MAPPING OF PHASE ANGLE RATIOS OF COLOR-INDEX *C*(610/480 nm) FOR EAST PORTION OF THE LUNAR NEARSIDE. S. Yu. Gerasimenko, V. G. Kaydash, Yu. G. Shkuratov, N. V. Opanasenko, Yu. I. Velikodsky, and V. V. Korokhin, Astronomical Institute of Kharkov V.N. Karazin National University, Sumskaya Street 35, Kharkov, 61022 Ukraine. gerasimenko@astron.kharkov.ua

Introduction: Phase angle dependences of different color-indexes of the lunar surface have been studied not enough. However, these data are necessary for interpretation of optical observations of the lunar surface. We here present results of mapping the **c**olor **i**ndex **p**hase **r**atios (CIPR) for east portion of the lunar nearside. We use photometric data (images) acquired with a telescope in the 2°-95° range of phase angles. We found that at phase angles from the range 0-50° the color index $C_{R/B}$=C(610/480 nm) of highlands grows with phase angle faster than that for dark mare areas. The opposite effect is observed at larger phase angles, 50°-95°.

Observations and data processing: Lunar imaging campaign was organized in 2006 at the Maidanak observatory (Uzbekistan) [1,2]. Observations with the Kharkov 0.5-m reflector and Canon EOS 350D camera were carried out. The camera CMOS sensor is exploited using raw format imaging in three wide spectral bands (λ_{eff} = 480 (B), 540 (G), 610 nm (R)). The pixel counts are calibrated to the numbers proportional to brightness of the lunar surface. In data processing we subtract the electric zero, bias signal, and account for the flat field. We improved the photometric accuracy of the data, averaging a series of images obtained during short time. To minimize geometric image distortions caused by the Earth atmosphere we applied a "rubber sheet" coregistration of images based upon a correlation method. All the images obtained at different solar illumination were transformed into common projection allowing their quantitative comparison.

Results of CIPR mapping: We apply the phase angle ratio method (e.g., [1]) to study the dependence of the color index on phase angles. We calculate the ratio of two $C_{R/B}$ images that are constructed for different phase angles α_1 and α_2. Thus, $C_{R/B}$ variations are suppressed on the phase angle ratio image CIPR= $C_{R/B}(\alpha_1)/C_{R/B}(\alpha_2)$, $\alpha_1 < \alpha_2$, and only the difference of $C_{R/B}$ phase dependences should remain. We here do not use an absolute photometric calibration, i.e. our estimates of the CIPR behavior are relative.

We have investigated the $C_{R/B}$ phase angle trend for east portion of the lunar nearside that comprises Mare Serenitatis, Mare Tranquillitatis and surrounding highlands. Figure 1 shows an image mosaic of the region in G filter. Figure 2 represents a $C_{R/B}$ image mosaic. Color variations over the image are about 14 %. Brighter tones correspond to higher $C_{R/B}$ values. Well-known color variations in Mare Tranquillitatis and the color difference between this mare and Mare Serenitatis are seen on the map; the surrounding highlands are more homogeneous.

Figure 1. Brightness distribution in G filter over the Mare Serenitatis and Mare Tranquillitatis in orthographic projection. Mosaic of images.

Figure 2. Color-index C(610/480 nm) distribution (mosaic). The cross shows the site used for color-index normalization (MS-2 standard [3]).

We have constructed a series of CIPR images of the region at different combination of phase angles. We here show only two CIPR distributions: for small (6°/21°) (Fig. 3) and large (75°/94°) (Fig. 4) phase angle ranges. Each CIPR image was normalized to its mean value. Analysis of the presented images reveals a relative excess of the CIPR (6°/21°) for mare regions over highlands up to 3-4 %. In general, anticorrelation of the CIPR with albedo (cf. Fig. 1) is observed. It should be noted that CIPR variations over the highlands are highly suppressed, bright young craters and ray system of the crater Proclus are not seen. The CIPR (75°/94°) distribution (Fig. 4) shows well-observed direct correlation with albedo. The average value of the CIPR for Mare Serenitatis is ~1.01; some areas in Mare Tranquillitatis are characterized by values 0.98 - 0.99. The CIPR for northeast highlands is about ~1.02. We note that for other regions of the lunar disk (e.g., Mare Humorum) CIPR images for the same phase angle ranges reveal similar behavior.

