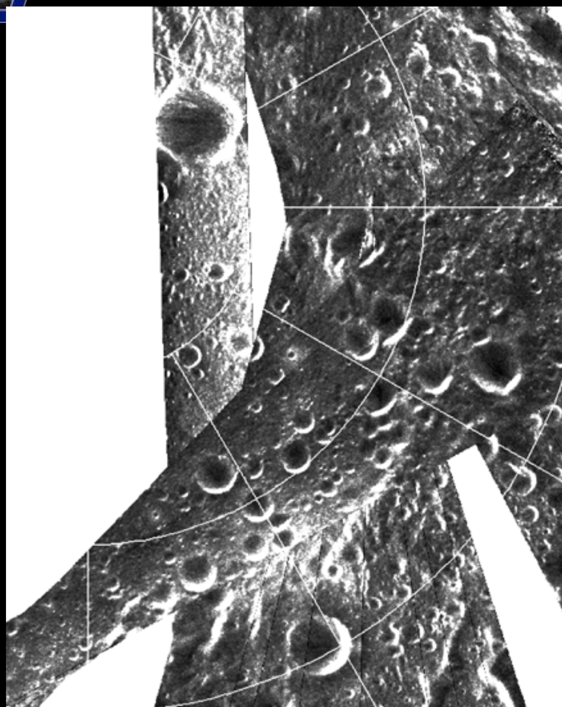


SAR mosaic

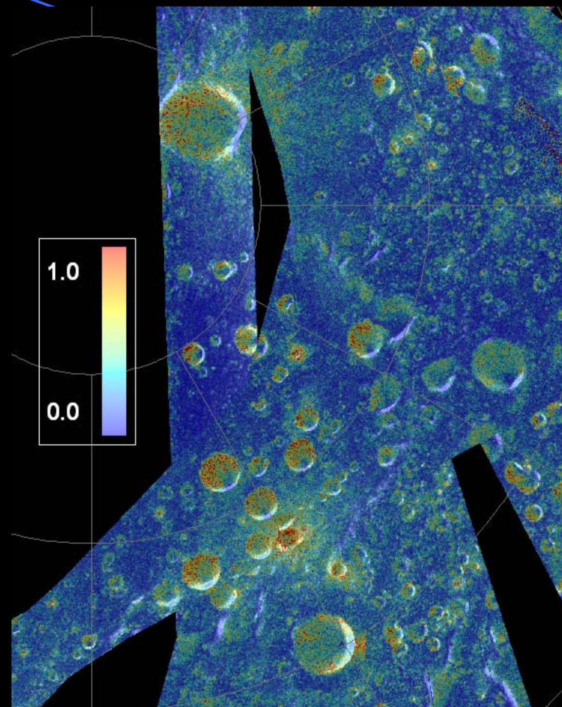
CPR mosaic



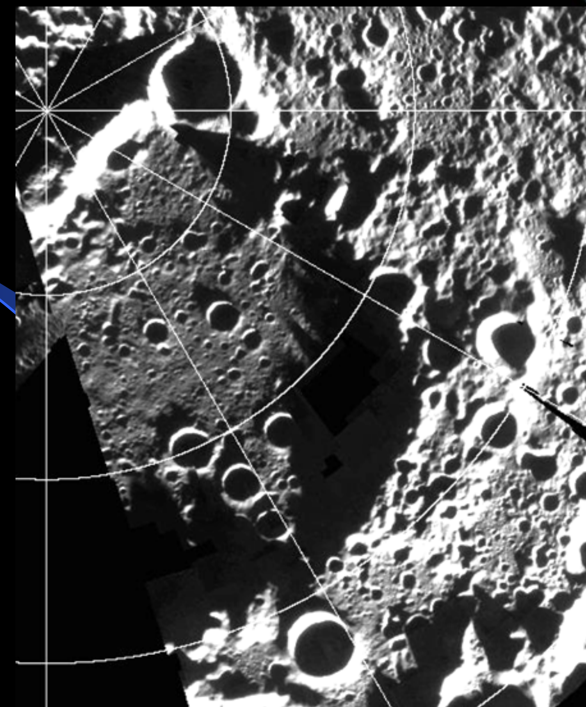
Main L, 14 km diameter,
81.4° N, 22° E



