

LIGHTCURVES OF TWELVE ASTEROIDS

Eric V. Dose
3167 San Mateo Blvd NE #329
Albuquerque, NM 87110
mp@ericdose.com

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We present lightcurves, synodic rotation periods, and G value (H-G) estimates for twelve asteroids, obtained by applying dozens of comparison stars from the ATLAS refcat2 catalog to each working image.

We present asteroid lightcurve photometry results obtained by following the workflow process described by Dose (2020a), with later improvements (Dose, 2020b). 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 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, 2018) 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 $G = 0.15$ for each asteroid unless otherwise specified.

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.

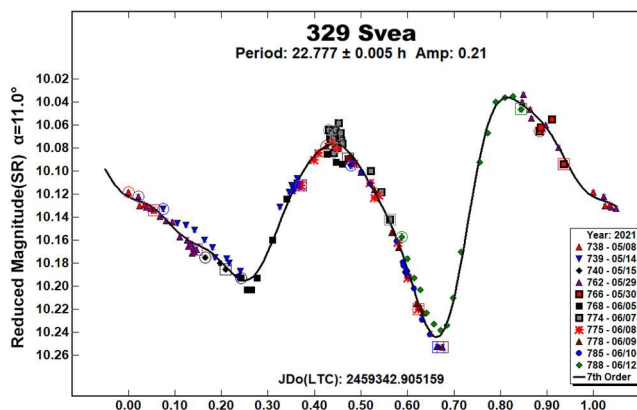
Lightcurve Results

Twelve 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; a 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 version 8.3 (DC-3 Dreams), running plan files generated for each night by the author’s python scripts (Dose, 2020a). Observations often cycled between 2-4 asteroids. Exposure times targeted 5-8 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.

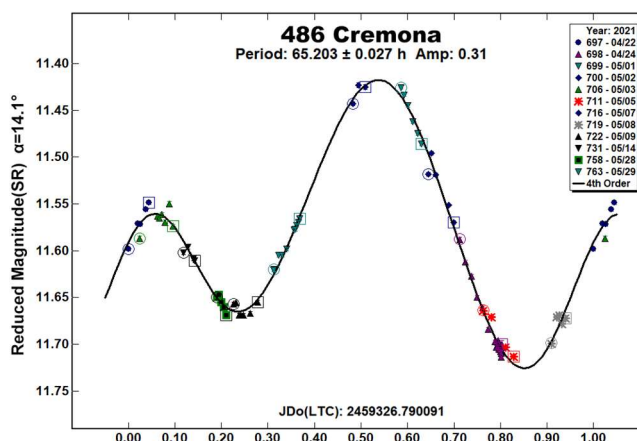
FITS images were plate-solved by *PinPoint* (DC-3 Dreams) or *TheSkyX* (Software Bisque) and were calibrated using temperature-matched, median-averaged dark images and recent flat images of a flux-adjustable flat panel. Every photometric image was visually inspected; all images with poor tracking, obvious interference by cloud or moon, or having stars or other 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, and “SR” denotes the Sloan r’ passband.

329 Svea. This bright inner main-belt asteroid was found to have a period of 22.777 ± 0.005 hours, in agreement with several previous reports (22.770 h, Behrend, 2006web; 22.6 h, Menke et al., 2008; 22.778 h, Marciniak et al., 2015; and 22.777 h, Marciniak et al. 2018) and consistent with another (>12 h, Behrend, 2017web), but differing from two reports (15 h, Weidenschilling et al., 1990; 15.201 h, Pray, 2006). Fourier fit to the present data has RMS error of 7 millimagnitudes and indicates a G value (H-G phase model) close to 0.20.



486 Cremona. This inner main-belt asteroid was found to have a period of 65.203 ± 0.027 h, in general agreement with most previous reports (65.90 h, Warner, 2006; 65.15 h, Cooney Jr. et al., 2007; 65.151 h, Hanuš et al., 2011; 65.178 h, McNeill et al., 2019; 65.0918 h, Pál et al., 2020), but differing from one early report (77.5 h, Behrend, 2006web). Fourier fit to the present data has RMS error of 7 millimagnitudes and indicates a G value close to 0.18.

