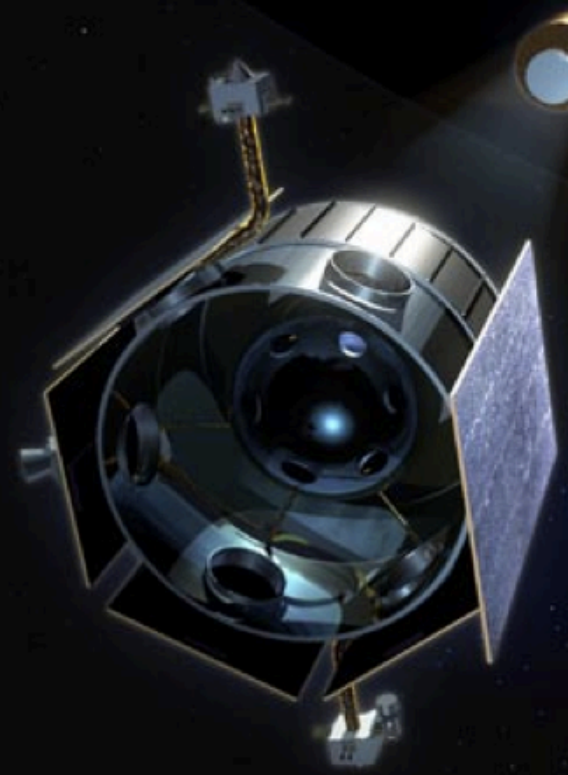
Poles of the Moon



Robert Citron

Lunar Seminar

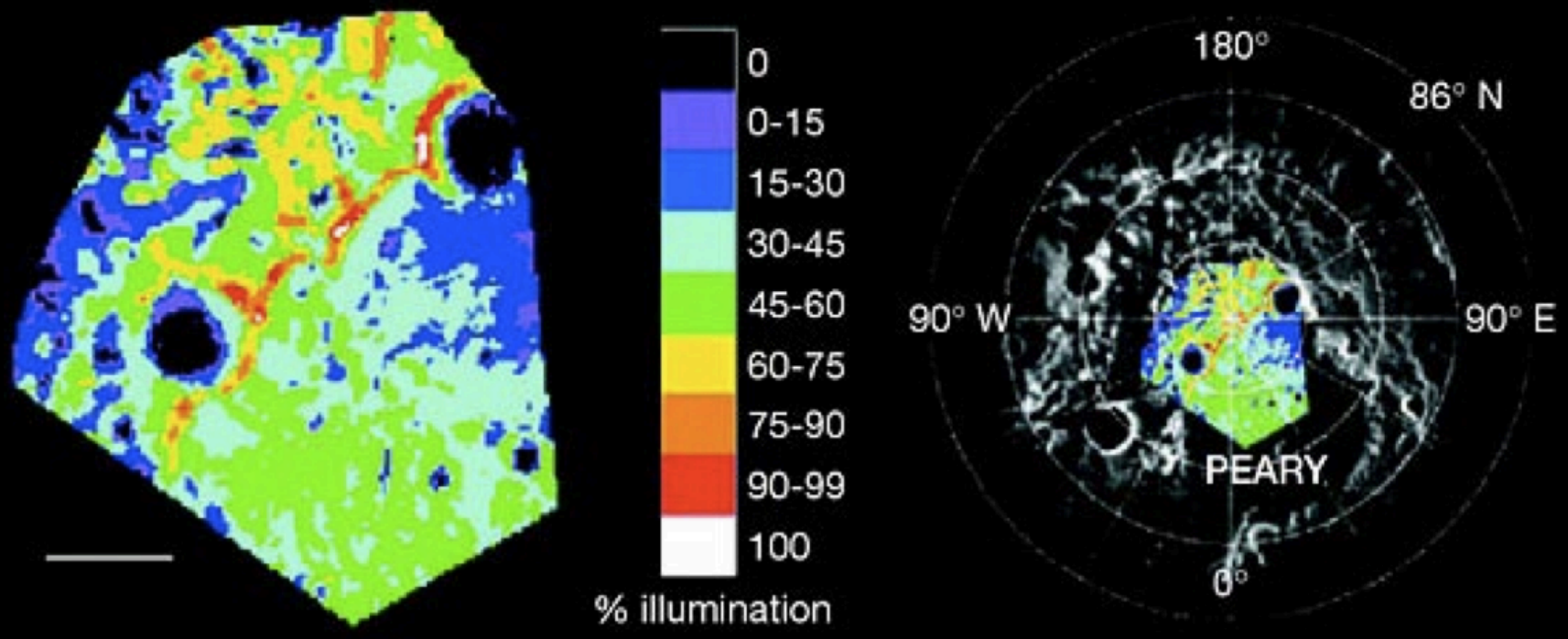
4/6/10

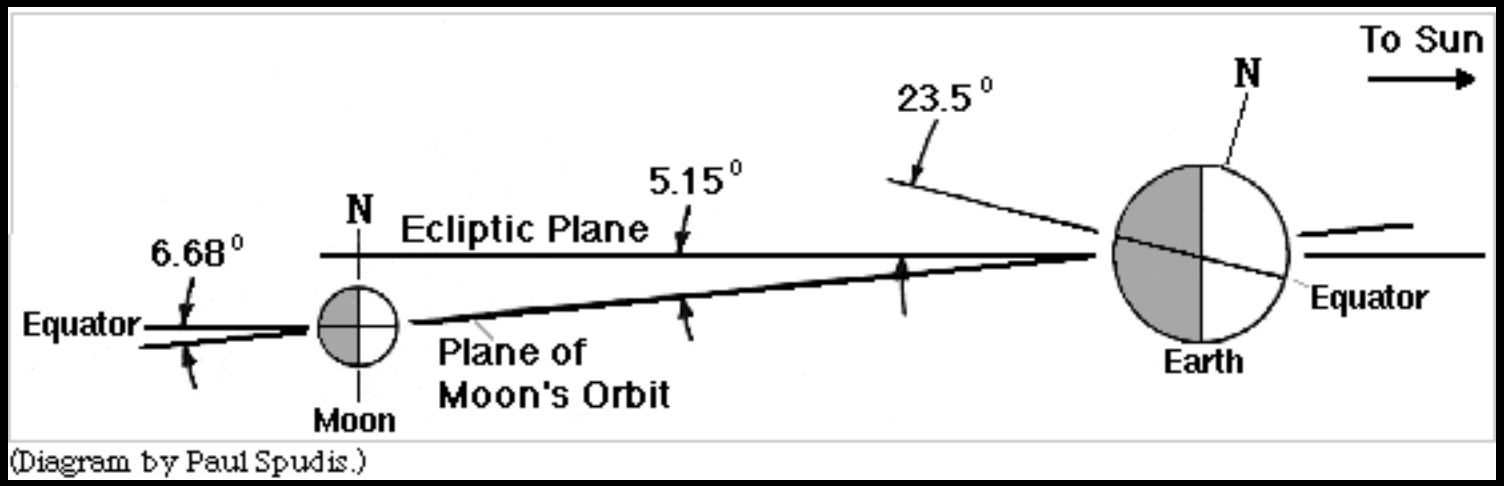
Outline

- Previous Observations
  - Clementine, Lunar Prospector
- Science at the Poles
- Recent Observations
  - LRO, LCROSS, Chandrayaan-1
- Exploration

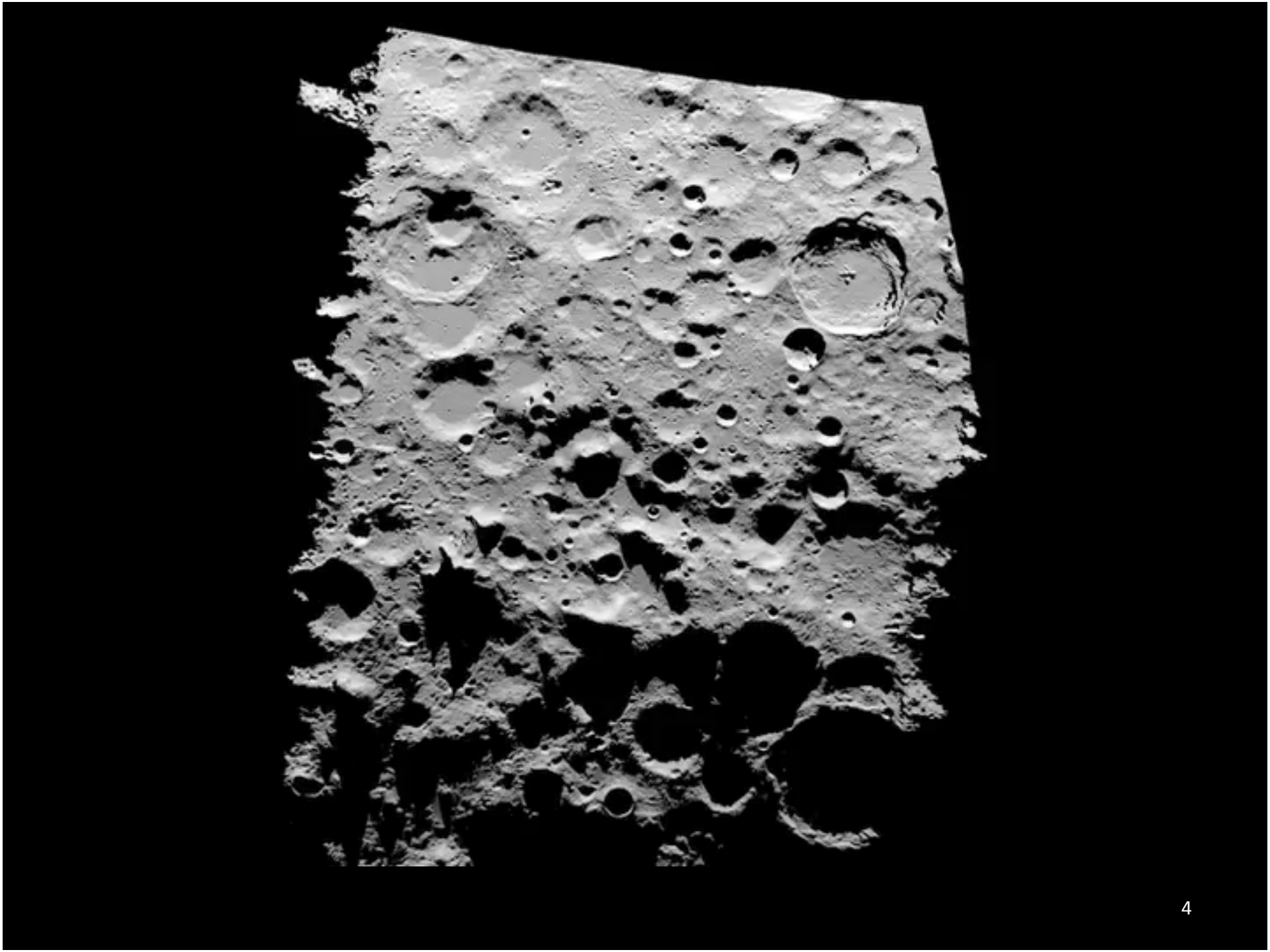
Previous Observations

Dark Sides of the Moon



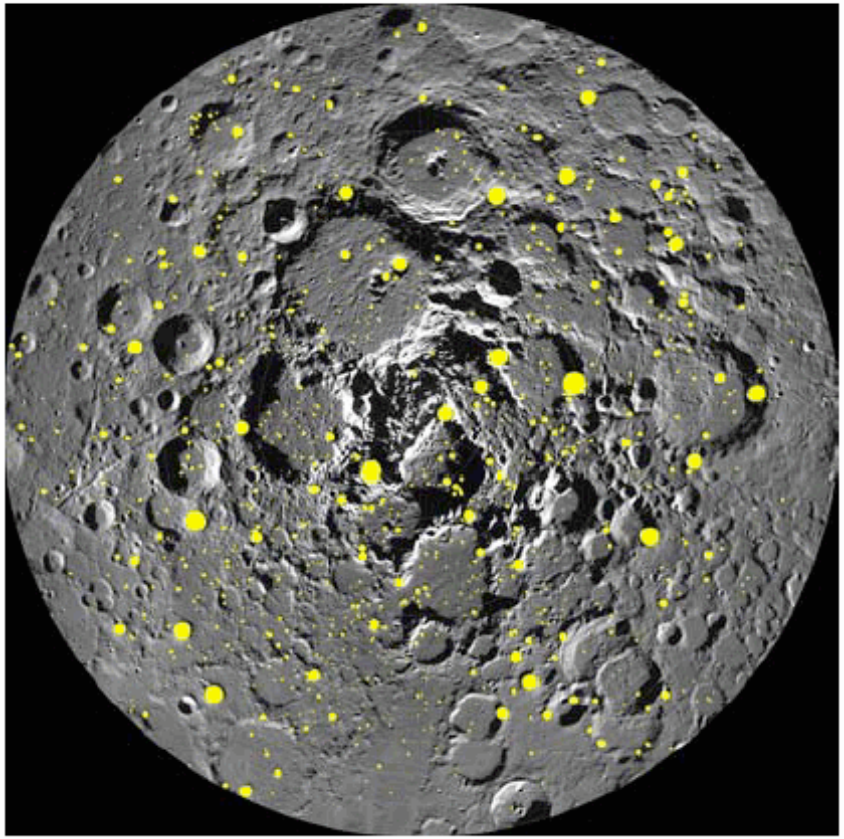


(Diagram by Paul Spudis.)



