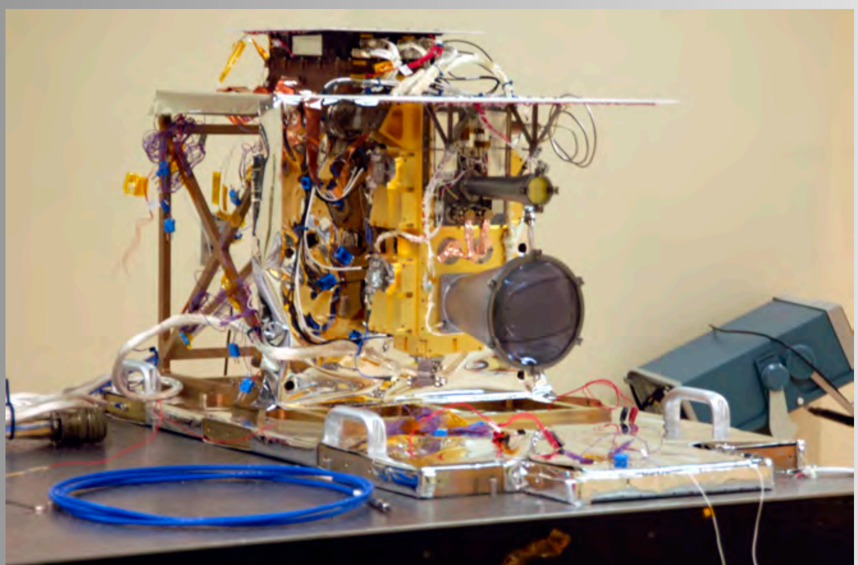
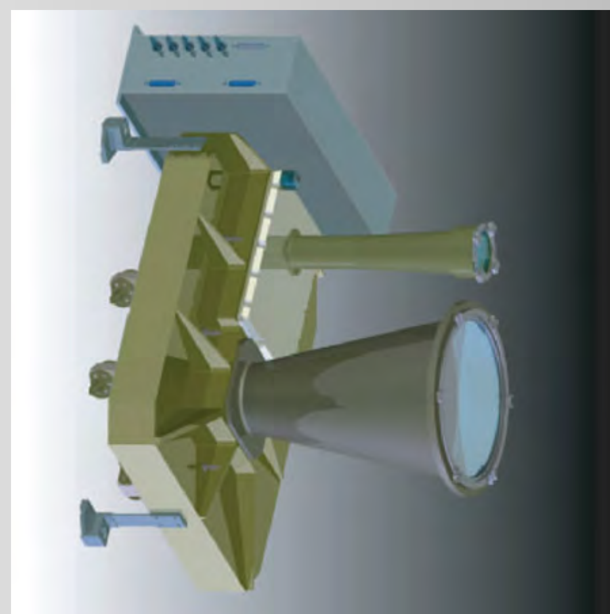
Recent Reflectivity Results

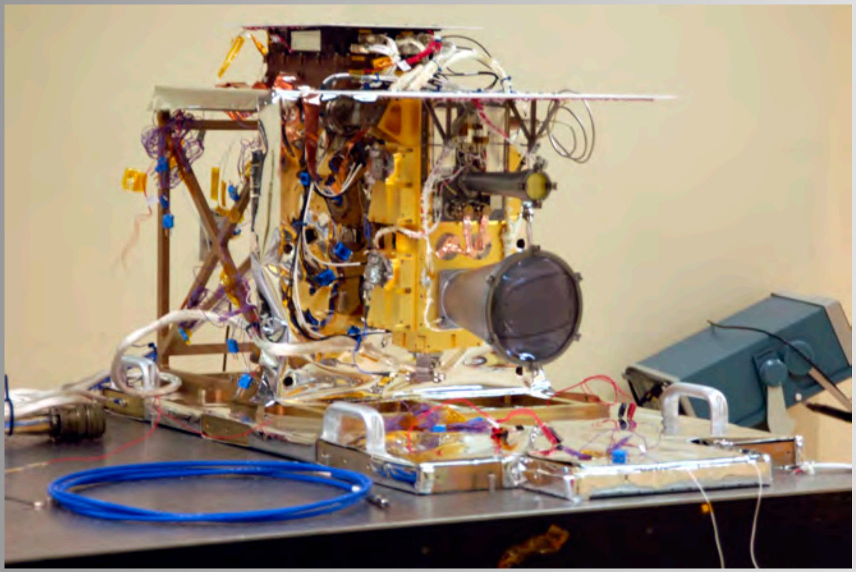
Paul G. Lucey
University of Hawaii
Greg Neumann
NASA Goddard Space Flight Center

