

LIGHTCURVES OF EIGHTEEN ASTEROIDS

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We present lightcurves and synodic rotation periods for eighteen asteroids.

We present asteroid lightcurves obtained via the workflow process described by Dose (2020) and later improved (Dose, 2021a). This workflow applies to each image an ensemble of typically 25-100 nearby comparison (“comp”) stars selected from the ATLAS refcat2 catalog (Tonry et al., 2018). This abundance of comp stars and our custom diagnostic plots allow for rapid identification and removal of outlier, variable, and poorly measured comp stars.

The product of this custom workflow is one night’s time series of absolute magnitudes, on Pan-STARRS r' (PR) catalog basis, for one target asteroid. These absolute magnitudes are corrected for instrument transforms, sky extinction, and image-to-image (“cirrus”) fluctuations, and thus they represent magnitudes at the top of earth’s atmosphere. These magnitudes are imported directly into *MPO Canopus* software (Warner, 2021) where they are adjusted for distances and phase-angle dependence, fit by Fourier analysis including identifying and ruling out of aliases, and plotted.

Phase-angle corrections are made by applying an H-G model to the night’s phase angle, using the G value minimizing best-fit RMS error across all nights’ data. For campaigns in which we cannot estimate an asteroid’s G value, usually due to a narrow range of phase angles, we apply the Minor Planet Center’s default value of 0.15. No nightly zero-point adjustments (Delta Comps in *MPO Canopus*) were made to any session, other than by estimating G .

Lightcurve Results

Eighteen asteroids were observed from New Mexico Skies observatory at 2310 meters elevation in southern New Mexico. Images were acquired by using a 0.50-meter PlaneWave OTA on a PlaneWave L-500 mount and equatorial wedge and an SBIG AC4040M CMOS camera cooled to -15°C or to -22°C (after December 13) that was fitted with a GG495 yellow filter (Schott).

This equipment was operated remotely via *ACP* software (DC-3 Dreams), running one-night plan files generated by python scripts (Dose, 2020). Exposure times targeted 2.5-5.0 millimagitudes uncertainty in asteroid instrumental magnitude, subject to a minimum exposure of 90 seconds to ensure suitable comp-star photometry, and to a maximum of 480 seconds.

FITS images were calibrated using temperature-matched, exposure-matched, median-averaged dark images and recent flat images of a flux-adjustable light panel. Calibrated images were plate-solved by *TheSkyX* (Software Bisque), and target asteroids were identified in *Astrometrica* (Herbert Raab). All photometric images were visually inspected; the author excluded images with poor tracking, excessive interference by cloud or moon, or having stars, satellite tracks, cosmic ray artifacts, residual image artifacts, or other apparent light sources within 12 arcseconds of the target asteroid’s signal centroid. Images passing these screens were submitted to the workflow.

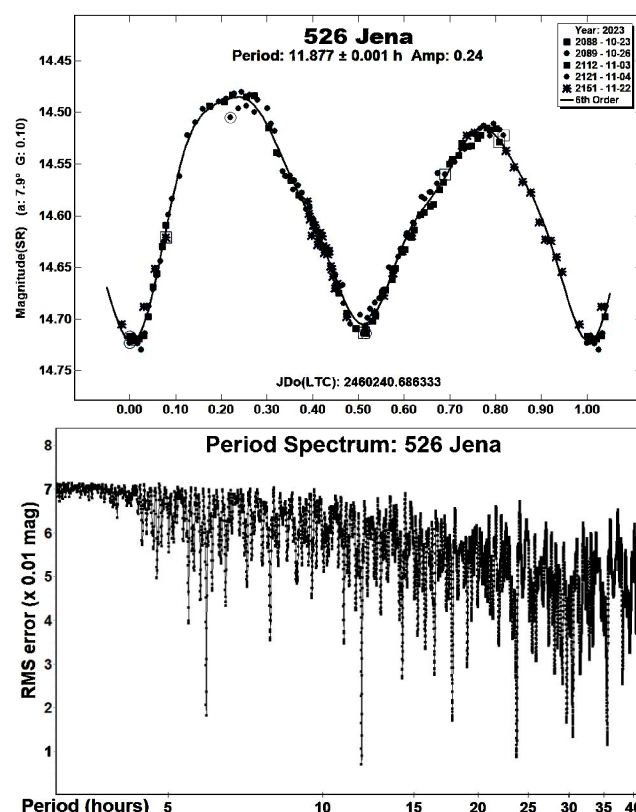
The GG495 yellow filter used here requires only modest first-order transforms to yield magnitudes in the standard Pan-STARRS r' (PR) passband. In our hands, using a light-yellow filter (rather than a clear filter or no filter) improves night-to-night reproducibility to a degree outweighing loss of signal-to-noise ratio caused by $\sim 15\%$ loss of measured flux.

Comparison stars from the ATLAS refcat2 catalog were selected only if they had a distance of at least 15 arcseconds from image boundaries and from other catalogued flux sources, no catalog VARIABLE flag, PR magnitude within $[-2, +1]$ of the target asteroid’s PR magnitude on that night (except that very faint asteroids used comp stars with magnitudes in the range 14 to 16), PR-I color value within $[0.10, 0.34]$, and absence of variability as seen in session plots of each comp star’s instrumental magnitude vs time.

In this report, “period” refers to an asteroid’s synodic rotation period and “mmag” denotes millimagitudes (0.001 magnitude). In the lightcurves, *MPO Canopus* v10 shows “SR” for both Pan-STARRS and Sloan r' values. The G value given in the lightcurve plot is that which optimized the Fourier fit.

526 Jena. For this asteroid of the Themis family, we estimate a synodic rotation period of 11.877 ± 0.001 h, agreeing with two recent survey results (11.877 h, Erasmus et al., 2020; 11.87651 h, Martikainen et al., 2021) but differing from other known reports (9.474 h, Barucci et al., 1994; 9.48 h, Behrend, 2008web; 9.479 h, Hamanowa and Hamanowa, 2011web; 9.51664 h, Hanuš et al., 2016), all of which appear to have captured an alias by one-half period per day of the actual rotation period.

The lightcurve is clearly bimodal in shape. Our best G value of 0.10 gave a modest fit improvement over the MPC default value of 0.15; our Fourier-fit RMS error is 7 mmag.

