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LIGHTCURVES OF NINETEEN ASTEROIDS

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Using a previously described workflow based on applying dozens of comparison stars from the ATLAS refcat catalog to each image, we have obtained and present lightcurves and synodic periods for nineteen asteroids. We also describe refinements to magnitude correction for airmass (altitude of the field of view), especially useful during periods of high extinction, for example, through atmospheric smoke resulting from recent forest fire events near the U.S. Pacific coast.

The present photometry workflow is based on that described previously (Dose, 2020b), relying on intensive application of very numerous (typically 30-150) ATLAS refcat catalog stars (Tonry et al., 2018) to each image.

Since that description, two improvements have been made to handling of atmospheric extinction, both prompted by this summer's widespread forest fires in the western United States which resulted in atmospheric smoke over the author's observing site in northern New Mexico. While prevailing upper-atmosphere winds very efficiently transported the smoke to the author's site at 1000-1500 km from the fires, extinction at the observing site changed only slowly, so that a single extinction coefficient sufficed for each night. ATLAS catalog stars were numerous enough to allow restriction of comp stars to a very narrow range of color index, so that observations continued through nights with extinction coefficients (Clear filter) up to about 0.70, where at 30° altitude only 25-30% of the light penetrates the atmosphere to reach the telescope. Exposure times were lengthened to compensate. Data from three nights with local extinction found to exceed 0.70 were rejected altogether.

In the first workflow improvement, one nightly extinction coefficient is first computed from comp stars for the night's asteroid target having the widest range in airmass; then, that extinction coefficient is applied to all targets for that night. The mixed-model regression (Gelman and Hill, 2006) on which the current workflow is based will segregate any remaining image-to-image systematic errors resulting from minor misestimation of the extinction. The advantage of starting with a good extinction estimation is not so much to get better photometric precision and accuracy, but more in clarifying the error structure so that outlier images, comp stars, and individual comp star observations can be removed properly. Nightly extinction estimation and application is not difficult and is now included in all the author's asteroid photometry.

The second workflow improvement computes an individual airmass value for each asteroid and comp star in each image, replacing the usual photometric practice of applying a center-image airmass value to all targets in that image. With extinction of 0.7, the extinction gradient near 30° above the horizon reaches 0.7 millimagnitude per arcminute of altitude; in the author's case, image corner-to-corner extinction range reached 30 millimagnitudes – much larger than ATLAS catalog magnitude uncertainties. Per-target airmasses are never worse than per-image

airmasses, and as the only disadvantage is in more computation time, the author plans to retain this improvement for future asteroid photometry.

With these two improvements, the author found it possible this summer to continue observing moderately bright targets when Clear-filter extinction reached 0.70, and to observe fainter targets (V~16-17) with normal precision when extinction reached about 0.40. In the end, by taking longer exposures and then applying the above workflow improvements, the present photometric data and lightcurves show very little effect of excess extinction from smoke. Were extinction to change more significantly during the night, especially when heavy smoke originates closer to the observing site, a proper nightly extinction value probably will not exist, and observing sessions will have to be kept shorter than the timescale of extinction change, or observations postponed to a better night.

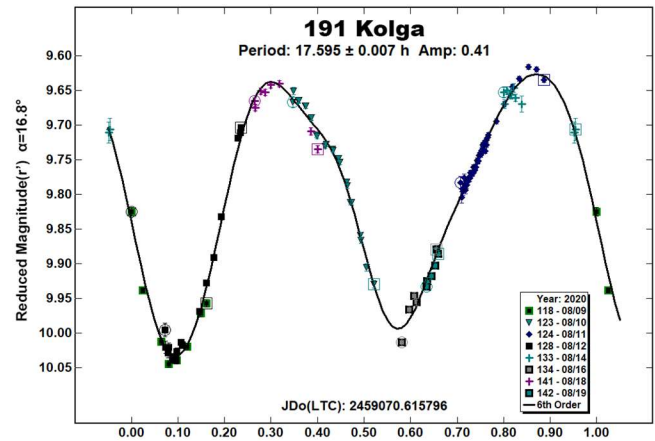
The present workflow results in the session's raw lightcurve, that is, best estimates of asteroid magnitude on catalog basis, unreduced and without H-G adjustment. These final, catalog-basis asteroid magnitudes are imported directly into *Canopus* software (Warner, 2018) for Fourier fitting, period analysis including ruling out of aliases, and plotting. In *Canopus*, magnitudes are then adjusted for distances and for phase-angle dependence with an H-G model, using $G = 0.15$ for each asteroid unless otherwise specified. No nightly zero-point adjustments were needed or made to any session herein. All lightcurve data herein have been submitted to ALCDEF.

