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LIGHTCURVE ANALYSIS OF THREE MAIN BELT ASTEROIDS: 2265 VERBAANDERT, 3787 AIVAZOVSKIJ, AND 4528 BERG

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2265 Verbaandert was imaged on seven nights between 2022 Feb 13 and 2022 Apr 03. A period of 2.8143 ± 0.0001 hours and amplitude of 0.105 magnitude are reported. 3787 Aivazovskij was imaged five nights between 2022 Jan 06 and 2022 Feb 07. A period of 2.9532 ± 0.0001 hours and amplitude of 0.191 magnitude are reported. 4528 Berg was imaged on eight nights from 2022 Apr 07 to 2022 May 07. A period of 3.5630 ± 0.0001 hours and amplitude of 0.345 magnitude are reported.

Photometric measurements of three main-belt asteroids were performed by first author Wiley at the Live Oaks Observatory near Pontotoc, Texas (MPC V62). Images were taken with a 0.36m f/7.2 corrected Dall-Kirkham telescope, SBIG Aluma 3200 CCD, and no filter. Nightly ephemeris positions were obtained from the Minor Planet Center. Exposure time of all images was 180 seconds. The image scale was 1.094 arcseconds/pixel binned 2×2. Images were calibrated with bias (N = 100), dark (N = 30) and flat frames (N = 21) in *MaxIm DL*. Flat images were taken using a full spectrum LED panel. Alignment, plate solving, and data reduction were performed using *Tycho Tracker* (Parrott, 2021). Comparison stars (five minimum) were picked from *Tycho Tracker*'s "Find Comp Stars" which presents those stars in the FOV ($19.6^\circ \times 13.3^\circ$) with suitable comp stars similar in color to the Sun, typically $0.55 < B-V < 0.90$. Clear instrumental magnitudes are converted to Sloan r' (SR) magnitudes using the Atlas All-Sky Reference Catalog (Tonry et al., 2018) within *Tycho Tracker*. (Two runs are exceptions as noted below.) Fourier analysis was used to find the periods. For each asteroid an initial search was conducted for periods between one and eight hours to investigate aliases. A final step size between one and four hours with 30,000 steps was used to determine the periods and amplitudes. A fit order = 6 was used for 2265 Verbaandert while a fit order = 4 was used for both 3787Aivazovskij and 4528 Berg. Figures were made in *MPO Canopus* (Warner, 2010) to conform to the Minor Planet Bulletin format by F. P. using ALCDEF files generated in *Tycho Tracker*.

2265 Verbaandert (1950 DB) was discovered by Sylvain J.V. Arend at the Observatoire royal de Belgique. It is a carbonaceous mid-main-belt (9105) asteroid of 12 km in diameter (JPL, 2022). Waszczak et al. (2015) estimated a rotation period of 2.990 ± 0.0006 hours based on sparse photometric data.

Verbaandert was imaged over seven nights in 2022 from late February, late March and early April; see Table I for details. Fourier analysis in *Tycho Tracker* and a fit order of 6 reported a new period of 2.8143 ± 0.0001 hours with an amplitude of 0.105 magnitude (Fig. 1). Photometric precision averaged 0.008 magnitude. Fitting a 2.8143-hour period to data from the existing ALCDEF yielded the

same fit as the analysis of our data but a slightly worse fit for the Waszczak et al. (2015) period. A period of 2.990 hours results is a poor fit to our data. The period spectrum is shown in Fig. 2.

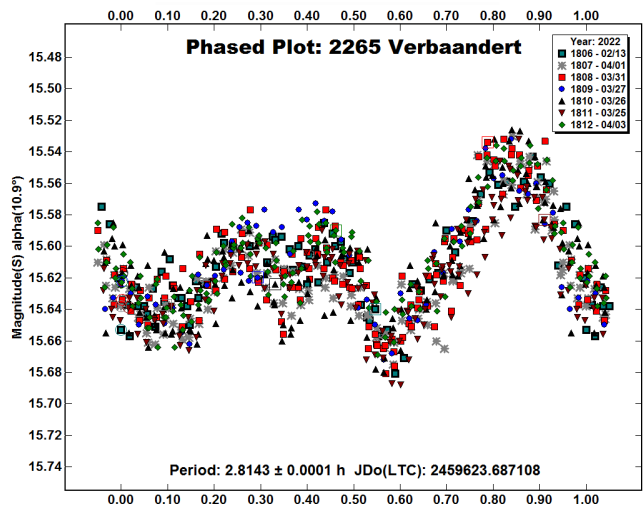


Figure 1. 2265 Verbaandert Phase Plot.

