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Lightcurve Analysis of Asteroids at the Astronomical Station Vidojevica for the first half of 2022

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We present one part of our long-term photometry program, targeted at studying the shape and spin state of asteroids. The CCD photometric observations were carried out in the first half of 2022 with two telescopes at the Astronomical Station Vidojevica (Serbia): 1.4m Ritchey-Chrétien-Coude "Milanković" and the 60cm Cassegrain "Nedeljković" telescope. In this work, lightcurves, the synodical periods of rotation, ellipsoid shape ratios *a/c*, and first assumptions about the shape of several main-belt asteroids are presented. Obtained results contribute to the database of rotational characteristics of the asteroids, enhancing the understanding of the creation of our planetary system.

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1. Introduction

Asteroids are small, irregularly shaped celestial bodies orbiting the Sun. Although small, they can reveal a wealth of information about the history, evolution, and future of our Solar system. One of the most commonly used methods for asteroid research is the asteroid photometry, a method based on measuring the change in their brightness. Namely, due to the reflection of the sunlight from different parts of its surface area, the brightness of the asteroid changes as the asteroid rotates. Graphical representation of this change (brightness versus time), the so called *lightcurve,* gives the basic information relevant for further asteroid studies. Often only one lightcurve (LC) is enough to obtain for example its synodical period. But generally, we need to observe the asteroid in longer time intervals than its period, to be sure that the asteroid has a regular LC with two maxima and two minima. These properties are almost impossible to be known if the asteroid was not observed before. So, to unequivocally determine the period of the asteroid, we need to compare observations from several nights.

Another property of the asteroid that can be determined using one or few LCs is the ratio between the smallest and largest observed area (the axis ratio). If there are LCs from more observations, we would be able to determine its sidereal period, shape, and axis of rotation. The set of different LCs means that the asteroid was observed for longer time intervals (years) and provides us with information from different viewing geometries. As the aspect angle and solar phase angle change during these long-time observations, the shape of the light curve will also change, and by tracking these changes in the LCs, we would be able to determine the above mentioned properties.

In this work we present our astronomical observations in the first half of 2022, for three asteroids (2525 O'Steen, 4528 Berg, and 4940 Polenov), carried out at the Astronomical Station Vidojevica (ASV).

2. Observations and Data Reduction

Astronomical Station Vidojevica (ASV) is an observation site founded by the Astronomical Observatory of Belgrade. It is located on the Vidojevica mountain near Prokuplje at an altitude of 1150m (Fig.1). ASV is currently equipped with two telescopes (1.4 m *Milanković* and 60 cm *Nedeljković*), which were used to observe the asteroids discussed here. All images were taken in the standard Johnson–Cousins R band by the Milanković telescope with the Andor iKon-L CCD, and by the telescope Nedeljković with the FLI PL230 CCD. The data were reduced by applying standard bias, dark and flat-field corrections. The differential aperture photometry was done using CCDPHOT [1]. Lightcurve analyses, including composite lightcurves, synodic rotational period, and estimation of the LC amplitude, were performed using MPO Canopus v10.7.7.0 [2].

(a) (b) (c)

Fig. 1. Astronomical station Vidojevica: (a) The newly built pavilion for the Milanković telescope (b) the *Milanković* telescope (the diameter of the mirror is 1.4m) (c) 60cm Nedeljković telescope .

The observing circumstances and aspect data for the observations of the asteroids 2525 O'Steen, 4528 Berg, and 4940 Polenov are given in Table 1. The columns give: the name of the asteroid, the date of the observation referring to the mid-time of the observed lightcurve, the asteroid distance from the Sun (*r*), distance from the Earth (Δ), the Sun-asteroid-observer angle (the so-called phase angle *α*), the asteroid's J2000.0 ecliptic longitudes (*λe*) and latitudes (*βe*).

Table 1. Observing circumstances and aspect data.

