PHOTOMETRIC PROPERTIES OF THE MOON WITH THE LUNAR ORBITER LASER ALTIMETER (LOLA).
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Introduction: The photometric properties of the Moon can reveal important clues to geological and space weathering processes operating on the lunar surface and airless planetary bodies, in general. This is because the reflectance of the lunar surface as a function of wavelength and viewing geometry is related to the scattering properties of the regolith particles and the structure of the regolith surface [1]. Thus, it is important to measure the reflectance behavior over as wide a range of wavelengths and viewing/illumination geometries as possible. The Lunar Reconnaissance Orbiter (LRO) has been mapping surface photometric properties (in reflectance and thermal emission) from the far-ultraviolet to the infrared [2,3,4]. As part of this effort, since December 2013, the Lunar Orbiter Laser Altimeter (LOLA) has been collecting photometric measurements at a wavelength of 1064-nm when the spacecraft altitude is too high for normal altimetric ranging [5]. The resulting dataset provides a more detailed view of the spatially-resolved phase function behavior over the whole surface than was possible with previous missions. Here, we present an update and some applications of this unique dataset.

Instrument and Data Description: The passive radiometry mode of LOLA does not involve the laser, but instead turns LOLA into a 4-pixel radiometer collecting reflected solar photons with a single-pixel full sampling rate of 28 Hz (~60 m spacing along-track), spatial resolution of ~15 - 70 m (full rate, depending on spacecraft altitude), horizontal geodetic accuracy ~10 m for nadir geometry, and signal-to-noise ratio of up to ~70 (full rate). Like other imagers, the raw data must be corrected for dark-current and responsivity variations, and calibrated to an absolute radiance scale. Corrections and calibrations for the first year of data were published in [5], and the data (after downsampling by 5x to boost signal-to-noise) are available from the Planetary Data System (PDS). We have derived updated corrections and calibrations for data collected through 2017. Data collection continues and future releases to the PDS are planned. Here we present an initial look at applications of the newly calibrated and expanded dataset.

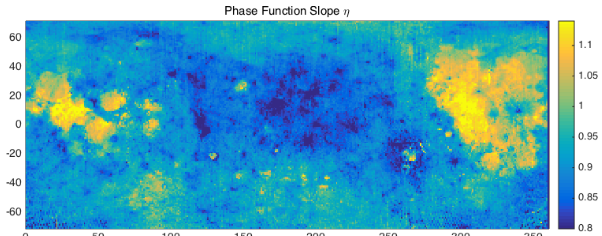

Figure 1- Map of phase function slope η at 1064-nm. Pixels are 1°x1°.

Results: As LRO's orbit evolves, we are gradually building up the phase angle coverage of LOLA's passive radiometry to produce a spatially-resolved map of the phase function at 1064-nm (the phase angle is the angle between the two vectors pointing from the surface to the Sun and from the surface to the observer). To keep the number of free parameters to a minimum, we initially use a simple empirical form for the phase function proposed by [6]:

$$f(g) = A_n \exp(-\eta\, g^\rho),$$

where A_n is the normal albedo, and η and ρ describe the slope and bend of the phase function curve, respectively. This function can be reduced to one free parameter by adopting the approximation $\rho = 0.5$ [6], and retrieving every point's A_n by interpolating the normal albedo map of [7] based on LOLA's 1064-nm active radiometry. Figure 1 shows the resulting map of η after normalizing LOLA's measured radiance factor, I/F, by a function to remove the incidence and emission angle dependence [8]. Figure 2 shows an example of the data in one particular map pixel with the best-fit

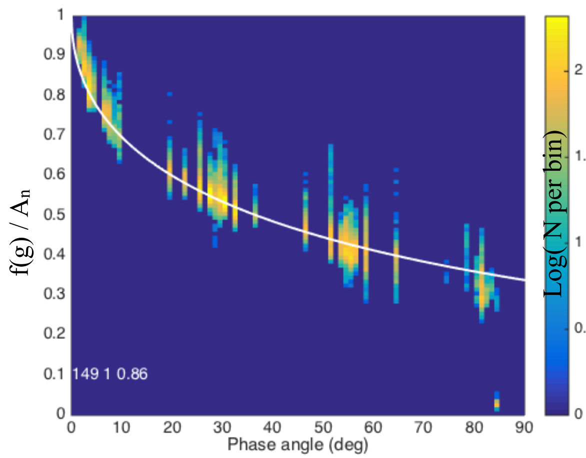

Figure 2- An example of the data in a 1°x1° pixel centered at 149.5° E and 1.5° N. The best-fit phase function for this pixel (white line) has η = 0.86.

