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167.

## CERTAINTIES, QUESTION MARKS AND VOIDS IN THE PRESENT-DAY DATA CONCERNING THE ROTATION PERIOD OF ASTEROIDS

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There are more than 700,000 asteroids with well-defined orbits. However, the LCDB data base (version Feb 2017) contains rotation period data for only 17,437 asteroids and yet, more than two thirds of those reported measurements still may be uncertain by 30% ( $U = 2$ ) and another 10% may be completely wrong ( $U = 1$ ). It should be possible to know the characteristics of asteroid spins without measuring every last one of them, on condition that our sample (1) is unbiased, and (2) it properly includes odd or outlier objects. In principle,  $U = 2$  data should be good enough for both statistical analysis and for identifying oddballs. Wide-field data now comprise the majority (~63%) of spin rates we have. However, due to the overwhelming volume of W-F data, their corresponding reliability is in practice almost impossible to assess on a case-by-case basis, so that a nominal  $U = 2$  has been basically assigned to them. This poses the question whether including W-F data actually improves or degrades statistical analysis performed using only the smaller but more carefully controlled data from the F-D file. This paper shows that for size ranges where both F-D and W-F data samples contains at least 100 values, the W-F mean significantly differs from the F-D value (with only one exception for the narrow range  $1 < D < 0.7$  km, where W-F data appears to be as almost unbiased). The spin rate percent difference for asteroids having diameters between 3 to 20 km is consistently uniform, and worsens for larger ones. With respect to studies of extremes of rotation, W-F surveys and less controlled samples can be useful, if the limitations are reasonably characterized.

Studies of asteroid rotation rates and lightcurve properties provide important data for development of theories of asteroid structure and physical processes. The Asteroid Lightcurve Data Base (LCDB; Warner *et al.*, 2009) is a set of files that collects and organizes the required information for these studies, obtained from

numerous journals and other sources. The LCDB provides a central location for basic information about asteroid rotation rates and related data that can be used in statistical studies involving a few or many parameters.

The LCDB assigns a code – namely the  $U$  code – that provides an assessment of the quality of the period solution. A quality code  $U = 3$  means that the corresponding rotation period is basically correct (thus unambiguous and reliable);  $U = 2$  means that the found rotation period is likely correct, although it may be wrong by 30% or it is ambiguous (e.g., the half or double period may be correct);  $U = 1$  means that the established rotation period may be completely wrong;  $U = 0$  means that the period is yet unknown or a reported solution has been determined to be incorrect. The assigned  $U$  quality code can also be highlighted with either a plus (+) or a minus (-) sign, meaning that the certainty of the found solution is respectively slightly better or worse than the corresponding grade.

It seems quite reasonable that we can know the characteristics of asteroid spins without requiring the measurement of every last one of them. (From thermodynamics we have learnt that it is possible to characterize the molecules of a gas – that is, the various components by molecular weight and the velocity distribution of the molecules – without measuring every single molecule.) The main problems we have with asteroid spins are: (1) being sure our sample is unbiased, so the spin rate distribution and the separate classes are truly representative of what we intend to be measuring, and (2) seeking and characterizing odd or outlier objects.

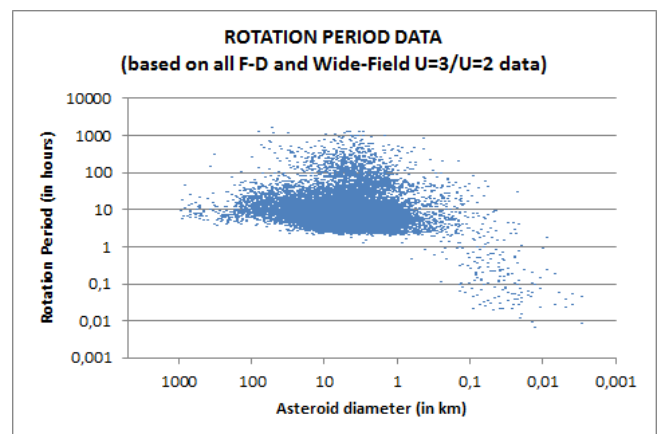


Figure 1. The rotation period data in terms of asteroid diameter. Each dot represents a reported solution been rated either  $U = 3$  or  $U = 2$ . Both axes appear in logarithmic scale.

Range of Asteroid Diameter (km)	F-D data			W-F data (only U = 3 and U = 2)			S-D data
	quantity	Mean log	Mlog P (h)	quantity	Mean log	Mlog P (h)	quantity
D > 150	137	0.980	9.55	2			0
150 > D > 100	163	1.137	13.71	0			0
100 > D > 70	242	1.138	13.73	1			0
70 > D > 45	367	1.136	13.67	5			0
45 > D > 30	451	1.092	12.36	27			0
30 > D > 20	495	0.998	9.96	118	1.182	15.21	1
20 > D > 13	476	0.992	9.82	310	1.074	11.86	3
13 > D > 10	381	0.913	8.19	427	0.985	9.67	4
10 > D > 8	354	0.858	7.21	532	0.963	9.18	3
8.0 > D > 6.5	443	0.881	7.60	667	0.943	8.76	3
6.5 > D > 5.2	396	0.893	7.82	804	0.974	9.42	2
5.2 > D > 4.0	434	0.860	7.25	1192	0.927	8.46	4
4.0 > D > 3.0	313	0.885	7.67	1350	0.954	9.00	5
3.0 > D > 2.2	305	1.012	10.29	1398	0.913	8.18	2
2.2 > D > 1.5	187	0.972	9.38	1371	0.918	8.27	1
1.5 > D > 1.0	161	0.836	6.85	1009	0.899	7.92	0
1.0 > D > 0.7	108	0.867	7.37	431	0.858	7.21	0
0.7 > D > 0.5	100	0.936	8.63	111	0.892	7.80	0
0.5 > D > 0.33	111	0.939	8.68	15			0
0.33 > D > 0.2	110	0.923	8.37	5			0
0.2 > D > 0.07	119	0.407	2.55	12			0
D < 0.07	125	-0.601	0.25	0			0
Totals	5978			9787			28

Table I. The overall distribution of present-day rotation period data with quality codes either U = 3 or U = 2, arranged by range of asteroid diameters (rows). In columns, the first arrangement corresponds to data origin: F-D data file, Wide-Field surveys or Sparse-Data objects (e.g. those with fewer than 60 data points from a short span of 2-4 nights). Size ranges go as  $D_i > D > aD_i$ , where the coefficient  $a \sim 1.2-1.5$ . For those asteroid size ranges where there were found at least 100 reliable spin values, the Mean Log column represents the Mean Logarithmic value and the adjacent MPeriod column shows (in hours) the corresponding rotation period for such Mean Logarithmic value.

For this study I utilize the LCDB version released on 2017 February 02, which includes reported rotation rate solutions for 17,437 asteroids. Respective quality codes have been assigned as follows: 4,046 (roughly one fifth) were found to be reliable data and therefore have U = 3; 11,838 (roughly two thirds) were assessed as fairly good quality solutions, so that they have U = 2; and 1,553 (roughly one tenth) were found rather poor quality solutions, achieving U = 1. (In this study I do not take into account the (+) or (-) second order quality assessment, so that all spin data are considered as having U quality codes just equal to 3, 2, 1 or 0.)

According to the U quality code criterion, it seems quite reasonable that data having a quality code of at least U = 2 should be good enough for both statistical spin analysis and for identifying oddballs. Figure 1 shows how present-day rotation period data having either U = 3 or U = 2 is distributed in terms of asteroid sizes. Two features immediately catch the eye: (1) period rate solutions embrace a wide time range (from under a minute to almost 2 months), and (2) period rate solutions are largely concentrated at the lower region of the time range (between 15 h and the so-called spin-barrier at 2.2 h).

Since 2012, wide-field asteroid photometric surveys have been revolutionizing the incoming flow of new data to the LCDB, now comprising the majority of data we have. Unlike “conventional” observing campaigns targeting just one single object’s lightcurve, wide-field photometric surveys are capable of measuring hundreds of asteroid lightcurves simultaneously.

However, period rotation data from wide-field photometric surveys were typically derived from undersampled lightcurves, thus making them often ambiguous (Harris *et al.*, 2012). Moreover, due to the overwhelming volume of these data, their

corresponding reliability is in practice almost impossible to assess on a case-by-case basis. (As a matter of fact, with regard to a large majority of wide-field survey results, it has been adopted the policy of automatically assigned them a nominal U = 2 without much scrutiny.) Consequently, the LCDB authors emphasize that data from wide-field surveys may be contributing biased statistics in Frequency versus Diameter (F-D) analyses. Thus the LCDB maintains a selective file for such studies, the so-called F-D data file, which does not include data rated lower than U = 2, wide-field or sparse-data objects (i.e., all data considered less than fully-reliable for rotation or other studies have been especially precluded).

The LCDB version I analyze contains 11,033 spin rates obtained from wide-field surveys, thus representing almost two thirds (63%) of the grand-total of published rotation period data. With regard to quality codes, those 11,033 solutions are divided as follows: only 235 (2%) correspond to U = 3 data; the large majority 9,552 (87%) have U = 2, while the remaining 1,246 (11%) have U = 1. On the other hand, the F-D data file only contains 5,978 spin rates, but all of them are at least of fairly good quality – almost two thirds (3,811 entries) were assessed U = 3, while the remaining (2,167 entries) were assessed U = 2. Figure 2 shows how reliable U = 3 and fairly good U = 2 present-day data are distributed according to their wide-field or “conventional” (non-wide-field) origin.

**SPIN RATES DATA DISTRIBUTION**  
(F-D plus Wide-Field U=3/U=2 data)

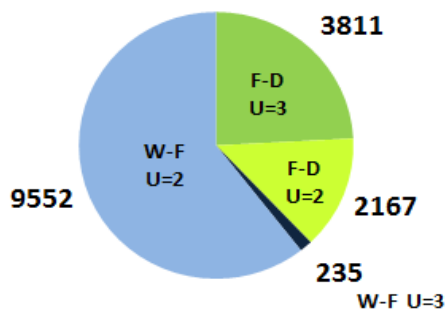


Figure 2. The 15,765 rotation period data that have been assigned either U = 3 or U = 2, divided with regard to their wide-field or non-wide-field origin. The reliable U = 3 spin rates represent about 25% of the overall “correct” and “likely correct” data.

Table I presents how the present-day U = 3 and U = 2 rotation rate solutions are distributed among different ranges of asteroid size. For each range, data have been separated according to their wide-field or non-wide-field origin. (Each size range embraces asteroid diameters from 1 D to ~1.5 D; I choose those size ranges in order to work with a meaningful range quantity (~20), but on condition each one having at least 100 reliable spin data from the same origin.) For those asteroid size ranges fulfilling such requirement, in adjacent columns appear the Mean Logarithmic value for that sample, and its corresponding rotation period (in hours). Figures 3 and 4 show the histogram distribution for F-D and W-D U = 3 and U = 2 data according to the chosen asteroid ranges.

**ASTEROID SIZE HISTOGRAM DISTRIBUTION**  
(FROM F-D DATA)

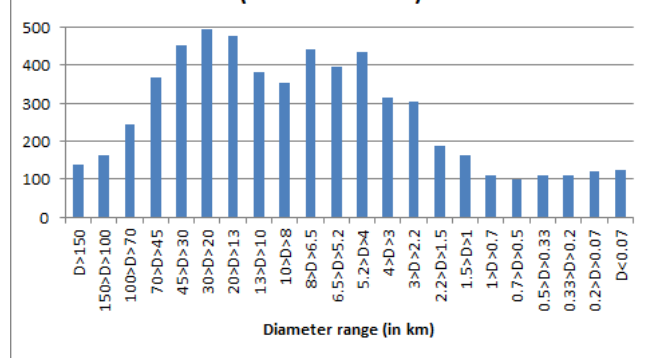


Figure 3. The histogram distribution according to the asteroid diameter ranges of Table I. As shown, ranges have been selected so that each one currently has at least 100 reliable spin data.

**ASTEROID SIZE HISTOGRAM DISTRIBUTION**  
(F-D AND W-F U=3/2 DATA)

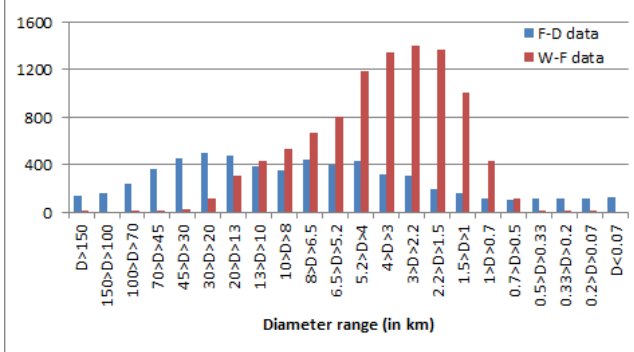


Figure 4. A comparison of the histogram distribution for F-D data (in blue) and W-F data (in red) from Table I. For those asteroids in the size range 0.7 < D < 10 km, data from W-F largely exceed corresponding F-D data.

Clearly, present-day W-F data is heavily concentrated in a much narrower size range than F-D data, showing a Maxwellian-like distribution peaking at D ~3 km.

Except for just an insignificant number of radar and direct flyby observations, all of our asteroid spin rate data have been derived from photometric measurements. Given the observational nature of such technique, it seems quite logical that all our data have been biased against faint, low-amplitude, or slowly rotating asteroids.

In spite of such “intrinsic” observational biases, present-day W-F data are inevitably *additionally* biased given the low success rate such surveys still yield. In effect, spin rate data from wide-field surveys were found for only about 20% of all observed objects, “meaning that only the ‘easier’ results were found” (Warner et al., 2015).

How biased is our wide-field data?

The logarithmic mean spin rate for the controlled, reliable F-D data corresponding to each one of the diameter ranges (as defined in Table I) is shown in Figure 5. In order to find out the degree of bias in the W-F data, in Figure 6 I compare the log mean period between wide-field surveys versus the F-D data in each size range having at least 100 U = 3 or U = 2 values.

**ROTATION PERIOD vs SIZE RANGE**  
(FROM F-D DATA)

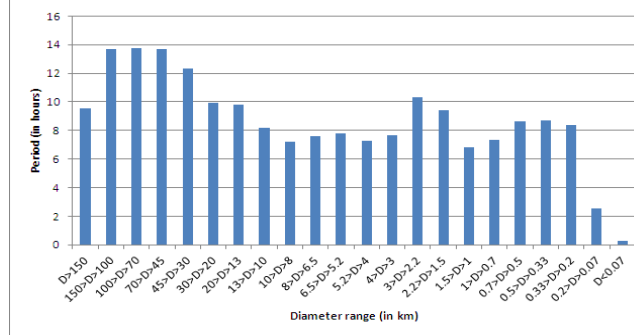


Figure 5. The log mean rotation rate distribution (plotted in terms of corresponding hours) for each one of the diameter ranges defined in Table I, according to our reliable F-D data.

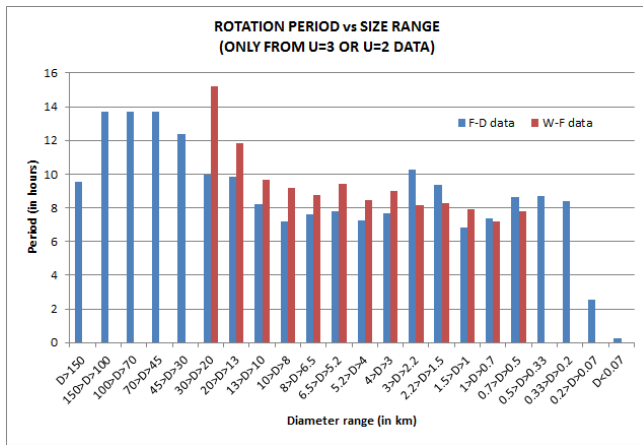


Figure 6. The comparison of the log mean period (in hours) between W-F data versus F-D data in each size range having at least 100 reliable values.

Figure 7 enlarges the results of such comparison. Of the thirteen size ranges considered, the W-F log mean spin rate significantly differs (by more than 15%) from the F-D value for ten of them, and for another two the difference still is important (~10%). Only for one particular diameter range ( $0.7 < D < 1$  km) there seems to be no ‘extra’ bias in W-F spin rate data, while quite the opposite occurs for the largest size compared ( $D > 20$  km) for which the discrepancy in the log mean spin rate is statistically remarkable (53%). The observed bias in the W-F data consistently enlarges the measured periods for asteroids having  $D > 3$  km. Interestingly, this trend seems to abruptly end and even reverse for the size range between 1.5 to 3 km.

The obvious conclusion is that the so-far available wide-field data are essentially and notoriously biased, most likely against faint, low amplitude and very short or long period asteroids, as already been warned by Warner and Harris (2011) and Harris *et al.* (2012).

Therefore, with regard to asteroid rotation statistics, the inclusion of the vast new sample from wide-field surveys to the smaller but more carefully controlled F-D data clearly degrades the results.

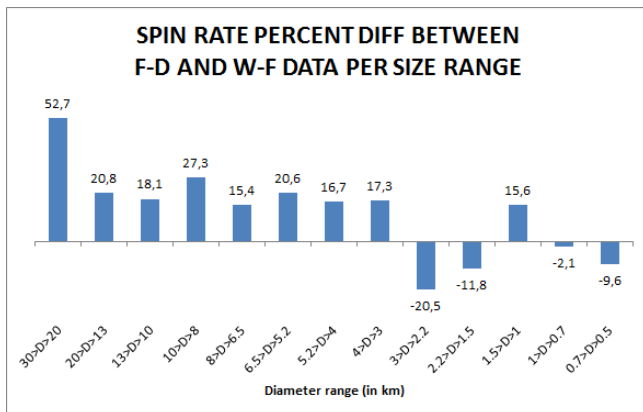


Figure 7. The percent difference in the log mean periods between F-D and W-F U=3/2 for each one of the considered size ranges.

The search for oddballs

Especially interesting and fruitful for development of theories of asteroid structure and physical processes are studies of extremes of rotation, both fast and slow rotators (Pravec and Harris, 2000).

Figure 8 shows the histogram of number vs rotation period (logarithmic binning) distribution for large asteroids ( $D > 30$  km) from F-D data (since so far there is almost no W-F data for those large asteroids). A Maxwellian-like distribution appears, peaking at  $P \sim 9$  hours.

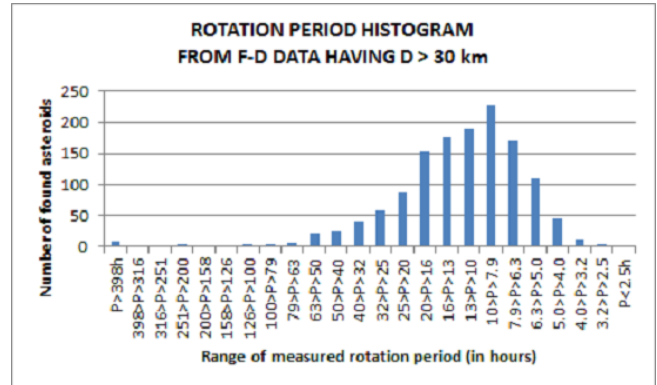


Figure 8. The histogram distribution corresponding to those currently known 1360 asteroids having a diameter larger than 30 km whose spin rate data have been rated either U = 3 or U = 2.

Figure 9 shows the histogram of number vs rotation period (logarithmic binning) distribution for smaller asteroids ( $D < 500$  m) from F-D data (since, once again, so far there is almost no W-F data for those smaller asteroids). Two subsets are shown:  $< 150$  meters and those in the range 150-500 meters. For those slower rotators greater than 2.5 hours the distribution resembles the left-side of a typical ‘bell-curve’ shape; these are primarily the larger members of this subgroup. However, for the  $< 150$  m subgroup, they appear to show a relatively flat distribution down that extends to extremely short periods to  $\sim 0.025$  hours. These fast rotators are the ‘monoliths’ having enough strength to spin faster than the ‘spin barrier’ described by Harris and Pravec (2000).

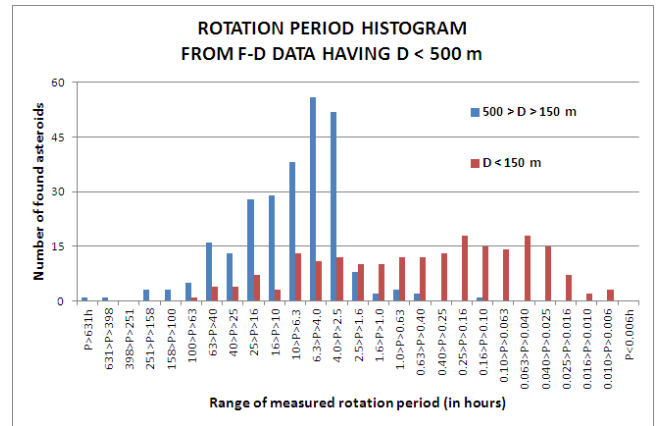


Figure 9. The histogram distribution corresponding to those currently known 465 asteroids having a diameter smaller than 500 m whose spin rate data have been rated either U = 3 or U = 2. The overall distribution is shown separated into two subsets: those 261 asteroids having  $500 > D > 150$  m for which the 2.5 ‘spin barrier’ becomes evident, and those 204 asteroids having  $D < 150$  m for which no ‘spin barrier’ prevents them from achieving faster spin rates (likely due to being coherent bodies)

Seeking and characterizing odd or outlier objects does involve ‘fishing’ a larger sample and paying less attention to biases of the sample. Observing single asteroids one at a time for that goal clearly represents an inefficient endeavor. Therefore, wide-field

surveys and less controlled samples can be very useful particularly for identifying oddballs, on condition the limitations are reasonably characterized.

As a matter of fact, of the currently known 10 slowest rotating asteroids with quality code either  $U = 3$  or  $U = 2$  (Figure 10), four of them (those 5-digit numbered) were found from wide-field surveys. The present-day record holder is 846 Lipperta, having a rated  $U = 2$  rotation period of 1641 h. On the other hand, as expected, the currently known 10 fastest rotator asteroids are all from the F-D data set.

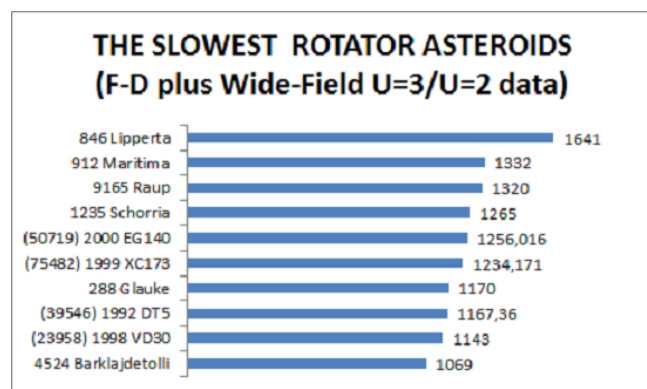


Figure 10. The 10 slowest rotator asteroids with reliable data (rated either  $U = 3$  or  $U = 2$ ) known at the beginning of 2017. The correspondent periods are expressed in hours.

At the beginning of the century, Pravec *et al.* (2002) had anticipated that in the following 10 years we would have had a much more detailed and complex picture of the asteroid rotational properties over wide range of sizes and orbits. We are seeing some fulfillment of this prediction, but much remains to be done. Wide-field asteroid photometric surveys certainly hold promise as important contributors, particularly if they can be conducted in ways that mitigate against the inherent biases identified.

#### Acknowledgements

Thanks to Alan W. Harris for several pertinent and fruitful suggestions that certainly corrected and improved this study.

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### ROTATION PERIOD OF ASTEROID 3494 PURPLE MOUNTAIN

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Data for asteroid 3494 Purple Mountain were collected from 2015 June 25 to 2015 August 17. The rotation period was determined to be  $2.928 \pm 0.0012$  h.

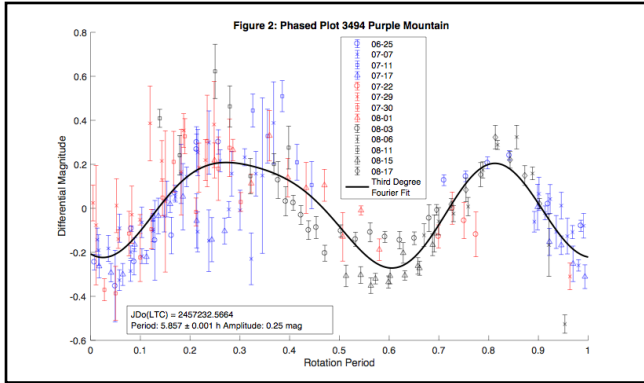
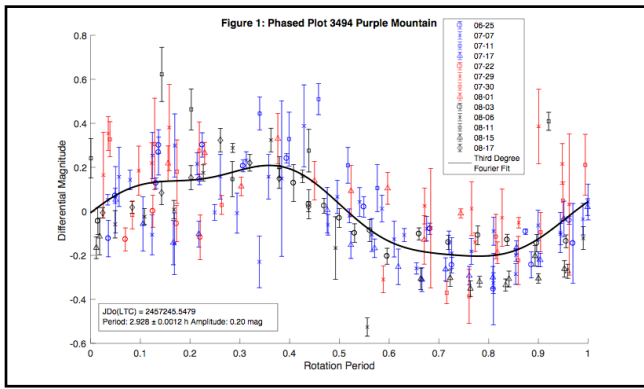
Asteroid 3494 Purple Mountain is located in the main belt. It has a semi-major axis of 2.349 AU, orbital period of 3.60 years, and eccentricity of 0.131 (JPL 2016). It was discovered by Purple Mountain Observatory at Nanking, China in 1980 (Zhang *et al.* 1983). Near-infrared reflectance spectra showed that Purple Mountain is a daughter of 4 Vesta (Kelley *et al.* 2003).

#### Data Collection and Analysis

Thirteen nights of data were collected at the MIT George R. Wallace Jr. Observatory from 2015 June 25 to 2015 August 17. Data were collected using two 14-inch Celestron Schmidt-Cassegrain telescopes equipped with SBIG STL-1001E cameras. Table 1 describes the location of Purple Mountain and number of images taken on each night.

In order to produce astronomical lightcurves, the data were first reduced using flats, darks, and biases in AstroImageJ (Collins & Kielkoph, 2013). Then, aperture photometry was performed on the reduced data to find the relative magnitude of Purple Mountain. We obtained apparent magnitudes by comparing Purple Mountain to field stars listed in the USNO-A2.0 Catalogue (Monet *et al.*, 1998). Afterwards, the asteroid motion was corrected to determine the absolute brightness using the Earth-asteroid and Sun-asteroid distance. Then a linear fit to the data was used to account for the phase angle change and to further correct for the motion.

After performing motion corrections, the data were binned by five and a lomb scargle periodogram was used to find the period of Purple Mountain (Vanderplas *et al.*, 2012). The highest peak corresponded to  $2.928 \pm 0.0012$  h, with lesser significant peaks at 2.609, 3.339, 3.879, 4.627, 5.731 h. Next, the binned data were phase folded over each of the significant peaks. The best visual fold matched the period of  $2.928 \pm 0.0012$  h (Fig. 1), which agrees with Cantu *et al.* (2016).



We also investigated the second, longer period discussed in Cantu et al. (2016) of  $5.857 \pm 0.001$  h (Fig. 2). This period was not a prominent peak in our periodogram and we therefore attribute the original peak to aliasing as our data span a longer baseline.

Results

We observed Purple Mountain 850 times over fourteen nights between June and August 2015. We determine the rotation period to be  $2.928 \pm 0.0012$  h which supports the shorter period determined by Cantu et al. (2016).

Acknowledgements

This research was supported by the George R. Wallace Jr. Astrophysical Observatory. We would also like to thank Dr. Michael Person and Tim Brothers for their advice and assistance.

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Table I: Details for Each Night of Observation

Date (UT) 2015-mm-dd	RA	DEC	Number of Images
06-25	16 27 49.96	-17 07 51.3	85
07-07	16 21 28.59	-16 29 08.9	195
07-11	16 20 22.47	-16 20 41.2	25
07-17	16 19 44.47	-16 12 15.6	80
07-22	16 20 09.50	-16 09 01.5	20
07-29	16 22 09.19	-16 09 48.9	75
07-30	16 22 34.07	-16 10 23.5	65
08-01	16 23 29.47	-16 11 51.6	50
08-03	16 24 32.25	-16 13 44.1	70
08-06	16 26 19.94	-16 17 15.2	50
08-11	16 29 54.28	-16 24 47.9	35
08-15	16 33 15.89	-16 32 07.2	60
08-17	16 35 06.33	-16 36 08.5	40

Number	Name	2016 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.	Grp
3494	Purple Mountain	06/25-08/17	895	6.6-28.0	255.13	3.98	2.928	0.0012	0.2	0.01	Vesta

Table II. Observing circumstances and results. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (JPL 2016). Grp is the asteroid family/group (Kelly et al. 2003).

**LIGHTCURVE ANALYSIS OF ASTEROIDS OBSERVED  
AT THE OAKLEY SOUTHERN SKY OBSERVATORY:  
2016 JULY – OCTOBER**

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On forty individual nights from 2016 July 29 to October 9, CCD images were taken in order to collect photometric data for 25 asteroids: 850 Altona, 1267 Geertruida, 1599 Giomus, 1945 Wesselink, 2280 Kunikov, 2428 Kamenyar, 2562 Chaliapin, 2989 Imago, 3038 Bernes, 3777 McCauley, 4103 Chahine, 4336 Jasniewicz, 4405 Otava, 4438 Sykes, 5937 Loden, 7389 Michelcombes, 9033 Kawane, 10287 Smale, 11003 Andronov, 11787 Baumanka, (14686) 1999 XA174, 17770 Baume, (18977) 2000 QK217, (21101) 1992 OJ1, and (69081) 2003 AZ64.

CCD photometric observations were made of 25 asteroids from 2017 July 29 to October 9. The images used for lightcurve analysis were taken at the Oakley Southern Sky Observatory, located in New South Wales, Australia, using a 0.5-meter *f*/6.71 Planewave telescope and a STX-16803 CCD camera binned 3x3 with a luminance filter. All images were collected in 2016: July 29-31; August 3-13, 25-29, and 31; September 4-7, 10-11, 19, 22-23, 25-26, and 29; and October 1 and 3-9. *Maxim DL* software was used to calibrate the images. Measurement, Fourier analysis, and lightcurve production were accomplished with *MPO Canopus* software.

Table I lists the results and observing circumstances. If no analysis results are listed, the period of that asteroid could not be

determined as a result of insufficient data available or excessive noise in the data. One of our targeted minor planets, 3038 Bernes, turned out to be a near-Earth object. Because of its rapid apparent motion, we did not make any measurements on this minor planet.

850 Altona. Pilcher *et al.* (2011) determined the period of 850 Altona to be  $11.197 \pm 0.002$  h. We attempted to fit our data to this period, but we were unable to find a recognizable pattern because of a lack of data.

1267 Geertruida. The period of  $5.5087 \pm 0.0007$  h we found for 1267 Geertruida matches to within uncertainty the period of 0.229 d (5.50 h) reported by Lagerkvist (1979) with no uncertainty given.

1599 Giomus. Clark (2010) reported the period of 1599 Giomus as  $6.46 \pm 0.05$  h, with high amplitude uncertainty. We were unable to determine a period for this asteroid because our measured magnitude variation was too small compared to the uncertainty in the individual data points.

1945 Wesselink. The period we determined for 1945 Wesselink matches the period of  $3.5457 \pm 0.0054$  h reported by Waszczak *et al.* (2015) to within stated uncertainty.

4405 Otava. Waszczak *et al.* (2015) determined the period of 4405 Otava to be  $2.8790 \pm 0.0011$  h. We tried to fit our data with this period but could not find a pattern because of excessive noise in our data.

17770 Baume. The period determined for 17770 Baume matches the period determined for that asteroid by Carbo *et al.* (2009) to within the stated uncertainty.

(21101) 1992 OJ1. The period of  $7.889 \pm 0.002$  h we determined for this asteroid agrees with the period of  $7.8914 \pm 0.0039$  h reported by Waszczak *et al.* (2015).

Number	Name	Dates (2016/mm/dd)	Points	Phase	LPAB	BPAB	Period (h)	PE	Amp	AE
850	Altona	08/25-08/31	47	4.7, 12.5	325	-9	-	-	0.14	0.03
1267	Geertruida	09/25-10/09	136	1.7, 9.1	359	-3	5.5087	0.0007	0.35	0.03
1599	Giomus	08/25-08/31	55	3.6, 11.4	327	-7	--	-	0.04	0.02
1945	Wesselink	09/22-10/09	131	3.5, 12.4	354	-3	3.5473	0.0002	0.50	0.05
2280	Kunikov	09/22-10/09	163	3.8, 11.9	359	-5	21.45	0.01	1.0	0.1
2428	Kamenyar	08/25-08/31	61	3.5, 11.1	328	-7	--	-	0.06	0.03
2562	Chaliapin	07/31-08/13	144	3.0, 6.6	305	-7	11.45	0.02	0.40	0.05
2989	Imago	09/04-09/11	80	6.5, 10.1	335	-6	11.457	0.004	0.45	0.05
3038	Bernes	08/25-08/31	58	1.9, 15.1	332	-2	-	-	-	-
3777	McCauley	09/04-09/11	92	4.8, 7.7	339	-6	-	-	0.10	0.05
4103	Chahine	08/25-08/31	124	20.5, 22.1	331	-30	-	-	0.35	0.05
4336	Jasniewicz	08/25-08/31	52	3.7, 17.2	330	-3	-	-	0.04	0.02
4405	Otava	09/22-10/09	135	3.5, 9.4	355	-7	-	-	0.20	0.05
4438	Sykes	07/31-08/13	159	8.4, 12.2	300	-16	-	-	0.10	0.05
5937	Loden	09/04-09/11	49	3.3, 6.3	340	-4	2.9189	0.0003	0.36	0.05
7389	Michelcombes	09/04-09/11	88	6.1, 9.4	337	-7	-	-	0.10	0.05
9033	Kawane	09/22-10/08	242	9.4, 11.8	359	-20	5.7656	0.0003	0.45	0.05
10287	Smale	08/25-09/19	66	4.5, 16.5	331	-6	-	-	0.25	0.05
11003	Andronov	09/22-10/09	94	2.9, 10.9	359	-4	4.5223	0.0006	0.19	0.05
11787	Baumanka	09/04-09/11	79	3.7, 6.3	339	-5	7.593	0.007	0.23	0.03
14686	1999 XA174	09/22-10/09	132	3.0, 11.3	356	-4	4.3283	0.0002	0.6	0.05
17770	Baume	09/04-09/11	85	5.7, 9.5	336	-6	3.263	0.001	0.35	0.1
18977	2000 QK217	07/29-08/13	194	12.3, 15.1	304	-20	-	-	0.15	0.05
21101	1992 OJ1	07/31-08/13	92	10, 14.9	300	-11	7.889	0.002	0.6	0.1
69081	2003 AZ64	07/31-08/13	93	16.9, 21.2	302	-21	-	-	0.15	0.05

Table I. Observing circumstances and results. The phase angle is given for the first and last date. LPAB and BPAB are the approximate phase angle bisector longitude and latitude at mid-date range.

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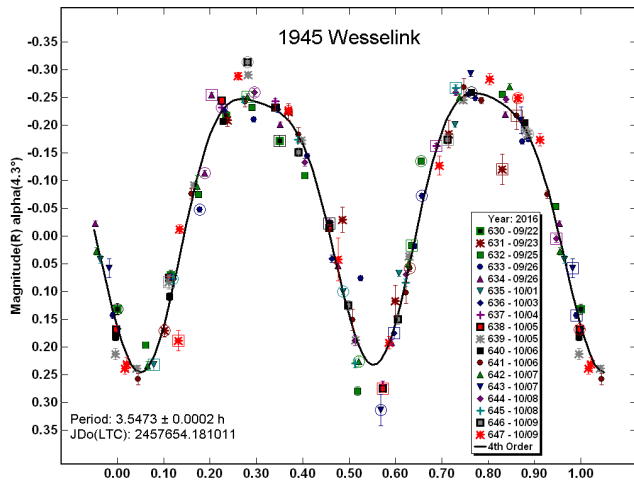
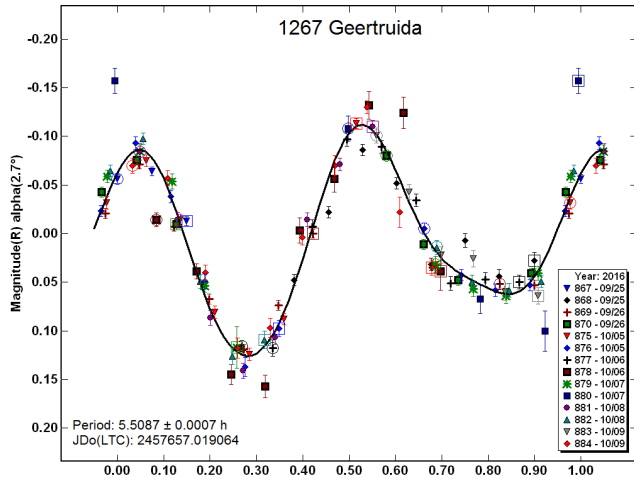
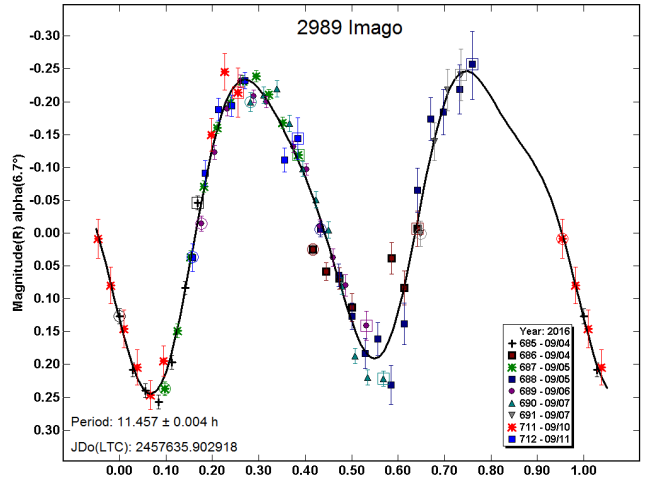
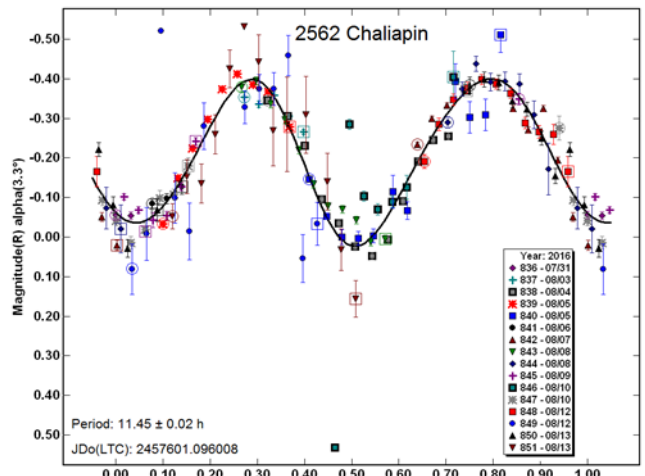
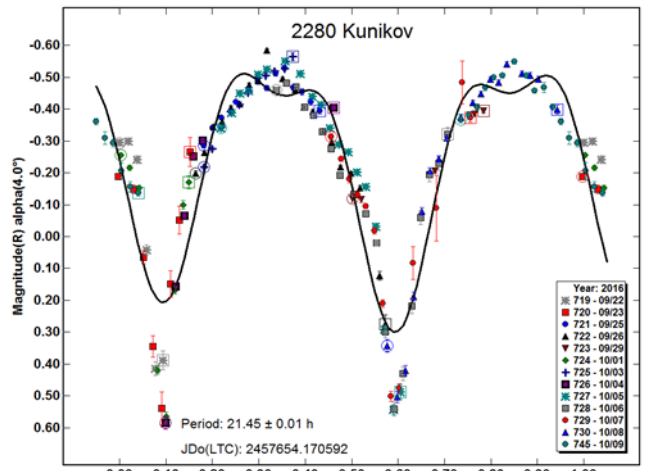
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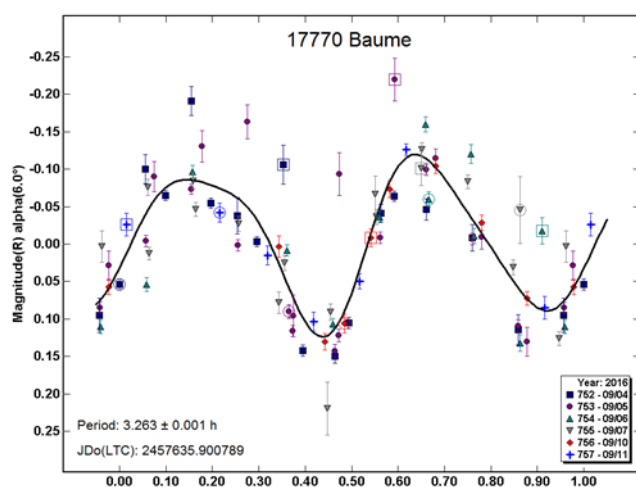
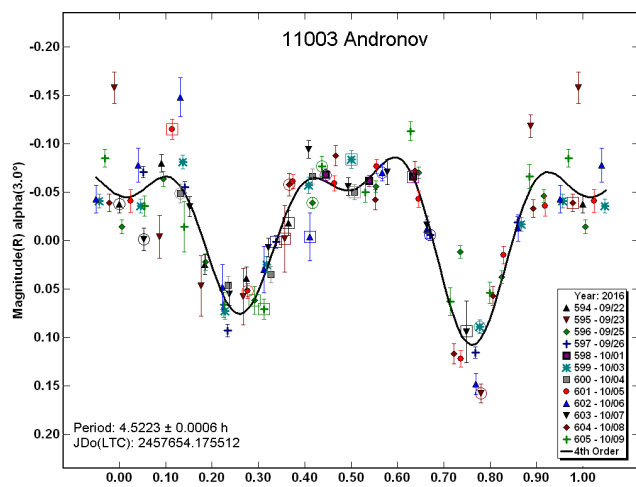
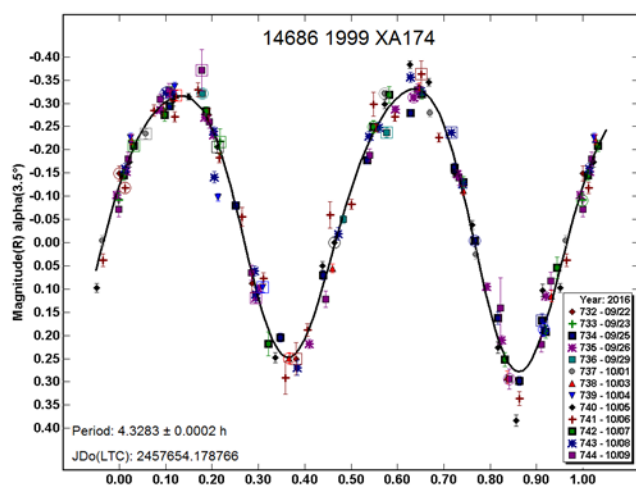
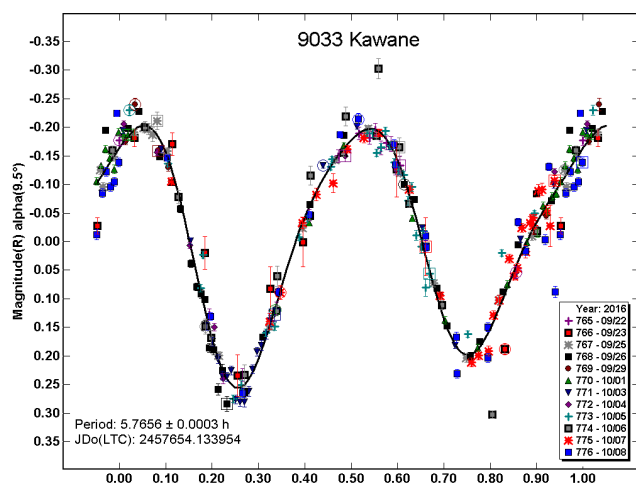
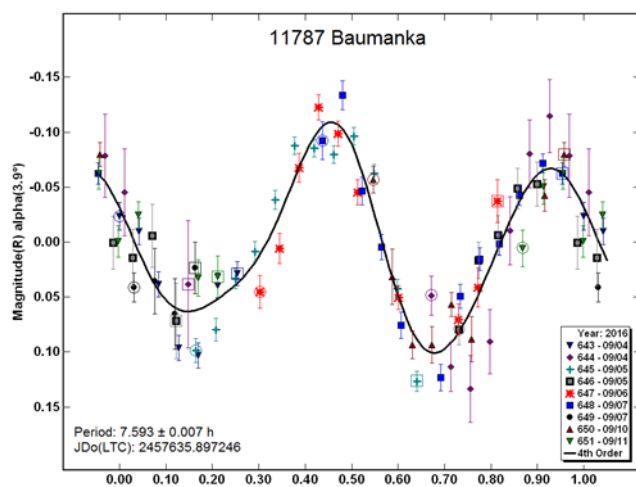
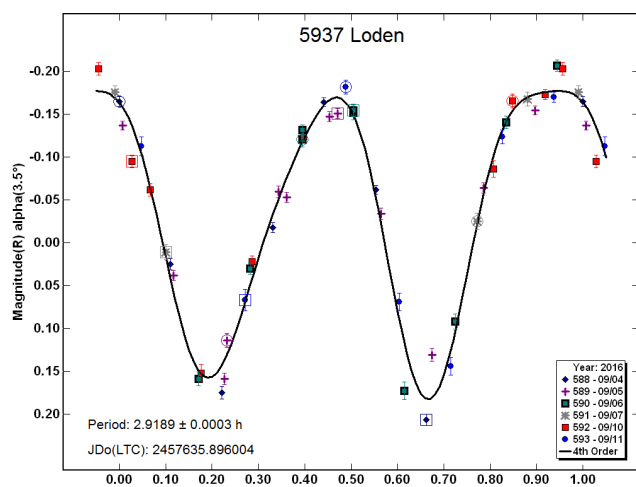
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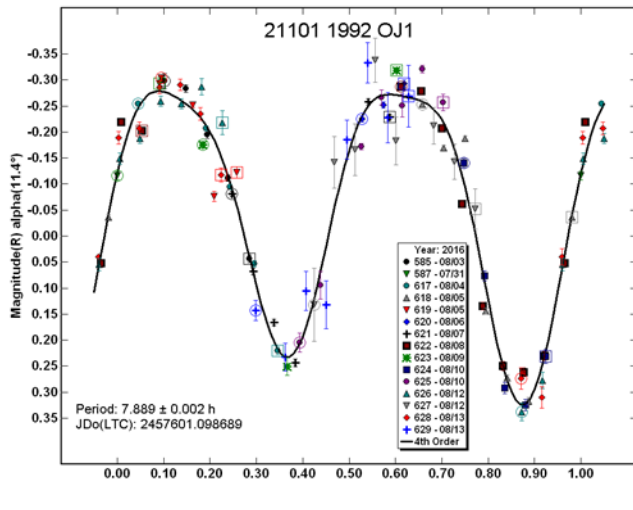
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**PHOTOMETRIC OBSERVATIONS OF THE NEAR-EARTH ASTEROIDS 326683 (2002 WP) AND 2016 LX48**

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We obtained photometric results for the near-Earth asteroids (326683) 2002 WP and 2016 LX48 during their close approaches in 2016 December and October, respectively. Our analysis found a synodic period for (326683) 2002 WP of  $P = 6.2772 \pm 0.0479$  h and, for 2016 LX48,  $P = 5.6742 \pm 0.0074$  h.

