POLARIZATION SIGNATURES OF YOUNG LUNAR CRATERS FROM DANURI POLCAM OBSERVATIONS, M. Kreslavsky, S. Kim, M. Jeong, Y.-J. Choi, C. Sim, Yu. Shkuratov, W. Farrand, C. Fassett, G. Videen, B. Moon, K.-I. Kang, D. Lee, Earth and Planetary Sciences, University of California – Santa Cruz, Santa Cruz, CA, USA, mkreslav@ucsc.edu, Korea Astronomy and Space Science Institute, Daejeon, Republic of Korea, Kyung Hee University, Karazin National University, Kharkiv, Ukraine, Space Science Institute, Boulder, CO, USA, Applied Physics Laboratory, Laurel, MD, USA, Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea.

Introduction: Solar light scattered by the lunar surface is partially polarized. Its polarization is linear and depends on the illumination/observation geometry, mainly, on the phase angle. The highest degree of linear polarization \( P_{\text{max}} \) (also known as the Korea Pathfinder Lunar Orbiter, KPLO) is carrying out the first ever imaging polarimetry studies have been carried out with Earth-based telescopic observations [e.g., 1-5]. Observations from the Earth, however, are limited in resolution and only a relatively small portion of the surface is accessible for observations under preferable illumination/observation geometry. The PolCam camera onboard the Danuri mission to the Moon (also known as the Korea Pathfinder Lunar Orbiter, KPLO) is carrying out the first ever imaging polarimetric observations from lunar orbit. Polarimetric images being obtained have an order of magnitude higher spatial resolution than telescopic data and near-global coverage for a wide low- and midlatitude zone under near-optimal illumination/observation conditions. Here we report preliminary findings of some potential scientific value of this data set.

Data processing: PolCam is a push-broom camera that obtains data in 3 spectral bands: 320 nm wavelength (no polarization data), 430 nm (3 polarization orientations), and 750 nm (2 polarization orientations). To optimize the illumination/observation conditions, PolCam is configured for an oblique view at \( \sim 45^\circ \) off nadir. Processing of PolCam observations includes precise photometric calibration, orthorectification to compensate for geometric distortion due to its oblique view, calculation of polarization from 3 or 2 co-registered or pho-terimages with different polarization orientations, repeating this for several phase angles, and derivation of \( P_{\text{max}} \) [6]. \( P_{\text{max}} \) is known to correlate with surface albedo; the dependence of \( P_{\text{max}} \) on albedo is called Umov’s law. The quantitative measure of deflection from Umov’s law is the so-called polarimetric anomaly. This quantity bears information about submillimeter soil structure and can be recalculated into a measure of characteristic particle size [e.g., 1].

Because of some technical issues, PolCam operates in a mode different from what was originally planned; this leads to a higher resolution, a lower signal-to-noise ratio, some image artifacts, and a limitation on surface coverage per orbit. As a result, multiple phase-angle coverage has not been obtained yet, and a precise photometric calibration is still being developed. Therefore, the data processing procedure described above cannot be fully implemented yet, although data quality and plans for the extended Danuri mission warrant that it be done in the future.

To get a preliminary look at the scientific content of PolCam data, the following simplified procedure was applied to polarimetric image pairs in the 750 nm filter. Only a single image pair for one phase angle was used. Precise photometric calibration was replaced with a simplified flat-field correction and artifact removal. A 3x3 boxcar median filter was applied to reduce noise. Orthorectification was replaced with a “warp”, a.k.a. rubber-sheet, coregistration. Then a principal component analysis was performed for each pair of images with shadows and steep slopes manually masked out. If the unknown dependence of detector response to received light intensity is linear, and polarization variations are relatively small, the second (minor) principal component is a linear uncalibrated proxy of the polarimetric anomaly, while the first (major) principal component is a proxy of albedo entangled with polarization, varying according to Umov’s law. A perfectly linear correlation between image pairs supports the validity of this approach.

This shortcut approach has several shortcomings: due to arbitrary normalization, the polarimetric-anomaly images can only be studied in a relative, qualitative sense; comparison of observations under different phase angles is complicated; processing includes manual masking and cannot be fully automated. The only and major advantage is that this approach enables preliminary scientific analysis of polarimetric anomalies with incomplete and uncalibrated data.
Observations: Figs. 1 and 2 show an example of results obtained. Fig. 1 shows a scene in Oceanus Procellarum centered at 8.8°N, 309.3°E. This is a small portion of an image in one of the polarimetric 750 nm filters. Solar illumination is from the right, the PolCam view is from the left, and the phase angle is ~110°. The scene contains a wrinkle ridge, a bright ray from crater Kepler, a young crater (800 m diameter) with bright immature proximal ejecta, and a number of impact craters without apparent ejecta. Fig. 2 shows an arbitrarily normalized polarimetric anomaly for the same scene. Spurious features in this image include inevitable noise, vertical stripes due to imperfections of the flat-field correction and artifact removal, and a residual topographic pattern, which occurs due to shadows, sub-pixel imperfection of coregistration, and photometric effects. The bright ray does not appear in the polarimetric anomaly image: it is along the Umov’s law polarization–albedo trend. However, similarly bright ejecta of the young crater demonstrate a prominent positive polarimetric anomaly: their polarization is higher than Umov’s law predicts for their albedo. This polarimetric anomaly is not resolved in the best Earth-based polarimetric anomaly map [5]. Our interpretation is that the fresh ejecta are coarser than the typical surrounding regolith. The other craters in the scene do not have associated polarimetric anomalies. Our interpretation is that they are older, and regolith gardening and comminution with micrometeoritic impacts already equilibrated the regolith particle size on their ejecta.

Several image pairs examined so far revealed a number of similar examples of young craters and a cluster of smaller (300 – 500 m) secondary craters with coarse ejecta. There are also some positive and negative polarimetric anomalies not associated with impacts; however, more work is needed to reliably distinguish them from possible artifacts.

Discussion: Aging of impact craters through ejecta comminution is a process different from optical maturation [e.g. 7], removal of thermal signatures due to disintegration of centimeter-size rock fragments [e.g., 8], radar-signature alteration due to disintegration of decimeter-size rock fragments [e.g., 9] and shallowing due to topographic diffusion [e.g. 10]. Systematic counting of craters with associated positive polarimetric anomalies on a large area will give quantitative estimates of the comminution rate and enable comparison of this aging process with the others.

Conclusions:
(1) Danuri PolCam data contain unique, important, interpretable scientific information.
(2) A principal component analysis enables geologic interpretation of arbitrarily normalized polarimetric anomalies if accurate calibration is not available.
(3) Ejecta of some young small craters have positive polarimetric anomalies due to coarse ejecta material.