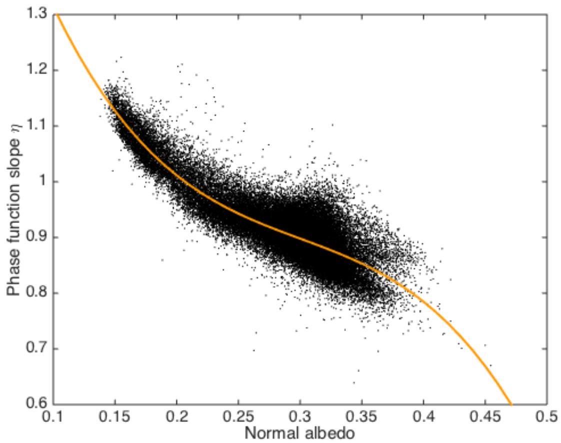

Figure 3- Correlation of the phase function slope parameter η with normal albedo A_n. The orange curve is the best-fit cubic polynomial.

model overlaid. The minimum phase angle in a pixel generally increases with latitude due to the nadir observing geometry of LRO. We can take advantage of the global correlation between η and A_n (Figure 3) to obtain a spatially-resolved model phase function at 1064-nm. Future work will investigate photometric anomalies by measuring changes in the phase function bend parameter, ρ, and will produce maps of Hapke parameters to complement the maps produced by the LRO Wide Angle Camera (WAC) at ultraviolet-visible wavelengths [3].

The LOLA 1064-nm passive radiometry has the ability to probe into permanently shadowed regions (PSRs) with scattered light from nearby illuminated terrain (Figure 4). This potentially offers a new method to identify systematic differences in albedo between PSRs and non-PSRs using the 1064-nm phase function. The actively-derived normal albedo map of [7] allows us to predict the phase function in the polar regions, where topographic shadows and lack of low-phase data prevent full characterization of the phase function using passive radiometry alone. This model phase function can be useful for studying spatial and temporal variations of illumination and thermal conditions in the polar regions including PSRs.

Summary: LOLA is now the longest-running narrow-band near-infrared passive radiometer ever to orbit the Moon. This mode of LOLA does not require any slewing although it does collect data while LRO is off-nadir to target specific regions of interest or to fill in the phase angle coverage. The resulting dataset provides a unique global view of the spatially resolved near-infrared phase function behavior. As the LRO orbit evolves, the phase angle and spatial coverage will also improve allowing higher resolution maps of photometric anomalies.

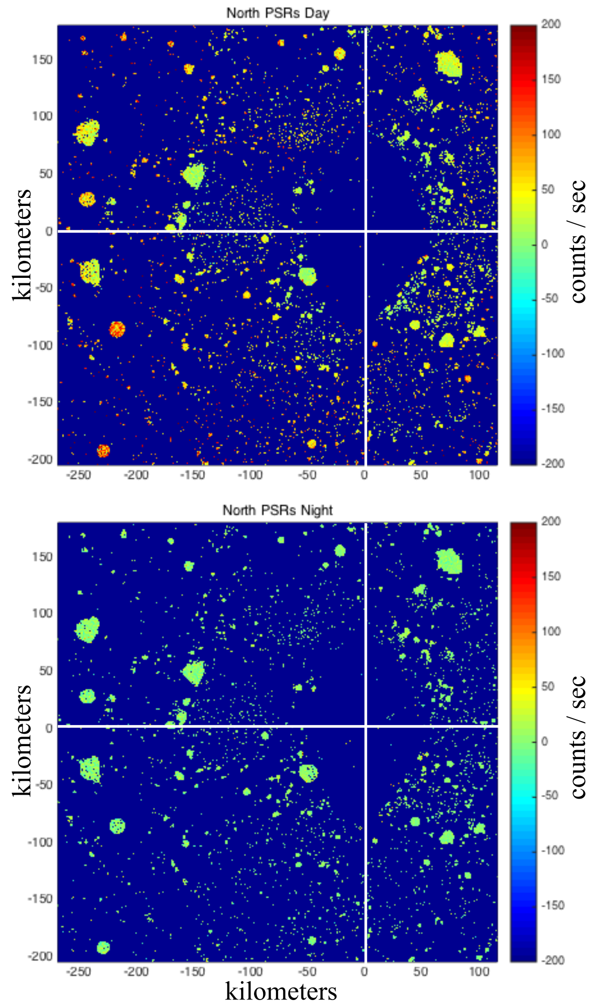

Figure 4- Polar stereographic maps of LOLA 1064-nm passive radiometry in northern PSRs during local day (top) and night (bottom). The pixel values are the median over the whole timespan of ~4 years (50 counts /sec ≈ 0.3 W/m²/μm/sr). The daytime data show an excess signal relative to the nighttime which is interpreted to be due to scattered light from nearby illuminated terrain.

References: [1] Hapke, B. (2012) Camb. Univ. Press, *Theory of Refl. and Emittance Spectroscopy*, 2nd ed. [2] Liu, Y. et al. (2018) *JGR Planets*, 123, 2550. [3] Sato, H. et al. (2014) *JGR Planets,* 119, 1775. [4] Bandfield, J. L. et al. (2015) *Icarus*, 248, 357. [5] Barker, M. K. et al. (2016) *Icarus*, 273, 96. [6] Korokhin, V. et al. (2016) *Plan. & Sp. Sci.*, 122, 70. [7] Lemelin, M. et al. (2016) *Icarus*, 273, 315. [8] Kreslavsky, M. A. et al. (2000) *JGR*, 105, 20281.