LIGHTCURVES OF SEVENTEEN ASTEROIDS

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We present lightcurves, synodic rotation periods, and G value (H-G) estimates for seventeen asteroids.

We present asteroid lightcurve photometry results, continuing with efforts to measure lightcurves with lower amplitude and generally longer periods. The lightcurves were obtained by following the workflow process described by Dose (2020), with later improvements (Dose, 2021). This workflow applies to each image an ensemble of typically 20-60 nearby ATLAS refcat2 catalog (Tonry et al, 2018) comparison ("comp") stars as a basis for asteroid photometry. Diagnostic plots and the numerous comp stars allow for effective identification and removal of outlier, variable, and poorly measured comp stars.

The custom workflow produces a time series of asteroid magnitude estimates on Sloan r´ (SR) catalog basis, unreduced and without H-G adjustment. 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 dependence is corrected with a H-G model, using the *G* value that minimizes best-fit RMS error across all nights' data.

No nightly zero-point adjustments (DeltaComps in *MPO Canopus* terminology) were made to any session herein, other than by adjusting the G value (H-G phase model). All lightcurve data herein have been submitted to ALCDEF.

Lightcurve Results

Seventeen asteroids were observed from Deep Sky West observatory (IAU V28) at 2210 meters elevation in northern New Mexico. Images were acquired with a 0.35-meter SCT reduced to f/7.7; an SBIG STXL-6303E camera cooled to -35 C and fitted with a Clear filter (Astrodon); and a PlaneWave L-500 mount. The equipment was operated remotely via *ACP software* (DC-3 Dreams, version 8.3), running plan files generated for each night by the author's python scripts (Dose, 2020). Observations often cycled among 2-4 asteroids. Exposure times targeted 4-6 millimagnitudes uncertainty in asteroid instrumental magnitude, subject to a minimum of 120 seconds to ensure suitable comp-star photometry, and to a maximum of 900 seconds. All exposures were autoguided.

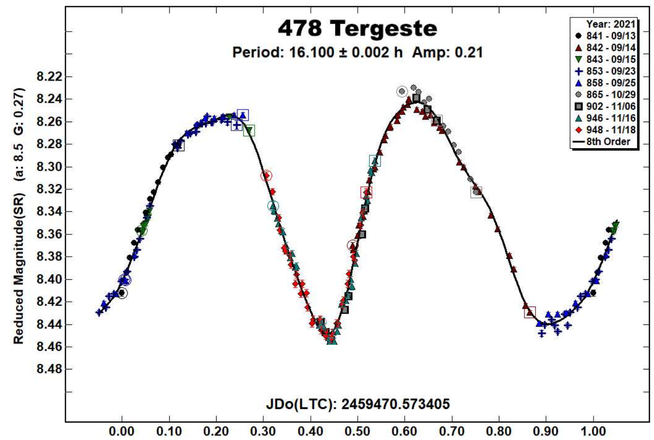
FITS images were plate-solved by *PinPoint* (DC-3 Dreams) or *TheSkyX* (Software Bisque) and were calibrated using temperature-matched, median-averaged dark images and recent flat images of a flux-adjustable flat panel. Every photometric image was visually inspected; all images with poor tracking, obvious interference by cloud or moon, or having stars, satellite tracks, cosmic ray artifacts, or other apparent light sources within 10 arcseconds of the target asteroid were excluded. Photometry-ready images that pass these screens were submitted to the workflow, which applies separately measured second-order transforms from Clear filter to deliver asteroid magnitudes in Sloan r´ passband.

In this work, "period" refers to an asteroid's synodic rotation period unless otherwise noted, "SR" denotes the Sloan r' passband, and "mmag" denotes millimagnitudes (0.001 mag).

478 Tergeste. This bright outer main-belt asteroid has been reported several times to have period of about 16 hours (16.104 h, Behrend 2005web; 16.105 h, Marciniak et al., 2015; 16.107 h, Aznar Macias et al., 2017; 16.101 h, Brines et al., 2017; 16.105 h, Marciniak et al., 2018; 16.1011 h, Pál et al., 2020; 16.1 h, Behrend, 2021web) with one known early report differing (15 h, Harris and Young, 1989). Reported lightcurves have varied in LCDB uncertainty score from 1 to 3-.

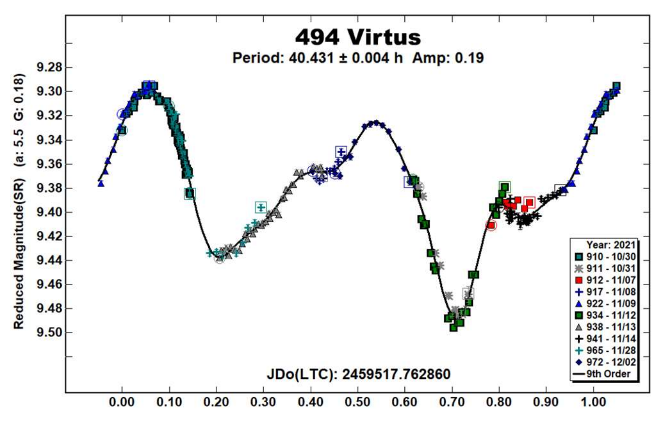
We add to the consensus with our period of 16.100 ± 0.002 h, with an amplitude of 0.21 mag. Fourier fit to the present data has RMS error of 5 mmag; best G value (H-G phase model) is 0.27; in the author's hands, Fourier fit to the same data using MPC-default *G* of 0.15 never gave RMS error lower than of 13 mmag.