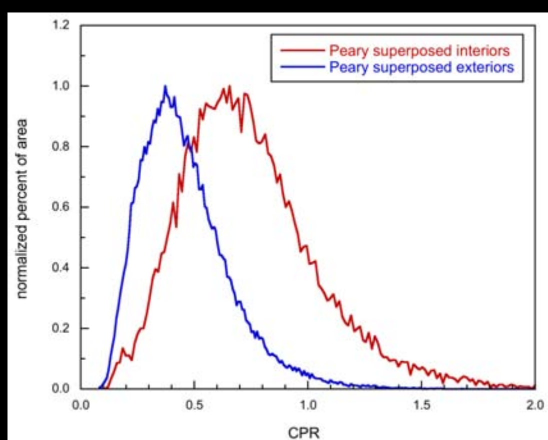
SAR mosaic



CPR mosaic



Clementine hires mosaic

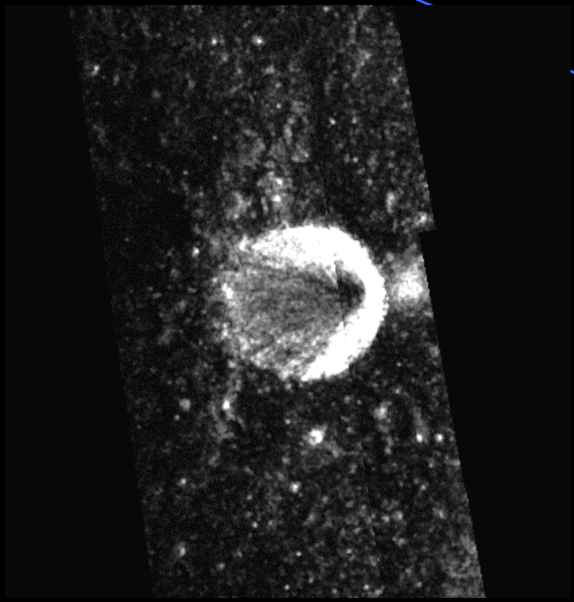


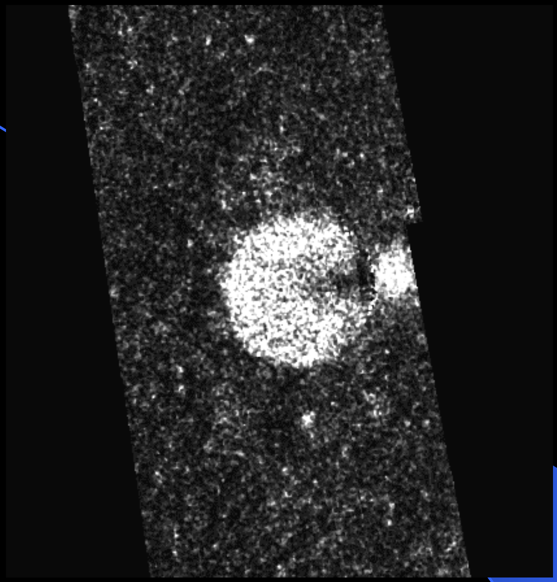
Floor of Peary, 73 km diameter, 88.6° N, 33° E

