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Unusual properties of asteroid (3200) Phaethon from polarimetric observations and modeling

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Abstract

The results of imaging and aperture polarimetric observations of the near-Earth asteroid (3200) Phaethon in November-December 2017 are presented. The unique phase-angle dependence of polarization within the range of phase angles 19.2–134.9° with $P_{max} = 48\%$ at $\alpha_{max} = 110°$ is obtained. To calculate the scattering properties of surface of Phaethon we used the modified *T*-matrix method, so called *Sh*-matrix method, for the conjugated random Gaussian particles. The best fit of simulated polarization curve and observational data was obtained for the particles composition of amorphous carbon (80%) with sizes within the range $r_{carb} = 0.09$–1.33 μm and silicon dioxide SiO_2 (20%) with $r_{carb} = 0.31$–1.91 μm.

1. Introduction

The polarimetric study of the near-Earth asteroids (NEAs) allows us to cover the large range of phase angles, including the value and position of polarization maximum, and thereby supplement the inaccessible angles for the Main Belt asteroids. Despite the long history of polarimetric studies, only several NEAs were studied at large phase angles and the most complete phase dependences of polarization were determined, including polarization maximum. The unprecedented close passage of Phaethon to the Earth at distance of 0.069 au on December 16, 2017 provided a good opportunity to measure the polarization in the large range of phase angles.

2. Observations

Observations of asteroid (3200) Phaethon were carried out at the 6-m BTA telescope with the multimode focal reducer SCORPIO-2 of the Special Astrophysical Observatory (Russia) in the imaging polarimetry (filter V) and spectropolarimetric (λ4100−8000 Å) modes from November 27 to December 26, 2017 within the range of phase angles 19.2–134.9°. The aperture polarimetry was made at the Crimean Astrophysical Observatory with the 2.6-m telescope in the B, V, and wide-R filters and 1.25-m telescope in the V, R, and I filters on December 8−16, 2017 within the range of phase angles 19.6–61.6°.

3. Results

We found that the maximum of polarization for Phaethon is $P_{max} = 48\%$ at phase angle 110° in the V band. The inversion angle α_{inv} and polarimetric slope *h* are 20.5° and 0.46 ± 0.01 %/°, respectively. Phaethon has the highest maximum degree of polarization that was determined among the earlier observed bodies in the Solar System, including the recently observed NEA (152679) 1998 KU_2 with a high polarization degree up to 44% at phase angle 81° [1]. The degree of polarization of asteroid Phaethon is slightly higher in the blue filter B than that in the red filter R. A similar spectral dependence of polarization was observed for two others low-albedo asteroids (1580) Betulia [2] and (2100) Ra-Shalom [3].

4. Modeling and analysis

For simulation of the scattering properties of the surface particles of enigmatic asteroid Phaethon, we used the modified *T*-matrix method [4], called *Sh*-matrix method [5] to calculate the scattering properties of arbitrary shaped particles. The small perihelion distance of Phaethon (0.14 au) can affect the surface properties, and particles of Phaethon may be rather smooth. Therefore, the model of conjugated random Gaussian particles was used for modeling our data. The best fit to the observational data was

obtained for the particles composition of amorphous carbon (80%) with sizes within the range $r_{carb} = 0.09–1.33$ μm and silicon dioxide SiO_2 (20%) with $r_{carb} = 0.31–1.91$ μm, which have power law distribution. Note, that our observations of Phaethon do not include the negative polarization branch which should be also described by our simulation. Since Phaethon could be a fragment of asteroid (2) Pallas [6], we used polarimetric data for this asteroid which were obtained at the small phase angles [7].

5. Conclusions

Our polarimetric data showed that asteroid Phaethon has the highest degree of polarization ($P_{max} = 48\%$) in the maximum of positive polarization branch ($\alpha_{max} = 110°$) among all earlier observed bodies in the Solar System, including the recently observed NEA (152679) 1998 KU_2 with a high polarization degree up to 44% at phase angle 81° [1]. Probably this property of the asteroid is associated with its close approach to the Sun and corresponding processes on the surface due to heat.

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