The lightcurve is bimodal. Despite difficulties in obtaining full phase coverage for a period very near 16 h, a synodic period of 16.10 h appears secure.



494 Virtus. This bright outer main-belt asteroid has had disparate previous reports of rotational period (4.99 h, Behrend, 2006web, 5.57 h, Warner, 2006; 4.9903 h, Behrend, 2008web; 5.57 h, Hamanowa and Hamanowa, 2009; 49.427 h, Polakis, 2018), none bearing a LCDB uncertainty score better than 2.

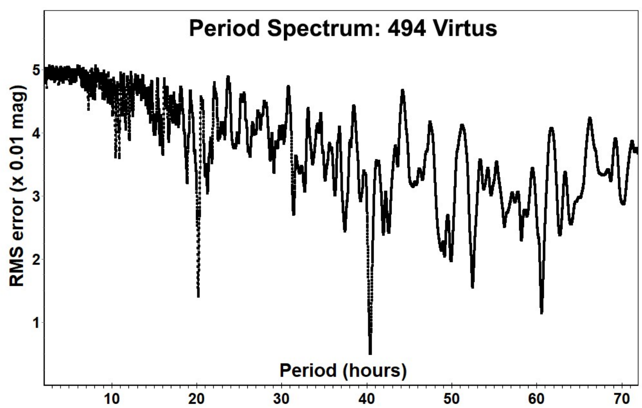
By contrast, we find a period of 40.431 ± 0.004 h. We were fortunate to view from a new aspect (phase angle bisector longitude) that yielded higher amplitude of 0.19 magnitude than previously reported (0.03-0.12 magnitudes). Our Fourier fit has RMS error of 5 mmag.



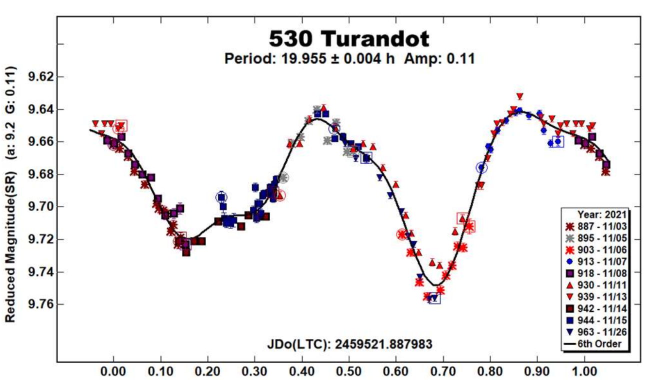
Number	Name	yyyy mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
478	Tergeste	2021 09/13-11/18	8.5,18.2	334	14	16.100	0.002	0.21	0.02	MB-O
494	Virtus	2021 10/30-12/02	*5.6,6.7	52	2	40.431	0.004	0.19	0.02	MB-O
530	Turandot	2021 11/03-11/26	*9.3,3.6	64	-10	19.955	0.004	0.11	0.01	UNK
579	Sidonia	2021-22 11/20-01/10	17.4,8.1	130	8	16.290	0.001	0.10	0.01	EOS
605	Juvisia	2021-22 12/17-01/12	13.9,7.5	126	16	15.834	0.003	0.14	0.02	MB-O
764	Gedania	2021 09/10-12/05	*12.0,17.2	18	11	24.984	0.002	0.07	0.02	MB-O
858	El Djezair	2021-22 10/05-01/05	*9.1,18.0	36	-5	29.639	0.003	0.15	0.02	MB-O
1159	Granada	2021 09/17-11/23	*16.1,16.6	27	11	72.750	0.030	0.28	0.04	MB-I
1180	Rita	2021 09/14-11/07	*6.6,9.3	12	-8	14.898	0.001	0.25	0.01	HIL
1654	Bojeva	2021-22 11/30-01/10	*13.4,5.1	106	12	11.443	0.001	0.11	0.02	EOS
1748	Mauderli	2021 10/29-11/09	*3.1,1.4	44	-4	6.002	0.001	0.10	0.03	HIL
1913	Sekanina	2021-22 12/07-01/04	15.7,20.7	37	1	14.035	0.003	0.15	0.03	KOR
2599	Veseli	2021-22 10/31-01/09	*20.5,10.4	93	19	13.251	0.001	0.36	0.04	MB-I
4162	SAF	2021 11/13-11/28	9.1,14.3	36	10	3.850	0.002	0.13	0.05	MB-O
4719	Burnaby	2021 11/11-12/06	22.5,15.5	100	10	10.451	0.001	0.12	0.03	UNK
5256	Farquhar	2021 10/29-11/20	9.8,17.7	19	5	11.504	0.002	0.13	0.03	EUN
6706	1988 VD3	2021 09/12-12/04	*21.9,22.9	28	2	53.398	0.008	0.06	0.02	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).

