LIGHTCURVES OF FOURTEEN ASTEROIDS

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By applying dozens of comparison stars from the ATLAS refcat2 catalog to each working image, we have obtained lightcurves and synodic rotation periods for fourteen asteroids.

We present asteroid lightcurve photometry results achieved by following the workflow process described by Dose (2020a), with later improvements (Dose, 2020b). This workflow applies to each image an ensemble of typically 30-150 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 present 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). All lightcurve data herein have been submitted to ALCDEF.

Lightcurve Results

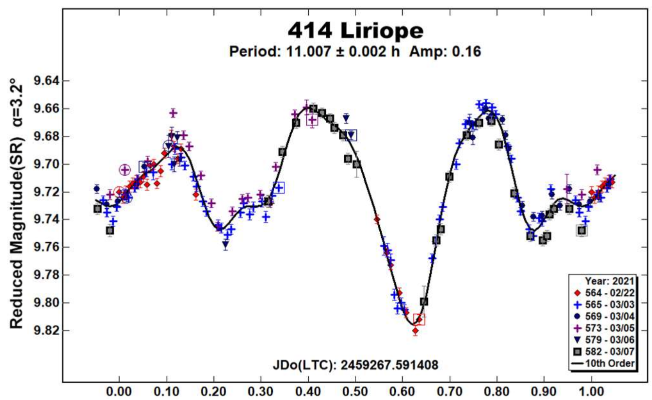
Fourteen asteroids were observed from Deep Sky West observatory (IAU V28) at 2210 meters elevation in northern New Mexico. Images were acquired with a 0.35-meter SCT reduced to f/7.7; a SBIG STXL-6303E camera cooled to -35C and fitted with a Clear filter (Astrodon); and a PlaneWave L-500 direct-drive mount. The equipment was operated remotely via ACP software version 8.3 (DC-3 Dreams), running plan text 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 maximum of 900 seconds and a minimum of 90 seconds to ensure suitable comp-star photometry. 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, "SR" denotes the Sloan r' passband, and errors are given in parentheses after the value and are in units of the last decimal place.

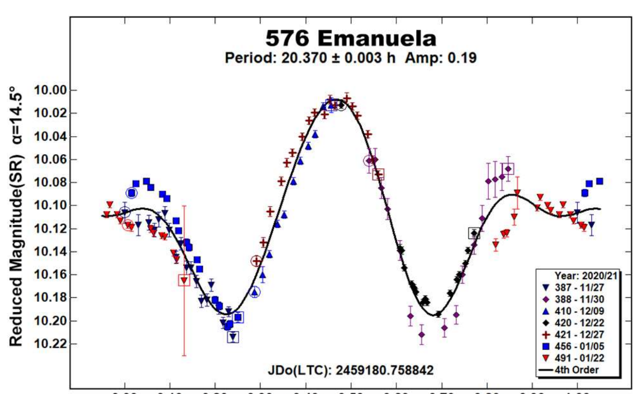
<u>414 Liriope</u>. This bright outer main-belt asteroid was found to have period 11.007(2) hours, differing from one early lightcurve report of 7.353 h (Alvarez, 2012) and two survey reports of 7.38 h (Chang, 2015) and 7.34 h (Waszczak, 2015), but in close agreement with two very recent reports of 11.005 h (Colazo, 2020) and 11.0065 h (Pál, 2020). The candidate periods near 7.36 h are close to 2/3 of 11.007 h, corresponding to bimodal interpretation of this apparently trimodal lightcurve. At the present viewing aspect, we observed a single deep minimum, which reduced aliasing and modal ambiguity.

Our trimodal lightcurve is generally similar in shape to that of (Colazo, 2020), except for being roughly mirrored in time about our phase of 0.62. Fourier fit to the present data has RMS error of 8 millimagnitudes and indicates a G value close to 0.10.