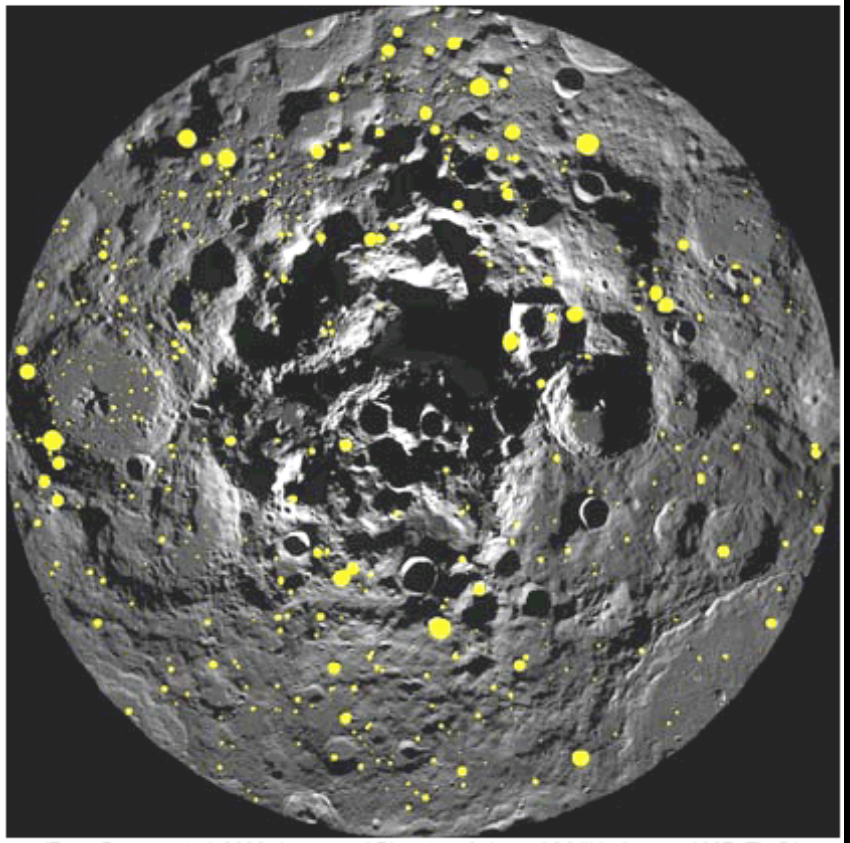
Permanently Shadowed Craters

Craters in the lunar north pole area containing permanent shadow



(From Bussey *et al*, 2003, *GRL*, v. 30, Fig.4 .)

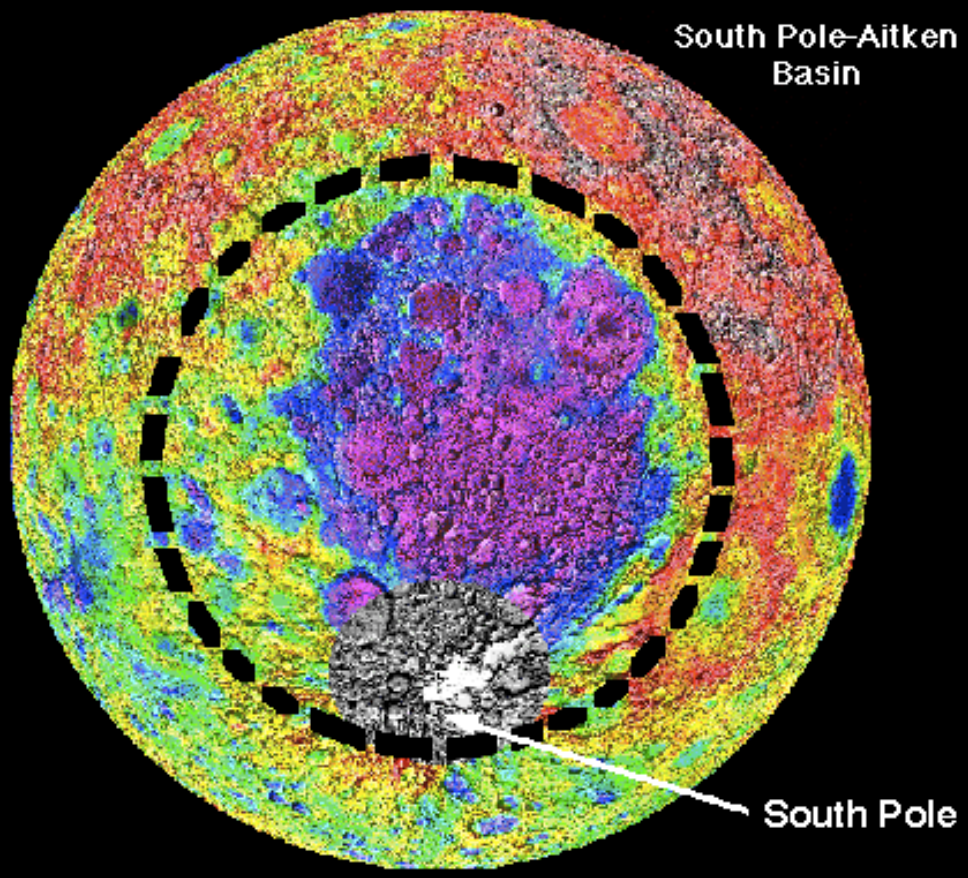
Craters in the lunar south pole area containing permanent shadow

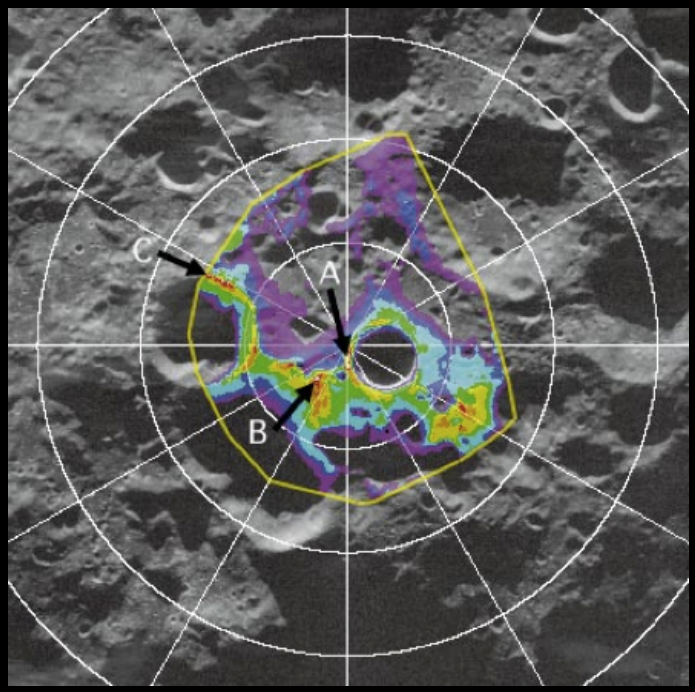


(From Bussey *et al*. 2003, *Lunar and Planetary Science XXXIV*, abstract 1897, Fig.5.)