The near-Earth asteroids (326683) 2002 WP and 2016 LX48 were observed from the Astronomical Institute of the Romanian Academy (MPC code 073) using a 0.4-m *f*/6 Ritchey-Chretien telescope and SBIG STL 11000M CCD camera cooled to  $-20$  °C. The field-of-view was 44x29 arcmin and the pixel scale 0.656 arcsec/pixel. The asteroid (326683) 2002 WP was observed by taking unfiltered images with 60 to 120 seconds integration time. The observations of 2016 LX48 were made using unfiltered exposures with an integration time between 60 and 180 seconds (considering the sky motion of the object during each observing night). In both cases we used differential tracking at half of the object motion rate.

The raw science images were calibrated with bias, flats, and darks using the standard procedures of *Maxim DL* (2016) software. Data processing and period analysis were made using *MPO Canopus* software (Warner, 2015). Differential photometric measurements

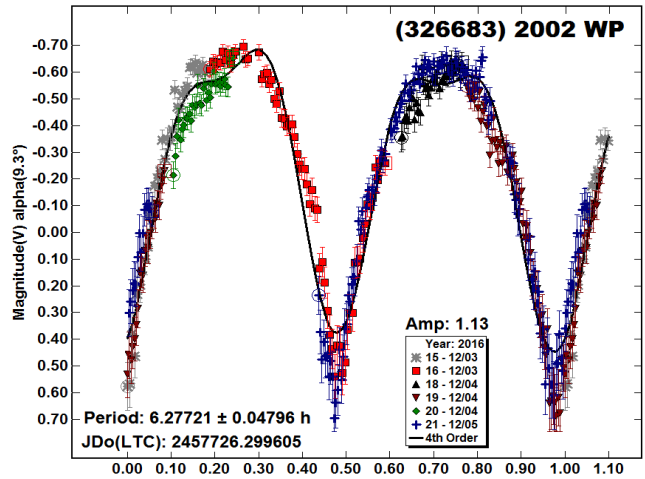
were performed using the Comp Star Selector (CSS) procedure in *MPO Canopus*, which allows selecting up to five comparison stars with a near solar color. The comp star magnitudes were taken from the CMC-15 catalog (<http://svo2.cab.inta-csic.es/vocats/cmc15/>).

Table I gives the results and general observing circumstances for both asteroids.

(326683) 2002 WP was observed between 2016 Dec 2-5, just before its close approach to Earth at 0.152 AU on 2016 Dec 7 at 20:07 (Minor Planet Center). During our observing run, the apparent magnitude of the asteroid varied from 15.3 to 15.0 as its distance to Earth decreased from 0.156 to 0.153 AU.

Detailed observation circumstances are given in Table II. Due to a sky motion of  $\sim 5.4$  arcsec/min, the asteroid crossed over more than one CCD field during a given night. However, in each field we identified solar type comparison stars and we were able to combine the photometric measurements.

For 2002 WP we determined a period of  $6.27721 \pm 0.04796$  h, with amplitude of 1.13 mag.



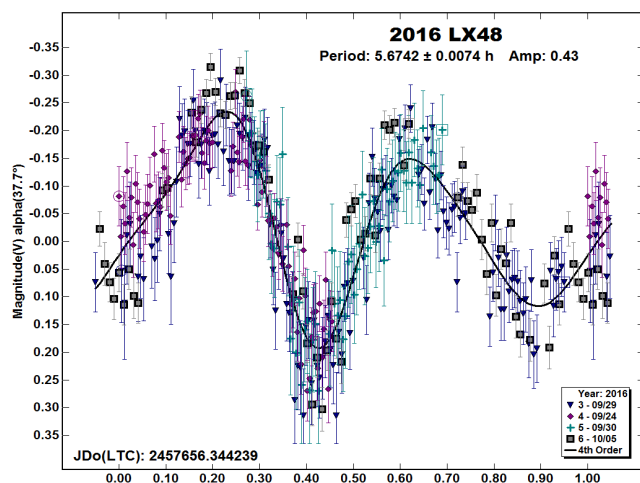
Date (2016)	UT	V	PA	Airmass
Dec 2/3	23:40-01:28	15.3	11.1	1.2-1.8
Dec 3/4	21:00-01:00	15.2	9.1	1.2-1.5
Dec 4/5	19:00-23:50	15.2	7.2	1.6-1.2
Dec 5	19:50-23:50	15.1	5.5	1.5-1.2

Table II. Detailed observation circumstances for (326683) 2002 WP: the date, the UT at the start and at the end of the observing session, apparent V magnitude, the phase angle and the air mass at the beginning and the end of the observations.

2016 LX48 was observed during a favourable apparition between 2016 Sep 24 and Oct 5, two weeks after a close approach to Earth at 0.045 AU on 2016 Sep 12 at 20:55 (Minor Planet Center). The asteroid's apparent magnitude varied during this interval from 15.8 to 16.9, and its distance to Earth increased from 0.087 to 0.159 AU. The detailed observation circumstances are given in Table III.

Number	Name	2016 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.
326683	2002 WP	12/02-12/05	427	11.1, 5.5	73	-5	6.27721	0.04796	1.13	0.05
	2016 LX48	09/24-10/05	859	43.8, 31.8	17	20	5.6742	0.0074	0.43	0.03

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984).



Our period of  $5.6742 \pm 0.0074$  h, with amplitude of 0.43 mag, is in agreement with the one found by (Warner, 2017) and (Benishek, 2017), but disagrees with the period of  $3.815 \pm 0.001$  h found by (Carbognani, 2017).

Date (2016)	UT	V	PA	Airmass
Sep 24	18:11–20:51	15.8	43.8	1.1–1.0
Sep 29	17:30–22:49	16.3	37.8	1.2–1.0
Sep 30	17:30–20:10	16.4	36.8	1.3–1.1
Oct 5/6	19:20–00:28	16.8	31.8	1.2–1.0

Table III. Detailed observation circumstances for 2016 LX48: the date, the UT at the start and at the end of the observing night, the apparent V magnitude, the phase angle and the air mass at the beginning and at the end of the observations.

#### Acknowledgements

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## LIGHTCURVE ANALYSIS FOR MINOR PLANET 703 NOEMI

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CCD images were taken of asteroid 703 Noemi from 2016 November 16 to 2017 January 31 to determine its rotation period. The data analysis gives a complex light curve with a rotation period of  $201.7 \pm 0.7$  hours.

The main-belt asteroid 703 Noemi was discovered by Johan Palisa on 1910 October 3 and is named for Baroness Valentine Noémi von Rothschild to celebrate her engagement to Baron Sigismund von Springer. Its orbital period is approximately 3.21 years. The absolute magnitude is  $H = 12.5$ , the geometric albedo is 0.368, and the estimated diameter is 7.25 km (JPL, 2017). A search in the asteroid lightcurve database (LCDB: Warner et al., 2009) did not provide any information about the rotation period for the asteroid. Consequently, we started an observational campaign aimed at estimating the period.

CCD photometric observations were carried out at three different amateur observatories, all of them located in the south of Italy, and by two remote telescope stations: iTelescope T7 (MPC I89; Nerpio, Spain) and iTelescope T21 (MPC H06; Mayhill, New Mexico, USA). Table I lists the telescope/CCD camera combinations used for the observations.

A total of 2197 images were collected in 43 observing sessions with exposure times ranging from 120 to 1080 s. All images were astrometrically aligned, dark, and flat-field corrected using *Maxim DL* and *Astrometrica*. *MPO Canopus* (Warner, 2016) was used to measure the magnitudes, perform Fourier analysis, and produce the final lightcurve. In particular, data were reduced in *MPO Canopus* using differential photometry. Night-to-night zero point calibration was accomplished by selecting up to five comparison stars with near-solar colors using the “comp star selector” feature. The MPOSC3 (Warner, 2007) star catalog was used for determining the comparison star magnitudes and the “StarBGone” routine within *MPO Canopus* was used to subtract stars that occasionally merged with the asteroid during the observations. *MPO Canopus* was also used for rotation period analysis. The software employs the FALC Fourier analysis algorithm developed by Harris (Harris et al., 1989).

The observations started at the middle of 2016 November. After accumulating 48 sessions that were completed at the end of 2017 January, it was very hard to obtain a solution using a short (from a few hours to tens of hours) period. The period analysis gave the best solution of  $201.7 \pm 0.7$  hours with an amplitude of  $0.78 \pm 0.15$  mag. The rotation period is associated with a lightcurve showing a

Site	Ap (m)	Type	f/	Camera	Array	Filter
Pontecagnano, Italy	0.24	SC	4.8	Moravian KAF1603 ME	1536x1024x9μ	Rc
Maiori-Erchie, Italy	0.20	N	4.0	StarlightX-Press ICX085AL	1300x1030x6.7μ	C
Somma Vesuviana, Italy	0.10	R	6.7	ATIK KAF-8300	3362x2537x5.4μ	C
Nerpio, Spain	0.43	DK	4.3	SBIG STL-11000M	4008x2672x9μ	Rc
Mayhill, USA	0.43	DK	6.8	FLI-PL6303E	3072x2048x9μ	Rc

Table I. List of telescope/camera combinations. SC:Schmidt-Cassegrain; N:Newtonian; R:Refractor; DK:Corrected Dall-Kirkham.

Number	Name	20yy/mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.	Exp (s)
703	Noemi	16/11/16-17/01/31	2197	2.84-29.4	56	-2	201.7	0.7	0.78	0.15	120-1080

Table II. Observing circumstances and results. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984). Exp is exposure range, seconds.

complex behavior with different maxima and bumps (Fig. 1) possibly attributed to an irregular shape of the asteroid. However, tumbling might also explain the irregular behavior. From the data shown in Figure 1, it is clear that the lightcurve is only partially sampled. Table II gives the observing circumstances and results. We rate this result U = 2 (see Warner *et al.*, 2009). *This is not necessarily the value that will be assigned in the LCDB.*

New observations and additional data of 703 Noemi at future oppositions will be required in order to improve the current analysis and eventually confirm its very long rotation period. A sufficient number of sessions to include full coverage of at least two rotations based on the suspected period are needed to confirm that 703 Noemi belongs to the very slow rotators class of asteroids.

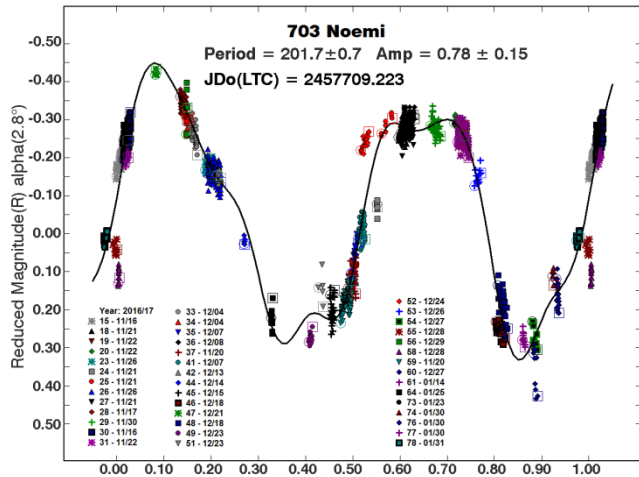


Fig.1. Lightcurve for asteroid 703 Noemi fit to a period of 201.7 ± 0.7 hours and with an amplitude of 0.78 ± 0.15 mag.

Acknowledgements

AN and AV are indebted to Brigida and Tatiana for their invaluable support.

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LIGHTCURVE ANALYSIS FOR TEN MAIN BELT ASTEROIDS

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Photometric observations of ten main-belt asteroids, 2854 Rawson, 3113 Chizhevskij, 5318 Dientzenhofer, (5563) 1991 VZ1, 7143 Haramura, 10421 Dalmatin, (11386) 1998 TA18, (18429) 1994 AO1, (23496) 1991 VN3, and (31782) 1999 KM6 were made at the Eurac Observatory (MPC C62). Results of lightcurve analysis are presented.

CCD photometric observations of ten main-belt asteroids were made at the Eurac Observatory (MPC C62). Asteroids 2854 Rawson, 3113 Chizhevskij, 5318 Dientzenhofer, (5563) 1991 VZ1, 7143 Haramura, 10421 Dalmatin, (11386) 1998 TA18, and (23496) 1991 VN3, were observed in 2016 with filter V (except (23496) 1991 VN3 with filter R). The observations for (18429) 1994 AO1 and (31782) 1999 KM6, were made in 2017 with filter R.

All images were obtained with a 0.30-m reflector telescope reduced to f/4.0, a QHY9 CCD camera, and then calibrated with dark and flat-field frames. The computer clock was synchronized with an Internet time server before each session. Differential photometry and period analysis were done using *MPO Canopus* version 10.4.3.17 (Warner, 2014).

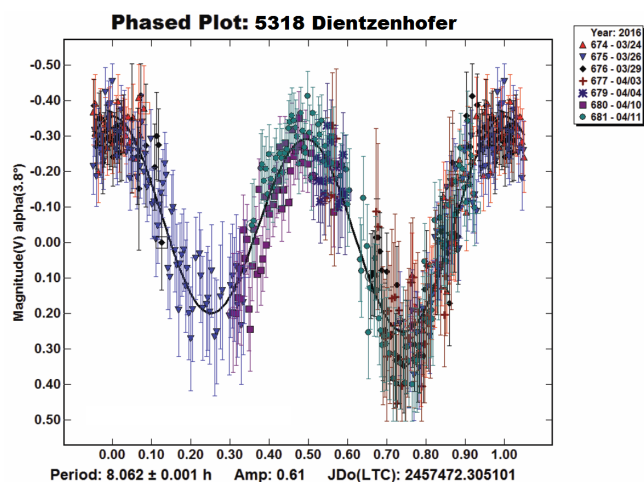
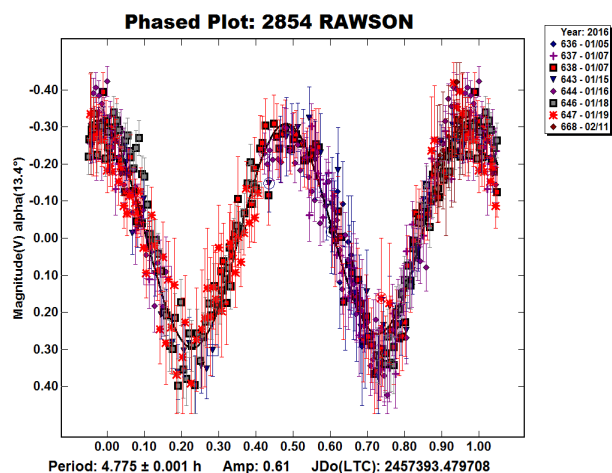
2854 Rawson This main-belt asteroid was reported as a lightcurve photometry opportunity for 2016 January on the MinorPlanet.info

Number	Name	yyyy mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.	TxC
2854	Rawson	2016 01/05-02/11	484	13.8, 6.9	129.7	-2.0	4.775	0.001	0.61	0.08	S
3113	Chizhevskij	2016 10/29-10/31	276	3.4, 4.4	30.4	-3.0	18.7919	0.0001	0.62	0.09	S
5318	Dientzenhofer	2016 03/24-04/11	476	3.5, 12.3	181.7	4.7	8.062	0.001	0.61	0.15	S
5563	1991 VZ1	2016 03/14-03/17	264	5.9, 5.9	174.6	12.9	3.019	0.002	0.25	0.09	SC
7143	Haramura	2016 08/12-08/24	529	9.3, 7.8	330.7	17.2	3.664	0.001	0.17	0.08	C
10421	Dalmatin	2016 10/03-10/07	373	6.8, 4.3	20.2	0.4	2.997	0.001	0.23	0.09	S
11386	1998 TA18	2016 10/30-11/08	380	16.4, 20.3	18.4	8.7	15.95	0.01	0.49	0.12	S
18429	1994 A01	2017 01/22-01/29	557	2.6, 4.3	123.3	-4.7	3.902	0.001	0.15	0.05	S
23496	1991 VN3	2016 11/29-12/02	363	2.3, 1.9	69.3	2.3	2.470	0.002	0.18	0.04	S
31782	1999 KM6	2017 01/17-01/20	388	2.0, 1.2	120.0	1.9	3.226	0.002	0.5	0.12	SC

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984). TxC is the asteroid taxonomic class.

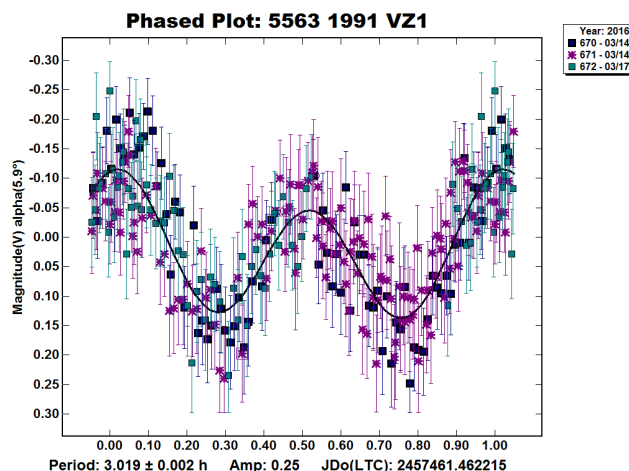
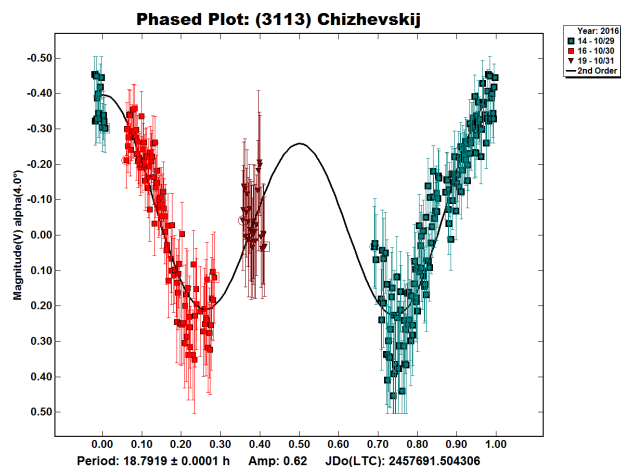
web site (<http://www.MinorPlanet.info>; hereafter referenced as MPI). The derived synodic period was  $P = 4.775 \pm 0.001$  h with an amplitude of  $A = 0.61 \pm 0.09$  mag. Black *et al.* (2016, Oakley Southern Sky Observatory in New South Wales, Australia), reported a period of 4.7755 h with  $A = 0.61 \pm 0.08$  mag., in agreement with the result given here.

5318 Dientzenhofer The main-belt asteroid 5318 Dientzenhofer was reported as a lightcurve photometry opportunity for 2016 March. The derived synodic period was  $P = 8.062 \pm 0.001$  h with an amplitude of  $A = 0.61 \pm 0.15$  mag. Salvaggio *et al.* (2016) reported a period of 8.062 h with  $A = 0.82$  mag., which is in agreement with the result given here.

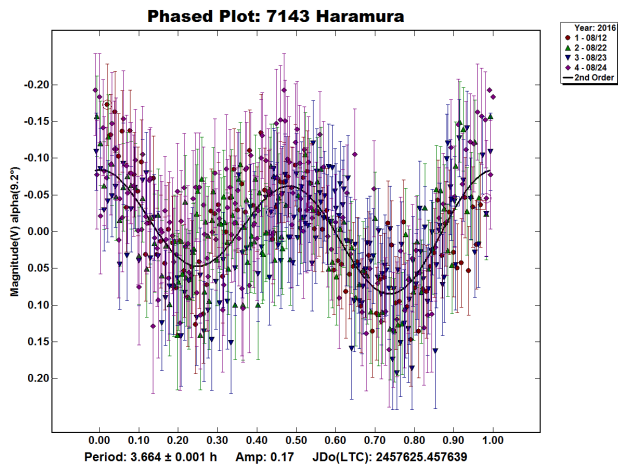


3113 Chizhevskij is a main-belt asteroid that was reported as a lightcurve photometry opportunity for 2016 October (MPI). The derived synodic period was  $P = 18.7919 \pm 0.0001$  h with an amplitude of  $A = 0.62 \pm 0.09$  mag. There were no entries in the LCDB (Warner *et al.*, 2009) for this asteroid. Unfortunately, for bad weather, it was followed for 3 nights only, therefore, the derived synodic period result is not secure.

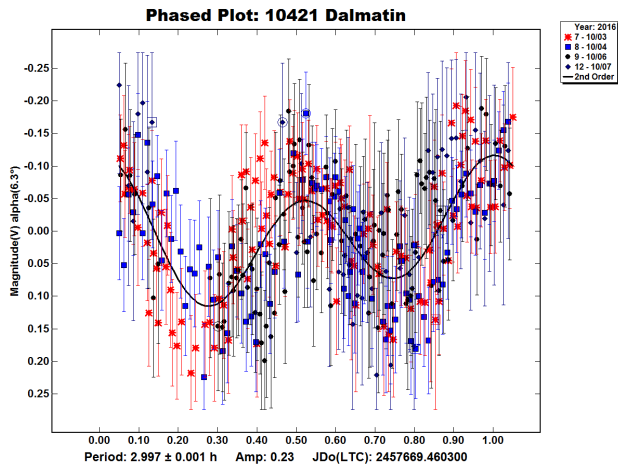
(5563) 1991 VZ1 The main-belt asteroid (5563) 1991 VZ1 was reported as a lightcurve photometry opportunity for 2016 March (MPI). The derived synodic period was  $P = 3.019 \pm 0.002$  h with an amplitude of  $A = 0.25 \pm 0.09$  mag. A synodic period of 3.223 h with an amplitude of  $A = 0.30$  were found by Behrend 2016, <https://obswww.unige.ch/~behrend/page5cou.html#005563>



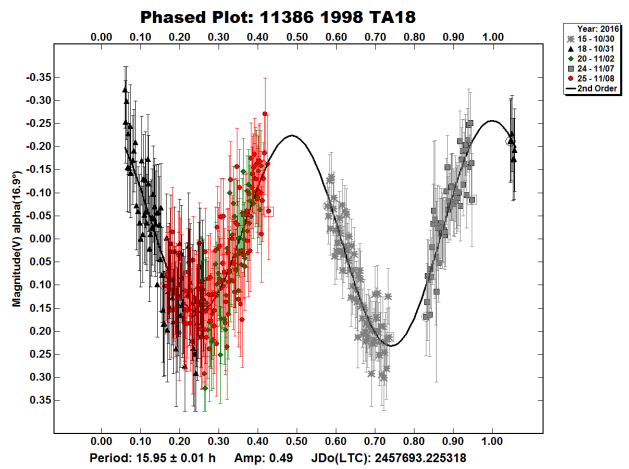
7143 Haramura The main-belt asteroid 7143 Haramura was reported as a lightcurve photometry opportunity for 2016 August (MPI). The derived synodic period was  $P = 3.664 \pm 0.001$  h with an amplitude of  $A = 0.17 \pm 0.08$  mag. There were no entries in the LCDB (Warner et al., 2009) for this asteroid.



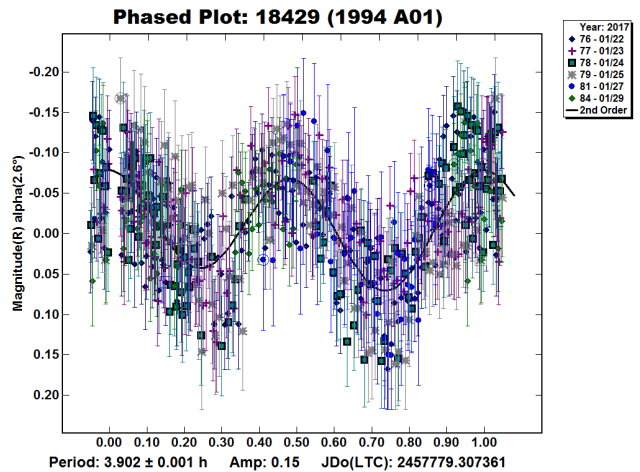
10421 Dalmatin This was a lightcurve photometry opportunity for 2016 October (MPI). Analysis found a synodic period of  $P = 2.997 \pm 0.001$  h with an amplitude of  $A = 0.23 \pm 0.09$  mag. There were no entries in the LCDB (Warner et al., 2009) for this asteroid.



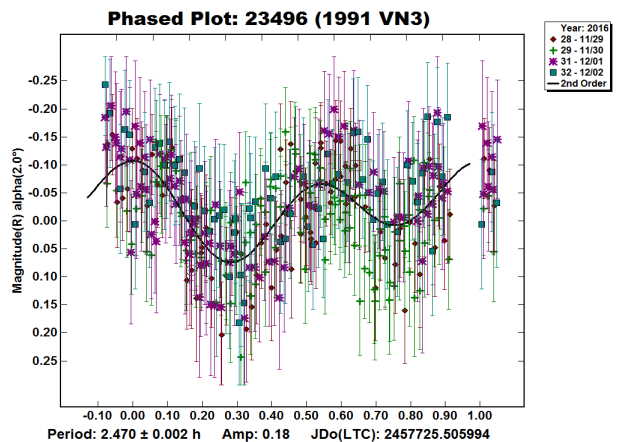
(11386) 1998 TA18 This was a lightcurve photometry opportunity for 2016 October (MPI). The derived synodic period was  $P = 15.95 \pm 0.01$  h with an amplitude of  $A = 0.49 \pm 0.12$  mag. Pravec et al. (2016) reported (11386) 1998 TA18 with a period of 15.959 h and amplitude of  $A = 0.65$  mag. Papini *et al.* (2017) reported a periods of 15.943 h, and Behrend (2016) reported a period of 15.962 h (<https://obswww.unige.ch/~behrend/page5cou.html#011386>).



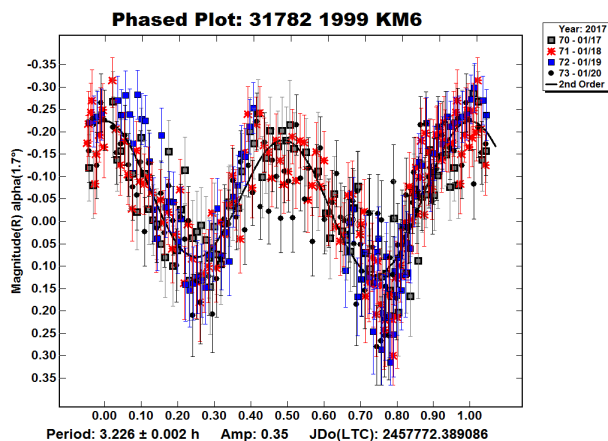
(18429) 1994 A01 The main-belt asteroid (18429) 1994 A01 was reported as a lightcurve photometry opportunity for 2017 January (MPI). The derived synodic period is  $P = 3.902 \pm 0.001$  h with an amplitude of  $A = 0.15 \pm 0.05$  mag. There were no entries in the LCDB (Warner et al., 2009) for this asteroid.



(23496) 1991 VN3 The main-belt asteroid (23496) 1991 VN3 was reported as a lightcurve photometry opportunity for 2016 November (MPI). The derived synodic period was  $P = 2.470 \pm 0.002$  h with an amplitude of  $A = 0.18 \pm 0.04$  mag. There were no entries in the LCDB (Warner et al., 2009) for this asteroid.



(31782) 1999 KM6 The main-belt asteroid (31782) 1999 KM6 was reported as a lightcurve photometry opportunity for 2017 January (MPI). The derived synodic period was  $P = 3.226 \pm 0.002$  h with an amplitude of  $A = 0.35 \pm 0.12$  mag. There were no entries in the LCDB (Warner et al., 2009) for this asteroid.



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## THE ROTATION PERIODS OF ASTEROIDS 4668 RAYJAY, 5152 LABS, 6581 SOBERS, AND 14917 TACO

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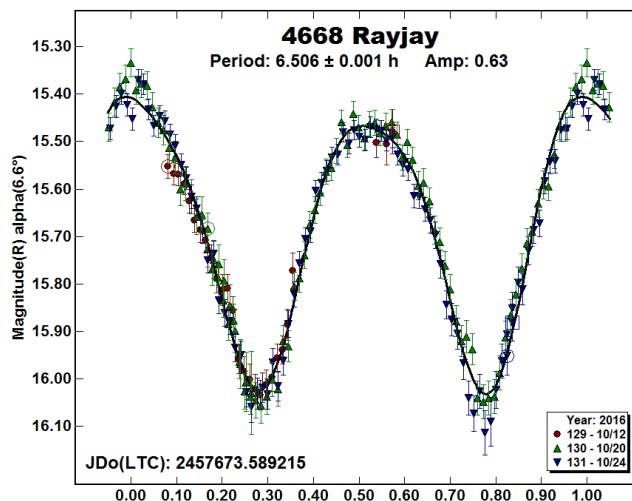
(Received: 2017 March 21)

Photometric observations of four asteroids were made over 14 nights from 2016 September to November. The measured synodic periods were: 4668 Rayjay,  $6.506 \pm 0.001$  h; 5152 Labs,  $3.8801 \pm 0.0001$  h; 6581 Sobers,  $6.635 \pm 0.001$  h; and 13917 Taco,  $9.7078 \pm 0.0001$  h.

CCD photometric observations of four asteroids were made from the Phillips Academy Observatory. They were chosen for their appealing names, relatively bright magnitudes, and high declinations. All observations were made with a 0.40-m  $f/8$  Ritchey-Chrétien by DFM Engineering and Andor Tech iKon DW436 CCD camera with a 2048x2048 array of 13.5-micron pixels. The resulting image scale was 0.86 arcseconds per pixel. All images were dark and flat-field corrected and guided.

*MPO Canopus* (Warner, 2013) was used to make photometric measurements of the images using differential photometry as well as to generate the final lightcurves. Comparison stars were chosen to have near solar-color using the Comp Star Selector tool in *MPO Canopus*. In addition, brighter comparison stars were favored. Data merging and period analysis were also done with *MPO Canopus* using an implementation of a Fourier analysis algorithm by Harris (FALC; Harris et al., 1989). The combined data set was analyzed by students in an astronomy research class taught by Caroline Odden.

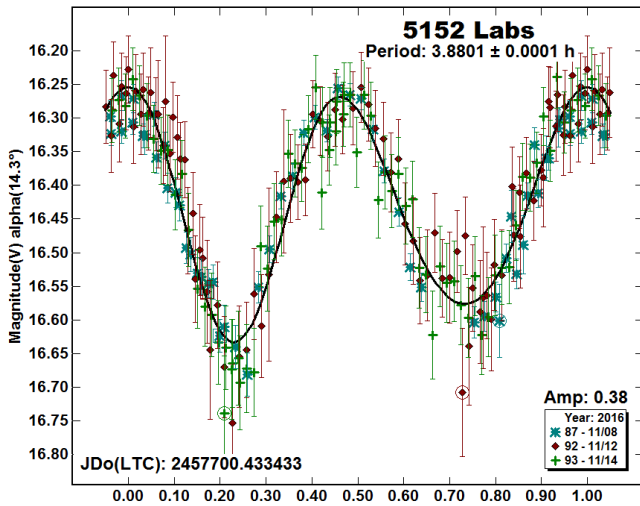
4668 Rayjay. The lightcurve of 4668 Rayjay was determined from three nights of data from 2016 October. A search of the asteroid lightcurve database (LCDB; Warner et al., 2009) and other sources revealed no previous entries. The resulting lightcurve was found to have amplitude 0.63 mag and period  $6.506 \pm 0.001$  h. The lightcurve was compiled by J. Jusuf.



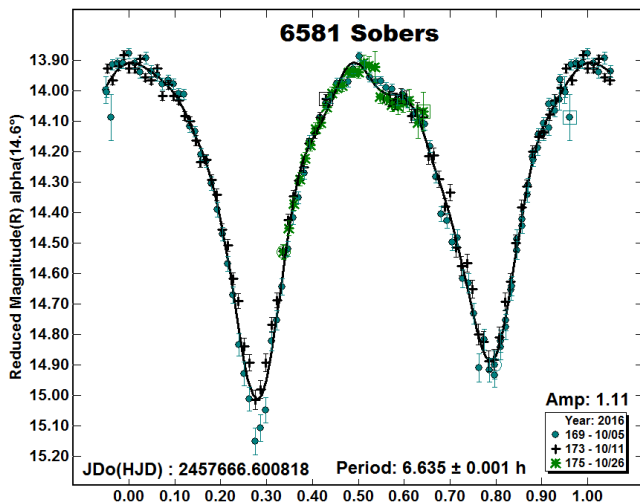
Number	Name	2016 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.	TxC
4668	Rayjay	10/12-10/24	206	6.7, 10.3	9.5	10.6	6.506	0.001	0.63	0.05	C
5152	Labs	11/08-11/14	212	14.3, 16.5	23.8	13.9	3.8801	0.0001	0.38	0.1	S
6581	Sobers	10/05-10/26	198	21.7, 20.7	36.5	5.7	6.635	0.001	1.11	0.02	S
14917	Taco	09/13-09/28	387	8.3, 6.4	2.7	10.4	9.7078	0.0001	0.65	0.05	C

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984). TxC is the taxonomic class as found in the LCDB (Warner *et al.*, 2009).

**5152 Labs.** The lightcurve of 5152 Labs was determined from three nights of data from 2016 November. A search of the asteroid lightcurve database (LCDB; Warner *et al.*, 2009) and other sources revealed no previous entries. The resulting lightcurve was found to have amplitude 0.38 mag and period  $3.8801 \pm 0.0001$  h. The lightcurve was compiled by E. Zaeder.

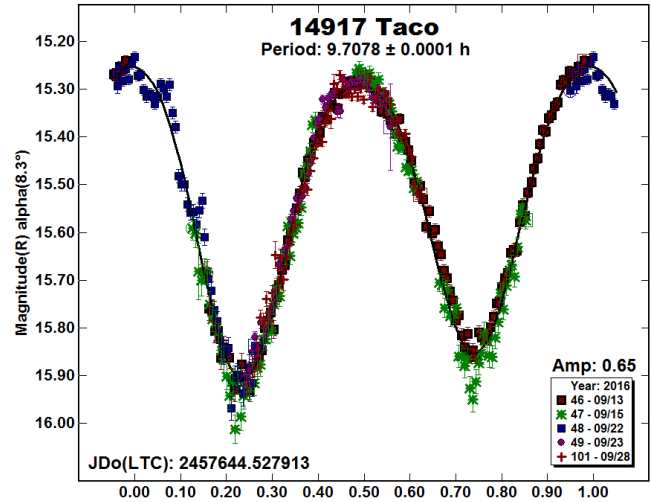


**6581 Sobers.** The lightcurve of 6581 Sobers was determined from three nights of data from 2016 October. The resulting lightcurve was found to have amplitude 1.11 mag and period  $6.635 \pm 0.001$  h. Pravec *et al.* (2016) report a period of 6.6338 h  $\pm$  0.0001 h and amplitude 1.14 mag, in good agreement with our results. The lightcurve was compiled by A. Wang.



**14917 Taco.** The lightcurve of 14917 Taco was determined using five nights of data from 2016 September to October. A search of the asteroid lightcurve database (LCDB; Warner *et al.*, 2009) and other sources revealed no previous entries. The resulting

lightcurve was found to have amplitude 0.63 mag and period  $9.7090 \pm 0.0005$  h. The lightcurve was compiled by O. Keefe.



#### Acknowledgements

Research at the Phillips Academy Observatory is supported by the Israel Family Foundation. Funding for the Andor Tech camera was generously provided by the Abbot Academy Association.