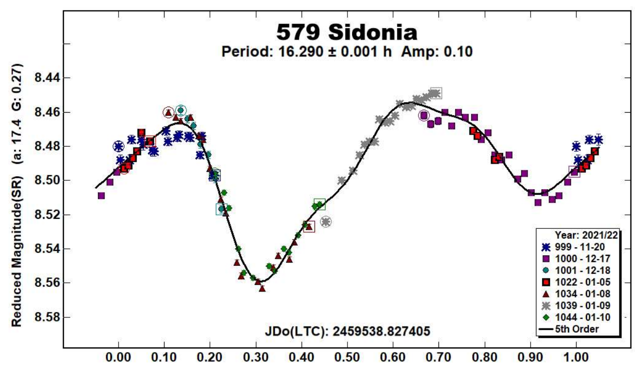
The period spectrum disfavors candidate periods of less than 20 h.



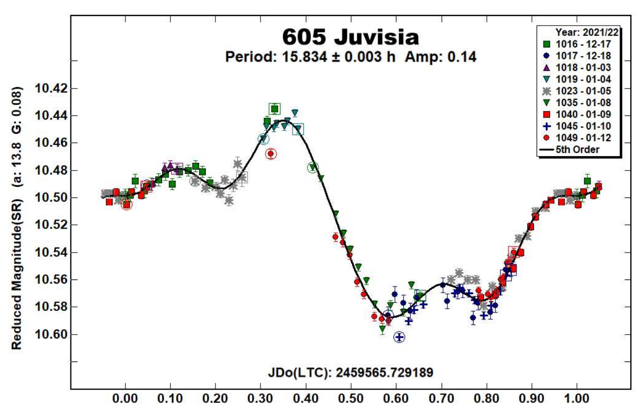
530 Turandot. This asteroid of undetermined type was found to have period of 19.955 ± 0.004 h, confirming most known, previous reports (19.95 h, Behrend, 2002web; 19.947 h, Behrend, 2005web; 19.96 h, Pilcher, 2014; 19.94 h, Colazo et al., 2021a) and differing from one early report (10.77 h, Di Martino et al., 1995), which is an alias of our solution by 1 period per 24 h. Fourier fit RMS error is 6 mmag. The *G* estimate (0.11) that we apply is made uncertain by the observations' narrow phase range.



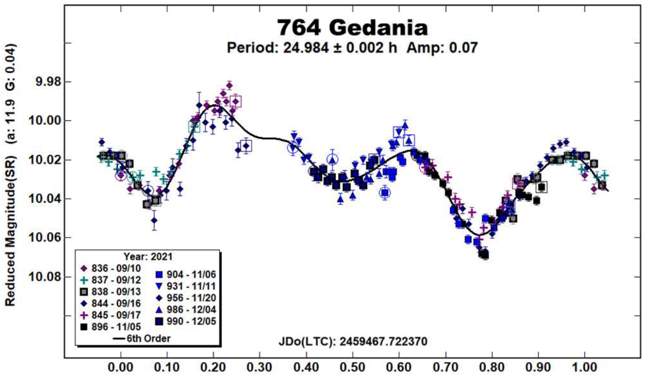
579 Sidonia. This Eos-family asteroid is approaching close consensus on its synodic period (16.286 h, Stephens, 2010; 16.2804 h, Ďurech et al., 2020; 16.279 h, Colazo et al, 2021b) after some disparate earlier reports (16.5 h, Binzel, 1987; 16.5 h, Weidenschilling et al., 1990; 18.72 h, Behrend, 2005web). We find a period of 16.290 ± 0.001 h with Fourier fit RMS error of 6 mmag. With recent reports in agreement from three apparitions, the time may be right to recompute a shape model.



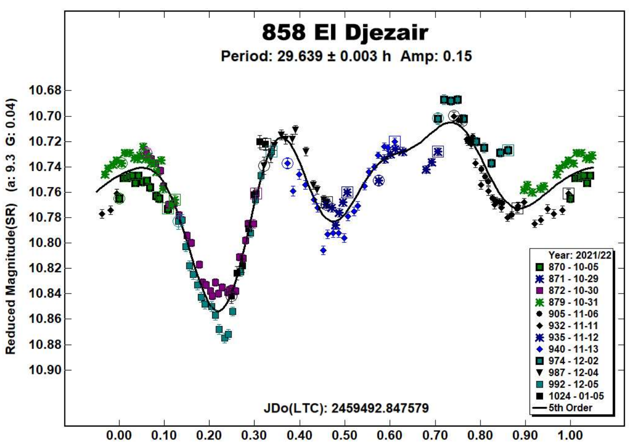
605 Juvisia. The author revisited this outer main-belt asteroid to confirm the period and to add to the viewing aspects for which data are available to future shape modeling. Our period solution of 15.834 ± 0.003 h agrees with known previous reports (15.855 h, Warner, 2000; 15.85 h, Menke, 2005; 15.93 h, Warner, 2011; 15.851, Dose, 2021; 15.844 h, Pilcher, 2021b) except one (31.6616 h, Ďurech et al., 2019). Our Fourier RMS error is 7 mmag.