<u>576 Emanuela</u>. This asteroid of undetermined type was found to have period 20.370(3) h, differing from reports of >26 h (Wetterer, 1999), 14 h (Behrend, 2003web), and 14.04 h (Behrend, 2019web), but agreeing reasonably with reports of 20.406 h (as monomodal; Pilcher, 2017), 20.404 h (Pilcher, 2018), and more closely with a very recent report of 20.372 h (Pilcher, 2020). Reports of about 14 h represent an alias of ½ period per 24 hours from ours.

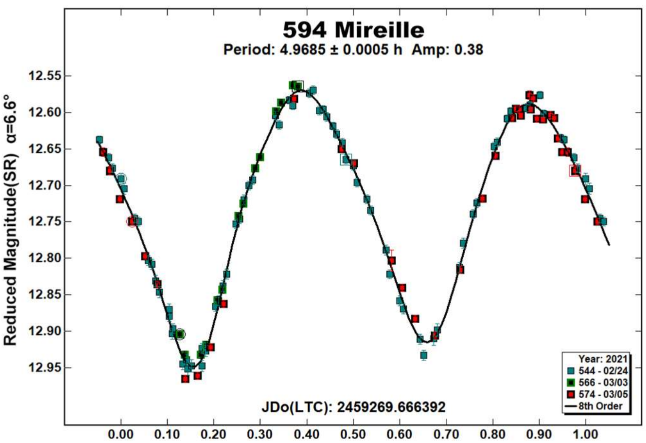
Small but systematic error trends are likely due to the lightcurve amplitude's depending on viewing phase angle (range 1.5-14.5º) (Zappalá, 1990), though a small tumbling effect is possible. Fourier fit to the present data has RMS error of 14 millimagnitudes and indicates a G value close to 0.08.



Number	Name	yyyy mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
414	Liriope	2021 02/22-03/07	3.2,6.9	147	7	11.007	0.002	0.16	0.01	MB-O
576	Emanuela	2020-21 11/27-01/22	*14.5,1.5	118	1	20.370	0.003	0.19	0.03	UKN
594	Mireille	2021 02/24-03/05	*6.8,5.6	164	7	4.968	0.001	0.38	0.02	UKN
768	Struveana	2021 02/11-02/20	8.4,6.9	157	18	10.753	0.001	0.35	0.02	UKN
783	Nora	2020-21 12/01-02/05	*19.0,1.5	134	-3	53.820	0.040	0.13	0.03	MB-I
786	Bredichina	2021 02/22-03/16	*8.2,8.5	164	18	10.753	0.001	0.35	0.02	UKN
983	Gunila	2020-21 12/08-01/22	*13.3,4.9	119	-13	33.385	0.012	0.07	0.01	MB-O
1041	Asta	2021 02/03-03/02	6.4,12.0	131	16	7.978	0.001	0.16	0.02	MB-O
1591	Baize	2021 03/07-04/01	*19,3,18.4	187	34	7.808	0.002	0.04	0.01	PHO
2180	Marjaleena	2021 01/24-03/20	*3.9,15.5	126	-11	7.702	0.001	0.34	0.03	EOS
2288	Karolinum	2021 02/11-03/16	*12.9,10.8	164	19	43.151	0.008	0.27	0.02	UKN
3061	Cook	2020-21 10/22-01/16	*5.8,19.7	42	-3	135.250	0.080	0.44	0.08	UKN
9563	Kitty	2020-21 11/18-01/18	*15.3,15.6	85	-2	5.382	0.001	1.06	0.12	MB-I
16452	Goldfinger	2021 02/08-04/11	*15.0,16.1	169	-2	3.884	0.001	0.19	0.05	V