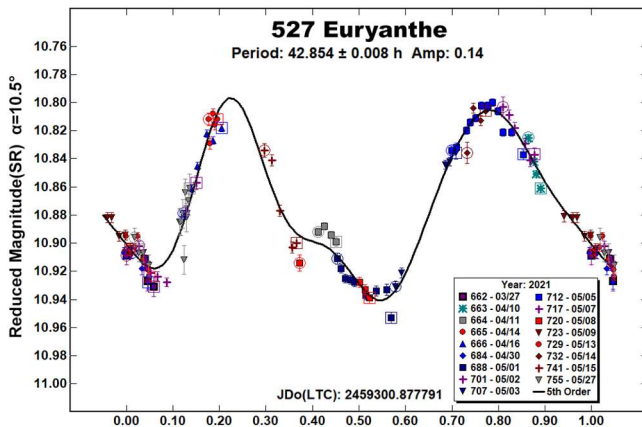


527 Euryanthe. This asteroid of unknown family was found to have a period 42.854 ± 0.008 h, agreeing at least generally with several recent reports (42.986 h, Polakis and Skiff, 2019; 42.9 h, Behrend, 2020web; 42.93 h, Pilcher, 2020; 43.40 h, Polakis, 2020; 42.3819 h, Pál et al., 2020; 42.75 h, Pilcher, 2021), but differing from one earlier report (26.06 h, Brinsfield, 2010). Our Fourier fit has RMS error of 9 millimagnitudes and indicates a G value close to 0.09.

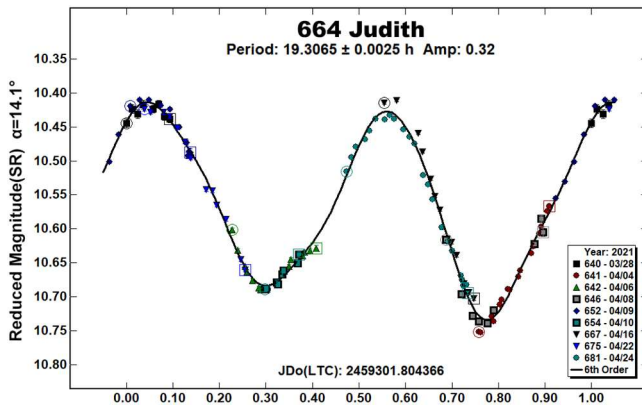
When adjusted for differing starting phases, the present lightcurve closely resembles the more complete lightcurve of (Pilcher, 2021), taken near the same date. They match especially in that the two minima appear to differ in shape; both lightcurves support a bimodal interpretation.

Number	Name	yyyy mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
329	Svea	2021 05/09–06/12	*10.9, 13.8	240	19	22.777	0.005	0.21	0.02	MB-I
486	Cremona	2021 04/22–05/29	*14.3, 11.8	231	12	65.203	0.027	0.31	0.02	MB-I
527	Euryanthe	2021 03/27–05/27	*10.6, 14.6	210	12	42.854	0.008	0.14	0.02	UNK
664	Judith	2021 03/28–04/24	13.9, 5.4	221	8	19.306	0.002	0.32	0.02	UNK
1056	Azalea	2021 03/23–05/03	*5.8, 15.9	191	7	15.032	0.002	0.53	0.04	FLOR
1118	Hanskya	2020–21 12/22–03/08	4.4, 17.1	90	11	25.310	0.002	0.29	0.04	MB-O
1428	Mombasa	2021 05/05–06/10	*7.6, 13.6	224	20	25.621	0.004	0.16	0.03	MB-O
1504	Lappeenranta	2021 04/11–05/30	*15.3, 11.7	228	11	15.187	0.002	0.18	0.02	MB-I
1886	Lowell	2021 03/27–06/12	*13.9, 19.7	215	14	157.872	0.074	0.72	0.10	EUN
2261	Keeler	2021 03/23–05/01	*23.4, 25.7	195	34	22.813	0.004	0.10	0.02	PHO
4107	Rufino	2021 03/29–05/09	17.4, 25.1	158	8	22.371	0.004	0.15	0.05	MB-I
5551	Glikson	2021 03/20–04/19	20.9, 23.8	184	33	148.352	0.144	0.82	0.10	PHO