Anomalous polar crater

On floor of Rozhdestvensky, 9 km diameter, 84.3 N, 157 W

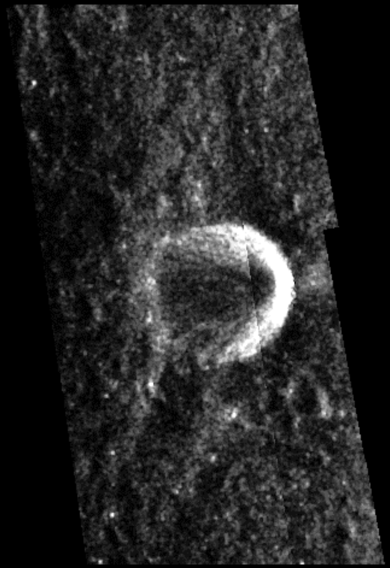
SC

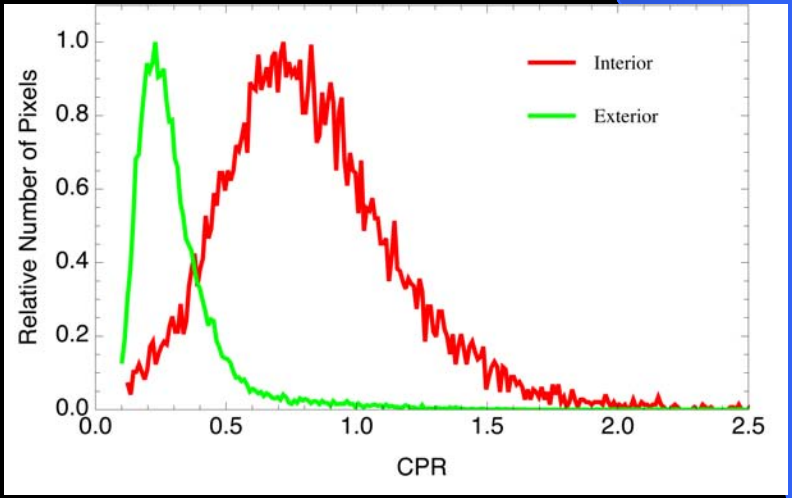




CPR

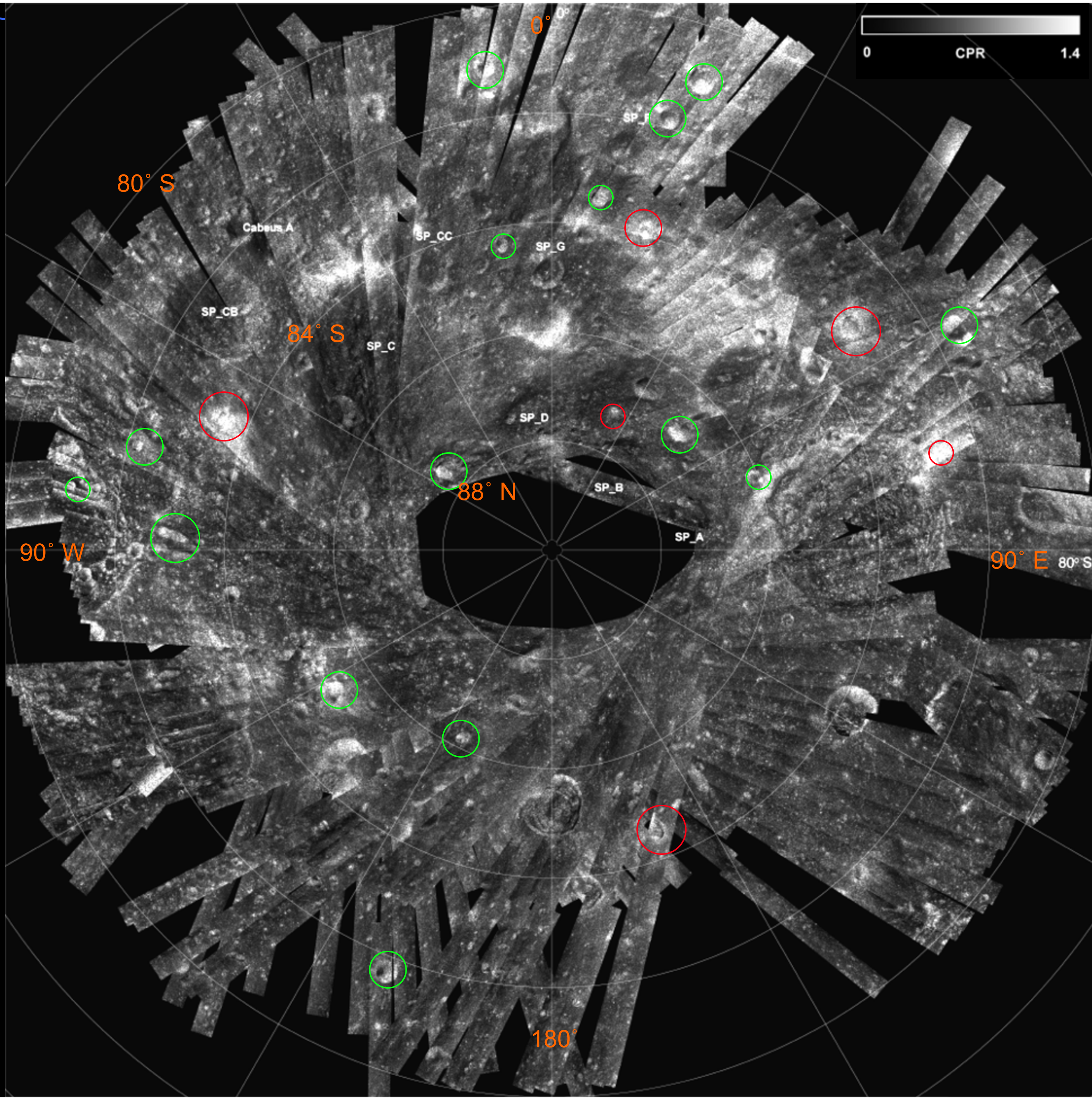
OC





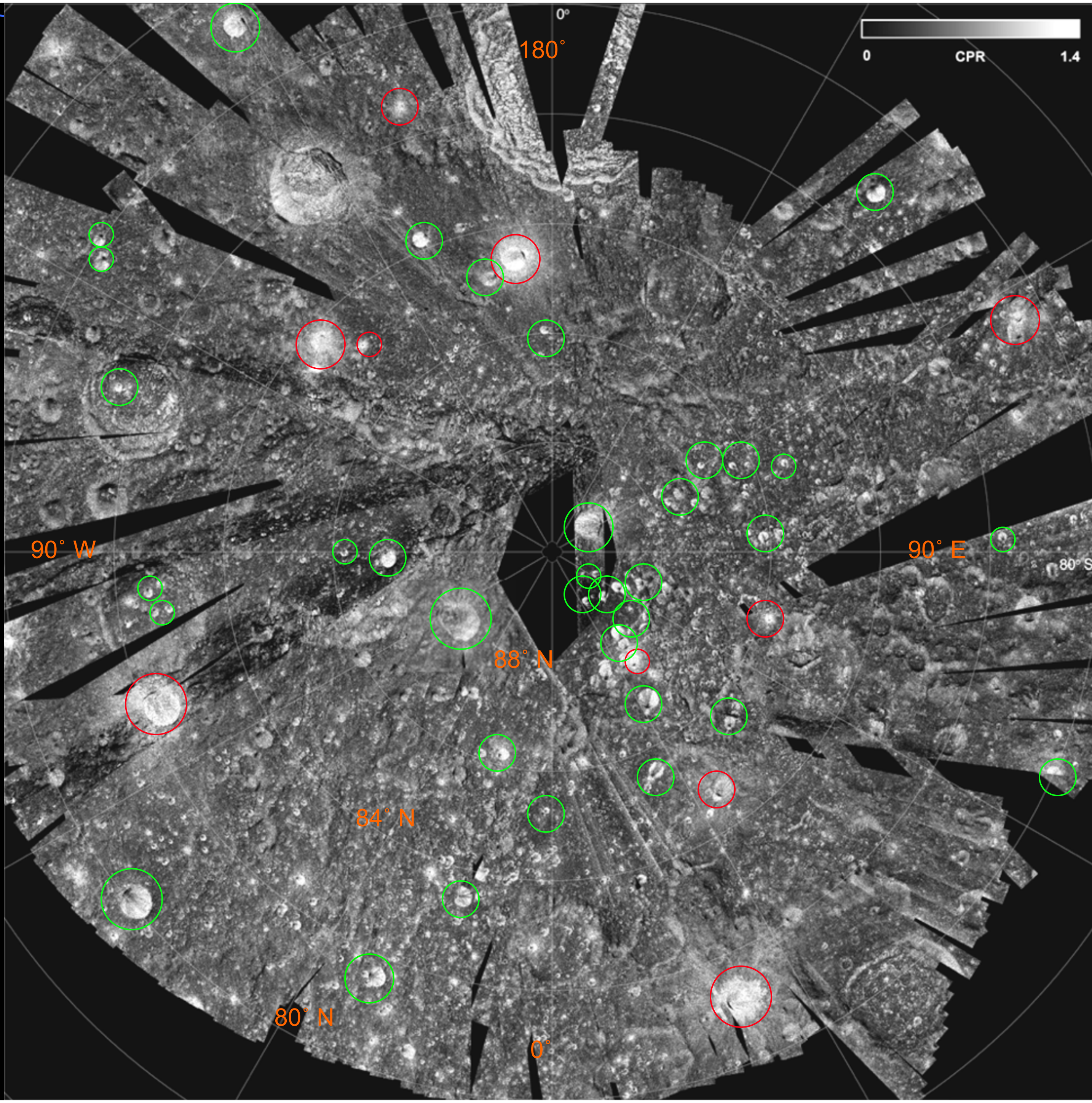
Fresh craters

Anomalous craters