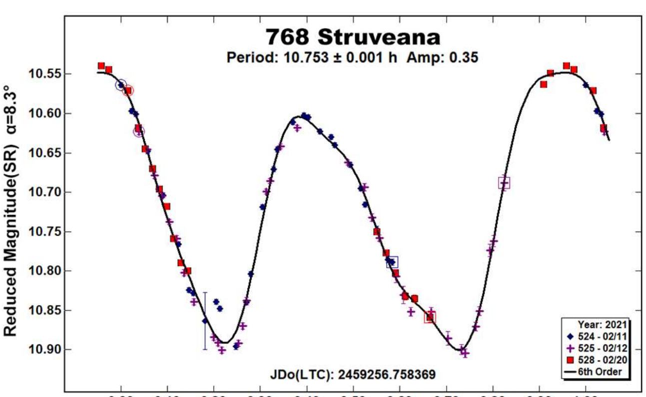
Table I. Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extrema during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984).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

594 Mireille. This high-albedo asteroid of undetermined type was found to have period 4.9685(5) h, in close agreement with previous reports of 4.966 h (Wisniewski, 1991), 4.9671 h (Polakis and Skiff, 2017), and 4.9688 h (Benishek, 2018).

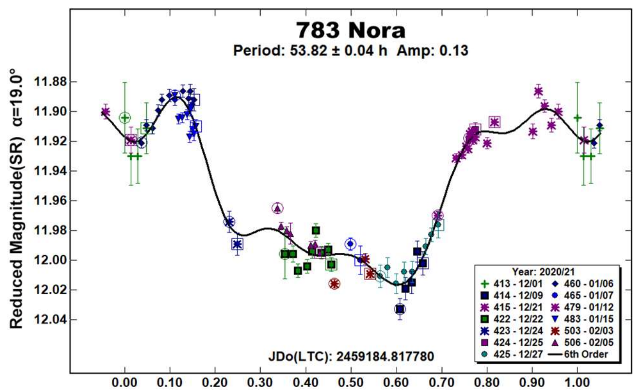


The present lightcurve represents a new viewing angle (phase angle bisector) for this asteroid, in which the two halves of the bimodal lightcurve are more nearly equal than seen before. Best Fourier fit has RMS error of 10 millimagnitudes and indicates G of 0.80.

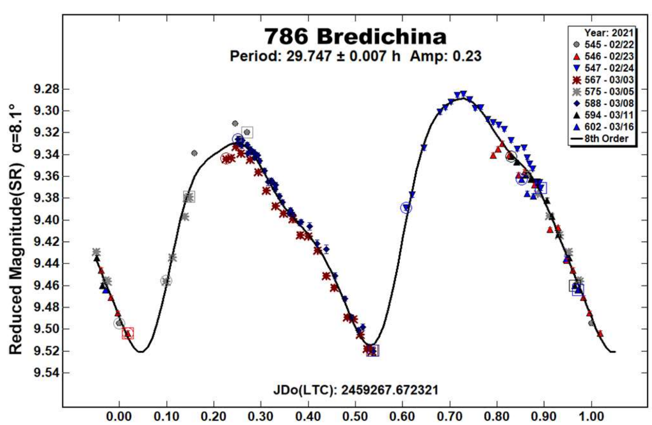
768 Struveana. The present period of 10.753(1) h for this asteroid of undetermined type matches the author's determination of 10.744(6) h (Dose, 2020a), made during its previous apparition. The best present Fourier fit has RMS error of 11 millimagnitudes.



783 Nora. This inner main-belt asteroid is found to have period 53.82(4) h, in reasonable agreement with the previously reported 55.53 h (Polakis, 2018) and 54.22 h (Polakis, 2020), and is consistent with a report of >24 h (Lagerkvist, 1992), but differs from earlier reports of 34.4 h (Florcazk, 1997), and 9.6 h (Behrend, 2007web). The current best Fourier fit has RMS error of 8 millimagnitudes and indicates a *G* value of 0.80.