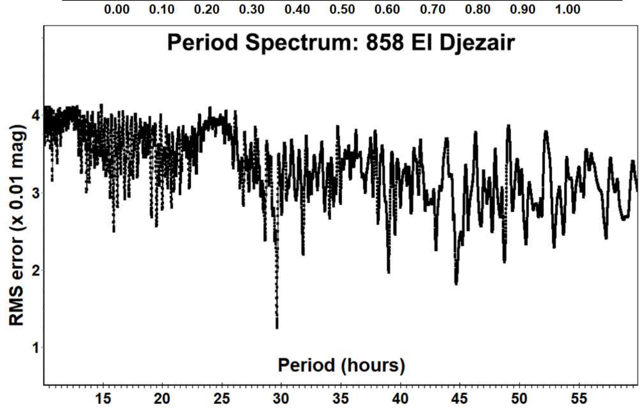


764 Gedania. This outer main-belt asteroid was found to have period of 24.984 ± 0.002 h and low amplitude of 0.07 magnitudes, confirming most known previous reports (24.9751 h, Behrend, 2006web; 24.817 h, Brinsfield, 2010; 24.97 h, Behrend, 2021web; 24.968 h, Pilcher, 2021a) but differing from two others (19.16 h, Aznar Macias et al., 2016; 25.1172 h, Pál et al., 2020). Fourier fit RMS error is 6 mmag.



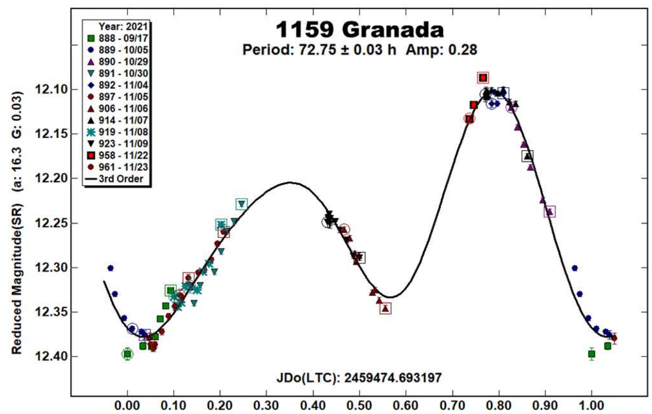
858 El Djezair. Four different periods have been reported for this outer main-belt asteroid (22.31 h, Warner, 2005; 19 h, Behrend, 2007web; 14.83 h, Polakis, 2019; 33.525 h, Colazo et al., 2021b), all with LCDB uncertainty scores of 2. We find ourselves reporting yet a fifth distinct synodic period of 29.639 ± 0.003 h, based on data taken over 12 nights. Our Fourier fit RMS error is 13 mmag. We can find no obvious aliases between our result and any of the four previous reports. The period spectrum is inconsistent with the four previous period reports.



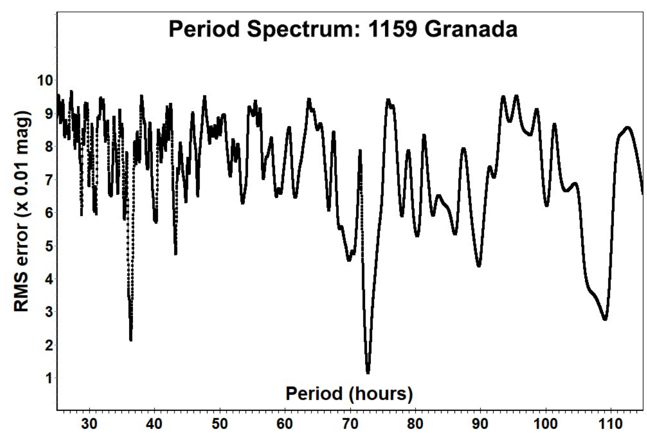


1159 Granada. All three previous period reports for this inner main-belt asteroid have LCDB uncertainty code of 2, and all differ (31 h, Binzel, 1987; 72.852 h, Waszczak et al., 2015; 77.28 h, Behrend, 2020web). We confirm the Waszczak et al. report with our period estimate of 72.75 ± 0.03 h. Fourier fit RMS error is 11 mmag.

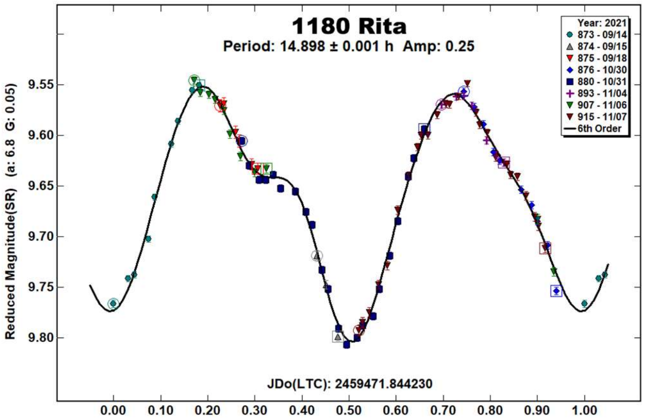
Phase coverage is incomplete as the period is very near 3 days; for a given time of night, the phase shifts by only about 0.1 period per month. This asteroid's orbit eccentricity and inclination are modest, so it will never appear at very high or low declinations. Full phase coverage within one apparition will very likely require multi-longitude observations.