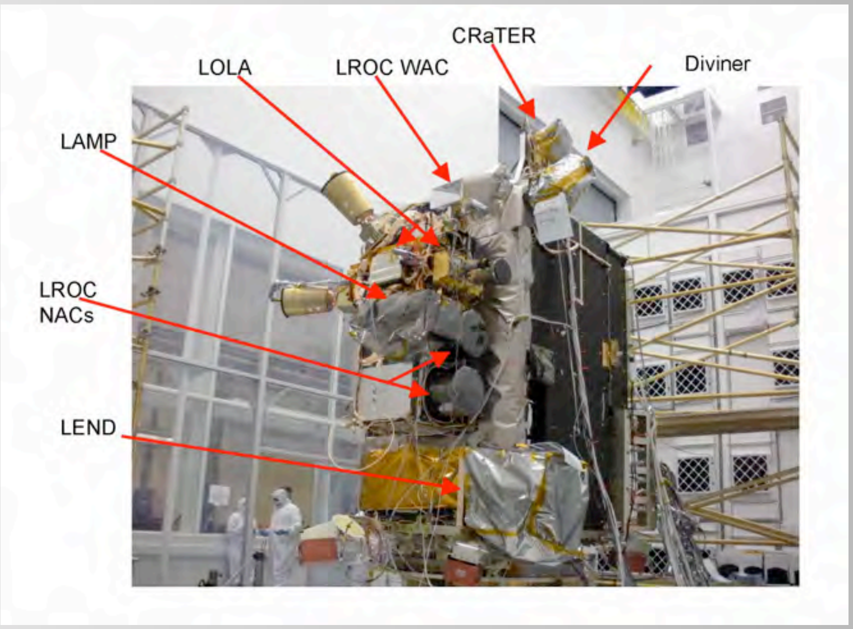
LOLA
Lunar Orbiter Laser Altimeter

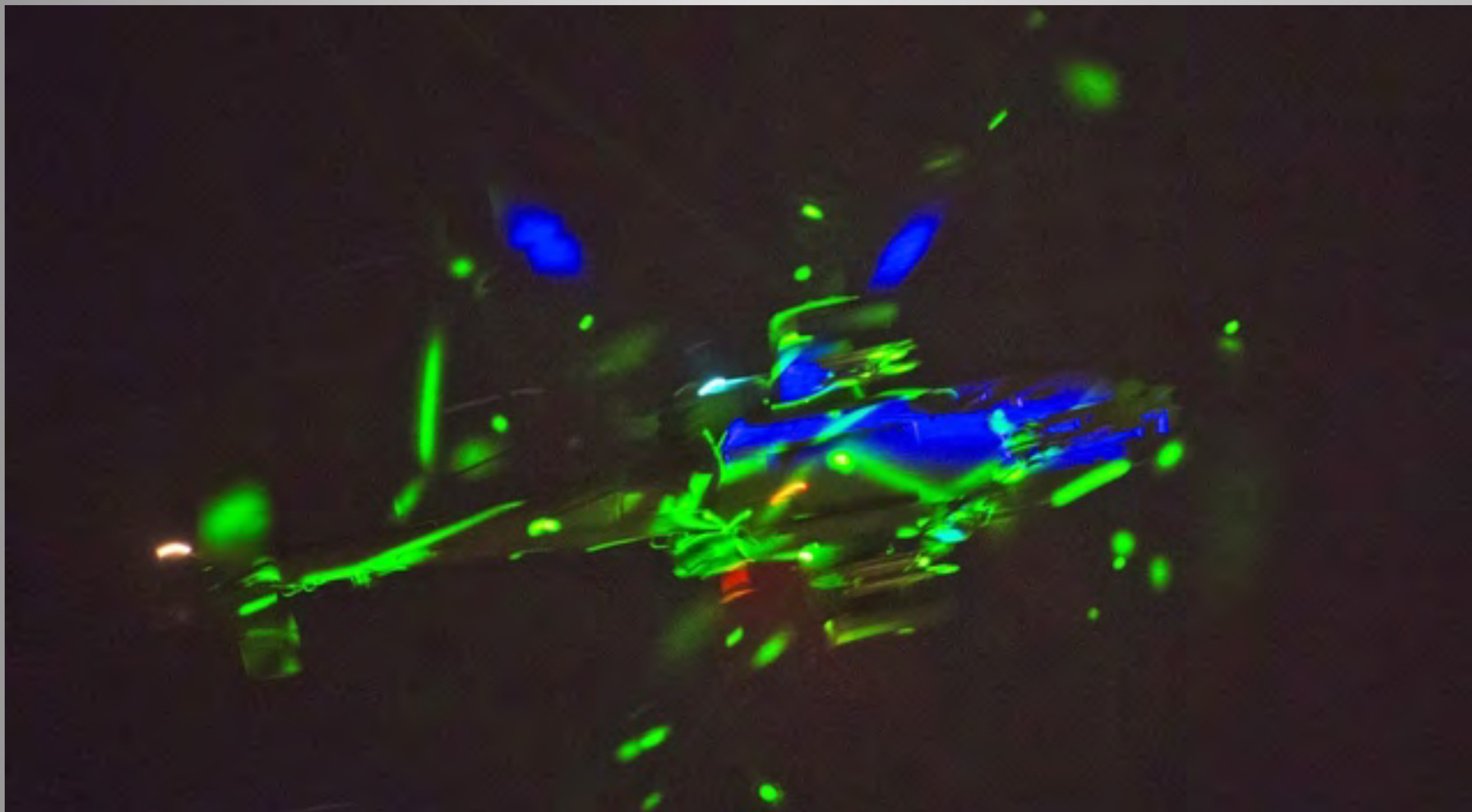


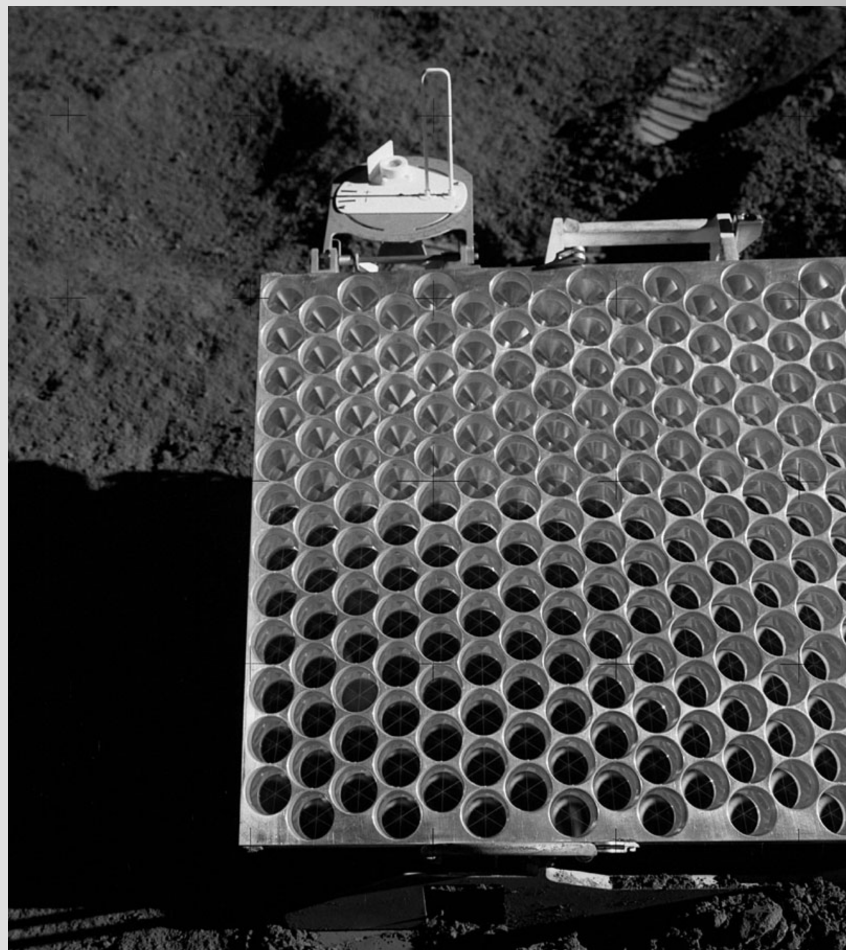


LOLA on LRO





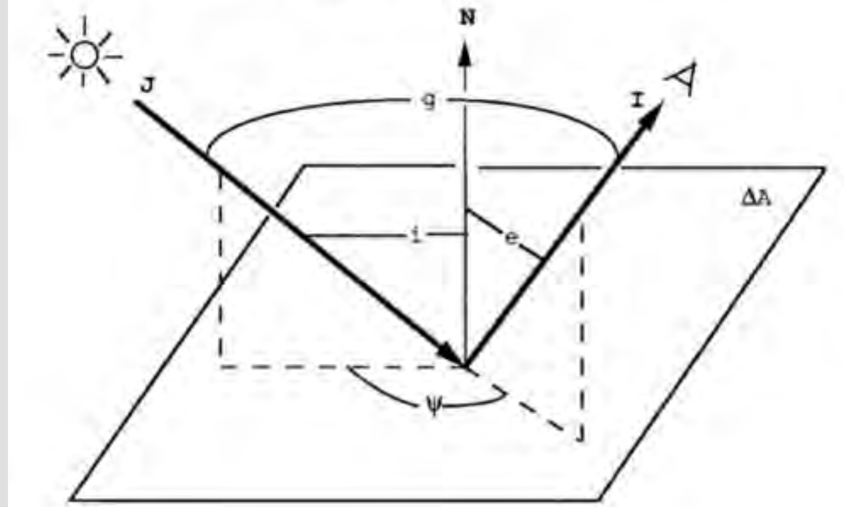


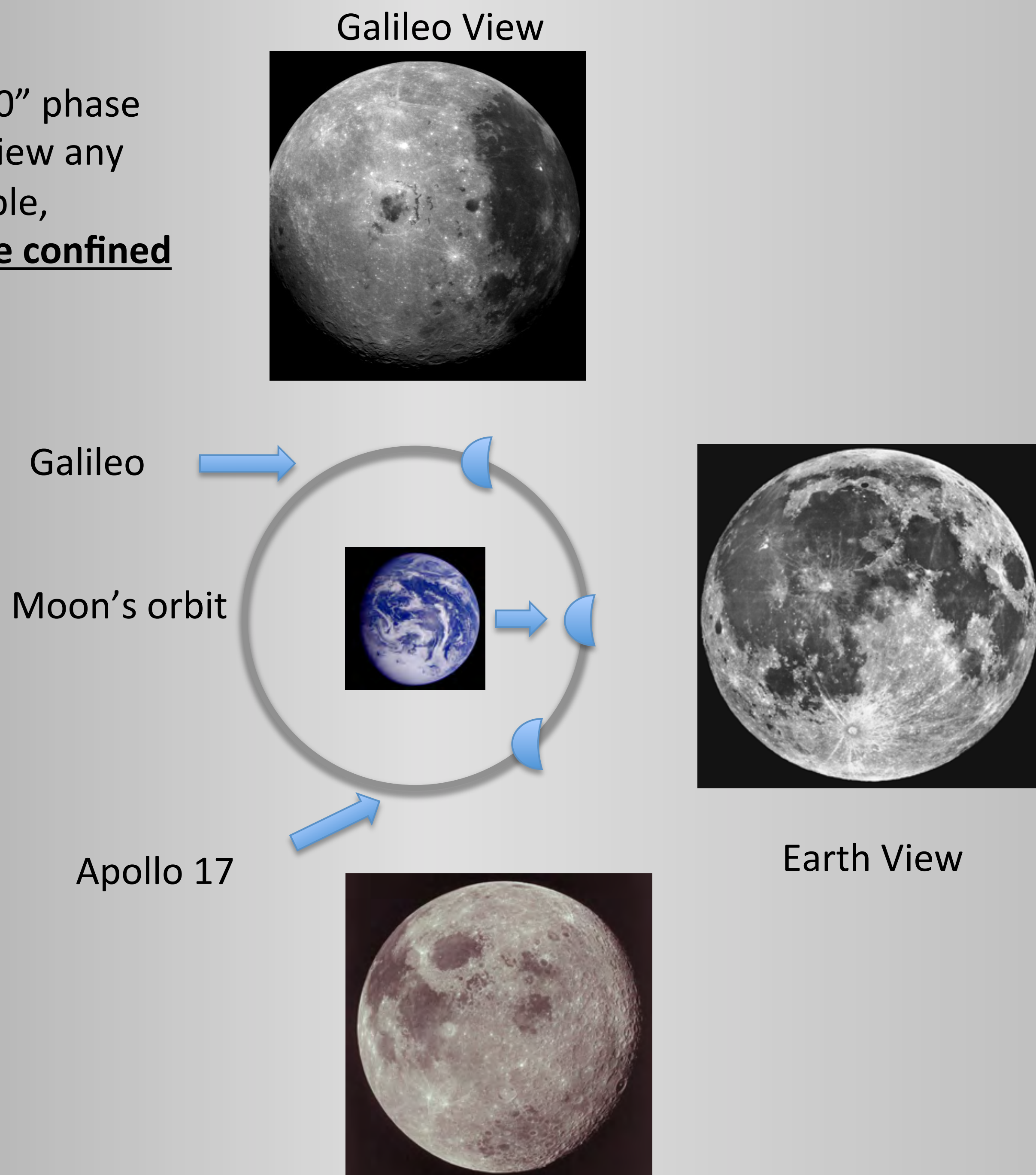
What LOLA measures: Normal Albedo

- Surface element observed with *i*-*e*=0 (phase angle *g* = 0) relative to a Lambert surface with *i*=*e*=0
- For dark surfaces (like the Moon) normal albedo is independent of *i* and *e*
- Removes the effect of topography from images

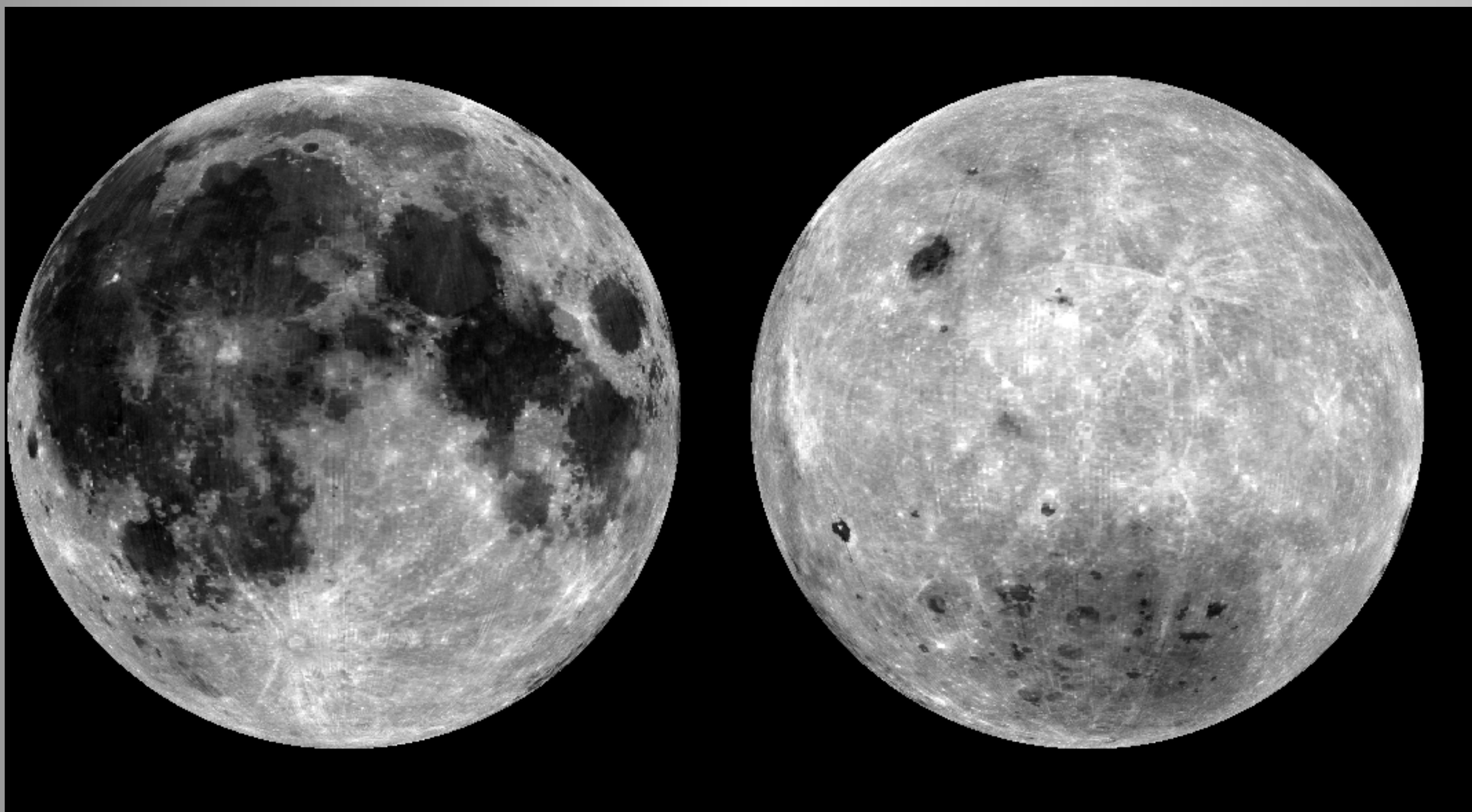
Figure 8.1. Schematic diagram of bidirectional reflectance from a surface element ΔA, showing the various angles. The plane containing **J** and **I** is the scattering plane. If the scattering plane also contains **N**, it is called the principal plane.



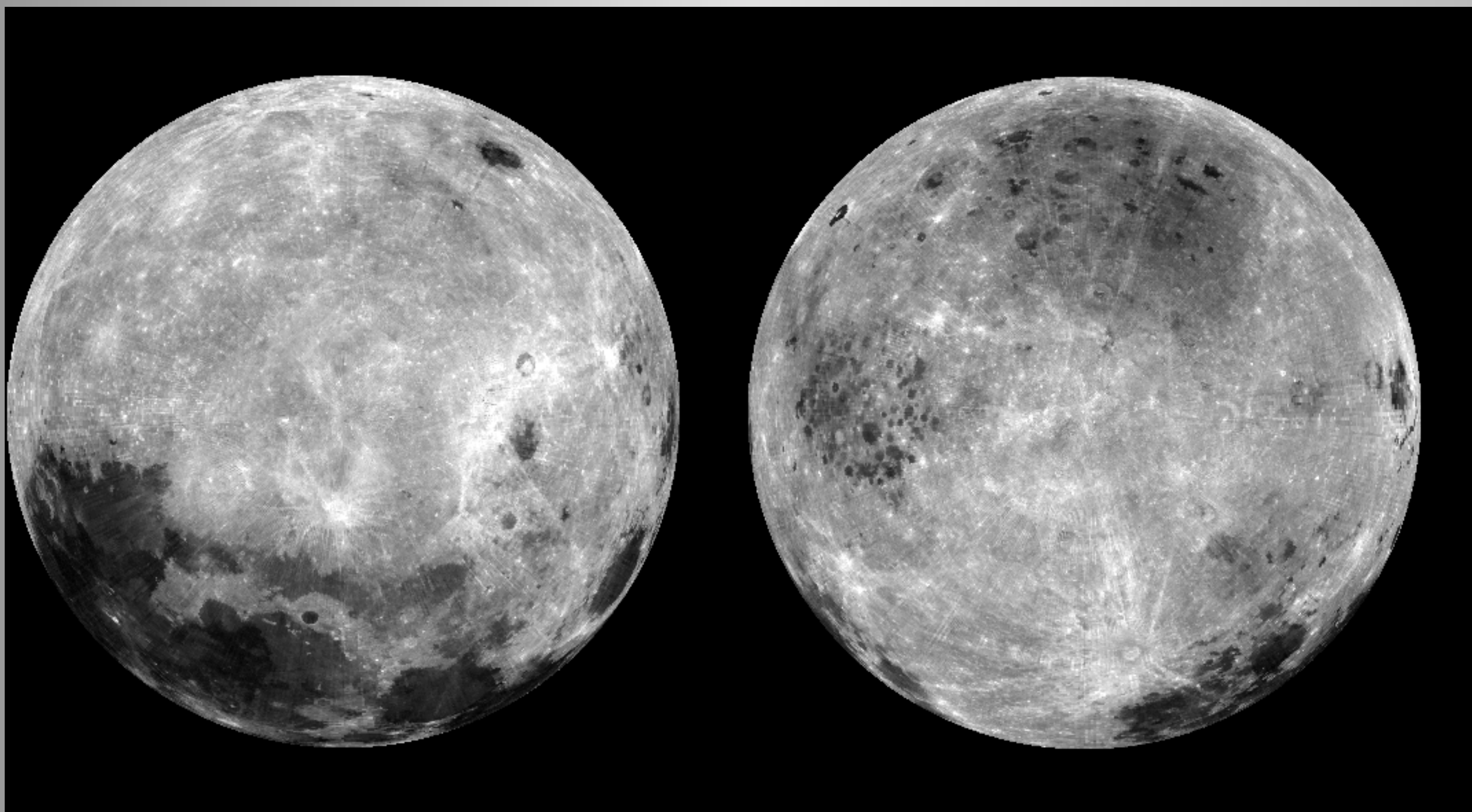
Solar illuminated “0” phase observations can view any longitude in principle,
<u>but nadir views are confined to the equator</u>