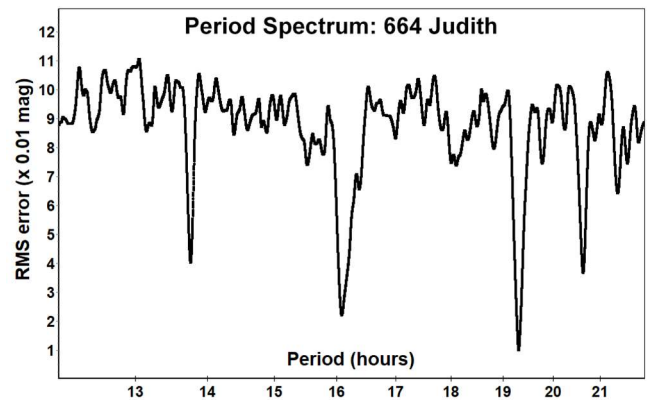
Table I. Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extrema during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984).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



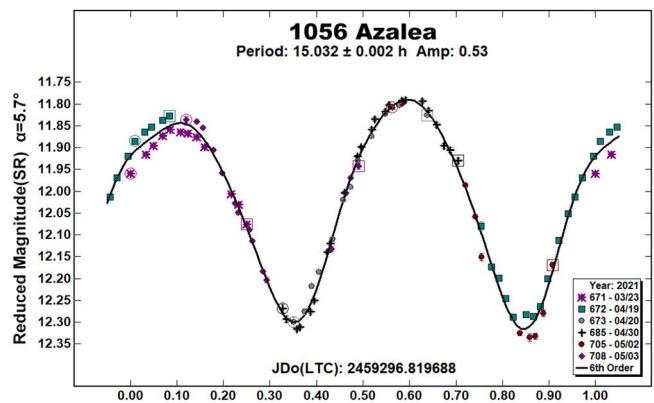
664 Judith. This asteroid of unknown family was found to have a period of 19.3065 ± 0.0025 h, in fair agreement with two previous reports (19.35 h, Melton et al., 2012; 19.3709 h, Pál et al., 2020) and consistent with another (>12 h, Behrend, 2009web), but differing from several others (10.76 h, Degraff et al., 1998; 13.764 h, Behrend, 2010web; 10.6829 h, Hosek et al., 2011; and 18.51 h, Garcerán et al., 2015).



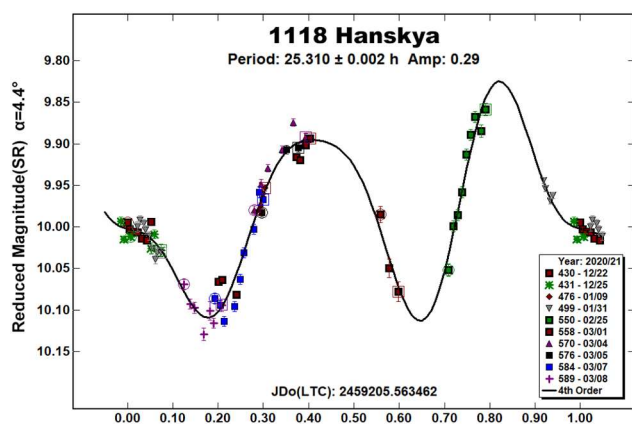
The previously reported period of 10.6829 h is an alias by exactly 1 period per 24 hours of our 19.3065 h; the previously reported 13.764 h is similarly an alias by exactly $\frac{1}{2}$ period per 24 hours. Fourier fit to the present data has RMS error of 10 millimagnitudes and indicates a G value close to 0.07.



