

POLARIZED LIGHT SCATTERED FROM ASTEROID SURFACES. VII. NEW INSIGHT INTO THE EFFECT OF THE WAVELENGTH DEPENDENCE OF NEGATIVE POLARIZATION DEGREE. L. F. Golubeva, D. I. Shestopalov, Shemakha Astrophysical Observatory, Shemakha AZ-3243 Azerbaijan, (lara_golubeva@mail.ru, shestopalov_d@mail.ru).

The wavelength dependence of a negative polarization degree for asteroids was discovered relatively recently, in the mid-eighties of last century [1]. Later on, it was found in [2, 3] that the depth of negative polarization branch for moderate-albedo asteroids with reddish spectra tends to be deeper for increasing wavelength. The tendency seems to be opposite for low-albedo asteroids with flatter spectra: the longer wavelength, the shallower the negative polarization branch. The variation of the polarization degree in the range of $0.37 - 0.83 \mu\text{m}$ is a subtle effect, less than 0.5%. Therefore, it is not surprising that there are exceptions to the above tendencies.

We have supposed in [4] that the wavelength dependences of the depth of negative polarization branch, i.e. $|P_{\min}(\lambda)|$ at $\alpha = \alpha_{\min}$, could arise due to the spectral variations of photometric roughness $c(\lambda)$ of asteroid surfaces. However, such an approach may come into conflict with the so-called effect of "the spectral reddening with phase angle" of the asteroid surfaces with high or moderate albedo. Therefore, the question about the nature of the negative polarization of the asteroids is quite relevant.

As is known, the degree of linear polarization P with respect to the scattering plain, the Stokes parameter Q , and the total intensity of radiation I are connected as follows: $P = -Q/I$. We can express the intensity I in terms of geometric albedo A and photometric function Φ , i.e. $I = \text{const} \times A \times \Phi$. Since the above variables are some functions of phase angle α (except for A) and wavelength λ , we can write:

$$P(\alpha, \lambda) = P(\alpha, \lambda_0) \times \frac{Q(\alpha, \lambda)}{Q(\alpha, \lambda_0)} \times \frac{A(\lambda_0)}{A(\lambda)} \times \frac{\Phi(\alpha, \lambda_0)}{\Phi(\alpha, \lambda)}. \quad (1)$$

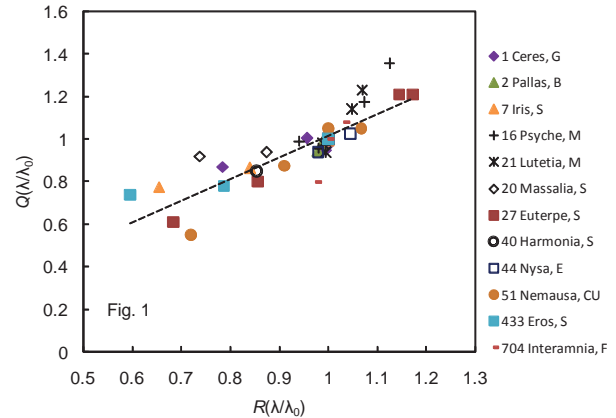
If $\alpha = \alpha_{\min}$, then we have

$$\begin{aligned} P_{\min}(\lambda / \lambda_0) &= \frac{P_{\min}(\lambda)}{P_{\min}(\lambda_0)} = \\ &= Q(\lambda / \lambda_0) \times R^{-1}(\lambda / \lambda_0) \times \Phi(\lambda_0 / \lambda). \end{aligned} \quad (2)$$

Reflection factor $R(\lambda / \lambda_0) = A(\lambda) / A(\lambda_0)$ is actually the scaled color index as $R = 1$ at $\lambda = \lambda_0$. By analogy with this, the ratio of $P_{\min}(\lambda / \lambda_0)$ can be termed the polarimetric color index. Using Eq. (2) we can estimate color ratio of Stokes parameter $Q(\lambda / \lambda_0)$ provided that other variables are known. We selected such asteroids for which both $P_{\min}(\lambda)$ measured in UBVRI bandpasses

[5, 6] and $R(\lambda / \lambda_0)$ formative the eight-color survey [7] are known. The effective wavelengths of UBVRI band-passes occupy the spectral range of $0.37 - 0.83 \mu\text{m}$, and the effective wavelengths of the five bands of ECAS (i.e. u, b, v, w, and x band) are very close to those of UBVRI photometric system.