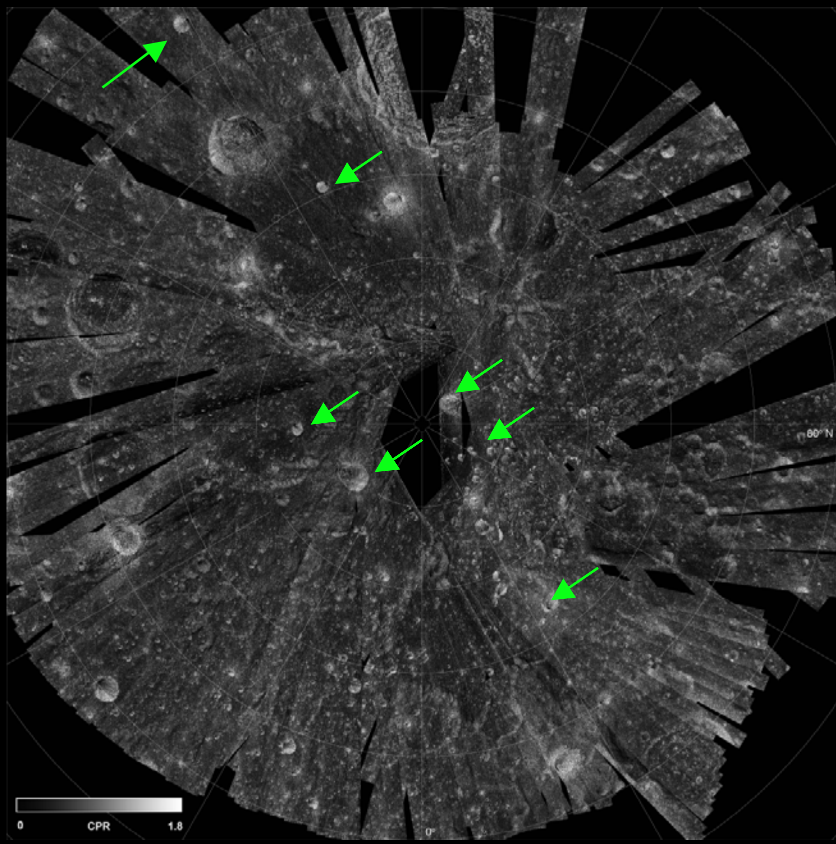


Fresh craters

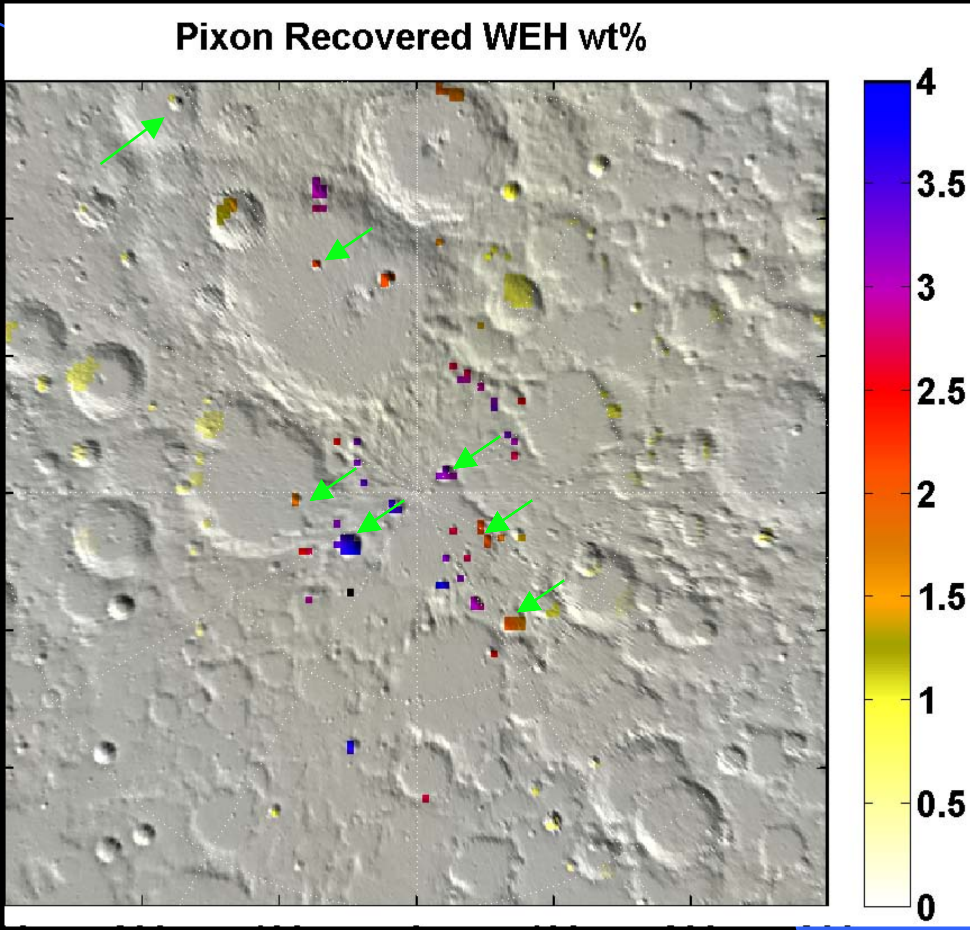
Anomalous craters



CPR v. LP neutron data