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## ROTATION PERIOD DETERMINATION FOR 467 LAURA

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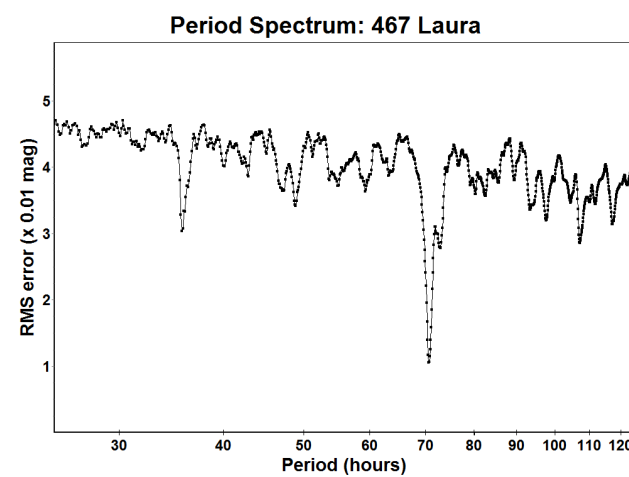
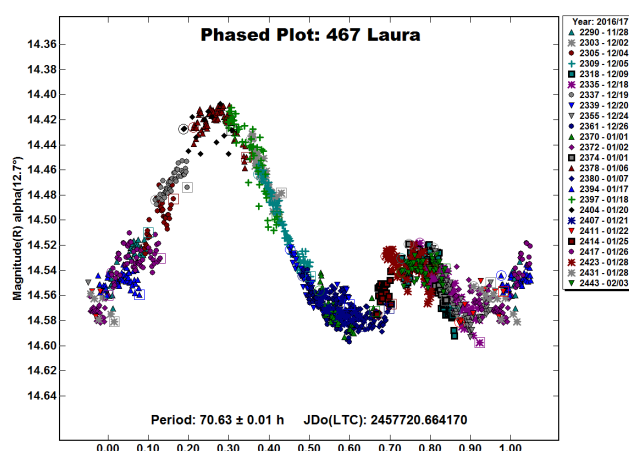
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(Received: 2017 February 16)

We find for 467 Laura a synodic rotation period of  $70.63 \pm 0.01$  hours, amplitude  $0.15 \pm 0.02$  magnitudes.

Previously published rotation periods for 467 Laura are by Behrend (2005), >12 hours, and by Ferrero (2012), 36.8 hours. Both are based on incomplete lightcurves and therefore of low reliability. The first few sessions of this investigation by first author Pilcher suggested a period that was nearly Earth commensurate and a small amplitude. He requested collaboration by V. Benishek, who kindly accepted, to enable observations from different longitudes to complete the lightcurve more readily. Pilcher at the Organ Mesa Observatory used a 0.35-meter f/10 Meade LX200 GPS Schmidt-Cassegrain (SCT) and SBIG STL-1001E CCD, clear filter and unguided. Benishek at Sopot Astronomical Observatory used a 0.35 m Meade LX200 GPS SCT operating at f/6.3, SBIG ST-8 XME CCD, unfiltered and unguided. Photometric measurement and lightcurve construction are with *MPO Canopus* software. To reduce the number of points on the lightcurve and make it easier to read, data points have been binned in sets of 3 with a maximum time difference of 5 minutes.

Observations of 467 Laura were made on 25 nights 2016 Nov. 28 – 2017 Feb. 3. All measurements were made using the Comparison Star Selector (CSS) of *MPO Canopus*. Solar colored stars were used for calibration. The Sloan  $r'$  magnitudes from the CMC15 catalog (VizieR web site) were converted to Cousins R magnitudes by  $R=r'-0.22$ . However, instrumental magnitude adjustments as large as 0.1 magnitude were required to make a good fit. Dymock and Miles (2009) state that in the crowded Milky Way star fields through which the target was moving reddening of starlight by interstellar dust reduces the accuracy of the usual conversion factors between  $r'$ , J, Ks of the CMC15 catalog and R and V. Reddening of starlight is the most likely explanation of the required large instrumental magnitude adjustments. With the adjustments there is a good fit to an asymmetrical bimodal lightcurve with rotation period  $70.63 \pm 0.01$  hours, amplitude  $0.15 \pm 0.02$  magnitudes. Both previously reported periods are now ruled out. A period spectrum between 20 hours and 120 hours is also presented.



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Number	Name	yyyy/mm/dd	Pts	Phase	LPA	BPAB	Period(h)	P.E	Amp	A.E.
467	Laura	2016/11/28-2017/02/03	6270	12.5, 2.7, 14.4	96	6	70.63	0.01	0.15	0.02

Table 1. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first date, minimum value, and last date. LPAB and BPAB are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984).

**LIGHTCURVE ANALYSIS OF ASTEROIDS OBSERVED AT THE OAKLEY SOUTHERN SKY OBSERVATORY: 2016 OCTOBER**

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(Received: 2017 March 7 Revised: 2017 May 17)

On seven individual nights between 18 October 2016 and 27 October 2016, CCD images were taken of five asteroids: 2541 Edebono, 2977 Chivilikhin, 5623 Iwamori, (16806) 1997 SB34, and (58143) 1983 VD7. These images were calibrated and measured, and lightcurves were produced for each asteroid.

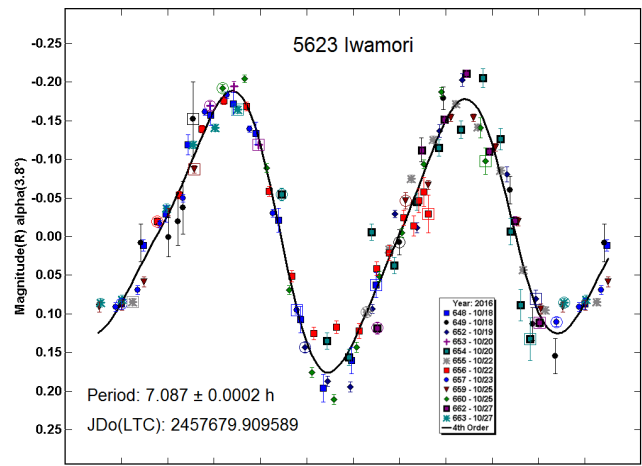
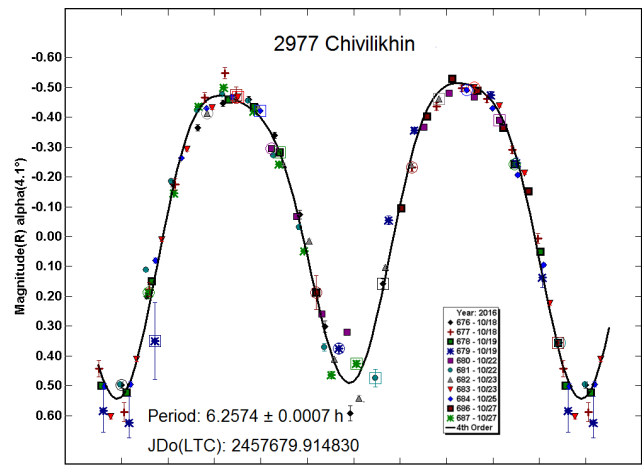
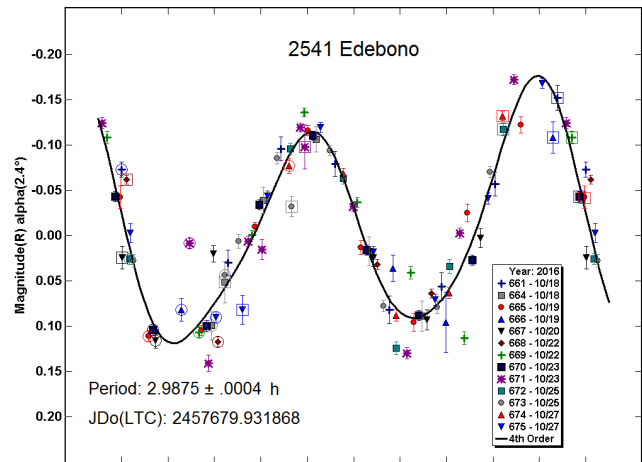
The images used for lightcurves were taken at the Oakley Southern Sky Observatory in New South Wales, Australia. The telescope is a 0.5 meter, f/6.71 Planewave telescope and uses a STX-16803 CCD camera binned 3x3 with a luminance filter. The images were collected on 2016 October 18-20, 22-23, 25, and 27. *Maxim DL* software was used to calibrate the images, and *MPO Canopus* software was used to measure the asteroids and create their lightcurves. The periods calculated from these lightcurves are displayed in Table 1 of this paper, but there is no data in the lightcurve database that can be used for comparison. For this reason, there will be no comparison section in this paper.

Table 1 below lists data for the five analyzed asteroids. The table shows the number of points used in each plot, phase, Lpab, Bpab, period, period error, amplitude, and amplitude error. The asteroid (58413) 1983 VD7 appears to have a long period (greater than 24h) and low amplitude. We did not get enough data to determine a period.

Of special interest is the lightcurve of (16806) 1997 SB34 which clearly shows the v-shaped minimum indicative of an eclipsing binary minor planet. Because the derived period is close to 24 hours, we were unable to get a complete lightcurve. More observations are needed to determine if this really is a binary minor planet and to determine the orbital period of the satellite if it exists.

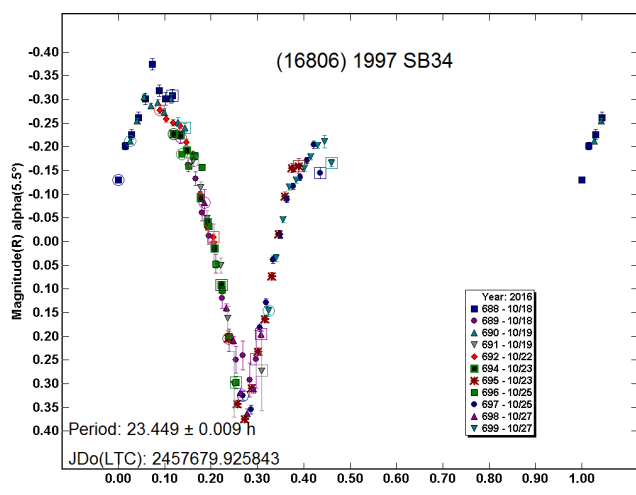
References

Light Curve Database. *Minor Planet Bulletin*.  
<http://www.minorplanet.info/lightcurvedatabase.html>



Number	Name	Dates (YR/MM/DD)	Pts.	Phase	Lpab	Bpab	Period (h)	PE	Amp (mag)	AE
2541	Edebono	2016/10/18-20,22-23,25,27	93	2.2, 5.3	21.2	-3.3	2.9875	0.0004	0.30	0.05
2977	Chivilikhin	2016/10/18-19,22-23,25,27	107	4.0, 6.5	22.6	-7.3	6.2574	0.0007	1.00	0.05
5623	Iwamori	2016/10/18-20,22-23,25,27	139	3.8, 5.1	24.9	-8.7	7.0870	0.0002	0.40	0.05
16806	1997 SB34	2016/10/18-19,22-23,25,27	104	5.2, 10.2	18.4	-1.4	23.449	0.009	0.80	0.05
58143	1983 VD7	2016/10/18-20,22-23,25,27	124	4.1, 7.8	21.3	-4.1	--	--	--	--

Table 1. Table of results for the five asteroids observed. The phase is given for the first and last date. Lpab and Bpab are the approximate phase angle bisector longitude and latitude at mid-date range.



**ROTATION PERIOD FOR 1218 ASTER**

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A collaborative campaign of lightcurve photometry of main-belt asteroid 1218 Aster was made over six nights in 2017 Jan-Feb. The resulting synodic rotational period is  $3.1581 \pm 0.0001$  h, amplitude  $0.30 \pm 0.02$  mag. From photometric sparse data we derived  $H = 13.44 \pm 0.04$  and  $G = 0.43 \pm 0.05$ .

CCD photometric observations were made over six nights from 2017 January-February at the Balzaretto (A81), Etscorn Campus, and Organ Mesa Observatories using the instrumentation described in Table I.

Obs	Telescope (m), CCD	Exp (s)
Balzaretto	0.20 f/5.5, SBIG ST7XME	420
Etscorn	0.35 f/5.0, SBIG ST10	120-360
Organ Mesa	0.35 f/10, SBIG STL1001-E	120

Table I. Observatory Instrumentation. All telescopes were Schmidt-Cassegrain design.

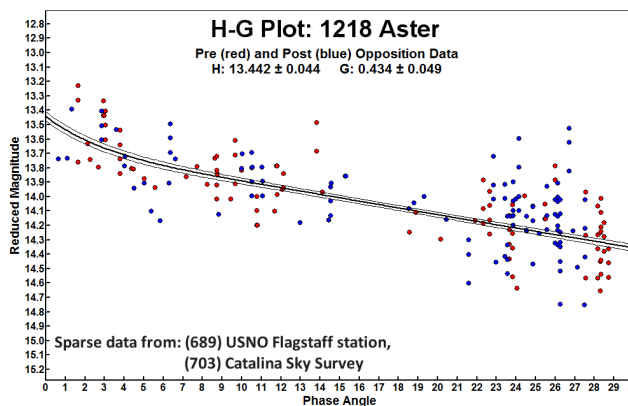
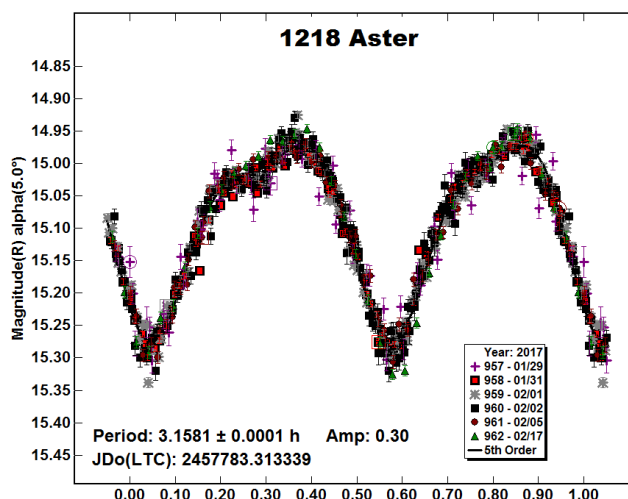
Number	Name	2017 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E	Amp	A.E.
1218	Aster	01/29-02/17	579	5.0, 14.7	124	4	3.1581	0.0001	0.30	0.02

Table II. Observing circumstances and results. Pts is the number of data points. The phase angle values are for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984).

The main-belt asteroid 1218 Aster was discovered on 1932 January 29 by Reinmuth K. at Heidelberg. The primary orbital elements are  $a = 2.263$  AU,  $e = 0.109$ , and  $i = 3.16^\circ$ . Its absolute magnitude is  $H = 13.2$  (JPL, 2017). The WISE survey (Masiero *et al.*, 2011) used  $H = 13.1$  to find  $D = 5.920 \pm 0.046$  km. The resulting albedo was  $p_V = 0.294 \pm 0.060$ .

The considerable observing effort and wide collaboration was justified by the hypothesis the asteroid was binary. Data processing and analysis were made with *MPO Canopus* (BDW Publishing, 2016). All the images, acquired with clear-filter, were calibrated with dark and flat frames and converted to the Cousins-R magnitudes using solar-colored field stars from the CMC15 catalogue (VizieR, 2014) Us  $R = r' - 0.22$  (Dymock and Miles, 2009).

Using sparse photometric data from USNO Flagstaff station (MPC 689; USNO, 2016) and from Catalina Sky Survey (MPC 703; CSS, 2016) we derived  $H = 13.44 \pm 0.04$  and  $G = 0.43 \pm 0.05$ ; this  $H$  value differs from the previous ones. The period analysis shows a bimodal solution for  $P = 3.1581 \pm 0.0001$  h and amplitude  $A = 0.30 \pm 0.02$  mag. There were no obvious signs of a satellite.



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**1943 ANTEROS:  
A POSSIBLE NEAR-EARTH BINARY ASTEROID**

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A collaboration of two observers at widely-separated longitudes made CCD photometric observations of the near-Earth asteroid (NEA) 1943 Anteros from 2016 August to October. Analysis of the data led to the possibility that the asteroid is a binary with  $P_1 = 2.86923 \pm 0.00006$  h,  $A_1 = 0.07$  mag and  $P_{ORB} = 23.548 \pm 0.002$  h,  $A_2 = 0.05$ -0.10 mag. The estimated effective diameter ratio is  $D_s/D_p \geq 0.22 \pm 0.02$ .

The near-Earth asteroid (NEA) 1943 Anteros was the target of CCD photometric observations from 2016 August to October as part of the on-going program at the Center for Solar System Studies to characterize NEAs by finding rotation periods and, when possible, use lightcurve inversion to determine a model of the asteroid.

The period for Anteros had been reported several times prior to our observations. Pravec et al. (1998) found a period of 2.8695 h based on four nights from 1997 July 29 to Aug 28. They reported no indications of a satellite. Waszczak et al. (2015) reported a period of 6.521 h based on a "sparse dense" data set derived from the Palomar Transient Factory observations (< 100 observations spread over 2-4 weeks). Warner (2015) found a period of 2.735 h in 2014 Sep, but the data were marginal and the result is rated U = 1 (probably wrong) in the asteroid lightcurve database (Warner et al., 2009).

Both observers used *MPO Canopus* to reduce and measure the CCD images. The Comp Star Selector was used to find up to five near solar color comparison stars from the CMC-15 catalog. Johnson V magnitudes were used. These are not native to the CMC-15 catalog, but were found from the CMC-15 native Sloan  $r'$  and 2MASS J-K magnitudes using

$$V = 0.9947 * r' + 0.6278 * (J-K) \quad (1)$$

The night-to-night zero points were generally  $\pm 0.05$  mag of one another.

The initial observations were made at CS3-Palmer Divide Station (CS3-PDS) from 2016 August 7-28. The analysis of the data to that point indicated the possibility that the asteroid was binary in that there were apparent attenuations in the composite lightcurve. These were taken to be indications of mutual events (occultations and/or eclipses) due to a satellite. However, the apparent orbital period of the purported satellite was very nearly 24 hours, making it impossible for a single station to resolve the question unambiguously, if at all.

A call for observations was put out to several observers located in Europe, or about 110-150° separation in longitude from the CS3 location in California. Benishek from his observatory in Belgrade, Serbia, was able to observe the asteroid on several occasions despite interference at times from the moon and between spells of bad weather. These additional data proved critical in finding a solution.

Table I gives the telescopes and CCD cameras used for the observations. Exposures were unfiltered and ranged from 180 to 240 seconds. Table II gives the dates and session numbers in the two lightcurves for each observer.

OBS	Telescope	Camera
Warner	0.30-m f/9.6 SCT	FLI ML-1001E
	0.35-m f/9.1 SCT	SBIG STL-1001E
	0.50-m f/8.1 R-C	FLI PL-1001E
Benishek	0.35-m f/6.3 SCT	SBIG ST-8XME

Table I. List of observers and equipment. SCT: Schmidt-Cassegrain. R-C: Ritchey-Chrétien. The Benishek SCT used a focal reducer to go from #10 to #6.3.

Obs	2016	Sess
Warner	Aug 7-20, 25-31	1-14, 15-17, 19, 21-23
	Sep 1, 25-30	24, 27-31, 33
	Oct 1-2, 12-13	34, 36-38
Benishek	Aug 27-28	18, 20
	Sep 2, 4, 29	25, 26, 32
	Oct 1	35

Table II. Dates of observation and session numbers in the lightcurves for each observer.

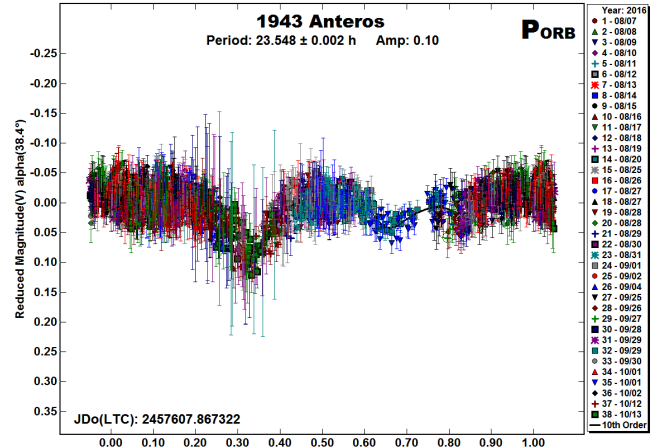
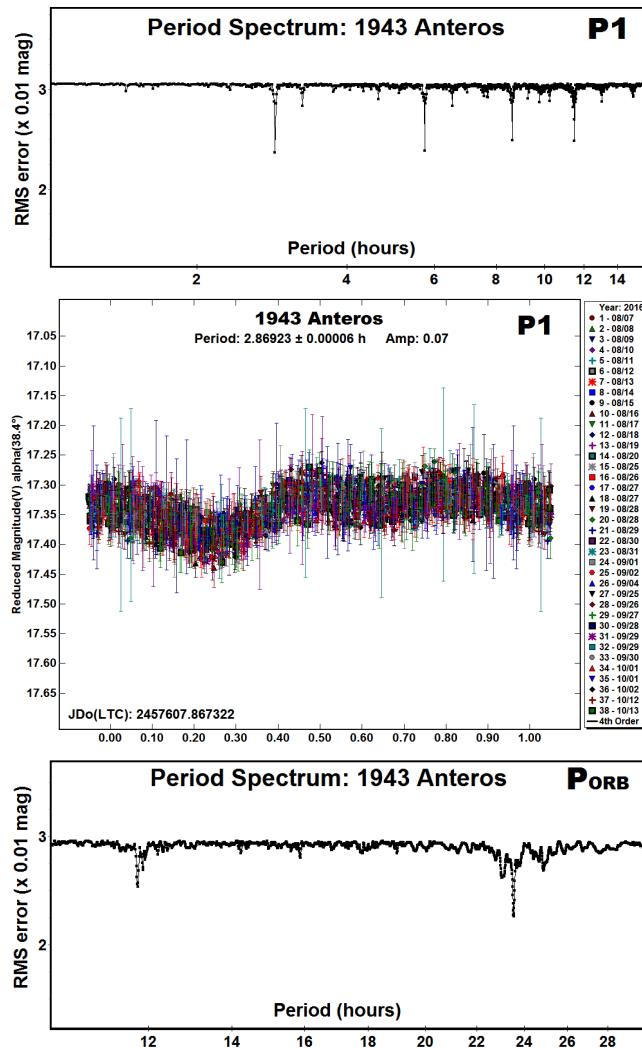
Number	Name	2016 mm/dd	Pts	Phase	$L_{PAB}$	$B_{PAB}$	Period(h)	P.E.	Amp	A.E.
1943	Anteros	08/01-10/13	1465	38.4, 8.7	15, 25	10	2.86923	0.00006	0.07-0.10	0.01
	$P_{ORB}$						23.548	0.002	0.05-0.10	0.01

Table III. Observing circumstances and results. The first line gives the summary for the entire data set and the primary ( $P_1$ ) period only. The second line gives the period and amplitude range for the secondary period ( $P_{ORB}$ ). Pts is the number of data points (summary line only). The phase angle is given for the first and last date.  $L_{PAB}$  and  $B_{PAB}$  are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984). Grp is the asteroid family/group (Warner *et al.*, 2009).

The asteroid was not an easy target at the start in early August, being V 18.5 at the time. However, by the end of the observations in mid-October, it had brightened to V  $\sim$  17. Even so, the full moon caused a nearly two week interruption in mid-September.

As shown in Table III, the phase angle bisector longitude (see Harris *et al.*, 1984) changed by only  $10^\circ$  and the latitude by only  $1^\circ$  over the range of observations. This meant that, other than the expected decrease in amplitude of the primary curve (Zappala *et al.*, 1990), the lightcurve for the purported satellite mutual events would not be expected to change significantly.

Benishek sent his data to Warner, who used the two-period search in *MPO Canopus* based on the FALC algorithm by Harris (Harris *et al.*, 1989) to analyze the data set. There is little or no doubt about the dominant, primary period of  $P_1 = 2.86923 \pm 0.00006$  h. The amplitude was 0.10 mag in early August ( $\alpha = 38.4^\circ$ ) and decreased to 0.07 mag by mid-October ( $\alpha = 8.6^\circ$ ).



Even with data from widely-separated longitudes, it was not possible to fill in the second lightcurve completely. The timing of bad weather and full moon was perfect and so the secondary event at about 0.7 rotation phase in  $P_2$  was not cover completely or as many times as the primary event. Even so, the period spectrum shows two very distinct possibilities. We chose the longer period of  $P_{ORB} = 23.548$  h as the most likely solution based on the raw data from those times when Warner and Benishek observed on the same night, although there was about a 12-hour difference between the mid-times of the two sessions. This being so nearly commensurate with an Earth day contributed to the inability to get a highly-reliable solution.

The two events have attenuations of about 0.10 (primary) and 0.05 (secondary) mag. Using the latter, it is possible to estimate the effective diameter ratio of the primary and purported satellite by using

$$D_s/D_p = \sqrt{10^{0.4 \cdot \Delta m} - 1.0}$$

where  $\Delta m$  is the depth of the attenuation for the secondary event. This gives

$$D_s/D_p = 0.22 \pm 0.02$$

To confirm these conclusions will require high-quality data at future apparitions from widely-separated longitudes.

#### Acknowledgements

Funding for PDS observations, analysis, and publication was provided by NASA grant NNX13AP56G. Work on the asteroid lightcurve database (LCDB) was also funded in part by National Science Foundation grant AST-1507535. This research was made possible in part based on data from CMC15 Data Access Service at CAB (INTA-CSIC) (<http://svo2.cab.inta-csic.es/vocats/cmc15/>). This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National

Aeronautics and Space Administration and the National Science Foundation. (<http://www.ipac.caltech.edu/2mass/>)

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### CCD LIGHTCURVES FOR MAIN-BELT ASTEROIDS 423 DIOTIMA AND 925 ALPHONSINA

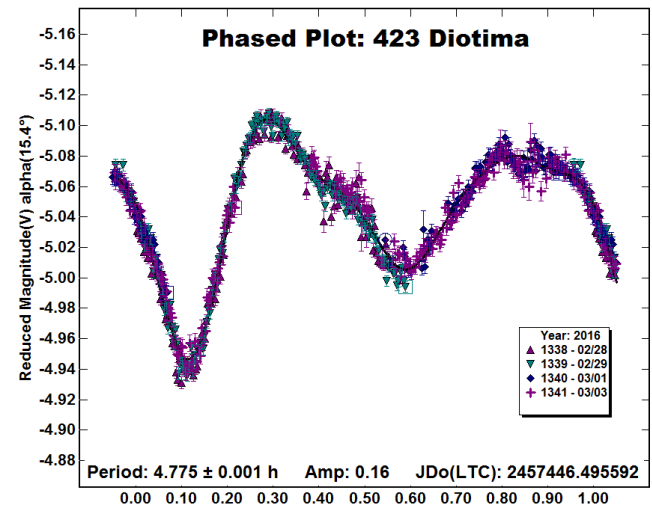
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Fourier analysis of a new CCD-derived lightcurves found synodic periods for 423 Diotima ( $4.775 \pm 0.001$  h) and 925 Alphonsina ( $7.879 \pm 0.001$  h).

The instrument used at UnderOak Observatory (UO) for this investigation was a 0.28-m SCT equipped with an SBIG ST-8XME thermoelectrically-cooled CCD camera. Image calibration/registration procedures employed at UO have been published elsewhere (Alton, 2013). Data reduction with *MPO Canopus* (Warner, 2015) used at least four non-varying comparison stars in the same FOV to generate lightcurves by differential aperture photometry. Data were light-time corrected but not reduced to standard magnitudes. Fourier analysis (Harris et al., 1989) yielded a period solution from the folded datasets and then independently verified with *Peranso* (Vannmunster 2006) using ANOVA (Schwarzenberg-Czerny, 1996). Phased lightcurve data are available upon request ([mail@underoakobservatory.com](mailto:mail@underoakobservatory.com)).

**423 Diotima.** This is a relatively large ( $D = 209 \pm 5$  km) but somewhat dark ( $p_V = 0.0515$ ) taxonomic type C main-belt asteroid that was discovered in 1896 by A. Charlois. Schober (1983) first proposed a synodic period of  $8 \pm 0.33$  h and the possible existence of a satellite. Both of these eventually proved to be inaccurate.



Further refinements to the now accepted synodic period ( $4.775$  h) were reported by Zappala et al. (1985), Dotto et al. (1995), Dymock (2005), Fauerbach and Bennett (2005), and Chiorny et al. (2007). A shape model for 423 Diotima was published by Āurech et al (2007). At UO, images (clear filter; 60 s) were taken over four nights from 2016 Feb 28 thru Mar 3.

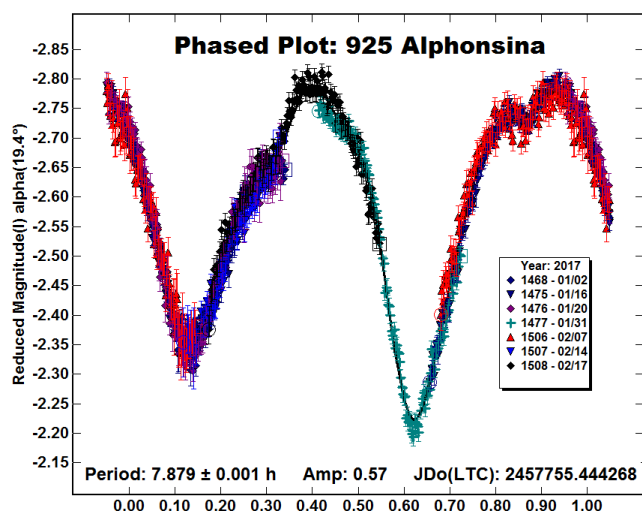
Fourier analysis of the 619 lightcurve data points produced a best fit at  $4.775 \pm 0.001$  h. The maximum peak-to-peak amplitude of 0.16 mag observed during the 2016 apparition was consistent with those reported in the Asteroid Lightcurve Database (LCDB; Warner et al., 2009).

**925 Alphonsina** was discovered in 1920 by J. Solà. It is a moderately sized ( $57.5 \pm 0.4$  km) type S asteroid with a somewhat inclined orbit ( $i = 21.1^\circ$ ). Harris and Young (1989) published the first lightcurve with a period solution of  $7.880 \pm 0.001$  h. Additional studies by Hanuš and Āurech (2010) and Hanuš et al (2011) established a *sidereal* period of  $7.87754 \pm 0.00005$  h. This

Number	Name	20yy mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.
423	Diotima	16/02/28-03/03	619	15.4,16.0	108	9	4.775	0.001	0.16	0.01
925	Alphonsia	17/01/02-02/17	1139	21.8	54	19	7.879	0.001	0.57	0.02

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris et al., 1984).

asteroid has also been shape modeled using a combination of lightcurve inversion and occultation silhouettes (Durech et al, 2011). At UO, images ( $I_c$  filter; 60 s) were taken over seven nights from 2017 Jan 2 thru Feb 17.



Fourier analysis of the 1139 lightcurve data points produced a best fit at  $7.879 \pm 0.001$  h. The maximum peak-to-peak amplitude of 0.57 mag observed during this most recent apparition was significantly higher than those of 0.11-0.31 mag reported in the Asteroid Lightcurve Database (Warner et al., 2009).

#### Acknowledgements

Many thanks to the SAO/NASA Astrophysics Data System, the JPL Small-Body Database Browser and the Asteroid Lightcurve Database (LCDB; Warner et al., 2009), all of which were essential to preparing this report.

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**THE LIGHTCURVE PERIOD FOR THE  
ASTEROID 201 PENELOPE**

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(Received: 2017 March 16)

Photometric observations of the main-belt asteroid 201 Penelope were made in 2017 January. Analysis found a rotation period of  $3.75 \pm 0.01$  h and amplitude of 0.16 mag.

Observations of main-belt asteroid 201 Penelope were made in 2017 (see Tables II and III). The details of the telescopes and cameras are shown in Table I. The focal length of Cerestron C11 was shortened using a 0.63x reducer. CERES III is 0.35m reflector that we built by ourselves.

Name	D (m)	FL (mm)	Camera
C11	0.28	1764	SBIG ST9
CERES III	0.35	1500	SBIG ST9

Table I. Equipment details.

UT Date/Time (2017)	Scope	Phase	Points
Jan 03 11:09-11:23	CERES III	4.0	14
Jan 06 10:42-12:45	CERES III	3.0	63
Jan 19 10:42-13:55	CERES III	3.8	142
Jan 25 09:31-11:31	C11	5.9	77
Jan 26 09:15-12:42	C11	6.3	113

Table II. Detailed observations List

The combined data set consisted of 424 data points. All images were unbinned with Johnson-Cousins R-band filter. Measurements were made using *Makalli*, which employs differential aperture photometry to produce the raw data. Period analysis was done using *MPO Canopus*, which incorporates the Fourier analysis algorithm (FALC) developed by Harris (Harris *et al.*, 1989). We found that the period is  $3.75 \pm 0.01$  h and the amplitude is 0.16.

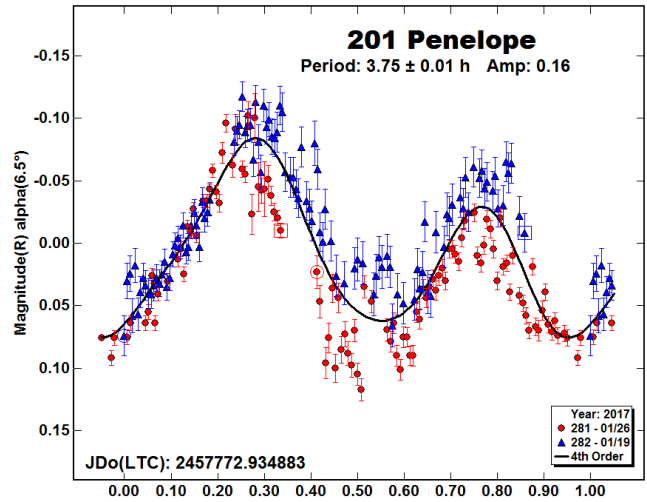
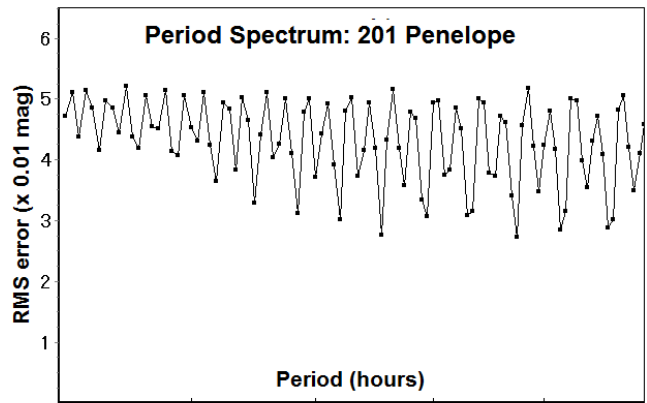
Shevchenko et al (2002) found  $P = 3.7474 \pm 0.0001$  h with an amplitude of 0.45 magnitude. Alton (2012) reported 3.7491 h and 0.16 mag amplitude. Our results are consistent with the others.

Acknowledgements

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Harris, A.W., Young, J.W., Bowell, E., Martin, L.J., Millis, R.L., Poutanen, M., Scaltriti, F., Zappala, V., Schober, H.J., Debehogne, H., Zeigler, K. (1989). "Photoelectric Observations of Asteroids 3, 24, 60, 261, and 863." *Icarus* **77**, 171-186

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Number	Name	2017 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.
201	Penelope	01/03-01/26	424	4.0, 3.0, 6.3	111	-5	3.75	0.01	0.16	0.02

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984).

## NEAR-IR MINOR PLANET PHOTOMETRY FROM BURLEITH OBSERVATORY

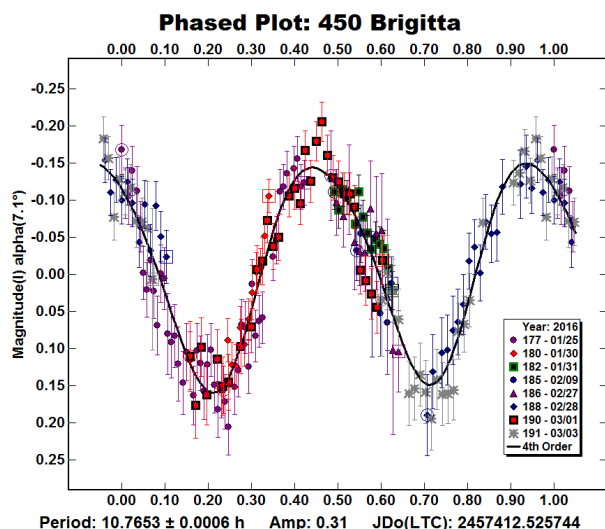
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(Received: 2017 March 19 Revised: 2017 May 17)

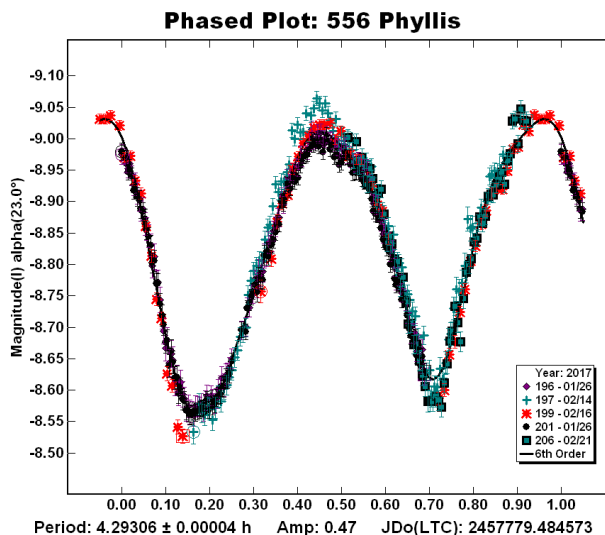
Near-IR observations from a bright-sky urban area provide rotation periods for six main-belt minor planets: 450 Brigitta, 556 Phyllis, 849 Ara, 984 Gretia, 1152 Pawona and 1310 Villigera.

The bright-sky near-infrared (NIR; Cousins Ic, 700-900 nm) photometry program of urban Burleith Observatory has been previously described in Schmidt (2016). Revised rotation periods are presented for six main-belt minor planets. All images were bias and sky flat-field corrected using CCDSoft version 5.00.217. Photometry and period analysis was performed using *MPO Canopus* version 10.7.7.0 (Warner, 2016); MPO CSS was used to select comparison stars with solar-like spectra. Lightcurve history was found using the MinorPlanet.info Asteroid Lightcurve Database (LCDB) 2016 December Release <http://www.MinorPlanet.info/lightcurvedatabase.html>.

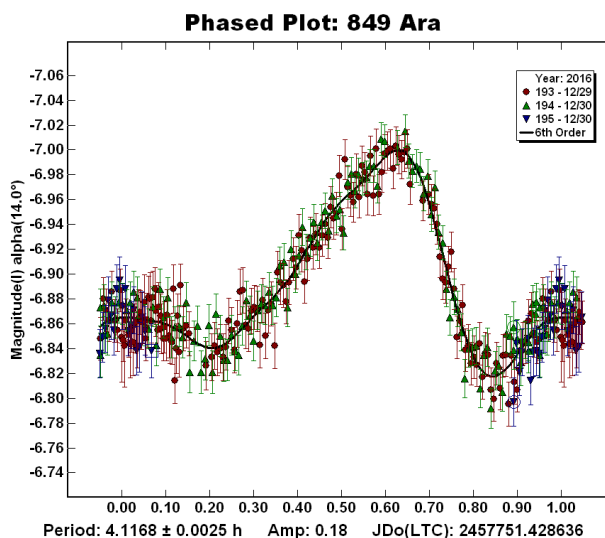
**450 Brigitta.** This Eos family member was discovered 1899 by M. Wolf and A. Schwassmann at Heidelberg (Schmadel (1999)). The observed period agrees with that of Hanuš, Delbo, et. al (2016d).



**556 Phyllis.** This S-type minor planet was discovered in 1905 by P. Götze, Heidelberg. Marciniak *et al.* (2007) found a period of  $4.292623 \pm 0.000001$  h.



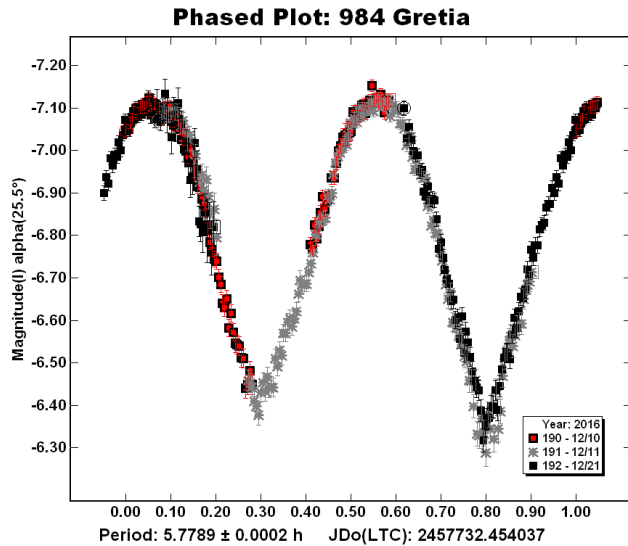
**849 Ara.** Discovered 1912 by S. Belyavskij, Semeis and named in honor of the American Relief Administration, which fed over 10 million Russians during the famine of 1921-23. Durech *et al.* (2011) found a period of  $4.116391 \pm 0.000005$  h.



