

A NEW PHASE FUNCTION OF THE LUNAR SURFACE DEDUCED FROM LROC WAC PHOTOMETRIC MEASUREMENTS. V. V. Korokhin¹, Y. G. Shkuratov¹, V. G. Kaydash¹, Yu. I. Velikodsky², and G. Videen³, ¹Institute of Astronomy, V. N. Karazin National University, 35 Sumska St, Kharkiv, 61022, Ukraine, ²National Aviation University, Cosmonaut Komarov Ave. 1, Kiev 03680, Ukraine, ³Space Science Institute, 4750 Walnut St. Suite 205, Boulder CO 80301, USA.

Introduction: The phase function is a necessary component for studying the physical properties of the lunar surface and for valid photometric transformations of data of ground-based and spacecraft observations [1]. The phase function $f(\alpha)$ bears information about the structure of a surface, as it is sensitive to changes of photometric conditions during observations.

Several different equations for the phase functions of the lunar surface have been proposed. One of the most commonly used is the 4-parameter formula by Akimov [1,2]:

$$f(\alpha) = A_1 \exp(-\mu_1 \alpha) + A_2 \exp(-\mu_2 \alpha), \quad (1)$$

where α is the phase angle, A_1 , μ_1 , A_2 , and μ_2 are coefficients. Note that $A_1 + A_2$ is equal to the normal albedo A_0 . This formula provides a good approximation of phase curves deduced from observations, but an ambiguity is observed frequently between the first and the second terms of (1). We here propose a new expression for the lunar phase function:

$$f(\alpha) = A_0 \exp(-\eta \alpha^\rho), \quad (2)$$

where A_0 , η , and ρ are, respectively, the normal albedo, slope and bend of the phase curve (the greater the parameter ρ , the smaller the bend). This formula has only 3 parameters and may be easily linearized, which is useful for effective photometric calculations.

Application to LROC WAC data: The LROC WAC data set suggests unique information for photometric investigations of the lunar surface, because it provides multiple coverage (up to hundreds of times) of the same areas under different illumination and observation conditions [3]. Building seamless photometric mosaics is a difficult task, as many things should be taken into account, e.g., (1) variations of α within a frame are large, up to 60°; (2) the influence of local slopes of the surface on photometric data; and (3) the position of the same point of the surface in different filters differs due to the parallax effect. The procedure of primary processing of the LROC WAC data has been described in detail [4].

To map the parameters of functions (1) and (2), we consider each point of the lunar surface in two scenes, applying the mean-square method to all available LROC WAC images (up to 150..200) acquired at different phase angles. The first scene comprises the Reiner- γ formation (Fig. 1). The phase curves of two points (P1 and P2 in Fig. 1) are shown in Fig. 2 with

approximations using Eqs. (1) and (2). P1 is located in the area of a photometric anomaly (negative correlation between the phase curve slope and albedo) and P2 is in a typical area. Tables 1 and 2 contain parameters of the approximations (r_c is the correlation index). The equations show good agreement, but Eq. (2) works better. In rare cases, when $\rho > 1$, the new approximation suggests unusual smoothing out of the phase curves at small α , which is, perhaps, a shortcoming of the approximation (see P1 in Fig. 2).

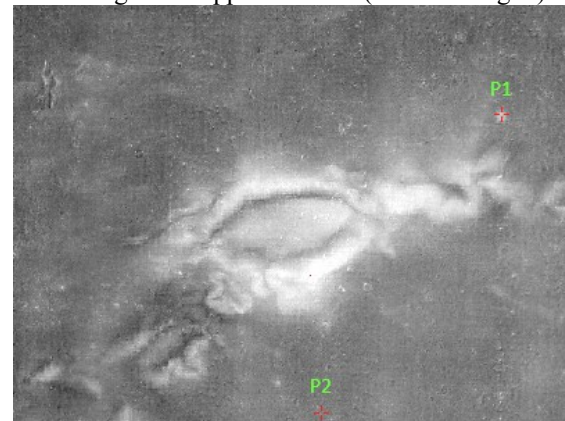


Figure 1. The albedo map of Reiner- γ swirl

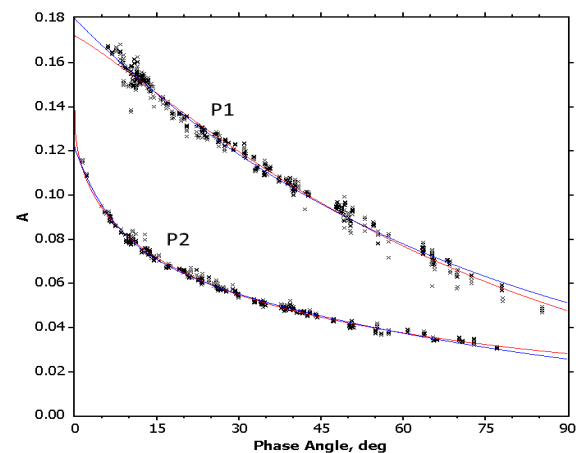


Figure 2. Approximations of phase curves of two lunar sites at $\lambda = 689$ nm using formula (1) shown in blue, and (2) in red

Table 1. Parameters of approximation by formula (1)

Site	A_1	μ_1	A_2	μ_2	r_c
P1	0.1801	0.8003	0.0000	0.0000	0.9903
P2	0.0795	0.7185	0.0424	8.0385	0.9948

Table 2. Parameters of approximation by formula (2)

Site	A_0	η	ρ	r_c
P1	0.1721	0.7633	1.1516	0.9942
P2	0.1382	1.2716	0.4940	0.9970

We also have applied Eq. (2) for mapping the phase-function parameters of the photometric anomaly in Mare Nubium [5] (Figs. 3-5). The anomaly is almost invisible on the map of η , but is clearly seen in the ρ map. We also found that parameter η demonstrates a close inverse correlation with albedo and depends on the wavelength; whereas, the parameter ρ is almost independent of the wavelength (Fig. 6).