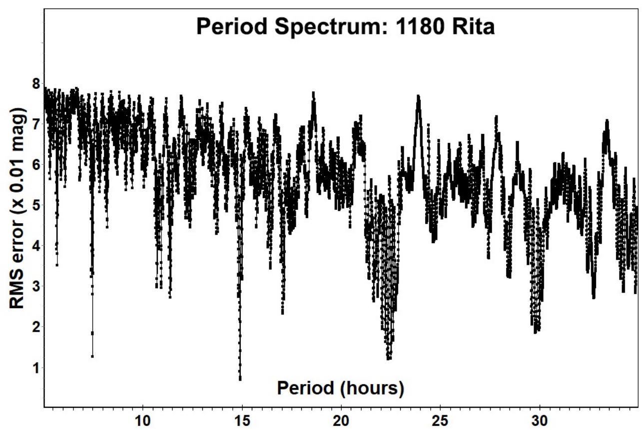
To compensate for incomplete phase coverage, we undertook twelve nights of extended-duration observations to get phase-overlapping results in the phase ranges that were available. The resulting period spectrum disfavors other solutions, including the previously reported periods of 31 h and 77.28 hours. Our second-best solution, near 36 hours, is simply the half-period, monomodal solution.



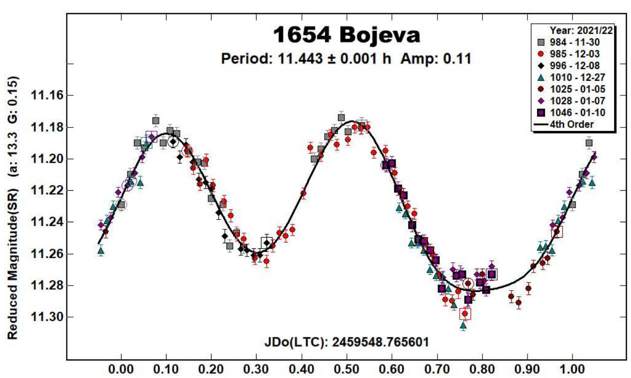
1180 Rita. This heavily studied Hilda-family asteroid was found to have period of 14.898 ± 0.001 hours. The best rotational period has been contentious, with many known reports close to our result (14.902 h, Dahlgren et al., 1998; 14.9 h, Behrend, 2006web; 14.928 h and 14.849 h, Warner and Stephens, 2018; 14.901 h, Behrend, 2020web; 14.8978 h, Ďurech et al., 2020), but others differing (14.72 h, Gonano et al., 1991; 9 h, Binzel and Sauter, 1992; 9.605 h, Polishook, 2012; 20.496 h, Slyusarev et al., 2012; 13.09 h, Warner and Stephens, 2017a; 29.78 h, Colazo et al., 2021a).



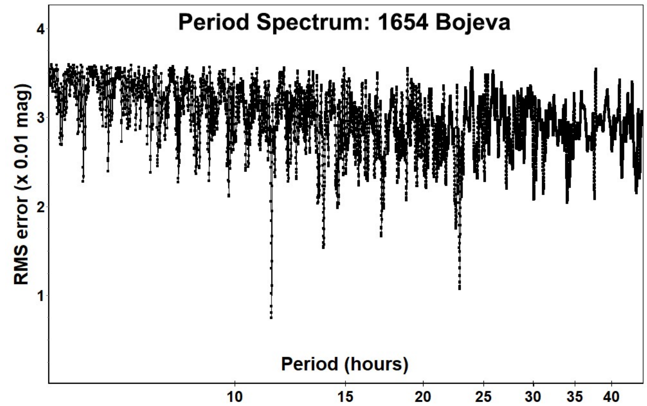
Our period spectrum contains signals at the half-, three-halves, and double durations, but it disfavors other credible candidates, including those near 9, 9.6, and 20 h. The previously reported 29.78 h is very near to twice our result.



1654 Bojeva. Known period reports for this Eos-family asteroid all differ (10.5559 h, Hayes-Gehrke et al., 2016; 11.44411 h, Ďurech et al., 2020; 25.4837 h, Pál et al., 2020). We find a synodic period of 11.443 ± 0.001 h, with a Fourier fit RMS error of 7 millimagnitudes and *G* very close to the MPC-default value of 0.15. Our lightcurve is clearly bimodal.