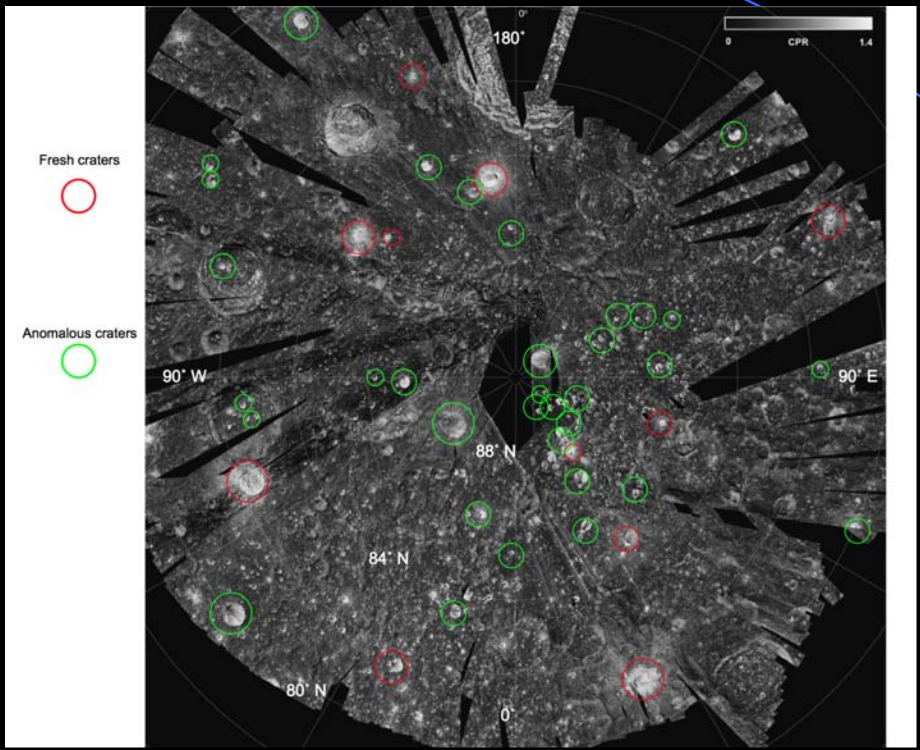


Mini-SAR CPR



LP Neutron Pixon Model

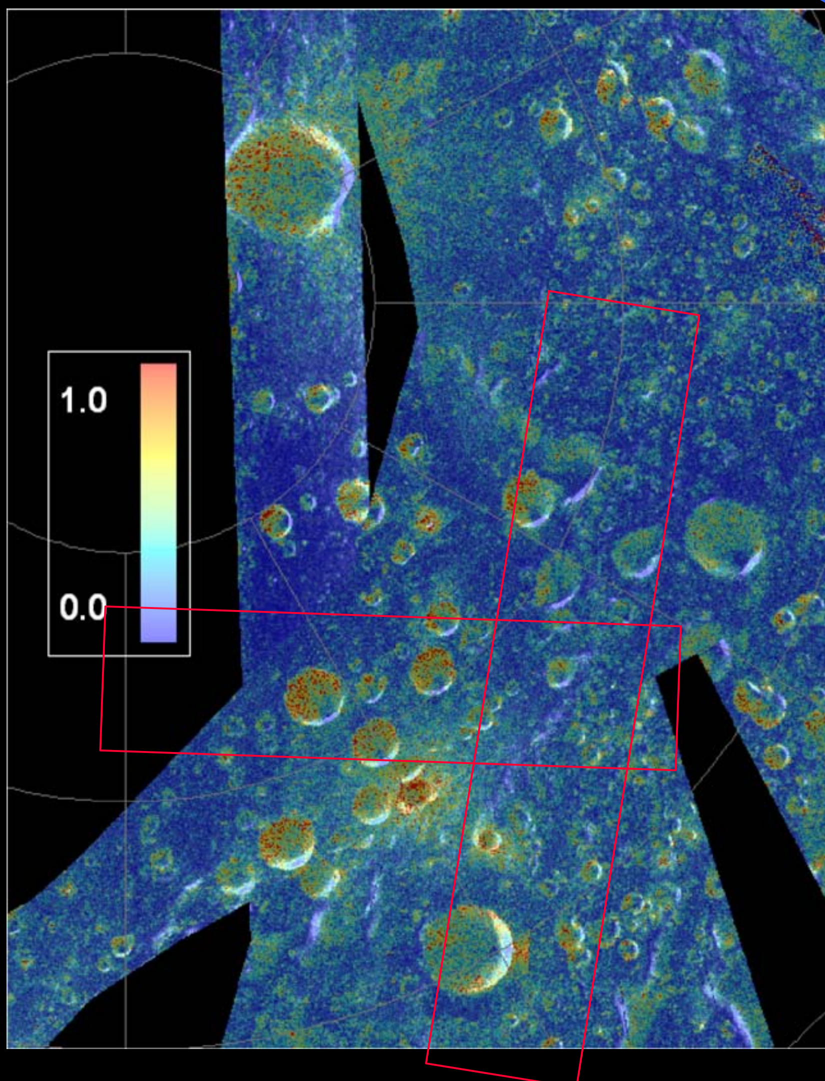
How Much Ice?

