PHASE-RATIO IMAGERY IDENTIFICATION OF THE SURFACE ALTERED IN THE APOLLO-16 LANDING SITE. V. G. Kaydash and Y. G. Shkuratov, Astronomical Institute of Kharkov V. N. Karazin National University, 35 Sumskaya Street, Kharkov 61022, Ukraine, vgkaydash@gmail.com

Introduction: The phase-angle dependence of the lunar reflectance is related to the surface composition, porosity and roughness [1]. *Phase-ratio imagery* allows the identification of natural surface structure anomalies and artificially altered regolith [2-4]. In this study we use the high-resolution images of the lunar surface obtained by the Narrow Angle Camera (NAC) onboard the Lunar Reconnaissance Orbiter (LRO) [5] to map phase ratios of the Apollo-16 landing site (LS). We interpret the maps in terms of how the regolith properties have been affected by human activity on the Moon.

Phase-ratio imagery: This method allows one to analyze the brightness phase function through calculating the quotient $\xi = A(\alpha_1)/A(\alpha_2)$ of coregistered images acquired at different phase angles. This suppresses the surface albedo variations. The resulting image presents variations of the phase-function slope that is dominated by the shadow effect and incoherent multiple scattering. For low-albedo surfaces (e.g., the Moon) the phase-function slope substantially depends on the morphological properties of the surface [1,2]. Large deviations of the ratio ξ from the average value can be interpreted as the presence of photometric anomalies. They can be explained by the disturbance of the lunar regolith structure at scales from wavelength to image resolution. Anomalies with smaller phase-curve slope indicate less surface roughness; whereas, a steeper phase curve corresponds to a rougher surface [1].

Recently the phase-ratio imagery was applied to analyze the LS of the Apollo-11, -12, -14, -15, and -17 expeditions [4,6]. This revealed photometric anomalies of ~170 x 120 m size that are characterized by lower phase-function slopes, indicating a smoothing of the surface microstructure caused by the engine jets of the landing modules. Anomalies with higher phase-function slopes are the result of regolith loosening by astronaut boots and the wheels of the vehichles. We here perform the phase-ratio analysis for the Apollo-16 LS to identify the regolith distrurbances.

Imagery of the Apollo-16 LS: We map a phase ratio using LRO NAC images that include the LS and have almost the same resolution and illumination (see Table 1). The images used were acquired at phase angles 17° and 58°. Figure 1 presents a fragment of the small-phase-angle image (α = 17°) with pixel numbers calibrated in radiance factor A, μW/cm^2·sr·nm (upper panel). The LS is shown by arrow. On average the LS vicinities of tens and hundreds of meters have close albedo values. At the phase angle 58º, the proximate landing area is somewhat brighter. The sun-facing crater walls and proximal ejecta blankets of craters are substantially brighter than the LS.

Table 1. LRO NAC images used

Image ID	M152777016R	M152770233R
Resolution, m/pix	0.50	0.51
Emission angle, deg	20.47	22.89
Incidence angle, deg	36.10	35.19
Phase angle, deg	17.13	57.55
Center latitude, deg	-9.10	-9.09
Center longitude, deg	15.52	15.51

We performed a coregistration of the images described in Table 1 using a rubber-sheet geometric transformation with subpixel accuracy. The algorithm we applied calculates optimal local shifts by maximizing the local correlation between overlapping small sub-frames scanning the images [1,3]. The quotient of the coregistered images, i.e. the phase-ratio image $\xi = A(17°)/A(58°)$, is shown in the lower panel of Fig. 1. The scale bar shows variations of ξ over the scene.

As can be seen, albedo variations over the scene are almost disappeared in the ξ image; thus, variations of the phase-function slope and the effect of large-scale topography only remain. The latter shows up as large contrast details in the ξ parameter, because of difference in local incidence and emission angles. Therefore, the resolvable surface topography cannot be analyzed in terms of phase-function steepness.

The LS shows up as a diffuse dark spot of 150 x 120 m size with low values of the ratio (ξ~1.4); whereas, neighboring lunar terrain is characterized by higher values, ξ~1.6. This represents an approximately 14% difference in ξ. The LS itself does not obey an inverse correlation "ξ – A" that is common for the lunar surface [1-4]. Lower ξ values correspond to smaller phase-curve a slope that indicates lower surface roughness. This is related to the soil blowing by the gas jets from the engine of the lander.

The full resolution image of the LS (Fig. 2, upper panel) clearly reveals the landing module (LM) *Orion*, lunar rover vehicle (LRV) parking spot, and tracks, as well as the Apollo lunar surface experiments package (ALSEP) installed by the crew. Inspection of the LM vicinity immediately reveals the dark halo of ~25 m size around the LM. The brightness of the LRV tracks is close to that of the undisturbed surface far from the landing area.