Nineteen asteroids were observed from Deep Sky West Observatory (IAU V28) in northern New Mexico. Images were acquired with a 0.35-m SCT reduced to $f/7.7$, a SBIG STXL-6303E camera without binning, cooled to -35C, and fitted with a Clear filter (Astrodon), on a PlaneWave L-500 direct-drive mount. The equipment is operated remotely via *ACP* software (DC-3 Dreams), running plan text files generated for each night by the author's python scripts (Dose, 2019 and 2020a). Most sessions cycled between 2-4 asteroids, as facilitated by the mount's rapid slews. Exposure times targeted an estimated maximum 10 millimagnitude per-observation uncertainty when possible, subject to a minimum of 90 seconds to ensure proper photometry

of numerous comp stars, and limited to 900 seconds. All exposures of 120 seconds or longer, and most shorter exposures, were autoguided.

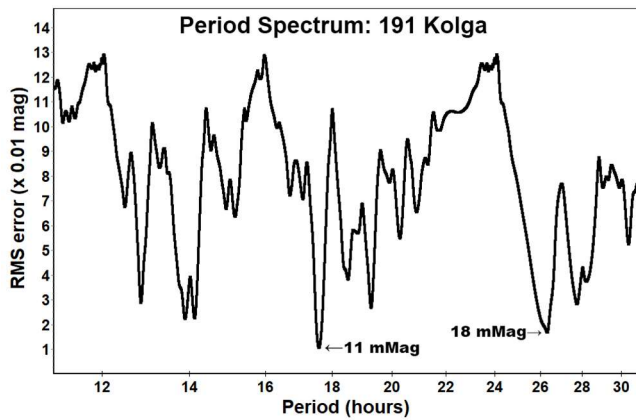
FITS images were plate-solved by *PinPoint* (DC-3 Dreams) or *TheSkyX* (Software Bisque) and calibrated using temperature-matched, median-averaged dark images and recent flat images of a flux-adjustable flat panel. Every photometric image was visually inspected; any images with poor tracking or with other light sources within 10 arcseconds of the target asteroid were excluded. Accepted photometry-ready images were submitted to the improved workflow, which applies separately measured second-order transforms from Clear filter to deliver asteroid magnitudes in Sloan r' passband.

191 Kolga. The present synodic period determination of 17.595(7) h confirms those of 17.625 h (Warner, 2009) and 17.604 h (Pilcher, 2013) but differs from numerous other reports (Gil-Hutton and Cañada, 2003, 13.078 h; Holliday, 2001, 27.8 h; Behrend, 2009web, 27.8 h; Behrend, 2005web, 28.7 h), and it most notably differs from a web-reported period of 27.8(5) h (Behrend, 2020web) from observations reportedly made only 2-3 weeks before the data presented here. RMS error is 10 millimagnitudes.



Number	Name	yyyy mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
191	Kolga	2020 08/09-08/19	16.8, 18.3	270	12	17.595	0.007	0.41	0.02	MB-O
424	Gratia	2020 09/19-09/26	10.9, 8.6	18	-11	40.118	0.014	0.20	0.02	MB-O
570	Kythera	2020 09/18-09/24	10.3, 8.4	23	1	8.123	0.004	0.10	0.02	MB-O
605	Juvisia	2020 10/01-10/10	12.0, 9.8	30	18	15.851	0.003	0.18	0.01	MB-O
999	Zachia	2020 07/09-08/14	*10.1, 14.9	299	14	22.835	0.003	0.53	0.02	UNK
1108	Demeter	2020 07/12-08/05	29.2, 26.5	324	36	9.834	0.002	0.17	0.03	PHO
1306	Scythia	2020 09/30-10/13	12.7, 9.3	36	16	7.531	0.002	0.06	0.01	MB-O
1404	Ajax	2020 09/18-09/26	3.2, 4.9	342	4	29.411	0.024	0.26	0.02	TR-J
1576	Fabiola	2020 09/18-09/21	4.0, 2.9	5	0	6.889	0.002	0.26	0.01	THM
3578	Carestia	2020 10/02-10/13	17.3, 15.1	58	21	9.974	0.003	0.18	0.02	UNK
4738	Jimihendrix	2020 09/14-09/16	10.2, 9.3	10	4	5.175	0.002	0.17	0.01	EUN
5408	The	2020 09/25-10/07	12.0, 6.9	29	0	7.374	0.001	0.82	0.03	FLOR
5996	Julioangel	2020 09/18-10/03	9.5, 15.0	344	12	9.741	0.002	0.24	0.02	EUN
11220	1999 JM25	2020 09/18-10/09	7.6, 15.5	355	9	11.277	0.001	0.67	0.03	FLOR
19019	Sunflower	2020 08/07-08/12	*4.0, 4.0	318	7	3.322	0.002	0.24	0.04	MB-I
23482	1991 LV	2020 09/29-10/05	18.8, 19.3	1	25	3.139	0.001	0.33	0.03	H
23989	Farpoint	2020 08/13-09/19	*6.5, 15.5	327	8	15.244	0.003	0.47	0.06	EUN
25332	1999 KK6	2020 10/05-10/08	14.8, 14.6	10	19	2.452	0.002	0.11	0.03	H
28565	2000 EO58	2020 09/06-09/17	18.0, 23.1	327	5	2.234	0.001	0.08	0.03	MC

