

ABSOLUTE PHOTOMETRY OF THE LUNAR SURFACE. Yu. I. Velikodsky, N. V. Opanasenko, L. A. Akimov, V. V. Korokhin, Yu. G. Shkuratov. Institute of Astronomy, Kharkiv National University, Sumskaya Ul., 35, Kharkiv, 61022, Ukraine, ds1pp@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. For instance, the catalog [1] (red light, $\lambda=660$ nm), based on Sytinskaya-Sharonov's absolute system obtained with visual photometry [2], has a good agreement with Saary-Shorthill's system [3] within accuracy about 10% [4]. But at the same time Clementine spacecraft lunar data, which have been calibrated using laboratory measurements of lunar samples, have albedos in about 2.5 times greater [5], than the catalog [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": 0.63 μm , "G": 0.52 μm , "B": 0.48 μm). 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.

Studying the device and the instrument: Since we want to achieve a high accuracy in photometry and absolute calibration, we have carried out some special studying of the camera and the telescope.

Nonlinearity. For studying the photometric nonlinearity of the camera we have performed laboratory measurements using an optical bench with a stable light source and varying its distance to the camera. We have found that a deviation from linearity is about several percents in interval of signals 0–3000, but it reaches about 15% at maximal signals near 4000. So, we used only interval 0–3000 for observations and have developed a correction procedure for measurements.

Exposures. Since we used different exposures for measurements of the Moon and the Sun as well as for the calibration measurements (see "Absolute calibration" below), we should know real ratios between different exposures hardwired in the camera. We have carried out laboratory measurements of a stable light source and have found that the exposures are generally described by the formula:

$$E_{mn} = 2^{m + \frac{3}{8}n}, \quad (1)$$

where m is an integer, $n = -1, 0, 1$. However this dependence is not strict and relative deviation from (1) is presented at Fig.1. Taking into account of this deviation results in 15% correction of lunar albedo.

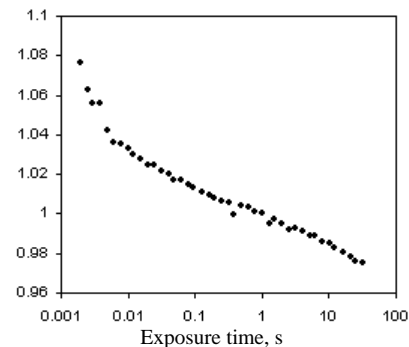


Fig.1. Ratio of real exposure times to nominal ones (1)

Accuracy of the photometry. Using laboratory measurements of the stable light source we have estimated photometrical accuracy of our camera. The dispersion of single pixel value equals:

$$D[S] = 3.42 + 0.105S, \quad (2)$$

where S is the signal in camera counts. The first term is produced by dark noise and the second one is due to photoelectronic noise which has a Poisson statistics. So, at signals about 1000 we have the accuracy (sigma) of single count about 1%.

Flat field measurements. Usually astronomers use images of bright homogeneous sky as a flat field of optical system. However this is correct only for ideal telescopes which have an ideal system of suppression of optical flares from slanting rays from outlying sky areas. Our telescope has good non-aberration optics, but has no such a system. This results in appearing of bell-like parasitic back-

ground on sky images, which is proportional to sky brightness and gives center-to-edge trend about 5%. To obtain the true flat field we have performed a special series of observations of the Moon near zenith. Each frame of this series contains the same images of the Moon at different places. Analysis of this series permitted us to obtain low-frequency part of the flat field that is not changed in time. So, to obtain the flat field for some date, we use the high-frequency part (containing dust traces) from daily sky images and low-frequency part (stable) from the “multilunar” flat field.

Primary processing algorithm. Whole algorithm of primary processing of observational data consists of: (a) subtracting electrical zero (individual for each frame and it is taken from shaded area of CMOS-array); (b) subtracting the BIAS-frame; (c) correction for nonlinearity; (d) dividing by the flat field; (e) correction of bad pixels; (f) subtracting the sky background (for day observations of the Moon) that is considered as bell-like function described above. After these procedures, data are ready for photometric studies.

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 above (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 747.8 times and that for the filter is 62.79 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 α , incidence angle i , and emergence angle ε . It is equal to the well-known bidirectional reflectance $r(\alpha, i, \varepsilon)$ multiplied by π . Albedo known as the normal albedo is $A(0,0,0)$. For describing the phase dependence, it is convenient to use the equigonal albedo $A(\alpha)=A(\alpha, \alpha/2, \alpha/2)$ [6].

The lunar albedo by definition can be calculated by formula:

$$A(\alpha, i, \varepsilon) = \frac{B_M}{B_S} \cdot \frac{D_{MS}^2}{kR_S^2}, \quad (3)$$

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 0.81.

Results: Using this algorithm we have obtained maps of albedo $A(\alpha, i, \varepsilon)$ for the visible and illuminated portion of the lunar surface at different phase angles. The albedo $A(\alpha, i, \varepsilon)$ can be converted to the equigonal or normal albedo using lunar photometric function [6,7]. On the other hand, analysis of our maps of albedo allows study of this photometric function with higher accuracy.

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 several maps for filter “R” with the catalog [1] based on Sytinskaya-Sharonov’s system. Ratios between the photometric systems are presented in Table 1. New albedo is about 20% higher than the albedo of catalog [1], 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”.

Table 1. Ratio of new albedo to albedo of catalog [1]

Date	Phase angle, deg	Ratio
2006.09.10	46.0	1.19
2006.09.11	59.8	1.21
2006.10.02	63.6	1.19

Table 1 shows that different dates reveal good agreement between themselves. This implies that the atmosphere did not introduce great error into our data. 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: [1] Akimov L. A., et al. (1986) *UkrNIINTI, Kiev*. [2] Sytinskaya N. N., Sharonov V. V. (1952) *Sci. Notes Leningrad Univ.*, 153, 114-154. [3] Saary I. M., Shorthill R. W. (1967) *NASA*. 35 p. [4] Akimov L. A., Olifer N. S. (1986) *Kinem. Phys. Cel. Bodies*, 2, iss.4, 63-69. [5] Shkuratov et al. (2001) *Astron. Vestnik*, 35, No.1, 33-38. [6] Akimov L.A. (1988) *Kinem. Phys. Cel. Bodies*, 4, iss.1, 3-10; iss.2, 10-16. [7] Akimov L.A., at al. (1999) *Kinem. Phys. Cel. Bodies*, 15, iss.4, 304-309.