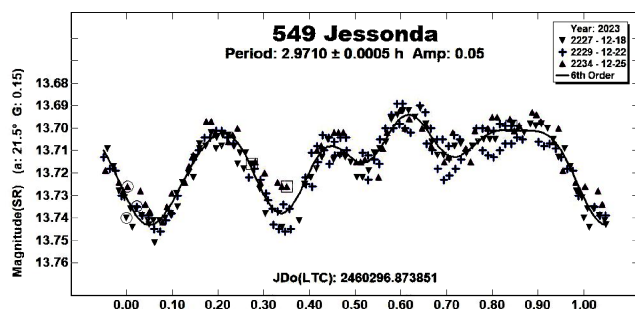


Suppression of aliases was greatly aided by our long observing sessions of which two were more than eight hours in duration, enough to capture two adjacent brightness minima or maxima. The often-reported alias near 9.48 h does not appear in our period spectrum.

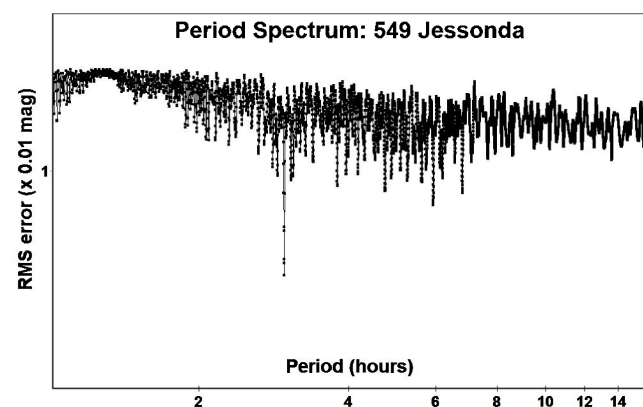
549 JESSONDA. Most reported estimates of the rotation period for this bright middle main-belt asteroid appear to have assumed a monomodal interpretation (2.97 h, Behrend, 2002web; 2.9709 h, Behrend, 2005web; 2.971 h, Warner, 2011; 2.962 h, Stephens, 2015; 2.9713 h, Pilcher, 2020; 2.972 h, Polakis, 2020b; but note 5.938 h, Warner, 2006 as a precursor to Warner, 2011), and except in one case (4.5 h, Brincat, 2002web) were near 2.97 h or twice that value. The similarity between successive cycles in the lightcurve and the uniformly low amplitude both present weak evidence that a monomodal interpretation is correct, but it always remains possible that the lightcurve is still bimodal and that the asteroid's two physical sides are very similar.

We were intrigued by some fine structure emerging in the recent lightcurves of Pilcher and Polakis, which our new data confirm. We suggest that this fine structure is the best evidence yet for the monomodal character of this lightcurve, because higher-order modality would require that opposite physical sides of the asteroid would have to match in their shapes, which seems unlikely (our three sessions were offset by an odd number of period cycles, so that, under bimodality, we would have sampled both sides of the asteroid). We conclude that the true rotation period of 549 JESSONDA is 2.971 h.

Our new estimate of 2.9710 ± 0.0005 h matches recent consensus. We adopted the MPC default G value of 0.15, and our Fourier fit RMS error is 5 mmag.



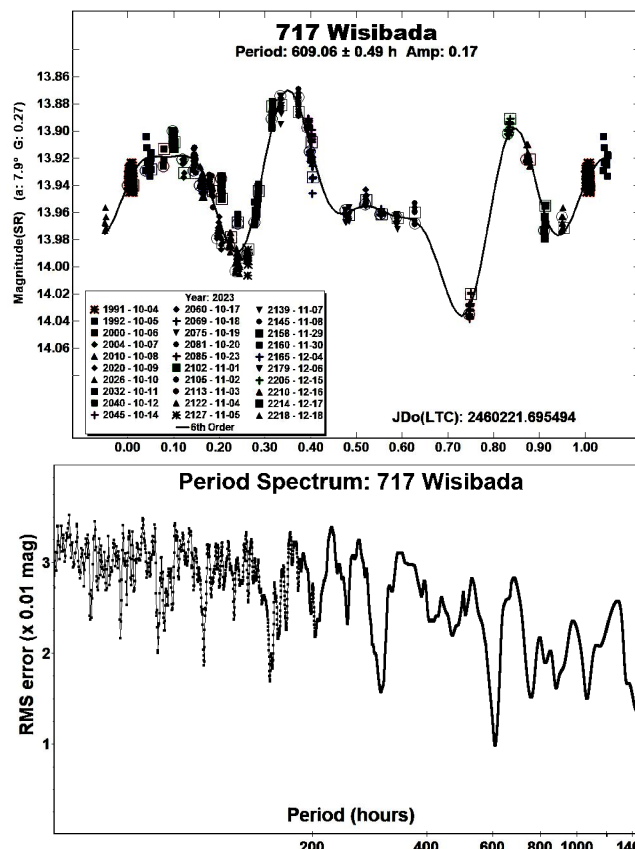
The period spectrum appears unequivocal. No meaningful signals appeared at periods longer than 15 h.



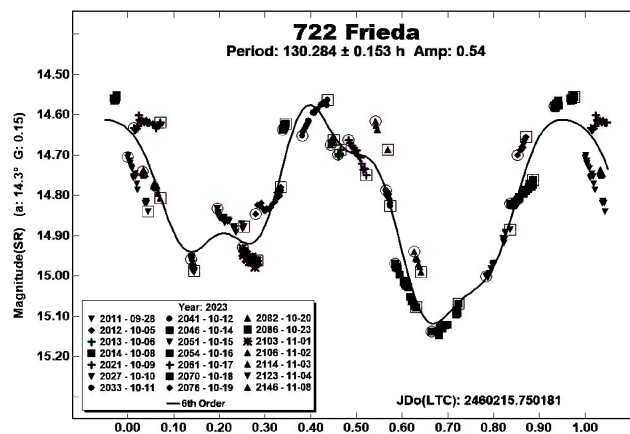
717 Wisibada. Arriving at a Fourier solution for this outer main-belt asteroid was exceptionally difficult due to its long rotational period

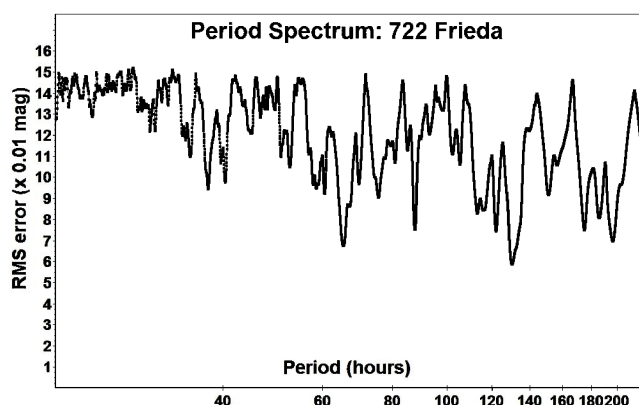
and its atypical lightcurve shape. Indeed, we know of no previous period reports, which remains true of very few low-numbered asteroids. From 30 nights' observations, we report a bimodal lightcurve with period 609.06 ± 0.49 h. Adopting our best G value of 0.27 markedly decreased the fit RMS error to 10 mmag.

