KHARKIV ABSOLUTE PHOTOMETRY OF THE MOON. Yu. I. Velikodsky, N. V. Opanasenko, L. A. Akimov, V. V. Korokhin, Yu. G. Shkuratov, and V. G. Kaydash, Institute of Astronomy, Kharkiv National University, 35 Sumskaya Street, Kharkiv, 61022, Ukraine, dslpp@astron.kharkov.ua.

Introduction: The purpose of this work is to obtain the absolute value of lunar albedo and study the phase dependence of lunar brightness. This information is very important for calibration of new Chandrayaan-1 and LRO data and finally to determine the composition and structure of the lunar regolith. Moreover, the new photometric system gives an opportunity to use the Moon as a photometrical standard for observations of planets and the Earth from space.

Observations: In 2006 we carried out a two-months series of quasi-simultaneous imaging photometric observations of the Moon and the Sun at a 15-cm refractor – the guide of the Kharkov 50-cm telescope at Maidanak Observatory (Uzbekistan) [1]. During 42 observational dates we have acquired with a Canon EOS 300D camera about 20,000 images of the Sun and the Moon in 3 spectral bands ("R": 603 nm, "G": 529 nm, "B": 472 nm) in a wide range of phase angles (1.6–168°) and zenith distances. Observations of the Moon were performed by night as well as by day in parallel with solar observations when the Moon's and the Sun's zenith distances were equal. The day observations in filter "R" have been described in [1]. We here present night observations in filter "R".

Absolute calibration: For absolute calibration the brightnesses of solar and lunar surfaces have been converted into the same photometric system that allows us to calculate the lunar albedo. The procedure of the calibration has been described in [1].

Albedo calculation. We use the albedo $A(\alpha,i,e)$ which is defined as a function of the phase angle α, incidence angle i, and emergence angle e. It is equal to the well-known bidirectional reflectance $r(\alpha,i,e)$ multiplied by π [2]. The albedo known as the normal albedo is $A(0,0,0)$. To describe the phase dependence, it is convenient to use the so-called equigonal albedo $A_{eq}(\alpha) = A(\alpha,\alpha/2,\alpha/2)$ [3]. The albedo $A(\alpha,i,e)$ can be calculated from the ratio of lunar and solar brightnesses [1].

Processing. Using the procedure of taking into account the extinction in the Earth's atmosphere [4], we have processed the data obtained at moonrise and moonset (at large zenith distances), and have calculated albedo for them. Then using the average coefficient of transparency for a night, we have calculated albedo from lunar images registered near culmination, when transparency errors have a minimal effect.

Results: Using this algorithm we have mapped the albedo $A(\alpha,i,e)$ for the visible and illuminated portion of the lunar disk at phase angles from 1.6° to 73°. The albedo $A(\alpha,i,e)$ can be converted to the equigonal or normal albedo using lunar photometric function [3,5]. On the other hand, analysis of our albedo maps allows study of the photometric function with higher accuracy.

Phase dependence. Examples of phase dependences of the equigonal albedo of lunar areas are shown in Fig. 1 (closed symbols). The phase dependence has a steep and narrow opposition peak at phase angles <5°. We note that fitting the curve with this peak with one (or a combination of two) exponent was not successful, because of the strong non-linearity of the phase function at small phase angles. Moreover, the slope of this peak is not reliably determined from albedo data only. Therefore, the approximation was performed using the following model phase function $f(\alpha) = m_1 e^{-\mu_1 \alpha} + m_2 e^{-\mu_2 \alpha} + m_3 e^{-\mu_3 \alpha}$ simultaneously for phase dependences of albedo and relative phase dependence at small phase angles. The latter was obtained from disk trend on images acquired near two oppositions at phase angles 1.5–3°. During these series the direction "sub-observer point – subsolar point" changed up to perpendicular orientation. This permits us to separate the phase angle trend of brightness over the lunar disk and albedo variations over it. Using the least-squares method, we have simultaneously fitted an equigonal albedo distribution and relative phase dependence (the values in the interval of phase angles 1.4-3.2° with step 0.1°). This phase dependence normalized using our absolute observations is shown in Fig. 1a with orange line.

Albedo of the Moon. Albedo maps for different phase angles allow us to introduce a new photometric system and calibrate existing data of lunar photometry. We have compared our maps for filter "R" with other existing photometric systems (with taking into account wavelength difference): (1) Sytinskaya-Sharonov's system [6] that was used for absolute calibration of Akimiov's photometric catalog [7]; (2) Wildey-Pohn's system [8]; (3) two systems of Gehrels [9]: 1956/57 and 1963/64; (4) Clementine UVVIS camera data that have been calibrated using laboratory measurements of lunar samples [10]; (5) the system of ROLO data [11].