Conclusions: We here propose an empirical phase function having only three parameters, which may describe the phase dependence of brightness over a wide range of phase angles better than the 4-parametric formula (1). The new approximation should be applied with caution at small phase angles if $\rho > 1$, which is observed rarely. The parameter η describes the general slope of the phase curve and inversely correlates with albedo. The parameter ρ describes the bend of the phase curve. The typical value of ρ is 0.63 ± 0.12 . This was calculated for seven lunar areas using more than 1 million points. The parameter ρ is almost independent of wavelength. Areas of photometric anomalies are characterized by increased values of ρ (smaller bend). This can indicate roughness caused by rock fields.

References: [1] Shkuratov et al. (2011) *PSS*, 59, 1326–1371. [2] Akimov (1988) *Kinemat. Phys. Celest. Bodies* 4(2), 10–16. [3] Robinson. et al. (2010) *Space Sci. Rev.*, 150, 81–124. [4] Korokhin et al. (2014) *PSS*, 92, 65. [5] Korokhin et al. (2014) *LPSC 46th*, #1343.

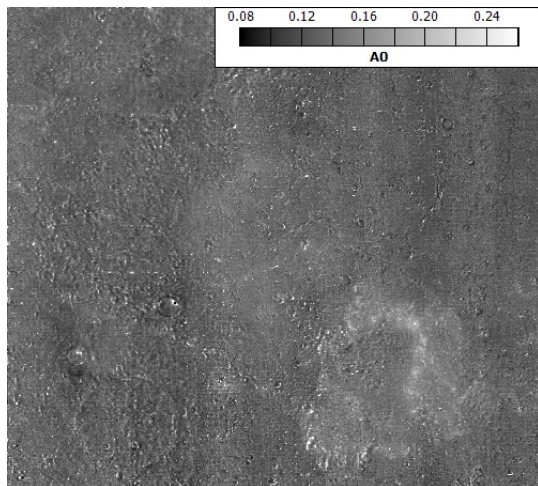


Figure 3. The distribution of the normal albedo A_0 for an area of the photometric anomaly in Mare Nubium at a wavelength 689 nm [5] (see a large central spot brighter than surroundings)

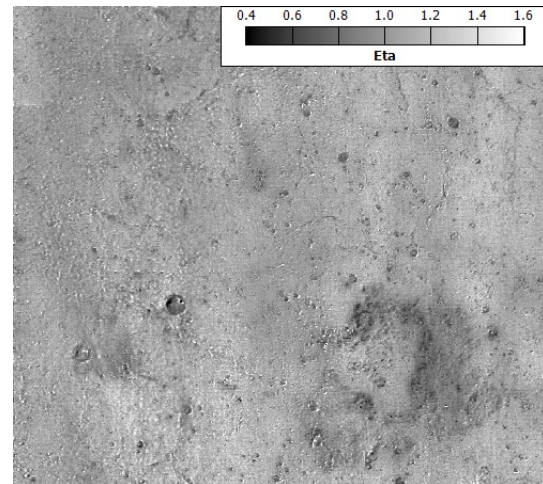


Figure 4. The distribution of the parameter η for an area of the photometric anomaly in Mare Nubium [5]

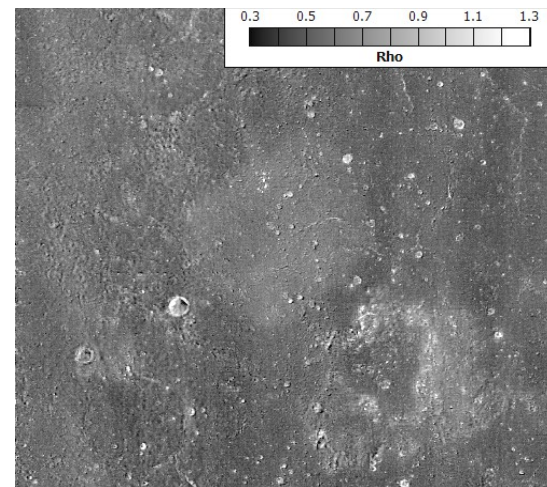


Figure 5. The distribution of the parameter ρ for an area of the photometric anomaly in Mare Nubium [5] (the central spot seen in Fig. 3)

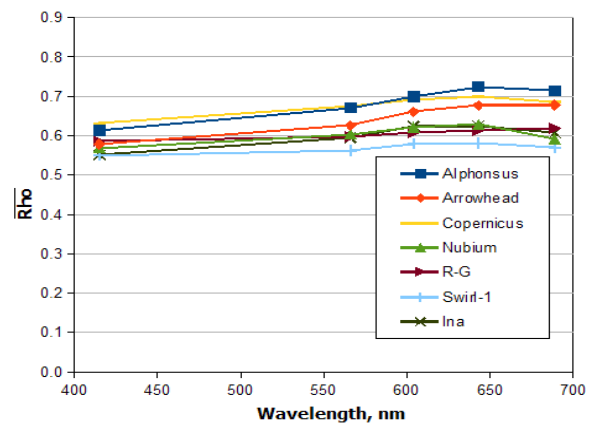


Figure 6. Values of ρ averaged over the scenes vs. the LROC WAC wavelengths