No periods shorter than 600 h can satisfactorily fit our data.



722 Frieda. We confirm the tumbling apparent in previous lightcurves (Polakis, 2019; Dose, 2021b), and we report here a rotation period of 130.284 ± 0.153 h, in reasonable agreement with most previous reports (131.166 h, Āurech et al., 2019; 131.1 h, Polakis, 2019; 128.99 h, Dose, 2021b). We cannot explain one differing report of 30.06 h (Olguin et al., 2020) via multiples or aliases but note that its phase coverage was incomplete.

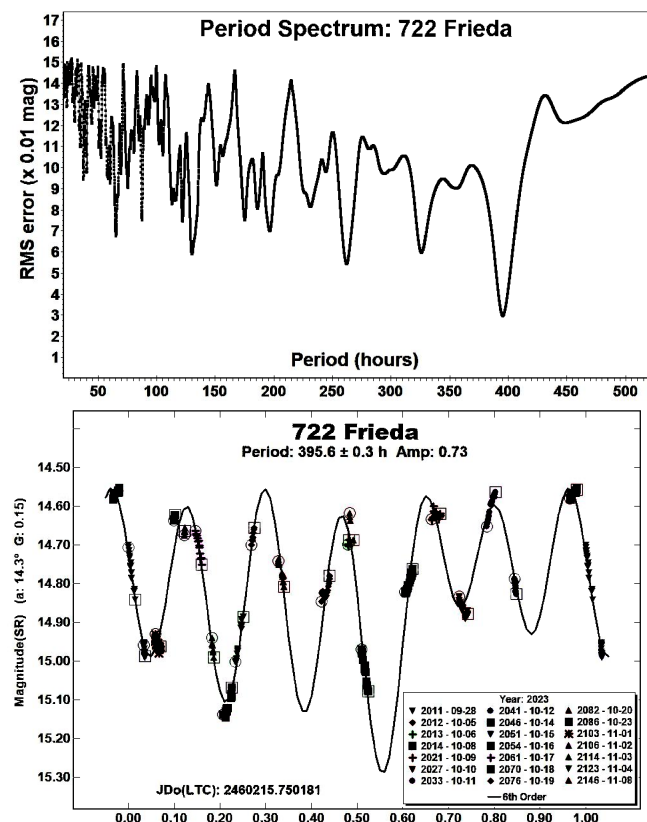




Night-to-night brightness variations caused by tumbling appear to have had several effects: scatter in reported periods around 130 h, our high Fourier fit RMS error of 59 mmag, and very low sensitivity of the fit to G value for which we kept MPC's default of 0.15.

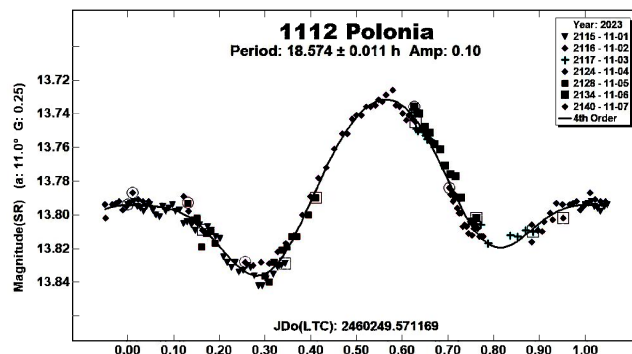
The period spectrum is not as clear as wished even with 21 nights' data, but the preponderance of recent reports around 130 h and the lightcurve's high amplitude support 130 hours as 722 Frieda's correct rotational period.

However, if one extends the period spectrum, a dominant new signal appears near 395 h, close to three times the bimodal period, and its RMS error is much lower than that for the bimodal period.

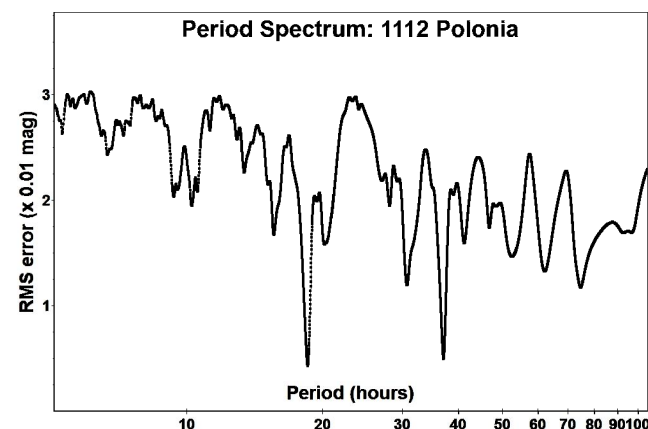


Of course, a hexamodal Fourier fit is unrealistic for rotation alone, but this period so strikingly matches our data - even within nights - as to suggest a precession period near 3 times the rotational period. However, it is important to note that *MPO Canopus* is not designed to analyze tumbling asteroids properly and that the longer period might be at a "beat frequency" of the true periods of rotation and precession.

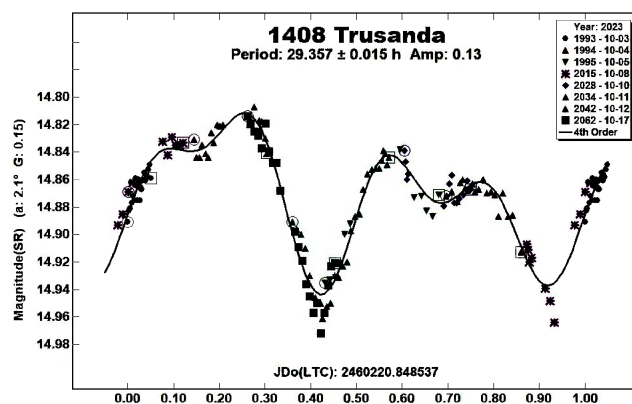
1112 Polonia. For this asteroid of the Eos family, we find a nominally bimodal lightcurve dominated by one maximum and a rotation period of 18.574 ± 0.011 h, in fair agreement with two reports (18.605 h, Behrend, 2018web; 18.71 h, Polakis, 2020a) but differing from another, earlier report (82.5 h, Warner, 2008). A period of 82.5 h represents an alias of our value by one period per day. Our best G value is 0.25 and our Fourier fit RMS error for this bright asteroid is 4 mmag.

