PHASE CURVE OF LUNAR COLOR RATIO. Yu. I. Velikodsky[1], Ya. S. Volvach[2], V. V. Korokhin[1], Yu. G. Shkuratov[1], V. G. Kaydash[1], N. V. Opanasenko[1], M. M. Muminov[3], and B. B. Kahharov[3], [1]Institute of Astronomy, Kharkiv National University, 35 Sumskaya Street, Kharkiv, 61022, Ukraine, dslpp@astron.kharkov.ua, [2]Physical Faculty, Kharkiv National University, 4 Svobody Square, Kharkiv, 61077, Ukraine, [3]Andijan-Namangan Scientific Center of Uzbekistan Academy of Sciences, 38 Cho'lpon Street, Andijan city, 170020, Uzbekistan.

Introduction: The dependence of a color ratio of the lunar surface on phase angle α is poorly studied. The ratio, which is defined as $C(\lambda_1/\lambda_2)=A(\lambda_1)/A(\lambda_2)$, where A is the radiance factor (apparent albedo), λ is the wavelength ($\lambda_1>\lambda_2$), is believed to increase monotonically in the visible spectral range with increasing α in the range 0–90° by 10–15% [1,2]. From the ground based colorimetry [3] it has been found that at α < 40–50° the color ratio *C*(603/472 nm) for lunar highlands grows with α faster than that of the mare regions. For α > 50° a reverse dependence is observed.

Laboratory measurements of lunar regolith samples, which are more accurate than telescope observations, have shown that a minimum of the *C*(α) curve can be observed at α ~ 10–15° [4–6]. Figure 1 shows phase curves of color ratio *C*(620/430 nm) for two lunar samples delivered by the Soviet probes *Luna-16* and *Luna-20*. The behavior of the samples is quite different. The samples of some other materials demonstrate the same [6]. Hapke et al. [7] also has found this minimum for eight lunar samples at α ≈ 4º.

Using data by Lane and Irvine [8], Korokhin et al. [9] have shown that the phase curve of the color ratio of the Moon in the range 359–1064 nm reveals a maximum at α near 50º and may probably have a minimum near 10º. On the other hand, data processing of *Clementine* UVVis data has shown a monotonic behavior of *C*(α) at small α [10,11] for *C*(750/415 nm) and *C*(950/750 nm). The same has been found recently with SELENE measurements [12] for NIR color ratios from *C*(999/753 nm) to *C*(1676/753 nm).

The controversial information on the minimum of *C*(α) at small α requires further consideration. The existence of such a colorimetric opposition effect can be considered as evidence of the coherent backscattering enhancement effect that predicts more prominent opposition peak of the lunar regolith in red light where the regolith is brighter [6,7].

In this work we present new independent investigation of phase curve of color ratio, which is based on new absolute measurements of lunar albedo and color.

Observational data: In 2006 we carried out a two-month series of quasi-simultaneous imaging photometric observations of the Moon and Sun at Maidanak Observatory (Uzbekistan) [13]. During 42 observational dates we have acquired about 20,000 images of these objects in 3 spectral bands ("R": 603 nm, "G": 529 nm, and "B": 472 nm) in a wide range of phase angles (1.6–168°) and zenith distances.

At present time, we have computed radiance factor maps in spectral bands "R" and "B" at α in the range 3–73° with a resolution of 2 km near the lunar disk center. Using the radiance factor distributions, we have obtained 22 maps of lunar color ratio *C*(603/472 nm). An example of such a map at α=16° is shown in Fig. 2.

Phase curve of color ratio: Using the maps of color ratio, we have plotted phase curves for two lunar areas (Fig. 3) and for the “average” lunar nearside (Fig. 4). The curves can be approximated by an empirical function $C(\alpha)=A\sin(B\ln(\alpha)+C)+D$, where *A*, *B*, *C*, and *D* are free parameters. This approximation significantly reduces the residual sum of squares in comparison with a constant with significance level 0.3%, and it shows that the phase curve of color ratio may have a minimum at α ≈ 6–12º. A trend at large phase angles is not reliable due to large data scattering.

We also have studied this effect computing phase curves of different color ratio using the ROLO model of integral albedo [14] (Fig. 5). We have found a minimum of *C*(549/475 nm) at α ≈ 5º. There is a hint of the minimum for *C*(665/475 nm) and no minimum for the ratios *C*(745/475 nm) and *C*(475/355 nm).

Interpretation: Analyzing the results of lunar measurements listed in Introduction together with ours, we can conclude that the minimum of color-ratio phase curves near α ≈ 5–10º is not observed regularly. It just can appear in specific spectral range (green–blue light). This does not support the hypothesis about the manifestation of the coherent backscattering enhancement effect of the Moon in the visible spectral range [7]. Figure 1 shows that the minimum is observed for the sample of *Luna-16* that is darker than that of *Luna-20*. This also contradicts to the coherent backscatter effect. Thus, we may conclude that the behavior of color ratio near small phase angles is noticeably defined by single scattering indicatrixes of regolith particles at different wavelengths.