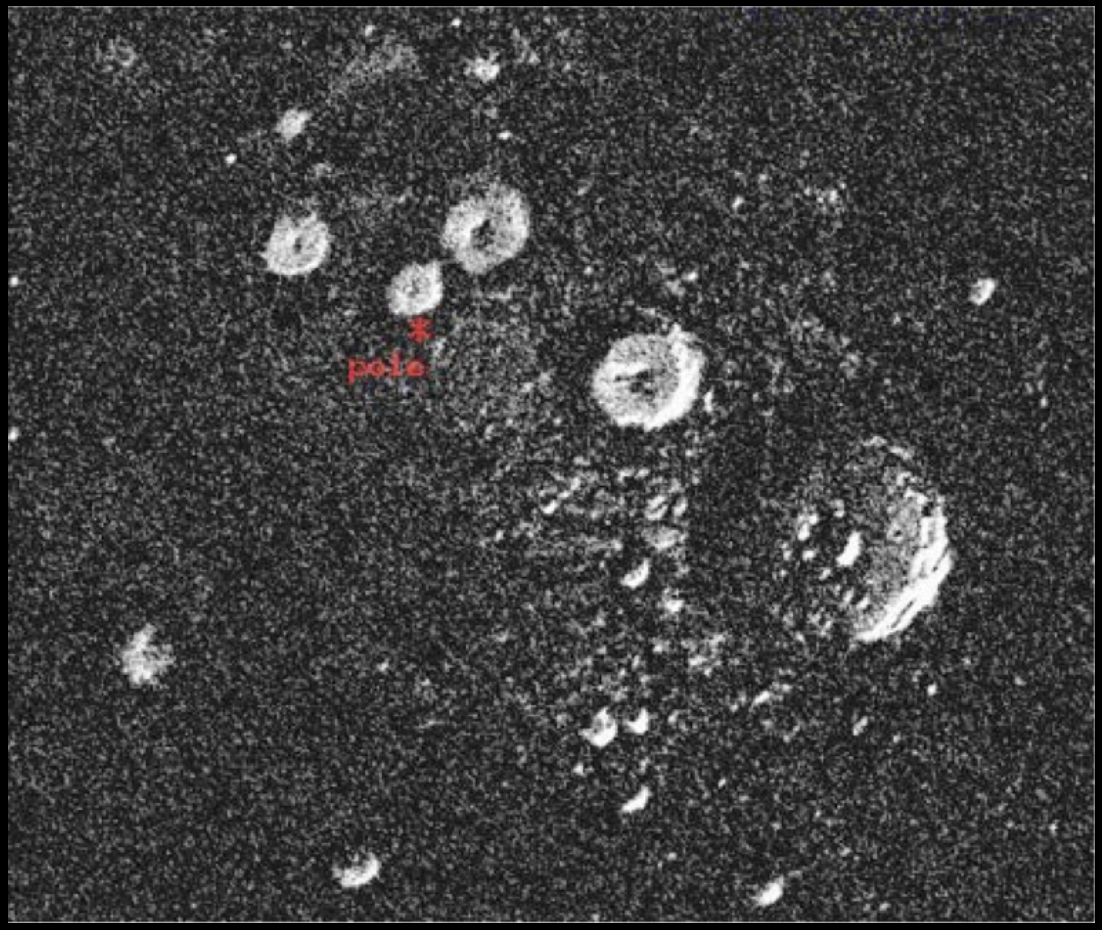
Images extend to 78 degrees North/South

South Pole Darkness



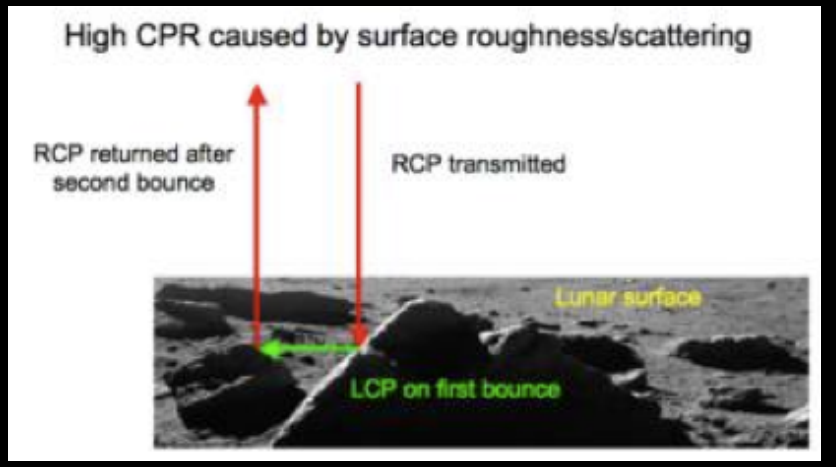


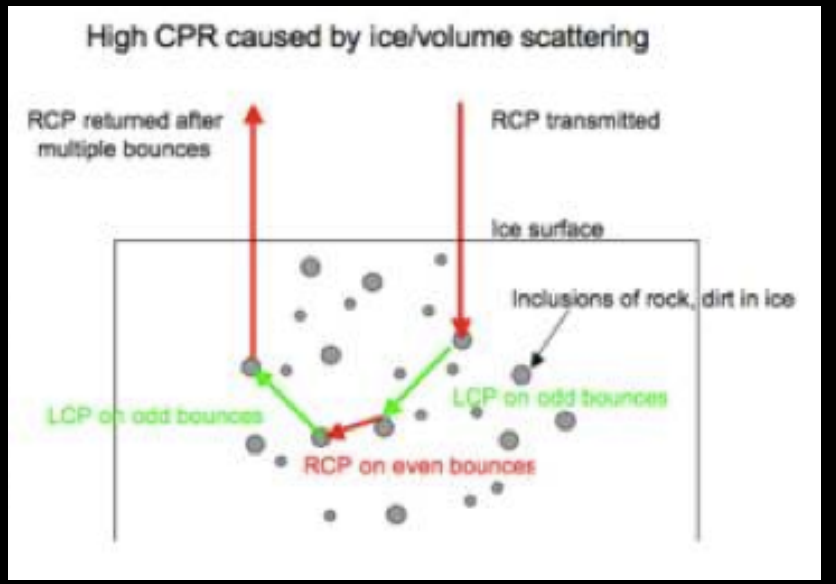
Poles of Mercury



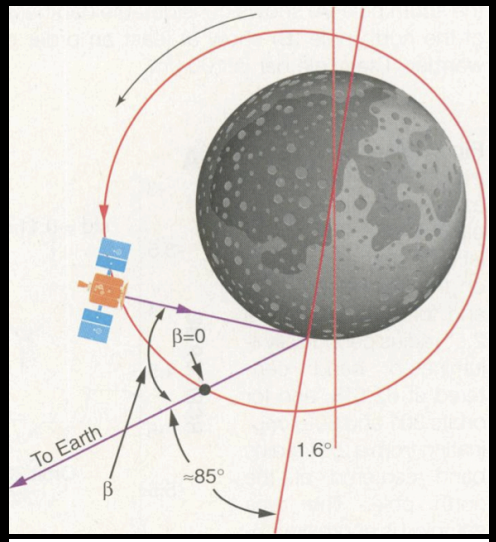
Why is ice radar-bright?

- Coherent Backscatter Opposition Effect
  - Radar magnitude
  - Ratio of outgoing to returned polarization
  - Angular dependence of these properties



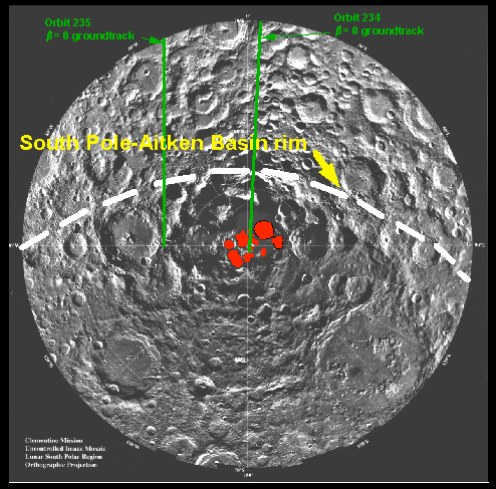


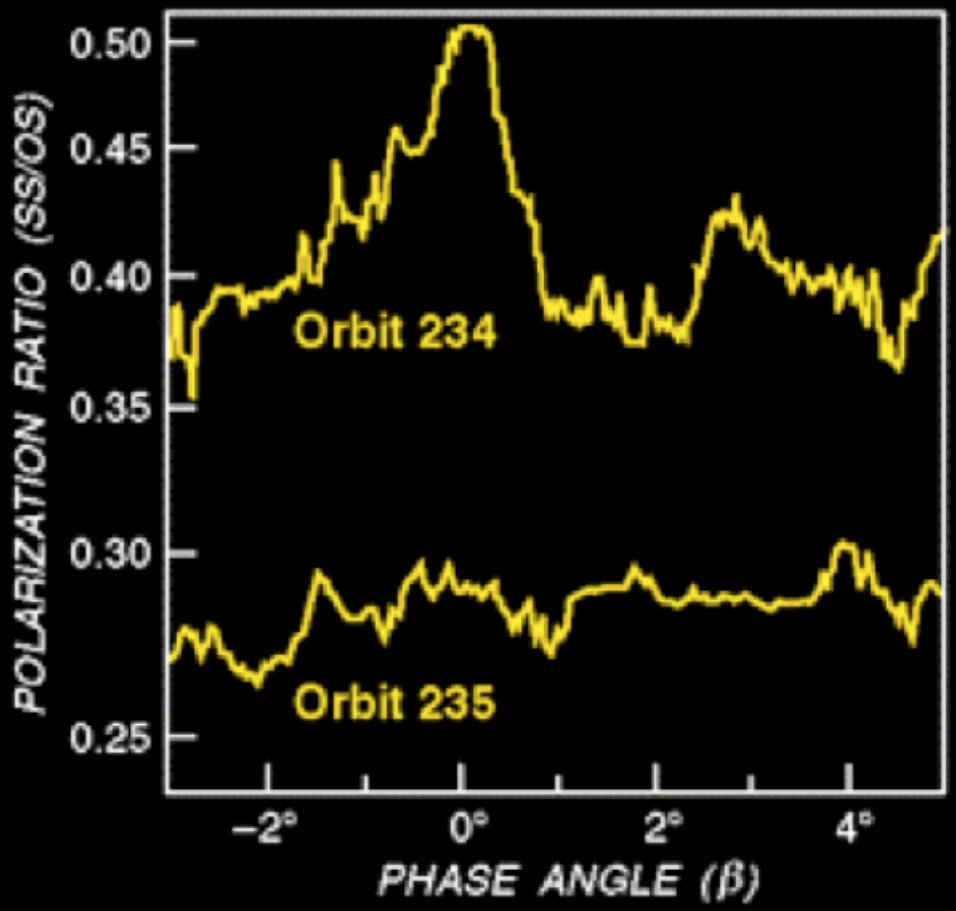
Clementine Observations



(Courtesy of Lunar and Planetary Institute, basemap from the Clementine Project; USGS image processing.)

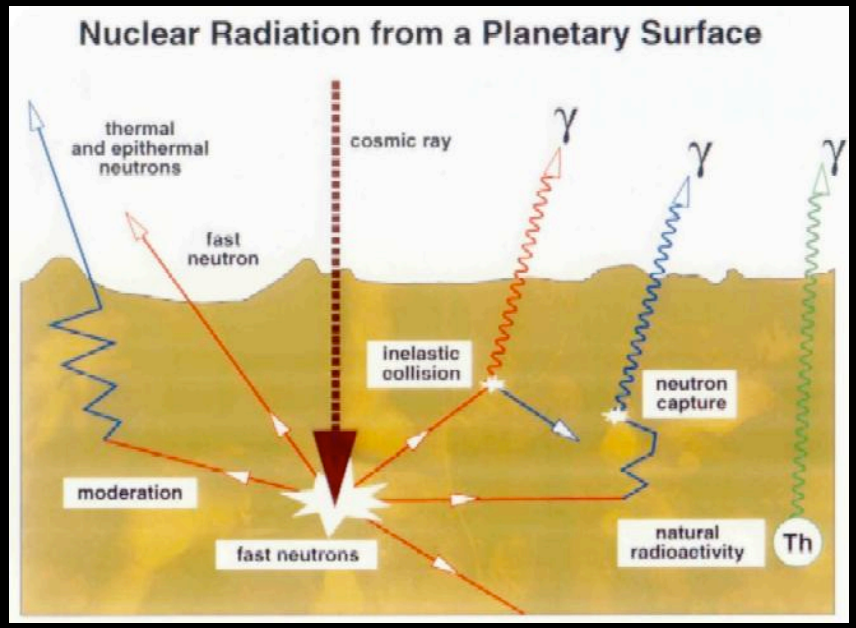
Clementine Map of the South Polar Region of the Moon