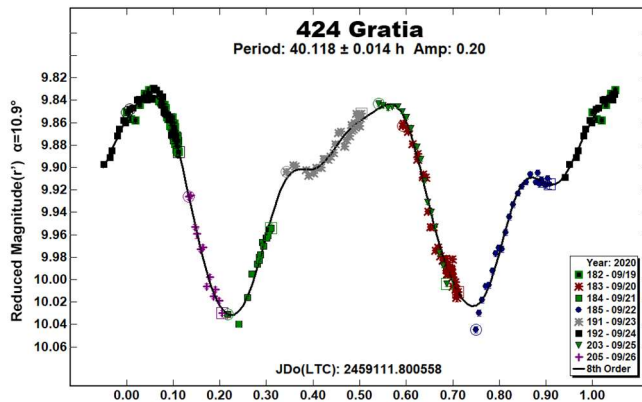
Table I. Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extremum during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al.,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



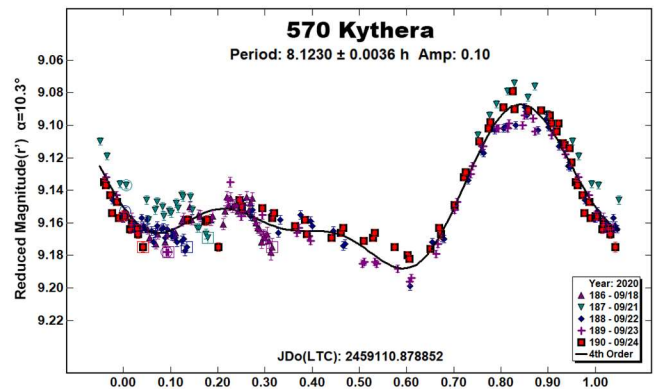
The persistence of reports of period 27.8 h for is almost certainly due to the alias (half-period per 24 hours) between 27.8 h and 17.595 h. The periodogram from present data, comprising eight sessions of observations, cannot support the 27.8 h alias; when using that candidate period, the lightcurve generated via Fourier fit is quadrimodal and not of reasonable shape. The report of 13.078 h is another alias of the present period, also of half-period per 24 h.

424 Gratia. The present synodic period of 40.118(14) h is roughly twice the two known determinations of 19.47 h (Florczak, 1997) and 20.075 h (Polakis, 2018), both assigned uncertainty codes of 3- in the LCDB (Lightcurve Data Base; Warner et al., 2009). The present data's high amplitude-to-noise and the difference in shape of the two maxima suggest that the secondary features seen at phases 0.38 and 0.86 (figure below) could be taken for a secondary minimum of a 20 h lightcurve, especially when observed at very different aspects (phase angle bisectors).

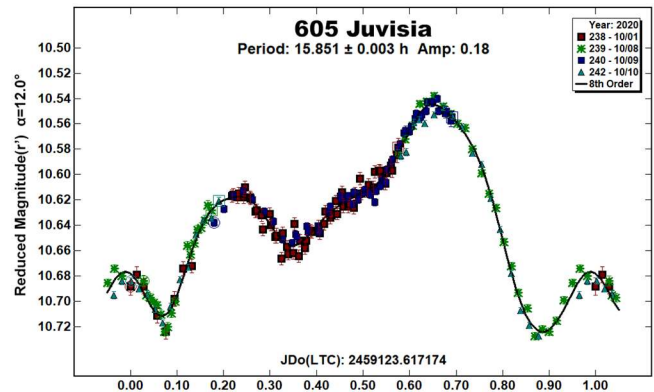
From the present observations, taken at a very different phase angle bisector from the previous ones, we propose a bimodal lightcurve of synodic period 40.118 h instead. A H-G (phase angle relation) G value of 0.0 was adopted for its superior Fourier fit to that using the standard G value of 0.15. RMS error is 6 millimagnitudes.



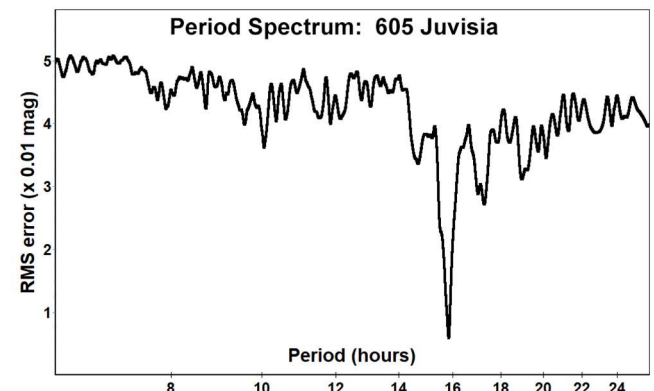
570 Kythera. This low-amplitude lightcurve yields a synodic period of 8.1230(36) h, in agreement with two previous period reports (Behrend, 2004web, 8.120 h; Aznar Macias et al., 2016, 8.074 h), but differing from previous period reports (Blanco et al., 2000, 6.919 h; Lagerkvist et al., 2001, 5.682 h; Gil-Hutton and Cañada, 2003, 6.903 h; and Chavez, 2014, 10.5 h). The proposed periods near 6.9 h differ from the present determination by one half-period per 24 h but do not appear in the present periodogram. The period of 10.5 h is based on a quite incomplete lightcurve. A G value of 0.40 markedly improved the present Fourier fit; RMS error is 8 millimagnitudes.