Discussion: Thus, we observe the following regularities in the CIPR behavior. At rather small phase angles the CIPR anticorrelates with albedo. When we go to larger phase angles the weakening "mare/highland" contrast on the CIPR image is observed. In the range of phase angles ~ 40°-50° the "mare/highland" contrast is disappeared. At larger phase angles the direct correlation of the CIPR parameter with albedo becomes distinguishable.

The phase reddening, i.e. growth of $C_{R/B}$ with α is explained by the progressive contribution of higher scattering orders to the total light flux reflected by the lunar regolith. The higher the albebo, the greater contribution of multiple scattering. Thus, for the surface with higher $C_{R/B}$ this contribution is greater, and, therefore, the phase dependence of the color-index is more expressed. Darker mare soils should have more neutral $C_{R/B}(\alpha)$ behavior in comparison with the highland material. Changing of the slope of $C_{R/B}(\alpha)$ curve for the phase angles $\alpha > 40°$ - 60° is connected with decreasing the role of multiple scattering at very large phase angles. This was shown in computer modeling of light scattering in particulate surfaces [4,5].

Conclusion: Using data of the Earth-based telescope observations of the Moon, we mapped phase ratios of the color-index $C_{R/B} = C(610/480\text{ nm})$ in the range 2°-95° of phase angles. These ratios reveal different behavior for mare and highland surface: for highlands the value $C_{R/B}$ increases with phase angle faster, than that for maria. This behavior remains up to the $\alpha \approx 45°$. Then, the $C_{R/B}$ dependence on α goes steeper for maria than that for highlands.

Investigations of phase angle dependences of different color indexes for the lunar surface are important, if any accurate spectrophotometric calibration is necessary. Particularly, it concerns data recently obtained by the space lunar missions LRO (USA), Kaguya (Japan), and Chandrayaan-1 (India).

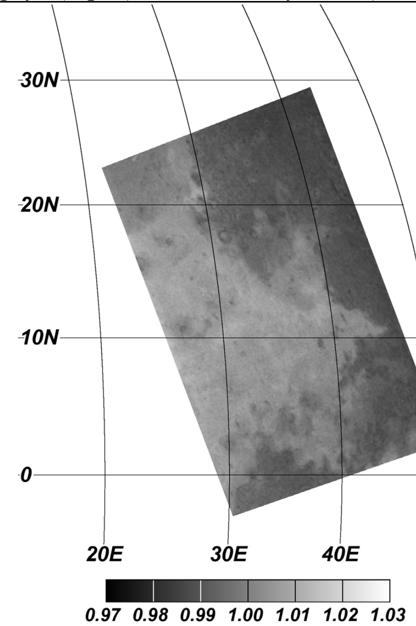

Figure 3. Image of the color index phase ratio $C_{R/B}(6°)/C_{R/B}(21°)$.

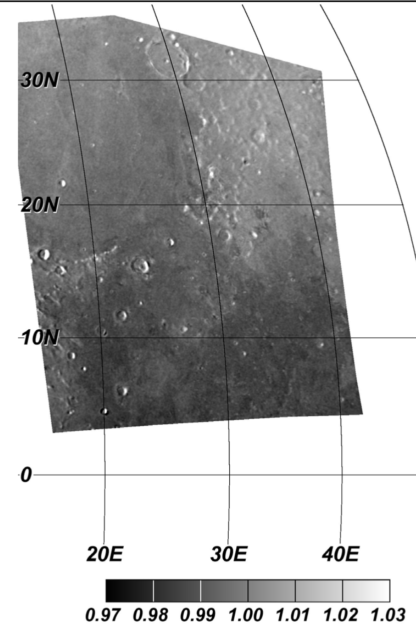

Figure 4. Image of the color index phase ratio $C_{R/B}(75°)/C_{R/B}(94°)$.

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