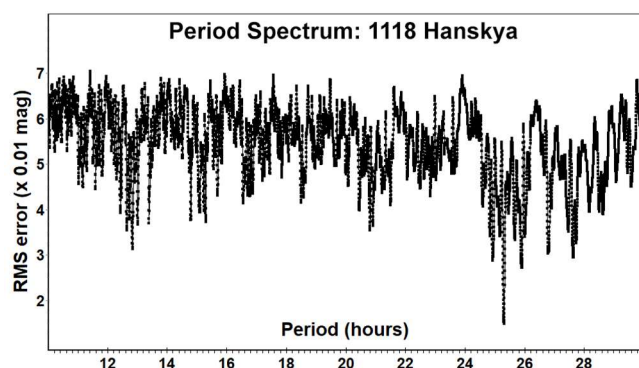
1056 Azalea. This Flora asteroid was found to have a period of 15.032 ± 0.002 h, agreeing with previous reports (15.15 h, Behrend, 2004web; 15.03 h, Kryszczyńska et al., 2012; 15.0276 h, Hanuš et al., 2013; 15.034 h, Erasmus et al., 2020). Fourier fit to the present data has RMS error of 18 millimagnitudes and indicates a G value close to 0.30.



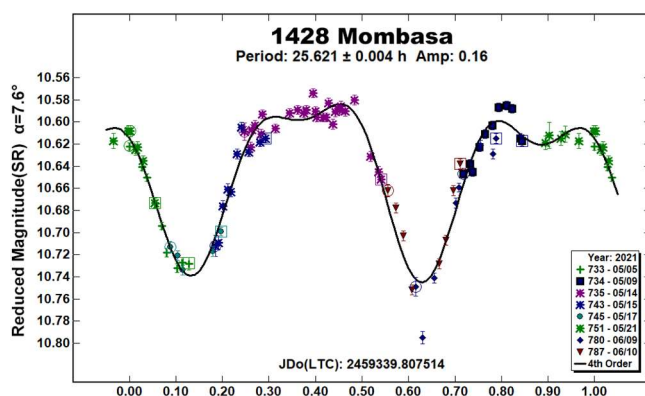
1118 Hanskya. This outer main-belt asteroid was found to have a period of 25.310 ± 0.002 h, differing from one early report (15.61 h, Robinson, 2002) but agreeing with all other period reports found (25.31 h, Behrend, 2007web; 25.348 h, Waszczak et al., 2015; 25.38 h, Dittion and Young, 2018; 25.305 h, Ďurech and Hanuš, 2018). Fourier fit to the present data has RMS error of 15 millimagnitudes and indicates a G value close to 0.12.



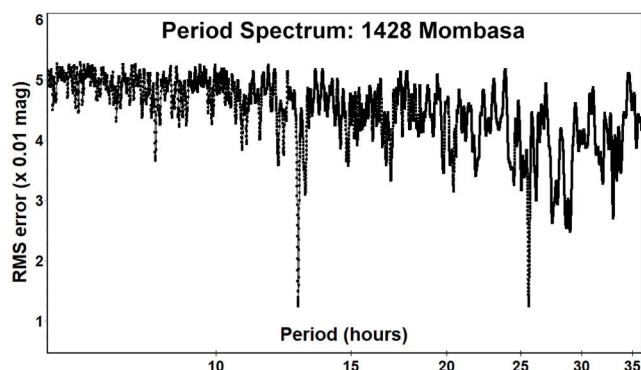
Despite sparser than ideal phase coverage within the current lightcurve, the 11 weeks' observing span and the resulting period spectrum strongly support the proposed period.



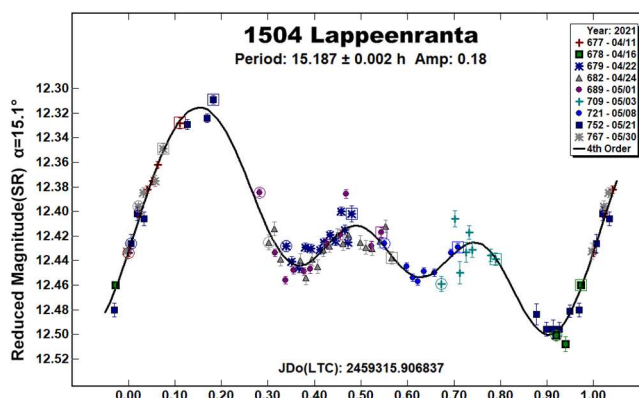
1428 Mombasa. This outer main-belt asteroid was found to have a period of 25.621 ± 0.004 h, agreeing only with one recent survey estimate (25.646 h, Pál et al., 2020), and differing from all three other reports known (17.6 h, Behrend, 2006web; 17.12 h, Hawkins and Ditteon, 2008; and 16.67 h, Stephens, 2012web). Fourier fit to the present data has RMS error of 12 millimagnitudes and indicates a G value close to 0.10.