605 Juvisia. This bright outer main-belt asteroid was studied to refine its somewhat uncertain synodic period. We report a synodic period of 15.851(3) h, which agrees with three known reports, each with uncertainty code of 2 in the LCDB (Warner, 2000, 15.855 h; Menke, 2005, 15.85 h; Warner, 2011, 15.93 h). Adjusting the G (H-G) value to -0.05 from the MPC default of 0.15 markedly improved the Fourier fit. RMS error is 6 millimagnitudes.

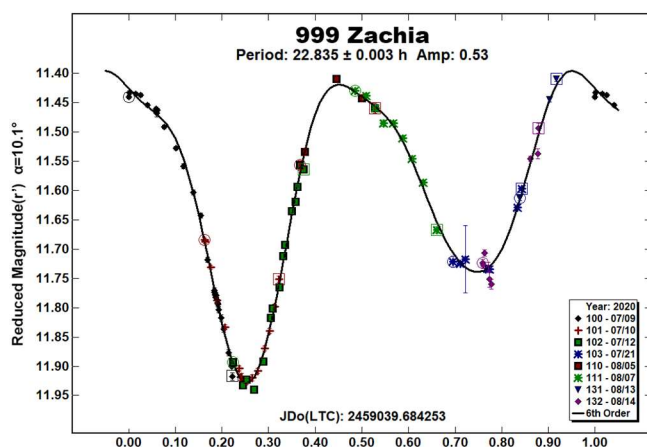


At different viewing aspect (phase angle bisector), the lightcurve has been reported to be symmetric, bimodal, and of higher amplitude (Warner, 2011). The present lightcurve shape is only loosely bimodal; the periodogram is unambiguous.

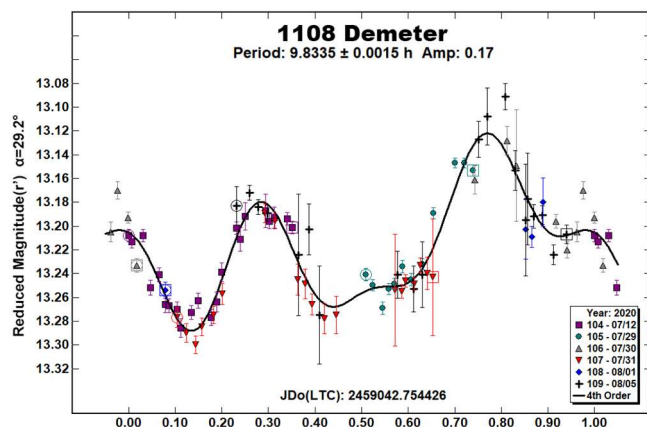


The present viewing aspect is new to this asteroid; this together with its changing lightcurve shape this suggests that asteroid shape modeling may be worthwhile. Juvisia's high orbital inclination will cause its 2022 January apparition to present another new viewing aspect as well.

999 Zachia. This well-studied asteroid of unknown group/family was observed at a new phase angle bisector to assist future shape studies. The present synodic period of 22.835(3) h agrees with all known previously reports (Warner, 2000, 22.77 h; Brines et al., 2017, 22.837; Pál et al., 2020, 22.812 h). The lightcurve is markedly bimodal and of relatively high amplitude. RMS error is 14 millimagnitudes.



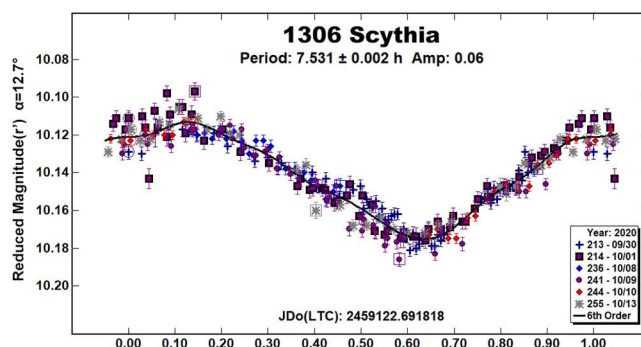
1108 Demeter. This well-studied Phocaea-family asteroid was observed to support future shape studies. The present synodic period is 9.8335(15) h, in reasonable agreement with previous reports (Behrend, 2001web, 9.701 h; Stephens, 2002, 9.70 h; Polakis and Skiff, 2016, 9.846 h; Brines et al., 2017, 9.870 h). The lightcurve is clearly bimodal and the amplitude is higher than previous reports. A G value of 0.6 optimized the Fourier fit. RMS error is 16 millimagnitudes.