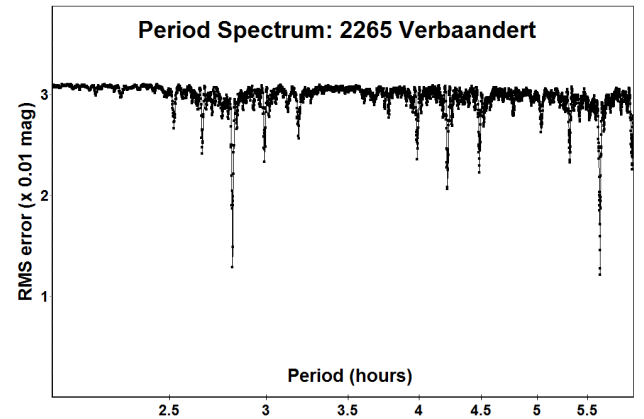


Figure 2. 2265 Verbaandert, period spectrum from 2 to 6 hours showing an alias at 5.6287 hours.

3787 Aivazovskij (1977 RG7) is an outer main-belt stony asteroid discovered by Nikolai Chernykh at the Crimean Astrophysical Observatory (Nauchnyj) belonging to the Itha family (633). It is about 12 kilometers in diameter and elongate. Period estimates in hours include Behrend (2018web: 2.95398 ± 0.0007), Sada (2008: 2.97 ± 0.01), Waszczak et al. (2015: 2.953 ± 0.0005), and Hanus et al. (2016: 2.980807 ± 0.000005) who also determined the spin axis (pole) and modeled the asteroid shape. The period listed in the Summary of the ALCDEF data page (Warner et al., 2009) is 2.95395 hours with an amplitude range of 0.18-0.24 magnitude.

Wiley picked this asteroid as a fast-rotating asteroid for training to perform asteroid lightcurves as the rotation period and amplitude seemed well established. To explore filters, Wiley used a Cousins R for two nights and no filter for three. Fourier analysis in *Tycho Tracker* and a fit order of 4 reported a period of 2.9532 ± 0.0001 hours with an amplitude of 0.191 magnitude (Fig. 3). Photometric precision average 0.007 magnitude. Because there was a difference between the ALCDEF period and ours that exceeded errors we downloaded the ALCDEF file and reanalyzed the data with the same parameters used for our data. The period returned was 2.9533 ± 0.0001 hours, within errors (in rounding) of our analysis. Given the period and amplitude shown in Table I, both similar to the re-analyzed period and amplitude in the ALCDEF gave confidence that Wiley could do further work with two asteroids that appeared on the January-March lightcurve opportunities list (Warner et al., 2022).

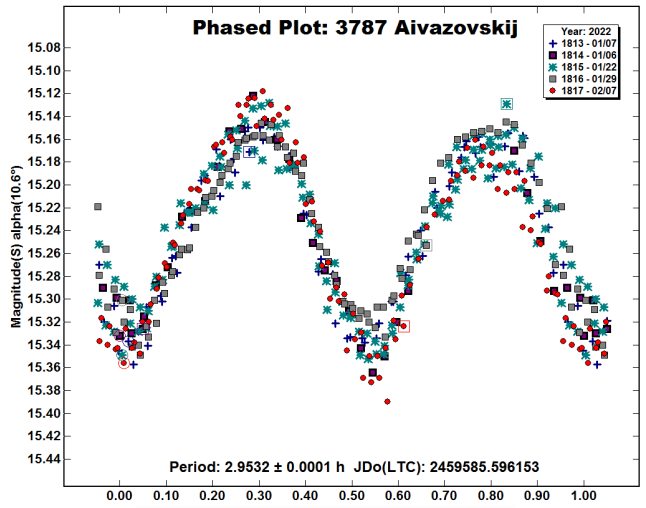


Figure 3. 3787 Aivazovskij, Phase Plot.