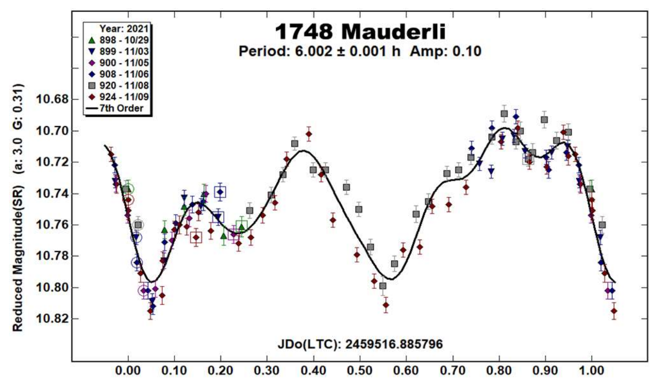


Our period spectrum disfavors periods near 10.6 or 25.5 hours, and these are not accounted for by multiples or by discernable aliasing from our value. The secondary signal seen near 23 h is twice our bimodal period.



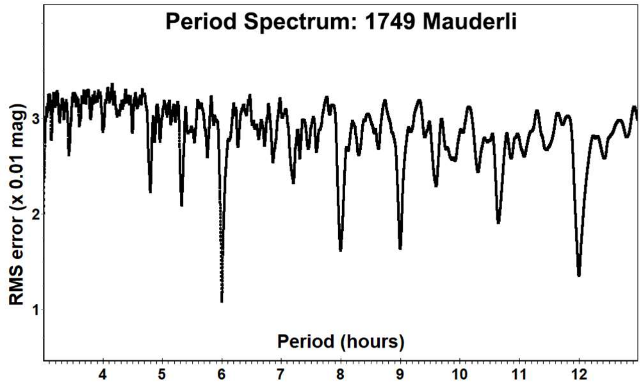
1748 Mauderli. This heavily studied Hilda has developed an increasing consensus for period very near 6 hours. Known reports are numerous (6 h, Gonano et al., 1991; 6 h, Dahlgren et al., 1998; 6.001 h, Slyusarev et al., 2012; 5.552 h, Warner and Stephens, 2017b; 5.32 and 5.551 h, Warner and Stephens, 2018; 6.012 h, Behrend, 2020web; 6.008 h, Romanishin, 2020; 6.003 h, Romanishin, 2021).

We add to the consensus with our new estimate of 6.002 ± 0.001 h. Our Fourier fit RMS error is 7 millimagnitudes; our *G* estimate of 0.31 is uncertain due to a narrow range of phase angles.

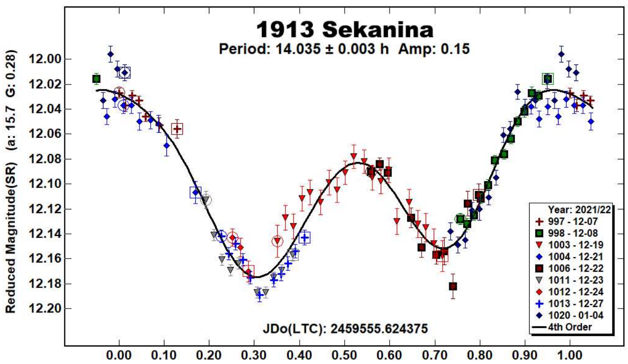


Periods near 6 hours can make for precarious period extraction due to potential cycle-counting errors and resulting aliasing, and indeed our period spectrum shows a minor alias solution near 8 hours (one cycle difference per 24 hours), as well as three-halves and double solutions near 9 and 12 hours. However, our results disfavor previously reported solutions near 5.3 and 5.55 hours.

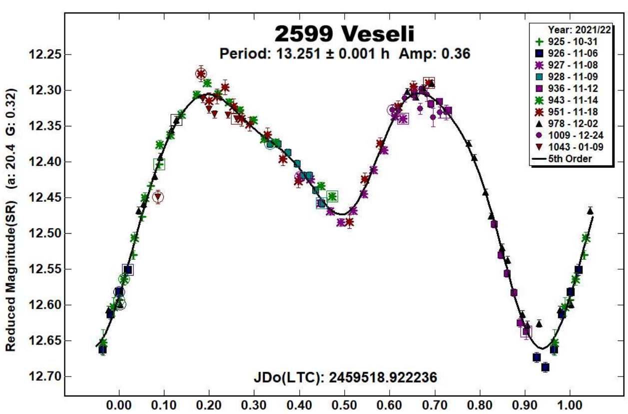
Our lightcurve contains a remarkably sharp minimum near our phase 0.05, but shows no evidence of this asteroid's being a non-synchronous or contact binary (Romanishin, 2020).

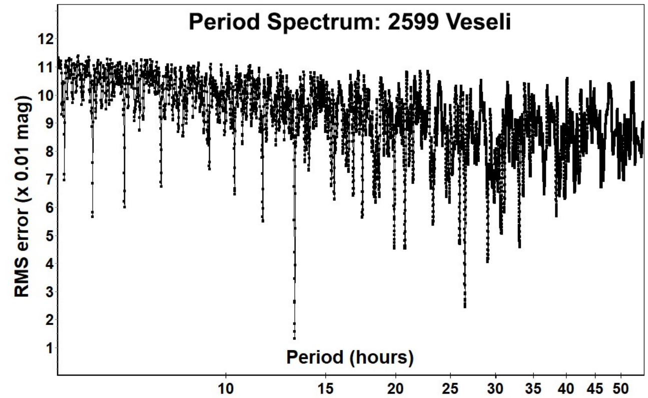


1913 Sekanina. We confirm four survey reports of synodic period (13.97 h, Chang et al., 2014; 13.985 h, Waczszak et al., 2015; 14.0313 h, Ďurech et al., 2020; 14.031 h; Erasmus et al., 2020) for this Koronis-family asteroid with our lightcurve and period estimate of 14.035 ± 0.003 h. The lightcurve is bimodal, and Fourier fit RMS error is 12 mmag.

