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

**Introduction:** To obtain the absolute value of lunar albedo is very important for studying the composition and structure of the lunar regolith. The albedo value gives the information about absorption in the lunar soil, phase dependence of albedo allows study of the opposition and shadow-hiding effects which are controlled by the structure of regolith. Moreover, knowledge of albedos of lunar areas allows one to use the Moon as a photometric standard for observations of planets and the Earth’s surface.

Absolute measurement of the Moon is a difficult task, because magnitudes of possible photometric standards (the Sun or stars) greatly differ from the lunar one. Using the Sun is more preferable, because the Sun is a light source for the Moon and such a measurement is direct. However in this case there is a problem of non-simultaneous observation of the Moon and the Sun. In all cases, there is a problem of taking into account a possible change of atmospheric transparency during observation. As a result of these difficulties, the accuracy of existing measurements is not high enough.

There are very few datasets of lunar absolute photometry, and they not always have agreement between themselves.

These are Sytinskaya-Sharonov’s data [1] (visual photometry, calibration using the screen illuminated by the Sun) and Akimov’s catalog [2] (red light, $\lambda=0.65\mu m$) based on system [1].

These are Wildey-Pohn’s data [3] (photoelectric photometry, calibration by stars), which have an agreement with [1] in mean albedo, but have a different mare–highland contrast [4].

These are two datasets of Gehrels et. al. [5], one of which has an agreement with [1], but albedo in another dataset differs on 20%.

At last, these are Clementine spacecraft lunar data, which have been calibrated using laboratory measurements of lunar samples, and have albedos in about 2.5 times greater [6], than in system [1].

Therefore we started our observational program to build a new absolute photometric system and calibrate existing data of lunar photometry.

**Observational data:** 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). We used CMOS-camera Canon EOS 300D, which allows us to obtain images of whole lunar disk in one frame (except for full-moon phase) simultaneously in 3 spectral bands ("R": $0.61\mu m$, "G": $0.53\mu m$, "B": $0.47\mu m$). We have carried out some special studying of the camera and the telescope (studying of nonlinearity, exposures hardwired in the camera, accuracy of the photometry, flat field of our system) which was described in [7].

During 42 observational dates we have obtained about 20,000 images of the Sun and the Moon in a wide range of phase angles (1.5–165°) and zenith distances. Resolution of the images is 1.91”/pix. Since solar brightness is about 10^6 times greater than lunar one, for solar observations we used a 5-mm aperture diaphragm, neutral filter with ~50 times weakening, and shorter exposure times. 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 equals.

**Absolute calibration:** For absolute calibration the lunar brightness should be compared with the solar brightness. For this we need to convert counts of lunar and solar images to the same photometric system dividing them by individual exposure times and multiplying the solar brightness by coefficients of the weakening because of the aperture diaphragm and of the neutral filter. Exposures have been obtained in [7] (the Sun was observed mainly at exposure 0.002–0.004 s, and the Moon was measured at 0.01–0.02 s). For the coefficients of weakening we have performed a special series of observations of the Moon near zenith with and without the diaphragm, with and without the filter. We have found that the diaphragm weakening is 740.3 times and that for the filter is 62.95 times (for the camera band "R").

After this conversion we have brightness of solar and lunar surfaces in the same photometric system and can calculate the lunar albedo. But at first we need to take into account extinction in the atmosphere that weakens the brightness.

**Atmospheric extinction.** In this work we use only data obtained at a quasi-simultaneous day observation of the Moon and the Sun at the equal zenith distances. For these data no correction for atmospheric extinction is needed. However because of some inequality of zenith distances we have found a small correction using an observation at neighbour zenith distances and roughly calculating atmospheric transparency.

**Albedo calculation.** We use the albedo $A(\alpha,i,\varepsilon)$ which is defined as a function of the phase angle $\alpha$, incidence angle $i$, and emergence angle $\varepsilon$. It is equal to the well-known bidirectional reflectance $r(\alpha,i,\varepsilon)$ multiplied by $\pi$. Albedo known as the normal albedo is $A(0,0,0)$. For describing the phase depend-
ence, it is convenient to use the equigonal albedo \( A(\alpha) = A(\alpha, \alpha/2, \alpha/2) \) [8].

The lunar albedo by definition can be calculated by formula:

\[
A(\alpha, i, \epsilon) = \frac{B_M}{B_S} \frac{D_{MS}^2}{kR_S^2},
\]

where \( B_M \) is the brightness of a lunar area, \( B_S \) is the brightness of center of the solar disk, \( D_{MS} \) is the Moon-to-Sun distance, \( R_S \) is the radius of the Sun, \( k \) is the ratio of average brightness of solar disk to brightness in the center. The coefficient \( k \) for the wavelength of filter "R" equals 0.82.

**Results:** Using this algorithm we have obtained maps of albedo \( A(\alpha, i, \epsilon) \) for the visible and illuminated portion of the lunar surface at several phase angles. The albedo \( A(\alpha, i, \epsilon) \) can be converted to the equigonal or normal albedo using lunar photometric function [8,9]. On the other hand, analysis of our maps of albedo allows study of this photometric function with higher accuracy.

Examples of phase dependences of equigonal albedo of lunar areas are showed at Fig.1.

Albedo maps for different phase angles allows us to build a new photometric system and calibrate existing data of lunar photometry. We have compared our maps for filter "R" with the catalog [2] based on Sytinskaya-Sharonov’s system. Ratios between the photometric systems are presented at Fig.2. New albedo is about 20-30% higher than the albedo of catalog [2], but about 2 times lower than the Clementine albedo. This is preliminary result.

We will process the rest of data. In particular, data in other filters allows us to take into account the wavelength difference between the catalog [1] and our filter "R".

Also we have calculated integral brightness of the Moon using our maps and have compared phase dependence of integral brightness with Irvine-Lane’s integral phase dependence [10] (Fig.2). Irvine-Lane’s data are not absolutely calibrated but have the reliable phase dependence. Our data have agreement with Irvine-Lane’s integral photometry data in the range of phase angles 27 - 73° within 3%.

Comparison with Irvine-Lane’s data also shows that our different dates reveal good agreement between themselves. This implies that the atmosphere did not introduce great error into our data.

Comparison with Akimov’s data shows some difference in phase curve’s shape. Possibly Akimov’s phase dependence systematically differs from our and Irvine-Lane’s ones.

Hopefully processing of all observational data will allow study of the lunar photometric function and, particularly, the phase dependence in a wide phase angle range. New photometric system will give us an opportunity to calibrate existing data in order to study composition of the lunar soil, and to use the Moon as photometrical standard for observations of planets and the Earth’s surface.

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**References:**


![Fig.1. Phase dependence of albedo of two lunar areas](image1)

![Fig.2. Comparison of photometric systems. Ratio of new albedo: (1) to Akimov’s catalog albedo (\( \lambda = 0.65 \mu m \)) – blue circles; (2) to average albedo by Irvine-Lane’s integral photometry data – red circles](image2)