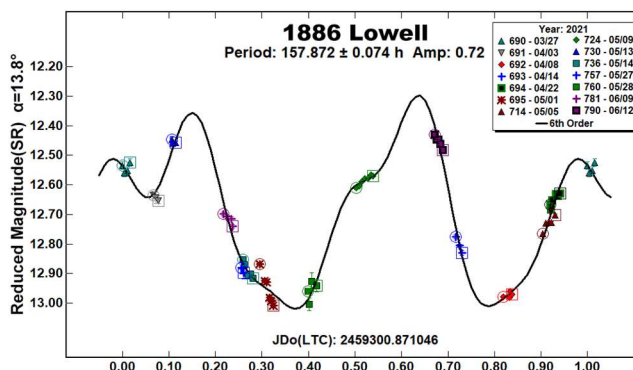
We note that a period estimate of 16.67 h is almost exactly an alias, by $\frac{1}{2}$ period per 24 hours, of our proposed period. Period candidates in the 16-18 h range are essentially absent from our period spectrum.



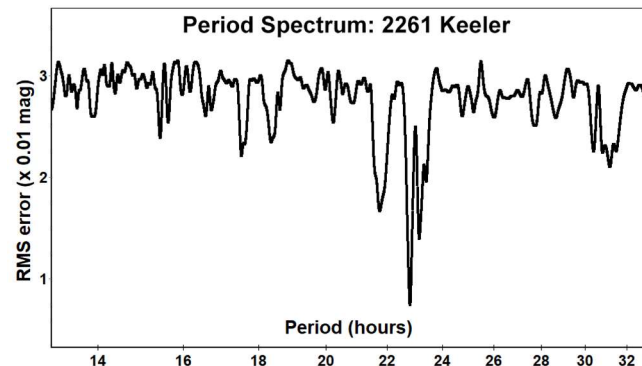
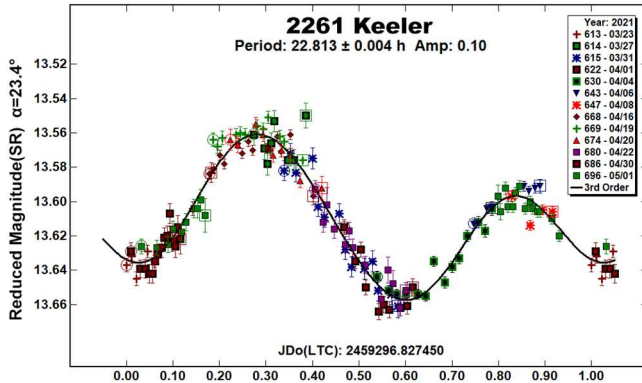
1504 Lappeenranta. This inner main-belt asteroid was found to have a period of 15.187 ± 0.002 h, agreeing with four recent reports (15.190 h, Garlitz, 2013web; 15.16 h, Polakis and Skiff, 2017; 15.18 h, Ditteon et al., 2019; 15.2385 h, Pál et al., 2020), but differing from three earlier reports (10.44 h, Binzel, 1987; 8 h, Behrend, 2002web; 8 h Behrend, 2006web). We find no evidence favoring a bimodal lightcurve shape (period ca. 30.4 h) over the proposed monomodal lightcurve shape, which is dominated by the sharp brightening from phase 0.9 to 0.15 (see phase plot). Fourier fit to the present data has RMS error of 10 millimagnitudes and yields G value close to 0.32.