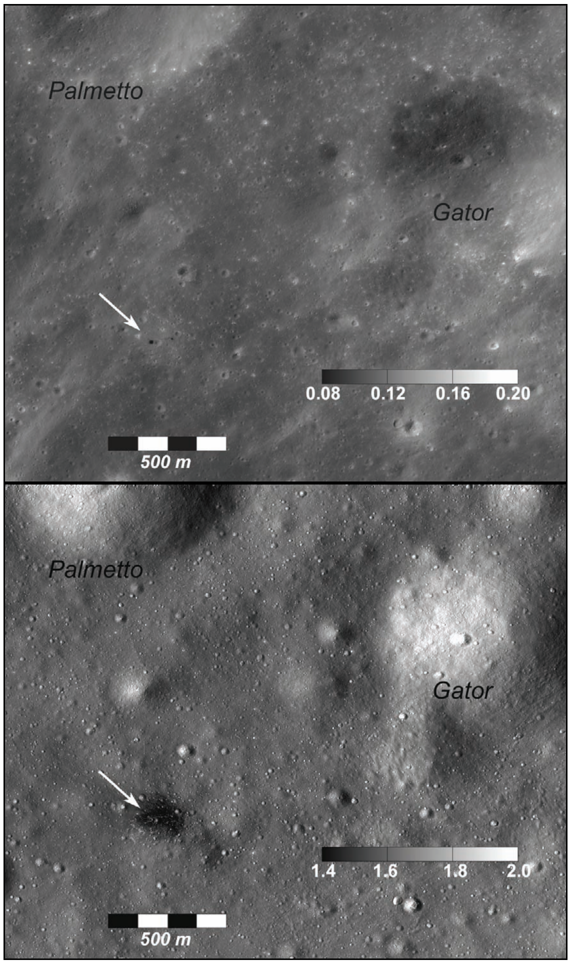

Figure 1. Vicinity of the Apollo-16 LS imaged by the LRO NAC. Upper panel: Radiance factor *A* at α=17°. Lower panel: Phase ratio image *A*(17°)/*A*(58°), the proper dynamic range bars are shown. Nearby craters Palmetto and Gator are marked. LS itself is pointed by arrow. North is up.

The phase-ratio image in full resolution (Fig. 2, lower panel) exhibits irregularly shaped diffuse photometric anomaly associated with the LS. Just as in the cases of Apollo-11, -12, -14, -15, and -17 landings, the anomaly center does not coincide with the landing point. This shift as well as the shape of the landing spot may be related to the distribution of the jets and the angle of LM approach to the lunar surface. We also note the small halo around LM with increased ξ~1.6 and LRV tracks that are perfectly seen as brighter details on the ξ distribution (~1.6-1.8). The halo and area surrounding the ALSEP deployment site are produced by the wheels of the LRV and boots of the astronauts.

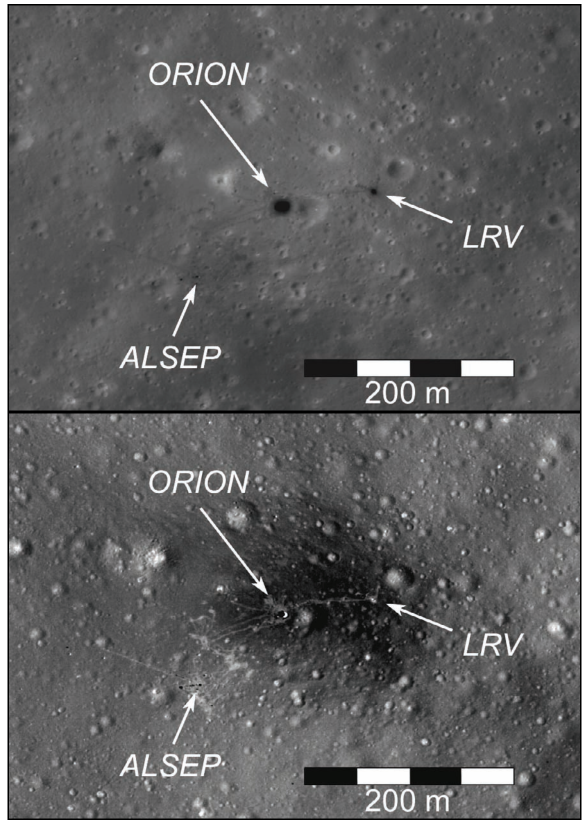

Figure 2. The LS in full resolution of 0.5 m/pixel. The LM *Orion* , LRV parking spot, and ALSEP installation location are shown by arrows. Upper panel: Radiance factor *A* at α=17°. Lower panel: Phase ratio image *A*(17°)/*A*(58°).

Conclusion: Thus, the phase ratio technique reveals the photometric anomaly (lower phase-function slope) in the vicinity the Apollo-16 LS. We interpret this as surface smoothing caused by the engine jets of the lander. Areas with higher phase-function slopes are the tracks left by the crew. Hence, with the phase ratio method we are able to estimate the shape and size of the regolith disruption areas caused by human activity. We suggest using this method to detect the areas of fresh impacts, slumps, slope processes on the lunar surface.

References: [1] Shkuratov Y. G. et al. (2011) *Planet. Space Sci., 59,* 1326-71. [2] Shkuratov Y. G. et al. (2010) *Icarus, 208,* 20–30. [3] Kaydash V. G. et al. (2009) *Icarus, 202,* 393-413. [4] Kaydash V. G. et al. (2011) *Icarus 211,* 89–96. [5] Robinson M. S. et al. (2010) *Space Sci. Rev., 150,* 81–124. [6] Kaydash V. G. and Shkuratov Y. G. (2012) *Solar Syst. Res., 46,* 2, in press.