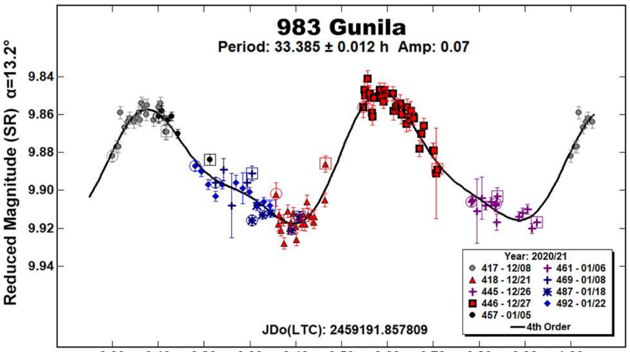


786 Bredichina. This low-albedo asteroid of undetermined type was found to have period 29.747(7) h, in fair agreement with recent reports of 29.434 h (Garcerán, 2015) and 29.8094 h (Pál, 2020), but differing from earlier reports of 18.61 h (Gil-Hutton and Cañada, 2003) and 27.88 h (Behrend, 2010web).

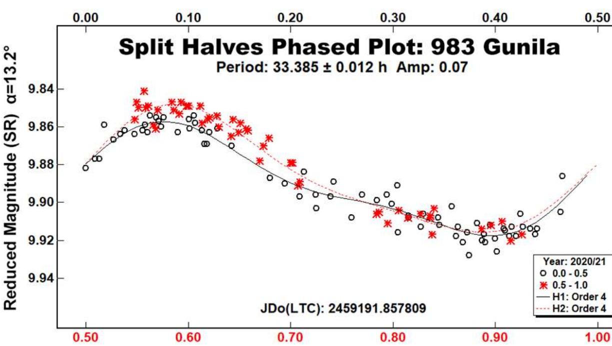


The previously reported 18.61 h is an alias of ½ period per 24 hours from our finding. The best Fourier fit for the present lightcurve has RMS error of 8 millimagnitudes and indicates *G* of roughly 0.80.

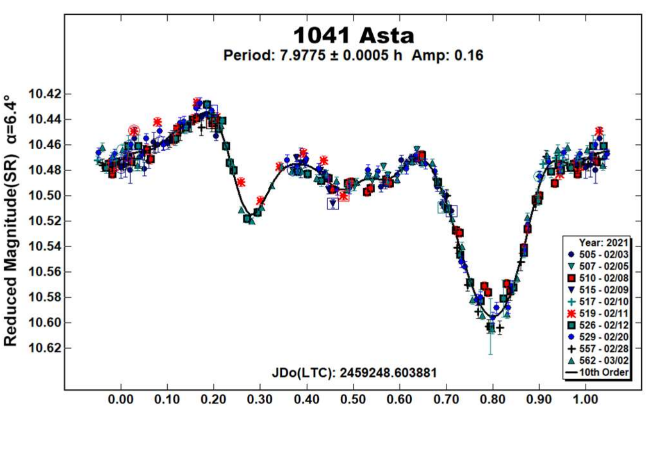
983 Gunila. Lightcurve modality for this outer main-belt asteroid has been difficult to determine with confidence. Using data from three nights, Hayes-Gehrke (2014) found a monomodal period of 8.37 h, and, from data obtainined on six consecutive nights, Polakis (2019) reported a monomodal period of 16.633 h. Our lightcurve results from nine nights' data taken over six weeks and is ambiguous between a bimodal period of 33.385(12) h or a monomodal period of half that. The low amplitude allows for either modality (Harris, 2014). Both fits yield RMS error of close to 5 millimagnitudes.



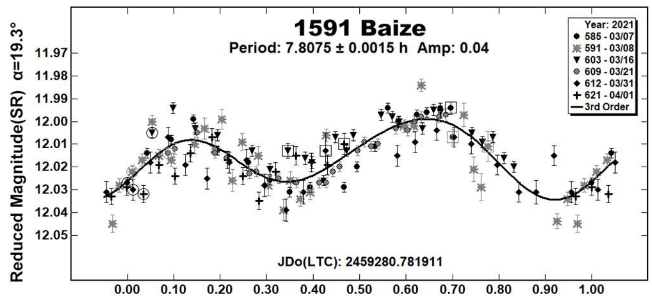
The split-halves phase plot slightly favors the bimodal period of 33.385 h as given in the figures, though the differences between halves are of low significance, being about 2 times the fit RMS error at lightcurve maximum and no perceptible difference at minimum.