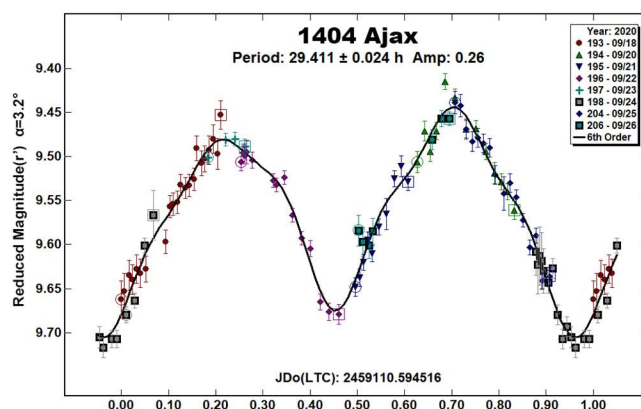
1306 Scythia. The lightcurve for this outer main-belt asteroid has been difficult to assign as monomodal or bimodal. The present observations were arranged to provide very high signal-to-noise as well as complete coverage of both monomodal and bimodal phases. The present data provide no support for a bimodal lightcurve interpretation, whether from inspection of phase plots or from periodograms or split-halves plots. The low amplitude, similar to those of other studies, allows for a monomodal lightcurve.

The proposed monomodal synodic period of 7.531(2) h matches one report (Behrend, 2008web, 7.525 h; amplitude 0.25) and is half the bimodal period in another report (Stephens, 2004, 15.05 h, amplitude 0.15). It is conceivable that the lightcurve could be

bimodal at high amplitudes but effectively monomodal at viewing aspects giving low amplitudes. However, no data found in the LCDB appear to support bimodal behavior, so monomodal interpretation seems preferred. Fourier fit to the present data is improved by reducing the G value (H-G) to 0.10. RMS error is 6 millimagnitudes.

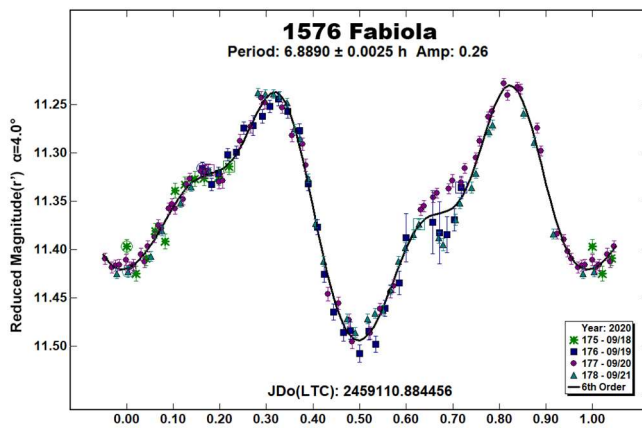


1404 Ajax. If any asteroid nomenclature contradicts history more unfortunately than does the classification of Ajax as a Trojan, the author is unaware of it. The present synodic period determination of 29.411(24) h agrees with the previous result of 29.38 h (French et al., 2011) with LCDB uncertainty code 3-, but differs from the result of 34 h (Behrend, 2009web) with uncertainty code 2- and from 28.4 h (Binzel and Sauter, 1992) with uncertainty 1. The present lightcurve is markedly bimodal. Adjusting the H-G value G to 0.35 improved the Fourier fit; RMS error is 14 millimagnitudes.

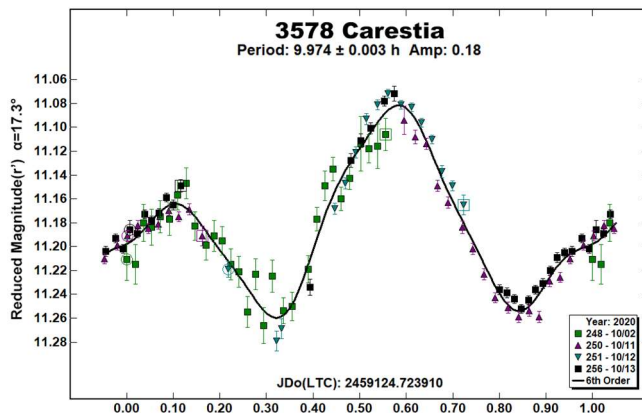


1576 Fabiola. This Themis-family asteroid was observed at a new phase angle bisector to support future shape studies. The synodic period was found to 6.889(2) h in exact agreement with that of Benishek (2018), and of very similar lightcurve shape despite the very different viewing aspect. The present result is also fairly close to an older report of 6.7 h from Lagerkvist (1978). G = 0 improved Fourier fits over the standard value of 0.15; RMS error is 12 millimagnitudes.

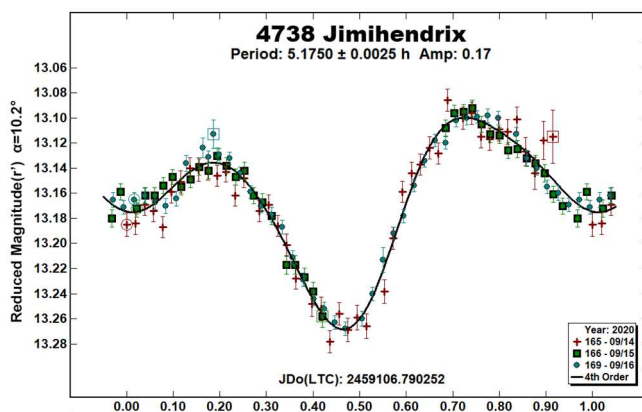
Night-to-night variation in the shelf feature at phase 0.6-0.7 (see figure) appears real but is difficult to explain as (a) the change is not monotonic with date of observation, and (b) the brightness decrease is not limited to one night in this one phase position, as would be likely for a binary in eclipse.