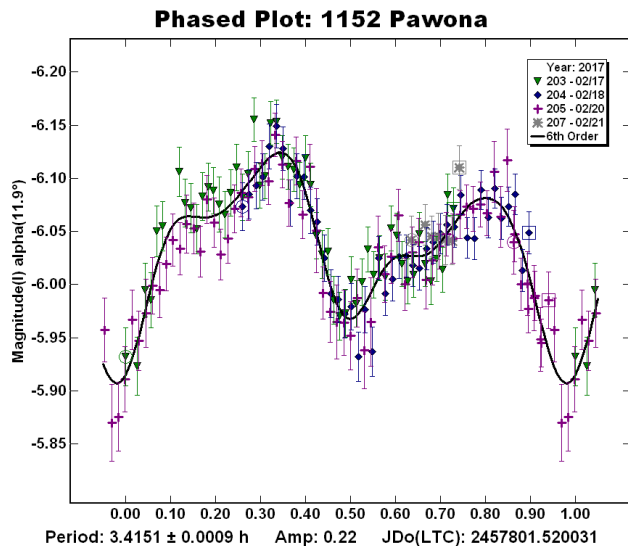
**984 Gretia.** Discovered 1922 by K. Reinmuth, Heidelberg, this and 1026 Ingrid were named for the sister-in-law and niece of Albrecht Kahrstedt (1897-1922), renowned computer of minor

Number	Name	Obs.Date Range		Images	Exp. (s)	Phase (°)	Period (h)	P.E. (h)	Amp Ic (mag)	A E Ic (mag)
		2016*-2017 (mm/dd)								
450	Brigitta	01/25*-03/03*		91	360	7.1	10.7653	0.0006	0.31	0.06
556	Phyllis	01/26 - 02/21		540	90	23.0	4.29306	0.00004	0.47	0.05
849	Ara	12/29*-12/30*		372	120	14.0	4.1168	0.0025	0.18	0.04
984	Gretia	12/10*-12/21*		400	90	25.5	5.7789	0.0002	0.75	0.03
1152	Pawona	02/17 - 02/21		96	180	11.9	3.4151	0.0009	0.22	0.08
1310	Villigera	03/06 - 03/17		398	105	24.3	7.8315	0.0006	0.46	0.03

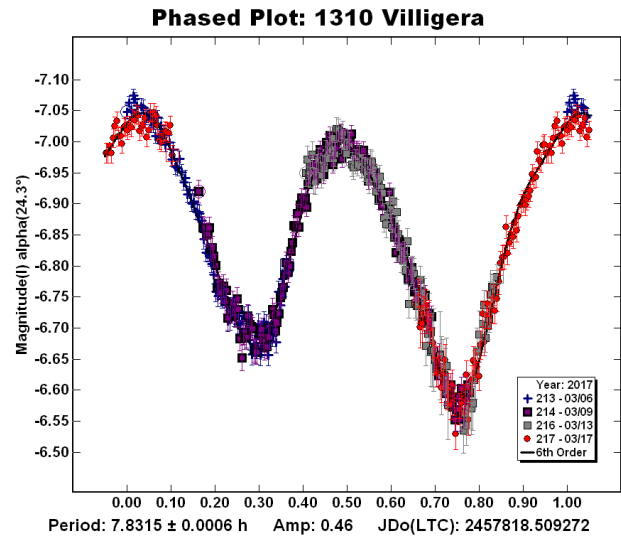
planet orbits at the Astronomisches Rechen-Institute, to celebrate niece Ingrid's baptismal day, 1926. Marciniak *et al.* (2008) found a period of  $5.778026 \pm 0.000001$  h.



1152 Pawona. Discovered 1930 by K. Reinmuth, Heidelberg. Its name combines those of astronomers J. Palisa and M. Wolf when it was found to coincide with 1925 SF, the final minor planet discovery of Palisa. Behrend (2011) found a period of  $3.41500 \pm 0.00005$  h.



1310 Villigera. Discovered 1932 by A. Schwassmann, Bergedorf, and named for W. Villiger (1872-1938), head of astronomical instruments at Carl Zeiss, Jena. The lightcurve of this Mars-approacher was first reported by R. A. Koff (Koff, 2002), and his result is here confirmed. Hanuš, Ďurech, *et al.* (2016) found a period of  $7.83001 \pm 0.00005$  h.



#### Acknowledgements

The author acknowledges B. D. Warner, for providing *MPO Canopus* to the minor planet photometry community.

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## LIGHTCURVE ANALYSIS OF BINARY AND POTENTIAL BINARY ASTEROIDS IN 2015

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It was known that asteroids with diameter of 15km (derived mainly from MPC estimated absolute magnitude (H)) or smaller were more likely to be binary systems than were larger objects. From a set of selection criteria, we used CCD photometry to determine whether the asteroids were binary systems.

CCD photometric observations were made in 2015 using four telescope systems from Blue Mountains Observatory, one from Darling Range Observatory, two from Sugarloaf Mountain Observatory, and one from Sopot Astronomical Observatory, in Serbia. Table I lists the instrumentation details. Further information of the instruments used at BMO can be found at the BMO website (BMO 2015). Table II shows the absolute magnitude (H), Diameter (D), and the instruments used.

Obs	Scope	Ap (m)	f/	Camera	Pixel	Bin	Scale
DRO	R12	0.30	7.4	ST-8XME	9.0	1x1	0.84
BMO	B14	0.35	6.0	ST-8XME	9.0	1x1	0.88
BMO	B5	0.12	7.5	ST-8300M	5.4	3x3	3.51
BMO	B24	0.61	6.8	U42	13.5	1x1	0.70
BMO	B12	0.30	5.5	ST-10XME	6.8	2x2	1.72
Sugarloaf	S20	0.50	4.0	ST-10XME	6.8	2x2	1.68
Sopot	S14	0.30	6.3	ST-8XME	9.0	2x2	1.66

Table I. Equipment specifications. The Scope column gives the code used in Table II. Pixels sizes are in microns. The Scale is arcsec/pixel. BMO = Blue Mountains Observatory. DRO = Darling Range Observatory

All raw images were calibrated with a median combined library of bias, dark and flats. Dark images were taken at the same temperature and exposure time as the raw images.  $R = V - 0.67$  was used to equalize the R and V data taken by different observers.

All asteroids were selected from the Photometric Survey of Asynchronous Binary Asteroids (PSABA). The asteroids were searched from a list of inner main-belt asteroids (MBA) at  $a < 2.5$  AU and  $D < 15$  km reaching a favorable apparition (Pravec 2015).

Number	H	D	Comment
1563	12.4	10.37	B14, B5
1741	11.5	27.66	R12, B14, B24
1829	12.5	9.91	B24f
2166	12.9	8.24	B24f, B12
2343	13.3	6.85	B14, B24, S20, S14
2468	13.0	7.87	B14, B24, B12
2850	12.6	9.46	B14, S14
3435	13.1	7.51	B14, S20
3782	12.6	9.46	B24f, B14
3951	12.8	8.63	B24f
3982	12.9	8.24	B5, B14, B24, S20, S14
8474	13.7	5.70	B14, B24, S20, S14, R12
9068	13.6	5.97	B24f
11579	13.7	5.70	B14, B24, S20, S14
16126	12.9	8.24	B24, B14
16698	13.5	6.25	B24, B14, R12
16831	14.0	4.96	B24, B14, B12, S20, S14
16955	12.6	9.46	B24, B14
17584	13.9	5.2	B24, S20
19289	15.4	2.61	B24f, B14, S20
41588	15.6	2.38	B24, B14
49953	14.4	4.13	B24, B14

Table II. An 'f' next to B24 indicates that nearly all sessions used the 0.61-m. The H values are from the MPC. Diameters (km) are from the LCDB (Warner et al., 2009)

Data measurement and reduction was done using *MPO Canopus* V10. The reduction used Fourier analysis algorithm (FALC) developed by Harris (Harris et al., 1989). Calibration of the data (generally  $< \pm 0.05$  mag) was done using field stars converted to approximate V magnitudes based on 2MASS J-K colors (Warner, 2007). The Comp Star Selector (CSS) feature in *MPO Canopus* was used to limit the comparison stars to near solar color.

2850 Mozhaiskij, 3435 Boury, 2166 Handahl, (16126) 1999 XQ86, (16698) 1995 CX, (16831) 1997 WM21, (16955) 1998 KU48, (19289) 1996 HY12, (41588) 2000 SC46, and (44953) 1999 XL215 were PSABA targets that showed unique synodic periods. When the period ( $P$ ) and amplitude ( $A$ ) satisfied the criteria for a binary asteroid candidate, the asteroid was placed in the prime suspect category so that future follow-up could be organized.

Collaborating with other observers from vastly different longitudes helped remove the ambiguities coming from observations done from only one station. Apart from additional data points, there were also improvements in determining the unique rotation period when the lightcurve had a rotation period nearly commensurate with Earth's rotation, or when it has a very low amplitude lightcurve. It also keeps the observing campaign as short as possible, reducing the phase-amplitude effect.

1563 Noel is a prime suspect for being a binary asteroid. This asteroid has been studied in the past (Pravec, 2015). This was the fourth apparition where no binary events were detected. "Prime suspect" was a term coined for an asteroid having a size, period, and amplitude where binaries are frequently seen.  $15 \pm 4\%$  of NEA with  $0.3 < D < 15$  km are known to be binaries. Out of these, if the period is between 2.2-2.8h, close to the critical fission spin rate for rubble pile asteroids, and the amplitude is  $< 0.2$  mag at low phase angles (assuming an equatorial view and not pole-on), the probability of the object being a binary rises to  $66 \pm 12\%$ . This is similarly true with the inner main-belt asteroids, but binaries there may have a somewhat larger size and longer period (Pravec, 2006).

Number	Name	2015/mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.
1563	Noel	06/19-08/14	204	11,17	287	-7	3.5483	0.0004	0.16	0.02
1741	Giclas	06/04-06/22	657	5,11	240	0	2.9426	0.0001	0.15	0.03
1829	Dawson	09/01-09/12	597	6,12	328	5	4.2496	0.0002	0.28	0.02
2166	Handahl	07/01-08/07	359	19,5	307	5	7.2259	0.0002	0.13	0.02
2343	Siding Spring	10/23-12/19	1549	4,25	40	0	<sup>P</sup> 2.10639	0.00001	0.15	0.02
2343	Siding Spring	10/23-12/19	1549	4,25	40	0	<sup>S</sup> 11.7884	0.0009	0.06	0.02
2468	Repin	08/29-12/05	587	16,26	7	4	5.1196	0.00003	0.57	0.02
2850	Mozhaiskij	05/11-05/25	247	5	234	8	7.827	0.002	0.13	0.02
3435	Boury	05/13-05/14	168	5	234	9	14.71	0.05	0.38	0.02
3782	Celle	03/26-04/24	554	11,6	205	-7	3.84	0.001	0.11	0.02
3951	Zichichi	04/24-04/27	315	12	189	-7	2.217	0.001	0.30	0.05
3982	Kastel'	07/17-10/06	4125	19,7,25	326	8	<sup>D</sup> 8.48548	0.00006	0.28	0.03
3982	Kastel'	07/17-10/06	4125	19,7,25	326	8	<sup>D</sup> 5.83574	0.00009	0.09	0.03
8474	Rettig	05/18-07/21	712	7,28	247	7	30.5595	0.0009	0.90	0.02
9068	1993 OD	06/19-06/27	254	15,11	286	-11	3.4076	0.0004	0.19	0.02
11579	Tsujitsuka	06/07-07/10	394	10,17	263	18	740.0	5.0	1.19	0.10
16126	1999 XQ86	07/06-07/17	324	15,12	312	-7	2.9783	0.0002	0.33	0.02
16698	1995 CX	15/11/09-16/01/01	114	29,18	58	-15	52.8	0.1	0.30	0.03
16831	1997 WM21	01/01-02/17	597	12,5,17	121	-8	8.1065	0.0006	0.14	0.05
16955	1998 KU48	12/04-12/31	195	6,10	80	-7	5.2608	0.0002	0.51	0.02
17584	1994 XF1	05/08-05/23	515	8,19	207	9	4.6392	0.0002	0.35	0.05
19289	1996 HY12	08/10-09/12	310	13,7	336	2	2.8519	0.0001	0.17	0.05
41588	2000 SC46	12/05-12/26	213	20	189	-3	5.8329	0.0002	0.43	0.02
49953	1999 XL215	07/21-08/19	694	13,4,7	315	6	2.99637	0.00005	0.38	0.03

Table III. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. If there are three values, the middle value is for the minimum during the range. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984). <sup>P</sup>Primary period in a binary system. <sup>S</sup>Orbital period in a binary system. <sup>D</sup>One of two periods in a suspected binary system where no mutual events were seen.

1829 Dawson is another unconfirmed binary prime suspect with the current apparition showing two very shallow attenuations. It was observed in 2005 and 2007 with no observable attenuations. This asteroid might still be binary but many factors prevented its discovery, such as unfavorable viewing geometry, a widely-separated pair resulting in a long orbital period, and events that were below the 0.04 mag event depth detection limit. (Pravec *et al.*, 2012)

2468 Repin shows an unusual asymmetrical bimodal lightcurve with different levels of maxima. Although such asymmetry does not necessarily indicate a binary system, an extensive observing campaign was made to further understand it. Bimodal asymmetry is common among NEAs in high solar phases where phase effects on irregular bodies are dominant. However, for MBAs, observed in low to moderate solar phases, such different levels of lightcurve maxima are unusual. The light curves are split into 3 plots during the 3-month observing period to highlight the asymmetry in late September 2015 (Petr Pravec, private communications).

3982 Kastel' was possibly observed to be a binary during its fourth apparition. The lightcurve did not fit into a single, bimodal solution. This was due to the presence of two rotational lightcurves with periods of 8.48548 h and 5.83574 h that were also detected in the three previous apparitions. These two rotation periods were caused by two separate bodies contributing their separate light fluxes. Despite four apparitions covering different viewing aspects, no observable events have been detected. This asteroid is likely to be a widely-separated binary with an asynchronous secondary (Pravec *et al.*, 2016)

8474 Rettig is a confirmed binary with a discovery announcement in *CBET* 1835. When the eclipse and occultation events were recorded, two further physical parameters of the binary system could be determined. The size ratio between the primary and secondary bodies was constrained to a minimum value of 0.86. The characteristic double humps, with very deep plunging minima, indicate a fully synchronous binary system where the

primary and secondary are rotating at the same rate as their mutual orbital period. This is unlike the more common asynchronous binaries where the primary rotates faster than the orbital period and the satellite rotation period is usually the same as the orbital period.

2343 Siding Spring, 3951 Zichichi, 3782 Celle are confirmed binary asteroids where further observational data during different apparitions could be used for physical modeling of the systems.

9068 1993 OD is a paired asteroid observed during its third apparition. Asteroid pairs are those that have been shown to have similar heliocentric orbital elements indicating a common origin. Pravec *et al.* (2010) suggested a gentle split of binary asteroids at low relative velocities as a cause for their formation. These paired asteroids also have a higher probability of being binaries themselves. We worked on such an assumption with 1741 Giclas, but despite a 14 nights campaign during very good observing conditions, the two attenuations observed could not be confirmed.

11579 Tsujitsuka is a long period MBA that has no past recorded work. In order to merge the data reduced from both V and R magnitude bands, we used  $V = R - 0.67$  to put all observations in V magnitudes. Assuming the lightcurve was bimodal, the lightcurve period was found to be 740 h with an amplitude of 1.19 mag. Despite the only single coverage, the large amplitude suggests that the lightcurve can only be bimodal and the period is unique (Harris *et al.*, 2014). A long period asteroid with large amplitude suggests an elongated body that is likely to be tumbling (Harris *et al.* 1994).

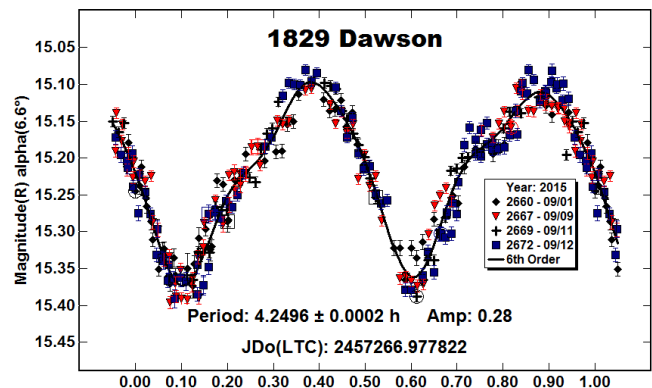
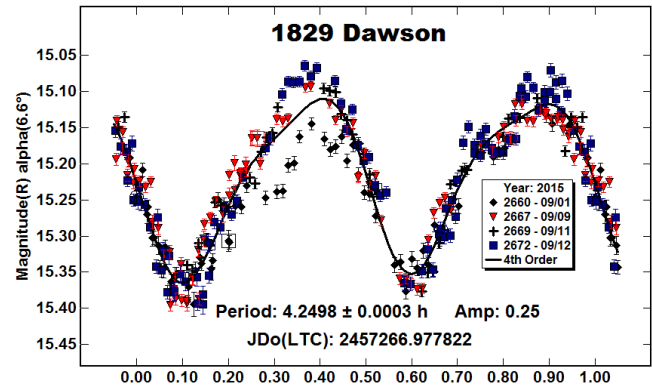
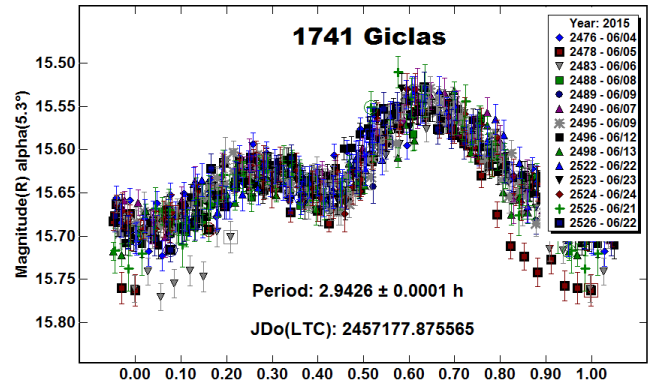
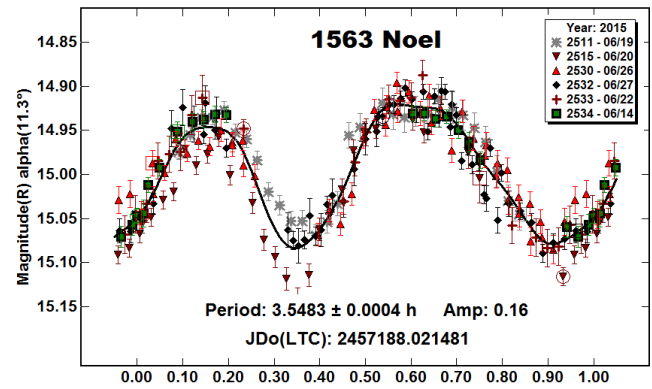
(17584) 1994 XF1 does not fit into any unique or additive lightcurve, indicating the asteroid is mildly tumbling despite its relatively fast rotation period. More complete analysis can be found at PSABA website (Pravec 2015). Our analysis shows only the primary rotation period.

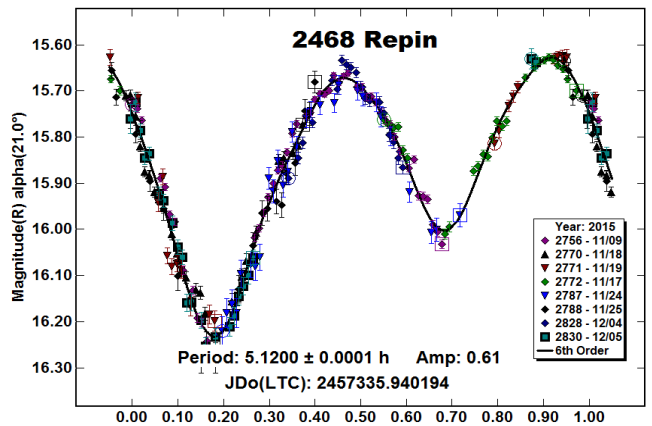
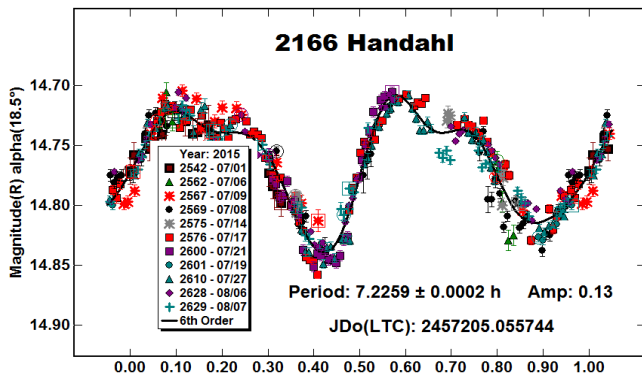
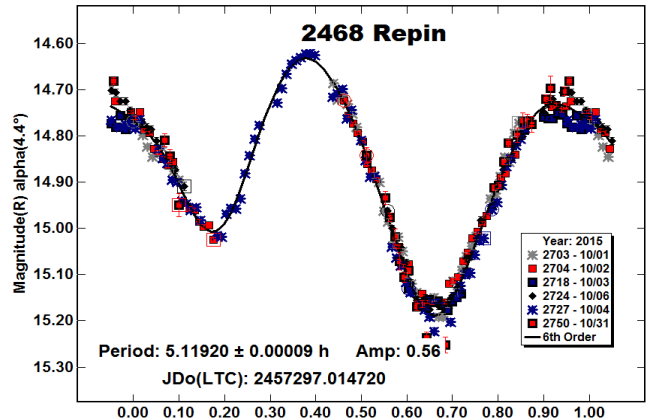
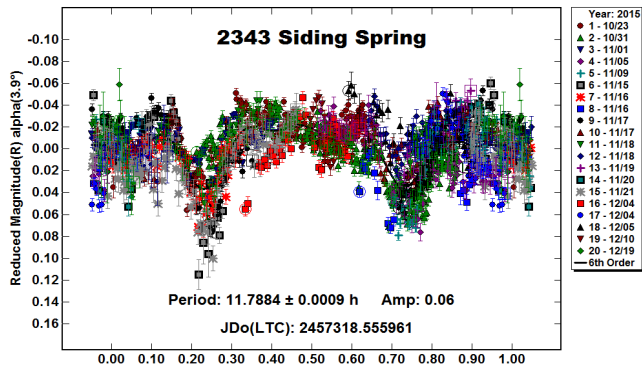
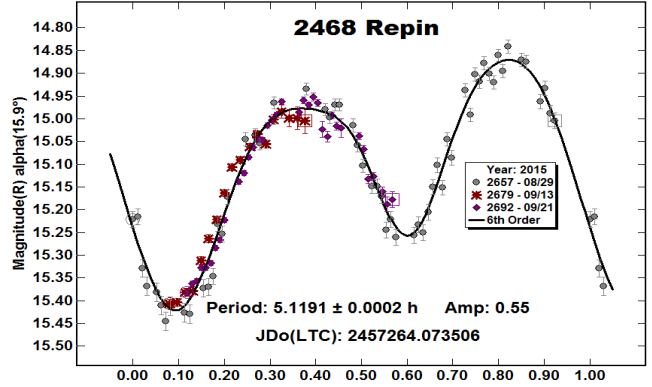
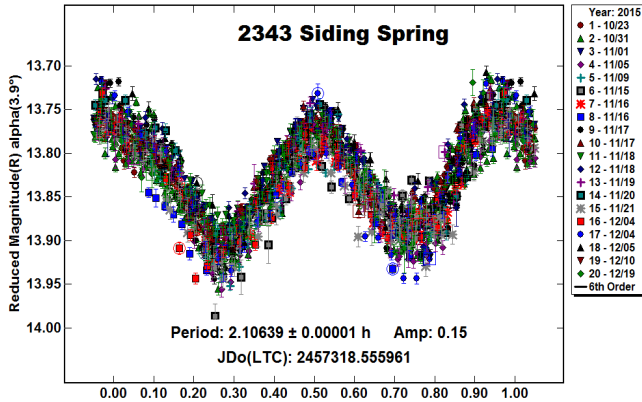
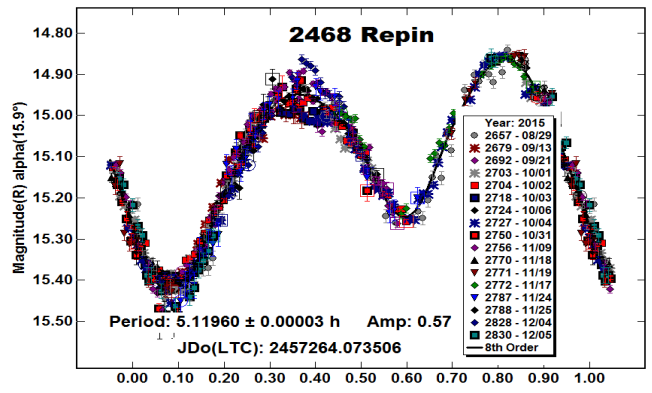
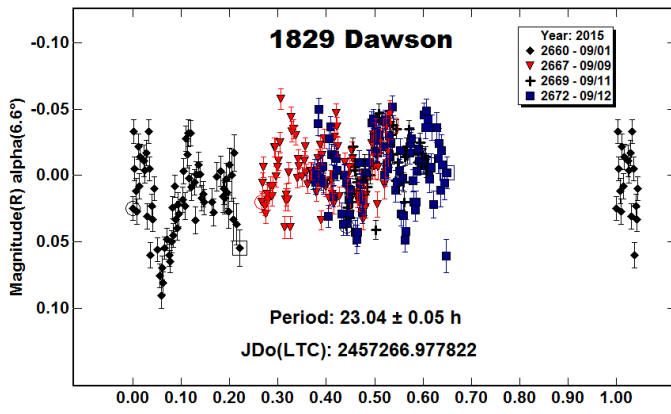
## Acknowledgements

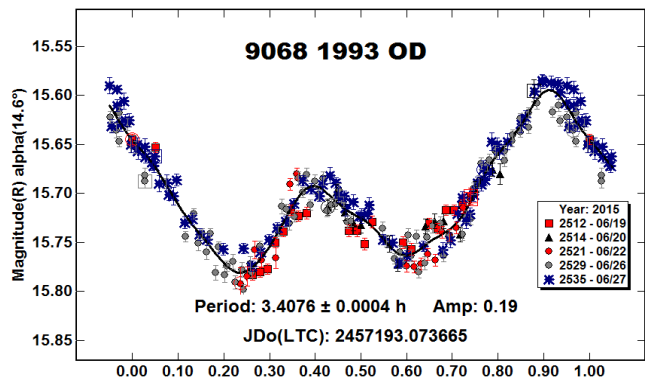
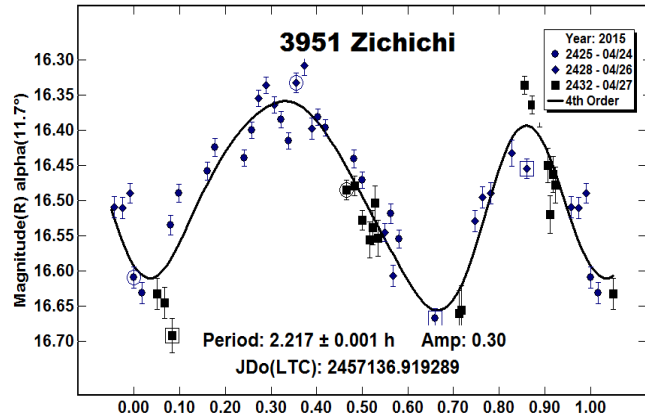
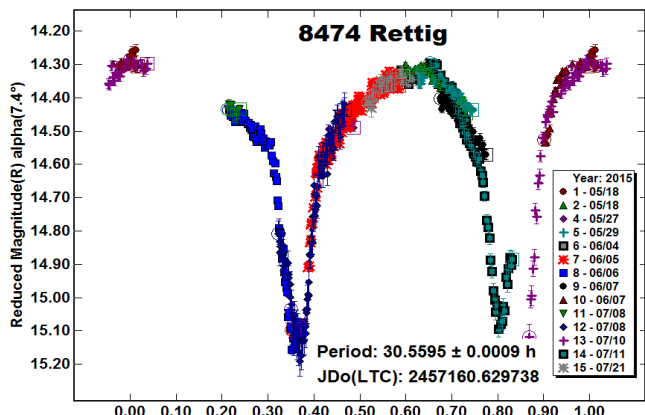
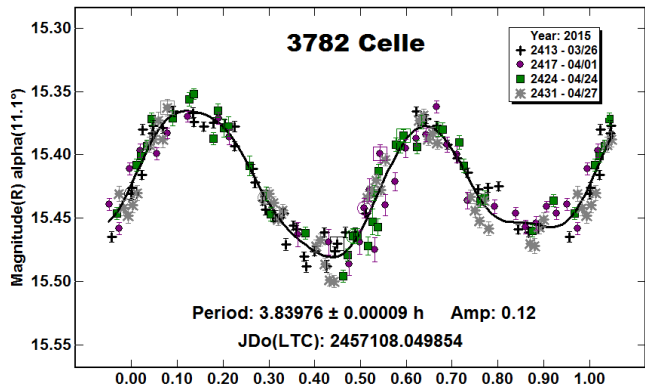
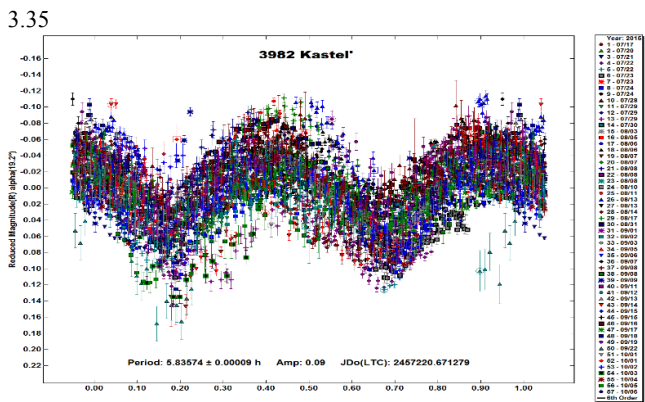
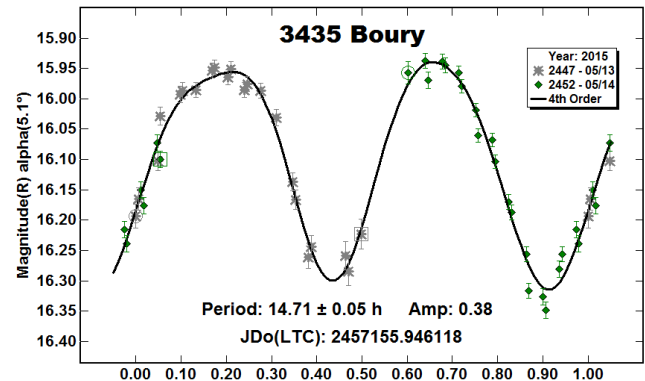
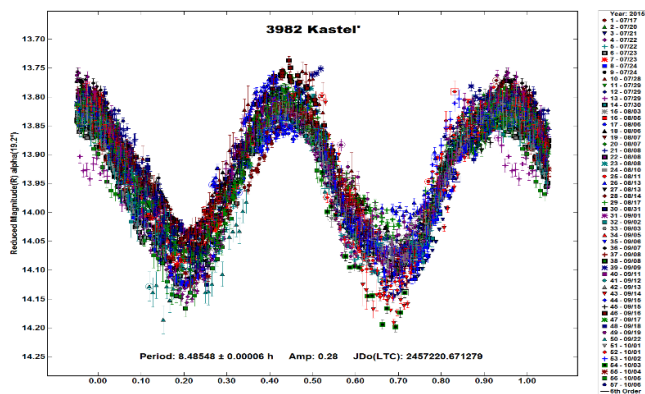
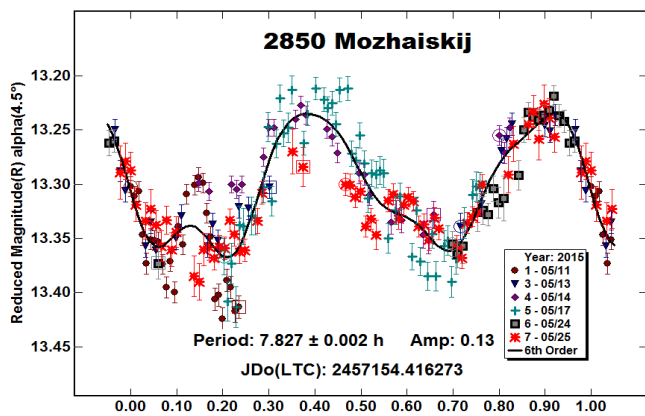
Work at the Blue Mountains Observatory is supported by a 2015 Shoemaker NEO Grant. Operations at Sugarloaf Mt. Observatory were assisted by a Gene Shoemaker NEO grant from The Planetary Society. I would like to thank Petr Pravec for his effort in coordinating and encouraging Pro-Am collaboration through PSABA.

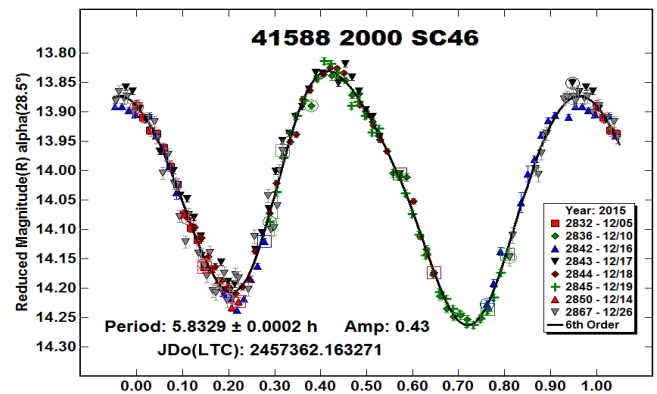
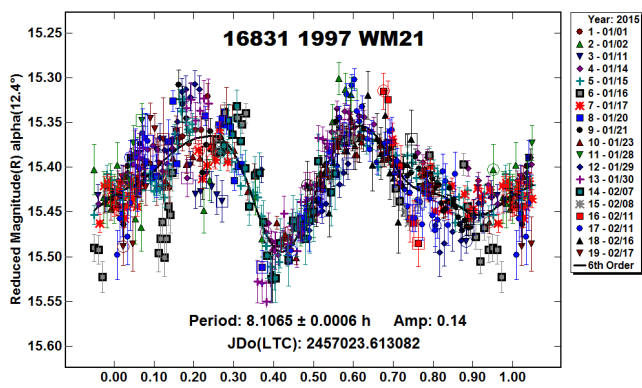
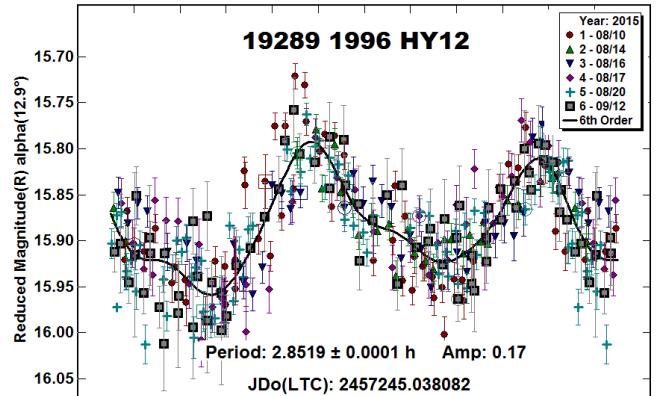
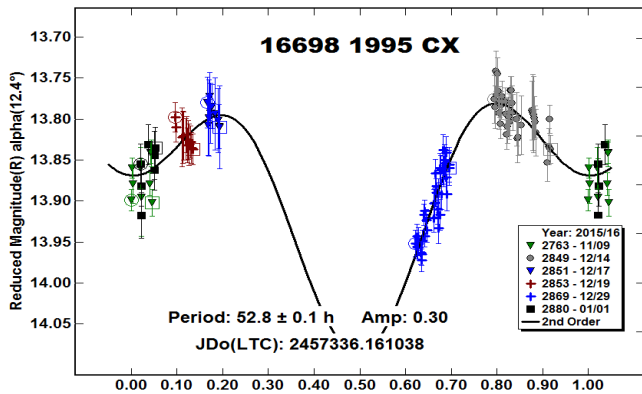
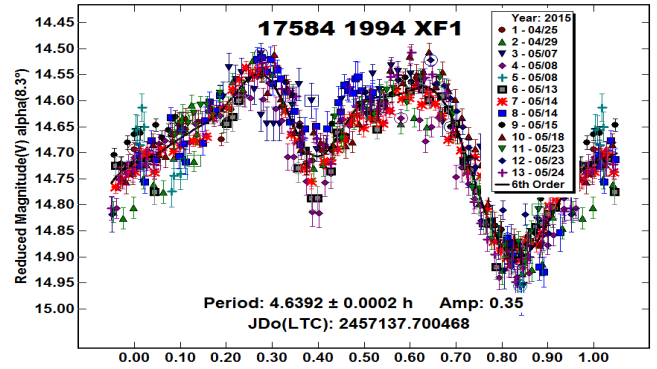
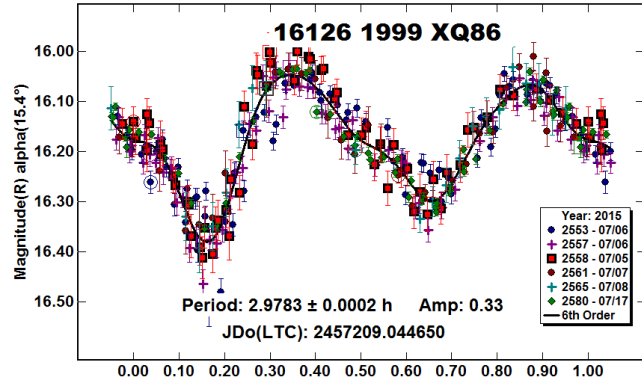
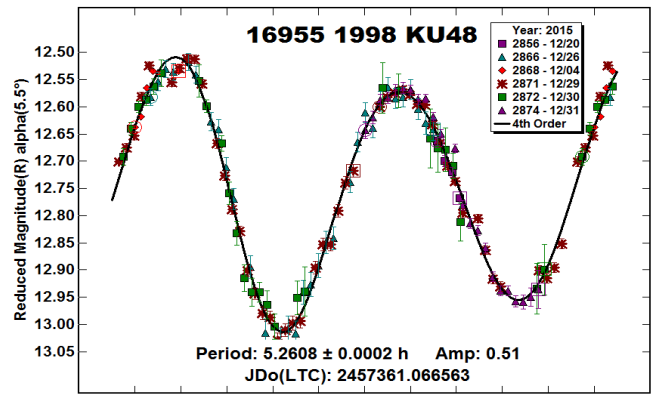
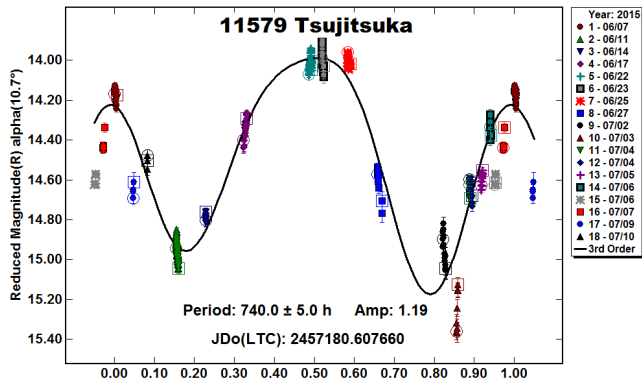
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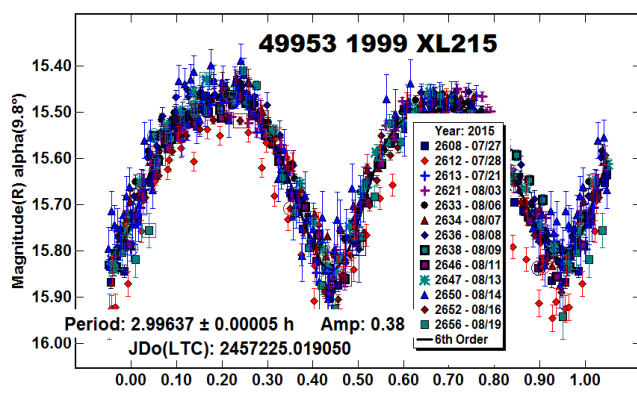
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## ROTATION PERIOD DETERMINATION OF ASTEROIDS 6199 YOSHIOKAYAYOI AND 9671 HEMERA

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Synodic rotation periods and amplitudes are reported for 6199 Yoshiokayayoi  $3.373 \pm 0.002$  hours,  $0.10 \pm 0.03$  magnitudes; and 9671 Hemera  $2.532 \pm 0.001$  hours,  $0.10 \pm 0.03$  magnitudes

Following the acquisition of an asteroid lightcurve target list, through the CALL website, two main-belt asteroids were selected for photometric monitoring in order to determine their synodic period and amplitude. Lightcurve analysis was performed using images taken from Flarestar Observatory at Malta. The equipment used to obtain the images was gathered through a Meade 0.25-m f/6.3 Schmidt-Cassegrain telescope and a Moravian G2-1600 CCD camera. This configuration yielded a pixel scale of 0.99 arcsec/pix at 1x1 binning mode. Exposures were of 300 seconds each. All images were calibrated through the software MPO Canopus (Warner, 2012). For accurate timekeeping, the software Dimension 4 (Thinking Man Software) that synchronizes the observatory's PC to an atomic clock was used. Image acquisition and telescope control was performed through Sequence Generator Pro - SGP Version 2.6 (SGP, 2016) that allowed remote operation and monitoring from a warm room at a nearby location.

All images were calibrated and analyzed through MPO Canopus - version 10.7.7.0 (Warner, 2012). The Comp Star Selector routine available through the same software was employed to simplify the selection of near solar-colored comparison stars for differential photometry use. Target and comparison star photometry were measured by equal-sized apertures in order to minimize the atmospheric effects produced by changing seeing conditions.