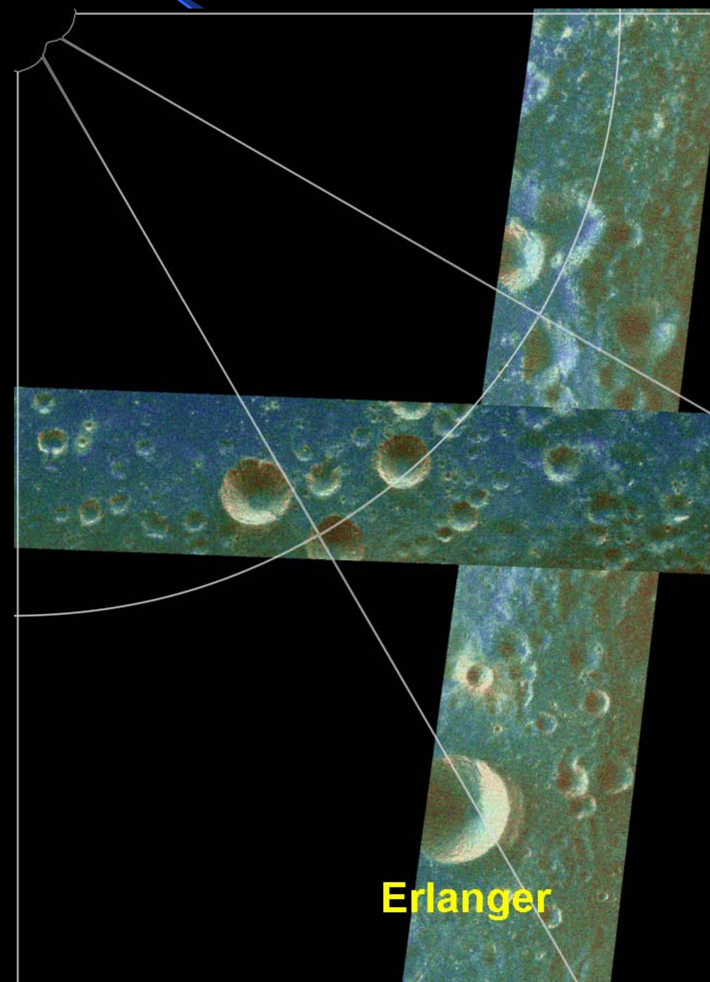


1	D (km)	A (km^2)	V (m^3)/m (mT)
2	12	113.04	24000000
3	8	50.24	16000000
4	7	38.465	14000000
5	5	19.625	10000000
6	6	28.26	12000000
7	8	50.24	16000000
8	3	7.065	6000000
9	5	19.625	10000000
10	4	12.56	8000000
11	4	12.56	8000000
12	8	50.24	16000000
13	21	346.185	42000000
14	18	254.34	36000000
15	7	38.465	14000000
16	12	113.04	24000000
17	3	7.065	6000000
18	8	50.24	16000000
19	6	28.26	12000000
20	11	94.985	22000000
21	6	28.26	12000000
22	4	12.56	8000000
23	5	19.625	10000000
24	4	12.56	8000000
25	6	28.26	12000000
26	4	12.56	8000000
27	3	7.065	6000000
28	3	7.065	6000000
29	8	50.24	16000000
30	17	226.865	34000000
31	4	12.56	8000000
32	34	907.46	68000000
33	4	12.56	8000000
34	6	28.26	12000000
35	5	19.625	10000000
36	4	12.56	8000000
37	4	12.56	8000000
38	3	7.065	6000000
39	8	50.24	16000000
40	5	19.625	10000000
41	11	94.985	22000000
42			
43	Total ice (m^3)		608000000
44			
45	Total reg (m^3)		5.652E+11
46			
47	Concentration		0.001075725

Observed high CPR area in shadowed craters x 10(λ) thickness
Total N. Polar ice ~ 6 x 10^8 m^3 = 600 million mT
Average fuel mass in Shuttle ET = 735 mT (735,000 kg)
Enough LH_2/LO_2 for one Shuttle launch equivalent *per day* for more than 2200 years

Mini-RF high resolution SAR of polar areas





The Lunar Hydrosphere

The Four Flavors of Lunar Water

- Water is or was in the lunar interior (as a *minor* component; 250-700 ppm)
  - Water from deep mantle (> 400 km depth) component of volatiles driving lunar pyroclastic eruptions
- Water and OH molecules present at latitudes > 65° at both poles
  - Present as adsorbed monolayer and bound in mineral structures
  - Increasing concentration with increasing latitude (~800 ppm and *greater*)
  - Temporally variable; preferentially located in cooler locales (it's moving)
- Water ice is admixed into regolith in polar regions
  - LCROSS site (floor of Cabaeus) is 5-10 wt.% water; both ice particles and water vapor ejected during impact
  - Other cometary volatiles are present (e.g., carbon dioxide, methane, sulfur dioxide, methanol, ethanol)
  - Concentrations vary laterally, vertically; "fluffy" physical nature
- **Thick (~2 m), "pure" water ice is found in some permanently shadowed craters near the poles**
  - **High CPR materials in over 40 craters (3-12 km dia.) near north pole**
  - **Suggest over 600 million metric tonnes of "pure" water ice; reserves of ice mixed with dirt are much greater**

The Lunar Hydrosphere

What do we need to know?