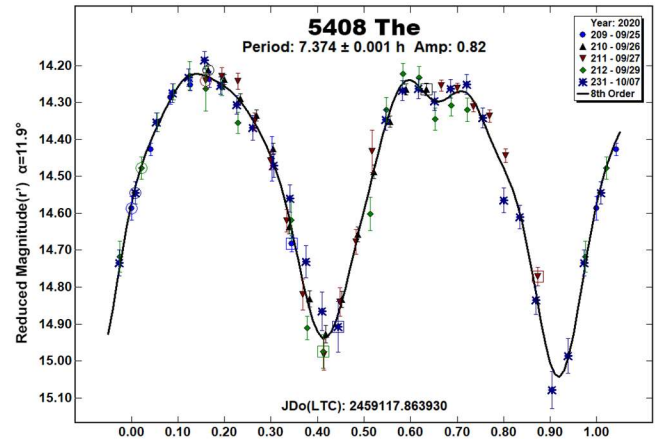
3578 Carestia. This large (diameter 59 km), very low albedo (0.02) asteroid of undetermined group was found to have a synodic period 9.974(3) h and a markedly bimodal lightcurve. This period agrees with one earlier report (Behrend, 2008web, 9.93 h) but disagrees with another (Holliday, 1997, 7.08 h) with incomplete phase coverage and substantial nightly shifts in zero-point. The present RMS error is 12 millimagnitudes.



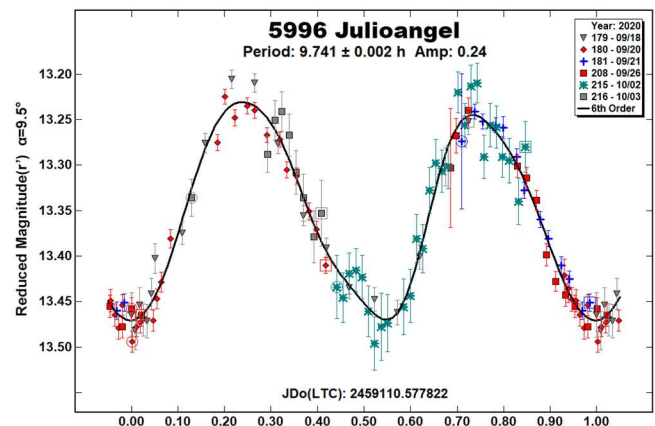
4738 Jimihendrix. This Eunomia-family asteroid was found to have a clearly bimodal lightcurve of synodic period 5.1750(25) h, in agreement with one previous survey period of 5.1729 h (Pál et al., 2020). G of 0.35 improved the Fourier fit over that of standard G of 0.15; RMS error is 9 millimagnitudes.



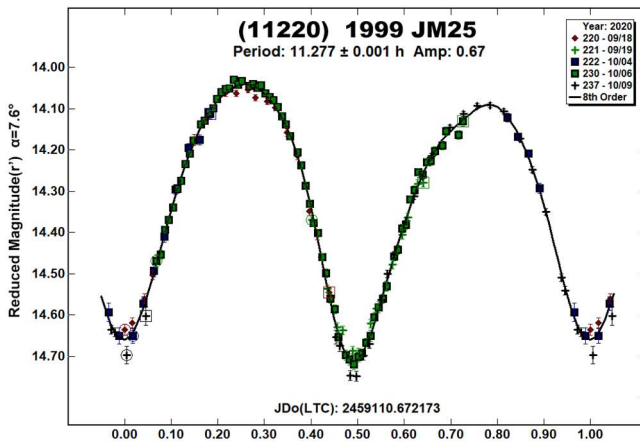
5408 The. This uniquely named Flora asteroid is confirmed to have synodic period 7.374(1) h, matching exactly the survey period previously reported (Waszczak et al., 2015, 7.374 h). The LCDB currently lists no other period reports. The slight brightness dip at phase 0.65 (see figure) appears real and is intriguing with regards to future shape modeling. A G value (H-G) of about 0.50 improved the Fourier fit over the default G of 0.15. RMS error is 41 millimagnitudes.