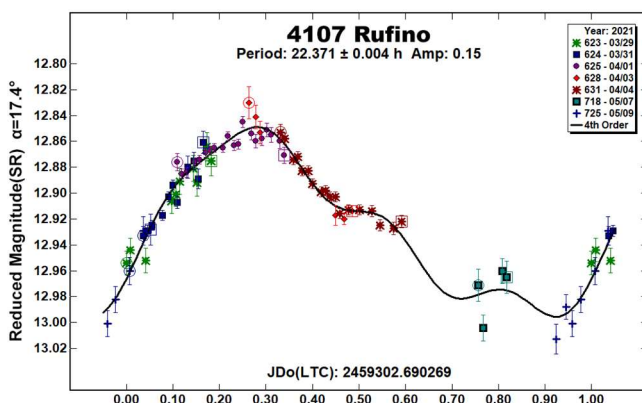
1886 Lowell. This Eunomia-family asteroid was found to have a period 157.872 ± 0.074 h. The lightcurve shape is bimodal, and is roughly twice the only known previous period report, a survey result (80.1898 h, Pál et al., 2020). The very high amplitude of the present lightcurve does not support a monomodal interpretation (Harris et al., 2014), and the two minima differ in shape, as well. Fourier fit to the present data has RMS error of 28 millimagnitudes and indicates a G value close to 0.45.



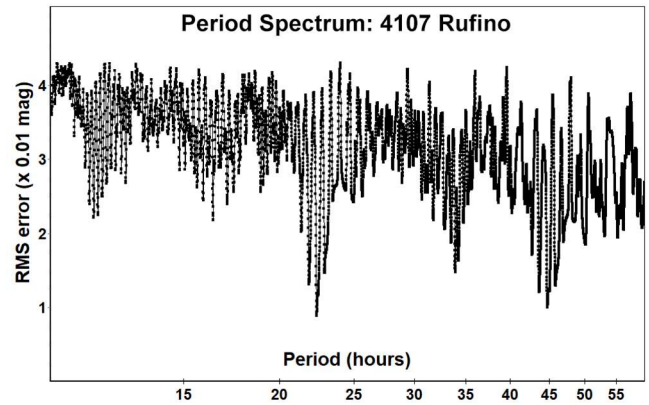
2261 Keeler. This Phocaea asteroid was found to have a period of 22.813 ± 0.004 h, agreeing approximately with both known previous reports (22.810 h, Warner et al., 2011; 22.7596 h, Pál et al., 2020). The lightcurve is clearly bimodal and appears to rule out the monomodal alternative interpretation mentioned by Warner et al (2011). Fourier fit to the present data has RMS error of 7 millimagnitudes, and though the observations' phase angle range is narrow, the best fits indicate a remarkable G value close to 1.05.



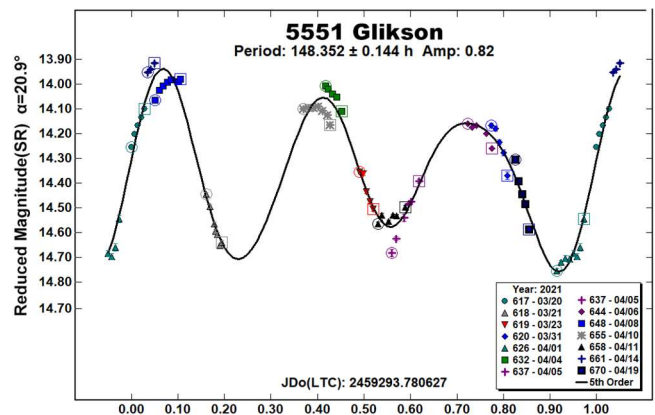
4107 Rufino. This inner main-belt asteroid was found to have a period of 22.371 ± 0.004 h, agreeing with one survey report of 22.352 h (Waszczak et al., 2015) but differing from a report of 15.31 h (Behrend, 2017 web) which appears to be an alias by $\frac{1}{2}$ rotation per 24 hours from our result. Fourier fit to the present data has RMS error of 9 millimagnitudes and indicates a G value close to 0.20.