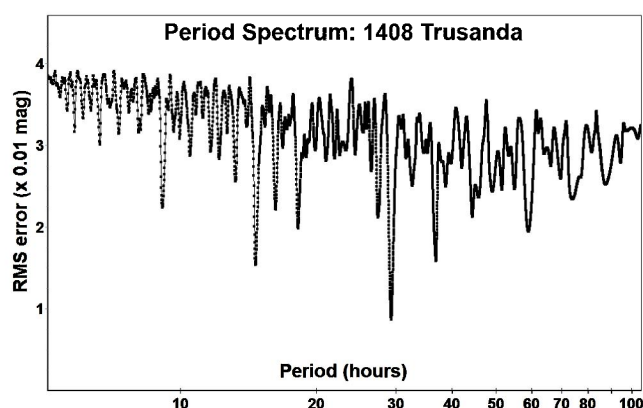


The period spectrum is unambiguous except for a double-period signal near 37 h. Our fortunate series of seven consecutive observation nights strongly suppressed aliases, including that at 82.5 h.



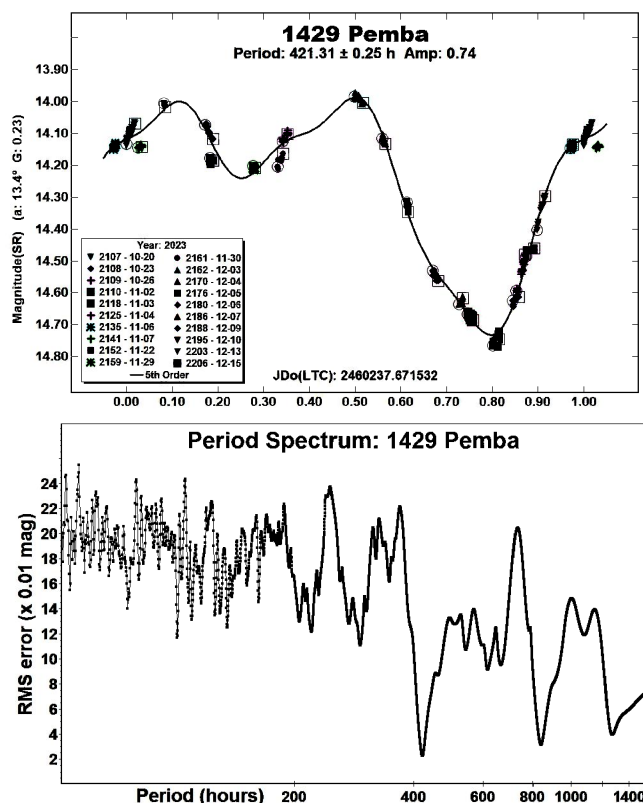
1408 Trusanda. For this asteroid of the Eos family, we report a rotation period of 29.357 ± 0.015 h and an asymmetric bimodal lightcurve. We know of no previous period reports. We adopted a default G value of 0.15, and the Fourier fit RMS error is 9 mmag.





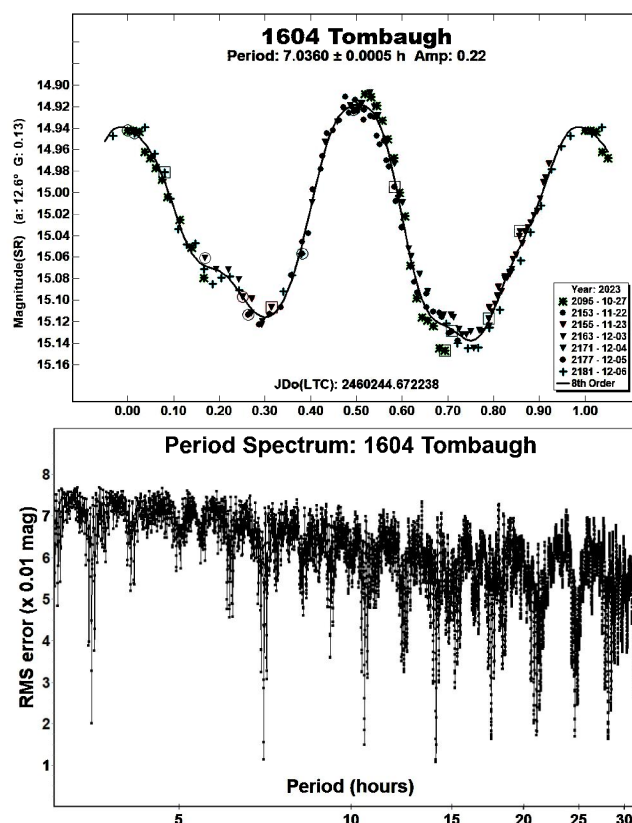
1429 Pemba. Finding a Fourier solution for this inner main-belt asteroid was complicated by its long period and its unusual, nominally bimodal lightcurve shape. After twenty nights' observation extending over more than three periods, we report a period of $421.31 \text{ h} \pm 0.25 \text{ h}$, consistent with one previously reported lower limit ($> 20 \text{ h}$, Harris et al., 1999); we know of no reported central estimates of the period. The lightcurve shows little evidence of tumbling effect. A G value of 0.23 markedly decreased our Fourier fit RMS error, which is 22 mmag.

No periods shorter than about 400 h can fit our observations.