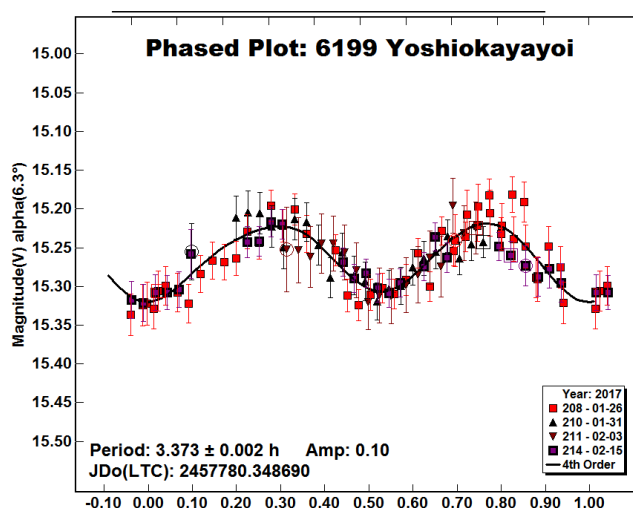
Number	Name	yyyy/mm/dd	Pts	Phase	$L_{PAB}$	$B_{PAB}$	Period(h)	P.E.	Amp	A.E.	Group
6199	Yoshiokayayoi	2017 01/26-02/15	112	6.8, 2.8, 4.3	138	-3	3.373	0.002	0.10	0.03	MB-M
9671	Hemera	2017 03/12-03/19	91	18.0, 14.2	191	-4	2.532	0.001	0.16	0.03	MB-M

Table 1. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date.  $L_{PAB}$  and  $B_{PAB}$  are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984). Grp is the asteroid family/group (Warner *et al.*, 2009).

Period analysis was accomplished by MPO Canopus, which implements the algorithm developed by Alan Harris (Harris *et al.*, 1989).

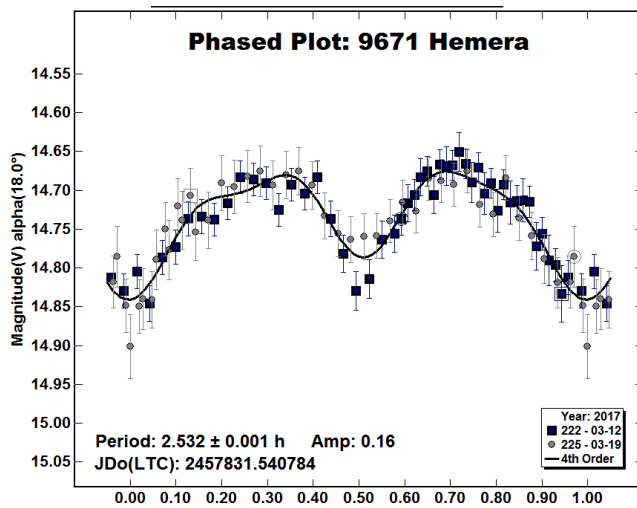
6199 Yoshiokayayoi is a main-belt asteroid discovered on 1992 Jan. 26 by A. Sugie at the Dync Astronomical Observatory and is named after Yayoi Yoshioka (1871-1959), a Japanese female physician. The asteroid orbits with a semi-major axis of about 2.59 AU, eccentricity 0.118, and a period of 4.18 years (JPL, 2016). According to the WISE satellite infrared radiometry, the diameter is  $9.663 \pm 0.235$  km based on an absolute magnitude  $H = 12.3$  (Masiero *et al.*, 2011).

No previously reported rotational periods could be found in the Lightcurve Database (LCDB; Warner *et al.*, 2009). Observations of the asteroid Yoshiokayayoi commenced on the night of 2017 January 26 and were concluded on 2017 February 15. In total, 112 clear-filtered images that were obtained on four separate nights and were analyzed through aperture photometry. The best-fit period for these data was measured to be  $3.373 \pm 0.002$  h, with an amplitude of  $A = 0.10 \pm 0.03$  mag. The phase-folded lightcurve is shown in the figure below.



9671 Hemera is a Mars-crossing asteroid discovered on 1997 October 5 by L. Sarounova at Ondrejov. This 10.4 km asteroid was named after the Greek goddess of the day, daughter of goddess of night Nykta and god of darkness Erebus. Hemera, meaning 'day' in Greek, gives rise to the word "ephemeris". 9671 Hemera orbits with a semi-major axis of around 2.69 AU, eccentricity 0.436 and a period of 4.42 years (JPL, 2016).

The 91 data points that constitute the lightcurve of this asteroid were carried out over two nights on 2017 March 3 and 19. Prior to the commencement of observations, the Lightcurve Database (LCDB; Warner *et al.*, 2009) revealed no prior synodic period results for this asteroid. The phased plot shows a bimodal curve with a period of  $2.532 \pm 0.001$  h and amplitude of 0.16 mag.



#### Acknowledgements

I would like to thank Brian Warner for his work in the development of *MPO Canopus* and for his efforts in maintaining the CALL website. Thanks are also expressed to Brian Skiff at Lowell Observatory for his advice and guidance. This research has made use of the JPL's Small-Body Database.

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## LIGHTCURVE ANALYSIS OF ASTEROIDS FROM BMO AND DRO IN 2015

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Photometric observations of selected asteroids were done from Blue Mountains Observatory (BMO) and Darling Range Observatory (DRO) in 2015. The observations were made during a favorable apparition for each asteroid. Most of these objects had poorly defined lightcurves or were never worked in the past.

CCD photometric observations were made in 2015 from Blue Mountains Observatory by Oey and Williams while observations from Darling Range Observatory were by Groom. Five telescope systems were used for the observations (see Table I). Further information of the instruments used at BMO can be found at BMO website (BMO 2015). Table II shows the absolute magnitude ( $H$ ) and the instruments used for each asteroid.

Obs	Scope	Ap (m)	$f$	Camera	Pixel	Bin	Scale
DRO	R12	0.30	7.4	ST-8XME	9.0	1x1	0.84
BMO	B14	0.35	6.0	ST-8XME	9.0	1x1	0.88
BMO	B5	0.12	7.5	ST-8300M	5.4	3x3	3.51
BMO	B24	0.61	6.8	U42	13.5	1x1	0.70
BMO	B12	0.30	5.5	ST-10XME	6.8	2x2	1.72

Table I. Equipment specifications. The Scope column gives the code used in Table II. Pixels sizes are in microns. The Scale is arcsec/pixel. BMO = Blue Mountains Observatory. DRO = Darling Range Observatory.

Unless otherwise specified, all images were taken unfiltered with exposures of 300s to maximize SNR but at the same time provide sufficient data point frequency for most common rotational periods. Data measurement and reduction was done using *MPO Canopus* V10. The reduction used Fourier analysis algorithm (FALC) developed by Harris (Harris et al., 1989).

Calibration of the data was done using the *MPO Canopus* MPOSC3 catalog. The comparison stars used Johnson-Cousins R magnitudes that were converted from 2MASS J-K values. This resulted in internal consistency of  $< 0.05$  mag however due to interstellar reddening, this result was inconsistent and required some adjustment in the zero point to compensate (Warner, 2007). The Comp Star Selector (CSS) feature in *MPO Canopus* was used to limit the comparison stars to near solar color to decrease errors caused by second order extinction.

*176 Iduna* was observed by Alton (2008) who derived a period of 11.2880 h from data covering several rotations. Despite a less reliable result from a single coverage, the result from BMO of 11.2928 h was in agreement.

Number	H	Group	Comment
176	8.30	MB-O	B5, B12
495	10.78	Nysa	B14, D12
908	10.69	MB-I	B24, B14, D12
910	10.50	MB-O	B5, B14
973	10.0	MB-O	B14
1264	9.60	MB-O	B24, B14, B12, B5
1566	16.90	Apollo	B24, B14
1685	18.60	Apollo	B14, D12
30776	15.10	MB	B14
44091	15.30	MB	B14
70799	15.50	MB	B24
77357	15.50	MB	B24
141527	18.90	Apollo	B24, B14, B12, B5
163696	16.50	Apollo	B24, B14, D12
413577	20.30	Aten	B14
2015 FS332	18.40	Apollo	B24

Table II. The H values are from the MPC. The orbital groups are from the LCDB (Warner et al., 2009a). MB = Main-belt, -I = inner, -O = outer.

495 Eulalia was observed for shape modelling and H-G determination. Each session was of short duration but sufficient to show the synodic period of 28.996 h consistent with previous work by Warner (2014) that showed a smaller amplitude of 0.15 mag compared to 0.40 mag due to the observations being at different phase angles.

908 Buda was observed on three separate times in 2015 and 2016 to get a large separation in phase angle during the apparition for shape modelling and H-G studies. The period found on the two occasions in 2015 September and December is consistent with result found previously by Warner (2009b).

973 Aralia was observed by Alkema (2013) and found to have a period of 7.291 h. Although the period obtained from BMO was consistent, our coverage over several rotations provided a more reliable result.

1264 Letaba. The previous work done by Stephens (2003) and Behrend (2006, 2016) derived the period of 32.16 h and >12 h, respectively. The observations from BMO were made from 2016 March 5 to July 9. The 23 nights of observations produced 873 data points. The best fit was to a bimodal lightcurve with a period of 63.74 h amplitude of 0.13 mag. Once the rotation period was found, some minor adjustments of the zero points to seven of the

sessions were done to within 0.05 mag limited by the MPOSC3 catalogue precision error for further refinement to the rotation period. Only data on Session 7 was not reduced with CSS method and the lightcurve was based on relative magnitude adjusted to fit into the main light curve. This asteroid may be a tumbler due to the inconsistent slope of its light curve segments.

When an attempting to match the period derived by Stephens (2003) using zero point adjustments, a 31.98 h period was found. Arbitrarily adjusting the zero-point based on relative magnitude may create a variety of low amplitude lightcurve periods; hence our latest period determination was more reliable. Due to the challenging nature of this asteroid, future observations including long sessions with more accurate data ( $\pm 0.03$  mag) will be needed to find a more reliable period.

1566 Icarus was observed in 2015 June during its close approach. The lightcurve was derived from data from two nights of observations. The period of  $2.2794 \pm 0.0005$  h is consistent with the period obtained by Warner (2015). The fast-moving NEA posed a challenge when it came to data reduction. During the close approach, the rapid sky motion of the asteroid required multiple sessions due to the small field-of-view. In turn, that meant different sets of comparison stars were required for the calibration. Due to the calibration errors described earlier, some adjustment of the zero points was necessary to get the best fit in the Fourier analysis.

1685 Toro was a Near Earth asteroid (NEA) observed in early 2016 July for the studies of the YORP effect. It had been observed previously by Warner (2013) and Higgins (2008) who derived the rotation period of 10.205 h and 10.1862 h, respectively. These values were consistent with the current 10.202 h.

(30776) 1987 QY, (70799) 1999 VY55, (77357) 2001 FW125 were all targets of opportunity. Only a single night data was obtained for each. There were no previously reported periods. The results here are only best estimates; they could vary up to  $\pm 2$  h.

(44091) 1998 FB106 was a target of opportunity. The derived rotation period was more reliable due to three overlapping multi-night sessions. There were no previous results found.

(141527) 2002 FG7 was observed during an exceptionally favourable close approach. Excellent data were obtained while it

Number	Name	2015 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.
176	Iduna	01/07-01/29	345	10	116	-27	11.2928	0.0005	0.34	0.02
495	Eulalia	04/15-06/28	312	22, 6	3	289	28.998	0.002	0.37	0.02
908	Buda	08/29-10/30	197	20, 8, 10	21	-16	14.576	0.002	0.13	0.02
908	Buda	12/10-12/31	90	22, 25	28	-10	14.604	0.007	0.10	0.02
910	Anneliese	05/06-05/09	58	1	227	1	12.15	0.02	0.15	0.05
973	Aralia	05/05-05/07	183	8	188	-8	7.3662	0.0003	0.23	0.02
1264	Letaba	03/05-07/09	926	13, 22	188	-20	63.74	0.01	0.13	0.04
1566	Icarus	06/19-06/20	422	68, 61	234	15	2.2794	0.0005	0.10	0.03
1685	Toro	07/01-07/06	142	23, 27	251	-3	10.202	0.002	0.80	0.02
30776	1987 QY	09/14-09/14	43	2	350	2	5.8	0.4	0.21	0.03
44091	1998 FB106	06/04-06/06	145	7	241	0	5.20	0.01	0.28	0.05
70799	1999 VY55	10/06-10/06	35	6	3	4	3.4	0.3	0.23	0.03
77357	2001 FW125	01/23-01/23	24	4	125	-7	2.65	0.04	0.26	0.03
141527	2002 FG7	03/14-03/19	1292	67, 21	182	-23	6.3140	0.0003	1.00	0.01
163696	2003 EB50	11/24-12/04	854	94, 60	25	-20	62.02	0.02	1.64	0.03
413577	2005 UL5	11/18-11/18	111	61	84	-14	4.0	0.3	0.50	0.03
2015 FS332		10/24-11/06	144	47	25	-35	2.3998	0.0002	0.55	0.05

Table III. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. If there are three values, the middle value is for the minimum during the range. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris et al., 1984).

was located deep in the southern hemisphere.

(163696) 2003 EB50. This Apollo NEA was observed in early 2015 December during its close approach. Its period was found to be 62.02 h based on an incomplete bimodal light curve with 1.64 mag amplitude. This result is consistent with observations from Arecibo radar (2015) observations and that from Warner (2016).

(413577) 2005 UL5. This Aten NEA was very close to the plane of the Milky Way during its fly-by in 2015 November 2015. It was a difficult target and, unfortunately, it was not possible to find a reliable rotation period.

2015 FS332 was observed to support radar modelling. The rotation period of 2.3998 h was consistent with their result. This appears to be the first reported lightcurve period for the asteroid.

#### Acknowledgement

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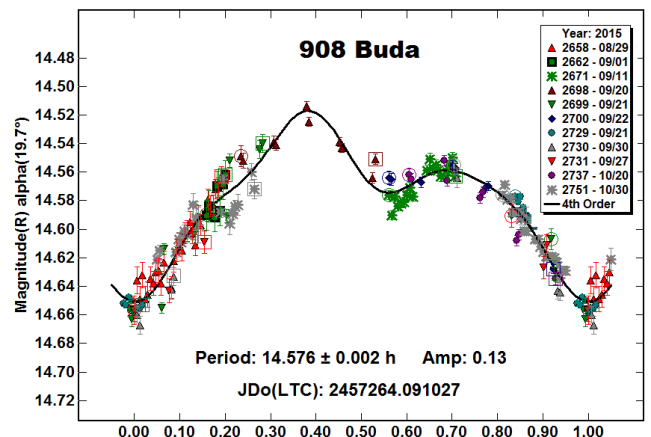
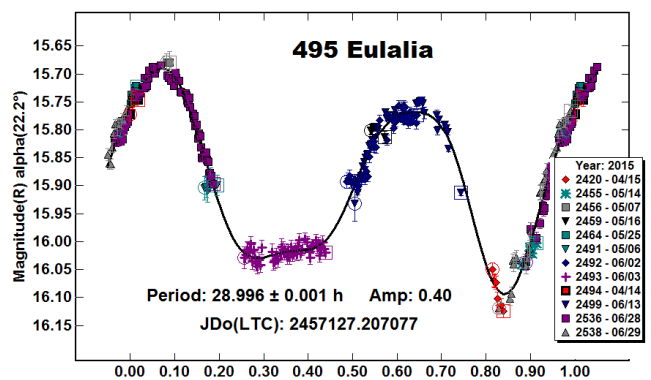
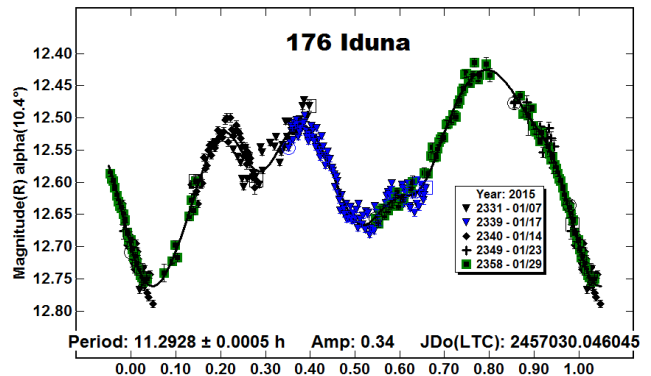
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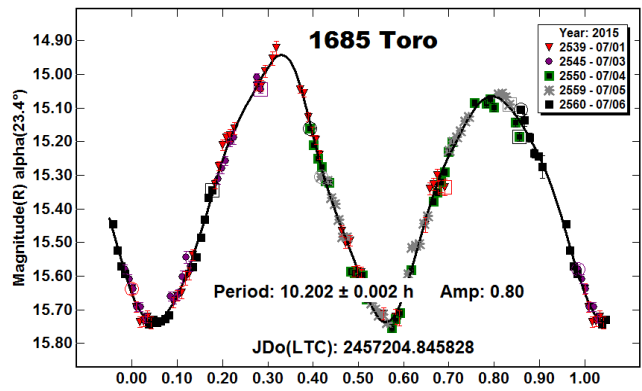
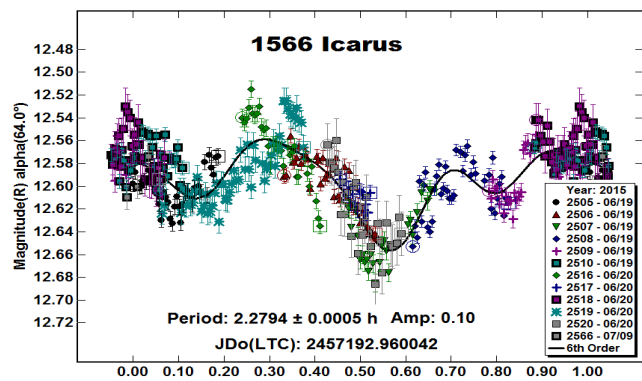
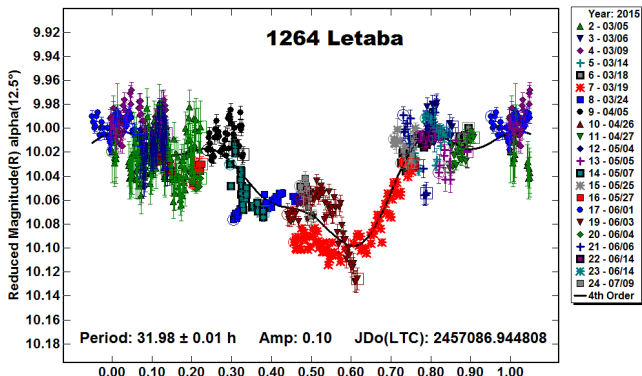
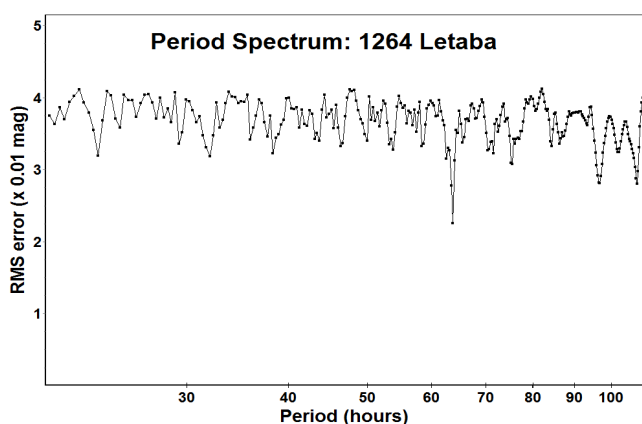
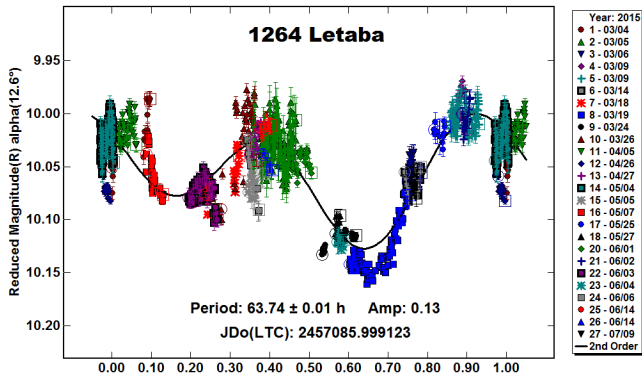
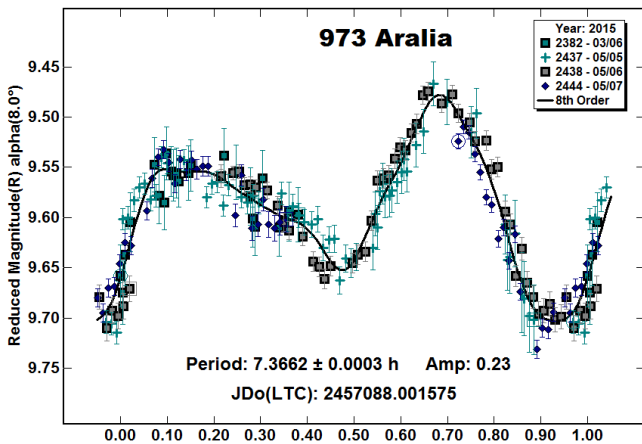
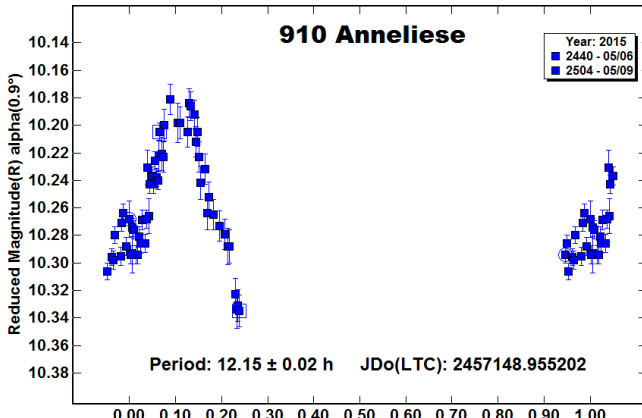
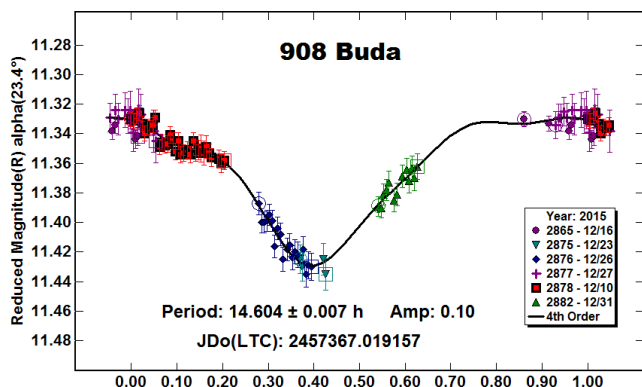
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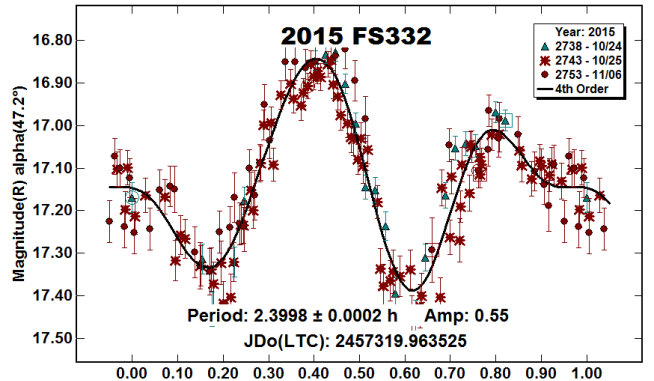
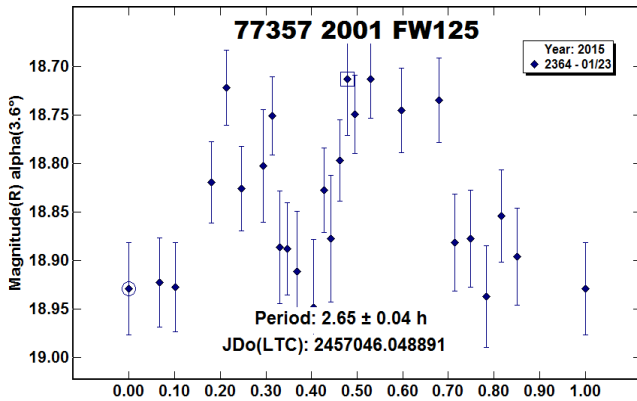
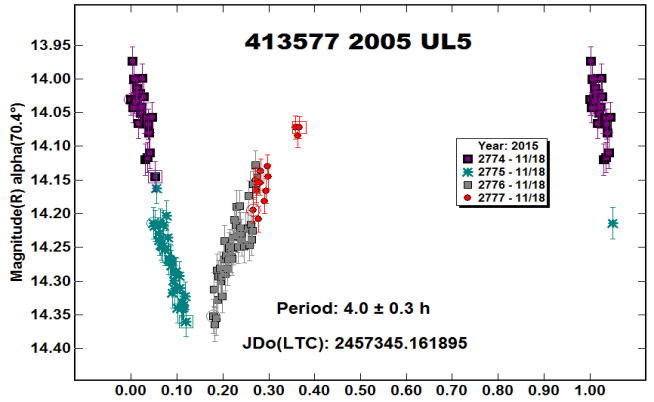
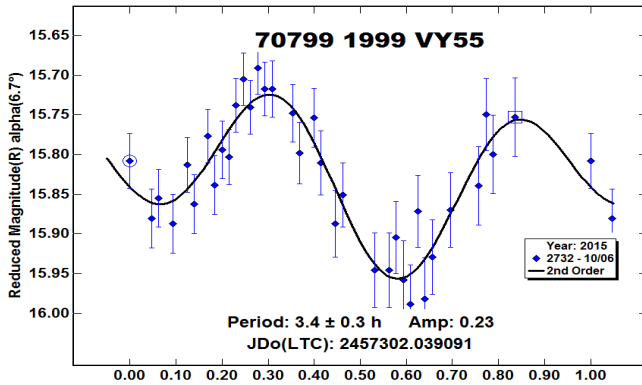
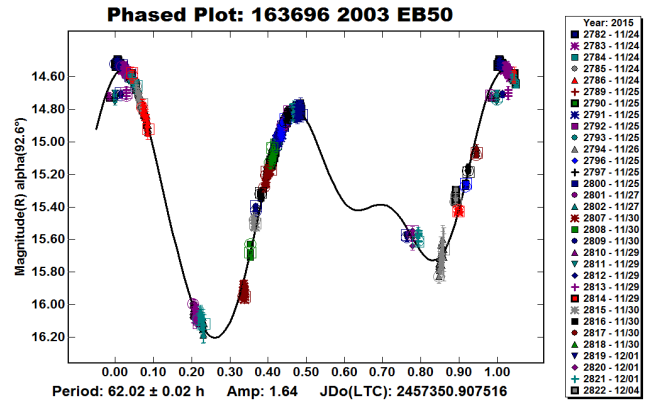
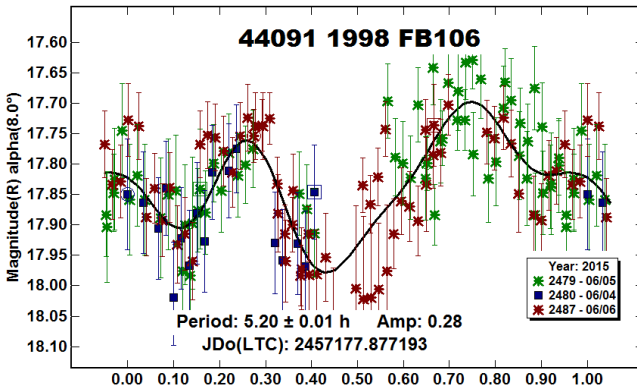
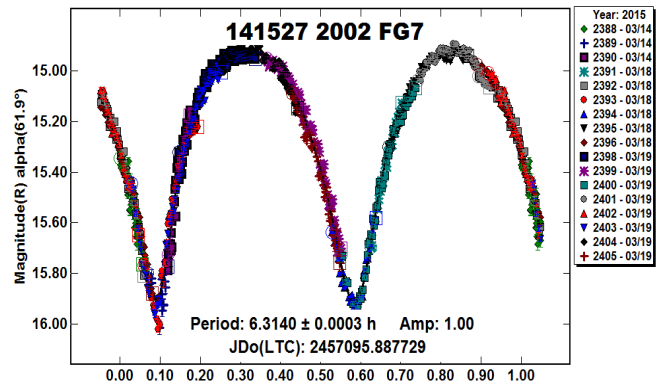
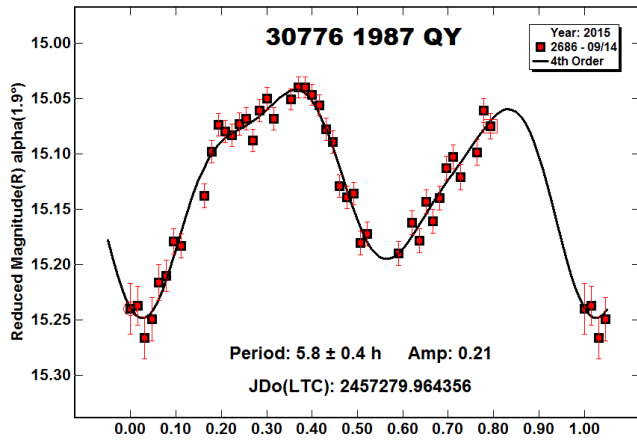
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## THE LIGHTCURVE AND ROTATION PERIOD OF ASTEROID 9414 MASAMIMURAKAMI

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Photometric observations of 9414 Masamimurakami were made at the Phillips Academy Observatory over eleven nights during 2016 March thru May. The rotation period of 9414 Masamimurakami was determined to be  $15.623 \pm 0.001$  hrs with amplitude 0.29 mag.

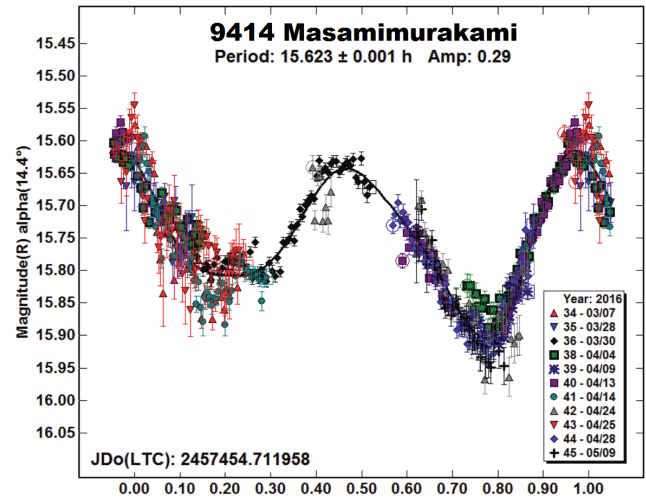
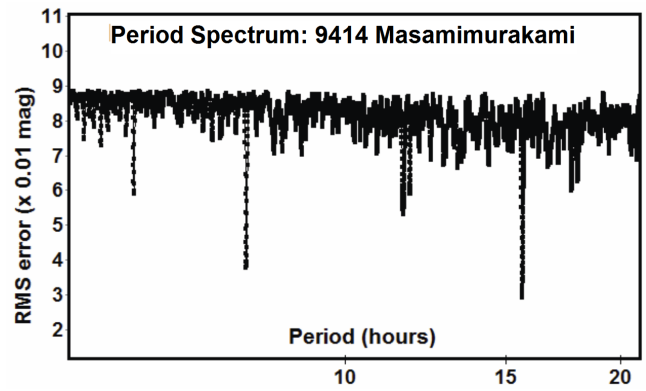
The purpose of this research was to obtain the lightcurve of 9414 Masamimurakami in order to determine its rotation period. The CALL website (<http://minorplanet.info/call.html>) was used to select the target, which was chosen for its favorable declination, appealing name, and relatively bright magnitude. A search of the asteroid lightcurve database (LCDB; Warner *et al.*, 2009) did not reveal previously reported lightcurve results. All observations were made with a 0.40-m *f*/8 Ritchey-Chrétien telescope by DFM Engineering. Images of the asteroid were taken using an Andor Tech iKon DW436 camera with a 2048x2048 array of 13.5-micron pixels. The resulting image scale was 0.86 arcseconds per pixel. All images were dark and flat-field corrected and guided.

*MPO Canopus* was used to make photometric measurements of the asteroid as well as to generate the final lightcurve and period spectrum. Comparison stars were chosen to have near solar color using the Comp Star Selector tool in *MPO Canopus*. In addition, brighter comparison stars were favored. Data merging and period analysis were also done with *MPO Canopus* using an implementation of the Fourier analysis algorithm of Harris (FALC; Harris *et al.*, 1989). The combined data set was analyzed by Durrett, Dolan, and Wang, who are students in an astronomy research class taught by Odden at Phillips Academy.

Due to a combination of bad luck with weather and a period that is close to 16 hours, the observations did not provide full coverage of the lightcurve. Nevertheless, the period spectrum strongly favored a period of  $15.623 \pm 0.001$  h. The amplitude of 0.29 mag suggests that the bimodal solution is the correct one. The lightcurve and period spectrum presented here include 524 data points taken over 11 nights.

### Acknowledgements

Research at the Phillips Academy Observatory is supported by the Israel Family Foundation. Funding for the Andor Tech camera was generously provided by the Abbot Academy Association.



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Number	Name	2016 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.	TxC
9414	Masamimurakami	03/07-05/09	524	14.4, 19.7	192.1	11.7	15.623	0.001	0.29	0.05	S

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984). TxC is the taxonomic class as found in the LCDB (Warner *et al.*, 2009).

## PRELIMINARY POLE AND SHAPE MODELS FOR THREE NEAR-EARTH ASTEROIDS

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Observations of three near-Earth asteroids (NEAs) were made between 1993 and 2016. The resulting data were used to find preliminary pole and shape models for 1863 Antinous, (5836) 1993 MF, and (154244) 2002 KL6.

CCD photometric observations of the near-Earth asteroids (NEAs) 1863 Antinous, (5836) 1993 MF, and (154244) 2002 KL6 were made by the authors at various observatories from 1997 to 2016. Additional data from Wisniewski *et al.* (1997) were also used. Table I gives the specific observing circumstances. We report on efforts to model pole and shape models for the three objects.

The minimum timespan between the earliest and latest data sets was about seven years (2002 KL6), while the longest timespan was nearly 23 years (1993 MF). Such long baselines of dense-in-time lightcurve data (DITD) are highly beneficial when attempting to find an accurate sidereal rotation period using the lightcurve inversion techniques developed by Kaasalainen and Torppa (2001) and Kaasalainen *et al.* (2001).

Sparse-in-time data (SITD) can be combined with the dense data to further enhance the inversion modeling, usually by providing data at a wide range of phase angle bisector longitudes ( $L_{PAB}$ ; see Harris *et al.*, 1984). Kaasalainen (2004) explored this possibility and found that if the sparse data were of sufficient quality and covered the full range (or nearly so) of longitudes, *i.e.*, 0-360°, a reasonably accurate pole and even shape model solution could be derived. This concept was further explored by Hanus and Durech (2012) by using sparse data from the Catalina Sky Survey.

In the past few years, a number of papers (*e.g.*, Durech *et al.* 2009; Hanus *et al.* 2011; 2013; 2016) have used both dense and sparse data to produce pole and shape models for almost 1000 asteroids. It's worth noting that most of those papers include a very large list of coauthors who are often *backyard astronomers* ("amateurs"). This emphasizes the constant need of high-quality data from that large group of observers who have considerable flexibility in making observations. It's also important to note that many of the 1000 models so far are for relatively bright asteroids, *i.e.*, within easy reach of modest telescopes, and that – despite having good dense data sets for a given asteroid – "more is often better."

## Modeling Considerations and Restrictions

It is tempting to try to model an asteroid after obtaining a single dense lightcurve and merging in sparse data. Don't expect to get good results, even if they appear to be so. The inversion process needs as much information as possible about how the asteroid's lightcurve changes with different phase angles and viewing aspects, the latter judged by the phase angle bisector longitude.

As mentioned above, any sparse data points should be evenly distributed about most of the asteroid's orbit. Just as important is that the dense lightcurves are not all within a small range of  $L_{PAB}$  values and that they not be diametrically opposed, *i.e.*, about 180° separation in  $L_{PAB}$ . Otherwise, there is little new information about the pole or shape from one dense lightcurve over another.

Usually, dense lightcurves are needed from several apparitions at different viewing aspects before a good model can be found, and it's particularly useful to have dense lightcurves at different phase angles during a single apparition such that the shape and/or amplitude changes significantly. Slivan (2012; 2013) discussed these requirements in detail; those papers should be mandatory reading before one starts modeling.

There is a possible exception to the multi-apparition requirement: when a near-Earth asteroid passes Earth and goes through a wide range of both phase angles and  $L_{PAB}$  values. In this case, especially if there are sparse data from other apparitions available, it may be possible to get a useful model. An example of this was the 2001 apparition of (5587) 1990 SB when Koff *et al.* (2002) obtained data over several months. Using their data alone, Warner (unpublished) was able to find a shape and pole model with a high degree of confidence and which compared favorably to one found by Kaasalainen *et al.* (2004) using additional dense and sparse data. It was this successful effort that initially prompted the attempts to model the three asteroids presented in this paper.

The "10 percent rule" is used to determine the quality of the period and pole solutions. In a perfect world, there would no other periods within 10% of the one with the lowest  $\chi^2$  value. However, most times there are several, even dozens, of points within 10% of the lowest  $\chi^2$  value. In these cases, the hope is for a single, well-defined minimum in the period search curve. In this case, the period with the lowest  $\chi^2$  value is used in the pole search. If the minimum is a broad curve, then – even if there are only a few data points below the 10% line – the sidereal period may still be too uncertain. The best solution is to get more data at future apparitions (or data from past ones) and so increase the total time span of the observations.

The same reasoning is applied in the pole search. Usually a large number of discreet poles are tested to find the one with the lowest  $\chi^2$  value. If there is only one solution (all others exceed the 10% rule), or there is a small number that are immediately adjacent to that solution, then the best solution based on the available data has been found.

However, the lightcurve inversion process has difficulty finding a unique ecliptic longitude when the asteroid has a low orbital inclination. Therefore, a pole search may have two clusters of discreet regions that are separated by about 180° longitude. The two regions may or may not be on the same side of the equator. This "double mirroring" is also not uncommon. In fact, it's possible to get four solutions that mirror in both longitude and latitude.

Number	Name	yyyy mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period	P.E.	Amp	A.E.	Obs
1863	Antinous	1999 08/07–09/14	336	43.8, 13.3	4, 6	-3, +7	7.4568	0.0017	0.23	0.02	OO
		2016 02/07–02/16	450	33.3	177, 182	+3, +1	7.453	0.005	0.18	0.02	PDS
		2016 08/06–08/10	159	42.8, 40.3	6, 7	-1, 0	7.471	0.005	0.33	0.02	PDS
		2016 10/03–10/06	251	7.7, 8.4	7	+11	7.443	0.006	0.13	0.02	PDS
5836	1993 MF	1993 09/15–09/15	130	31.2	8	+19.2	4.96	0.01	0.53	0.02	WIS
		1997 10/23–11/04	116	22.9, 16.0	67	+1, 0	4.9543	0.0002	0.74	0.03	OO
		2016 06/05–06/09	157	53.6, 55.2	304, 308	+10	4.948	0.005	0.82	0.03	PDS
		2016 09/09–09/11	212	46.1, 44.9	31	+11	4.953	0.005	0.88	0.02	PDS
		2016 10/14–10/18	337	19.4, 15.9	40, 41	+7, +6	4.955	0.001	0.74	0.02	PDS
154244	2002 KL6	2009 06/18–07/13	151	43.7, 74.5	293, 335	+12, +15	4.605	0.002	1.15	0.01	LO
		2009 09/24–09/26	104	35.4, 33.3	31, 32	+3	4.610	0.002	0.90	0.05	LO
		2009 10/16–10/22	82	12.5, 6.6	35	+1, 0	4.6081	0.0003	0.85	0.05	LO
		2016 06/10–06/27	1086	13.6, 29.6	254, 264	+8, +14	4.60869	0.00005	0.65	0.02	WEA
		2016 09/09–09/11	210	41.3, 39.0	14	+7	4.609	0.005	0.98	0.02	PDS
		2016 10/14–10/19	228	3.4, 1.8	23, 24	+2, +1	4.607	0.001	0.47	0.03	PDS

Table I. Observing circumstances and synodic period results. Pts is the number of data points used in the analysis. The phase angle ( $\alpha$ ) is given for the first and last date (0h UT). L<sub>PAB</sub> and B<sub>PAB</sub> are, respectively, the phase angle bisector longitudes and latitudes for the first and last date (0h UT). The Obs column gives the observatory involved: LO = Lowell Observatory (Koehn *et al.* 2014); OO = Ondrejov Observatory (Pravec *et al.* 1999web); PDS = Palmer Divide Station (Warner 2016a, 2017, this work); WEA = Warner *et al.* (2016); WIS = Wisniewski *et al.* (1997).

One way to determine which pole solution is the more likely one is to plot the dense lightcurve data against each model’s curve to check which model provides the best fit. This doesn’t always work since no one model shows a significantly better fit. The only reliable way to break the ambiguity is to combine the lightcurve data with other observations such as adaptive optics, occultation profiles, and/or radar observations. The projected profiles of the model onto the sky plane at the time of the additional observations can be compared against the profiles from the other observations and so, with a little luck, resolve the ambiguities.

Another weak point of lightcurve inversion is that, when using data that are not all well-calibrated (they rarely really are), they are treated as “relative data” and so the process cannot accurately confine the Z-axis dimension. In other words, the asteroid may be “taller” or “flatter” than the model indicates. It can also happen where the model has a Z-axis that is that greater than either the X- or Y-axis dimensions. In the extreme, this would be like a pencil rotating about its longest axis instead of its shortest, such as when it is rolling off the desk. It is possible to manipulate the Z-axis in the model so that it is the shortest one and then check the resulting model curve against actual data. However, this is an arbitrary process and does not always succeed. The solution is, again, “More Data!”

Despite all these apparent obstacles, the situation is not hopeless, as confirmed by the approximately 1000 models found to-date. Like many other things, modeling takes preparation, an understanding the process and its limitations, patience, lots of practice, and more than a little luck.