Figure 1 shows albedo differences between photometric systems for several lunar areas. Average ratios of albedo in old photometric systems to our albedo are presented in Table 1. The ratio for ROLO data has been obtained by comparison of our calibrated integral lunar brightnesses with ROLO's approximation of phase dependence of disk-equivalent albedo [11]. Relative phase dependence of our albedo and ROLO's one have good agreement. The ratio for Clementine has been obtained for α=30°; it is very high, as has been noted earlier [12]. The ratios for other photometric systems obtained in a wide range of phase angles and have no notable phase dependence.

Table 1

Photometric system	Ratio to our albedo
Sytinskaya-Sharonov	0.73
Wildey-Pohn	0.85
Gehrels 1956/57	0.81
Gehrels 1963/64	0.66
Clementine	1.63
ROLO	0.86

Conclusions: Our new albedo turns out about 15-25% higher, than that in the most previous photometric systems (Gehrels 1963/64 system and Clementine data reveal questionably extremal albedo). The standard deviation of our data from the phase curve is 2%. It is somewhat higher than for ROLO data (1.5%), but is lower, than for Gehrels' (3-5%), Wildey-Pohn's (10%) and Sytinskaya-Sharonov's (18%) observations. Our phase curves show good agreement with all previous works.

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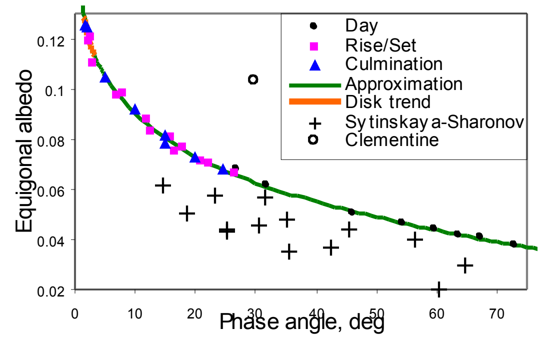
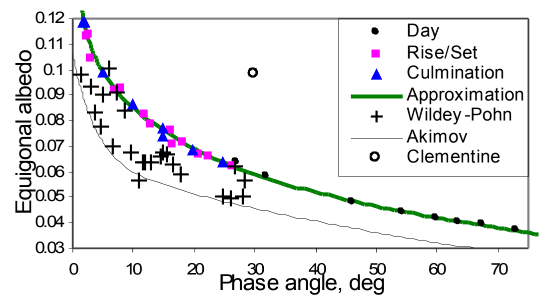
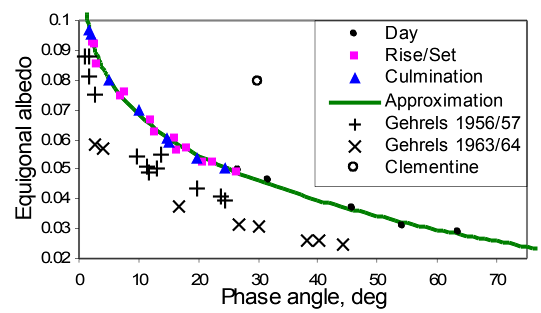
a. Sinus Medii (*l*=-1°17', *b*=0°35')



b. Mare Vaporum (*l*=1°55', *b*=14°50')



c. Mare Tranquill. near Palus Somni (*l*=39°10', *b*=11°34')



d. Copernicus, NNW of central peak (*l*=-20°08', *b*=10°11')

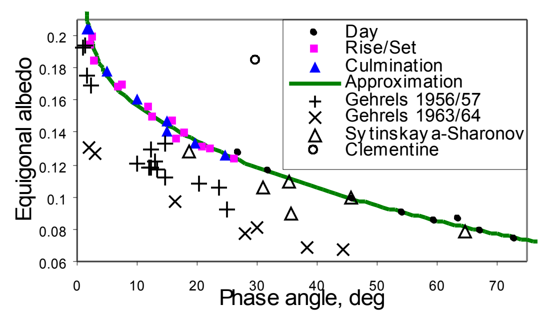


Fig.1. Phase dependence of albedo of lunar areas. Closed symbols are our data, orange curve (in panel **a**) is our phase slope from disk trend, green curve is approximation of all our data. Crosses, open symbols, and thin line (in panel **b**) are data of other authors.