EXAMINING SURFACE PROPERTIES WITH ROBUST PHOTOMETRIC SEQUENCES A. C. Martin, E. J. Speyerer, A. K. Boyd, M. S. Robinson and the LROC Team, Arizona State University, School of Earth and Space Exploration, PO Box 873603, Tempe AZ, 85287-3603 acmart19@asu.edu

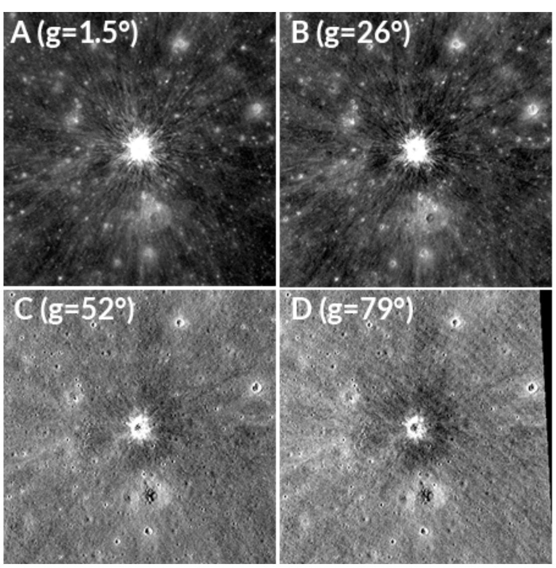
Introduction: Surface reflectance changes under different lighting and viewing geometries which provides insight into surface properties (composition, grain size, porosity, etc.). We use high-resolution images acquired by the Narrow Angle Camera (NAC) on the Lunar Reconnaissance Orbiter (LRO) [1] to investigate regions of interest on the Moon. Through rigorous geometric and photometric correction of tens of images covering a single location, we can analyze the surface reflectance and its dependence on the photometric angles (phase, emission, and incidence) and infer properties of the surface that are otherwise unknowable from a single observation.

Processing Methods & Updates: A rigorous set of routines to register the image sets and remove topographic distortion maximizes the accuracy of photometric products. Photometric sites typically require images with a wide range of phase angles. Each image in a site is tied to a NAC Digital Terrain Model (DTM) orthophoto (ground truth) allowing for precise surface angle measurements. Up to 100 images can comprise a single photometric site, with phase angles ranging between 0° and 115°.

NAC images are pre-processed and calibrated using tools from the USGS Integrated Software for Imagers and Spectrometers (ISIS). An ISIS routine attaches spacecraft position and orientation information from NAIF SPICE kernels to the image header. A control network created in the ISIS program *qnet,* spatially ties all the images to ground truth [2].

Jigsaw Bundle Adjustment Update: The images are ‘controlled’ to the NAC DTM orthophoto though jigsaw, a 'bundle block adjustment' module in ISIS. There are many parameter options available for jigsaw, which we optimized for photometric applications [3]. For photometric sites, we tie ground points in each image individually and do not allow the points to move. This avoids warping of the images around the ground points. Other jigsaw parameters have been adjusted based on these new constraints.

We analyze the accuracy of the bundle adjustment using a calculated set of residuals from jigsaw to create offset plots of the pointing information. The plots show where ground points are being pulled or twisted. We scrutinize the errors and modify the bundle adjustment parameters if large deviations exist. Often large errors in offset plots and residuals stem from the images themselves. Images with extreme high or low phase angles cause most offset issues due to shadows in the images and difficulties in making accurate ground points. Once problematic residuals are corrected, the NAC DTM is used to calculate photometric angles and map project the images for the final photometric product [2].



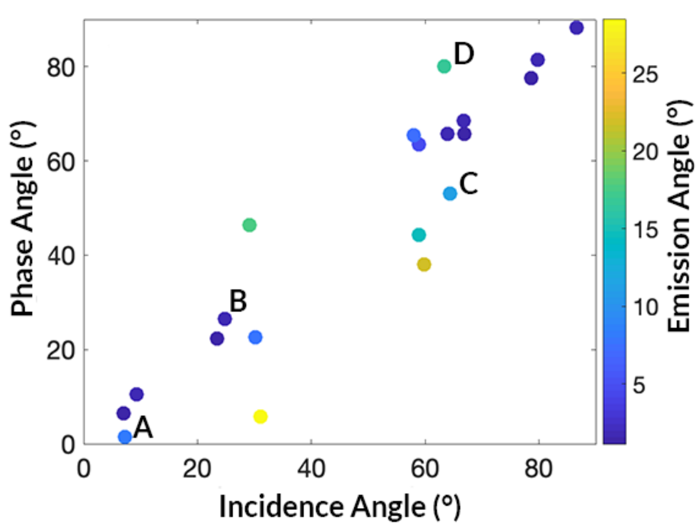


Figure 1. (Left) Four LROC NAC images from the New 50 m Crater photometric site. Phase angles range from a) 1.5°, b) 26°, c) 52°, and d) 79°. *The changes in appearance of the ejecta blanket over the phase range give clues to the surface properties of the ejecta. (Right) The plot graphs photometric angles for all images included in the New 50 m Crater photometric site. The four NAC images displayed are labeled in the plot.*

Analysis of Photometric Sites: Lunar regolith reflectance is dominantly controlled by mineralogy, maturity, particle size, shape, compaction, and transparency [4]. Recording reflectance is useful for any type of site such as new impacts, compositional anomalies, and landing sites [4,5]. Changes occurring in sites, such as a new impact, (**Figure 1**) evaluates the disturbance of the regolith caused by the cratering process.