#### Modeling the Three Candidates

All three candidates were observed at CS3-PDS at least twice during 2016 with the intent of trying to find a pole and shape model. The PDS data were combined with those from the other authors obtained from 1997 to 2016 for the analysis and from Wisniewski *et al.* (1997). Pravec, Kusnirak, and Ferrero sent their data directly to Warner for the analysis. The dense data for (154244) 2002 KL6 from Lowell Observatory (see Koehn *et al.* 2014) were downloaded from the ALCDEF web site (<http://alcddef.org>) and are used with permission.

Table II gives the number of dense lightcurves for each asteroid as well as the number of sparse data points obtained by the Catalina Sky Survey. The dense lightcurves were given a weight of 1.0. The CSS data were given a weight of 0.2 based on the work by Hanus *et al.* (2013) that evaluated the quality of sparse data from CSS and other surveys.

Asteroid	N <sub>dense</sub>	N <sub>sparse</sub>
1863	25	111
5836	13	120
154244	39	64

Table II. N<sub>dense</sub> is the number of dense lightcurves used in the modeling. The sparse data are considered a single lightcurve, so the N<sub>sparse</sub> column gives the number of sparse data points.

#### Interpreting the Modeling Plots

There are several plots for each asteroid that were generated by *MPO LChInvert*, a program that provides a Windows interface to the C/FORTAN code available on the DAMIT web site (<http://astro.troja.mff.cuni.cz/projects/asteroids3D/web.php>). For each group of plots below, the left-hand plot on the first line shows the L<sub>PAB</sub> distribution. Green circles represent the mid-point of each dense lightcurve. Red squares represent each sparse data point. The right-hand plot of the first line shows the period search  $\chi^2$  values versus period. The horizontal green line is at 1.1x the lowest  $\chi^2$  value, i.e., the 10% rule mentioned above.

On the second line, the left-hand image is the 10% pole search plot. Each small region represents a 15x15° area of the sky in ecliptic coordinates. An ideal solution would have only one dark blue region and all the others dark red (maroon). The additional image on the second line shows profiles of the asteroid model as view from over the north and south poles and in the asteroid’s equatorial plane at Z = 0° and Z = +90° rotation.

Since the inversion algorithms used here find only a convex hull, concavities appear as large flat areas on the asteroid. A good analogy is to imagine wrapping the asteroid with paper without punching holes in the paper to fill depressions. This creates flat areas in the wrapping that are covering concavities. Towards the end of this paper, we discuss some specific interpretations of these flat areas for the models that were found.

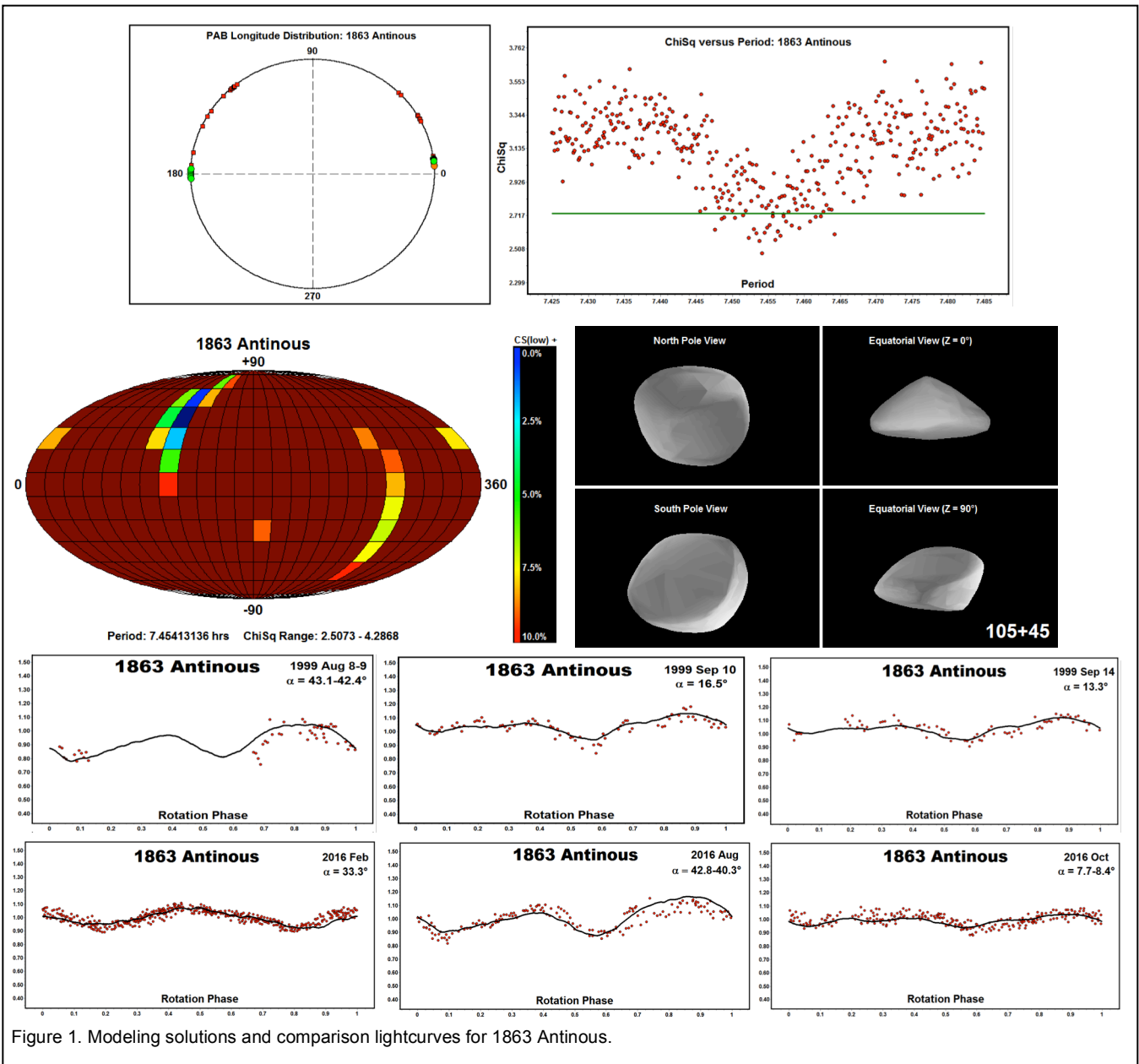


Figure 1. Modeling solutions and comparison lightcurves for 1863 Antinous.

The remaining plots compare the dense data with the model curve at specific times. The red dots represent the dense data while the solid black line is the model lightcurve. The main consideration is that the dense lightcurve has the same amplitude and shape as the model. If there are multiple pole solutions, then the one that gives the best fits for all the dense lightcurves is the more likely solution – assuming it has a realistic shape.

1863 Antinous. The main obstacles for this asteroid were the dense lightcurves being almost diametrically opposed in  $L_{PAB}$  and the poor distribution in  $L_{PAB}$  values. Even with high-quality dense lightcurves, a period search with a range of  $\pm 0.02P$ , about 7.3 to 7.6 h in this case, would be the norm. This would have taken several days and so the search range was limited to 7.43 to 7.49 h. This covered all the reported synodic periods. Even so, the search took more than five hours. The large number of results below the 10% line in the period search plot is a good indication that the model could be improved significantly with data from previous or later apparitions.

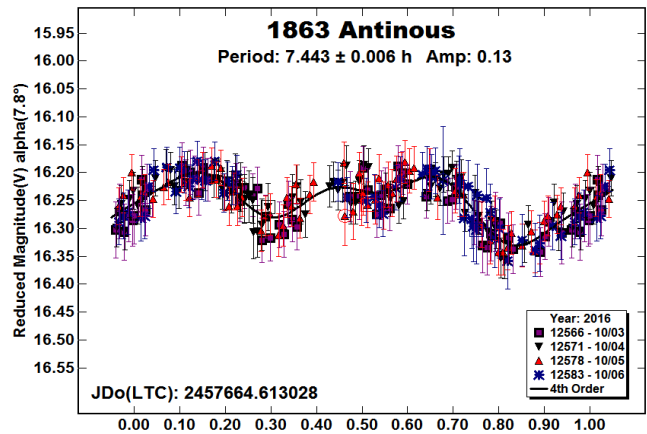
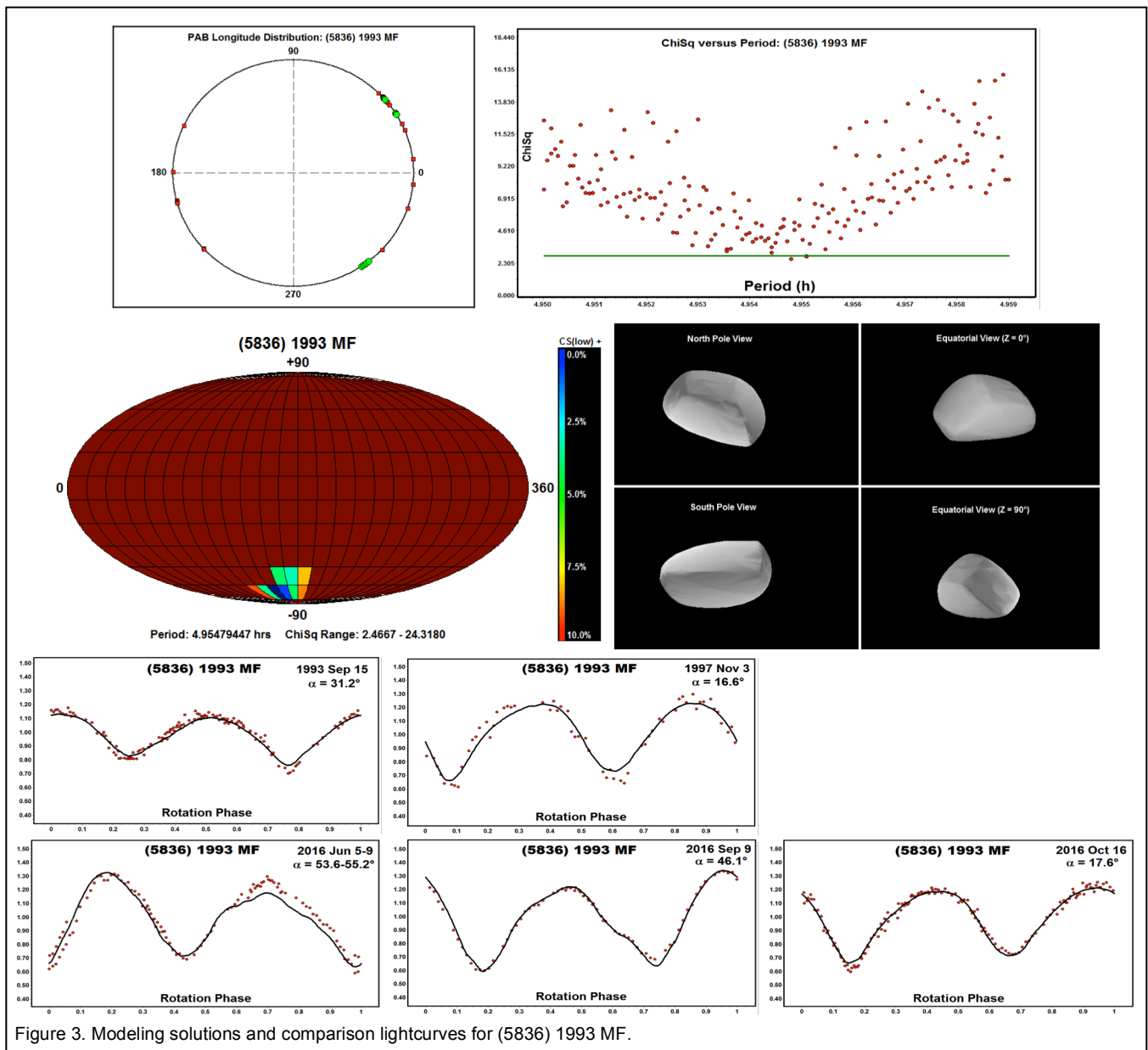


Figure 2. Dense lightcurve based on the 2016 Oct PDS data.



The pole's ecliptic longitude seems secure and, given the positive ecliptic latitude, it's likely that the asteroid has a prograde rotation (counter-clockwise when looking down on the North Pole).

(5836) 1993 MF. Dense lightcurves were available from apparitions in 1993, 1997, and 2016. The 2016 data covered a significant range of  $L_{PAB}$  and phase angles and the sparse data were distributed over about 3/4 of the asteroid's orbit. Given the success modeling of (5587) 1990 SB mentioned earlier, we first tried to model this NEA using only the 2016 data. When data from all apparitions were used, the pole latitude was about the same, but the favored longitude was opposite the one found from using only the 2016 data.

Initially, only the 1997 and 2016 data were available. These led to two possible solutions at  $(149^\circ, -73^\circ)$  and  $(331^\circ, -53^\circ)$ . When the Wisniewski et al. data from 1993 were added, the period solution was improved by having only one solution below the 10% line.

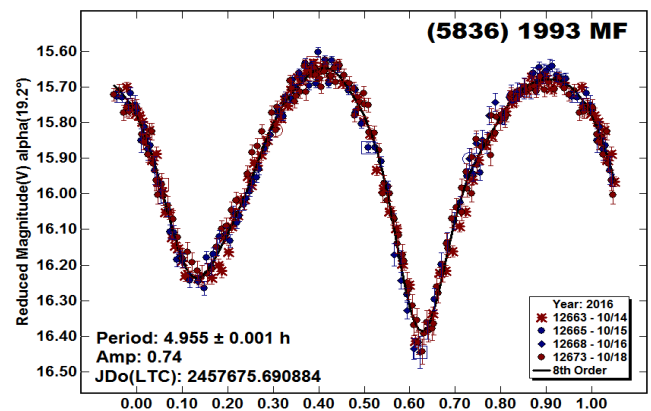


Figure 4. Dense lightcurve based on 2016 Oct PDS data.

The pole search found only one solution at  $(121^\circ, -79^\circ)$ , thus eliminating the second pole solution and reducing the uncertainty

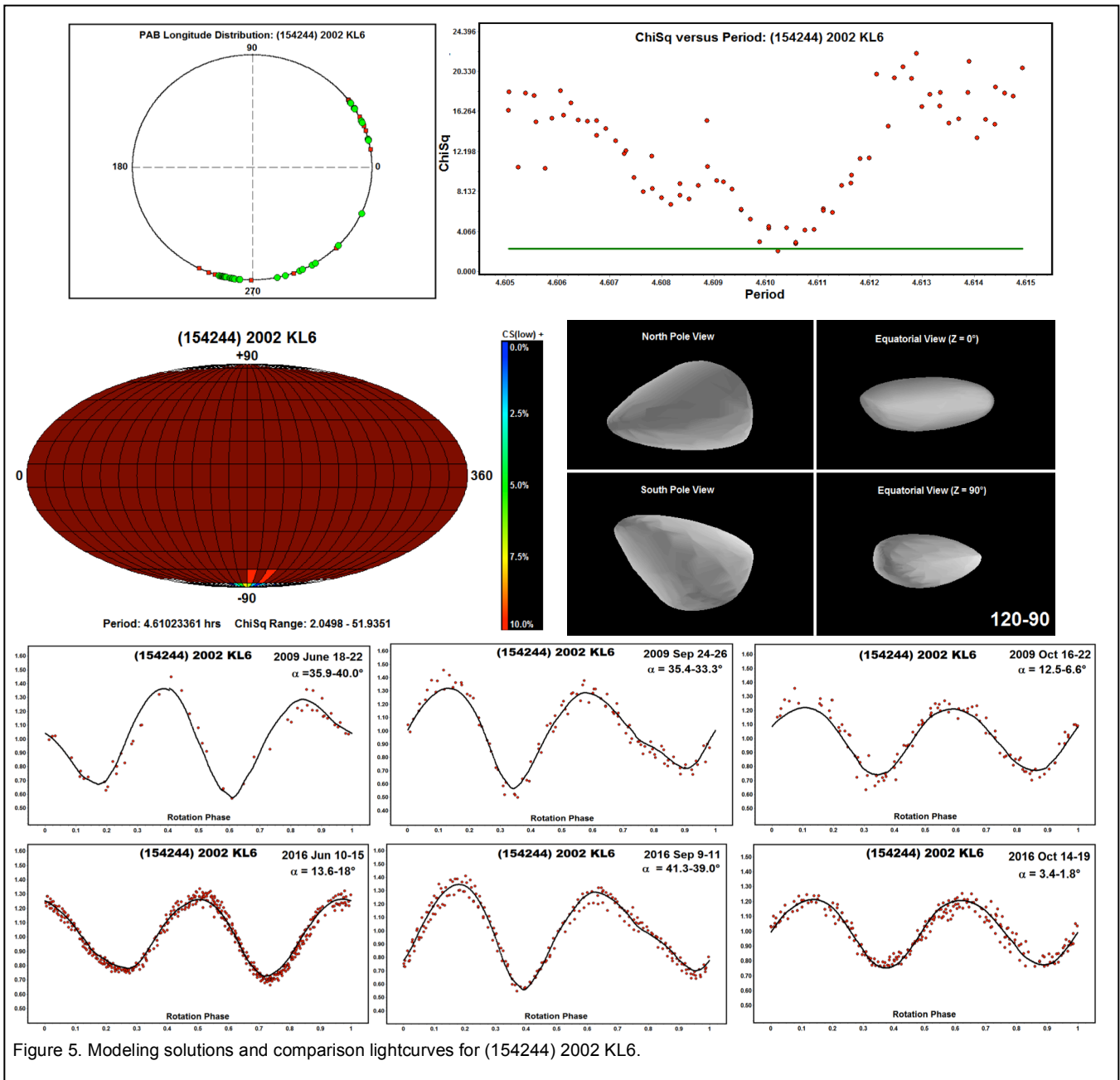


Figure 5. Modeling solutions and comparison lightcurves for (154244) 2002 KL6.

for the first. Given the negative latitude, the asteroid's rotation is retrograde.

(154244) 2002 KL6. Modeling for this NEA was aided by having dense lightcurves spanning almost seven years (2009-2016) and a large range of  $L_{PAB}$  values. On the negative side was the lack of sparse data at  $L_{PAB}$  values other than within the range of those for the dense data. The former appears to have outweighed the latter, since both the period and pole solutions were found with a high level of confidence.

The elongated shape of the model is reflected in the large amplitudes of the lightcurves at all viewing aspects. As with (5836) 1993 MF, the high, negative ecliptic latitude indicates a retrograde rotation for the asteroid.

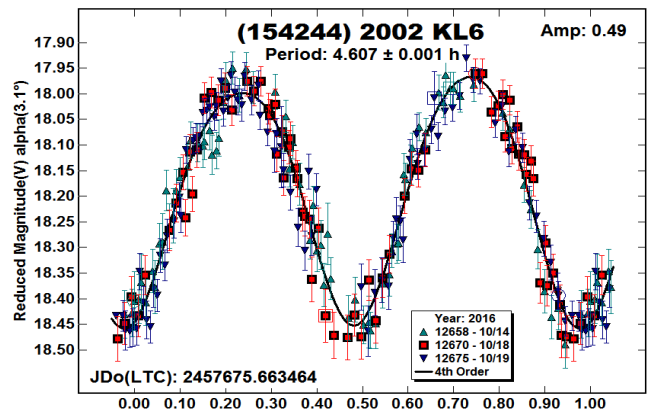


Figure 6. Dense lightcurve based on 2016 Oct PDS data.

Number	Name	$L_1$	$B_1$	$P_1$	a/b	a/c
1863	Antinous	108	+56	7.454130	1.09	1.68
5836	1993 MF	121	-79	4.954794	1.30	1.44
154244	2002 KL6	129	-89	4.610233	1.21	2.22

Table III. Pole solutions.  $L$  = ecliptic longitude;  $B$  = ecliptic latitude;  $P$  = sidereal period. The longitude and latitude errors are on the order of  $\pm 10^\circ$ . The period error is approximately 2 units of the last decimal place. The a/b column gives the ratio of the two longest axes ( $X/Y$ ) of the model. The a/c column gives the ratio of the longest axis ( $X$  or  $Y$ ) versus the  $Z$ -axis.

#### About the Derived Shapes and Pole Solutions

As mentioned previously, the lightcurve inversion process employed here does not handle concavities very well. All three asteroid models show flat areas, or straight contours, that suggest concavities. These can be relatively large craters or even a “waist” or “neck” connecting two large lobes. The model for (5836) 1993 MF may represent either a highly-bifurcated body or even a so-called “contact binary.” For (154244) 2002 KL6, one interpretation could be a small component sitting on a larger one.

Observations at high solar phase angles are generally critical for revealing the presence of concavities, although a unique non-convex solution is not possible in such a case. While the maximum solar phase angles at which the three asteroids were observed are not quite extreme, it is most useful to look at the model fits at higher phase angles. For example, in Figure 1 the model-data fit for 1863 Antinous in 2016 August shows what might be systematic residuals due to unmodeled concavities. See also Figure 3, where the fit at about  $\alpha = 55^\circ$  in early June for (5836) 1993 MF shows a significant deviation at the second maximum around 0.7 rotation phase. At lower phase angles in Figure 3, the model-data fits are much tighter.

The pole solution errors are a circle with a radius of  $\pm 10^\circ$ . The sidereal periods have errors on the order of 1-2 units of the last decimal place.

#### YORP Considerations

The YORP effect (Yarkovsky–O’Keefe–Radzievskii–Paddack; Rubincam 2000) is the thermal re-radiation of sunlight by a body that can impart a small torque and so cause that body’s rotation to increase or decrease over time. The YORP effect increases with decreasing distance from the Sun, making NEAs the most likely candidates to find YORP acceleration after only a decade or so, as has been shown by, among others, Lowry et al. (2007), Durech et al. (2008), and Kaasalainen et al. (2008).

The change in rotation period due to YORP increases quadratically with time, meaning that a plot of sidereal period versus time would not show a linear but exponential trend. This implies that at least three data points are needed to help determine if an asteroid’s rotation rate is being influenced by YORP. Save for 1993 MF, our dense data sets were from only two apparitions. For those two, even if the modeling code allowed factoring in YORP acceleration, there would be little point in trying. Should additional data become available, either within or outside the range of dates covered by our data sets, then it may be worthwhile to revisit these two asteroids to see if there are signs of YORP acceleration.

#### The ALCDEF Database

The Asteroid Lightcurve Data Exchange Format (ALCDEF) database (<http://alcdef.org>) was used to obtain some of the data

used for this paper. The web site provides access to a database of raw asteroid time-series (lightcurve) photometric data. As of 2017 Mar 29, there were almost 2.89 million observations for 11495 individual asteroids. Those doing asteroid time-series work are encouraged to upload their data for use by other researchers. Those needing raw time-series photometry can freely download data from the website. For a more complete description of the site and links to ALCDEF documentation, see Warner (2016b).

#### Conclusions

Trying to model an asteroid based on dense data from only one apparition is discouraged. However, it is sometimes possible to obtain a good, *preliminary* model if 1) there are sufficient sparse data to use in the modeling and/or 2) there are multiple dense lightcurves from the same apparition covering a sufficient range of phase angles *and*  $L_{PAB}$  values. Dense lightcurves from a single apparition that have nearly the same  $L_{PAB}$  will usually *not* provide sufficient information for the lightcurve inversion algorithms to find a reliable model.

All this adds up to say that NEAs are the only *good* candidates for modeling based on single apparition dense lightcurves. The viewing aspects and phase angles for most asteroids farther out, those in the main-belt and beyond, do not change sufficiently during a single apparition to derive a model beyond, at best, a modest level of confidence. These factors point out the importance of obtaining new dense lightcurves for main-belt asteroids even when the period has been well established. The most good comes when those new data are from viewing aspects and/or phase angles significantly different from previous observations.

#### Acknowledgements

Thanks to Alan Harris for providing the data for (5836) 1993 MF obtained by Wisniewski et al. Funding for PDS observations, analysis, and publication was provided by NASA grant NNX13AP56G. Work on the asteroid lightcurve database (LCDB) was also funded in part by National Science Foundation grant AST-1507535. This research was made possible in part based on data from CMC15 Data Access Service at CAB (INTA-CSIC) (<http://svo2.cab.inta-csic.es/vocats/cmc15/>) and the AAVSO Photometric All-Sky Survey (APASS; Henden et al., 2009) funded by the Robert Martin Ayers Sciences Fund. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. (<http://www.ipac.caltech.edu/2mass/>)

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**ASTEROID LIGHTCURVE ANALYSIS AT  
CS3-PALMER DIVIDE STATION:  
2016 DECEMBER THRU 2017 MARCH**

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(Received: 2017 April 11)

Lightcurves for 18 main-belt asteroids were obtained at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2016 December thru 2017 March. Many of the asteroids were “strays” in the field of planned targets, demonstrating a good reason for data mining images. Analysis shows that the Hungaria asteroid (45878) 2000 WX29 may be binary.

CCD photometric observations of 18 main-belt asteroids were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2016 December thru 2017 March. Table I lists the telescope/CCD camera combinations used for the observations. All the cameras use CCD chips from the KAF blue-enhanced family and so have essentially the same response. The pixel scales for the combinations range from 1.24-1.60 arcsec/pixel.

Desig	Telescope	Camera
Squirt	0.30-m f/6.3 Schmidt-Cass	ML-1001E
Borealis	0.35-m f/9.1 Schmidt-Cass	FLI-1001E
Eclipticalis	0.35-m f/9.1 Schmidt-Cass	STL-1001E
Australius	0.35-m f/9.1 Schmidt-Cass	STL-1001E
Zephyr	0.50-m f/8.1 R-C	FLI-1001E

Table I. List of CS3-PDS telescope/CCD camera combinations.

All lightcurve observations were unfiltered since a clear filter can result in a 0.1-0.3 magnitude loss. The exposure duration varied depending on the asteroid’s brightness and sky motion. Guiding on a field star sometimes resulted in a trailed image for the asteroid.

Measurements were made using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. Catalog magnitudes were usually taken from the CMC-15 (<http://svo2.cab.inta-csic.es/vocats/cmc15/>) or APASS (Henden et al., 2009) catalogs. The MPOSC3 catalog was used as a last resort. This catalog is based on the 2MASS catalog (<http://www.ipac.caltech.edu/2mass>) with magnitudes converted from J-K to BVRI (Warner, 2007). The nightly zero points for the catalogs are generally consistent to about  $\pm 0.05$  mag or better, but on occasion reach 0.1 mag and more. There is a systematic offset among the catalogs so, whenever possible, the same catalog is used throughout the observations for a given asteroid. Period analysis is also done with *MPO Canopus*, which implements the FALC algorithm developed by Harris (Harris et al., 1989).

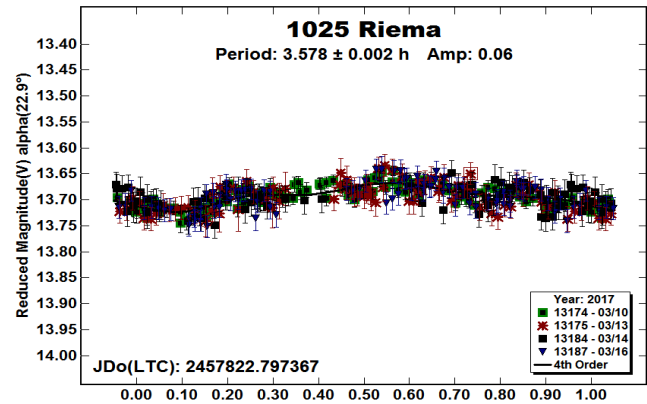
In the plots below, the “Reduced Magnitude” is Johnson V as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distance by applying  $-5 \cdot \log(r\Delta)$  to the measured sky magnitudes with  $r$  and  $\Delta$  being, respectively, the Sun-asteroid and Earth-asteroid distances in AU. The magnitudes were normalized to the given phase angle, e.g.,

$\alpha(6.5^\circ)$ , using  $G = 0.15$ , unless otherwise stated. The X-axis is the rotational phase ranging from  $-0.05$  to  $1.05$ .

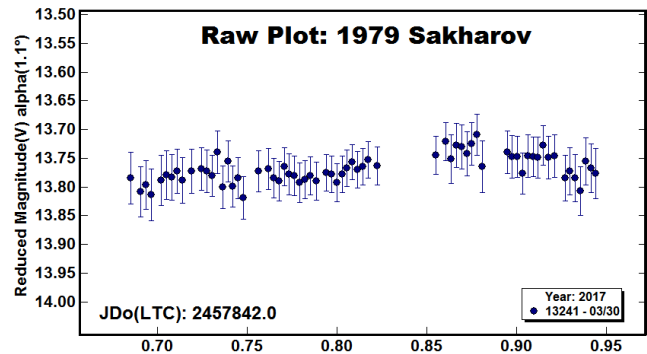
If the plot includes an amplitude, e.g., “Amp: 0.65”, this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*.

For the sake of brevity, only some of the previously reported results may be referenced in the discussions on specific asteroids. For a more complete listing, the reader is directed to the asteroid lightcurve database (LCDB; Warner et al., 2009a). The on-line version at <http://www.minorplanet.info/lightcurvedatabase.html> allows direct queries that can be filtered a number of ways and the results saved to a text file. A set of text files of the main LCDB tables, including the references with bibcodes, is also available for download. Readers are strongly encouraged to obtain, when possible, the original references listed in the LCDB for their work.

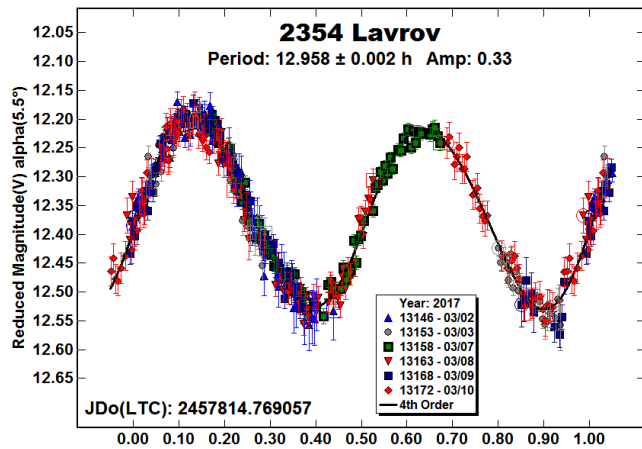
1025 Riema. The period of 3.578 h found from the PDS data agrees with earlier results, e.g., Stephens (2003; 3.580 h).



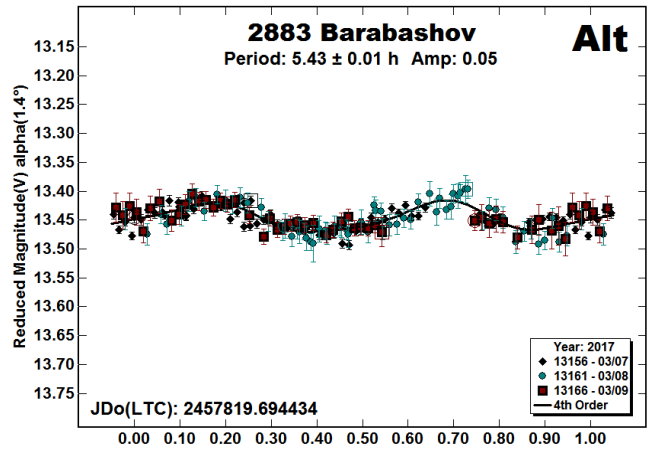
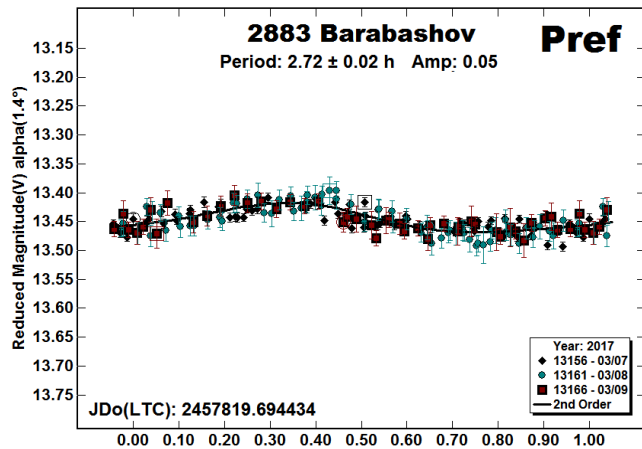
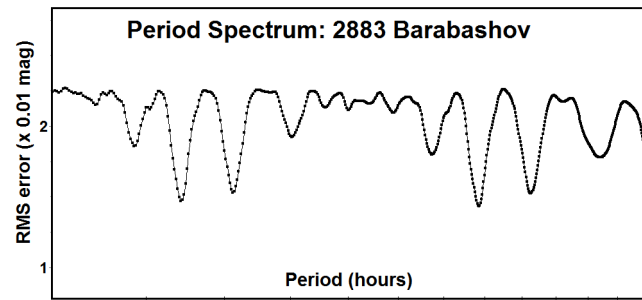
1979 Sakharov was in the same field as a planned target for one night. No period could be found. Earlier results include Pravec et al. (2011 web, 7.5209 h) and Oey (2014; 7.589 h);



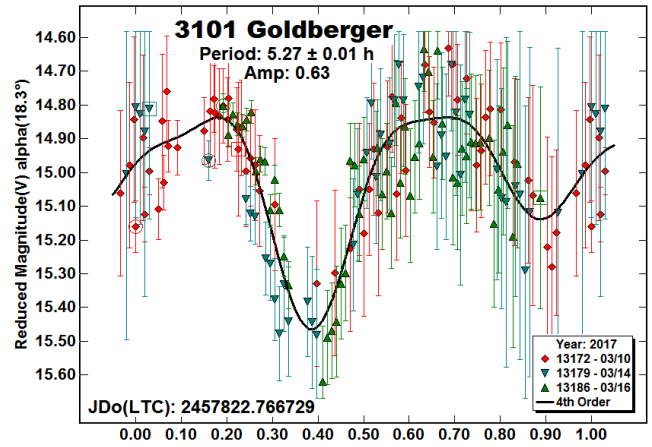
2354 Lavrov. Waszczak et al. (2015) found a period of 12.961 h from a limited data set. The denser data set from PDS confirms that earlier result.



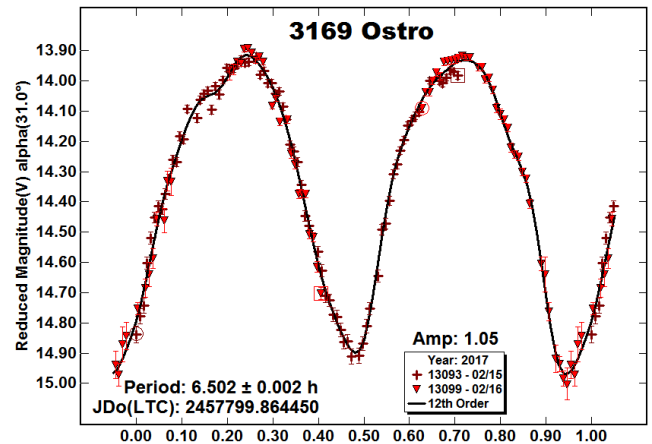
2883 Barabashov. The low amplitude (0.06 mag) and low phase angle in 2017 meant that a bimodal solution could not be assumed (Harris et al., 2014). The period spectrum showed nearly equal solutions at 2.7 and 5.4 hours. The preferred solution is 2.72 h since it provides complete coverage of the curve and has a slightly lower RMS fit to the Fourier model. Pravec et al. (2017web) also found an ambiguous solution. Their shorter period was 2.6840 h and the alternate period was 5.3680 h. Both of their solutions had an amplitude of 0.04 mag.



3101 Goldberger. This Hungaria member was worked by the author twice before: Warner (2014, 5.268 h; 2016, 5.270 h). The asteroid was considerably fainter than in previous years and there was a nearly full moon in the sky. This meant lower SNR values and so this solution is not as highly rated in the LCDB (Warner et al., 2009a).

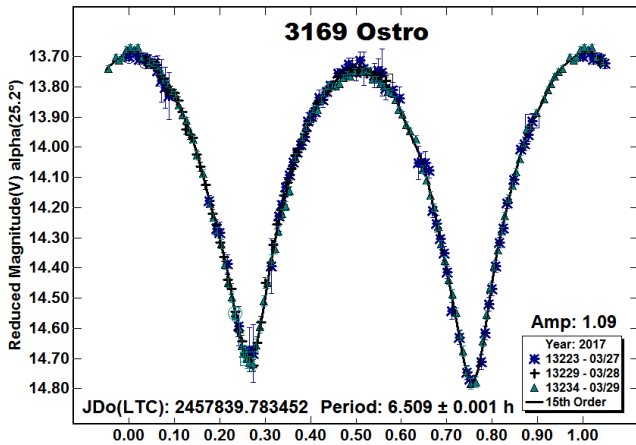


3169 Ostro. This Hungaria asteroid is a suspected “contact binary”, or at least a single body that is highly bifurcated (Descamps et al., 2005). This would be more likely if the lightcurve featured “shoulders” on the descending and ascending braches. The 2017 apparition was the fourth that was observed by the author. All previous results in the LCDB are statistically the same as the average period of 6.505 h reported here.

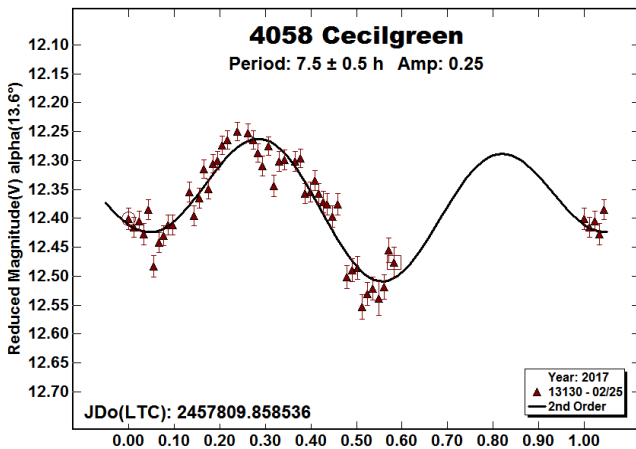


Number	Name	2017 mm/dd	Pts	Phase	$L_{PAB}$	$B_{PAB}$	Period	P.E.	Amp	A.E.	Group
1025	Riema	03/10-03/16	315	23.0, 21.3	203	20	3.578	0.002	0.06	0.01	H
1979	Sakharov	03/30-03/30	66	1.2	188	-2	7.79	0.01	0.07	0.01	V
2354	Lavrov	03/02-03/10	401	5.5, 2.3	176	0	12.958	0.002	0.33	0.01	MB-O
2883	Barabashov	03/07-03/09	130	1.2, 1.4	168	2	2.74	0.01	0.06	0.01	MB-I
3101	Goldberger	03/10-03/16	162	18.3, 17.0	194	23	5.27	0.01	0.63	0.05	H
3169	Ostro	02/15-02/16	149	31.0, 30.9	194	33	6.502	0.002	1.05	0.02	H
3169	Ostro	03/27-03/29	251	25.2, 24.9	202	36	6.509	0.001	1.09	0.02	H
4058	Cecilgreen	02/25-02/25	48	13.6	197	10	7.5	0.5	0.25	0.02	EOS
5745	1991 AN	01/29-01/29	278	5.0	124	7	4.087	0.005	0.92	0.02	FLOR
26703	2001 FB144	03/19-03/19	54	2.6	172	2	8.4	0.5	0.37	0.04	MB-I
26934	Jordancotler	01/29-01/29	174	4.3	125	8	28	5	0.35	0.1	FLOR
43662	2002 FP8	02/25-02/25	46	15.3	186	-5	4.5	0.3	0.67	0.04	V
45566	2000 CK58	03/10-03/26	174	12.8, 9.8	198	21	4.704	0.005	0.47	0.03	MB-O
45878	2000 WX29	16/12/12-01/06	197	22.4, 7.0	115	4	3.9207	0.0003	0.1	0.01	H
47170	1999 TE33	03/29-03/29	59	14.2	165	0	>16.		>0.4		FLOR
53595	2000 CK62	03/01-03/02	76	9.8, 10.3	179	-1	4.10	0.02	0.14	0.02	FLOR
59636	1999 JJ81	01/30-01/30	48	6.6	142	-7	3.7	0.2	0.2	0.03	MB-I
67525	2000 RW83	03/30-03/30	60	1.2	188	-2	16	4	>0.3		FLOR
68435	2001 RF81	02/16-02/16	49	4.1	141	0	6.5	0.2	0.82	0.04	FLOR

Table II. Observing circumstances. The phase angle ( $\alpha$ ) is given at the start and end of each date range. If a single value is given, the phase angle did not change significantly and the average value is given.  $L_{PAB}$  and  $B_{PAB}$  are, respectively, the average phase angle bisector longitude and latitude (see Harris *et al.*, 1984). The Group column gives the orbital group to which the asteroid belongs. The definitions and values are those used in the LCDB (Warner *et al.*, 2009a). FLOR = Flora; H = Hungaria; MB-I/M/O = main-belt inner/middle/outer; V = Vestoid.

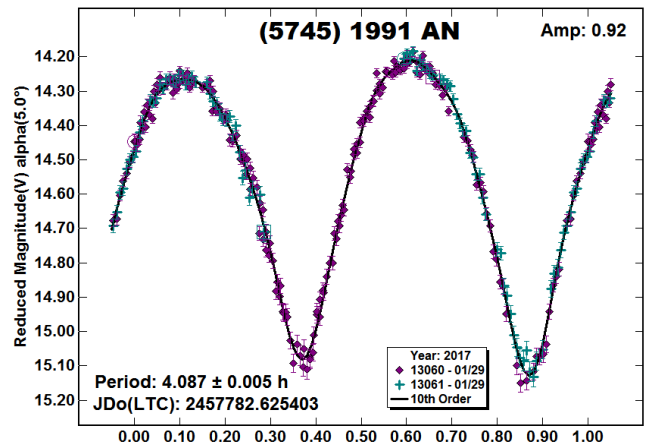


4058 Cecilgreen is a member of the Eos group. It was in the same field as a planned target for one night. Even with the limited data set, a reasonable estimate of the period was possible.