LOLA Equatorial Views



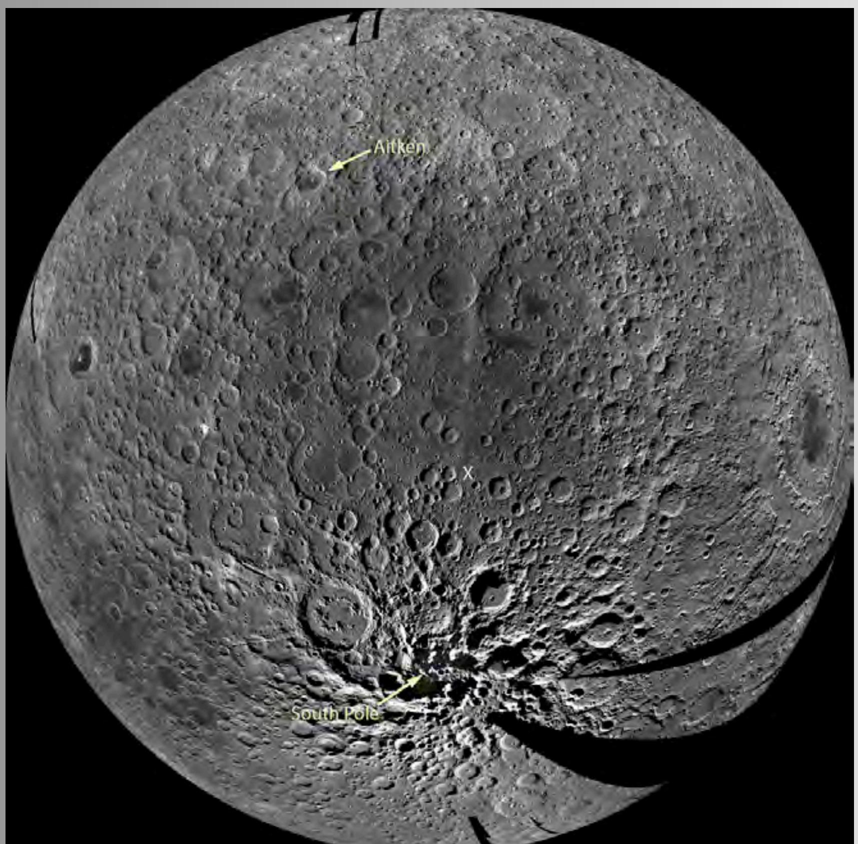
LOLA Polar Views



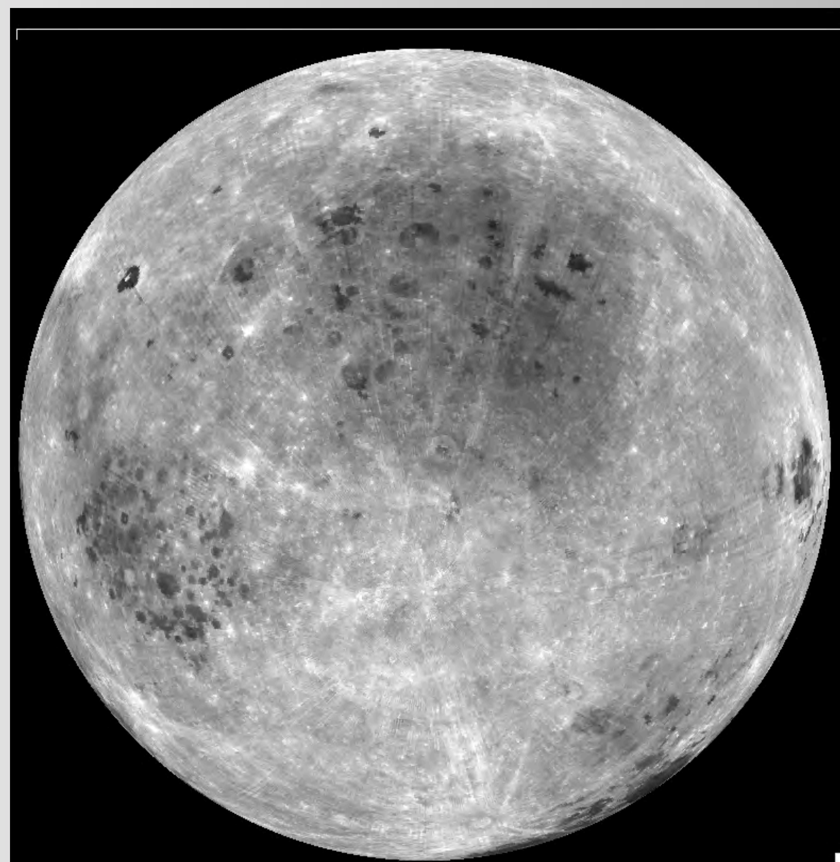
North Pole

South Pole

LOLA v Conventional imaging



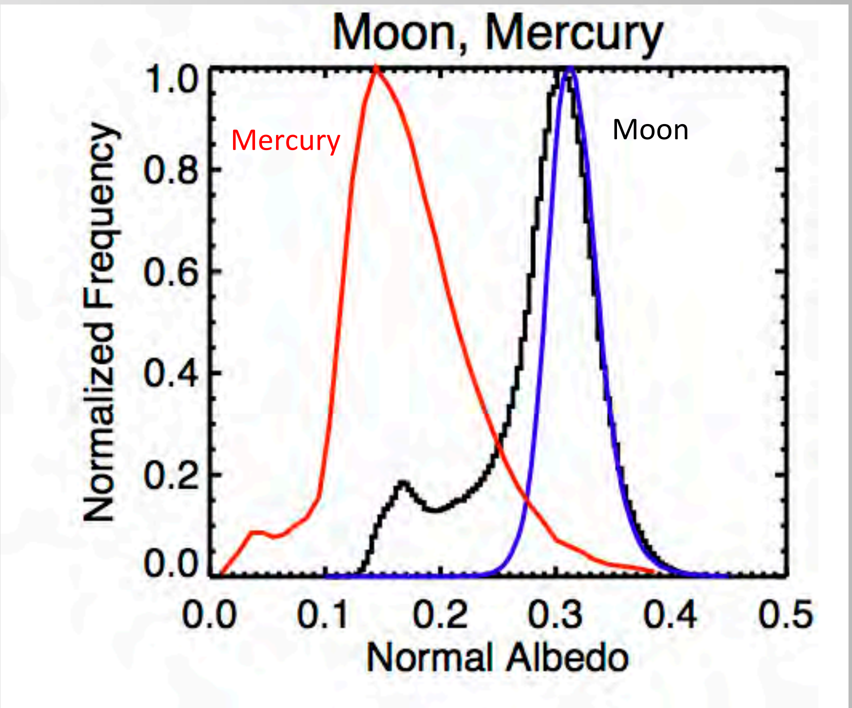
LRO LROC WAC



LOLA

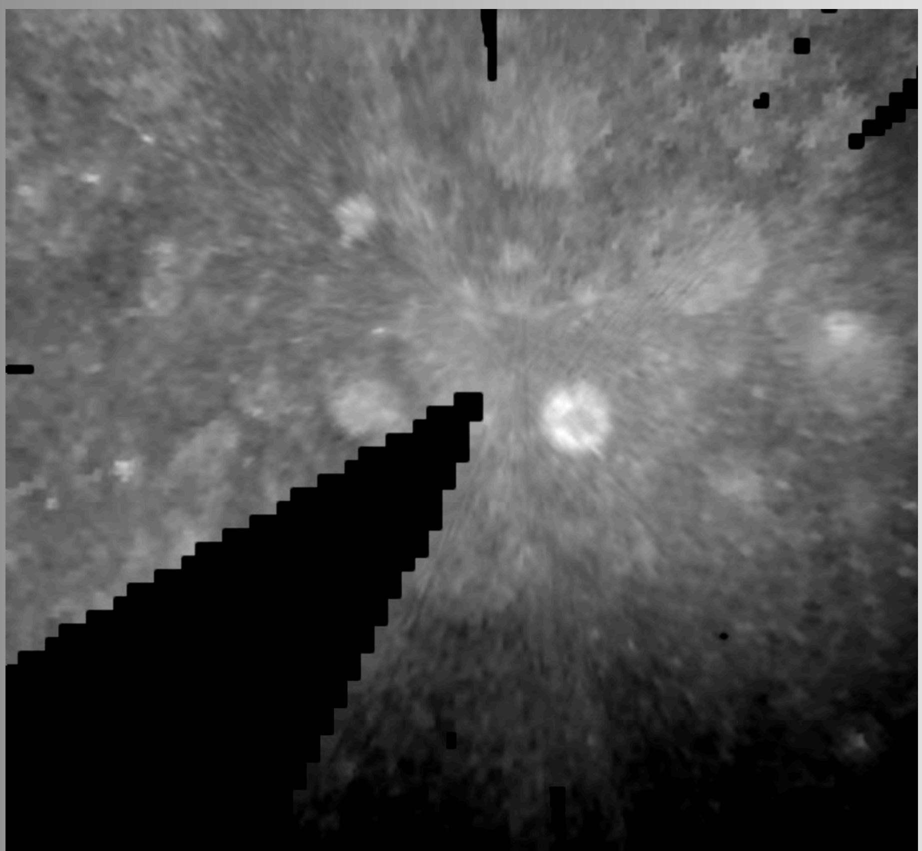
Comparison With Mercury

- Moon ~2-3x brighter than Mercury
  - Previously recognized
  - Typical Mercury similar to lunar maria in reflectance
    - May indicate similar submicroscopic iron abundances, requires more intense space weathering at Mercury
- <u>No lunar polar exposures similar to MLA dark material</u>



N Pole Mercury from Neumann et al. 2012

South Polar Crater Shackleton



- Zuber et al. 2012, first use of LOLA reflectance in a study of the crater Shackleton
- Noted its anomalous brightness
- Offered several hypotheses including the presence of small amounts of frost

Shackleton, Floor

- Shackleton floor anomalously bright relative to peers
- New result: Japanese report pure anorthosite in upper wall of Shackleton