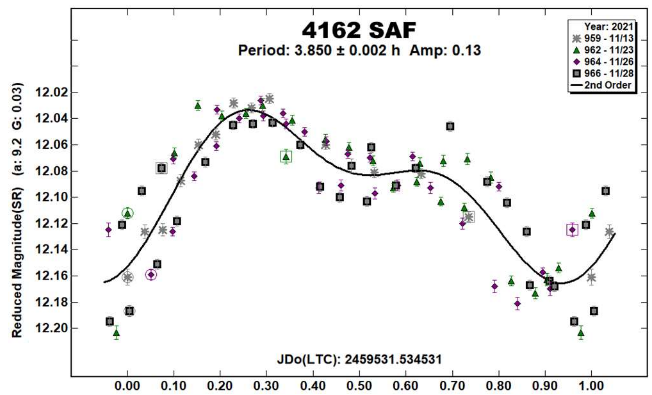


2599 Veseli. The sole known lightcurve report (Bolt and Bembrick, 2007) for this main-belt asteroid offered two period interpretations: 18.54 h, and 13.25 h which the authors preferred. These two offered periods are aliases of each other by ½ (bimodal) period per 24 hours. From 10 nights' observations, we find a period of 13.251 ± 0.001 h. Fourier fit RMS error is 13 mmag. Our period spectrum disfavors a 18.54 h period.

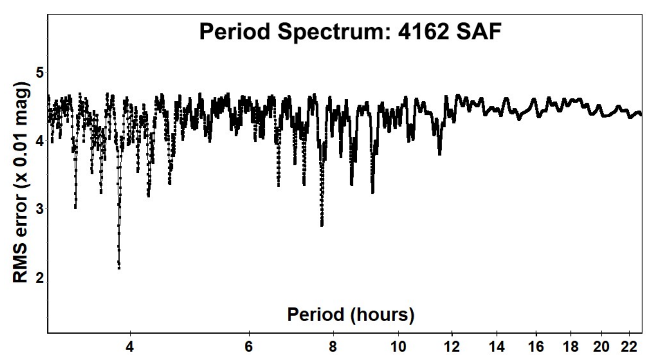




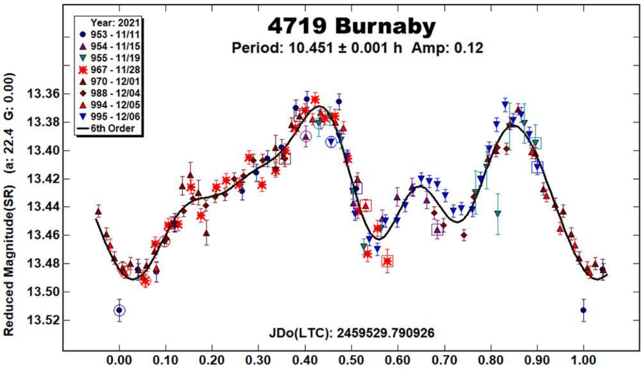
4162 SAF. For this outer main-belt asteroid, we know of only two reports of a rotational period (7.5 h, Behrend, 2002web; 15.2195 h, Pál et al., 2020), and both carry a LCDB uncertainty score of 2. We find a period of 3.850 ± 0.002 h on a monomodal basis. Fourier fit RMS error is 21 mmag. *G* value estimate of 0.03 is uncertain due to narrow phase angle range.



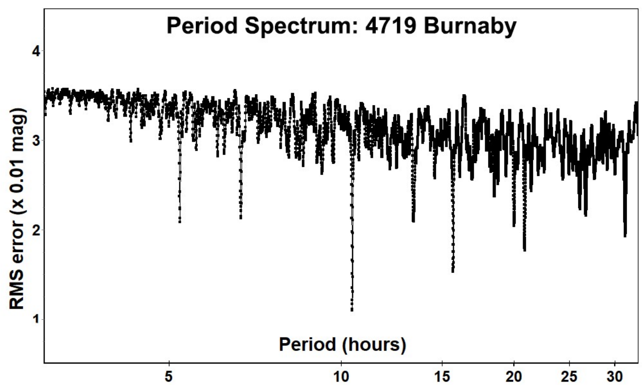
The period spectrum strongly disfavors period candidates near 15 hours, and neither it nor split-halves plots favor a bimodal lightcurve (period 7.7 hours) over the monomodal solution proposed here, though either interpretation is possible. To be certain which is correct may require lightcurve campaigns at various viewing aspects.