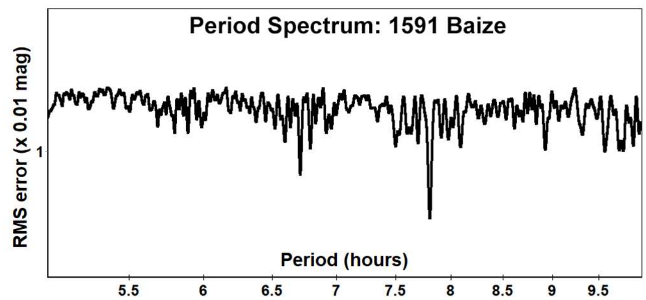


1041 Asta. Our lightcurve for this outer main-belt asteroid is complex and yields a period of 7.9775(5) h, agreeing with a previous report of 7.99 h (Carbo, 2009), but differing from a separate report of 7.554 h (Behrend, 2010web), which is entirely absent from our period spectrum. Our Fourier fit has RMS error of 7 millimagnitudes and indicates *G* value of about 0.03.



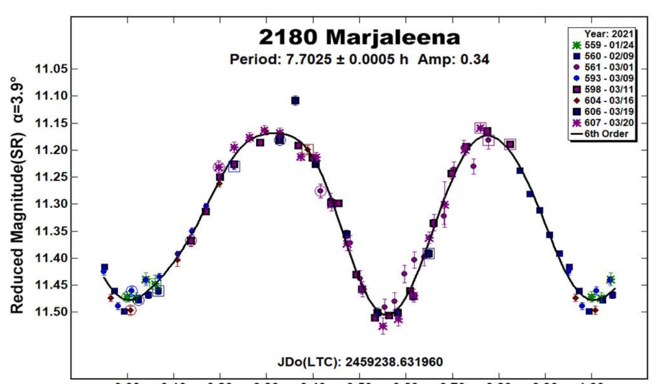
1591 Baize. One goal of our evolving data-reduction program is to improve acquisition of very low-amplitude lightcurves. Our latest such effort resulted in this lightcurve for 1591 Baize, from which we obtained an unambiguous period even with amplitude of 0.04 magnitudes. Our period of 7.808(2) h is comparable to previous reports of 7.78 h (Garlitz, 2013web), 7.788 h (Bentz, 2018) and 7.794 h (Mas, 2018), but differs from an earlier report of 10 h (Barucci, 1994). We found no previous report of amplitude smaller than 0.19 magnitudes, so we may well have observed 1591 Baize from a viewing angle near its pole. Indeed, the very largest magnitude reported to date was determined from a phase angle bisector nearly perpendicular to ours. RMS error of our Fourier fit is 7 millimagnitudes, and *G* values near 0.55 optimize the fit.



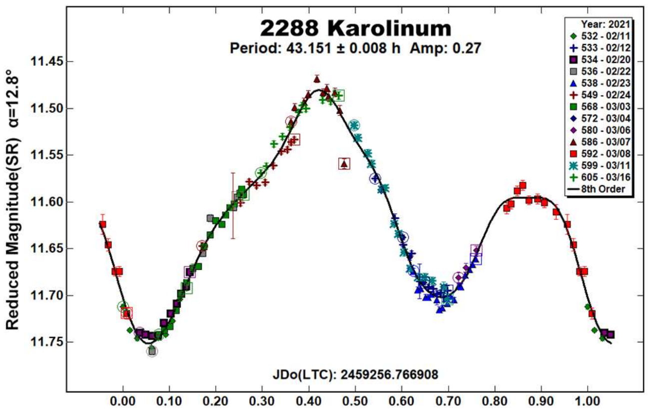


These 1591 Baize data were reduced with three experimental improvements to our session workflow: non-circular photometric apertures for asteroids, elongated in direction and extent to account for asteroid motion; unconditional exclusion of comp stars having any catalog indication of nearby flux; and iterative statistical treatment of comp-star and asteroid photometric annuli, to get much more robust estimates of sky background brightness and uncertainty.