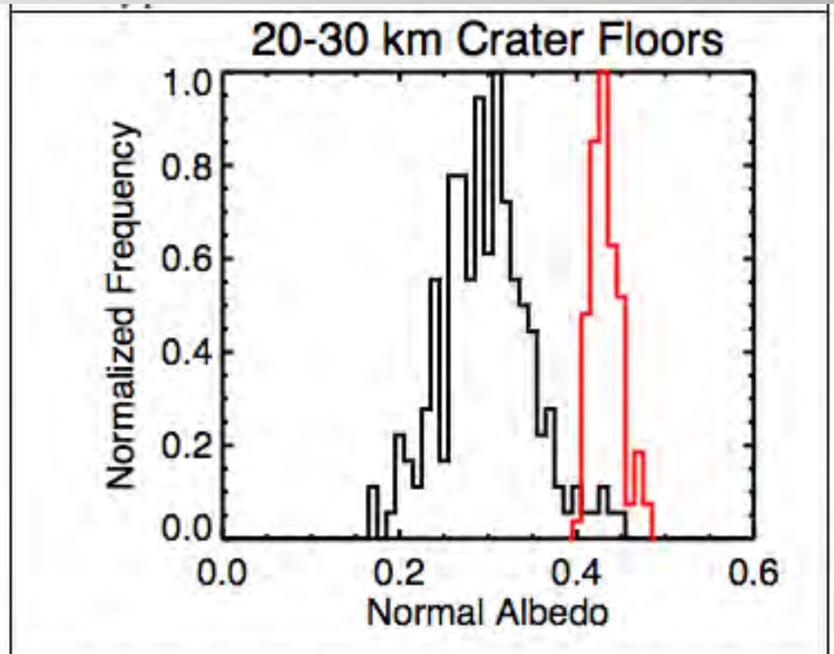
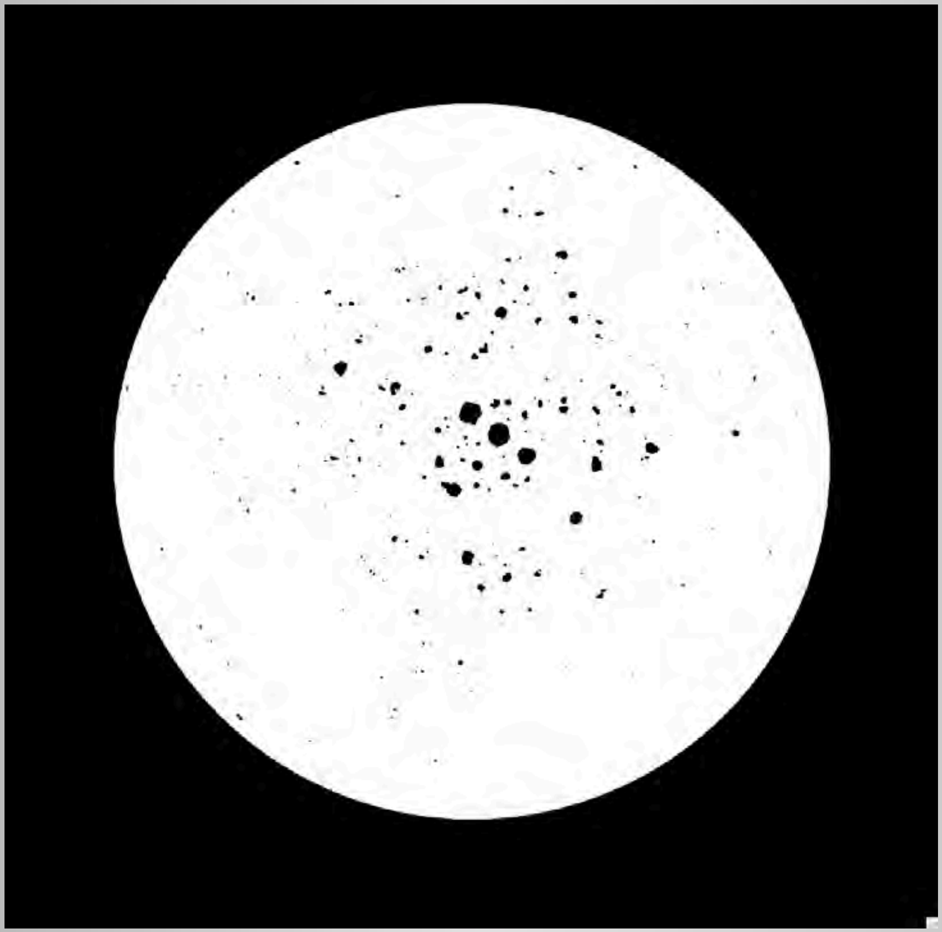
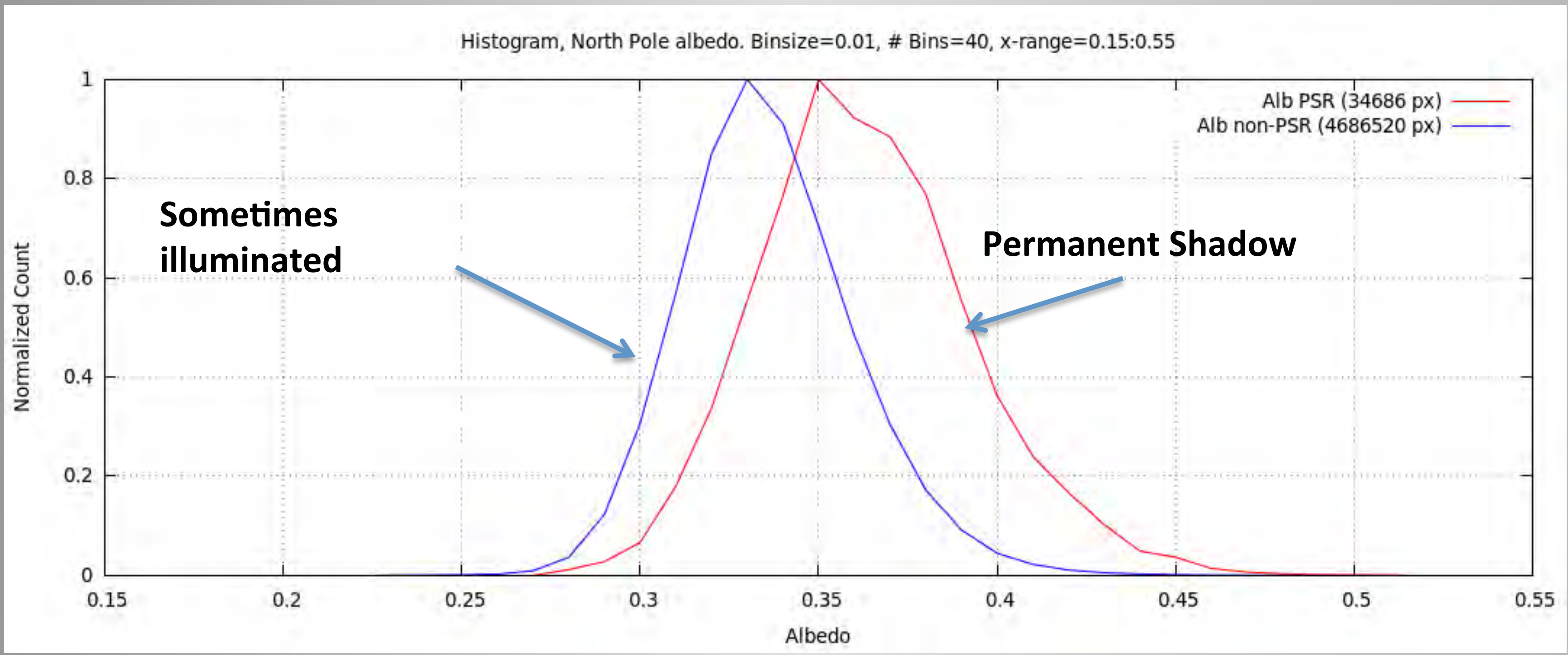


Figure 3: The normal albedo of Shackleton floor (red) and the median normal albedo of the floors of similarly preserved 20-30km craters.

