A COMBINED SPECTRAL-FREQUENCY METHOD OF INVESTIGATIONS OF SMALL OR DISTANT PLANETS.

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Summary: We propose a combined method of astronomical investigations of small or distant planets incorporating registration of a set of integral spectra of an object and their frequency analysis. Investigation of brightness variations in different regions of planetary reflectance spectra allows detection of spots of geological materials having distinct spectral features and determination their distribution along of planetary surface. An application of the method is shown on example of asteroid 21 Lutetia.

Spectral data: A necessary condition of a successful application of the proposed spectral-frequency method is availability of a set of qualitative reflectance spectra of a planetary object obtained by astronomical methods at corresponding technical facilities (e. g., [1]).

Spectrophotometric (0.37 - 0.74 μm) observations of 21 Lutetia were carried out in the Crimean Astrophysical Observatory with a 0.5-m meniscus telescope MTM-500 by Bochkov [2]. The system included a digital television facility equipped with an LI804 superisocon television camera tube with an electron–optical preamplifier stage. The analog signal was digitized and summarized on a personal computer. Usually, the information from several hundreds of television pictures was summarized. A slitless spectrograph with two exchangeable transparent gratings which provided a resolution capability of 40 or 30 Å was used for the spectrophotometric observations [2]. The observations were continued for 14 nights from August 31 to November 20, 2000. For the whole observation period it was obtained 186 original spectra of 21 Lutetia. Its phase angle changed from 2.7° to 23°; the magnitude in the *V*-band, from $9^m.27$ to 11.02; and the aspect angle, from 62° to 68°. Atmospheric extinction coefficients were usually determined on spectra of standard-stars observed in the region of asteroid location (within a ring of 15-degree radius on the sky around the observed asteroid) and during the next or previous 30-minute interval after or before of asteroid observation. Accuracy of the relative intensity measurements was about 1-2 % at exposure time of 0.5-6 min. A solar analog star, HD10307 [1], was also observed for obtaining the approximate asteroid reflectance spectra. Further, we calculated standard (Johnson) synthetic magnitudes *B, V* and *R*, and corresponding color-indexes (*B-V* and *V- R)* from the extra-atmospheric asteroid averaged spectra. Additionally, to describe variations in an overall shape of Lutetia's blue-visible reflectance spectrum with asteroid rotation we selected artificial bands 0.40-42 μm (1), 0.50-51 μm (2) and 0.58-0.62 μm (3) (Fig. 1) and calculated the synthetic color indexes as Δm_{1-2}, and Δm_{1-3}. The resulting values were recalculated for a unit distance from the Sun and the Earth to the asteroid and for zero phase angle.

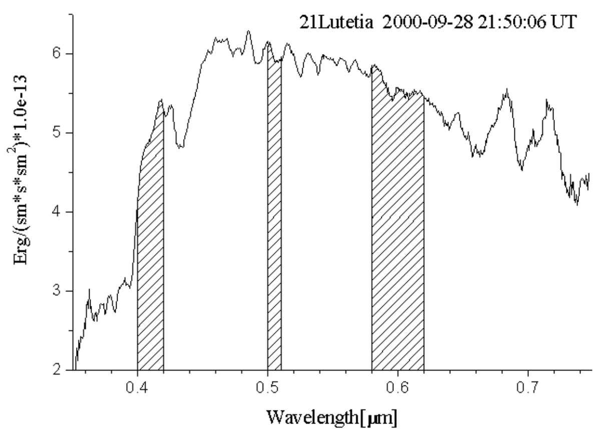

Fig. 1. Positions of three artificial photometric bands in the out-atmosphere spectrum of Lutetia obtained on 28 September 2000 in 21^h 50^m 06^s UT.

As it was shown in our previous publications [3, 4], 21 Lutetia has spectral signs of presence of hydrated silicates (of serpentine-chlorite type) in the form of an absorption band centered at 0.43 μm. To estimate variations in intensity of the absorption band in asteroid reflectance spectra with asteroid rotation we calculated the equivalent width of it [6] according to the formula:

$$W = \sum_{i=1}^{N} (1 - r(\lambda_i))\Delta\lambda , \qquad (1)$$

where W is the equivalent width, $\Delta\lambda$ is the spectral step, $r(\lambda_i)$ are the residual intensities in the spectrum, and N is the number of points in the band.

Results of the frequency analysis: To investigate nature of Lutetia's brightness changes with rotation we analyzed the synthetic (*V* and *B–V* and *V–R*) and artificial (Δm_{1-2}, and Δm_{1-3}) values of asteroid brightness and color-indexes and, similarly, values of the equivalent width of a 0.43-μm absorption band (*W*) by four methods of frequency analysis (the Breger, Lafler–Kinman, Jurkewich, and Deeming ones) [5]. In spite of the frequency analysis of the *V*–values confirmed known period of Lutetia's rotation ($0.^{d}3405$ or $8.^{h}172$), it was found several new frequencies different from this. It should be noted that every new frequency found in the data was whitened from them before subsequent analysis. The procedure guarantees an independence of the frequencies [5].

Under analysis of 40 determined values of the equivalent width of a 0.43-μm absorption band, it was found eight significant periodic oscillations with frequencies from 6 to 45 c/d (cycles per day) [6]. The most pronounced ones turned out to be in the range from 11 to 14 c/d and may characterize distribution of phyllosilicate spots on the asteroid surface. Assuming hydrosilicate spots are located in equatorial zone of the asteroid, the most possible estimates of their sizes are in the range from 30-40 km and smaller. It supports a hypothesis [6] that hydrosilicates may be brought on the asteroid surface by smaller hydrated bodies after completion a period of Lutetia's magmatic melting.

The frequency analysis of the synthetic and artificial values of color-indexes gave also periods of the spectral continuum slope variations of the asteroid with periods of $P_1=2.^{h}0$ (or $1.^{h}8$) и $P_2=2.^{h}93$ (or $2.^{h}62$). The periods were confirmed at a high confidence level of 7-10σ (the accuracy of the estimated value is taken as 1σ) under *BVR*-photometric observations of Lutetia in 2004 and after subsequent frequency investigations of the data [8]. Interestingly, the color data have not a known period of the asteroid rotation ($8.^{h}172$). That contradicts a notion of Lutetia as a monolithic body. It allows us to suggest a binarity of the asteroid [8, 9]. The supposition is supported by detections of splitting of Lutetia's spectrum into two on three nights in November 2004 (4/5, 5/6 and 7/8). The effect was also confirmed on 4/5 March 2006 [9].

Thus, the example of 21 Lutetia's spectral-frequency investigations show an effectiveness of the method.

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