Nature, locations, and properties of polar microenvironments

- Sunlit areas: durations and timings, thermal conditions, electrical and plasma properties
- Dark areas: temperatures, thermal gradients, conductivity, physical nature of regolith and rocks

Distribution and state of polar ice and other volatiles

- Locations, concentrations, lateral and vertical continuity
- Physical state, temperatures, mixture of silicate contaminants

Composition of polar ice and other volatiles

- Concentration of water, other volatile species, ammonia, methane, organics
- Variation laterally and vertically in composition
- Processes of deposition and addition, processes of destruction
- Origin and history of volatiles

Physical properties of polar deposits

- Mechanical strength, penetration resistance, excavation properties, soil and rock mechanics inside polar cold traps
- Lateral and vertical variations in physical properties

The Value of Lunar Polar Ice

- A concentrated, easily usable form of H_2, a rare lunar element
  - Two orders of magnitude *less* energy to extract H_2 from icy regolith than from dry regolith
- A source of life support consumables
- Reactants for fuel cell electrical power
- Shielding for lunar surface habitats
- Propellant for the cislunar transportation system

Table 1. Energies required for selected lunar resource processes

Operation	Specific Energy
Equatorial Moon	
Excavation of regolith	0.01 kWh/kg regolith (electric)
Reduction of SiO_2 to Si + O_2	10.4 kWh/kg O_2 (electric)
Extraction of hydrogen from dry regolith[1]	2250 kWh/kg H_2 (thermal)
Polar regions	
Excavation of regolith	0.01 kWh/kg regolith (electric)
Extraction of water from icy regolith[2]	2.8 kWh/kg H_2O (thermal)
Electrolysis of water	4.7 kWh/kg O_2 (electric)
Electrolysis of water	48 kWh/kg H_2 (electric)

1. Assumes 100 ppm H_2, heated 800° C above ambient 2. Assumes 1% ice, heated 100° C above ambient

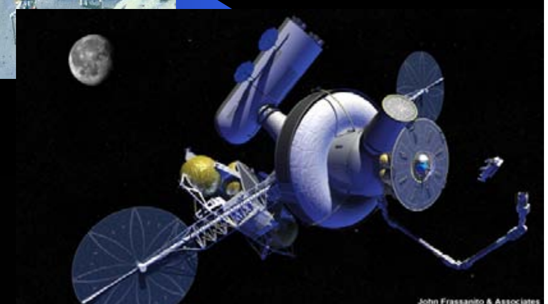
The Value of Lunar Resources

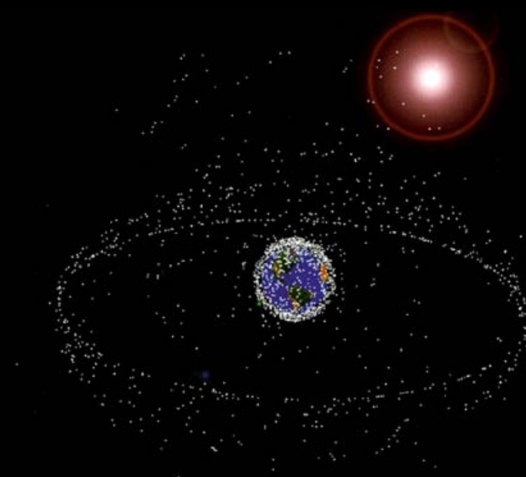
Materials on the Moon can be processed to make hydrogen and oxygen for use on the Moon and for export to Earth-Moon (cislunar) space

Propellant produced on the Moon can make travel within and through cislunar space routine

This eventuality will completely change the spaceflight paradigm

Routine access to cislunar space has important economic and strategic implications



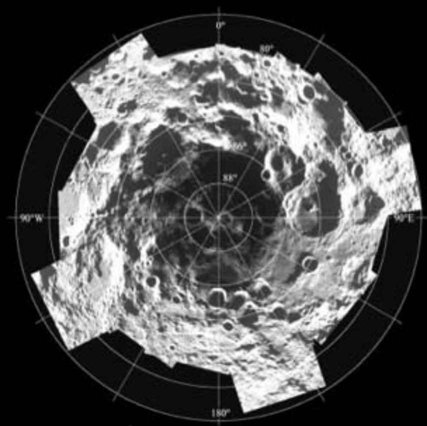


For More Information:

Spudis Lunar Resources

Using the Moon to learn how to live and work productively in space

What's this web site all about?



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The Moon: Port of Entry to Cislunar Space (April 2010)

The New Space Race (SpaceRef, Feb. 2010)

Moonwake - Two Novels for Young Adults **Free Downloads**

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