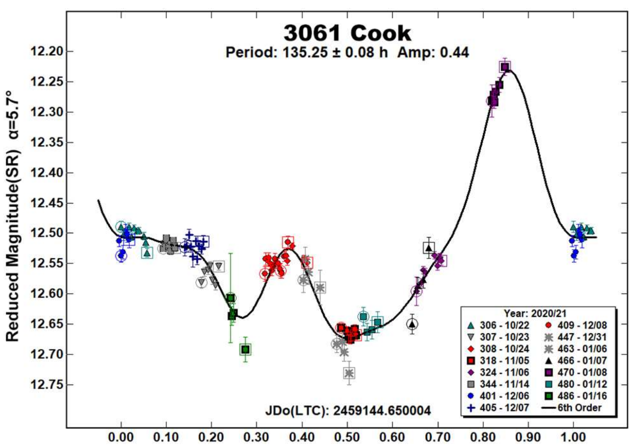
2180 Marjaleena. This Eos-family asteroid was found to have a clearly bimodal lightcurve with period 7.7025(5) h, in agreement with previous reports of 7.703 h (Waszczak, 2015) and 7.717 h (Polakis, 2020), but differing from reports of 7.396 (Behrend, 2014web), 6.702 h (Waszczak, 2015), and 8.346 h (Hanuš, 2018a). Our RMS error is 19 millimagnitudes; the best *G* estimate is 0.12.



2288 Karolinum. Observations over 13 nights have been combined to make the first known complete lightcurve for this asteroid of undetermined type. We find a period of 43.151(8) h, agreeing generally with previous reports of 42.16 h (Warner, 2006) and 42.8335 h (Pál, 2020), but not with a reported 23.31 h (Behrend, 2006web). Our RMS error is 9 millimagnitudes, and *G* of 0.30 improved the Fourier fit over the default *G* value of 0.15.

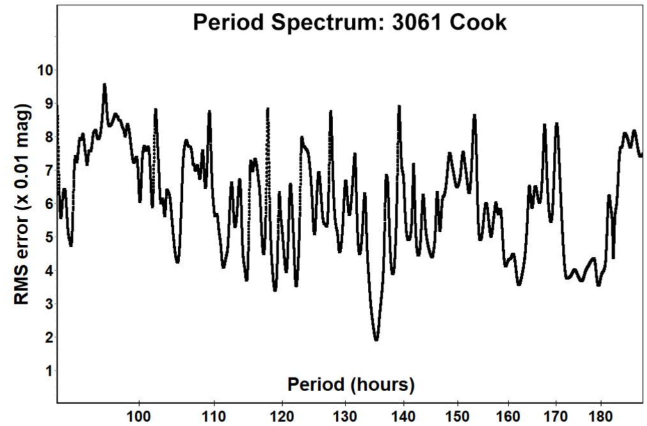


3061 Cook. This asteroid of undetermined type was found in images targeting (2689) Bruxelles (Dose, 2021), and then followed in its own right. We report here a period of 135.25(8) h; no tumbling was apparent from the lightcurve.