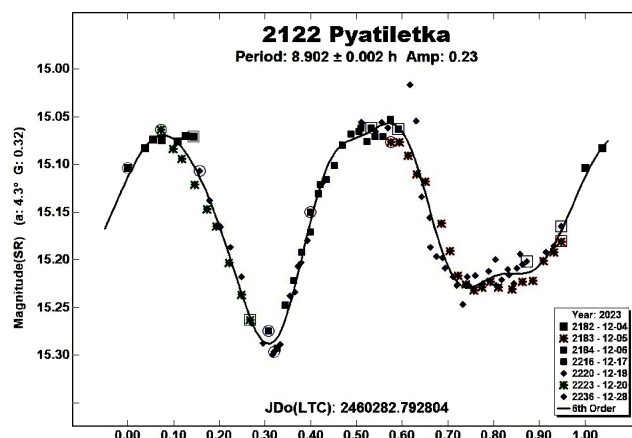


1604 Tombaugh. For this Eos-family asteroid, we add to the growing rotation-period consensus (8.2 h, Lagerkvist, 1978; 7.04 h, Binzel, 1987; 6.15 h, Sárneczky et al., 1999; 7.047 h, Albers et al., 2010; 7.056 h, Strabla et al., 2013; 7.24 h, Behrend, 2017web; 7.0359 h, Āurech and Hanuš, 2018; 7.03598 h, Āurech et al., 2019) with our estimate of $7.0360 \pm 0.0005 \text{ h}$. Our best G value of 0.13 modestly improved the fit over a default value of 0.15; our Fourier fit RMS error is 9 mmag.

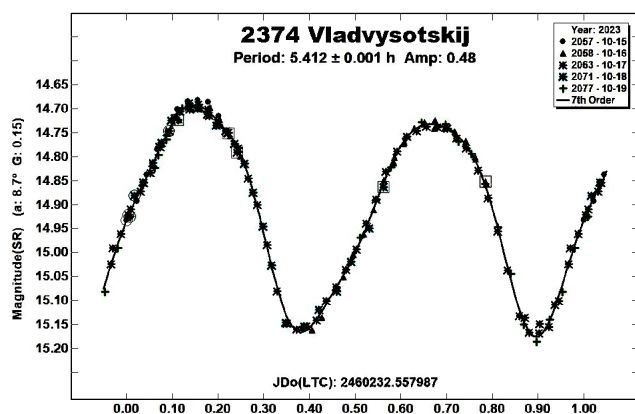
Our period spectrum is dominated by signals at multiples of one-half our proposed period, as expected for a nearly symmetric bimodal lightcurve.



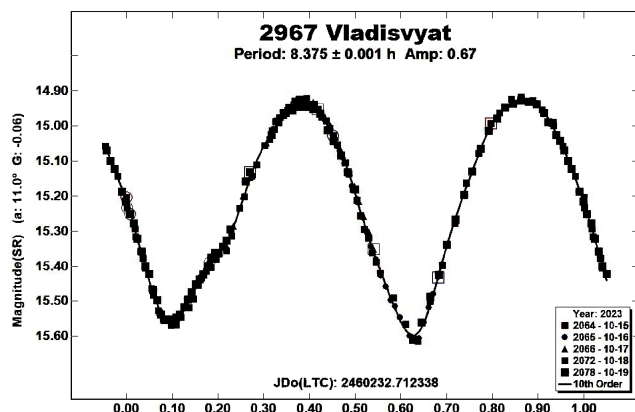
2122 Pyatiletka. Our period estimate of $8.902 \pm 0.002 \text{ h}$ for this inner main-belt asteroid agrees with two previous reports from surveys (8.899 h, Waszczak et al., 2015; 8.90167 h, Āurech et al., 2020). The lightcurve is clearly bimodal. Our best G value is 0.32, and our Fourier fit RMS error is 14 mmag.



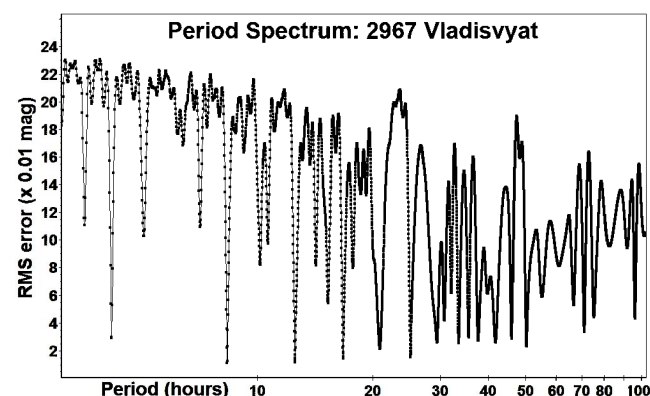
2374 Vladvysotskij. For this asteroid of the Meliboea family, we report a rotational period of $5.412 \pm 0.001 \text{ h}$, in agreement with two previous survey reports (5.398 h, Waszczak et al., 2015; 5.41401 h, Āurech et al., 2018). The lightcurve is bimodal. The Fourier fit was insensitive to G value, given the small phase angle range covered, and its RMS error is 8 mmag.



2967 Vladisvyat. For this Ursula-family asteroid, we report a rotation period of 8.375 ± 0.001 h. The LCDB lists no previous period reports. The lightcurve is bimodal with the two halves differing only slightly. Our best G value is -0.06 and our Fourier fit RMS error is 9 mmag.

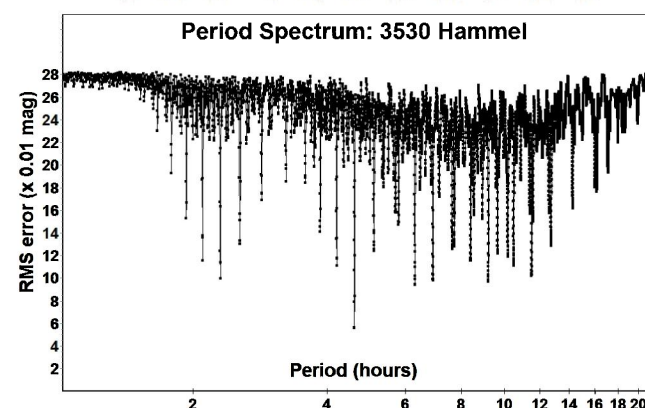
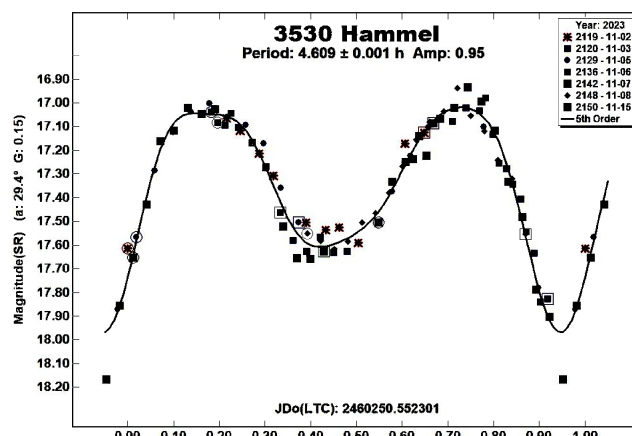


The period spectrum is dominated by signals at multiples of one-half period, consistent with a slightly asymmetric bimodal lightcurve. Complete phase coverage, with overlaps, was made possible by observing for 60% or more of the period during three of the five consecutive nights. The relatively large lightcurve amplitude also supports our bimodal interpretation.