South Pole Permanent Shadow

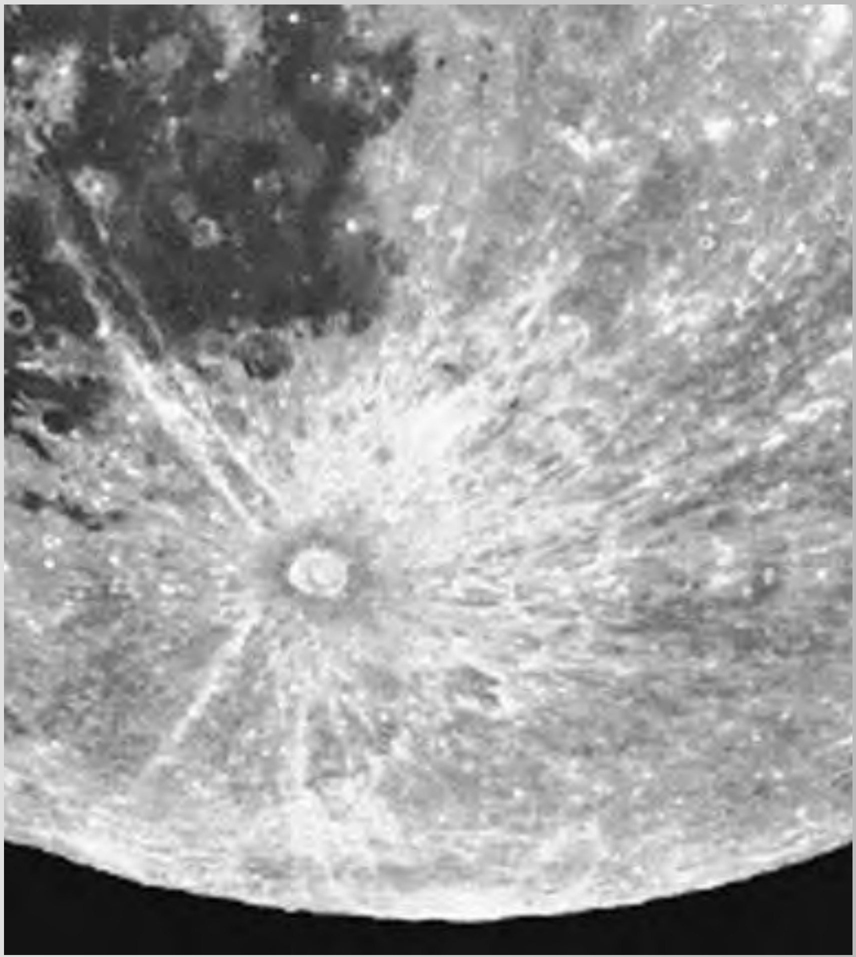


Permanent shadow vs. sometimes illuminated

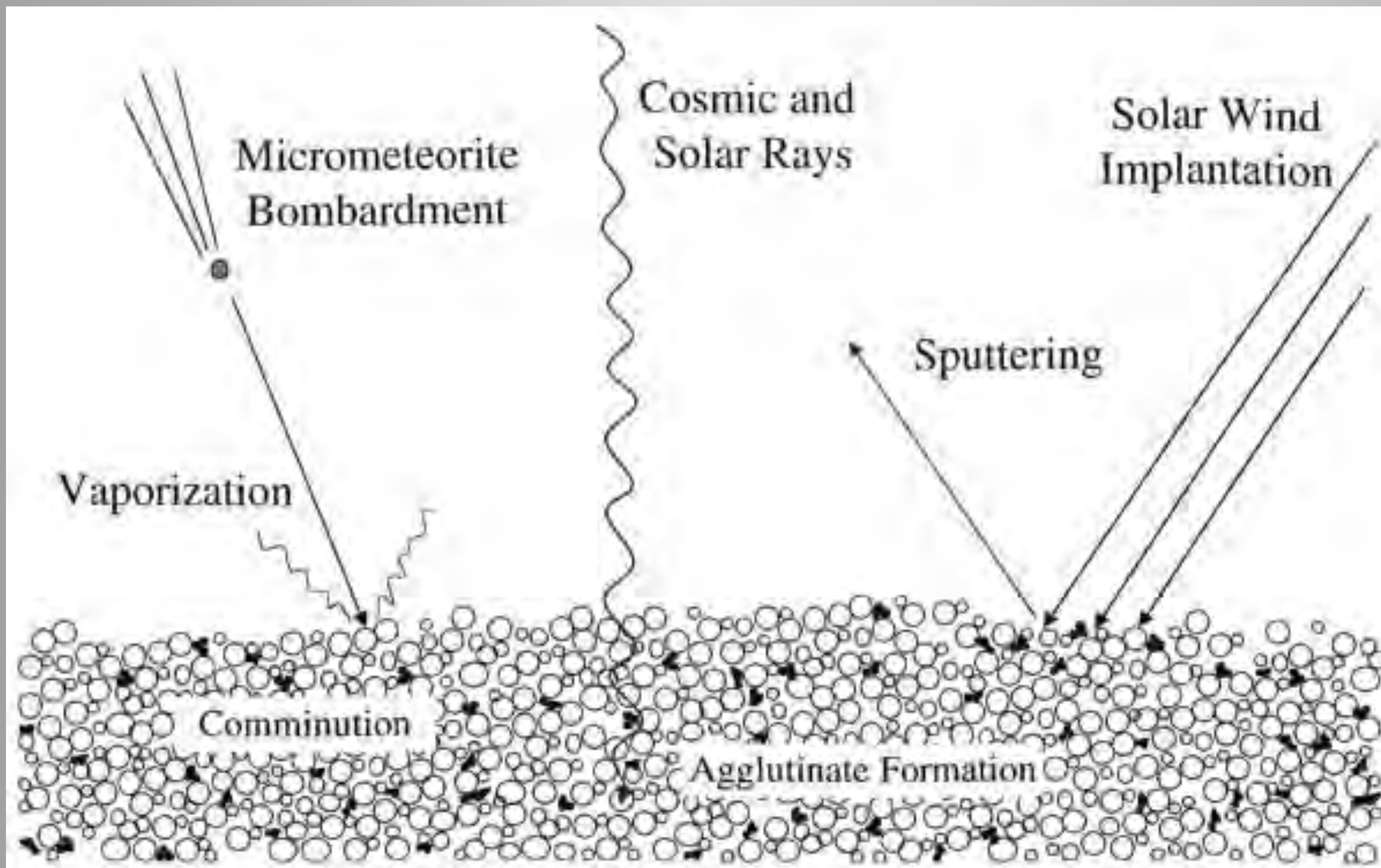


Alternative to Volatiles: Space Weathering

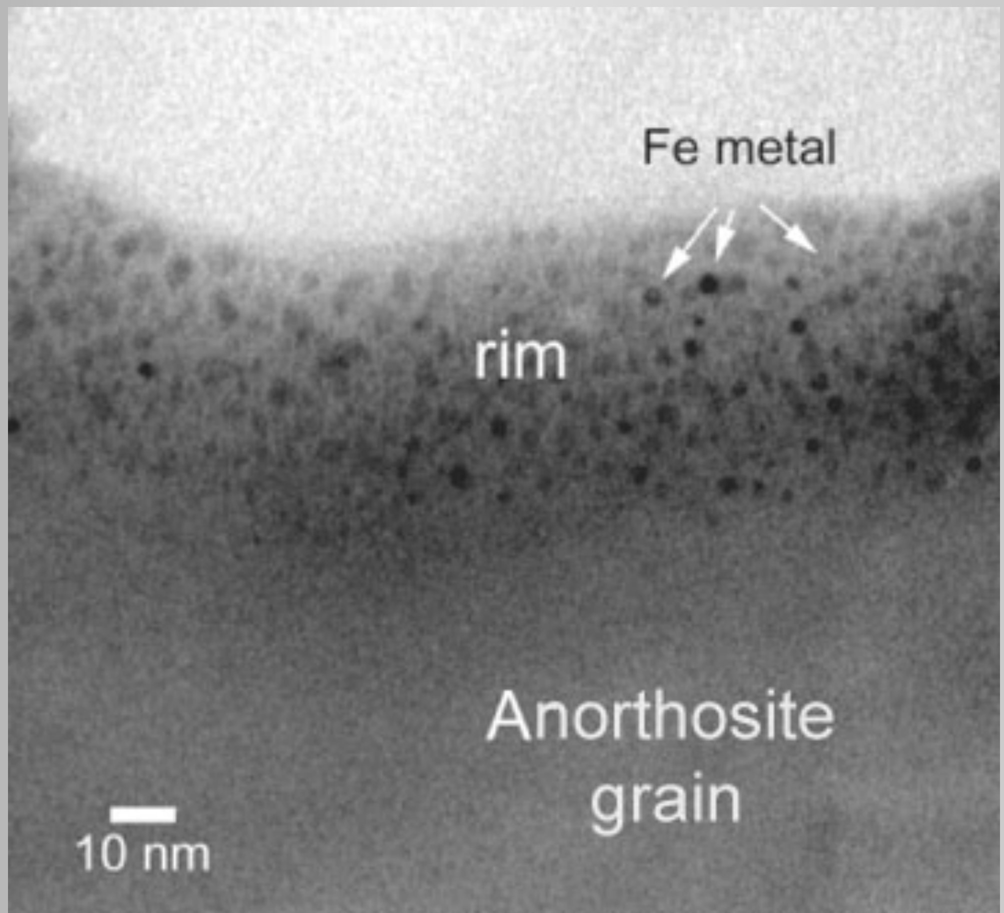
- Gold 1955
  - Only some well-preserved lunar craters exhibit rays
  - Rayed craters superpose craters that lack rays
  - Some process is altering the uppermost lunar surface on relatively short timescales



Space Weathering

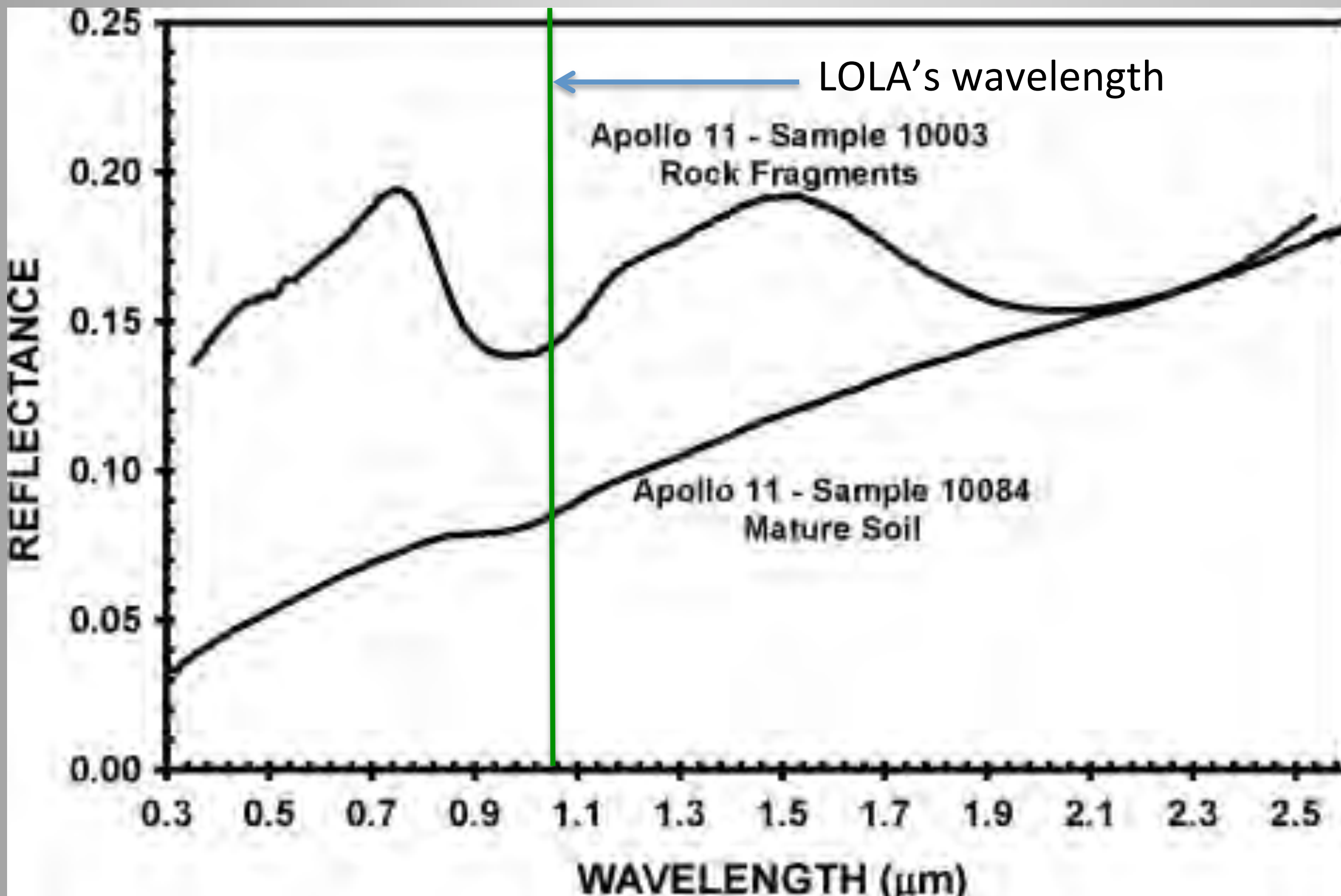


Space Weathering

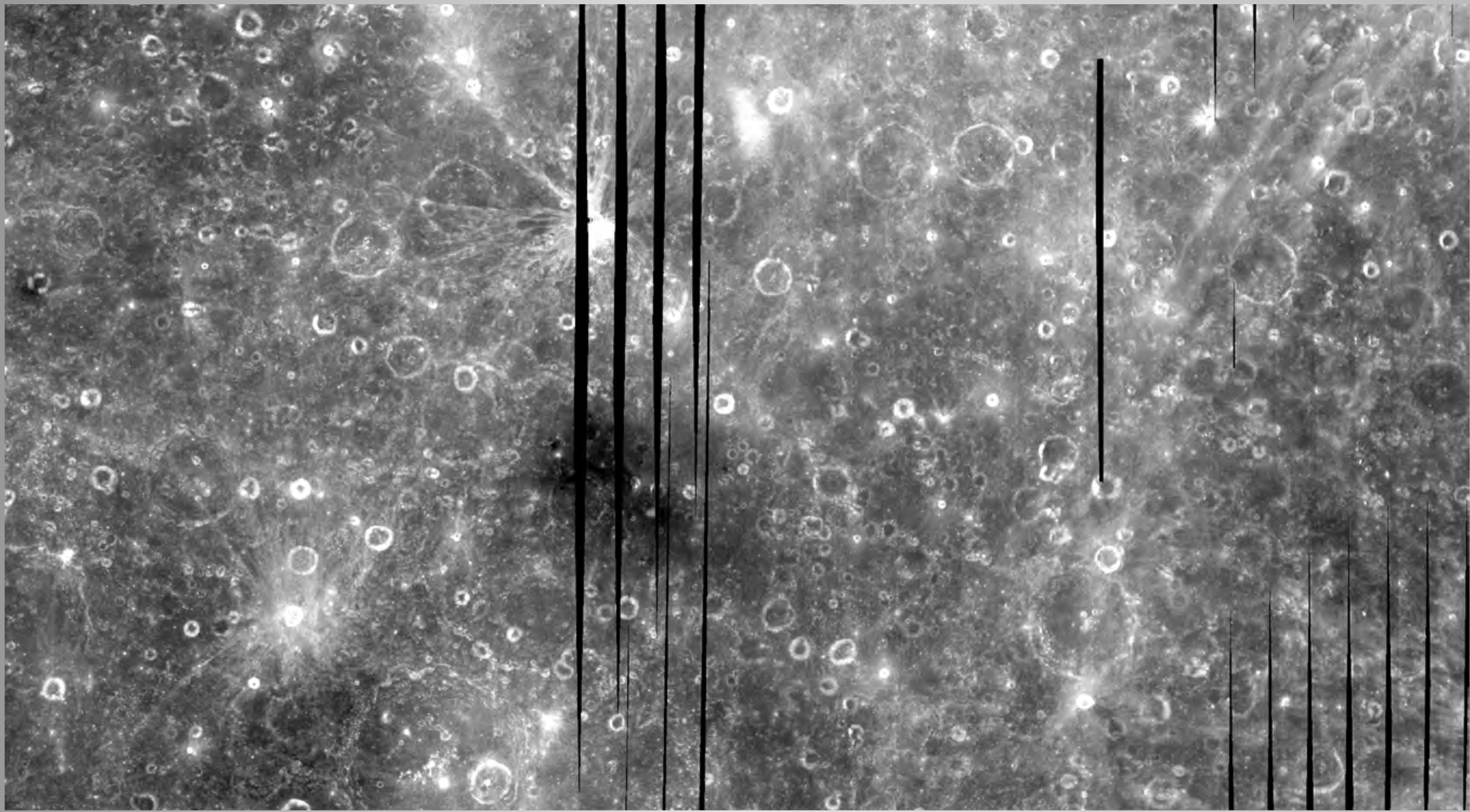


(From Keller *et al.*, 1999; Pieters *et al.*, 2000.)