Asteroid	Date (UT)	*r* (AU)	*Δ* (AU)	*α* (°)	*λe* (°)	*βe* (°)
2525 O'Steen	2022 Apr 5.80	3.4426	2.9425	15.64	127.89	2.71
4528 Berg	2022 Jan 6.04	2.2387	1.6536	23.71	171.89	-2.77
	2022 Apr 5.98	2.3302	1.4455	14.62	160.26	3.22
	2022 May 3.87	2.3665	1.7341	22.34	160.30	4.29
4940 Polenov	2022 Apr 5.03	3.5965	2.6016	1.93	188.94	3.00
	2022 Apr 6.00	3.5972	2.6039	2.24	188.73	3.01

3. Results

The asteroid **2525 O'Steen** is the first object we observed from the AS Vidojevica [3]. It is a 30 km-sized member of the asteroid family Themis located in the outer part of the main belt. O'Steen has a low albedo of 0.07, which indicates a dark surface, meaning that it is a carbonaceous C-type asteroid. O'Steen was observed for 2.15h on 5/6 April 2022 using the 1.4m telescope after its opposition at the phase angle of 15.7°. The first published period for O'Steen of 3.55±0.01h, was obtained in 2003 from observation performed at the Bulgarian National Astronomical

Rozhen [4]. Our observation from 2022 lasted slightly longer than the asteroid's half-period. Its lightcurve (given in Fig. 2) was constructed based on a published period of 3.569h in the asteroid lightcurve database [9]. The obtained amplitude *A*=0.26 mag allows us to calculate the ratio of the largest to smallest reflecting surface areas during the observed asteroid to be *a/c*=1,27. Although the observations lasted slightly longer than its half-period, the obtained partial lightcurve, in combination with our previous lightcurves, will be valuable for calculating the asteroid's pole coordinates and shape.