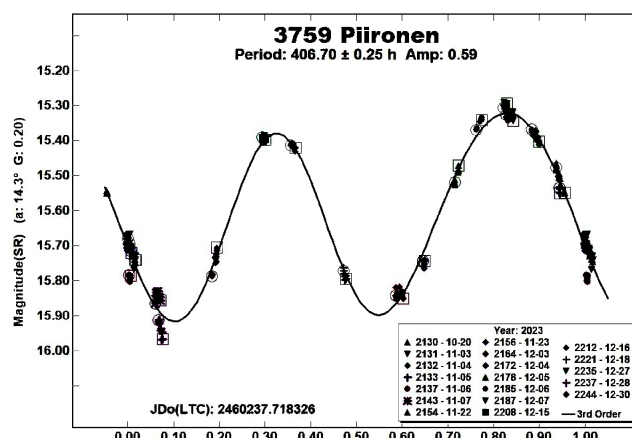
3530 Hammel. For this faint Hertha-family asteroid, we report a rotation period of 4.609 ± 0.001 h, in reasonable agreement with two previous reports (4.53 h, Erasmus et al., 2019; 4.59 h, Behrend, 2023web). The lightcurve is bimodal with very large amplitude and differing minimum brightnesses. Given the narrow phase-angle

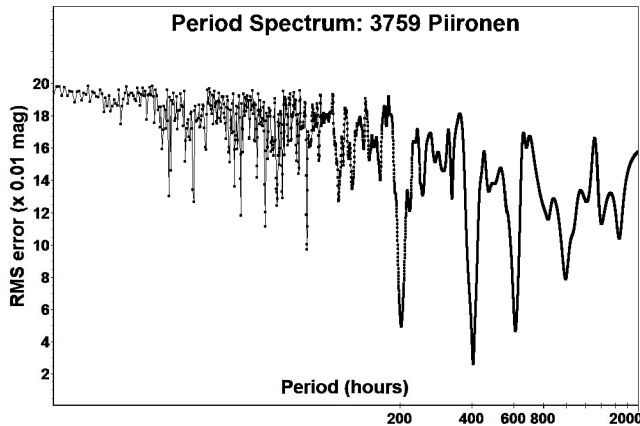
range covered, we could not distinguish our best G value from the MPC default of 0.15 and so we adopted the latter. Our Fourier fit RMS error is 52 mmag.



3759 Piironen. Previous attempts to determine the period for this outer main-belt asteroid have resulted in three widely differing reported periods (15.02 h, Behrend, 2011web; 8.213 h, Klinglesmith et al., 2015; 409.848 h, Waszczak et al., 2015). Our result of 406.70 ± 0.25 h, based on 19 nights' observations over 13 weeks (more than 5 periods), agrees fairly well with that of Waszczak, and the lightcurve is bimodal. Our best G value is 0.20; our Fourier fit RMS error is 26 mmag. We saw little or no effect of any tumbling.

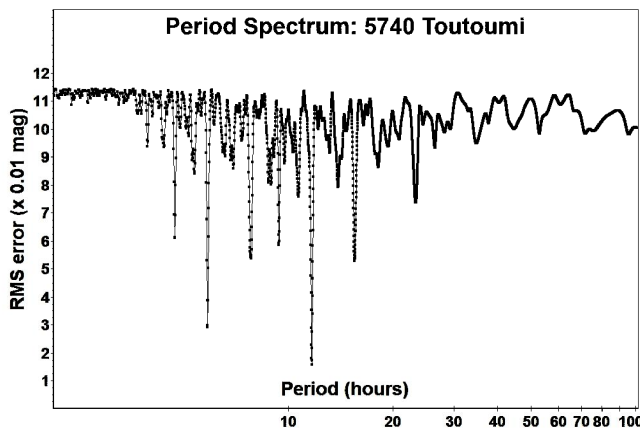
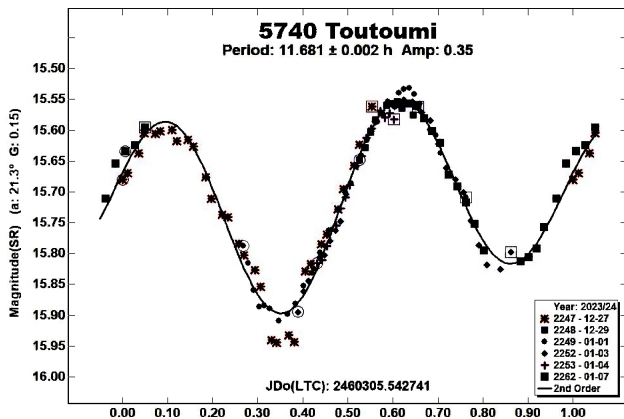
The period spectrum's primary signal falls at our proposed period, and two secondary signals fall at one- and three-halves of that period.





5740 Toutoumi. Previous rotation period estimates for this middle main-belt asteroid have been based on monomodal (5.83981 h, Pál et al., 2020) and bimodal (11.68 h, Vander Haagen, 2007; 11.686 h, McNeill et al., 2019; 11.67974 h, Āurech et al., 2020) assumed shapes for the lightcurve. Our lightcurve shape strongly confirms the bimodal interpretation and our estimate for the rotation period is 11.681 ± 0.002 h. Our narrow range of phase angles caused us to adopt the MPC default G value of 0.15, and our Fourier fit RMS error is 16 mmag.