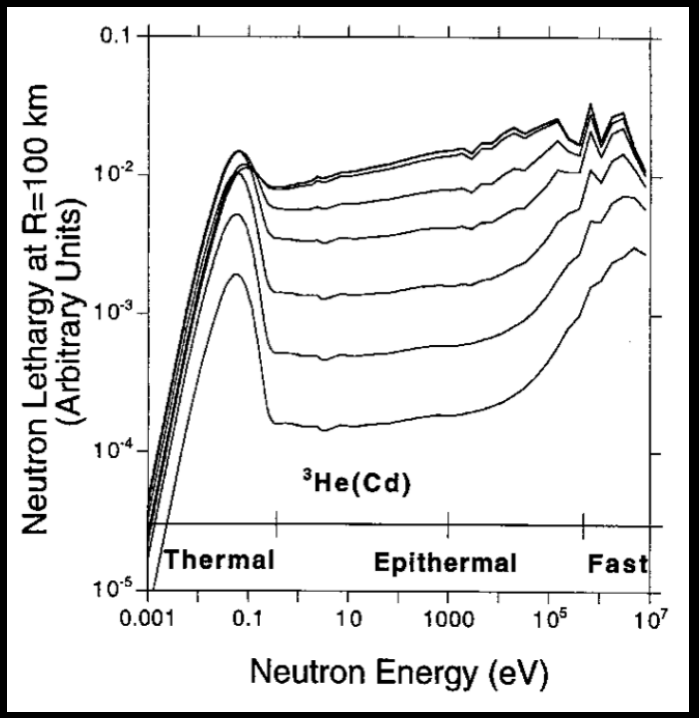




Neutron Measurments

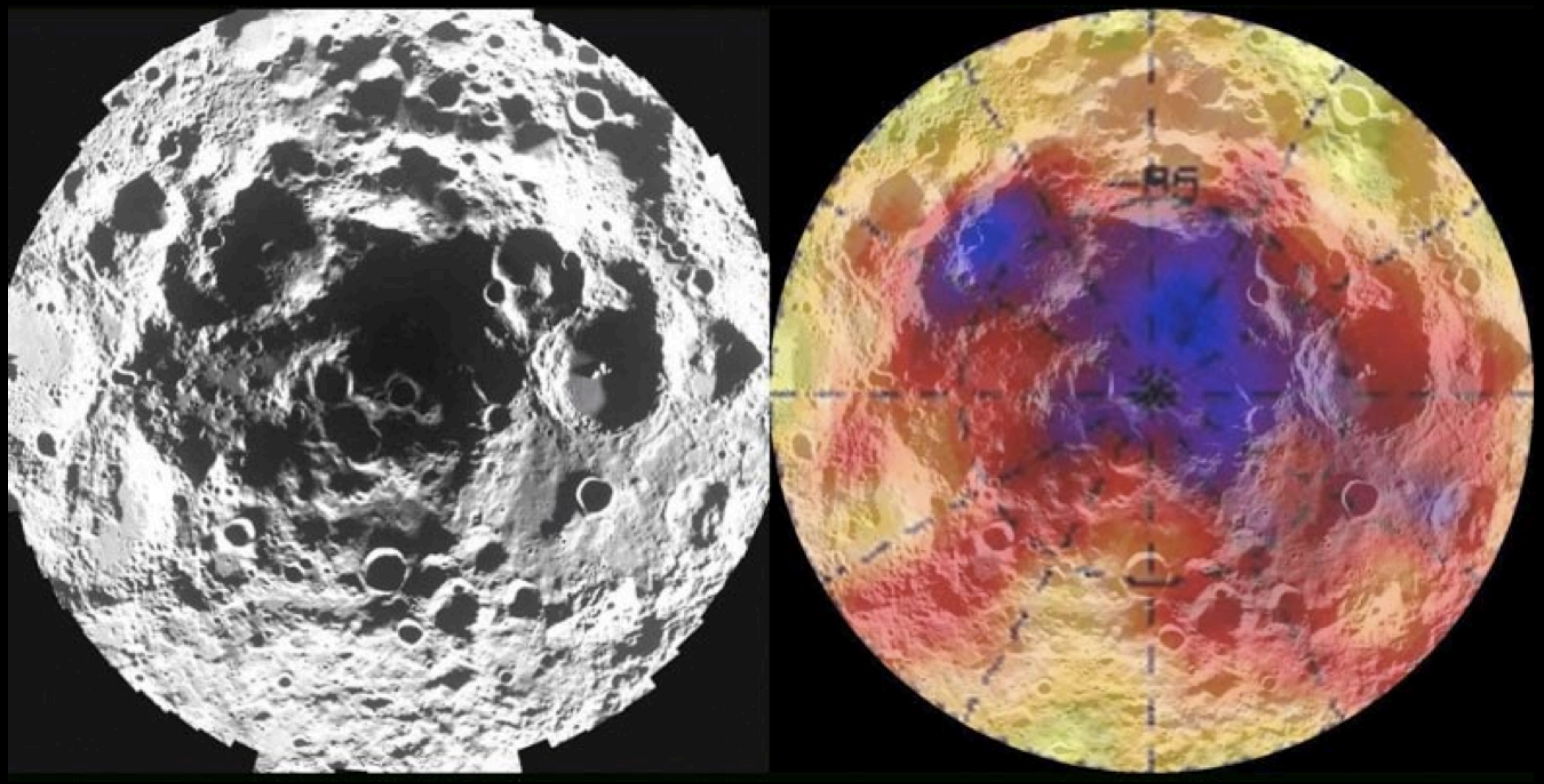
Fast neutrons – **high** energy
Epithermal neutrons – intermediate energy
Thermal neutrons – low energy (thermalized)





H20 → Depletion in epithermal neutron flux

Lunar Prospector



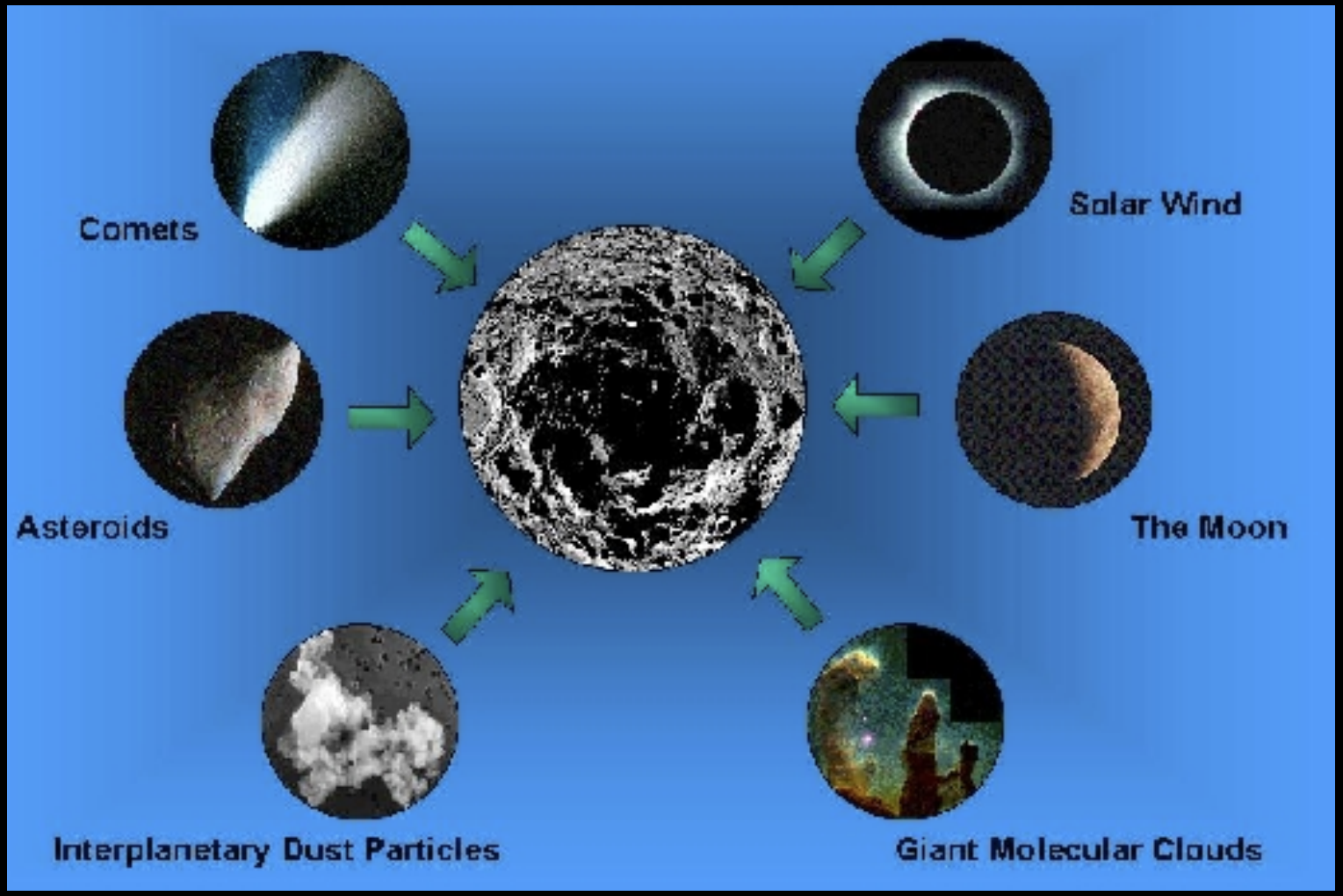
Depletion in epithermal neutron flux → H2O

Results and Controversy

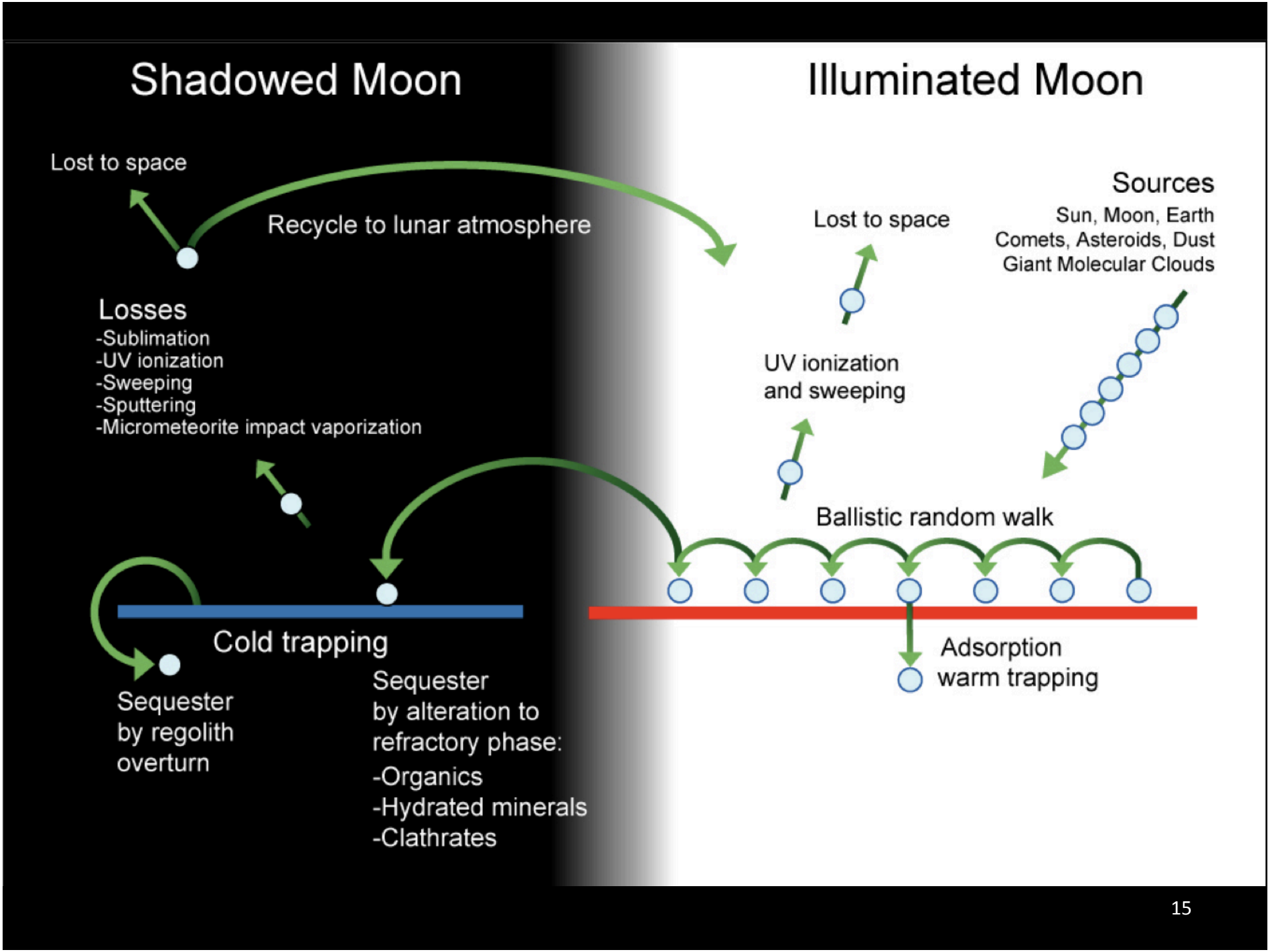
- Results: **1.5 wt % H_2O** from Radar and Neutron measurements
- Radar observations
  - High CPR in sunlit and dark regions
  - Surface roughness or water ice?
- Neutron Measurements
  - Hydrogen could be implanted by solar wind
  - No thermal neutron excess
    - Explained by 10cm layer overlying the water rich soil