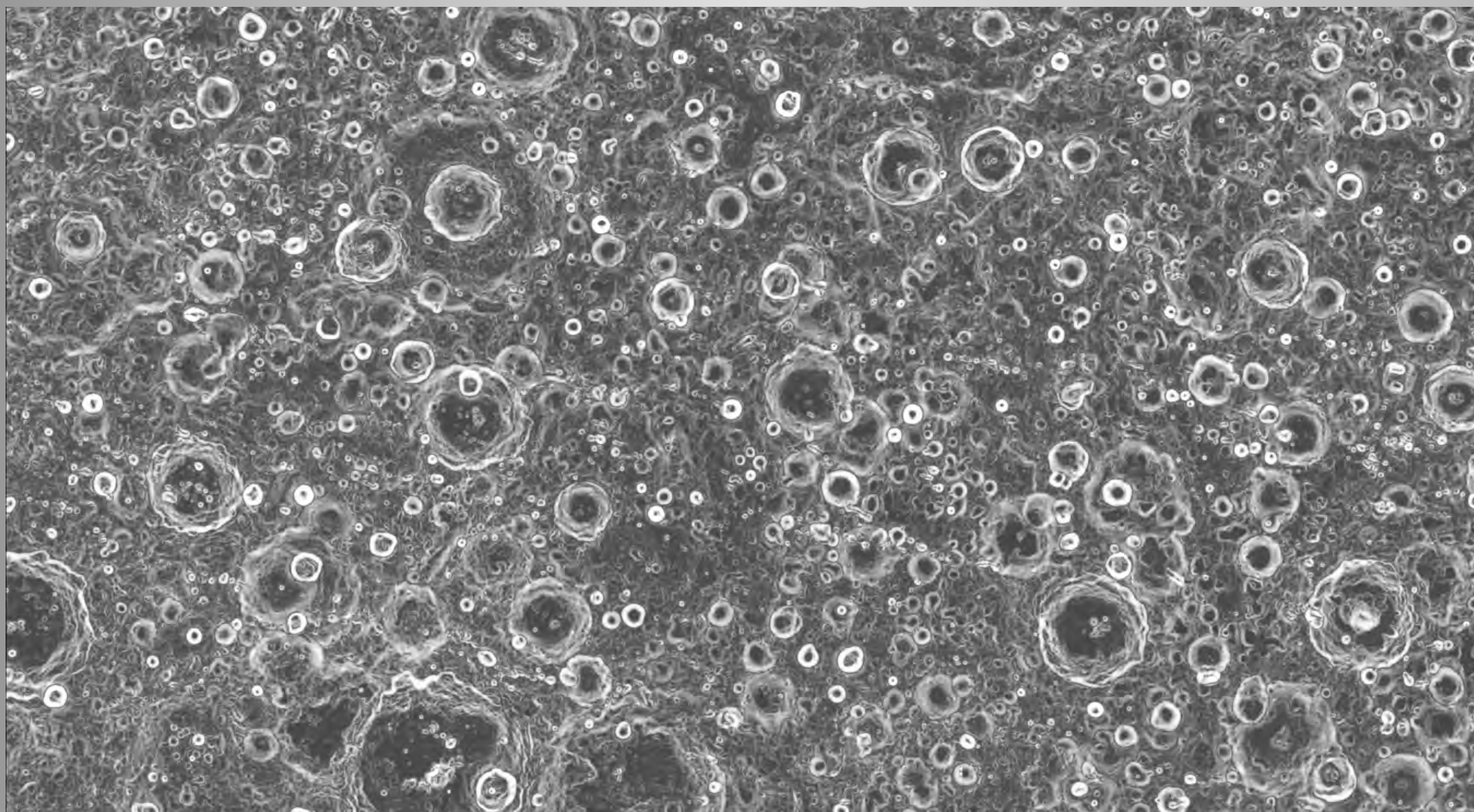
Space Weathering



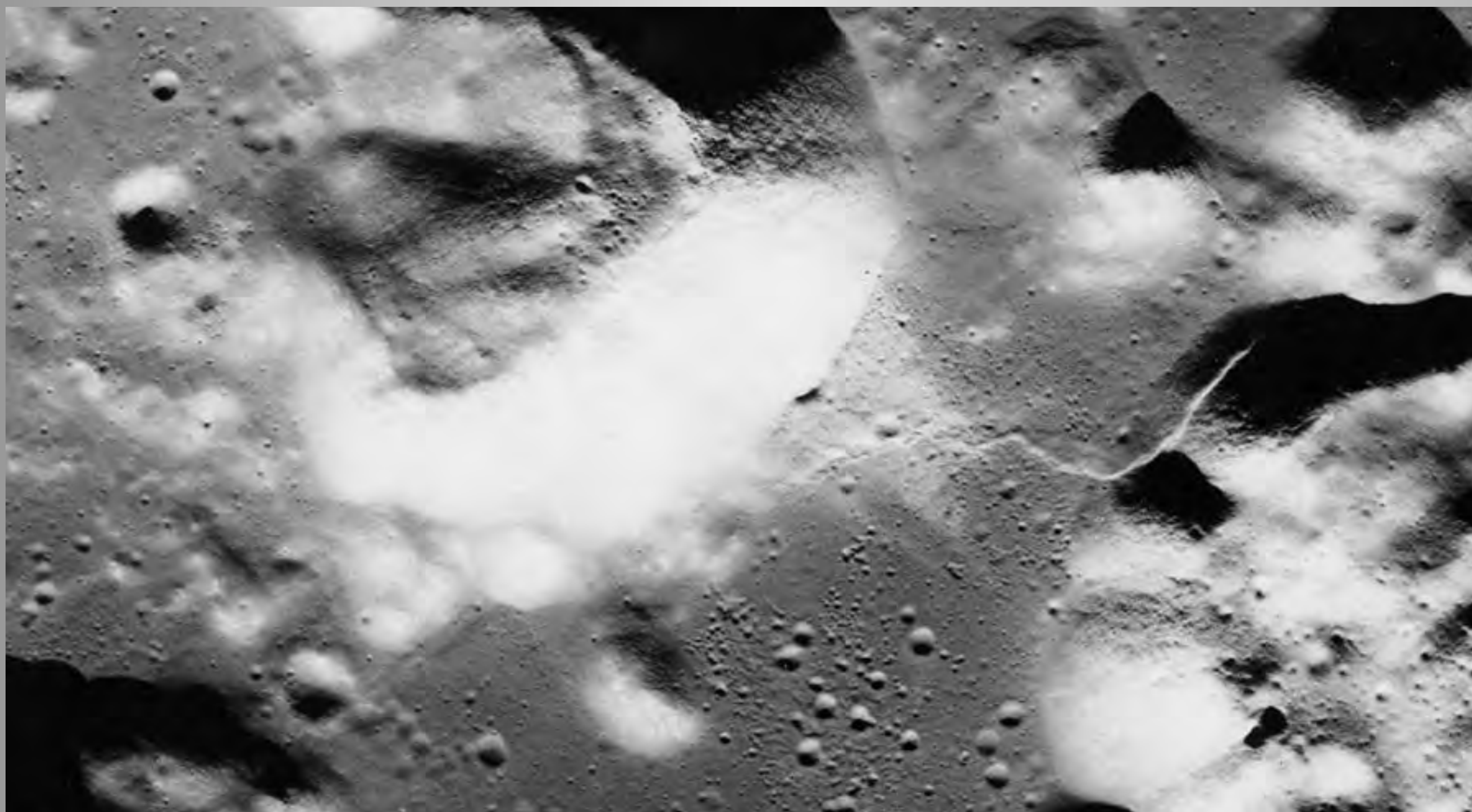
Space Weathering



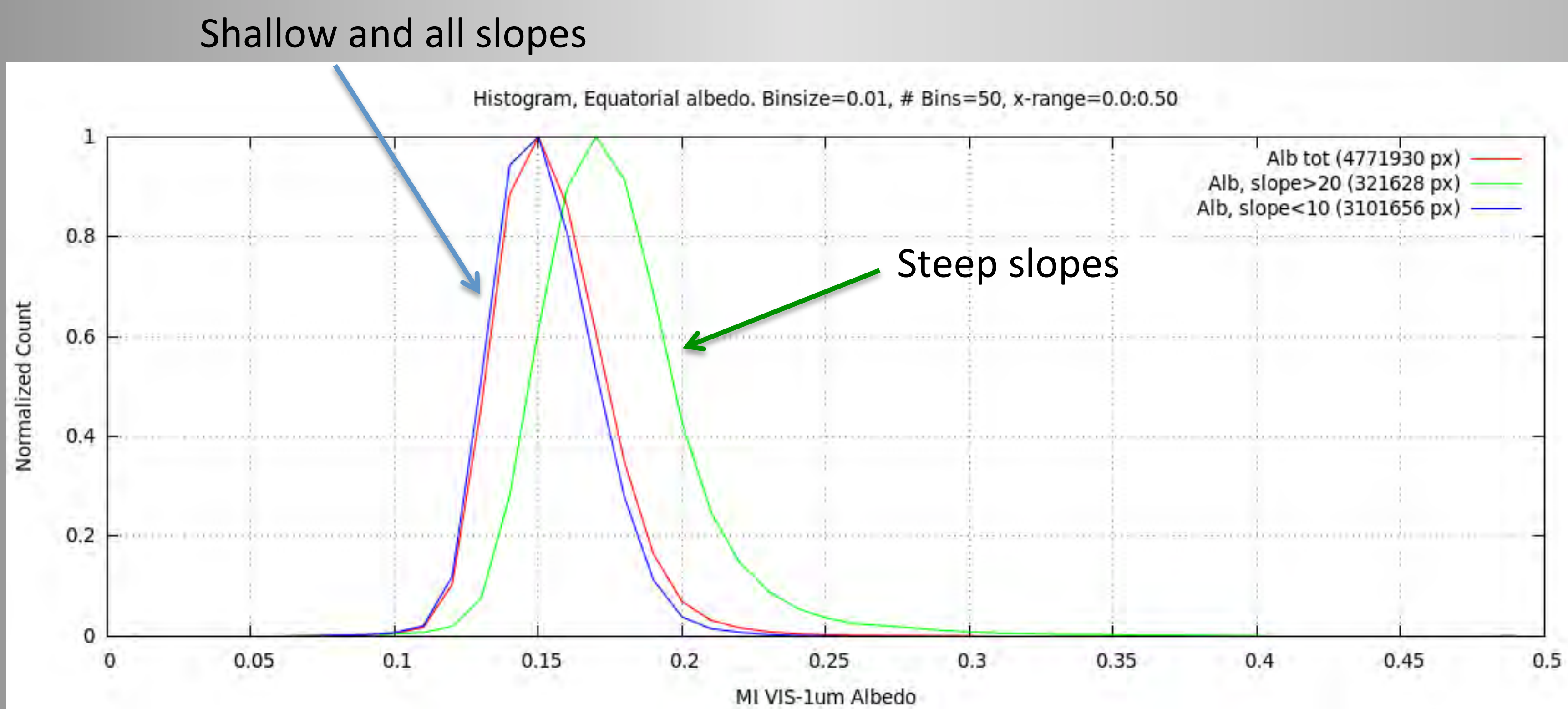
Space Weathering



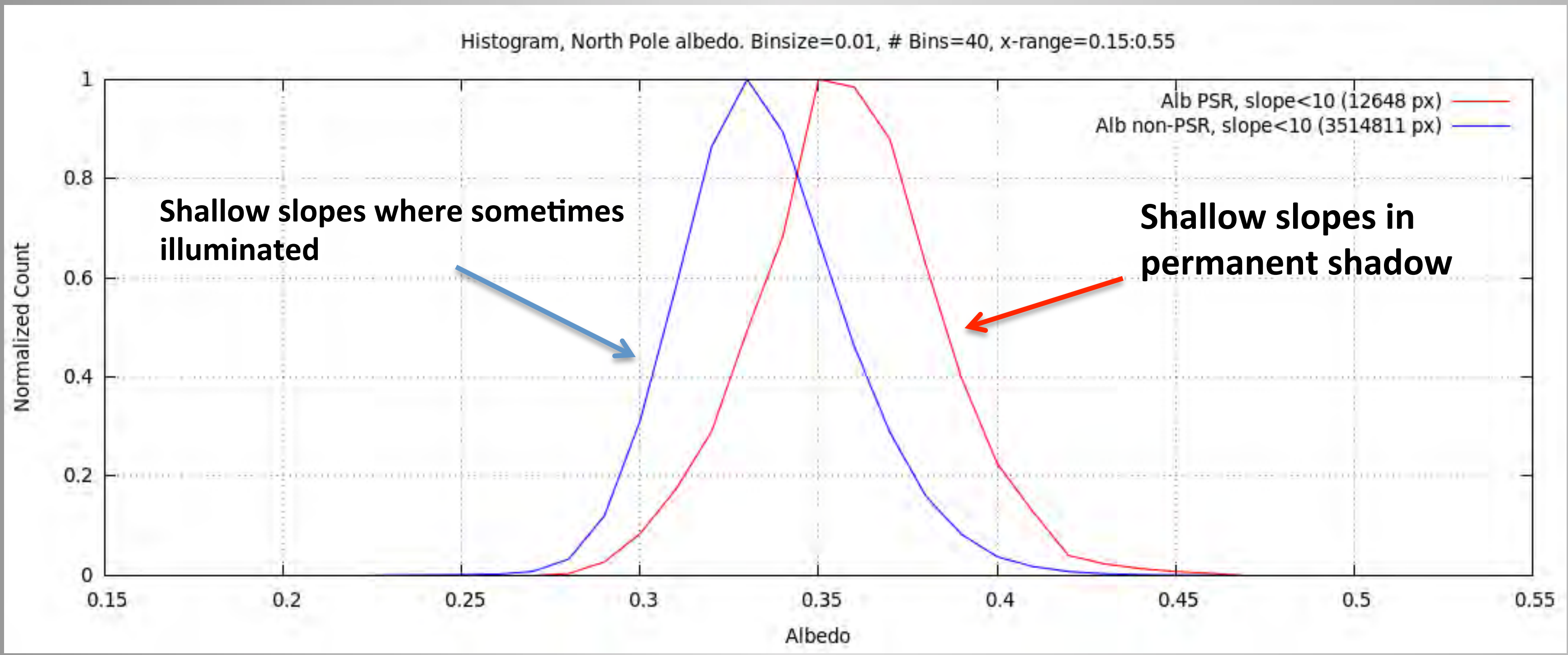
Mass wasting increases reflectivity



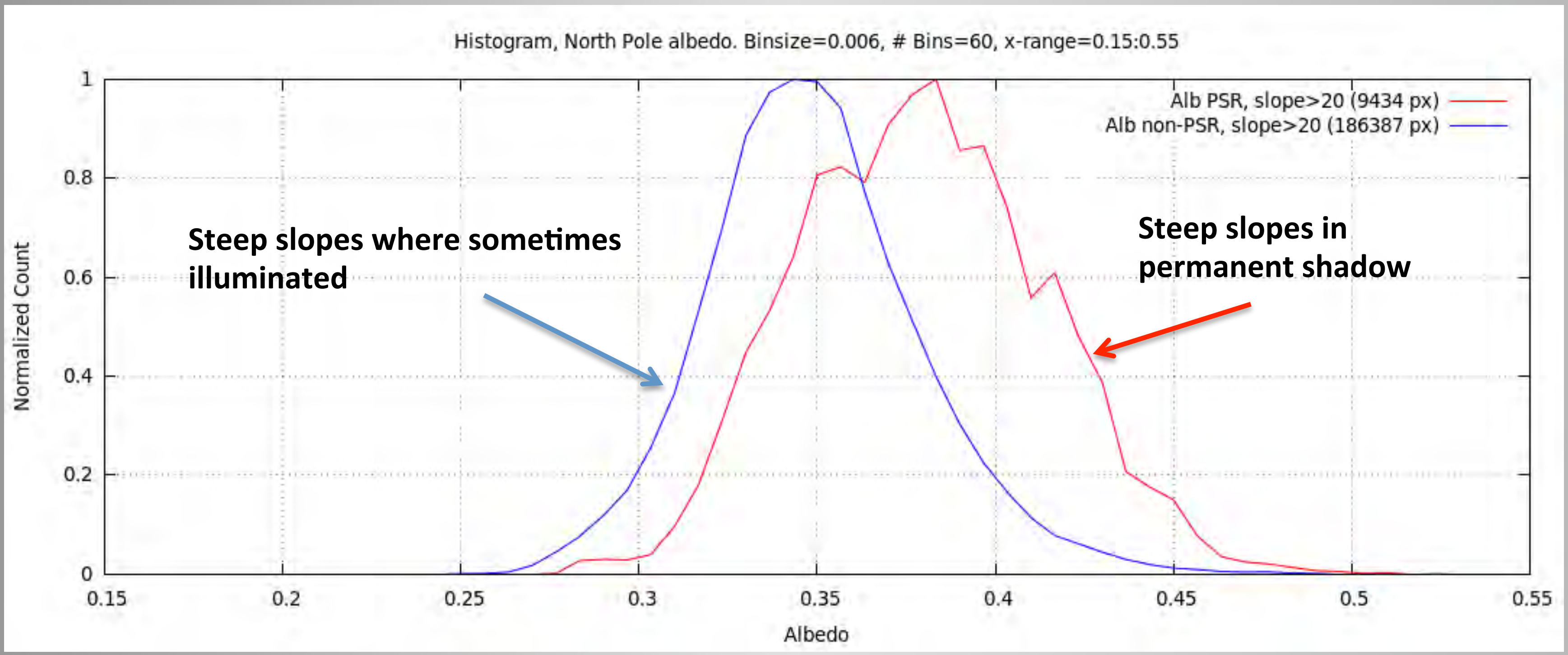
Space Weathering at the Equator



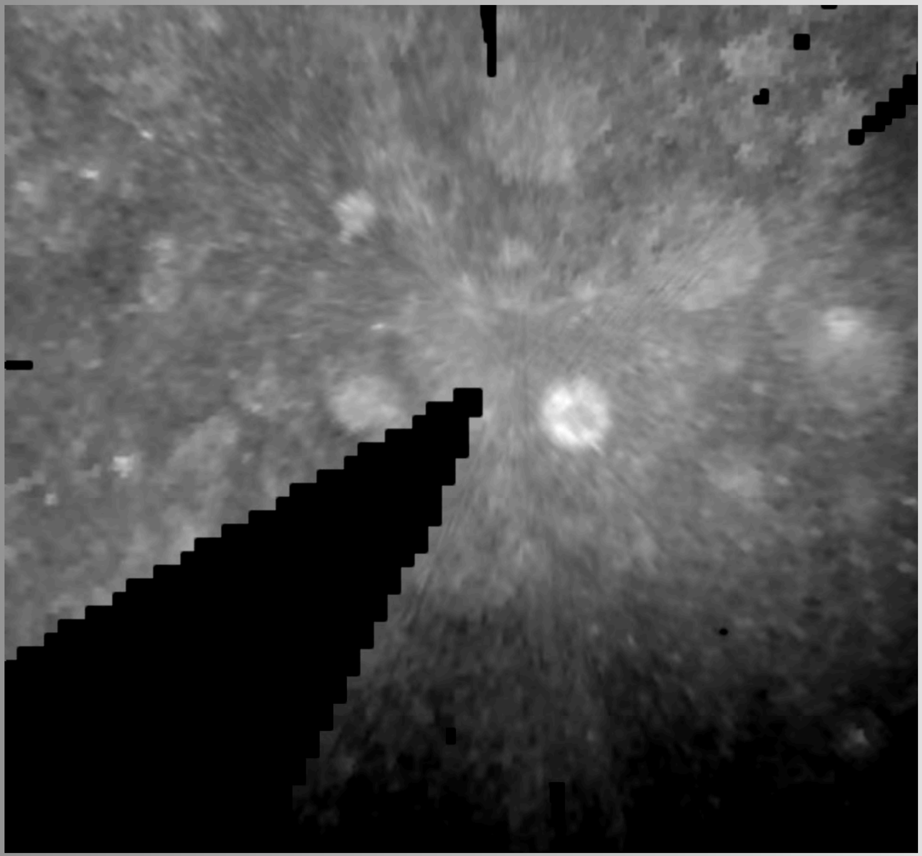
Shallow slopes: no mass wasting



Steep slopes show similar differences



Slope analysis conclusion

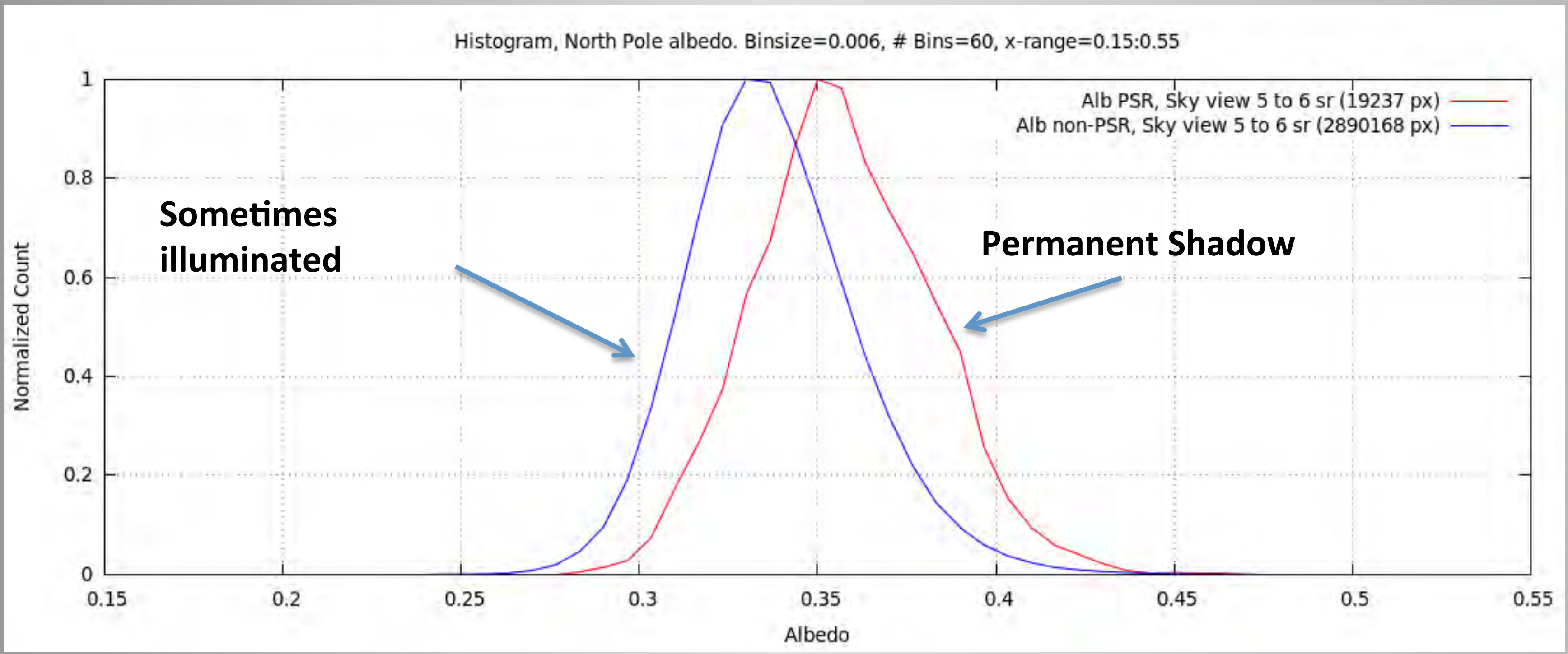