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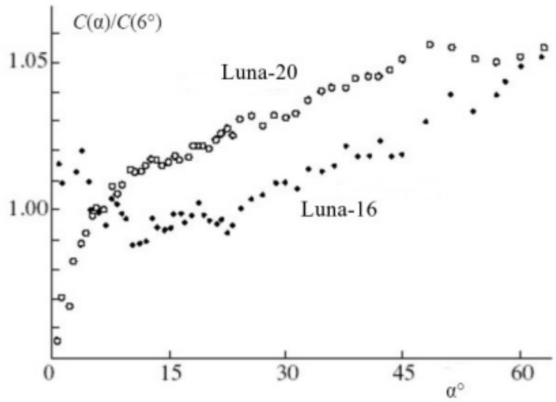

Figure 1. Phase curves of color ratio *C*(620/430 nm) for two lunar samples [6].

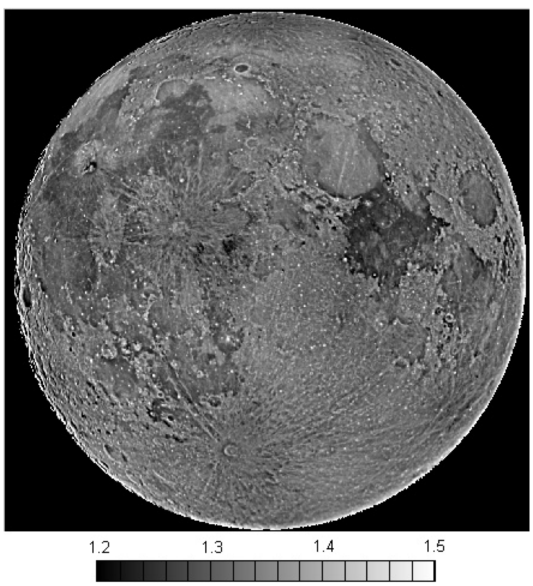

Figure 2. Map of color ratio *C*(603/472 nm) at α=16°.

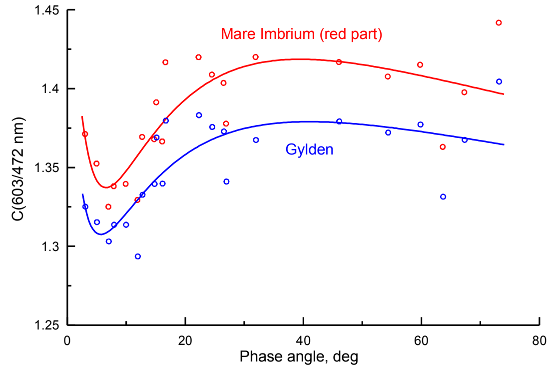

Figure 3. Phase curves of color ratio *C*(603/472 nm) for mare (a red portion of Mare Imbrium) and highland (Gylden) sites.

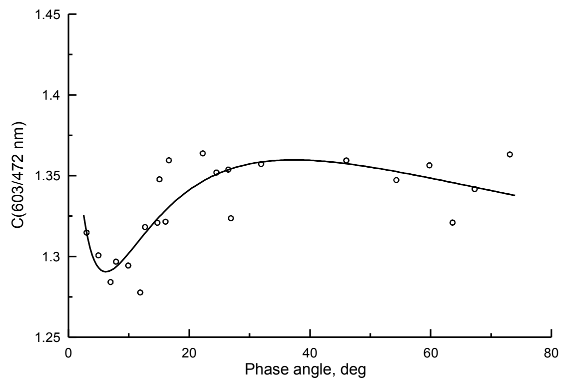

Figure 4. Phase curve of color ratio *C*(603/472 nm) averaged over lunar disk.

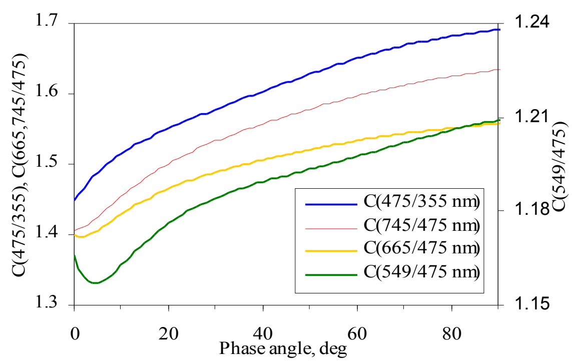

Figure 5. Ratio of pairs of ROLO's model phase curves of disk-equivalent albedo [14].