Science at the Poles

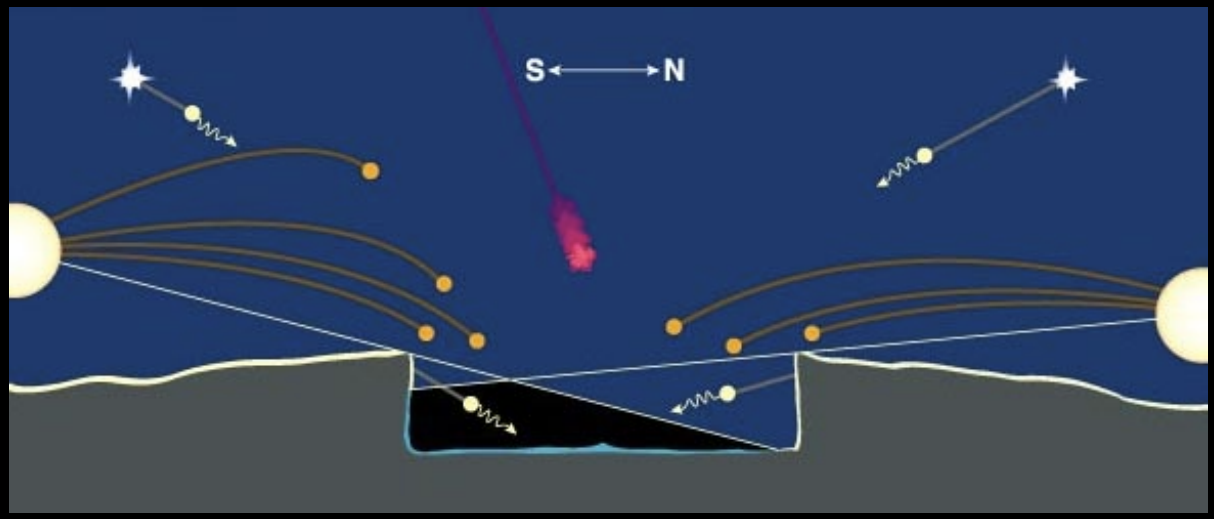
Sources of Volatiles at the Poles



Lucey 2001


Shadowed Moon
Illuminated Moon
Lost to space
Recycle to lunar atmosphere
Losses
-Sublimation
-UV ionization
-Sweeping
-Sputtering
-Micrometeorite impact vaporization
Lost to space
Sources
Sun, Moon, Earth
Comets, Asteroids, Dust
Giant Molecular Clouds
UV ionization
and sweeping
Ballistic random walk
Cold trapping
Sequester
by regolith
overturn
Sequester
by alteration to
refractory phase:
-Organics
-Hydrated minerals
-Clathrates
Adsorption
warm trapping

A Natural Laboratory

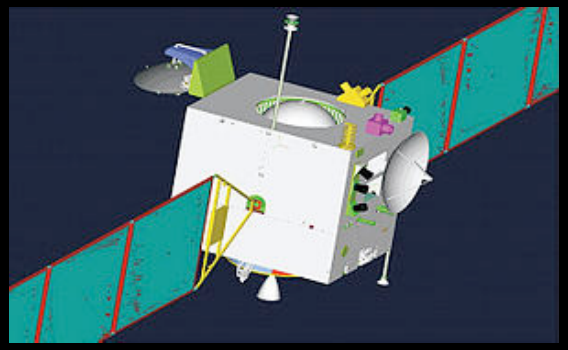


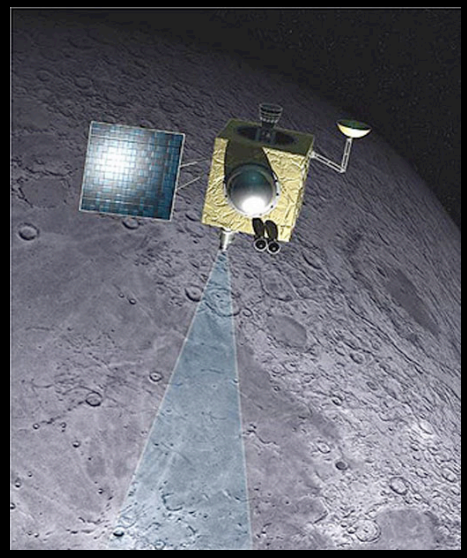
- Organic synthesis of trapped volatiles
- Temperature cycling
- Clathrates promote retention of methane and CO2
- Monolayers of ice form hydrated minerals
- Hydrothermal systems in hot ejecta blankets

Lunar Atmosphere

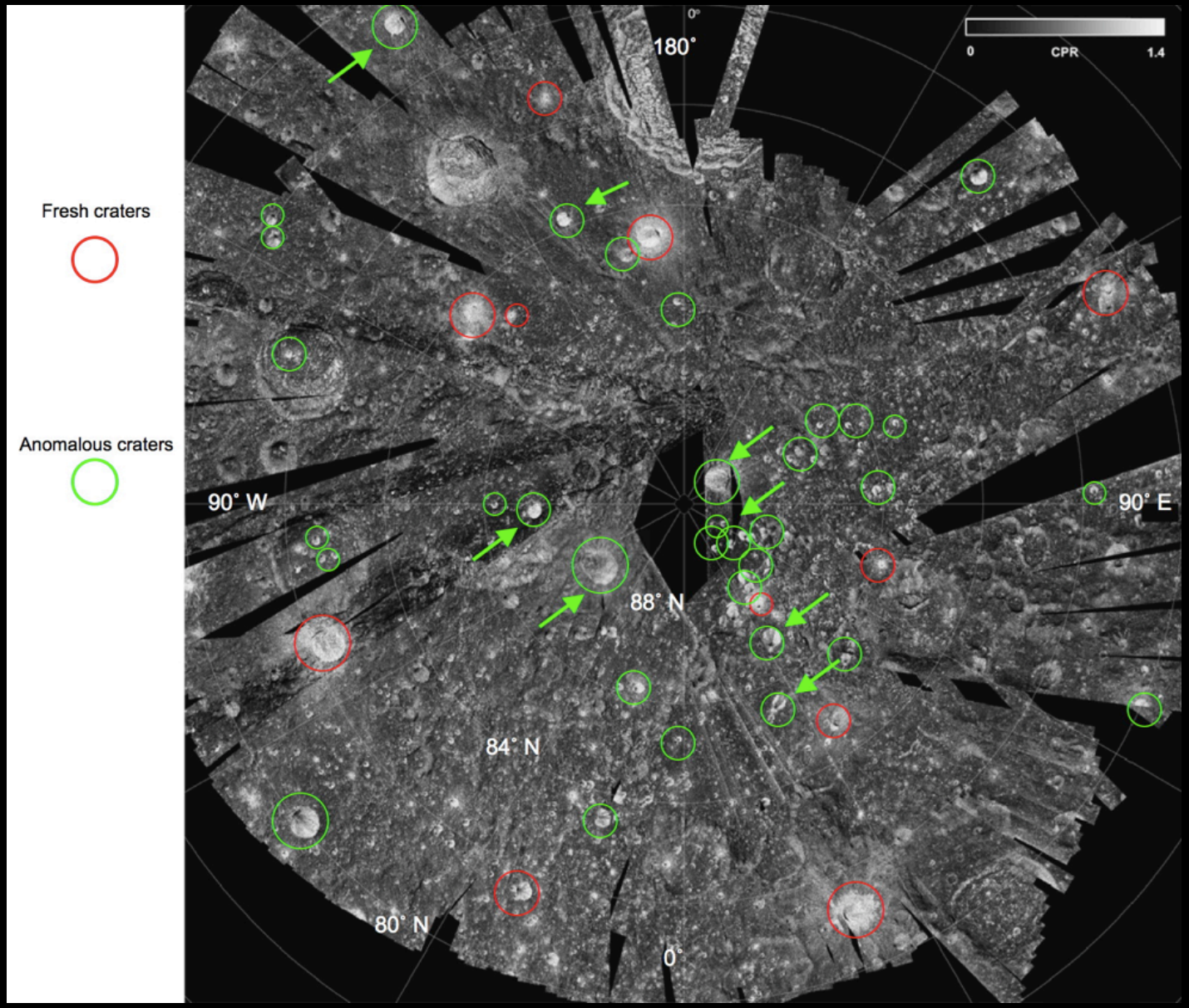
- Cold traps at poles interact with lunar exosphere
- Equilibrium between cold trapping and escape
- Lifetime of gases depends on flux of volatiles in and out of poles
  - Probably different than on Mercury
- Observational Evidence: Na column density decreases at the poles