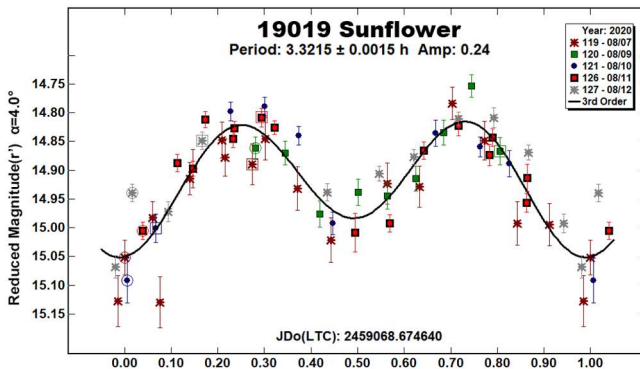
5996 Julioangel. This Eunomia-family asteroid was found to have synodic period 9.741(2) h, in agreement with the single known period report of 9.74 h (Durkee, 2018). Adjusting G value from 0.15 to 0.25 improved the Fourier fit; RMS error is 19 millimagnitudes.



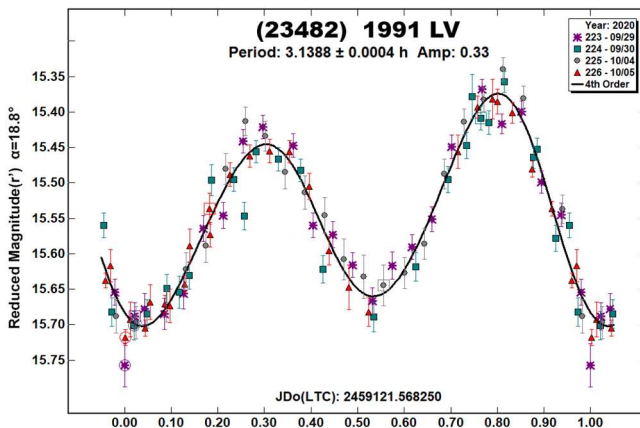
(11220) 1999 JM25. This Flora-family asteroid was found during its very favorable 2020 apparition to have synodic period of 11.277(1) h, confirming three reported periods from sparse photometry, each with LCDB-assigned uncertainty code of 2 (Waszczak et al., 2015, 11.280 h; Āurech et al., 2018, 11.27965 h; Pál et al., 2020, 11.2733 h). A G value (H-G) of 0.20 improved the Fourier fit over G of 0.15; the present RMS error is 14 millimagnitudes. The present data suggest slightly higher amplitude at higher phase angles, as described by Zappalá et al. (1990).



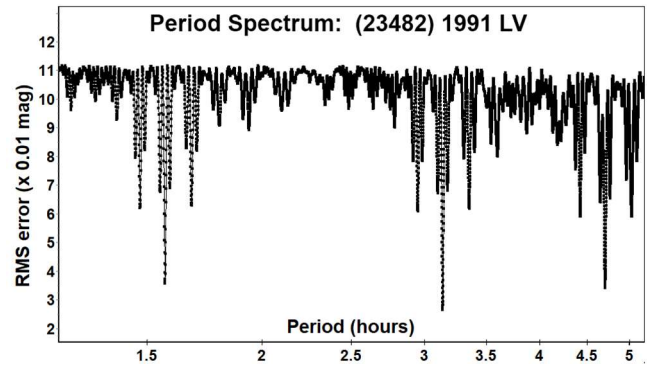
19019 Sunflower. This inner main-belt asteroid of estimated diameter 3-4 km was found to have synodic period of 3.3215(15) h, in close agreement with survey period reports of 3.320 h and 3.322 h (Waszczak et al., 2015). RMS error is 44 millimagnitudes.



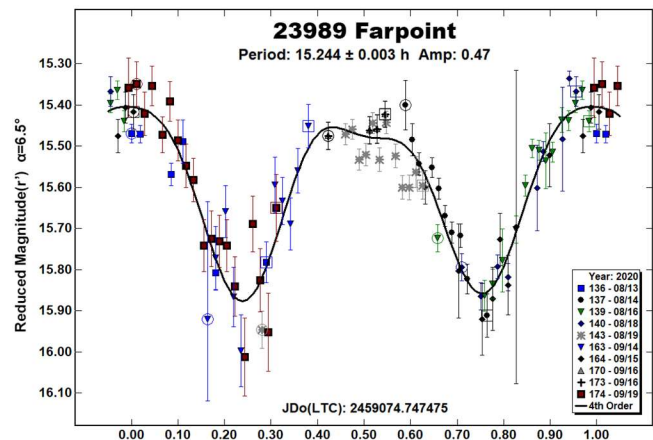
(23482) 1991 LV. This faint Hungaria was studied to rule out alises that have been problematic for this asteroid's lightcurves. We found an unambiguous synodic period of 3.1388(4) h, in agreement with 2012 observations of (Warner, 2012, 3.1388 h; Warner, 2016, 3.126 h) but not with the same author's 2015 observations (Warner, 2016, 3.357 h). RMS error is 26 millimagnitudes.