The photometric function of asteroids was calculated according to the equation $\Phi(\alpha, \lambda) = S(\alpha, \lambda) \times D(\alpha)$, where the phase function $S(\alpha, \lambda)$ and the disk-integrated function $D(\alpha)$ were taken from [8, 9]. The data obtained previously in [10] were used to calculate the $\Phi(\lambda / \lambda_0)$ ratio at different wavelengths. We chose $\lambda_0 = 0.55 \mu\text{m}$ as is commonly accepted for the scaled reflectance $R(\lambda / \lambda_0)$. As it results from computations, the $\Phi(\lambda / \lambda_0)$ ratio ~ 1 for asteroids under study and is almost unchanged at $\alpha \sim \alpha_{\min}$ in the studied spectral range.



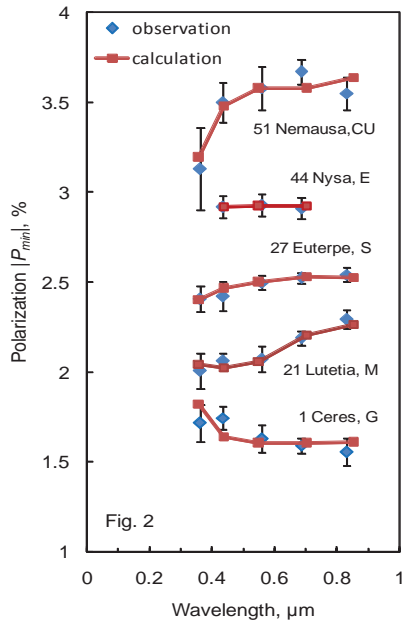
By doing so, we managed to find the Stokes color ratio $Q(\lambda / \lambda_0)$ for several asteroids of various optical types. A small number of the asteroids is explained by a slight intersection of the polarimetric and colorimetric samples. Nevertheless, it became clear that a correlation between $Q(\lambda / \lambda_0)$ and $R(\lambda / \lambda_0)$ is observed for every one of the asteroids of our sample. Figure 1 shows a group of asteroids of various optical types, for which the overall tendency is valid: $Q(\lambda / \lambda_0)$ increases with increasing $R(\lambda / \lambda_0)$. Moreover, the following correlation equation exists for each asteroid of this group:

$$Q(\lambda / \lambda_0) = aR(\lambda / \lambda_0) + b. \quad (3)$$

We have found the coefficients of the equation, a and b , which were slightly different for various asteroids. Since $\Phi(\lambda / \lambda_0) \sim 1$, the polarimetric color index depends only on scaled reflectance (see Eq. (2)):

$$P_{min}(\lambda / \lambda_0) = a + b/R(\lambda / \lambda_0). \quad (4)$$

Eq. (4) proves to be sufficiently accurate to predict $P_{min}(\lambda)$, knowing $P_{min}(0.55 \mu\text{m})$ and the scaled reflectance spectrum of the asteroid. Figure 2 gives an example the observed and calculated values of $|P_{min}(\lambda)|$ for several asteroids. All the calculations are situated within measurement errors. On this plot, the pairs of curves are shifted for clarity.



So, the experience leads us to conclude the following.

(i) The polarimetric color index $P_{min}(\lambda / \lambda_0)$ of asteroid surfaces is sufficiently well approximated to the product of $Q(\lambda / \lambda_0)$ by $R^{-1}(\lambda / \lambda_0)$.

(ii) In turn, the Stokes color ratio $Q(\lambda / \lambda_0)$ of asteroids is in direct proportion to the scaled spectral reflectance $R(\lambda / \lambda_0)$.

(iii) Thus the polarimetric color index of asteroids is the one-variable function of $R(\lambda / \lambda_0)$.

One can append to the statements that the shape of curves on Fig. 2 depends both on the shape of scaled spectra $R(\lambda / \lambda_0)$ and on the values of the coefficients a and b in Eq. (4). Since a sole cause of changing of $P_{min}(\lambda)$ with wavelengths is the spectral variation of $R(\lambda / \lambda_0)$ rather than $A(\lambda)$, then the spectral analog of well-known regularity "the larger the polarization degree, the lower albedo" can be unrealizable for individual asteroids, at least in the range of phase angles corresponding to the negative polarization degree.

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