New Observations



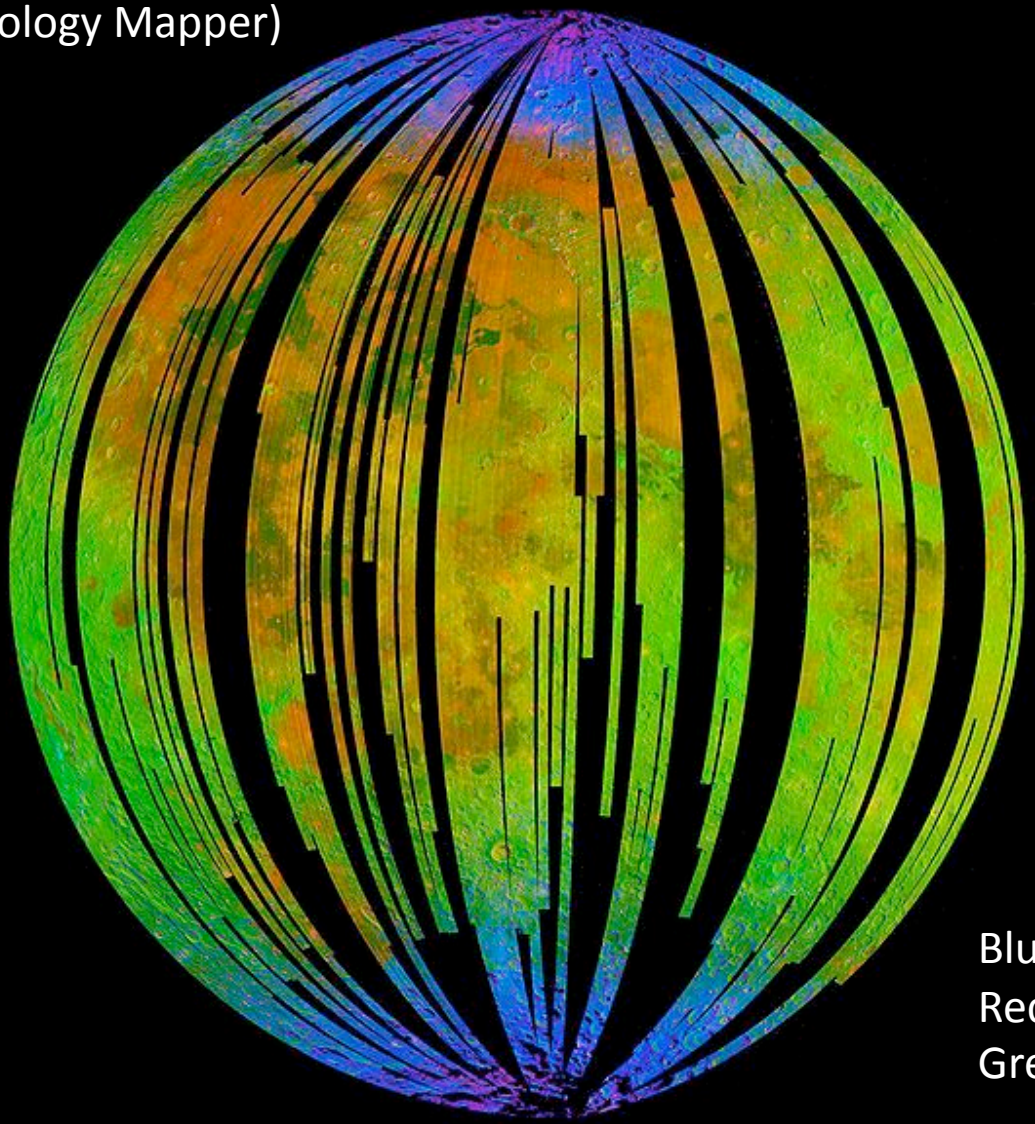


Chandrayaan-1



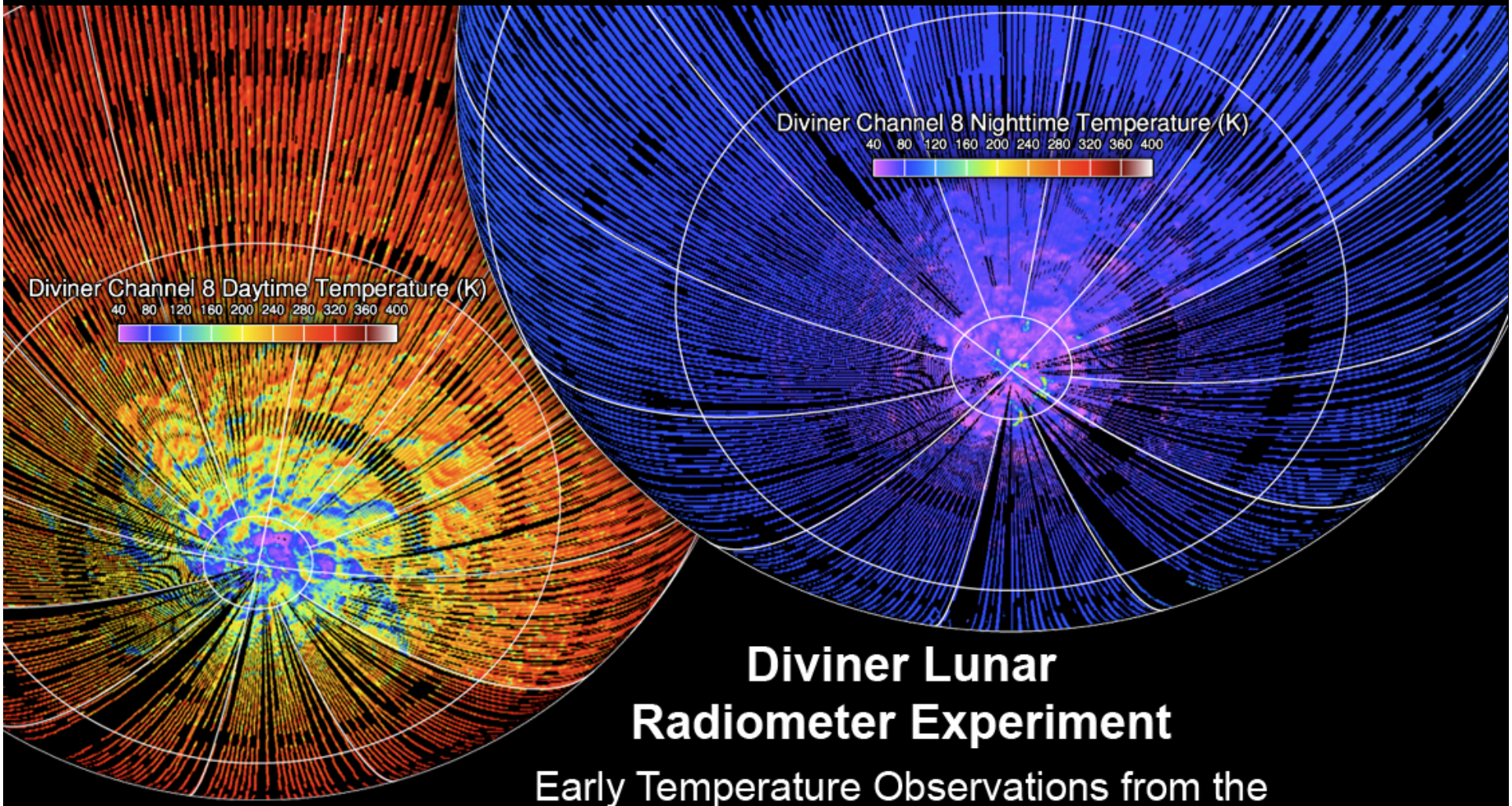
Chandrayaan-1

M^3 (Moon Minerology Mapper)



Blue – hydroxyl
Red – pyroxene
Green – brightness

LRO

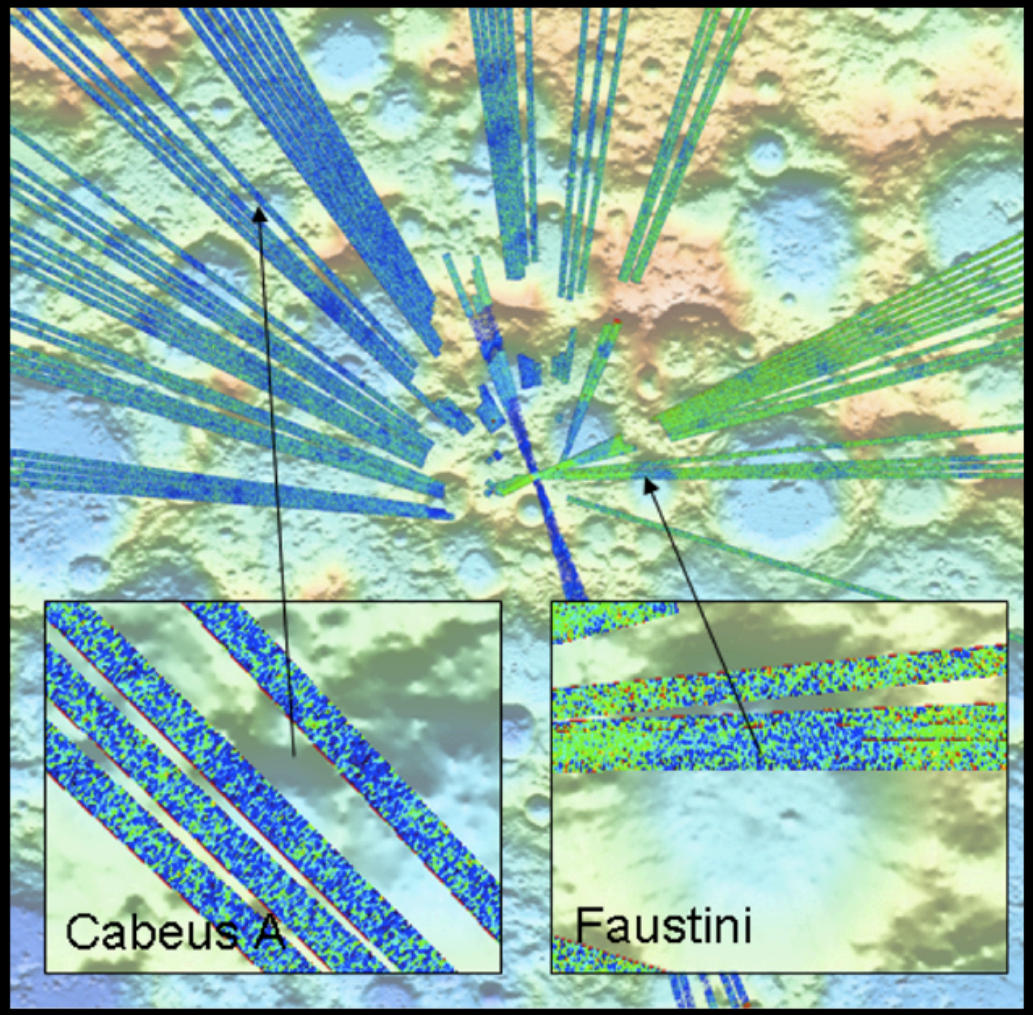


Diviner Lunar Radiometer Experiment

Early Temperature Observations from the Lunar South Pole

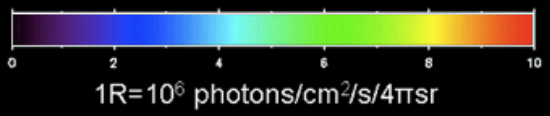
NASA

LRO

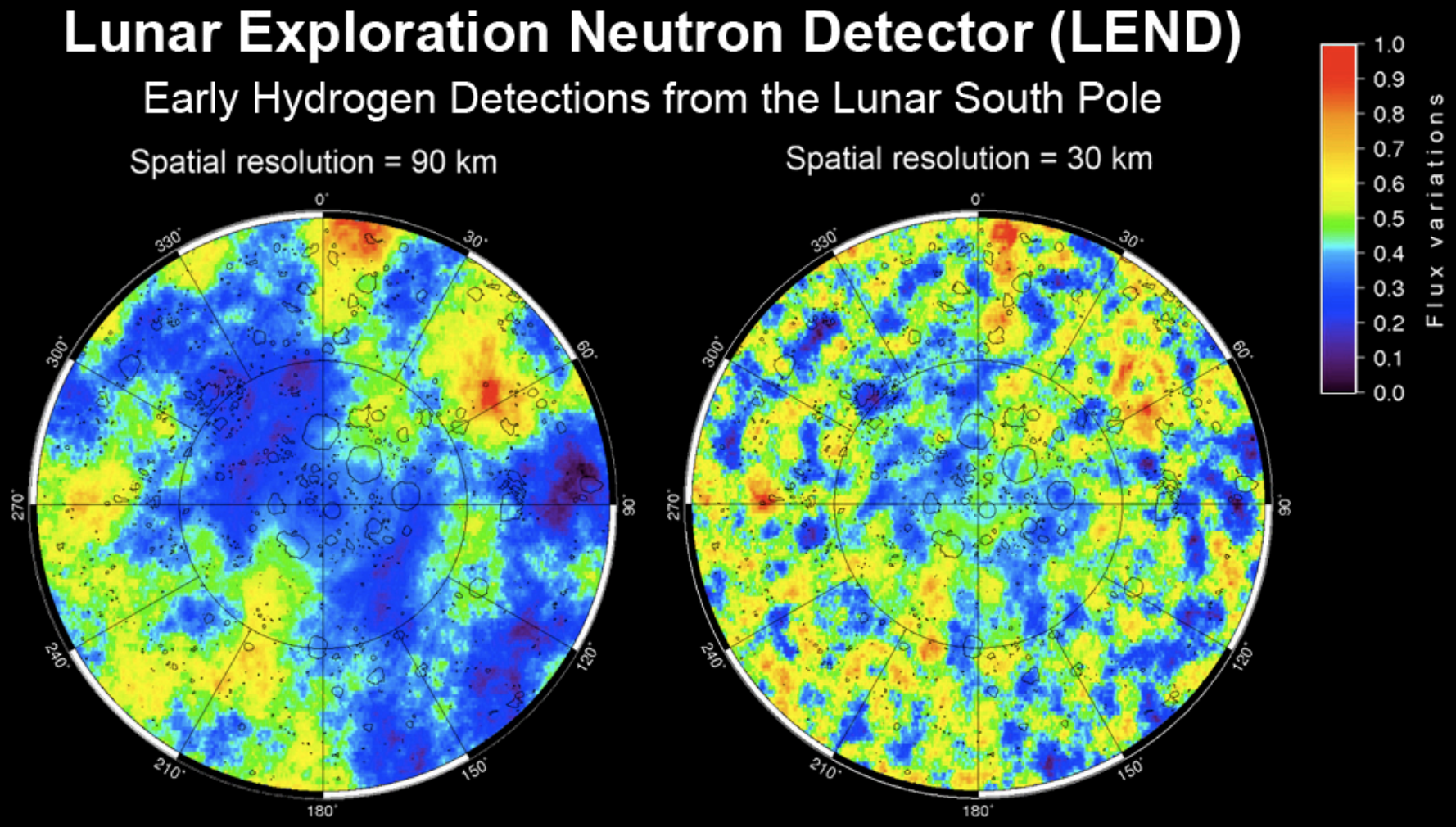


Lyman-Alpha Mapping Project (LAMP)