- Increased reflectivity in permanent shadow is independent of mass wasting

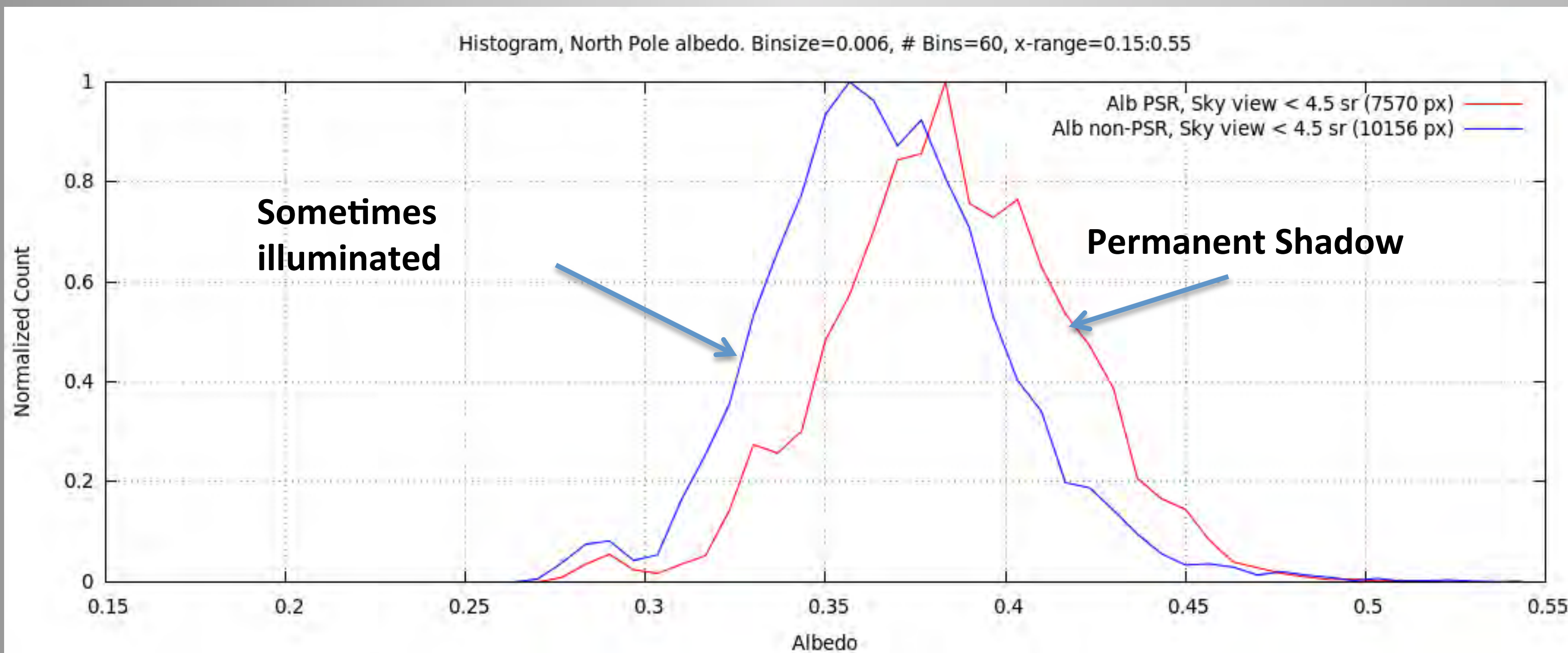
Sky access: Proxy for space weathering intensity

- Permanent shadow tends to be in proximity to steep slopes and near the bottoms of craters
- Steep topography partially shields the surfaces from solar wind and micrometeorites by limiting exposure to the sky
- Sky access is computed from LOLA topography via ray tracing

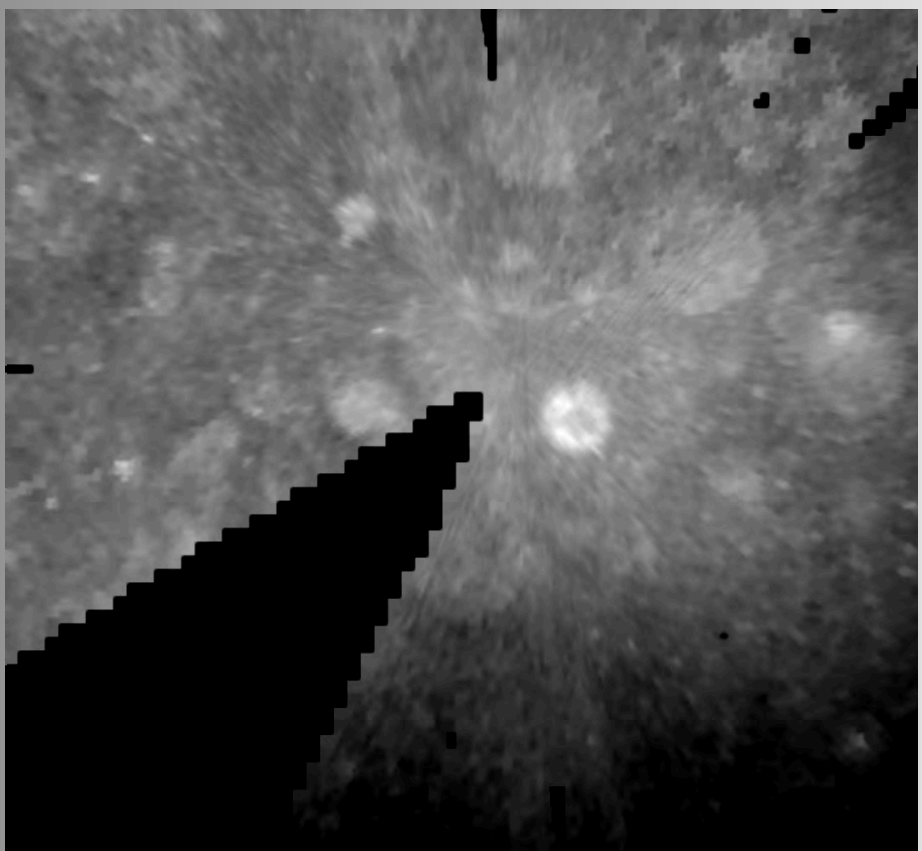
Large Sky View (no shielding)