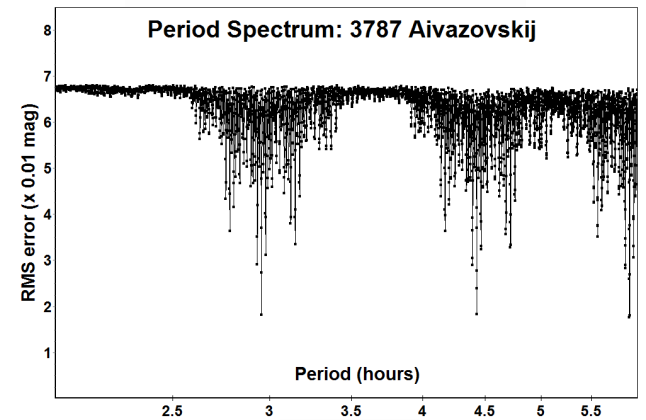


Figure 4. 3787 Aivazovskij, period spectrum from 2 to 6 hours showing aliases to period solution.

Number	Name	2022/mm/dd	Pts	Phase	LPAB	BPAB	Period(h)	P.E.	Amp	A.E.	Grp
2265	Verbaandert	02/13-04/03	811	16.9,10.9	162	16	2.8143	0.0001	0.105	0.0173	9105
3787	Aivazovskij	01/06-02/07	438	10.2,19.3	91	-14	2.9532	0.0001	0.191	0.0199	633
4528	Berg	04/07-05/07	587	22.9,21.7	169	3	3.5630	0.0002	0.345	0.0295	9104

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last dates. LPAB and BPAB are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/grup (Warner et al., 2009).

4528 Berg (1983 PP) is a main-belt asteroid discovered by Edward Bowell (Lowell Observatory) and named for the Austrian composer Alban Berg. It is 9 km in diameter (JPL, 2022). Behrend (2006web), using observations from Pierre Antonini posted a provisional rotation period of 3.5163 ± 0.004 hours. Stecher et al. (2015) estimated a period of 3.47 ± 0.47 hours. With almost complete coverage Polakis (2018) found the period to be 3.5626 ± 0.0004 hours. Data from Polakis (2018) for one night in 2014 in Johnson V (Pts = 109) and six nights in 2018 in C (Pts = 342) were downloaded from the ALCDEF database. Fourier analysis resulted in the same period and uncertainty reported here. 4528 Berg was recently found to be binary (Benishek et al., 2022) using a much larger data set than reported here and reported a primary rotation period (3.5627 ± 0.0001 hr), a satellite orbital period (35.02 ± 0.02 hr) and a light curve amplitude (0.23 magnitude at solar phases 1-4 degrees).

Berg was imaged over eight nights between 2022 April 07 and 2022 May 07 with a total of 587 images covering all phases of the lightcurve. Precision was in the millimagmitudes in April (0.007) and decreased to an average 0.01 magnitude in May as the asteroid dimmed. Fourier analysis of fit = 4 in *Tycho Tracker* returned a rotation period of 3.5630 ± 0.0001 hr (Figs. 5, 6). This is close to the primary rotation period reported by Benishek et al. (2022). We note that the minima from two nights (2022/05/07, phase 0 and 2022/04/08 at phase 0.50) show a magnitude drop of ca. 0.10 magnitude. To explore these possible mutual events, we employed the dual period algorithm of MPO Canopus to extract the secondary period. Further analysis of our data was carried out using *MPO Canopus* (Warner, 2010) to investigate possible mutual events, using the dual period feature as detailed below. *Peranso* (Vanmunster, 2013) was used to estimate or calculate minima of mutual events.

Our primary lightcurve is shown in Fig. 7 and the satellite lightcurve in Fig. 8. Using the original data from both nights on which a mutual event was observed we were able to calculate a time of minimum HJD 2459706.67713 (2022 May 7, 04:15:4.03 UT) for the 05-07 date using the Kwee-van Woerden (1956) algorithm implemented in *Peranso*. There were insufficient data points to calculate the minimum for the April 8 mutual event, an estimate based on the minimum magnitude observed is HJD 2459677.72 (2022 April 8 05:16:48 UT). See Table I for details.