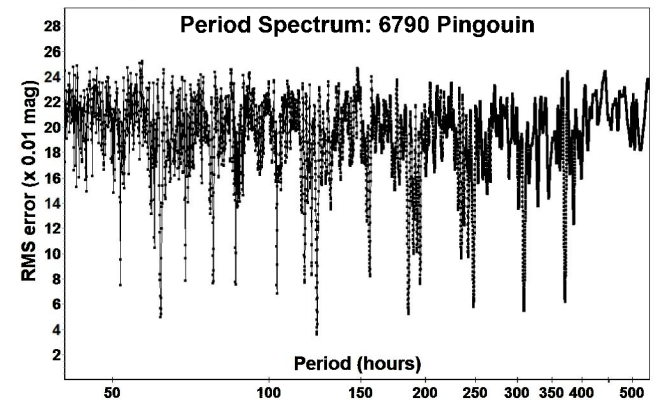
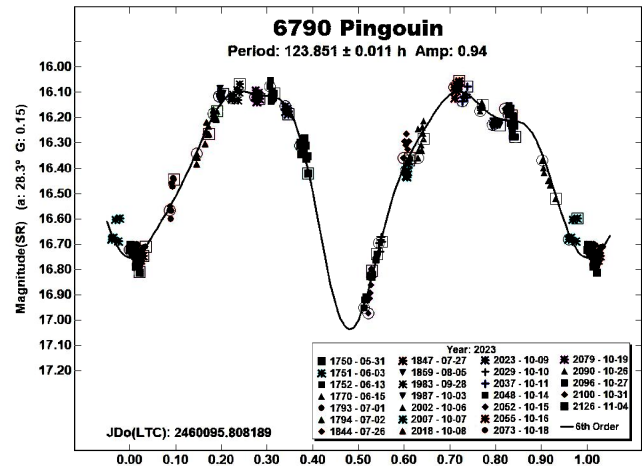
Our period spectrum confirms the bimodal interpretation.



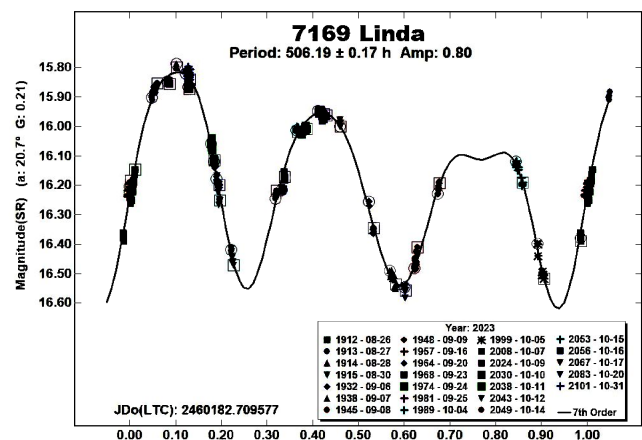
6790 Pingouin. For this inner main-belt asteroid, we find a bimodal lightcurve with period 123.851 ± 0.011 h, in agreement with one previously reported result (124.16 h; Āurech et al., 2020) but differing from another (6.38 h, Clark, 2007). Even with 26 nights'

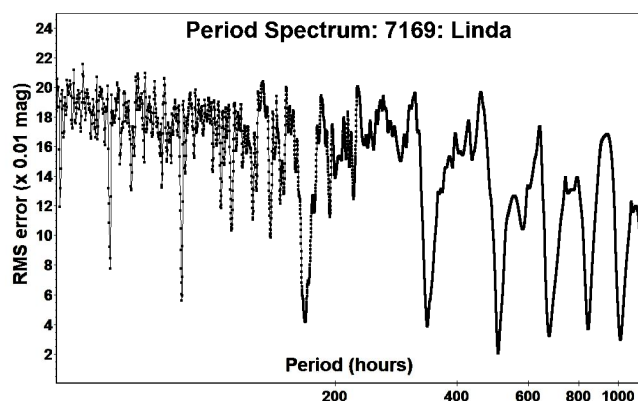
observations over a campaign of five months (30 rotational periods), the phase coverage is imperfect. The lightcurve amplitude is very large, supporting the bimodal lightcurve shown. Our best G value was indistinguishable from the MPC default of 0.15, and our Fourier fit RMS error is 36 mmag. We saw no clear suggestion of tumbling effect.

The period spectrum is dominated by signals at multiples of one-half of our proposed period.



7169 Linda. Several previous attempts to determine the rotation period of this Matterania-family asteroid have led to widely differing reported estimates (> 28 h; Higgins and Gonçalves, 2007; 8.355 h, Clark, 2008; 27.864 h, Hanuš et al., 2013; 341.68 h, Waszczak et al., 2015; 336.276 h, Pál et al., 2020).



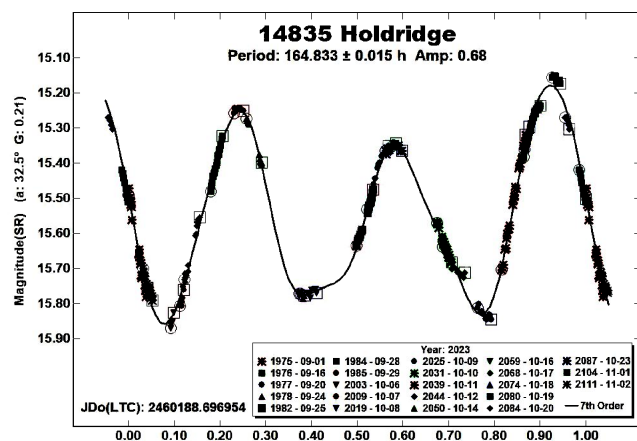


Our 26 nights' observation over nine weeks leads us to report a trimodal lightcurve and best period estimate of $506.19 \text{ h} \pm 0.17 \text{ h}$. Attempts to constrain the fits to monomodal or bimodal models met with frustration; our trimodal result is indeed approximately 1.5 times the duration of the two most recent period reports.

There is little or no evidence of tumbling effect on our lightcurve. Our best G value is 0.21, and our Fourier fit RMS error is 20 mmag.

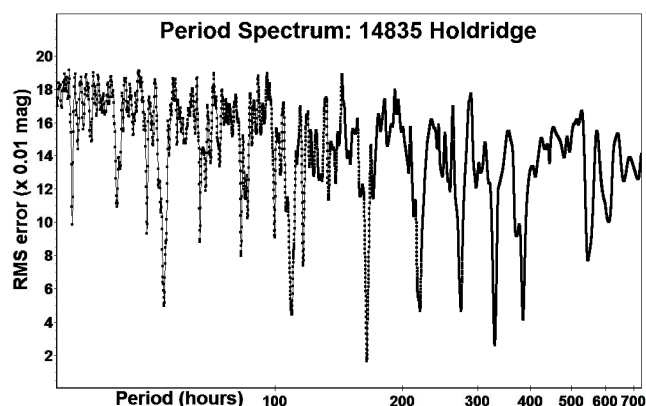
Our lightcurve phase coverage is nearly complete. To cover every minimum, maximum, brightening, and dimming within this complex, high-order lightcurve might require about 50 nights' observation in a single apparition, which suggests a future campaign of observations from multiple locations with largely uncorrelated weather. In compensation, the period is so long that only a few observations need be taken each night. The next promising opportunity is the 2026 apparition, which favors the Southern Hemisphere.