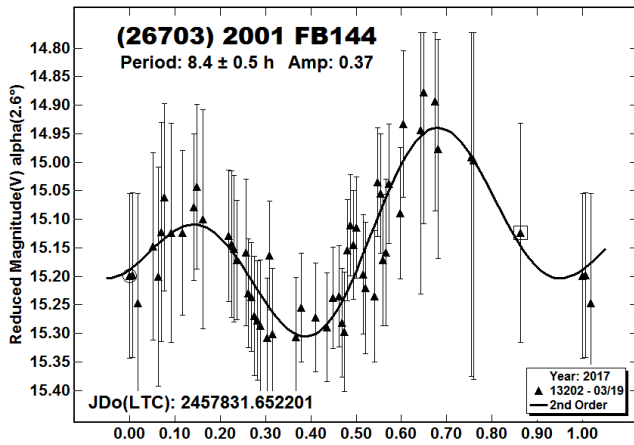


(5745) 1991 AN. This was another asteroid in the same field as the planned target for one night. However, the length of the run and

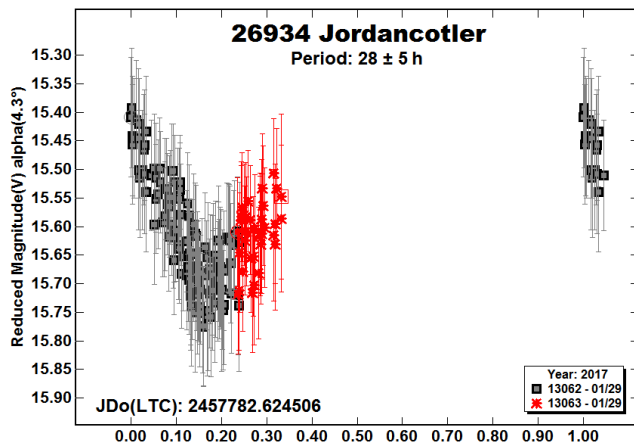
the relatively short period allowed finding an accurate synodic period for the Flora group member.



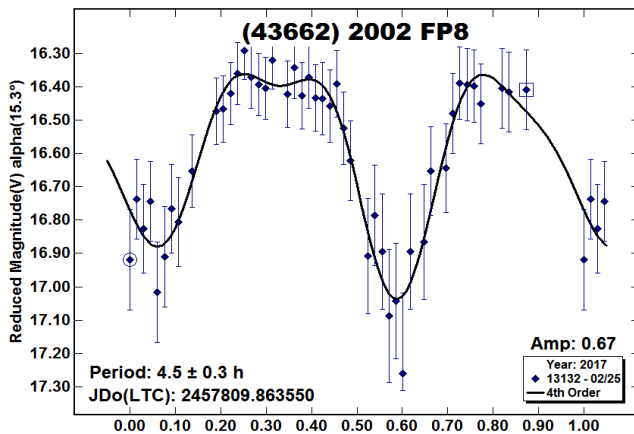
(26703) 2001 FB144 is an inner main-belt asteroid with an estimated diameter of about 3.5 km (LCDB; Warner *et al.*, 2009a). That any data were obtained was the result of making something good out of something bad. The telescope was misaimed for its planned target, which was out of the field entirely. A check was made for any asteroids that might be in the field; 2001 FB144 was the only one that had a sufficient SNR. The presumed period is hardly definitive but will serve as a guide for any future observations.



26934 Jordancotler. Here is another example of data mining images taken of a planned target. Not only was this Flora member in the field, but several possible variable stars were found as well. Given the amplitude of at least 0.3 mag, the final result should almost certainly be a bimodal lightcurve. The period reported here is based on looking at possible half-periods (monomodal) around 14 hours. The 28 h period adopted here was the most likely result but should be taken with a great deal of skepticism.

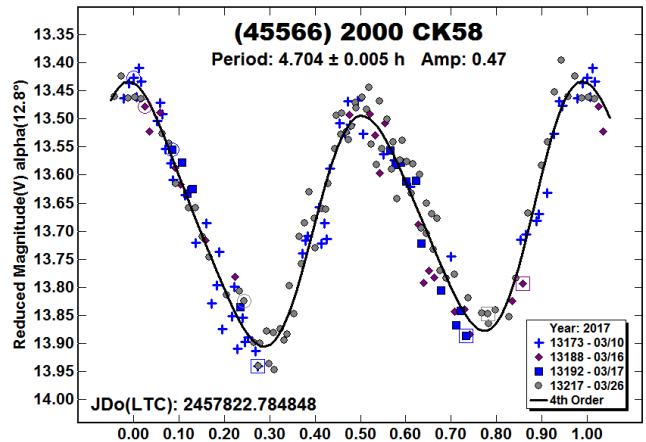


(43662) 2002 FP8. There were no previously reported periods for this Vestoid, yet another stray asteroid around for only one night.



(45566) 2000 CK58. Much of the data were taken with a nearly full moon in the sky, and so the error bars were large (very low SNR), so much so that they are not included here to make the

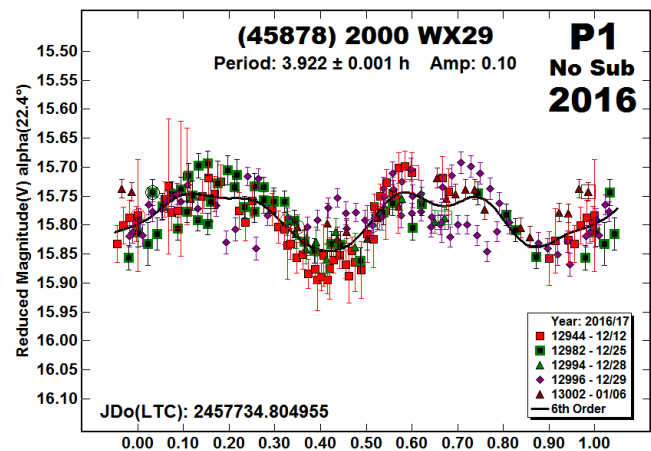
lightcurve readable. Even under these circumstances, it was possible to find an acceptable rotation period, mostly because of the large amplitude.

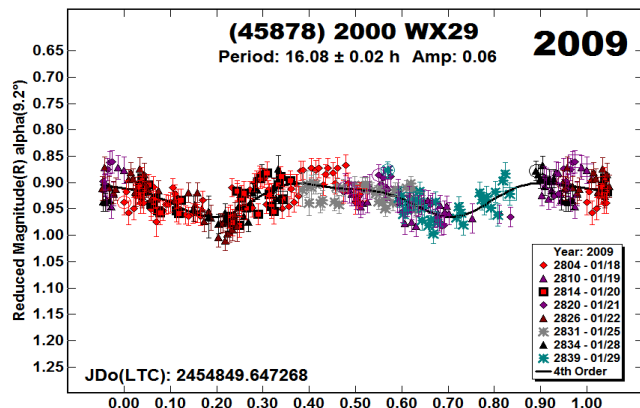
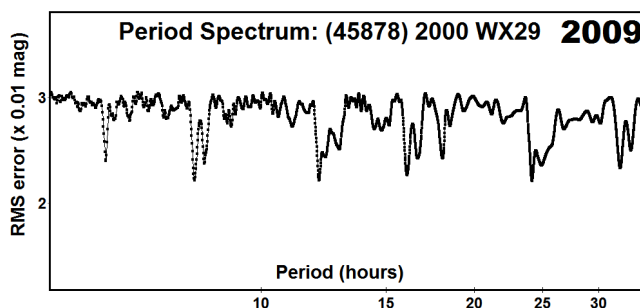
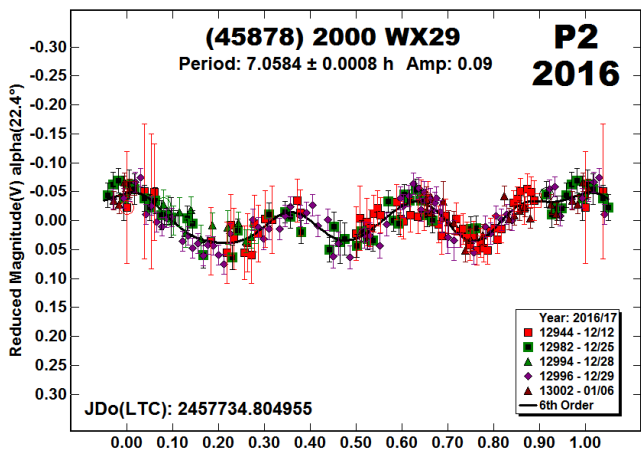
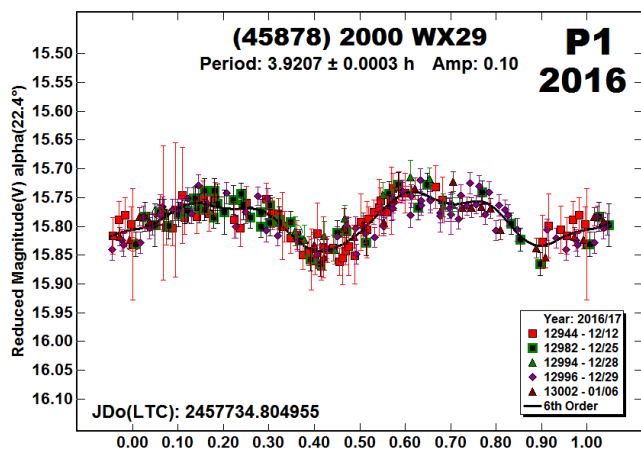
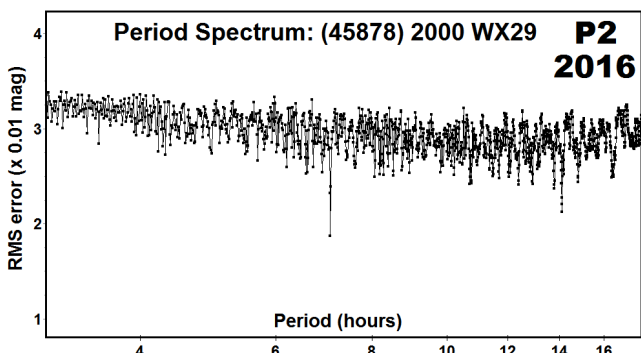
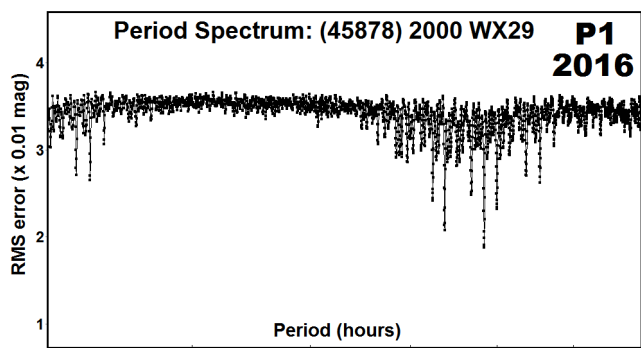


(45878) 2000 WX29. Analysis of the 2016 data indicates that this Hungaria might be a binary. The single period analysis shows what appeared to be deviations that could not be attributed to systematic causes. The dual-period search feature in *MPO Canopus* was used to find two distinctive periods:  $P_1 = 3.9207$  h and  $P_2 = 7.0584$  h. The two are related by a 9:5 integer ratio, so it is possible that the Fourier analysis was simply finding a second period that was harmonically related to the first.

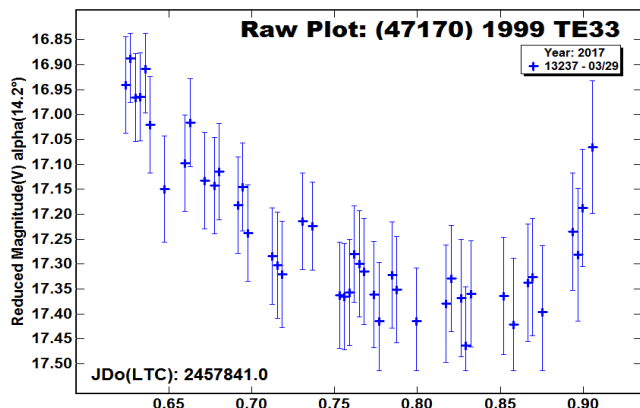
The shape of the  $P_2$  lightcurve is unusual, which adds additional doubt as to its veracity. However, on the assumption that the second period is not an analysis or systematic artifact, then a possible explanation is a binary system with each body rotating independently of the orbital period of the satellite. No mutual events (occultations and/or eclipses) were detected, which would have confirmed the binary nature of the asteroid.

This analysis prompted another look at the data obtained in 2009 (Warner, 2009b). At that time, an ambiguous, but single, period of 16.07 h was found, the alternate being the half-period of 8.03 h. A dual-period search on the 2009 data failed to find reasonable solutions, especially any near the periods found from the 2016 data. Observations at future apparitions are strongly encouraged.

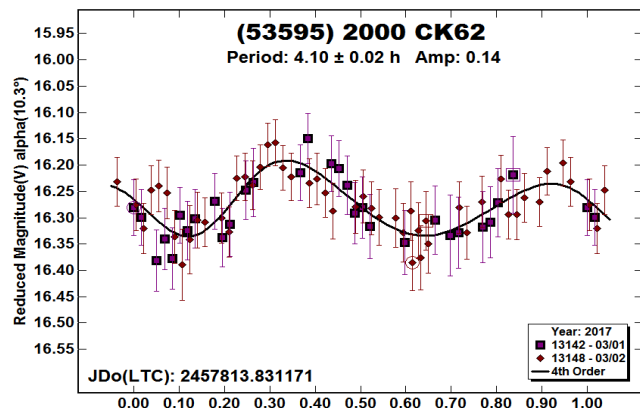




(47170) 1999 TE33. This Flora member was in the field for only one night. A best estimate for a period is  $P > 16$  h with an amplitude  $A > 0.4$  mag.

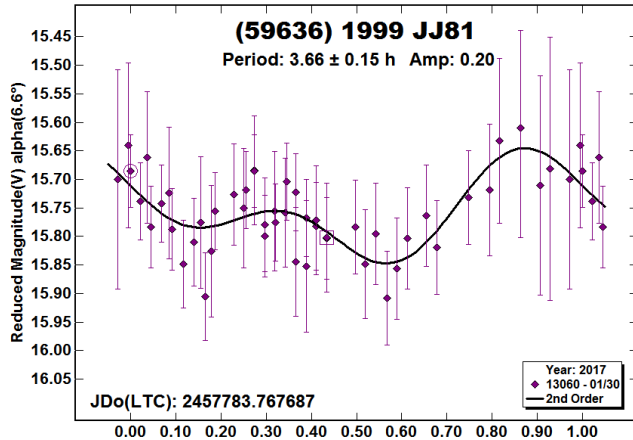


(53595) 2000 CK62. There were no reports of a period in the LCDB for this Flora member.

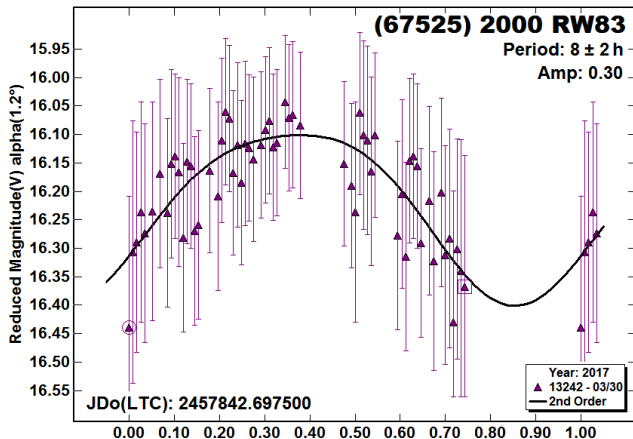


Like many of the other asteroids, this was a target of opportunity but for two nights instead of just one. This and the length of the runs allowed finding a reasonably secure period of  $4.10 \pm 0.02$  h. While the amplitude does not assure a bimodal solution (Harris et al., 2014), the asymmetry of the lightcurve makes it likely that the correct period was found.

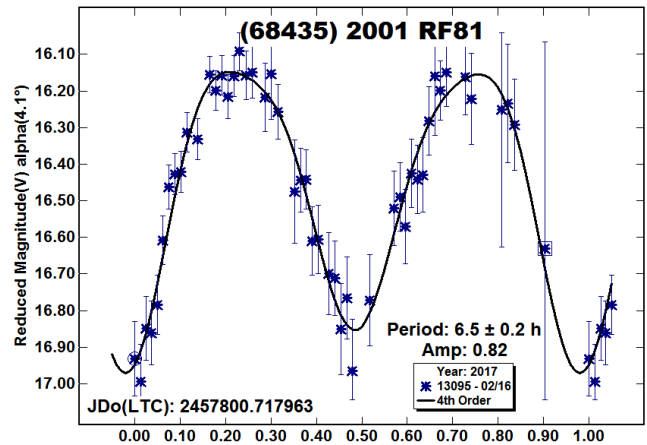
(59636) 1999 JJ81. There were no previously reported periods in the LCDB for this 3 km inner main-belt asteroid that was another single night target of opportunity.



(67525) 2000 RW83. The lightcurve plot shows one of several half-period solutions. Based on this, the true period may be on the order of 16 hours. However, without having at least one minimum, that is not certain. At the very least, the period is greater than 12 hours. This 2 km Flora member was another single-night only stray in a planned target field.



(68435) 2001 RF81. Also a single-night opportunity, the 1.9 km Flora member had no previously reported period in the LCDB. The amplitude and low phase angle assure that the lightcurve should be bimodal (Harris et al., 2014). Fortunately, there were enough data to cover almost a complete cycle of the purported period. While the period uncertainty is several tenths of an hour, the period is secure in the sense that it was the only one that fit the requirements for a bimodal lightcurve that was approximately symmetrical (Harris et al., 2014).



#### Acknowledgements

Funding for observations, analysis, and publication for Warner and Stephens was provided by NASA grant NNX13AP56G. Work on the asteroid lightcurve database (LCDB) by Warner was also funded in part by National Science Foundation grant AST-1507535. The author gratefully acknowledges a Shoemaker NEO Grants from the Planetary Society (2007). This was used to purchase one of the telescopes used in this research. This research was made possible through the use of the AAVSO Photometric All-Sky Survey (APASS), funded by the Robert Martin Ayers Sciences Fund; and based in part on data from CMC15 Data Access Service at CAB (INTA-CSIC) (<http://svo2.cab.inta-csic.es/vocats/cmcl5/>). This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. (<http://www.ipac.caltech.edu/2mass/>)

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### LIGHTCURVE ANALYSIS OF 1773 RUMPELSTILZ AND 2040 CHALONGE

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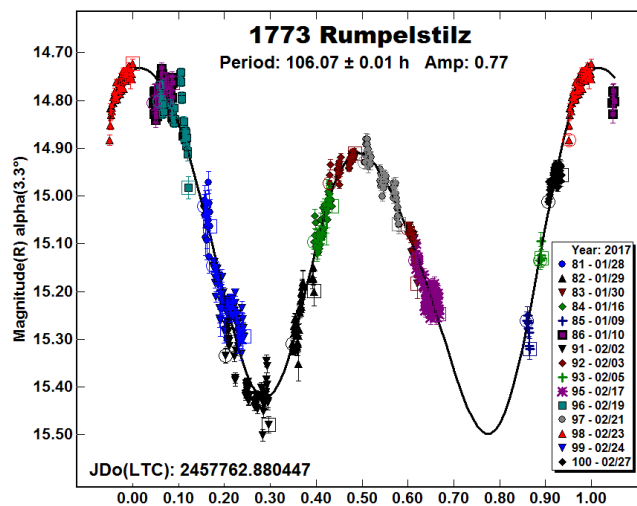
Photometric observations of asteroids 2040 Chalonge and 1773 Rumpelstilz were made at the Phillips Academy Observatory from 2016 December 2016 through 2017 February. 1773 Rumpelstilz was found to have rotational period  $106.075 \pm 0.001$  h with amplitude 0.78 mag. 2040 Chalonge was found to have rotational period  $10.383 \pm 0.001$  h with amplitude 0.22 mag;

CCD photometric observations of 1773 Rumpelstilz and 2040 Chalonge were made at the Phillips Academy Observatory as part of a high school astronomy research course between 2016 December and 2017 February. The CALL website (<http://minorplanet.info/call.html>) was used to select the targets, which were chosen for their favorable declinations, appealing names, and relatively bright magnitudes. A search of the asteroid lightcurve database (LCDB; Warner *et al.*, 2009) did not reveal previously reported lightcurve results for the asteroids. All observations were made with a 0.40-m  $f/8$  Ritchey-Chrétien telescope by DFM Engineering. Images were taken with an Andor Tech iKon DW436 camera with a 2048x2048 array of 13.5-micron pixels. The resulting image scale was 0.86 arcseconds per pixel. All images were dark and flat-field corrected, 1x1 binning mode, and guided.

*MPO Canopus* was used to make photometric measurements of

the asteroid as well as to generate the final lightcurve and period spectrum. Comparison stars were chosen to have near solar color using the Comp Star Selector tool in *MPO Canopus*. In addition, brighter comparison stars were favored. Data merging and period analysis were also done with *MPO Canopus* using an implementation of the Fourier analysis algorithm of Harris (FALC; Harris *et al.*, 1989). The combined data sets were analyzed by the authors.

1773 Rumpelstilz was discovered on 1968 April 17 by P. Wild at Zimmerwald. We observed the asteroid for fifteen nights from 2017 January to February; the composite lightcurve includes 580 data points. This asteroid has a rather long period of  $106.075 \pm 0.001$  h with amplitude of 0.78 mag. Although full coverage was not achieved, the large amplitude of the lightcurve requires the bimodal solution (Harris *et al.*, 2014) that was favored by the period spectrum.

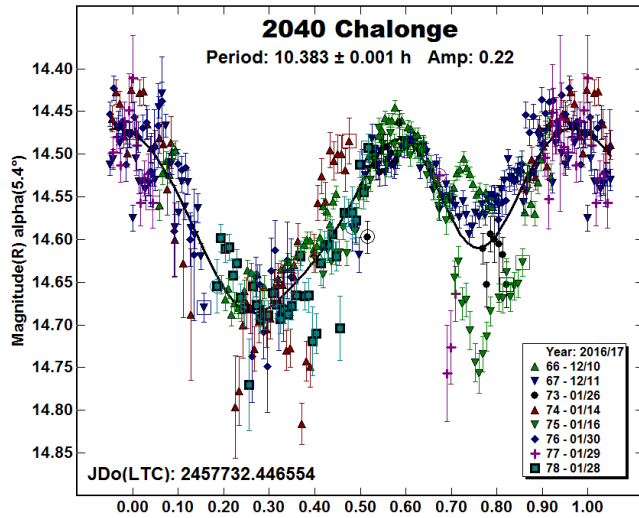


2040 Chalonge was discovered on 1974 April 19 by P. Wild at Zimmerwald. We observed the asteroid for six nights from 2016

Number	Name	2016/2017 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.	TxC
1773	Rumpelstilz	01/09-02/27	580	10.6, 12.9	132.0	6.0	106.070	0.001	0.77	0.01	S
2040	Chalonge	12/10-01/30	419	5.4, 19.8	72.2	11.7	10.303	0.001	0.22	0.05	C

Table 1. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984). TxC is the taxonomic class as found in the LCDB (Warner *et al.*, 2009).

December to 2017 January. A total of 419 data points were used to find a period of 10.383 hours and amplitude 0.22 mag. Data taken on the night of 01/16 was suggestive of a possible eclipse event, but this behavior was not observed again.



Acknowledgements

Research at the Phillips Academy Observatory is supported by the Israel Family Foundation. Funding for the Andor Tech camera was generously provided by the Abbot Academy Association.

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Number	Name	2016/7 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period	P.E.	Amp	A.E.
1162	Larissa	04/03-04/06	175	6.8, 7.6	170	2	6.514	0.003	0.12	0.01
1180	Rita	12/12-01/26	304	11.1, 3.2	139	6	13.090	0.002	0.06	0.01
1902	Shaposhnikov	03/14-03/24	608	8.7, 10.0	133	13	20.987	0.005	0.29	0.02
7027	Toshihanda	12/01-12/29	568	8.0, 14.6	47	-6	36.304	0.007	0.30	0.02

Table II. Observing circumstances. The phase angle ( $\alpha$ ) is given at the start and end of each date range, unless it reached a minimum, which is then the second of three values. If a single value is given, the phase angle did not change significantly and the average value is given. L<sub>PAB</sub> and B<sub>PAB</sub> are each the average phase angle bisector longitude and latitude (see Harris *et al.*, 1984), unless two values are given (first/last date in range).

**LIGHTCURVE ANALYSIS OF HILDA ASTEROIDS AT THE CENTER FOR SOLAR SYSTEM STUDIES: 2016 DECEMBER THRU 2017 APRIL**

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(Received: 2017 April 6)

Lightcurves for four Hilda asteroids were obtained at the Center for Solar System Studies (CS3) from 2016 December thru 2017 April.

CCD photometric observations of four Hilda asteroids were made at the Center for Solar System Studies (CS3) from 2016 December thru 2017 April. This is another in a planned series of papers on this group of asteroids, which is located between the outer main-belt and Jupiter Trojans in a 3:2 orbital resonance with Jupiter. The goal is to determine the spin rate statistics of the group and find pole and shape models when possible. We also we look to examine the degree of influence that the YORP effect (Rubincam, 2000) has on distant objects and to compare the spin rate distribution against the Jupiter Trojans, which can provide evidence that the Hildas are more "comet-like" than main-belt asteroids.

Table I lists the telescopes and CCD cameras that are combined to make observations. Up to nine telescopes can be used for the campaign, although seven is more common. All the cameras use CCD chips from the KAF blue-enhanced family and so have essentially the same response. The pixel scales ranged from 1.24-1.60 arcsec/pixel. All lightcurve observations were unfiltered since a clear filter can result in a 0.1-0.3 magnitude loss. The exposures varied depending on the asteroid's brightness and sky motion.

Telescopes			Cameras
0.30-m	f/6.3	Schmidt-Cass	FLI Microline 1001E
0.35-m	f/9.1	Schmidt-Cass	FLI Proline 1001E
0.35-m	f/11	Schmidt-Cass	SBIG STL-1001E
0.40-m	f/10	Schmidt-Cass	
0.50-m	f/8.1	Ritchey-Chrétien	

Table I. List of available telescopes and CCD cameras at CS3. The exact combination for each telescope/camera pair can vary due to maintenance or specific needs.

Measurements were made using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. Catalog magnitudes were usually taken from the CMC-15

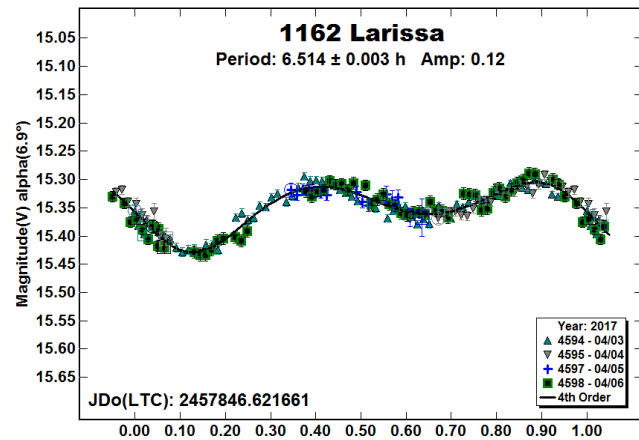
(<http://svo2.cab.inta-csic.es/vocats/cm15/>) or APASS (Henden *et al.*, 2009) catalogs. The MPOSC3 catalog was used as a last resort. The last catalog is based on the 2MASS catalog (<http://www.ipac.caltech.edu/2mass>) with magnitudes converted from J-K to BVRI (Warner, 2007). The nightly zero points for the catalogs are generally consistent to about  $\pm 0.05$  mag or better, but on occasion reach 0.1 mag and more. There is a systematic offset among the catalogs so, whenever possible, the same catalog is used throughout the observations for a given asteroid. Period analysis is also done with *MPO Canopus*, which implements the FALC algorithm developed by Harris (Harris *et al.*, 1989).

In the plots below, the “Reduced Magnitude” is Johnson V as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distance by applying  $-5 \cdot \log(r\Delta)$  to the measured sky magnitudes with  $r$  and  $\Delta$  being, respectively, the Sun-asteroid and Earth-asteroid distances in AU. The magnitudes were normalized to the given phase angle, e.g.,  $\alpha(6.5^\circ)$ , using  $G = 0.15$ , unless otherwise stated. The X-axis is the rotational phase ranging from  $-0.05$  to  $1.05$ .

If the plot includes an amplitude, e.g., “Amp: 0.65”, this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*.

For the sake of brevity, only some of the previously reported results may be referenced in the discussions on specific asteroids. For a more complete listing, the reader is directed to the asteroid lightcurve database (LCDB; Warner *et al.*, 2009). The on-line version at <http://www.minorplanet.info/lightcurvedatabase.html> allows direct queries that can be filtered a number of ways and the results saved to a text file. A set of text files of the main LCDB tables, including the references with bibcodes, is also available for download. Readers are strongly encouraged to obtain, when possible, the original references listed in the LCDB for their work.

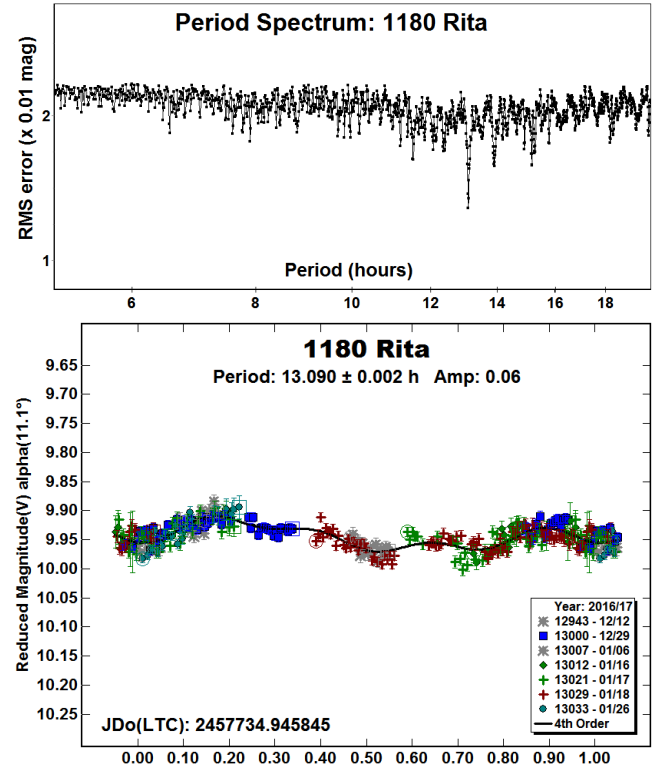
**1162 Larissa.** Waszczak *et al.* (2015) found a period of 6.520 h for Larissa, which has an estimated diameter of 44 km. Pligge *et al.* (2011) found a period of 6.514 h, which corresponds to the period we found based on our 2017 observations.



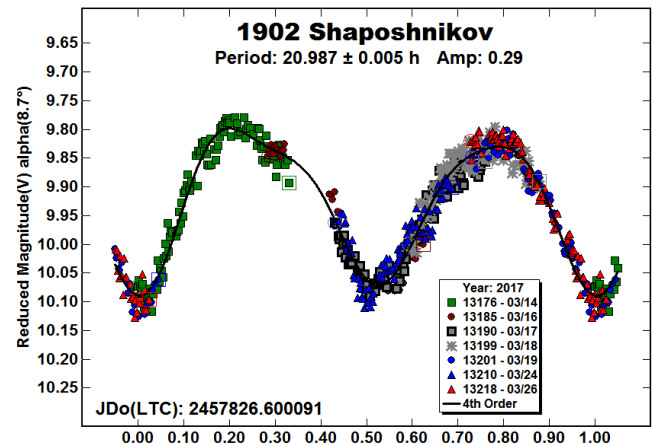
**1180 Rita.** Several significantly different periods have been reported in previous years for Rita, which has an estimated diameter of 83 km (LCDB; Warner *et al.*, 2009). Gonano *et al.* (1991) reported a period of 14.72 h from observations in 1989. Dahlgren *et al.* (1998) found a similar period of 14.902 h. On the other hand, Slyusarev *et al.* (2012) found a period of 20.496 h and Polishook (2012) reported 9.605 h. The results from PDS based on

observations from 2016 Dec 11 thru 2017 Jan 26 only add to the uncertainty.

The period spectrum shows one strong solution at 13.090  $\pm$  0.002 h. There is no simple integral ratio that ties this period to any of the other results. Attempts to fit the most recent data to the other periods by adjusting nightly zero points failed to find a convincing solution.

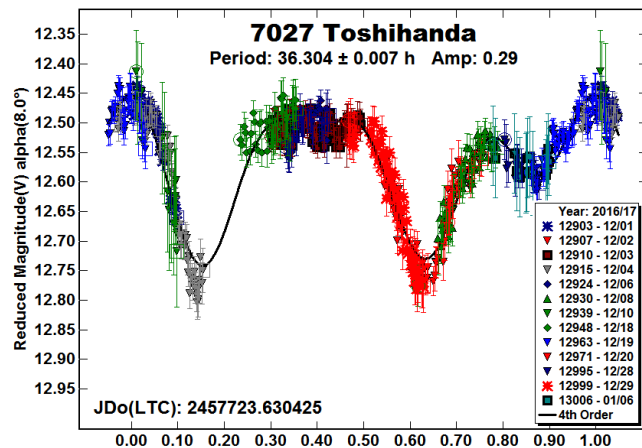


**1902 Shaposhnikov.** Gonano *et al.* (1991) reported a period of 21.34 h for this Hilda, which has an estimated diameter of 97 km. Dahlgren *et al.* (1998) closely agreed with their result of 21.2 h. Hanus *et al.* (2016) found a shape model using lightcurve inversion. They also reported two possible pole solutions; the preferred solution had ecliptic coordinates of ( $\lambda = 326^\circ$ ,  $\beta = 37^\circ$ ) while the second had coordinates of ( $\lambda = 144^\circ$ ,  $\beta = 79^\circ$ ). The *sidereal* rotation period was 20.9959 h.



The analysis of the PDS data found a synodic period of 20.987 h, which is in keeping with the earlier results. The additional data will be sent to Hanus to see if they might help resolve the pole ambiguity.

**7027 Toshihanda.** The only previously reported period was from Waszczak et al. (2015), who found a period of 18.148 h. The PDS data led to a period double that, 36.304 h and the strong probability that the asteroid is a binary.



The period makes it a good candidate for being a partially asynchronous binary with a faster spinning primary (period 4-5 h). The lack of “shoulders” on the descending and ascending branches would seem to rule out that the object is a fully synchronous binary (Alan Harris, private communications). On these assumptions, and using the attenuations of about 0.25 mag, this allows finding the approximate effective diameter ratio of the satellite to the primary, i.e.,

$$D_s/D_p \geq \sqrt{10^{\Delta m \cdot 0.4} - 1.0} = 0.51 \pm 0.03$$

where  $\Delta m$  is the magnitude drop of 0.25 mag. The value is a lower limit because the minimums are not flat, indicating a total eclipse.

The unusual tertiary minimum at about 0.9 rotation phase would correspond to the satellite being near elongation. Given the low phase angle of the observations, it’s very unlikely these are shadow eclipses. The physical cause of the additional minimum is unknown. It’s possible that observations at future apparitions may help solve the mystery.

#### Acknowledgements

Thanks to Alan Harris for his additional analysis of 7027 Toshihanda. Funding for observations, analysis, and publication for Warner and Stephens was provided by NASA grant NNX13AP56G. Work on the asteroid lightcurve database (LCDB) by Warner was also funded in part by National Science Foundation grant AST-1507535. The authors gratefully acknowledge Shoemaker NEO Grants from the Planetary Society (2007, 2013, 2015). These were used to purchase some of the telescopes and CCD cameras used in this research. This research was made possible through the use of the AAVSO Photometric All-Sky Survey (APASS), funded by the Robert Martin Ayers Sciences Fund. This research was made possible in part based on data from CMC15 Data Access Service at CAB (INTA-CSIC) (<http://svo2.cab.inta-csic.es/vocats/cmc15/>). This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the

Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. (<http://www.ipac.caltech.edu/2mass/>)

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**NEAR-EARTH ASTEROID LIGHTCURVE ANALYSIS  
AT CS3-PALMER DIVIDE STATION:  
2016 DECEMBER THRU 2017 APRIL**

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(Received: 2017 April 11)

Lightcurves for 36 near-Earth asteroids (NEAs) obtained at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2016 December through 2017 April were analyzed for rotation period and signs of satellites or tumbling. In addition, using the recent and previously obtained dense data along with sparse data from NEA surveys, lightcurve inversion was used to produce spin axis and shape models for four asteroids: 3103 Eger, 4055 Magellan, (40267) 1999 GJ4, and (90075) 2002 VU94. Analysis of the observations of 2102 Tantalus and (5693) 1993 EA indicates that they might each be a singly-asynchronous binary. There is some evidence that (5626) 1991 FE may be another so-called “very wide binary.”

CCD photometric observations of 36 near-Earth asteroids (NEAs) were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2016 December thru 2017 April. Table I lists the telescope/CCD camera combinations used for the observations. All the cameras use CCD chips from the KAF blue-enhanced family and so have essentially the same response. The pixel scales for the combinations range from 1.24-1.60 arcsec/pixel.

Desig	Telescope	Camera
Squirt	0.30-m f/6.3 Schmidt-Cass	ML-1001E
Borealis	0.35-m f/9.1 Schmidt-Cass	FLI-1001E
Eclipticalis	0.35-m f/9.1 Schmidt-Cass	STL-1001E
Australis	0.35-m f/9.1 Schmidt-Cass	STL-1001E
Zephyr	0.50-m f/8.1 R-C	FLI-1001E

Table I. List of CS3-PDS telescope/CCD camera combinations.

All lightcurve observations were unfiltered since a clear filter can result in a 0.1-0.3 magnitude loss. The exposure duration varied depending on the asteroid’s brightness and sky motion. Guiding on a field star sometimes resulted in a trailed image for the asteroid. If necessary, an elliptical aperture with the long axis parallel to the asteroid’s path was used.

Measurements were made using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. Catalog magnitudes were usually taken from the CMC-15 (<http://svo2.cab.inta-csic.es/vocats/cmcl5/>) or APASS (Henden *et al.*, 2009) catalogs. The MPOSC3 catalog was used as a last resort. This catalog is based on the 2MASS catalog (<http://www.ipac.caltech.edu/2mass>) with magnitudes converted from J-K to BVRI (Warner, 2007). The nightly zero points for the catalogs are generally consistent to about  $\pm 0.05$  mag or better, but on occasion reach 0.1 mag and more. There is a systematic offset among the catalogs so, whenever possible, the same catalog is used throughout the observations for a given asteroid. Period

analysis is also done with *MPO Canopus*, which implements the FALC algorithm developed by Harris (Harris *et al.*, 1989).

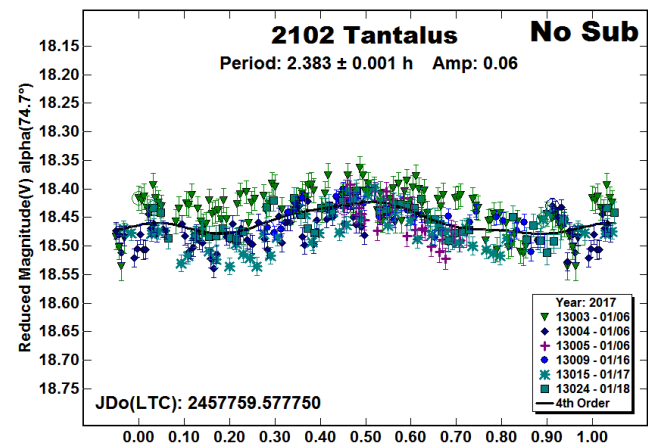
In the plots below, the “Reduced Magnitude” is Johnson V as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distance by applying  $-5 \cdot \log(r\Delta)$  to the measured sky magnitudes with  $r$  and  $\Delta$  being, respectively, the Sun-asteroid and Earth-asteroid distances in AU. The magnitudes were normalized to the given phase angle, *e.g.*,  $\alpha(6.5^\circ)$ , using  $G = 0.15$ , unless otherwise stated. The X-axis is the rotational phase, ranging from  $-0.05$  to  $+1.05$ .

For the sake of brevity, only some of the previously reported results may be referenced in the discussions on a specific asteroid. For a more complete listing, the reader is directed to the asteroid lightcurve database (LCDB; Warner *et al.*, 2009). The on-line version at <http://www.minorplanet.info/lightcurvedatabase.html> allows direct queries that can be filtered a number of ways and the results saved to a text file. A set of text files of the main LCDB tables, including the references with bibcodes, is also available for download. When possible, readers are strongly encouraged to check against the original references listed in the LCDB.