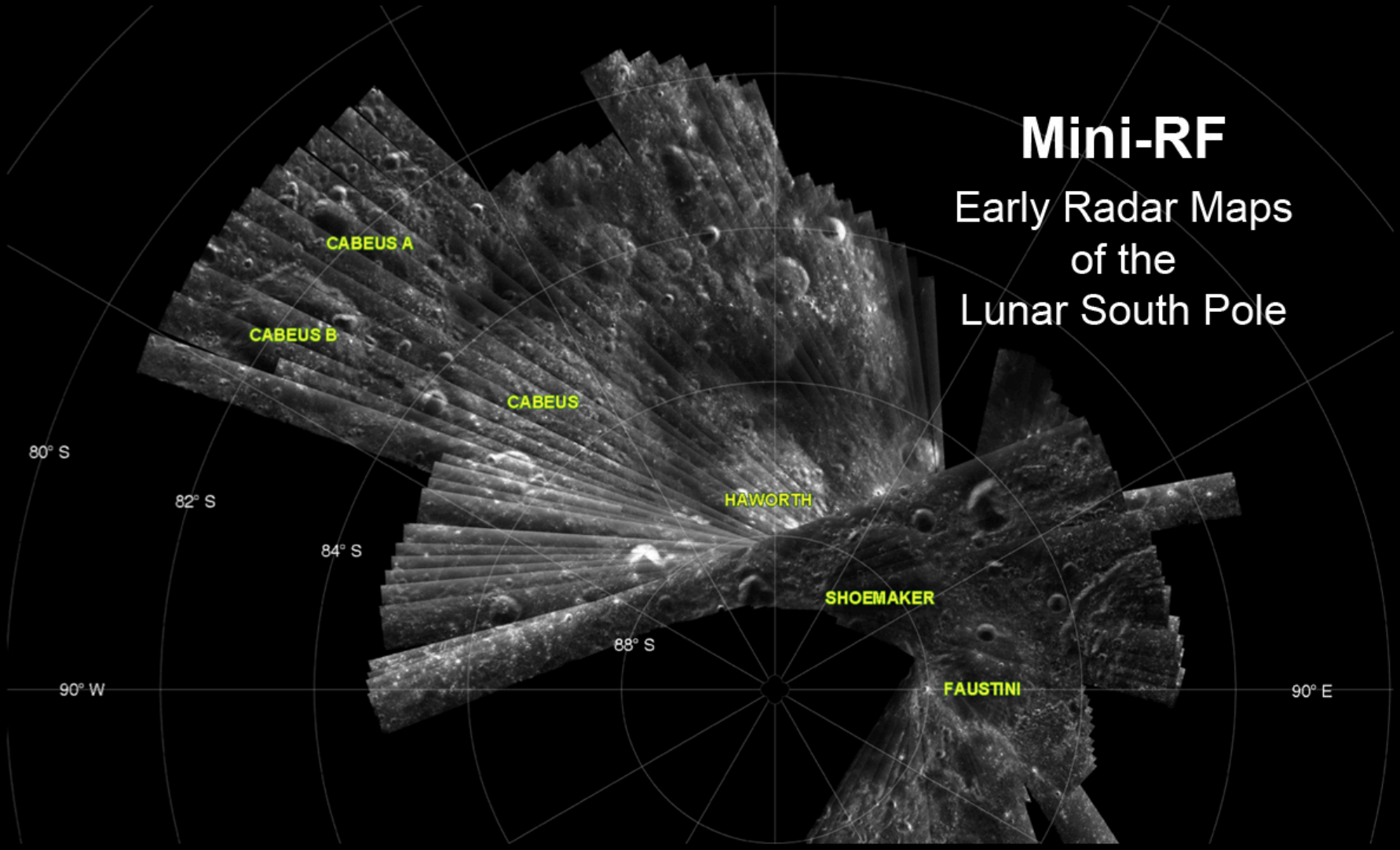
Early UV-Mapping from the Lunar South Pole



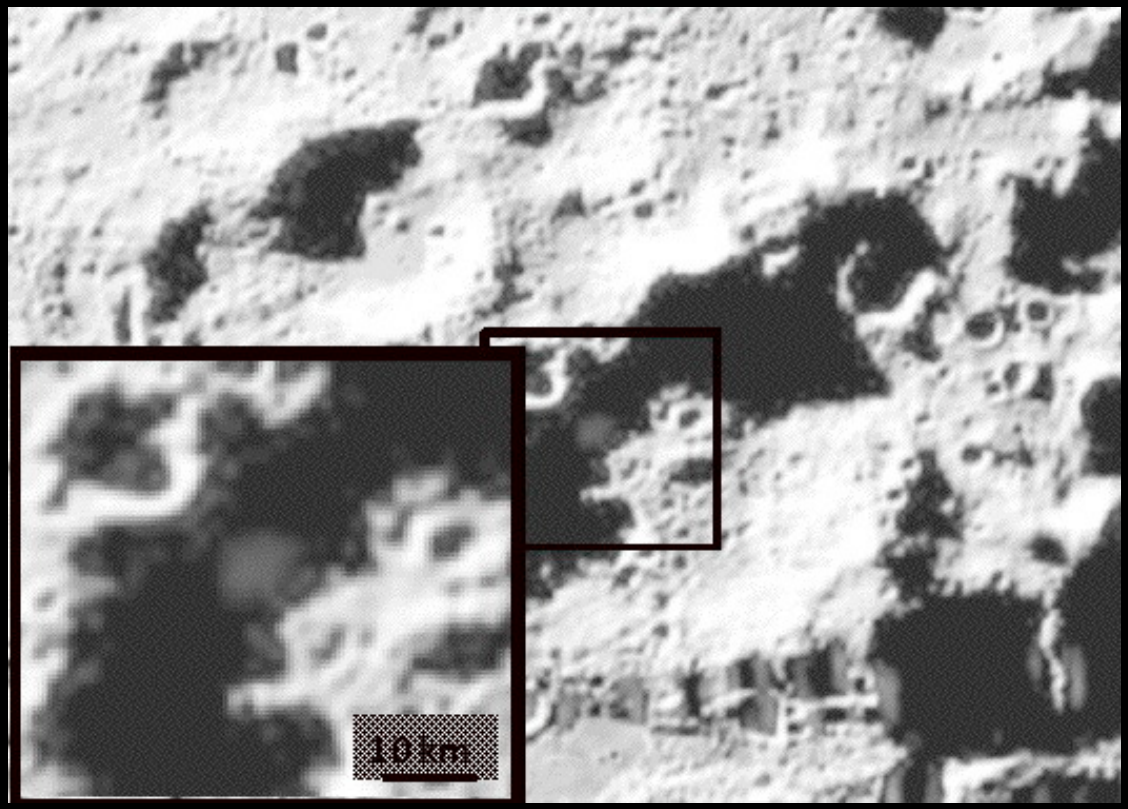
LRO


Lunar Exploration Neutron Detector (LEND)
Early Hydrogen Detections from the Lunar South Pole
Spatial resolution = 90 km
Spatial resolution = 30 km
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Flux variations

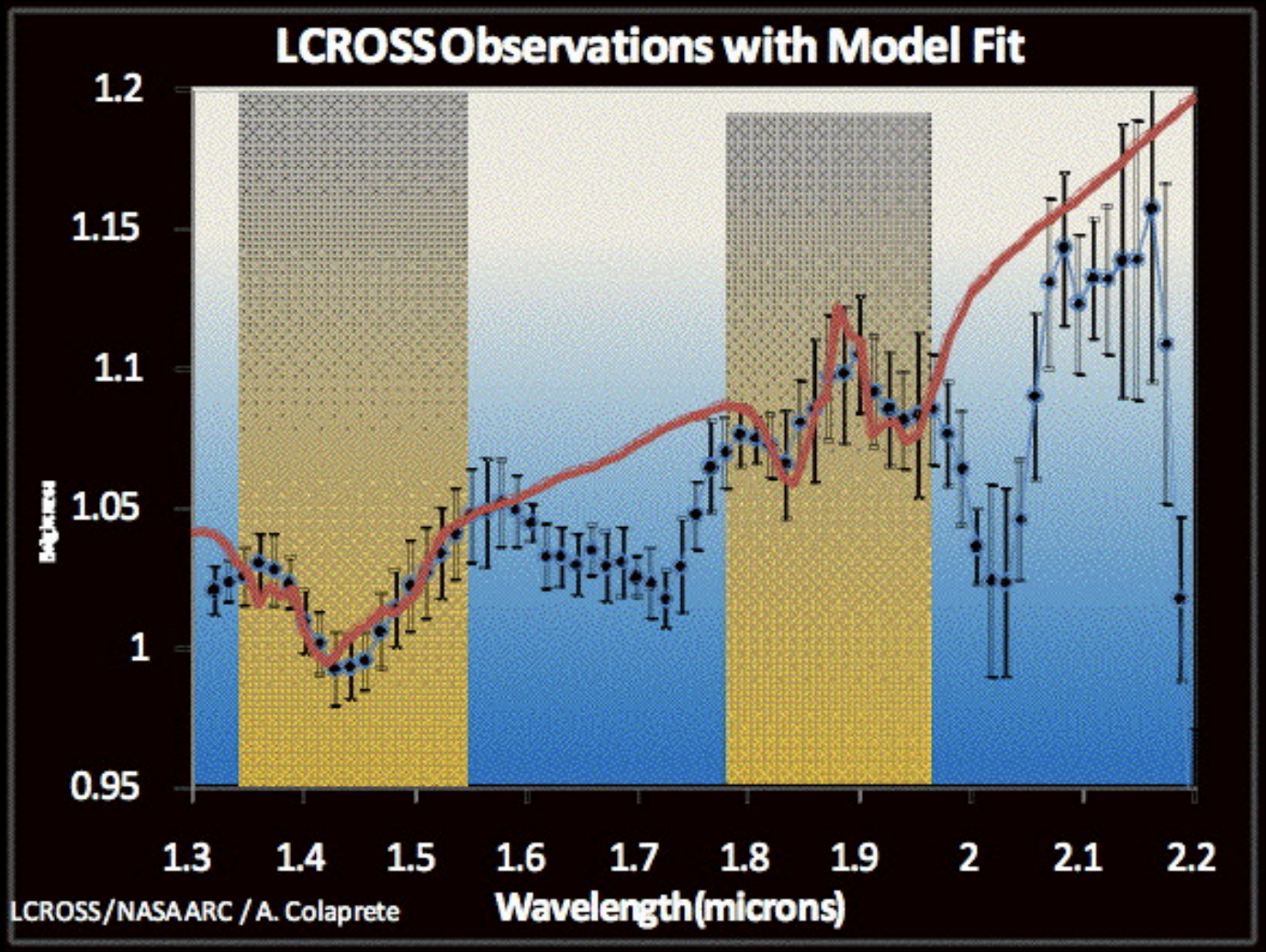
LRO


Mini-RF
Early Radar Maps
of the
Lunar South Pole
CABEUS A
CABEUS B
CABEUS
HAWORTH
SHOEMAKER
FAUSTINI
80° S
82° S
84° S
88° S
90° W
90° E