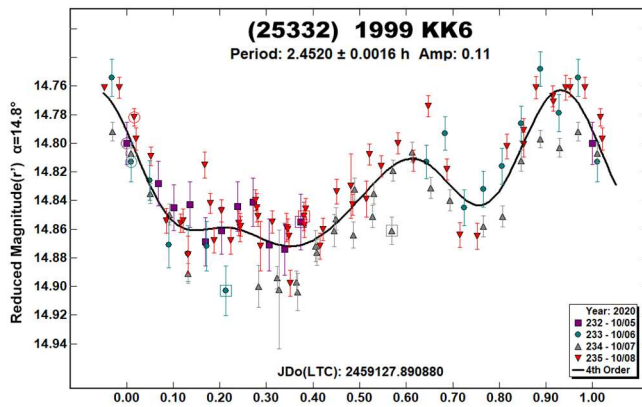
The present observations benefited from an advantageous pattern of session dates, a clearly bimodal lightcurve, and very favorable declinations permitting unusually long observations (up to 2.4 periods per session), so that the present data effectively rule out the candidate period of 3.357 h as an alias (half-period per 24 hours), as confirmed by the periodogram. No evidence of a secondary period (Warner, 2012) was seen in the present data.



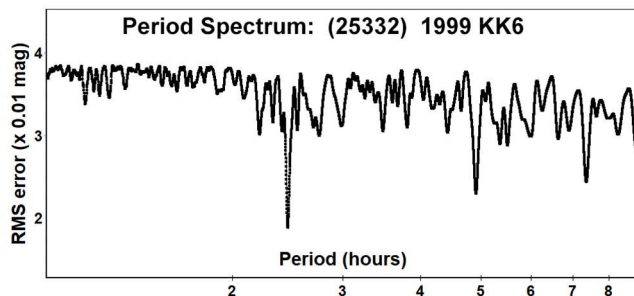
(23989) Farpoint. This Eunomia-family asteroid, named for the Kansas observatory in which the author performed his first asteroid astrometry, was discovered 1999 by Gary Hug and Graham Bell who established the observatory. The LCDB lists no previous period reports. The present synodic period of 15.244(3) appears correct despite Sloan r' magnitudes frequently exceeding 18 as measured with a 0.35-m telescope, and despite a few sessions' occurring during the western U.S. atmospheric smoke events of August-September. RMS error is 67 millimagnitudes. This asteroid will be difficult to observe again through at least 2024.



(25332) 1999 KK6. This Hungaria was observed in an effort to distinguish between a monomodal (period near 2.45 h) or bimodal (ca. 4.9 h) lightcurve. The lightcurve appears monomodal, with synodic period 2.4520(16) h, in agreement with earlier results reported as monomodal (Warner, 2008, 2.4531 h; Warner, 2013, 2.453 h; Warner, 2016, 2.4531 h). The present lightcurve is dominated by a rapid dimming of 0.09 magnitudes, 80% of the total amplitude, within 20-25 minutes (phase 0.95-0.10 in figure). RMS error is 19 millimagnitudes.

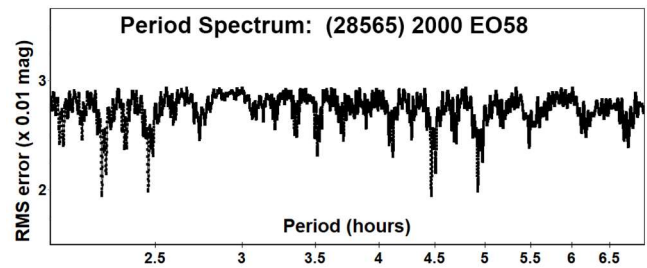
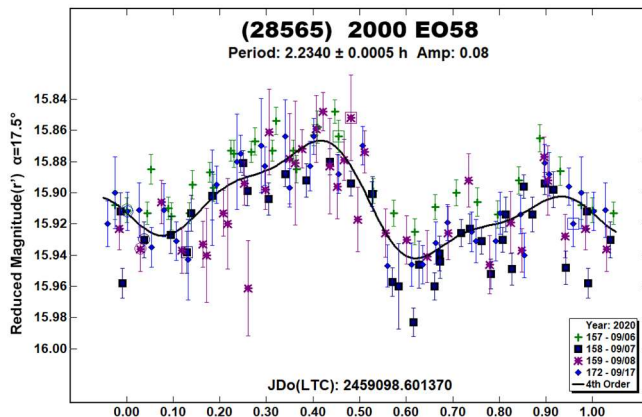


At fourth-order Fourier fitting, the monomodal period dominates; RMS error decreased very little when applying Fourier terms beyond fourth order. The low amplitude, to date always reported as 0.11 mag or less, allows for a monomodal lightcurve. Our results support a monomodal interpretation and period near 2.452 h.



(28565) 2000 EO58. The synodic period for this small (estimated diameter 2.8-3.0 km), low-amplitude Mars-crosser remains ambiguous due to 24-hour aliasing, yielding two period estimates: 2.234 h and 2.460 h. The present observations do appear to rule out the previously reported period of 3.83 h (Behrend, 2004web) assigned a LDB uncertainty code of 1. G value of 0.25 improved the Fourier fit over that with G assumed to be 0.15; RMS error is 19 millimagnitudes.

Given the lightcurve's low amplitude, it may not be practical to resolve this aliasing from a single geographic location; observing from at least two locations widely separated in longitude would be the best approach.



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