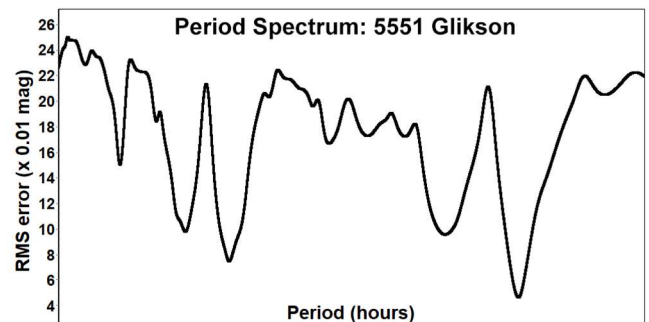
Our lightcurve suffers incomplete phase coverage, but with 7 nights' observations the period spectrum supports the proposed period, certainly in preference to candidate periods of 15-16 h.



5551 Glikson. This Phocaea asteroid was found to have a period of 148.352 ± 0.144 h, differing from the sole known previous period report of 91.43 h (Pravec et al., 2014web). The lightcurve shape is trimodal and suggests some tumbling effect. Fourier fit to the present data has RMS error of 46 millimagnitudes and indicates a G value close to 0.60.



The previously reported period of 91.43 h and the $\frac{2}{3}$ (bimodal) candidate period of ca. 99 h appear as minor signals in the period spectrum. But from our 14 nights' observations, the trimodal period proposed here emerges as a superior fit to the observations.



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The author thanks all authors of the ATLAS paper (Tonry et al, 2018) and numerous contributors for providing without cost the ATLAS refcat2 release catalog and its technical descriptions. 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, and without which this work would have been infeasible.

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MAIN-BELT ASTEROIDS OBSERVED FROM CS3: 2021 APRIL-MAY

Robert D. Stephens

Center for Solar System Studies (CS3) / MoreData!
11355 Mount Johnson Ct., Rancho Cucamonga, CA 91737 USA
rstephens@foxandstephens.com

Daniel R. Coley

Center for Solar System Studies (CS3)
Corona, CA

Brian D. Warner

Center for Solar System Studies (CS3) / MoreData!
Eaton, CO

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CCD photometric observations of 11 main-belt asteroids were obtained at the Center for Solar System Studies (CS3) from 2021 April-May. In addition, recovered data from 2019 allowed finding lightcurve parameters for 1413 Roucarie. New pole/shape modeling results are presented for 323 Brucia and 1106 Cydonia. The recovered data for 1413 Roucarie did not have an effect on a previously published shape model.

The Center for Solar System Studies (CS3) has nine telescopes which are normally used in program asteroid family studies. The focus is on near-Earth asteroids, but when suitable targets are not available, Jovian Trojans and Hildas are observed. When a nearly full moon is too close to the family targets being studied, targets of opportunity amongst the main-belt families were selected.

Table I lists the telescopes and CCD cameras that were used to make the observations. Images were unbinned with no filter and had master flats and darks applied. The exposures depended upon various factors including magnitude of the target, sky motion, and Moon illumination.

Telescope	Camera
0.30-m f/6.3 Schmidt-Cass	SBIG 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.35-m f/10 Schmidt-Cass	SBIG 1001E
0.35-m f/10 Schmidt-Cass	FLI Proline 1001E
0.40-m f/10 Schmidt-Cass	FLI Proline 1001E
0.40-m f/10 Schmidt-Cass	FLI Proline 1001E
0.50-m F8.1 R-C	FLI Proline 1001E

Table I: List of CS3 telescope/CCD camera combinations.

Image processing, measurement, and period analysis were done using *MPO Canopus* (Bdw Publishing), which incorporates the Fourier analysis algorithm (FALC) developed by Harris (Harris et al., 1989). For the images reduced in 2021, the Comp Star Selector feature in *MPO Canopus* was used to limit the comparison stars to near solar color. Night-to-night calibration was done using field stars from the ATLAS catalog (Tonry et al., 2018), which has Sloan *griz* magnitudes that were derived from the GAIA and Pan-STARR catalogs and are "native" magnitudes of the catalog. Those adjustments are usually $\leq \pm 0.03$ mag. The rare greater corrections may have been related in part to using unfiltered observations, poor centroiding of the reference stars, and not correcting for second-order extinction.