

**PHOTOMETRIC ANOMALIES OF THE LUNAR SURFACE: NEW RESULTS FROM CLEMENTINE DATA ANALYSIS.** *M. A. Kreslavsky*<sup>1,2</sup> and *Yu. G. Shkuratov*<sup>1</sup>, <sup>1</sup>Astronomical Observatory, Kharkov National University, 35 Sum'ska, Kharkov, 61022, Ukraine, <sup>2</sup>Dept. Geol. Sci., Brown University, Providence, RI 02912-1846, USA. misha@mare.geo.brown.edu

**Introduction:** Brightness of the lunar surface depends on the illumination/observation geometry. This dependence (the photometric function) is controlled by the regolith structure at a wide range of spatial scales. Unusual behavior of the photometric function indicates anomalies in the regolith structure.

We have reported on the discovery of photometric anomalies in the vicinity of Apollo-15 landing site with Clementine data [1]. Here we report on other anomalies found [2].

**Clementine UVVIS data usage to search for photometric anomalies:** If some area of the lunar surface was imaged more than once at different observation and/or illumination geometry, this gives a potential possibility to map parameter(s) of the photometric function and identify photometric anomalies. For good results, the following requirements on the source images should meet. (a) The source images have low noise and/or the number of images is large; noise is a problem because the majority of UVVIS images suffer from lossy compression. (b) The illumination/observation geometry of the source images is quite different; otherwise the corresponding brightness change is too small. (c) The illumination/observation geometry is not too different; otherwise the effect of minor topographic slopes would mask photometric anomalies. (d) The scene is flat enough, otherwise the topography effect would dominate; this actually limits the study with mare surfaces. (e) The source images have comparable resolution; otherwise the resolution difference would produce artifacts completely masking the anomalies.

Our inspection of the whole Clementine UVVIS data set showed that there are only a few sites, where the conditions (a)-(e) meet. Here we report on results obtained at 6 sites. For 2 of them, only a pair of low-noise images is available; these sites are crater Krafft M (14°N 289°E) and the site to NE of crater Cardanus (18°N 284°E). For the other 4 sites, there are series of images taken along the same orbits [3]. These sites are: Apollo-15 landing site [1] (26°N 3°E), a site in Mare Cognitum (7°S 337°E), a site in Oceanus Procellarum near crater Galilaei (9°N 298°E) and Reiner  $\gamma$  albedo feature (7°N 301°E). We continue our work on several other series, but they are less promising.

**Data processing:** For each site, the source "raw" UVVIS frames underwent standard calibration procedure [4] excluding the photometric correction and absolute normalization. In this way we obtained the data

numbers proportional to the bidirectional reflectance with an unknown proportionality coefficient. Then the source images were carefully coregistered with a specially developed algorithm. The illumination/observation geometry was calculated for each pixel of each source image. Then from a set of reflectance values at different geometries, the parameter(s) of an approximation of photometric function were derived for each pixel (see [3] for details about the approximation used).

**Results and interpretation:** If the surface is isotropic, the illumination/observation geometry is completely determined by three angles, and the photometric function describing the photometric properties of the surface depends on three variables. Thus, this is a rather complex object even for an isotropic surface. Fortunately, as a first simplified approach, at small and moderate phase angles ( $< \sim 60^\circ$ ), it is possible to consider the variability of the photometric function as the variability of the dependence of reflectance on the phase angle only (the phase function). Moreover, since the phase function monotonically decreases, we can roughly characterize the phase function with its steepness (the logarithmic derivative). We use the maps of the logarithmic derivative to search for the photometric anomalies, that is the areas where the phase function is steeper ("positive" anomaly) or less steep ("negative" anomaly) than typical for the scene. Below we overview all types of photometric anomalies found so far.

**Albedo-related anomalies.** Several sites give examples of an inverse correlation of the steepness of the phase curve and the surface albedo: darker surfaces usually have steeper phase functions. General trend of the same sense has been found in astronomically-obtained data for dark parts of the lunar nearside [5]. This correlation is easily explained by the shadow hiding mechanism. The correlation is not described by a simple universal functional relationship: There are regional variations of this dependence. The quantitative study, however, is obstructed by the UVVIS image calibration inaccuracy.

