Recent Reflectivity Results

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

- No lunar polar exposures similar to MLA dark material
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
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

LOLA’s wavelength
Space Weathering
Space Weathering
Mass wasting increases reflectivity
Space Weathering at the Equator

Shallow and all slopes

Steep slopes
Shallow slopes: no mass wasting

Shallow slopes where sometimes illuminated

Shallow slopes in permanent shadow
Steep slopes show similar differences

- Steep slopes in permanent shadow
- Shallow slopes where some illuminated

![Histogram, North Pole albedo. Bin size=0.006, # Bins=80, x-range=0.15:0.55](image)

- Steep slopes where sometimes illuminated
- Steep slopes in permanent shadow
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

Equator-facing steep, and all slopes

Pole-facing Steep 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

- $3 \times 6.6 \times 10^{-20}$ J/ph (1 um)
- 3mJ/pulse
  - $1 \times 3 / 6.6 \times 10^{-20}$

- $1.5 \times 10^{16}$ ph / pulse
  - National debt is $\sim$1.5x10^13
  - Assume output loss of 30%
  - $1 \times 10^{16}$ ph / pulse
- $1 \times 10^{16}$ ph/sr x 0.35 /$\pi$(albedo of moon,$\pi$)
  - $0.1 \times 10^{16}$ ph/sr
  - 1x1015
- From surface, receiver subtends $6 \times 10^{-12}$ sr

- Receiver intercepts 6000 photons per pulse
- Assume 10% optical efficiency
- 600 photon/pulse detected
- $1.5 \times 10^{16}$ 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 extraordinarily 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
• 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, Iro, diffuse v specular
  – Lossy process, needs extreme sensivity
  – Speaking of reflectivity

• Results
  – PSR more reflective than not
  – Are we done? No
  – spac
Prof Paige describes the importance of temperature, and how it explains the reflectance of mercury.

What does the reflectance of the moon’s poles tell us?

Like mercury we use a device that carries its own light source to peer into lunar polar craters where the sun never shines.

That device is called the Lunar Orbiter Laser Altimeter that is still operating on the Lunar Reconnaissance 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 planet).

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. Stealth 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 measurements, 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 definition

PSRs are brighter (more reflective) than places that receive some sun. I say more reflective to avoid making 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 brightness
- Omat image
- PSRs are typically in little craters, with slopes that might with every moonquake or meteorite impact, cause a little landslide revealing bright material.
- So lets control for slope, shallow slopes mean little mass wasting (college joke).
South: General Permanent Shadow

(Excludes very near pole where effect is most apparent)