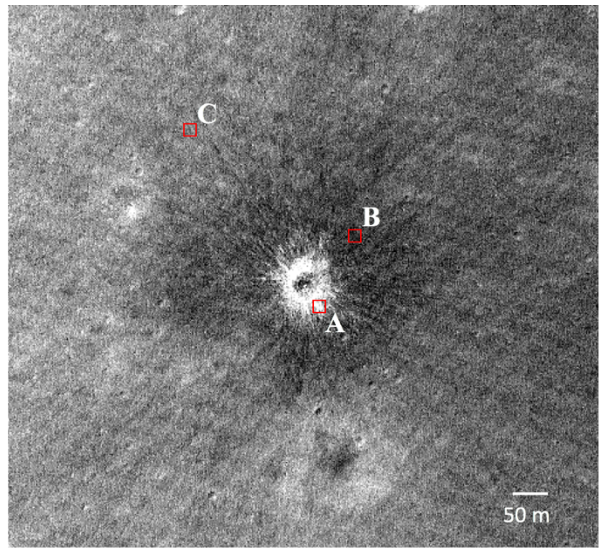
Phase ratio imaging is one way the surface properties are examined. We create a phase ratio image using images acquired at different phase angles. A phase ratio takes the light scattered from the surface at two different viewpoints and measures changes in surface reflectance. The phase angle is the position between two vectors: spacecraft to ground and sun to ground. We divide the lower phase angle (α_1) image by the higher phase angle (α_2) image. The resulting product depicts the steepness of a phase function between the two measured angles. The slope of the phase curve helps analyze material composition and particle size. Phase function slope and the surface albedo are negatively correlated on the Moon. Deviations from this can indicate anomalies in the regolith depending on illumination of shadows [4].

New 50m Crater: Impact cratering processes are complex and not fully understood. Investigating ejecta deposition zones from new craters adds constraints to impact crater modeling and regolith processes on airless bodies. Craters often feature four zones, two proximal and two distal. The images and phase angles of the 50m Crater in **Figure 1** highlight distinct ejecta zones generated through the impact cratering process. This crater has at least three zones but only two are visible in the reflectance images [6].

The phase curves (**Figure 2**) for these regions show the broadening of the opposition surge for the proximal high reflectance zone and a narrowing of the opposition surge for the proximal low reflectance zone. The phase curves also show where the shadowing starts affecting the phase curve at high phase angles. The proximal high reflectance zone is just outside the crater rim. This zone exhibits high reflectance from 0° to 70° phase and a shallow slope in the phase curve < 10° phase. The shallow phase curve at low phase and steep slope at high phase indicate that there could be larger particle sizes creating an increased opposition surge width and an increase in roughness causing more shadowing at high phase angles.

The proximal low reflectance zone exhibits a narrower opposition surge and increased slope at high phase angles compared with the surrounding regolith. The narrower opposition surge could be attributed to small grain sizes on the surface that underwent bulking caused by shearing. The increased slope at high phase could also stem from the emplacement of more hummocky terrain produced during the cratering process.

Summary: We report on updated processing methodologies for developing photometric sites using LRO NAC data. Photometric products provide unique information for understanding lunar surface properties since surface reflectance changes under different lighting and viewing geometries. We demonstrate with '50 m crater' that phase-ratio images and multi-temporal pairs can reveal changes not noticeable in individual observations.



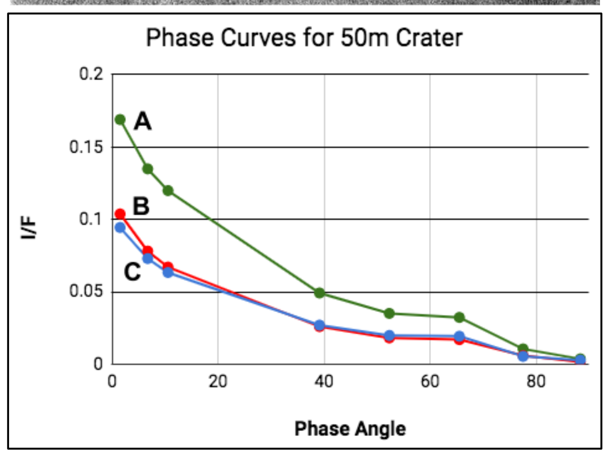


Figure 2. (Top) NAC image of New 50m Crater photometric site with phase=10.55 with three labeled locations for the phase curve measurements. Locations A and B are in two proximal zones and C is potentially in a distal zone. (Bottom) Phase curve of the locations, A, B, and C, illustrates the I/F values within each zone.

References: [1] Robinson, M.S. et al. (2010) *Space Science Reviews* 150:81-124. [2] Martin, A.C. et al. (2018) *LPSC* No. 2083. [3] J.A. Anderson et al. (2004) LPSC XXXV, Abstract #2039 [4] Kaydash, V. et al. (2011) *Icarus* Volume 211 (Issue 1, p. 89-961) [5] Clegg-Watkins, R.N. et al. (2016) *Icarus* Volume 273 (p. 84-95). [6] Speyerer et al. (2016) *Nature*, 258, 215-218.