14835 Holdridge. In the previous issue of the *Minor Planet Bulletin*, the author reported a trimodal lightcurve for this Phocaea-family asteroid (Dose, 2023). We have now extended our previous 15 nights of observation to 22 nights (over nine weeks, which is about nine period durations), with an emphasis on long observing sessions whenever possible, to capture brightness changes within each night.



In the end, the trimodal lightcurve shape is strongly confirmed, and a new period estimate of $164.833 \pm 0.015 \text{ h}$ is little changed from our previous estimate of $164.401 \pm 0.029 \text{ h}$; both are consistent with one known period report, a lower limit of 10 h (Prevec et al., 2005web). Each brightness minimum and maximum in the lightcurve is now covered, and we still see no evidence of tumbling effect.

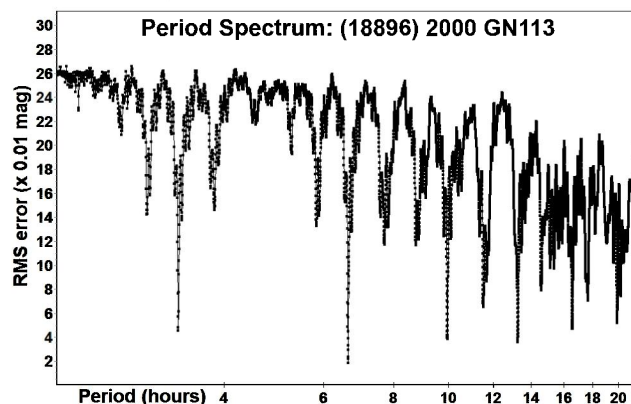
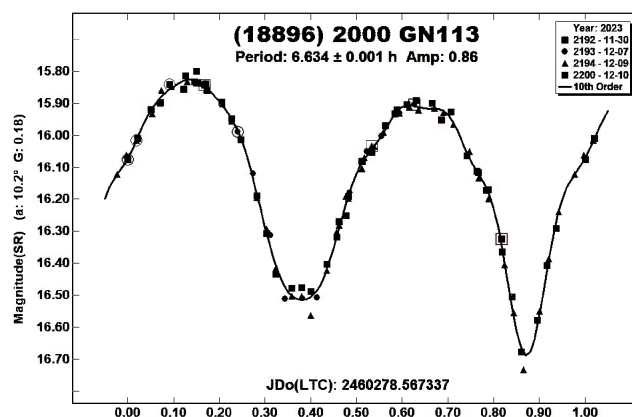
With a best G value of 0.21, our updated Fourier fit has RMS error of 16 mmag.



The updated period spectrum is very similar to the previous plot, except that signals other than those at $1\times$ and $2\times$ the proposed period are even weaker.

The next readily accessible apparition will center on 2026 May and will slightly favor the Southern Hemisphere.

(18896) 2000 GN113. We observed this inner main-belt asteroid for four nights rather late in its 2023 apparition. We report a rotation period of $6.634 \pm 0.001 \text{ h}$, in agreement with one previous set of reports (6.631 h, 6.633 h, 6.630 h, Waszczak et al., 2015) but differing from another previous report (7.22 h, Behrend, 2005web).



Number	Name	yyyy mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
526	Jena	2023 10/23-11/22	*8.0, 3.6	50	-3	11.877	0.001	0.24	0.02	THM
549	Jessonda	2023 12/18-12-25	21.7, 19.0	125	0	2.971	0.001	0.05	0.01	MB-M
717	Wisibada	2023 10/04-12/18	*8.1, 21.4	28	2	609.060	0.490	0.17	0.03	MB-O
722	Frieda	2023 09/28-11/08	*14.5, 9.3	29	-3	130.284	0.153	0.54	0.10	MB-I
1112	Polonia	2023 11/01-11/07	10.9, 12.8	15	11	18.574	0.011	0.10	0.02	EOS
1408	Trusanda	2023 10/03-10/17	2.3, 7.7	5	3	29.357	0.015	0.13	0.03	EOS
1429	Pemba	2023 10/20-12/15	*13.6, 17.9	48	0	421.310	0.250	0.74	0.06	MB-I
1604	Tombaugh	2023 10/27-12/06	*12.7, 5.2	65	11	7.036	0.001	0.22	0.03	EOS
2122	Pyatiletka	2023 12/04-12/28	4.2, 14.0	66	-6	8.902	0.002	0.23	0.04	MB-I
2374	Vladvysotskij	2023 10/15-10/19	8.7, 10.3	6	8	5.412	0.001	0.48	0.03	MEL
2967	Vladisvyat	2023 10/15-10/19	11.1, 9.7	48	4	8.375	0.001	0.67	0.04	URS
3530	Hammel	2023 11/02-11/15	29.3, 30.6	350	1	4.609	0.001	0.95	0.12	HER
3759	Piironen	2023 10/20-12/30	*14.4, 18.2	55	14	406.700	0.250	0.59	0.08	MB-O
5740	Toutoumi	2023-4 12/27-01-07	21.2, 24.1	55	5	11.681	0.002	0.35	0.04	MB-M
6790	Pingouin	2023 05/31-11/04	*28.4, 30.1	311	14	123.851	0.011	0.94	0.10	MB-I
7169	Linda	2023 08/26-10/31	*20.9, 18.6	5	8	506.190	0.170	0.80	0.10	MAT
14835	Holdridge	2023 09/01-11/02	*32.5, 10.4	30	20	164.833	0.015	0.68	0.06	PHO
18896	2000 GN113	2023 11/30-12/10	10.1, 14.8	49	2	6.634	0.001	0.86	0.08	MB-I

Table I. Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extrema during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009).

The lightcurve is bimodal, with one unusually sharp and brief minimum (phase 0.8 - 0.95 in our lightcurve plot), before and after which the brightness changes by about 0.4 magnitudes within 15 minutes. Our best *G* value is about 0.18, and our Fourier fit RMS error is 19 mmag.

As for most bimodal lightcurves, this period spectrum is dominated by signals at multiples of one-half the bimodal period, and especially by a signal at the period itself. No major signal occurs at the previously reported period near 7.22 h.

Acknowledgements

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