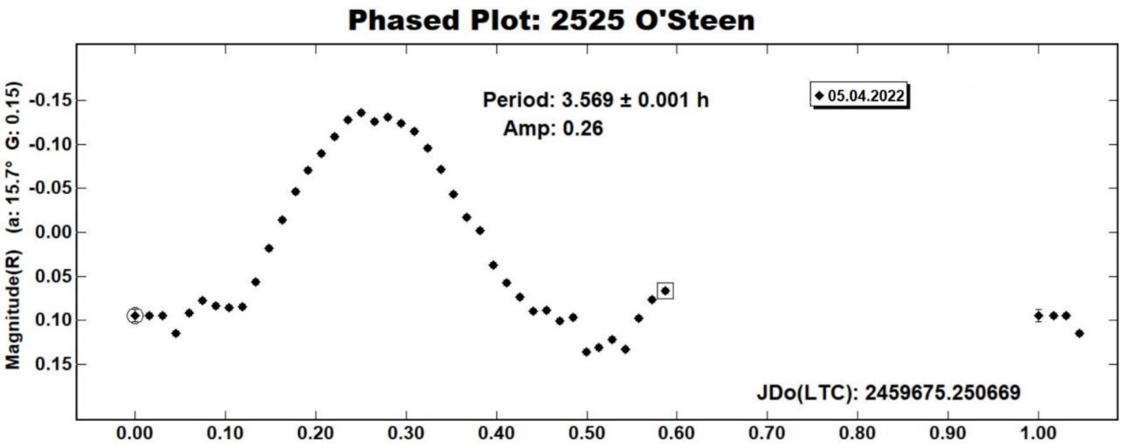

Fig 2. Phased partial lightcurve of 2525 O'Steen observed on 5/6 April 2022

4528 Berg is a 9.3 km asteroid located in the inner part of the main belt. Our 2022 observations of Berg were carried out in two nights: 5/6 January and 5/6 April with the 1.4m telescope and 3/4 May with the 60cm telescope. During the first night, the asteroid was at a solar phase angle of 23.7°. The observation covered the whole rotational period; the compositional lightcurve (given in Fig.3) was constructed based on a published period of 3.5163h in the asteroid lightcurve database. During the following observations, the solar phase angle increased from 14.6° to 22.4°. The composite lightcurve in Fig. 4 was constructed from the lightcurve that covered the whole rotational period and another lightcurve interrupted by unfavorable weather conditions. The composite lightcurves, with Fourier fit of order 9, reveal a period of 3.5634±0.0005h, a value closer to the period of 3.5626 obtained by Polakis [5]. The lightcurves show small differences in sharpness and depth of the minima, indicating a slightly unsymmetrical shape of the asteroid. The obtained amplitudes of the composite lightcurves are 0.35 mag and 0.34, which give us axal ratios *a/c*=1,39 and *a/c*=1,37, indicating a slightly elongated shape of the asteroid. Photometric observations given by Benishek et al. [6] revealed that Berg could be a binary system with an orbital period of 35.02± 0.02h.

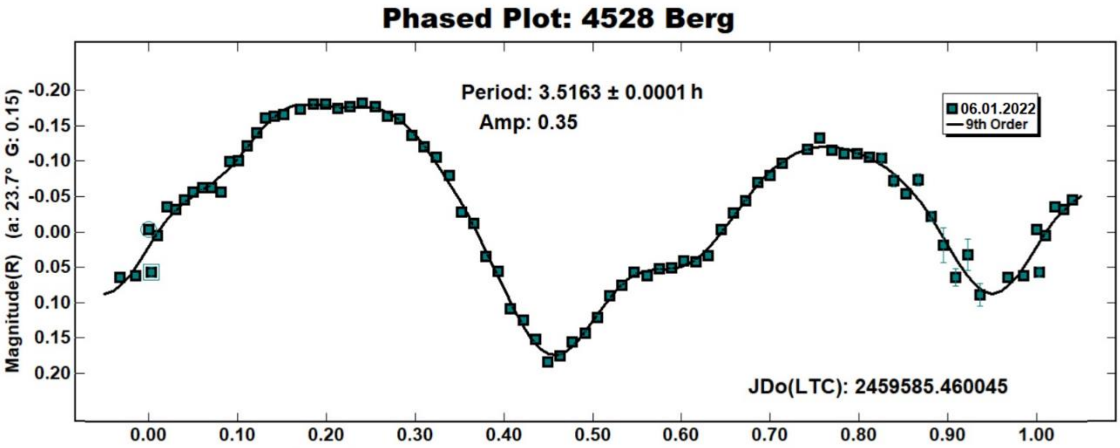

Fig 3. Composite lightcurve of 4528 Berg from observations on 5/6 January 2022

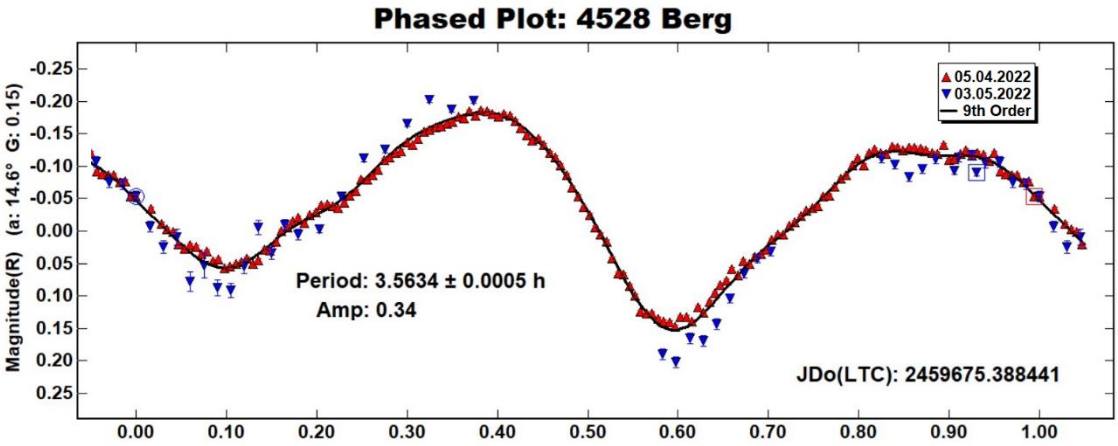

Fig 4. Composite lightcurve of 4528 Berg from observations on 5/6 April and 3/4 May 2022