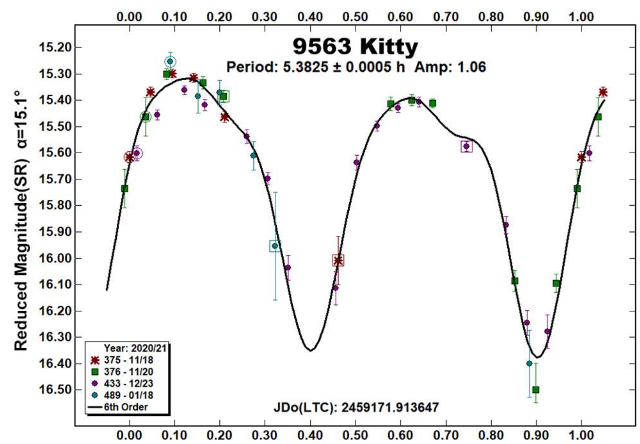


No previous reports of rotation period were found. RMS error is 19 millimagnitudes. A *G* value of 0.03 minimized fit errors; our *G* value differs from one previous survey-derived report of 0.472 (Vereš, 2015).

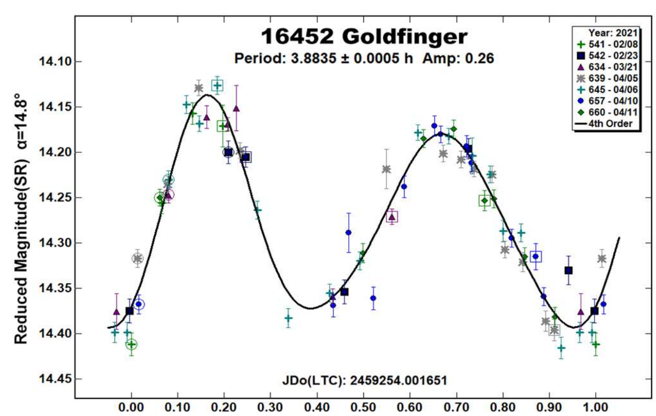
Even with 15 nights of observations, the lightcurve still suffers unfortunate gaps, especially in allowing for only one night near the apparent maximum (phase 0.85 in the phase plot), but the Fourier fit is close throughout, and the period spectrum shows no prominent aliases or other signals, so we assess the proposed period as likely correct. Confirming observations are encouraged.



9563 Kitty. This asteroid, whose orbit is characteristic of the Eunomia family, was found to have period 5.3825(5) h, in agreement with previous reports of 5.36 h (Chang, 2015), 5.367 h (Waszczak, 2015), and 5.38191 (Hanuš, 2018b). The asteroid was faint during this apparition, leading to significant observational noise, but the large lightcurve amplitude somewhat compensated for this. RMS error is 61 millimagnitudes, best *G* value is 0.38.



16452 Goldfinger. This high-albedo Vestoid was found to have period 3.8835(5) h.



No previous period reports are known to the author. RMS error is 24 millimagnitudes; a *G* value of 0.35 markedly improved the Fourier fit over the standard 0.15 value.

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357 NININA AND 748 SIMEISA – TWO ASTEROIDS WITH EARTH COMMENSURATE ROTATION PERIODS

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A global collaboration of observers from Australia, Europe, and North America found synodic rotation periods and amplitudes for 357 Ninina 35.983 ± 0.001 h, 0.11 ± 0.01 magnitudes; 748 Simeisa 11.903 ± 0.001 h, 0.08 ± 0.01 magnitudes.

Observations to produce the results reported in this paper have been contributed by Frederick Pilcher in the USA, Lorenzo Franco and Alessandro Marchini in Italy, and Julian Oey in Australia. Equipment details are on Table II. Image photometric measurement and lightcurve construction were done by *MPO Canopus* software. To reduce the number of data points on the lightcurves and make them easier to read, data points have been binned in sets of 5 with maximum time difference 10 minutes.

357 Ninina. Previously published rotation periods for 357 Ninina are by Tedesco (1979), > 20 h; Behrend (2005), 35.98h; Oey (2014), 35.9 h in year 2007 observations and 36.0105 h in year 2013 observations. Twenty sessions of new observations 2020 Dec. 7 - 2021 Feb. 13 provide a good fit to a period of 35.983 ± 0.001 h, amplitude 0.11 ± 0.01 magnitudes.