
Introduction: The opposition spike of the Moon manifests itself as a sharp increase of brightness with the decrease of the phase angle in the range from ~5° to 0. This spike is one of the most exciting photometric effect of the Moon. It occurs due to the shadow-hiding and coherent backscatter enhancement. Its characteristics depend on the properties of the regolith particles, their average size, and optical heterogeneity, and aggregate structure. Thus, the spike parameters (amplitude and width) bear important information about the lunar regolith structure. To investigate this, it is necessary to measure the lunar surface brightness at small phase angles that are not achieved from the Earth because of lunar eclipses. Only observations from a spacecraft orbiting the Moon allow one to study the brightness of the Moon at the zero phase angle. A few images of the lunar surface containing the zero-phase-angle point were taken during Clementine mission to the Moon by the UVVIS camera in the following filters: 415 nm (filter A), 750 nm (B), 900 nm (C), 950 nm (D), and 1000 nm (E).

Studies of the wavelength dependence of the opposition spike parameters gave rather contradictory results. Buratti et al. [1] showed that there is no difference in the opposition spike for all spectral bands of the Clementine UVVIS camera. On the other hand, in [2, 3] such a difference was found. Here we present a new method to study the lunar opposition spike using UVVIS camera images. This method confirms existing of the spectral dependence of the opposition spike.

Data processing: Earlier we applied two methods to extract the information about the lunar phase function from Clementine images [2,3]. One of them is a "direct" method. It uses two images of the same site, one image contains the zero-phase-angle point that is the phase changes across the image from 0 to~1.5°, and the other one is taken at a larger phase angle. The ratio of these images is devoid from intrinsic albedo variations, and can be used to extract the phase function in 0 – 1.5° phase angle range. In the whole Clementine data set there are only a few pairs of images, where this method is applicable. This method has two main shortcomings: (1) the images from each pair are obtained in one-month interval, and the unknown drift of camera parameters decreases the reliability of phase curve determination; (2) the surface topography spoils the results.

The second, "differential" method [2, 3] uses pairs of images taken consequently in one orbit; hence, this method is free from the camera parameters drift errors. Further, the difference in illumination conditions is minimal, and topography does not influence the results. Both images contain the zero phase point, which is shifted on the surface from one image to another due to motion of the spacecraft. The ratio of such images is devoid of the intrinsic albedo variations and shows a specific pattern resulting from a ratio of two mutually shifted opposition spots. Knowing the phase angle in each point of both images, one can reconstruct the phase function in 0 – 1.5° phase angle range. This method is largely free of the camera calibration drift errors. Unfortunately, the whole UVVIS image set does not contain any pair of images suitable for the analysis of this kind and taken with the same filter. In [2, 3] the images taken in two different but spectrally close filters, C (900 nm) and D (950 nm), were used. In this case, the ratio image, in addition to the phase-function-controlled pattern, contains true color variations. Due to the closeness of the wavelengths, the color variations are small. The most prominent color variations were actually related to immature ejecta of small fresh craters. This small patches of the images were simply excluded form the analysis. The "differential" method gave good results [2, 3], however it cannot be used to study the spectral dependence of the opposition effect, because in the visible range the filters (A and B) are not spectrally close, and color variations are not small.

Our new idea is to combine advantages of both methods. We suggest to use the "differential" method to extract the phase function, therefore to avoid the camera parameters drift problems and reduce the influence of surface topography. In addition, we suggest to use large-phase images to suppress real color variations. This allows us to study the wavelength dependence of the opposition spike. We use filters C (900 nm) and D (950 nm) to characterize the opposition spike in the near infrared. The wavelength difference between these filters is small, and we do not expect any difference in the opposition spike parameters between these filters (we took characteristic wavelength as (900+950)/2=925 nm). We use filters A (415 nm), B (750 nm) to characterize the opposition spike in the visible range. The wavelength difference is not small in this case, and the difference of the opposition spike parameters between these spectral bands is possible. As a first approach, we ignore this difference and consider the results ob-
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Observe that the phase curves in the near infrared are systematically steeper, than in the visible range. Thus, in the range 0°–2° the color-index (925/583 nm) grows with the decrease of the phase angle. On the other hand, as was shown in our previous studies [2], similar color-indices of the Moon slightly increase with the phase angle increase in the range of phase angles 3°–50°. Hence, at a phase angle within the range of 2°–3°, a minimum of the phase dependence of the color-index occurs. This conclusion is in agreement with laboratory measurements of lunar samples and optical analogs of Martian and lunar soils [2].

![Figure 1](https://example.com/figure1.png)

**Figure 1.**

**Future work:** We intend to apply a similar technique to Clementine NIR data. These data are not well calibrated yet and the quantitative spectrophotometric study of NIR data is rather difficult [4]. Our method is rather insensitive to the calibration errors, and its application is promising.

The described method can be applied also to future AMIE/Smart-1 data. The AMIE camera onboard Smart-1 lunar orbiter will be able to take images of the lunar surface in three NIR filters with high resolution and photometric precision. This will give an opportunity to combine these data with the photometric data obtained by Clementine.

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