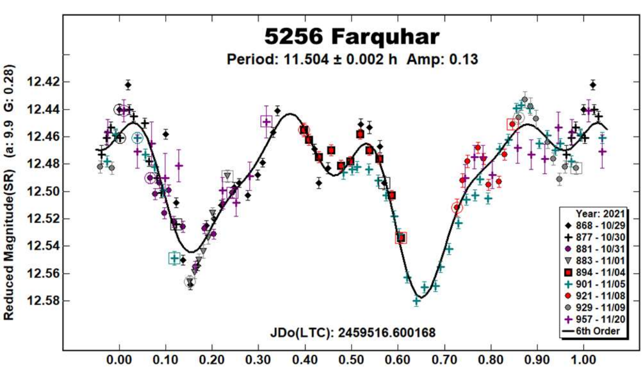
4719 Burnaby. For this asteroid of undetermined class, we find a period of 10.451 ± 0.001 h, differing from two previous reports (8.2 h, Behrend, 2009web; 13.01 h, Warner, 2013). The lightcurve is distinctly bimodal with secondary features just after each minimum. Fourier fit RMS error is 11 mmag.



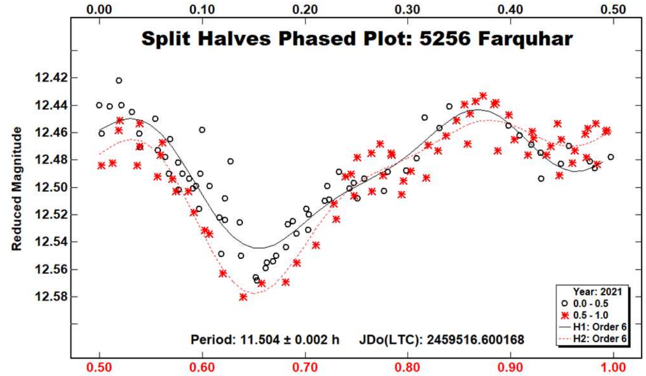
The period spectrum constructed from our data does not support either previously reported period. The 13.01 h reported period is fairly close to an alias of ½ period per 24 hours from our proposed period, and a minor signal near 13 h does appear in our spectrum.



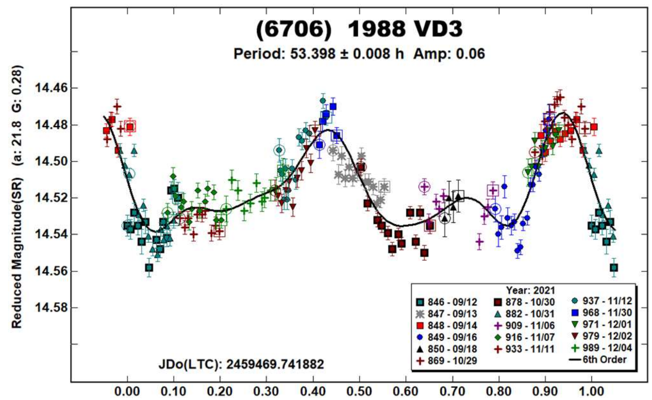
5256 Farquhar. For this Eunomia-family asteroid, we find a period of 11.504 ± 0.002 h, agreeing with one previous report (11.513 h, Odden et al., 2014) but differing from another (16.2215 h, Pál et al., 2020). Fourier fit RMS error is 14 mmag.



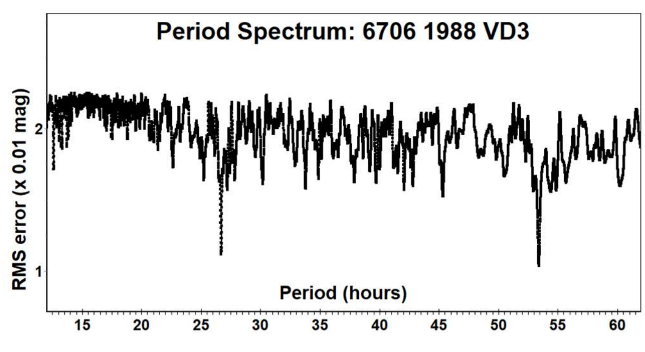
From the present data, neither the lightcurve's shape nor a split-halves plot leads us to prefer unequivocally a bimodal or monomodal solution. Based on the split-halves plot, we adopt the bimodal solution, though monomodal remains a possibility. The period's proximity to 12 (or 6) hours suggests a multi-longitude observation campaign to ensure continuous coverage through a duration of one bimodal period.



(6706) 1988 VD3. For this relatively faint inner main-belt asteroid, we find a period of 53.398 ± 0.008 h, which is close to twice that of the sole known report (27.021 h; Waszczak et al., 2015). Fourier fit RMS error is 10 mmag.



Despite being built from 16 nights of data with low Fourier fit error, our lightcurve shape, period spectrum, and split-halves plot all fail to indicate a clear preference between monomodal and bimodal solutions. Only the small, secondary maximum shapes (near our phases 0.15 and 0.70) differ enough to recommend the bimodal solution, which we adopt here.



Acknowledgements

The author thanks all authors of the ATLAS paper (Tonry et al, 2018) and its numerous contributors for providing without cost the ATLAS refcat2 catalog release. This project makes extensive use of the python language interpreter and of several supporting packages (notably: pandas, ephem, matplotlib, requests, astropy, and statsmodels), all provided without cost.

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