MODELING POLARIZATION PROPERTIES OF LUNAR REGOLITH WITH T-MATRIX APPROACH.

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Introduction: The lunar regolith has well-studied dependence of the linear polarization degree on the phase angle α. The main features of this dependence are the negative polarization branch at small phase angles and the positive polarization branch with maximum near 105°. The negative polarization of the Moon is demonstrated in Fig. 1 that presents the integral polarimetric data [1]. The negative polarization branch for different lunar regions is almost the same; it has a parabolic shape with the inversion angle (near 23°) and the depth (near 1%). The average albedo of the lunar surface is rather low, near 12 % in the visible spectral range. This means that single particle scatter can dominate the lunar surface polarization response. Thus it is reasonable in first approximation to use theories of single particle scatter by particles with irregular shapes to model the polarization features. In this work we exploit the T-matrix method for calculations of scattering by wavelength-size scatterers to study a role of shape of scatterer in formation of the observed polarization.

Model of regolith particles: The shape of particle can be described with an angular dependence of the distance from the particle center to the particle surface, $R(\theta,\varphi)$, where θ and φ are polar and azimuth angles, respectively. As a model of lunar regolith particles we used randomly shaped grains with a Gaussian distribution of radii. The Gaussian shape can be generated by expansion of $R(\theta,\varphi)$ into series over spherical harmonics and Legendre polynomials. Thus the shape can be described by the following equation [2]:

$$R(\theta,\varphi)=\frac{e^{s(\theta,\varphi)}}{\sqrt{1+\sigma^2}}, \quad (1)$$

where

$$s(\theta,\varphi)=\sum_{l=0}^{\infty}\sum_{m=0}^{l}P_l(\sin\theta)[\alpha_{lm}\cos m\varphi+\beta_{lm}\sin m\varphi] \quad (2)$$

where the coefficients α_{lm} and β_{lm} are independent Gaussian random variables with zero mean and equal variances:

$$\beta_{lm}^2=(2-\delta_{m0})\frac{(l-m)!}{(l+m)!}c_l\beta^2 \quad (3)$$

$$\beta^2=\ln\left(1+\sigma^2\right), \quad (4)$$

$$c_l=(2l+1)\exp[-\kappa]I_l(\kappa), \quad (5)$$

$$\kappa=\frac{1}{4}\left(\sin\frac{\Gamma}{2}\right)^{-2}, \quad (6)$$

where σ^2 is the radii variance, Γ is the correlation angle, $I_l(z)$ is the modified spherical Bessel function, $P_l(z)$ is the Legendre polynomials.

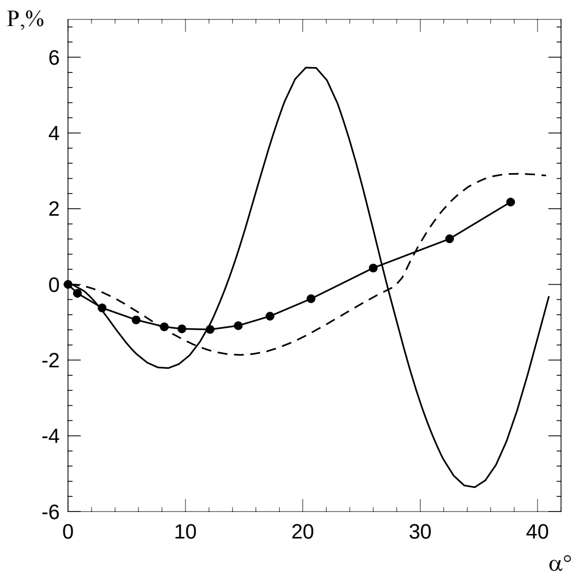

Fig. 1. Phase dependence of the linear polarization degree of the Moon (line with points) [1]. To model the lunar regolith particles, a Gaussian random shape with $\sigma = 0.3$, $\Gamma = 15°$, and the refractive index $m = 1.5$ were used. Curves shown correspond to particles with the size parameter $x = 15$ (solid curve) and for averaging over sizes $x = 10.5 \div 15.9$ (dashed curve).

This method allows us to generate irregular particles. An example of such particles is given in Fig. 2. As can be seen the correlation angle strongly affects the shape of irregular particles.

Method of calculations: We used the T-matrix method to calculate scattering properties of particles. This method allows us calculations of the scattered field in any point of space. The main idea of this method is the expansion of the incident and scattered fields in spherical wave functions [3]. The T-matrix gives a relationship between the expansion coefficients of incident and scattered fields. The T-matrix method allows one to carry out averaging over orientations [4] and sizes [5].

Results and discussion. Using this method we have calculated the phase dependence of the linear polarization degree of model particles (Fig. 2.); we have found scattering properties of all types of the particles shown. We used the refractive index $m = 1.5+i0$. The most appropriate type is the particle (d) with $\sigma = 0.3$ and $\Gamma = 15°$. Curves shown in Fig. 1 correspond to particles with the size parameter $x = 15$ (solid curve) and for the case of averaging over sizes $x = 10.5 \div 15.9$ (dashed curve). In all cases averaging over orientations was carried out. For comparison we show also the linear polarization degree of the lunar regolith (line with points). As can be seen, the curve corresponding to the lunar regolith cannot be reproduced with the only size parameter. However, if one uses the averaging over sizes, the model phase function, at least qualitatively can be fitted to the observed curve.

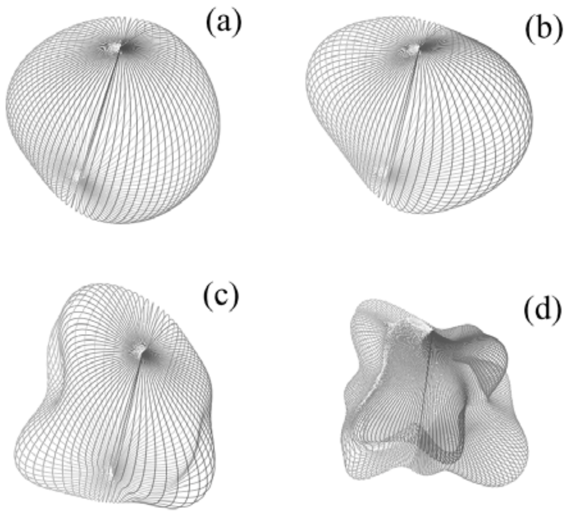

Fig. 2. Examples of random Gaussian shapes. $\sigma = 0.3$; (a) $\Gamma = 60°$; (b) 45°; (c) 30°; (d) 15°.

References: [1] Lyot, B. 1929. *Ann. Obs. Meudon*. 8, No. 1. 1-161. [2] Lagerros, J. 1998. *Thermal physics of asteroids*. Acta Universitatis Upsaliensis. 45p. [3] Mishchenko M., et al. 2002. Scattering, absorption, and emission of light by small particles. Cambridge University Press. [4] Khlebtsov, N. 1992. Appl Opt. 31, 5359–5365. [5] Mishchenko, M. et al. 2000. In: Mishchenko M. et al., Eds. Light scattering by nonspherical particles: theory, measurements, and applications. San Diego: Academic Press; 147–172.