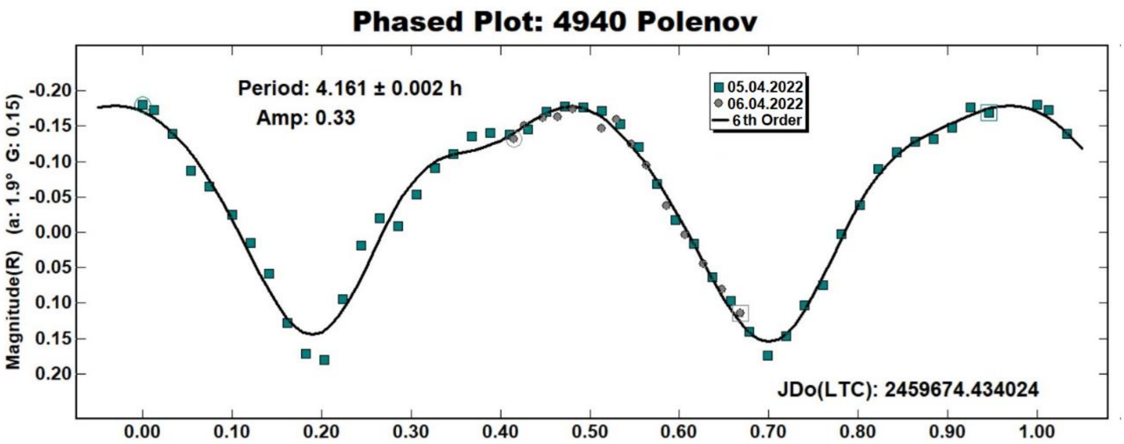

Fig 5. Composite lightcurve of 4940 Polenov from observations on 4/5 and 5/6 April 2022

4940 Polenov is a 17.7 km sized carbonaceous (C-type) asteroid located in the outer part of the main belt. It belongs to the asteroid family Themis. Polenov was observed with the 1.4 m telescope during two consecutive nights on 4/5 and 5/6 April 2022, at a 1.9° solar phase angle, after its opposition on 30th March. Fourier fit of order 6 reveals an approximately symmetric shape of the lightcurve with a period of 4.161±0.001h and amplitude of 0.33 mag (Fig.5). The same period was first published from our observations performed at AS Vidojevica and BNAO Rozhen [7]. The obtained amplitude is 0.33mag which is smaller than the previously published value of 0.44, is suggesting that during our last osbervations, the angle formed by the rotation axe of the asteroid and radius vector Earth-asteroid was smaller.

4. Conclusion

The period of 2525 O'Steen and 4940 Polenov are consistent with the previously published results [9] and [7] consequently. On the other side, observations of 4528 Berg show new results for the rotational period. Considering that asteroid shapes are approximated with triaxial ellipsoids, with $a > b > c$, and that they rotate around the *c*-axis [8], we calculated the *a/c* ratio. The amplitude of 0.35 mag for 4528 Berg and 0.33 mag for 4940 Polenov imply their *a/b* ratios are $a/c \geq 1.34$ and $a/c \geq 1.36$, respectively. The amplitude of 0.26 mag for 2525 O'Steen indicates that $a/c \geq 1.27$. Calculated ratios suggest that the three asteroids do not have elongated shapes. The true a/b ratios, giving the results for the shape of the asteroid, could be obtained only when the maximum amplitudes are known.

In order to reconstruct the asteroid shape and spin axis direction using the lightcurve inversion method [10], we need a set of dense lightcurves obtained at different geometrical conditions during several oppositions (i.e. several years of observations). A search through the Asteroid Lightcurve Database [9] and DAMIT [11] shows that there are no previously reported results for the pole and shape of the three presented asteroids.

Acknowledgements

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