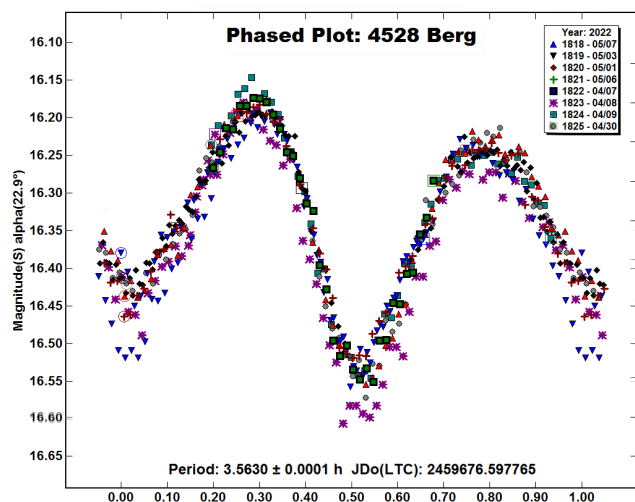


Figure 5. 4528 Berg, Phase plot.

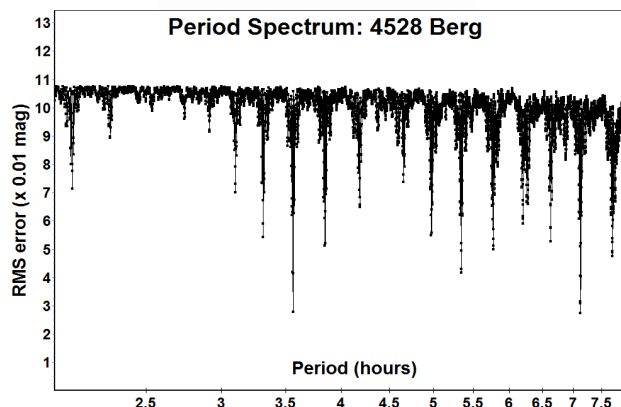


Figure 6. 4528 Berg, Period Spectrum from 2 to 8 hours showing alias at ca. 7.12 hours.

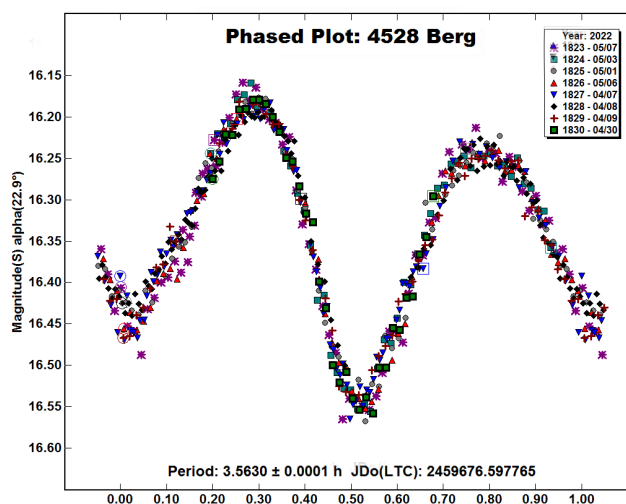


Figure 7. 4528 Berg primary light curve.

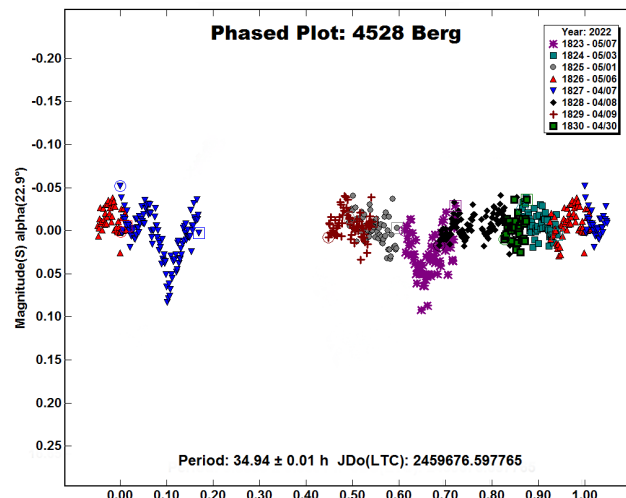


Figure 8. Light curve of the 4528 Berg satellite showing the mutual events (Occultations, eclipses, or transits) based on the orbital period of the satellite from Benishek et al. (2022). Magnitude zero is the average magnitude of the primary.

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