Small Sky View (partial shielding from space weathering)

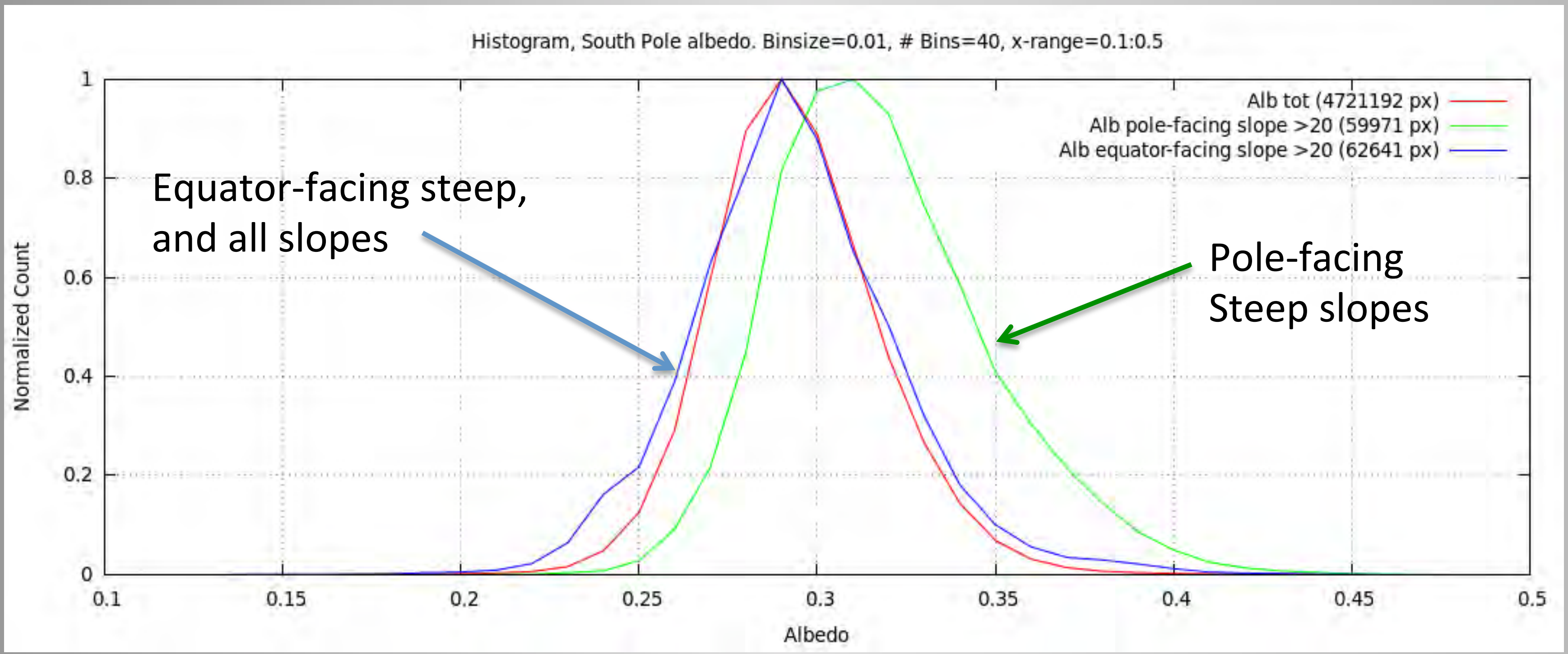


Sky view analysis conclusion



- Increased reflectivity in permanent shadow is independent of sky view and hence space weathering intensity

Pole Facing Slopes



Reflectivity Conclusions

- Permanent shadow is generally more reflective than areas sometimes illuminated
- Slope (proxy for mass wasting) and sky access (proxy for intensity of space weathering) do not account for the differences between regions in and out of permanent shadow
- Steep pole-facing slopes are more reflective than equator-facing slopes
- Two hypotheses remain:
  - Surfaces in permanent shadow are somewhat less susceptible to space weathering
  - Volatiles

Photons/pulse

- $3x6.6 \times 10^{-20}$ J/ph (1 um)
- 3mJ/pulse
  - 1e-3/6.6 x 10^{-20}
- 1.5×10^{16} ph / pulse
  - National debt is ~$1.5x10^13
  - Assume output loss of 30%
  - 1. x 10^{16} ph / pulse
- 1×10^{16} ph/sr x 0.35 /!pi(albedo of moon,pi)
  - .1 x 10^{16} ph/sr
  - 1x1015
- From surface, receiver subtends 6×10^{-12} sr

- Receiver intercepts 6000 photons per pulse
- Assume 10% optical efficiency
- 600 photon/pulse detected

- 1.5×10^{16} ph /600

So for every number of photons equal to the number of dollars in the national debt that lola transmits, lola receives one photon back. Now that is a government program

LOLA receiver is extraordinarilty sensitive!

600 photons is plenty for range, less so for reflectance

Outline

- Porosity, directional hemispherical reflectance vs bidirectional reflectance
  - Could porosity darkening be overcome by a strong opposition surge?
  - Why porous anyway
- Calculation of amazing sensitivity of lola
- Lola polar v wac polar
- Diffuse v specular reflectance (find moon in the water?)
- Def PSR
- Need classic space weathering diagram, search internet
  - Omat showing mass wasting

title

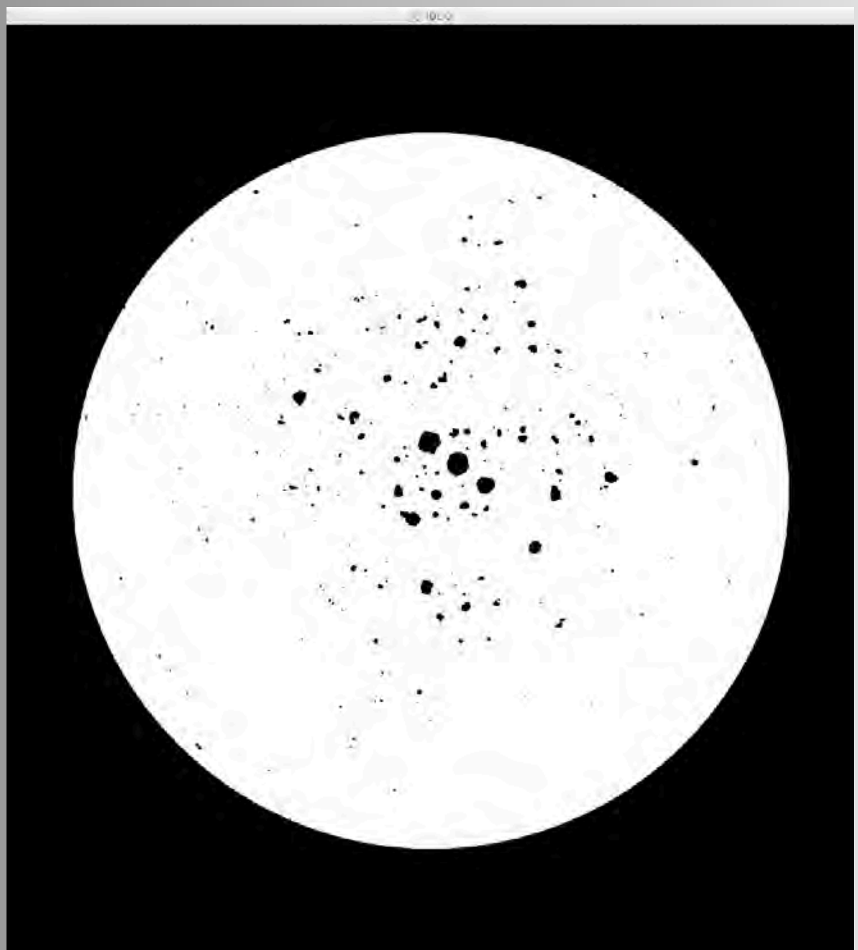
- Permanent shadow is generally more reflective than areas sometimes illuminated
- Controlling for slope (a proxy for controlling for increase in reflectivity due to mass wasting) shows that both steep and shallow slopes in permanent shadow are more reflective than regions sometimes illuminated

- What is laser reflectivity
  - Lola, lro, diffuse v specular
  - Lossy process, needs extreme sensivity
  - Speaking of reflectivity
- Results
  - PSR more reflective than not
  - Are we done? No
  - spac

narrative

- Prof paige describes importance of temperature, and how it explains the reflectance of mercury
- What does the reflectacne of the moon's poles tell us?
- Like mercury we use a instrument that carries its own like source to peer into lunar polar craters where the sun never shines
- That instrument is called the Lunar Orbiter Laser Altimeter that is still operating on the Lunar Reconnaisance orbiter satellite around the moon
- LOLA as it is affectionately called, is primarily designed to measure the distance from the Moon to the LRO satellite, and combining that range with knowledge of the orbit of LRO LOLA provides the most precise knowledge of the shape of the Moon (any other plant).
- But like the Mercury Laser Altimeter, built by the same team at the Goddard space flight center (true?), lola measures not only the range, but the intensity of the return signal
  - Moon one pixel at a time, up to 7 billion measurements over x years. 5x28 pixels per second, ~100, "flash photograph"
  - Sonar analogy, radar analogy. Slealth analogy
  - Amazing loss of signal
  - Sensitive much avoid apollo sites
  - Would take 14 hours to build up a typical cell phone image, but been operating long enough to take 1400 cell phone images, 7 billion separate measuements, all could fit in an ipod. Selfies
- So how did we do?
  - Nice full moon photo
  - Mercury v moon (dark)
  - Polar pair, wac v lola
  - PSR defnition
- PSRs are brighter(more refelctive!) than places that recive some sun. I say more reflective to avoid makign the statement that the darkest place on the moon are the brightest.
- Game over?
- Geologic processes
  - Space weathering causes moon to be dark, and or causes variation in brightnees
  - Omat image
  - PSR are typically in little craters, with slopes that might with every moonquake or meteorite impact, cause a little landslide reveailing bright material.
  - So lets control for slope, shallow slopes mean little mass wasting (college joke).

South: General Permanent Shadow



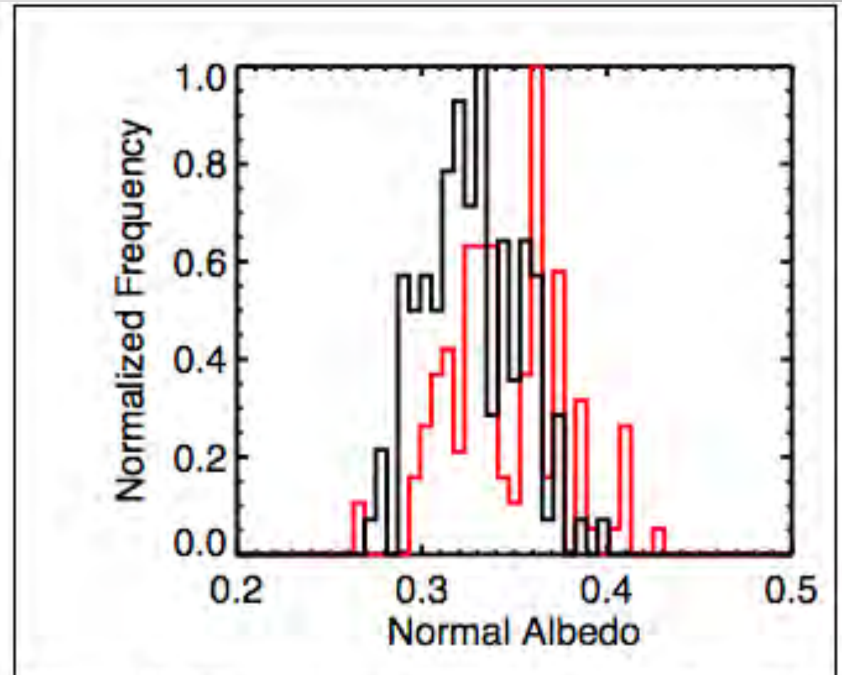


Figure 1: Frequency of normal albedo values for 124 PSR craters (red) and low latitude farside lunar highlands craters (black) with the same approximate size distribution.

(Excludes very near pole where effect is most apparent)