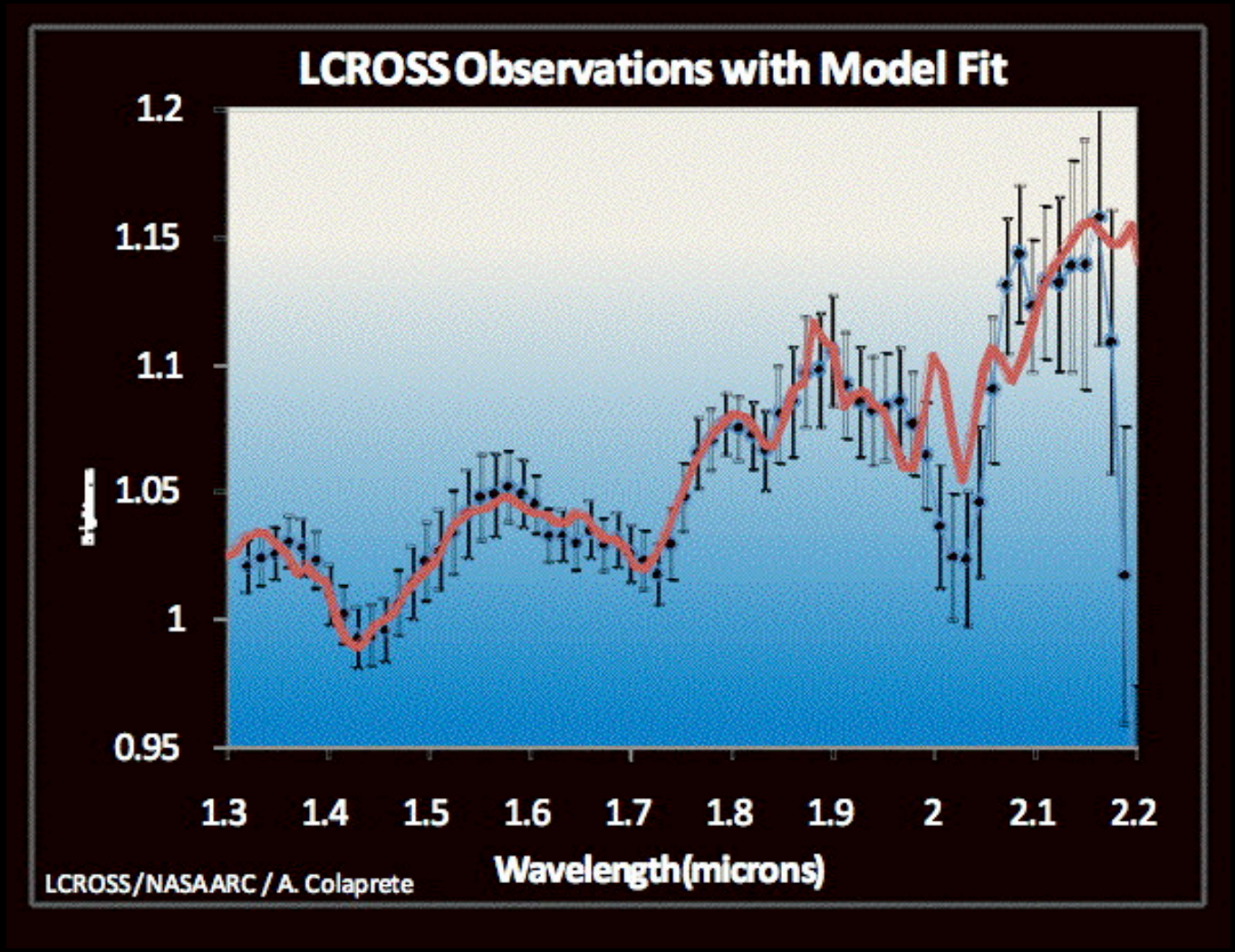
LCROSS



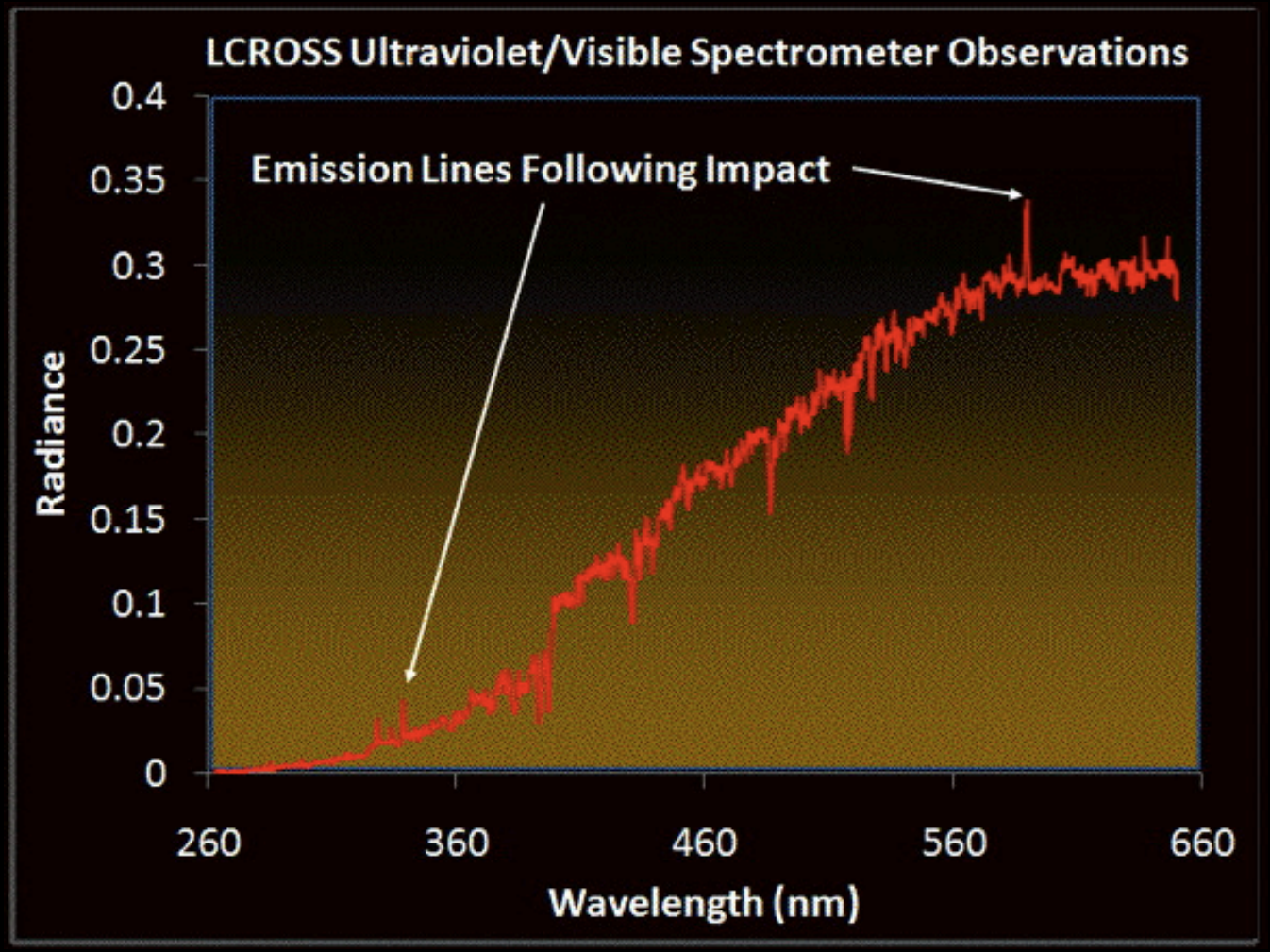
LCROSS


LCROSS Observations with Model Fit
1.2
1.15
1.1
1.05
1
0.95
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
LCROSS/NASA ARC / A. Colaprete
Wavelength (microns)

LCROSS

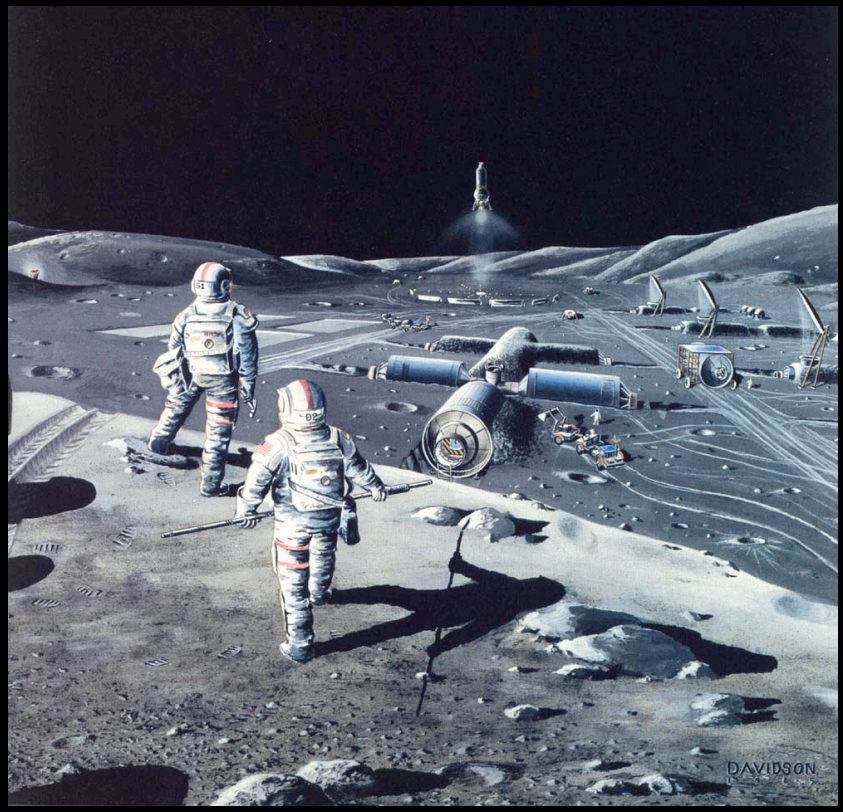

LCROSS Observations with Model Fit
1.2
1.15
1.1
1.05
1
0.95
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
2.2
Wavelength (microns)
LCROSS/NASA ARC / A. Colaprete

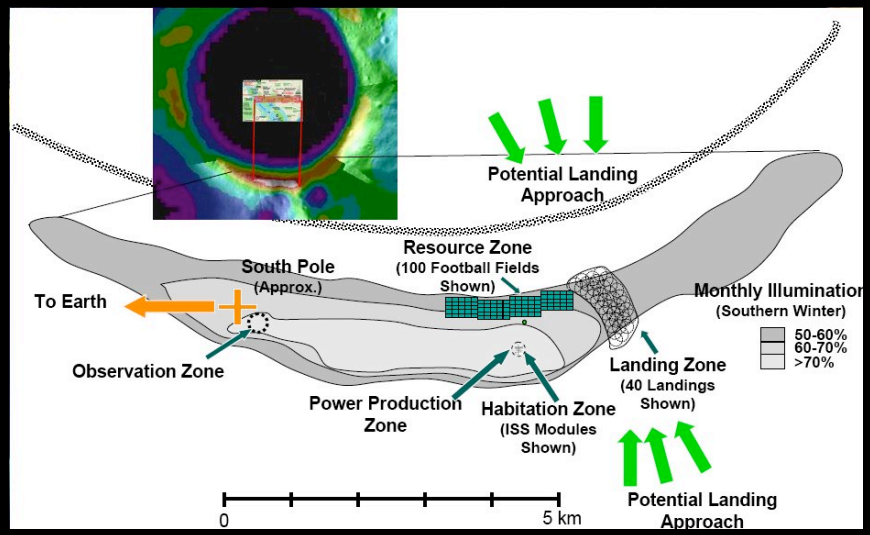
LCROSS


LCROSS Ultraviolet/Visible Spectrometer Observations
Emission Lines Following Impact
Radiance
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
260
360
460
560
660
Wavelength (nm)

Poles and Exploration

- Ideal lunar outpost site
- Areas of constant illumination/darkness
- Ice is a valuable resource, hard to extract
- Interesting science





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- Paul G. Lucey, *Potential for pre-biotic chemistry at the poles of the Moon*, 2000
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- www.spudislunarresources.com