**Anomalous crater halos.** Some small ( $\sim 100$ m) fresh craters have halos of negative anomaly [1]. Old craters never have such halos. Many morphologically fresh craters, exhibiting bright ejecta zones, do not have the anomalous halos. The halo is usually 0.5-5 km in diameter, several times wider than the bright ejecta area of the associated crater. The latter proves that we

do observe a structure anomaly. The halos have less steep phase curves than the background; this means that the uppermost layer of the regolith has smoother microtopography and/or higher packing density. We interpret this in the following way. The uppermost regolith layer has a specific porous openwork, "fairycastle" millimeter-scale structure, which is created by the space weathering factors, primarily, due to the micrometeoritic bombardment. The impact damages this structure in some vicinity of the impact site. Particular mechanism of this damage may be shaking of the regolith by the impact-induced shock/seismic wave. Alternatively, a shower of fine-grain distal ejecta could be powerful enough to damage the structure, but not enough to overturn the regolith and expose the brighter immature material. At geological time scale the micrometeoritic bombardment reestablishes the openwork structure and, hence, erases the anomalous halo. The time scale of this process is probably shorter than the regolith gardening, which erases bright ejecta and softens the crater morphology. The difference in the time scale is responsible for the existence of fresh craters with no anomalous halo.

**Landing site.** There is a negative anomaly at the Apollo 15 landing site [1]. We interpret it as an area of an "openwork" regolith structure damaged by the lander jets. Some brightening of the surface at the landing site attributed to the regolith disturbance by the jets had been observed in images taken from the orbit by Apollo 15 astronauts [6]. Study of microphotographs of the regolith at the landing sites [7] has shown a difference in mm-scale topographic characteristics between locations close and far from the landers.

**Swirl.** Bright Reiner  $\gamma$  albedo feature as a whole displays a negative anomaly according to the trend mentioned above. However, within the bright area, there are one well pronounced and a few weaker negative anomalies not correlated with the albedo pattern. These anomalies indicate that the regolith here have unusual and spatially variable millimeter-scale structure.

**Other anomalies.** There is a halo of negative anomaly near Krafft M rim around a small (diameter of ~200 m) dome. The dome might be a volcanic edifice and the halo might be related to pyroclastic deposits around it. Earth-based astronomical data [3] had shown a weak negative photometric anomaly at Marius hills known to be volcanic centers. If this is the case, we observe here an anomaly of the regolith source material rather than recent regolith structure disturbance.

There are a few positive anomalies in the studied areas. They indicate unusual regolith structure, but the

physical nature and geological reasons for these anomalies are not clear yet.

**Conclusion and prospects:** Our results show that photometric studies of the lunar surface at 10-100 m resolution are of great interest and are very promising. They can be useful in future geomorphologic studies. The discovery of anomalous halos of some fresh craters opens a principally new possibility to estimate regolith gardening rate. Advanced statistics of craters with anomalous halos could give unique information on the recent impactor population in the Solar System. Recent shallow high-amplitude seismic events (if they occurred) should also leave traces of the disturbed regolith, which would appear as photometric anomalies. Thus the photometric studies can be used to search for sites of recent seismic activity in the lunar crust.

Unfortunately, Clementine data do not allow any extensive survey of the photometric anomalies. They give only several examples. Earth-based astronomical observations are limited in resolution; all interesting features that we found in Clementine data set are principally unresolved from the Earth. A part of Oceanus Procellarum was imaged by Hubble Space Telescope in 1998 with the resolution similar to that of Clementine UVVIS camera [8]. There are several Clementine images with no compression loss in the area imaged by HST. We plan to combine these Clementine and HST images and continue our overview of the photometric anomalies. New imaging of the Moon with HST potentially can be a base for a global search for kilometer-scale photometric anomalies on the lunar nearside. We also consider possibilities to use the AMIE/SMART-1 camera data. The SMART-1 spacecraft will orbit the Moon in 2003. We hope to combine Clementine images with no compression loss with AMIE images for several sites in Mare Humorum and Mare Nubium.

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