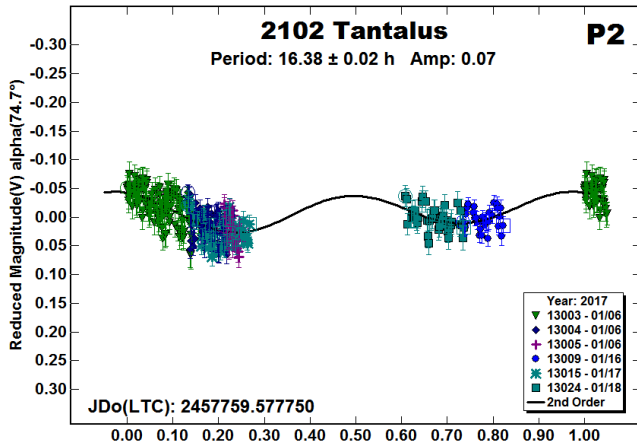
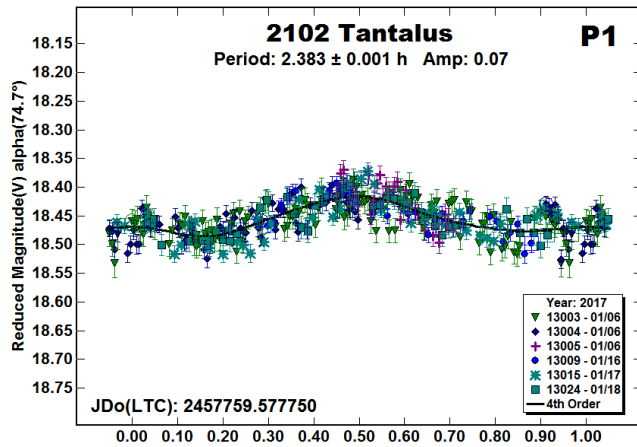
If the plot includes an amplitude, *e.g.*, “Amp: 0.65”, this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*. The value is provided as a matter of convenience.

2102 Tantalus. When observed in 2015 (Warner, 2015b), there were indications that this 1.9 km asteroid might be binary. At that time, a suspected orbital period of  $P_{ORB} = 16.49$  h was found. The observations were made at a phase angle bisector longitude ( $L_{PAB}$ ; see Harris *et al.*, 1984) of about  $255^\circ$ . The 2017 observations were at  $L_{PAB} = 60^\circ$ , a difference of  $195^\circ$ . This meant that the viewing aspect would be similar but favor the opposite asteroid pole.

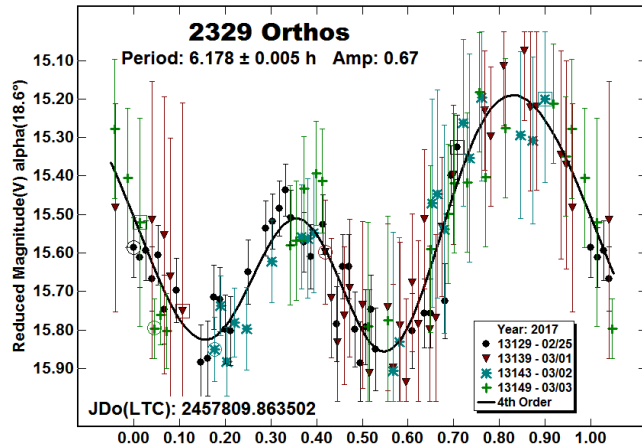
Analysis of the 2017 data again showed a poor fit to a single period and so a dual-period search was done using *MPO Canopus*. The result was a primary period of  $P_f = 2.383$  h, almost identical to the one found in 2015. The lightcurve appears to have only one maximum, but this may be attributed to the high phase angle and a nearly spheroidal shape of the primary.



The secondary period, based on its shape, is presumed to be that of a satellite that is tidally-locked to its orbital period, meaning that its rotational and orbital periods are the same. Given the lack of coverage for the lightcurve, the  $P_{ORB} = 16.38$  h found here is in good agreement with the earlier result. This asteroid merits careful observations at future apparitions.



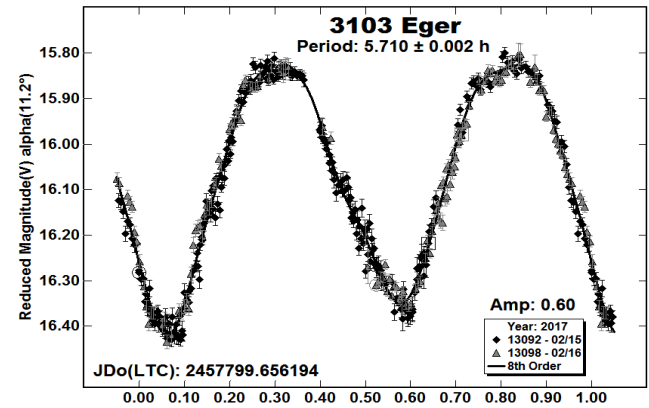
2329 Orthos. There were no periods reported in the LCDB (Warner et al., 2009) for Orthos, estimated to have an effective diameter of 3.4 km (Warner et al., 2009).



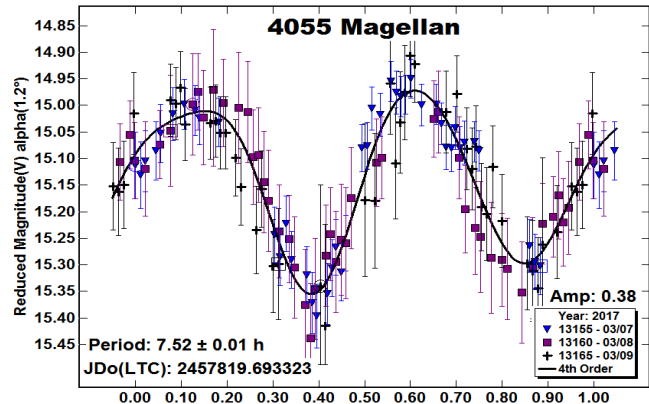
3103 Eger. This was the third apparition at which this NEA was observed from PDS. The most recent result,  $P = 5.710$  h, is in excellent agreement with the earlier efforts, e.g. Warner (2016b).

Durech et al. (2012) used observations from several apparitions to determine that this NEA's rotation rate is being altered by YORP (Yarkovsky–O'Keefe–Radzievskii–Paddack). This is a thermal effect caused by the sunlight being reradiated from an asteroid's surface that can result in an asymmetric torque that either speeds up or slows down the rotation rate. In the case of Eger, Durech et al. (2012) found that the rotation period was decreasing by 4.2

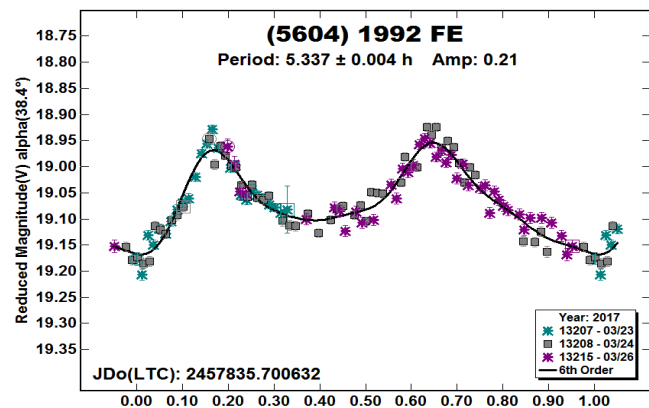
ms/year. The new data from PDS were used by Durech (private communications) to refine the estimate. Durech will publish the results in a future publication. The data from the three apparitions and sparse data from the Catalina Sky Survey (<http://www.lpl.arizona.edu/css/>) were used to find a spin axis and shape model. Those results are reported below.



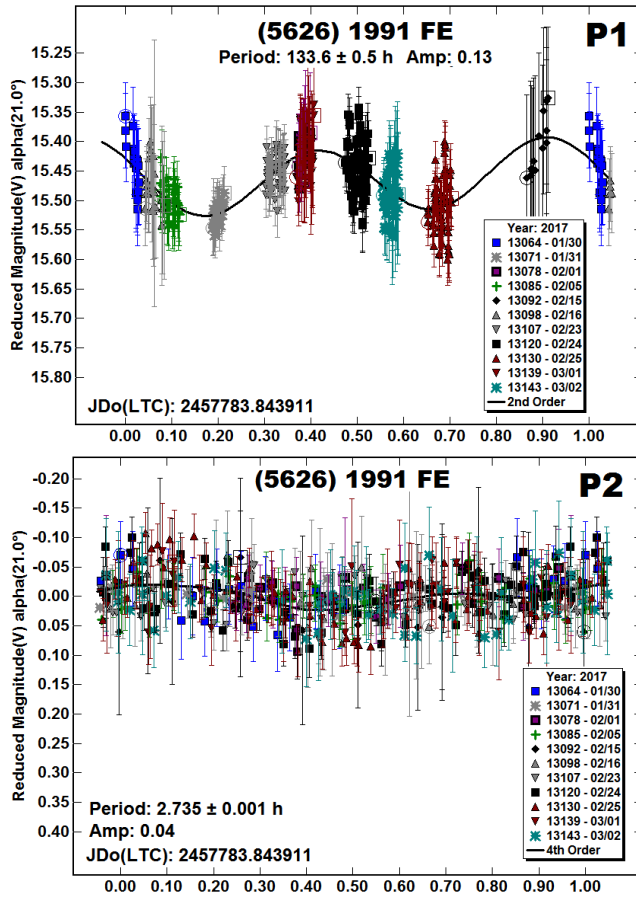
4055 Magellan. Pravec et al. (2000web) first reported a period of 7.475 h. Warner (2014a) found a period of 6.384 h. This difference could not be explained, especially in light of additional observations at CS3 in 2015 (Warner, 2015e) and those for this work, both of which led to periods of about 7.5 h, or in agreement with Pravec et al. (2000web). Spin axis and shape models are presented in a later section.



(5604) 1992 FE. Bembrick and Peregny (2003d) first reported a period of 6.026 h. Subsequent observations found periods near 5.34 h (Higgins and Warner, 2009), which was confirmed by the analysis of the PDS data obtained in 2017 March.



(5626) 1991 FE. Krugly et al. (2002) found a period of 2.4606 h based on six nights of observations from 1996 Jul 21.96 to Sep 4.12. On some nights, several cycles of their period were covered but they noticed “subtle, systematic differences” from one cycle to the next. They were not able to explain why. The PDS data, on the other hand, seemed to find a long period of 133.6 h.



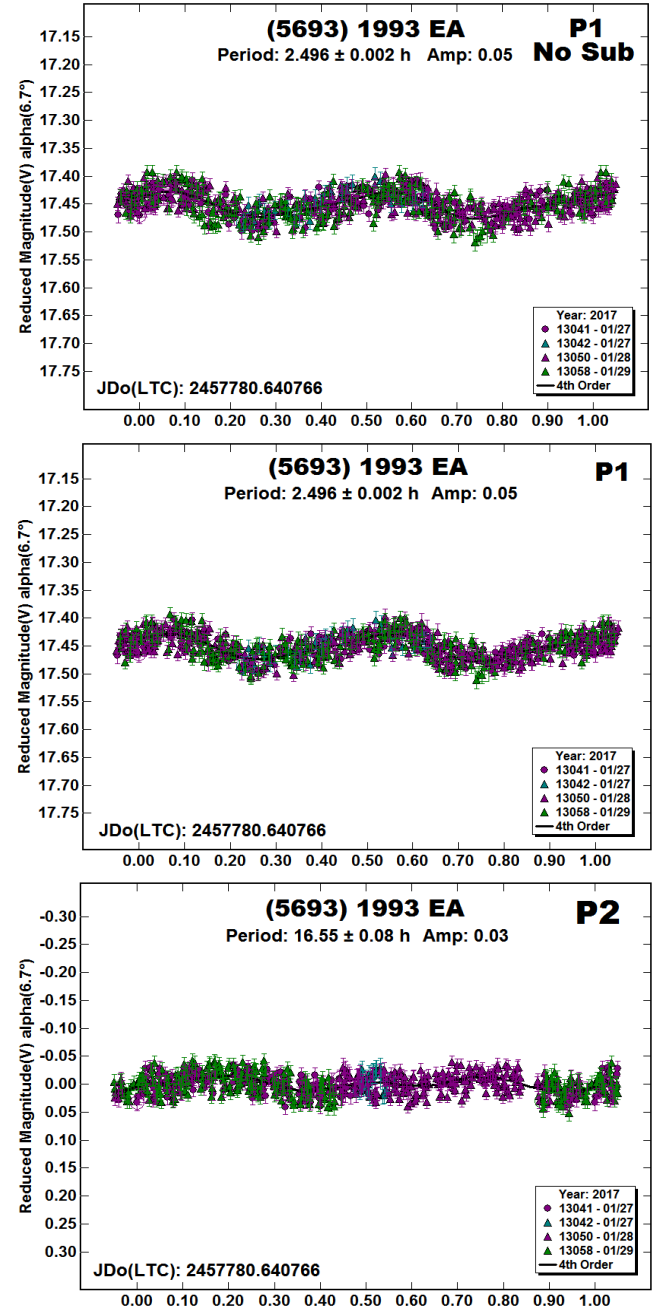
The behavior Krugly et al. (2002) described was similar to that seen in the proposed group of very wide binaries (see Warner, 2016a). In these systems, there is a primary with a very long period. Superimposed on its lightcurve is another with much shorter period and low amplitude. That second lightcurve is often similar to the primary of typical small binary asteroid systems. The unexplained differences seen by Krugly et al. may have been due to the very slow change in amplitude due to the long period.

On that assumption, and given the long period found with the PDS data, a dual-period search was done in *MPO Canopus*. The results are suggestive, but not conclusive. The noise in the data exceeds the amplitude of the  $P_2$  lightcurve, so it is uncertain if the solution is valid or just the Fourier analysis locking onto the noise. A check for a period near the 2.46 h period from Krugly et al. produced an even poorer fit after subtracting the long period. High-quality data at future apparitions are needed to confirm the true nature of the asteroid.

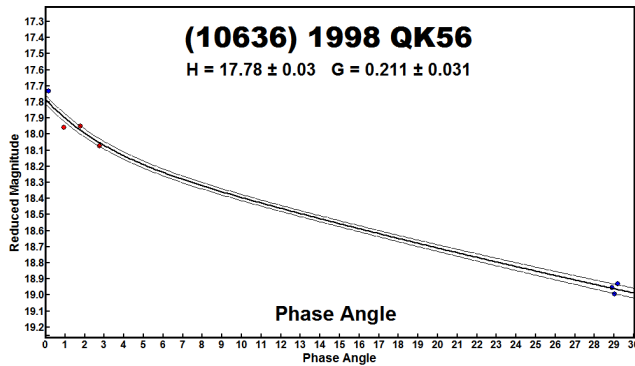
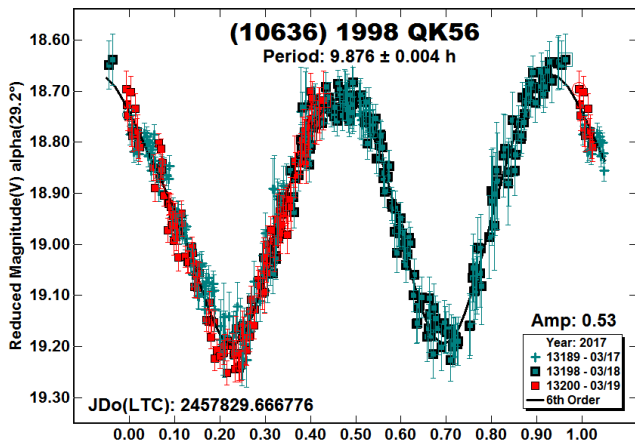
(5693) 1993 EA. Polishook (2012) found a period of 2.496 h for 1993 EA. The same period was found using the 2017 PDS data. Here was another case where a single period fit showed signs of a second period.

A very weak second period of  $P_2 = 16.55$  h was found using the dual-period search in *MPO Canopus*. The two periods are what might be expected for a small binary asteroid. The shape of the lightcurve for  $P_2$  would indicate that the purported satellite is slightly elongated and tidally-locked to its orbital period.

One check on the validity of the second period is to see if it is an integral multiple of the shorter period. If so, then the second period might be an artifact of the Fourier analysis. In this case, the two are not related by a simple integer ratio. As is often seen and heard, the solution to the puzzle is “More Data!”

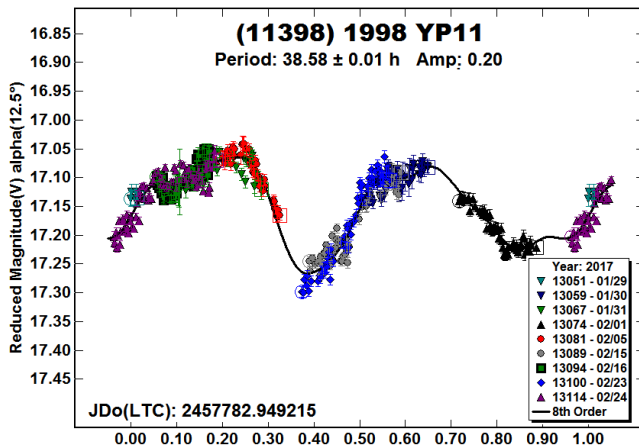


(10636) 1998 QK56. When observed in 2016 September (Warner, 2017a), the amplitude was 0.32 mag at a solar phase angle of  $\alpha = 1.3^\circ$ . The 2017 March observations, at  $\alpha = 29^\circ$ , showed an amplitude of 0.53 mag. The increase in amplitude at a higher phase angle is expected (Zappala et al., 1990).



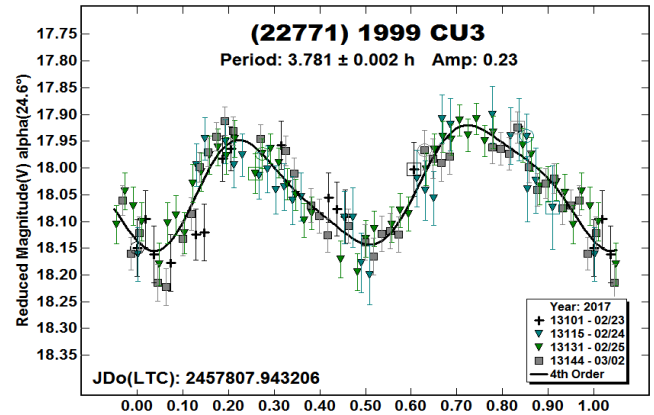
With data at very low and large phase angles, it was possible to calculate the absolute magnitude ( $H$ ) and phase slope parameter ( $G$ ) using the mid-amplitude reduced magnitude for each session. The value of  $H = 17.78$  is close to the  $H = 17.7$  from the MPCORB file. The value of  $G = 0.211$  is consistent with moderate albedo asteroids, e.g., taxonomic class S and Q (Warner et al., 2009), that are typical among the NEA population. However, only proper spectroscopic data can confirm the class.

(11398) 1998 YP11. Pravec et al. (2005) first reported a period of 38.60 h. Given the period and size, the chances are good that the asteroid would be tumbling (see Pravec et al., 2005; 2014).

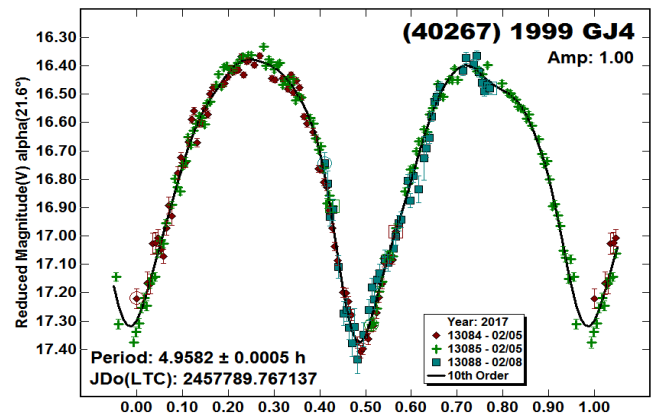


However, they did not find any signs of tumbling. Neither did observations by Warner (2008). The 2017 data from PDS did not fully cover the period of 38.59 h, but those sections covered more than once repeated in shape and amplitude within the limits of detecting low-level tumbling.

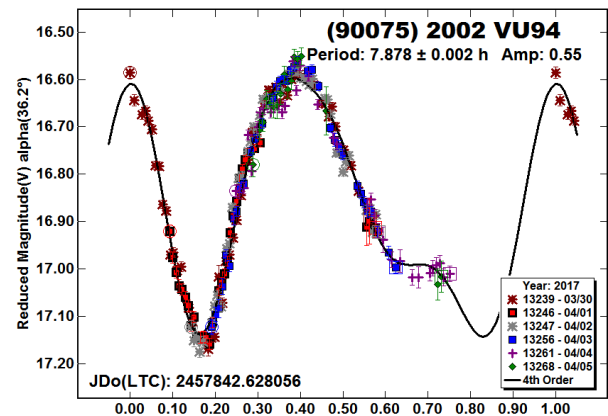
(22771) 1999 CU3. The period found from the 2017 PDS data is consistent with previous results, e.g., Pravec et al. (2003web; 3.7819 h) and Warner (2015d, 3.780 h).



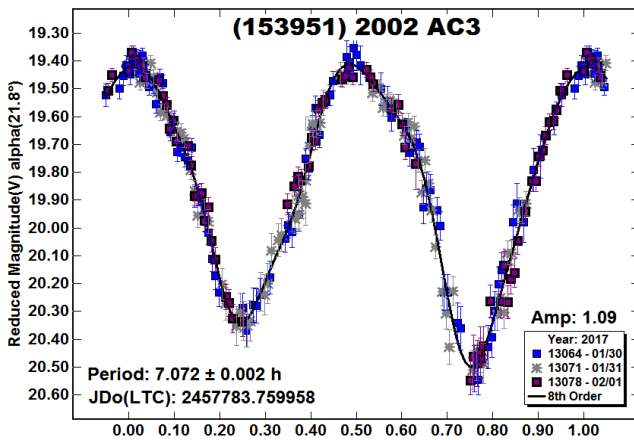
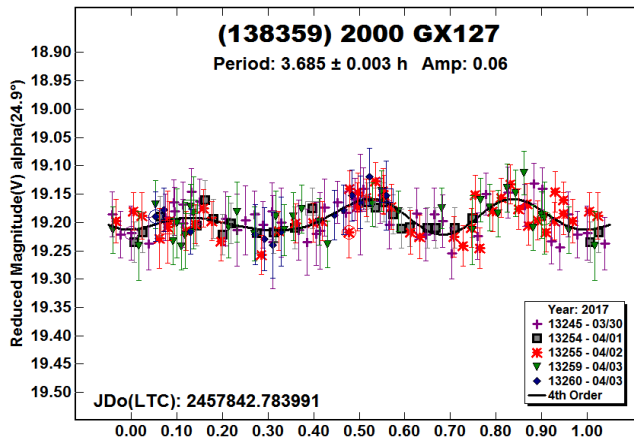
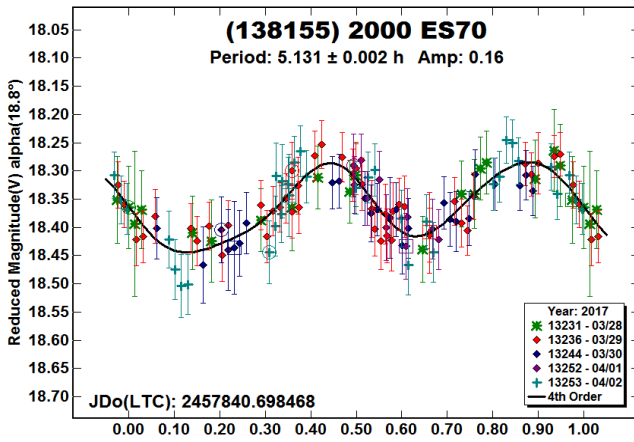
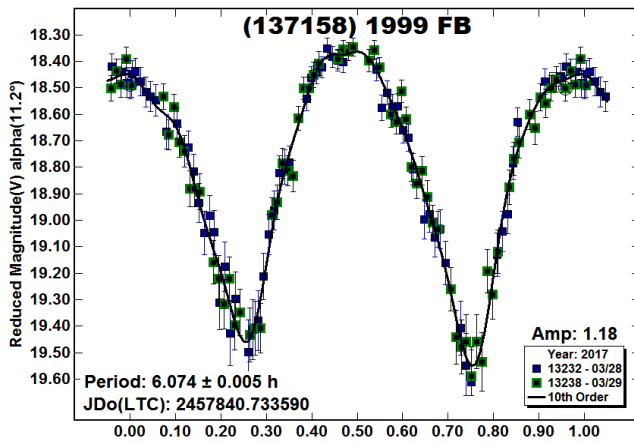
(40267) 1999 GJ4. Only two sessions were required to find a secure period. The period is consistent with previous results. Spin axis and shape models were derived and are presented later.



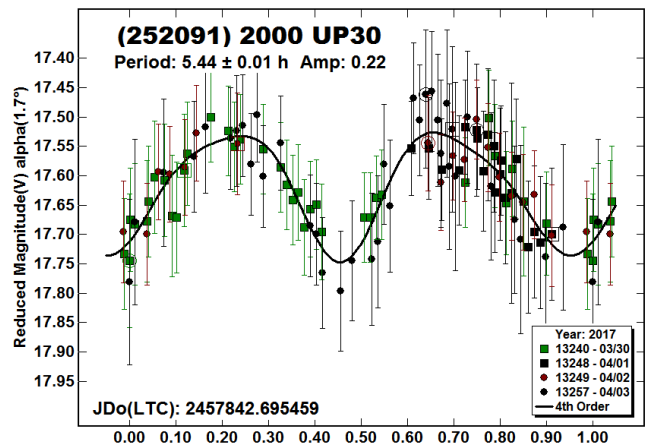
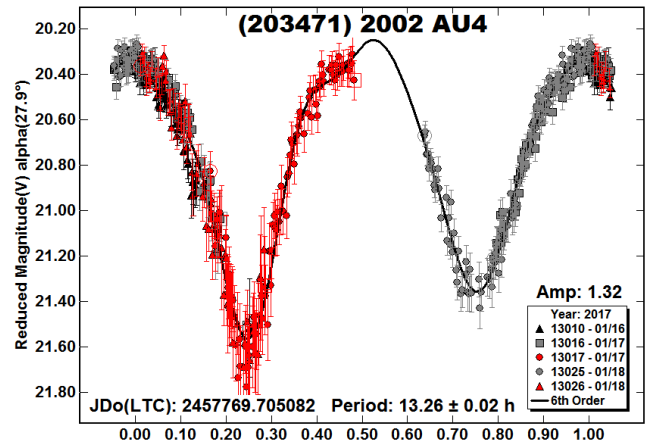
(90075) 2002 VU94. Despite the incomplete coverage of the lightcurve, a secure period was found. The period is consistent with earlier results from PDS (Warner, 2015a; 2015c). Spin axis and shape models are given in a later section.



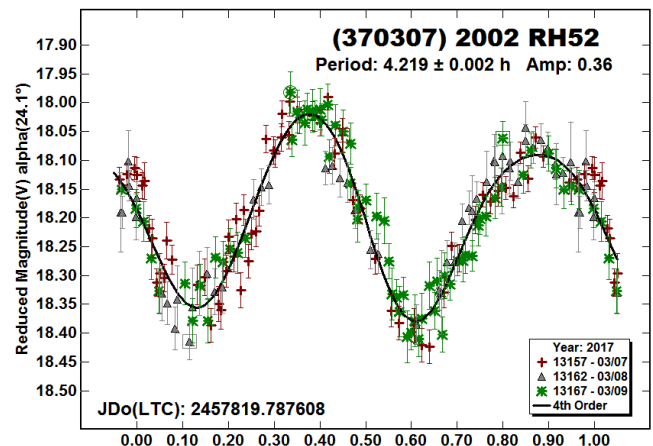
(137158) 1999 FB, (138155) 2000 ES70, (138359) 2000 GX127, and (153951) 2002 AC3. These appear to be the first reported periods for the four NEAs.



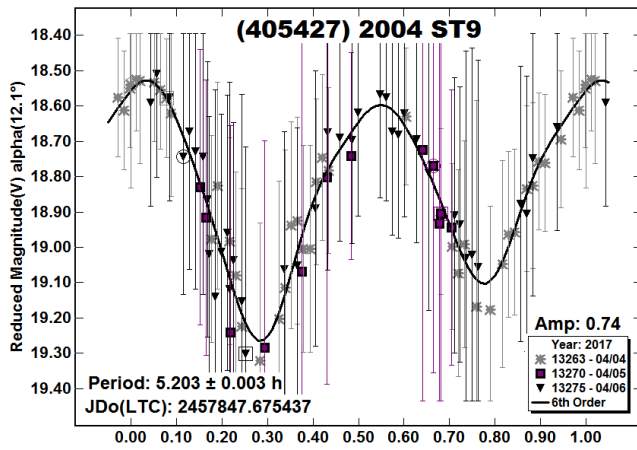
(203471) 2002 AU4 and (252091) 2000 UP30. These appear to be the first reported periods for the two asteroids.



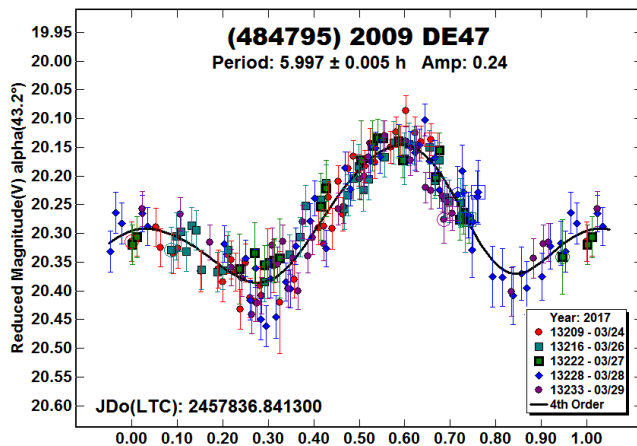
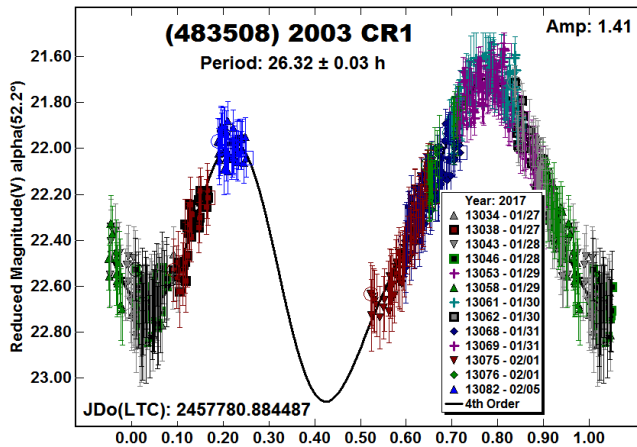
(370307) 2002 RH52. Pravec et al. (2003web) first reported a period of 4.222 h. Warner (2017a) found a period 4.218 h using data from 2016 September, almost exactly the same as derived from the 2017 March observations.



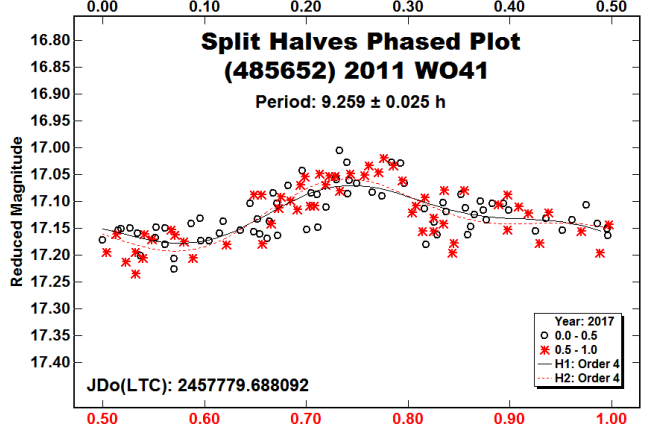
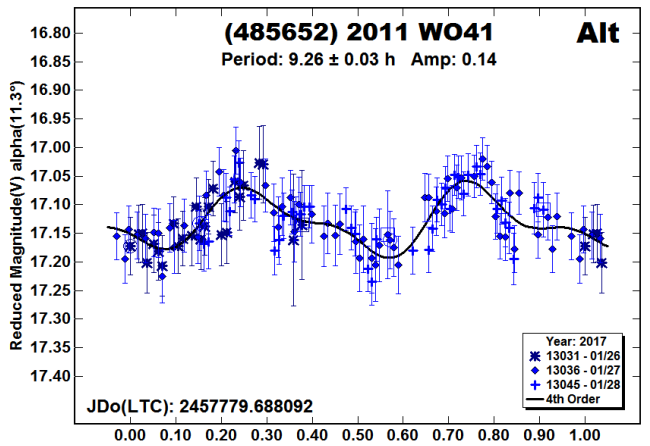
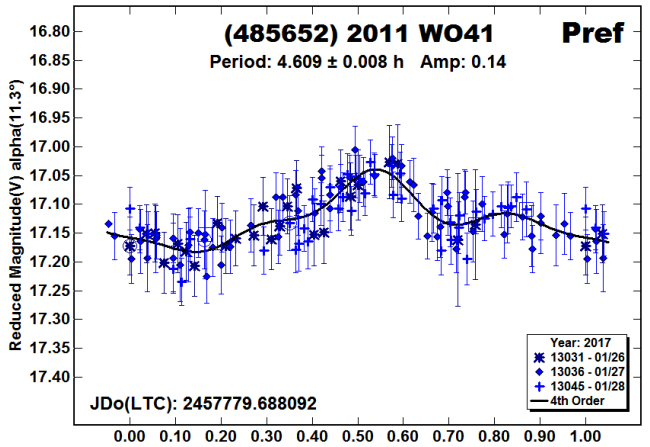
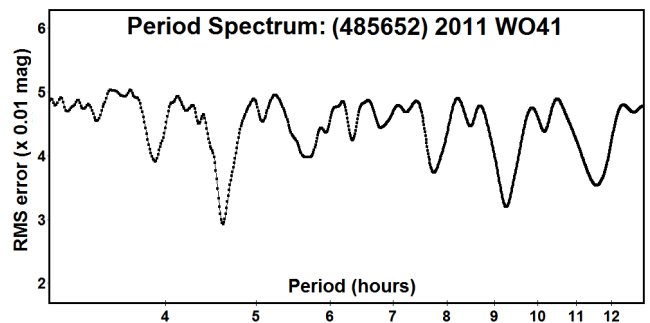
(405427) 2004 ST9. Finding a period for this asteroid was almost defeated by three of the five "Fatal F's": Fast, Faint, Fading, Fast rotator, and Full Moon. The only ones missing were Fast and Fast rotator. The error bars were almost as large as the amplitude but it was still possible to find a period because of the large amplitude, 0.74 mag.



(483508) 2003 CR1, (484795) 2009 DE47. These appear to be the first reported periods for the two NEAs. Koehn et al. (2014) did observe 2003 CR1 in 2009 April, but could not find a period. The period of 26.32 h reported here is reasonably secure given the multiple coverage of parts of the lightcurve. Data from a station well-removed in longitude might have allowed filling in the missing parts.



(485652) 2011 WO41. There was no period reported in the LCDB for this 1.5 km NEA.



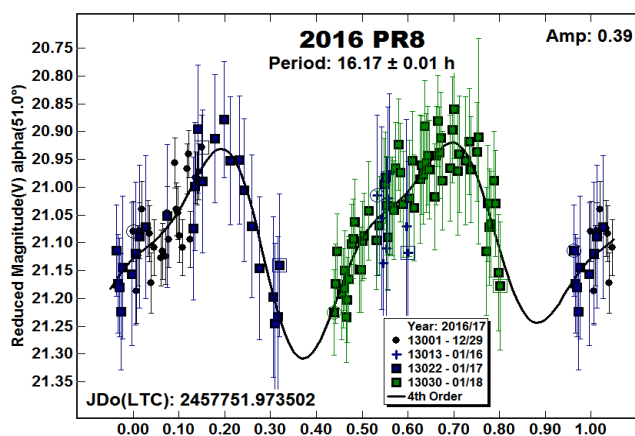
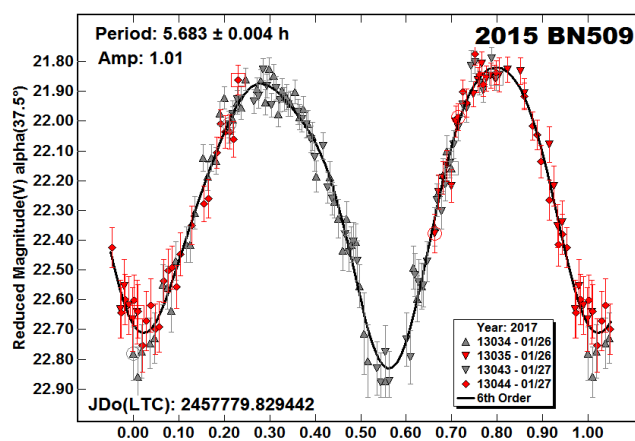
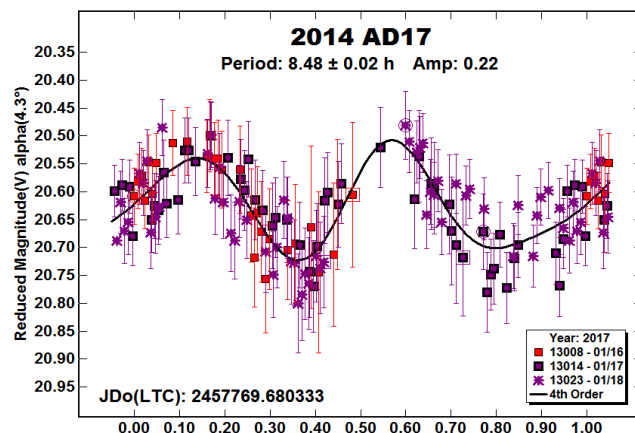
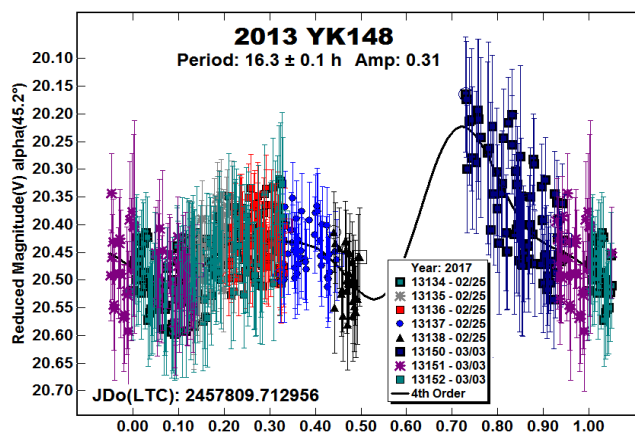
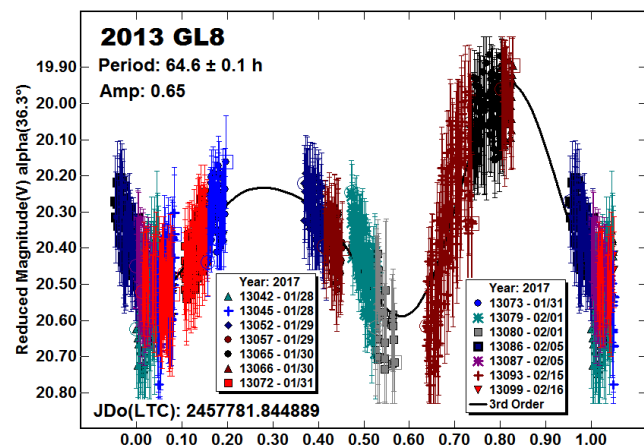
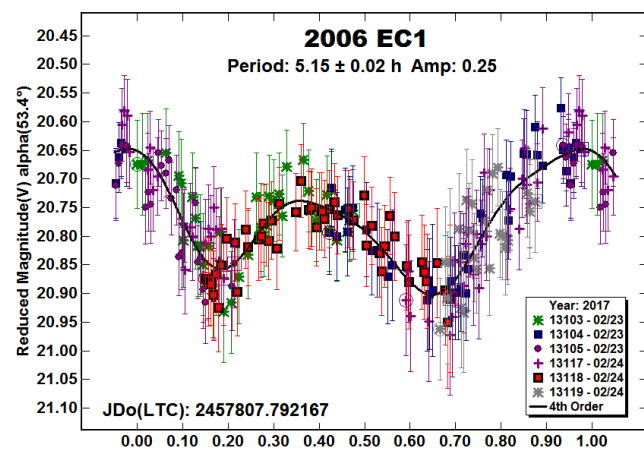
The low amplitude and relatively low phase angle meant that a bimodal lightcurve could not be assumed without supporting evidence. In this case, that evidence was lightcurve that was too symmetrical when the data were forced to a period of about 9.26

hours, i.e., the two halves were so alike as to imply a body that had identically-shaped east/west hemispheres.

A check the help resolve the ambiguity is to plot the data assuming the full period but to overlay the first half of the lightcurve with second half, as shown in the Split Halves plot. If the two halves are essentially identical then, combined with the other information, the half-period with its monomodal shape is the more likely, but not necessarily correct, solution.

2006 EC1, 2013 GL8, 2013 YK148, 2014 AD17, 2015 BN509, and 2016 PR8. These appear to be the first reported periods for the six NEAs. The solutions for 2013 GL8 and 2013 YK148 are the best estimates based on the obviously noisy data. Of the two, the 64.6 h for 2013 GL8 is the more secure: the lightcurve shape is reasonable and there is multiple coverage of at least one section.

Given the diameter and long period, 2013 GL8 is a good candidate for tumbling (Pravec et al., 2005; 2010). The slopes of the data match the slopes of the Fourier curve; not doing so would be evidence of tumbling. The only thing suspect is the significantly different amplitudes of the two halves. With the amplitude of about 0.65 mag, a more symmetrical lightcurve is usually expected. However, the relatively large phase angle of  $37^\circ$  may have led to shadowing effects that, combined with surface features, produced the asymmetrical shape.



2017 EK. This is a case of being defeated by all five of the “Fatal Fs”: Faint, Fast (sky motion), Fast rotator, Fading, and Full Moon. At the time of the observations in 2017 mid-March, the asteroid was moving at about 80 arcsec/minute and the almost full moon was less than 50° away. Exposures were kept to 10 seconds. Usually, this is short enough to cover the cases of fast rotator; that was not so in this case.

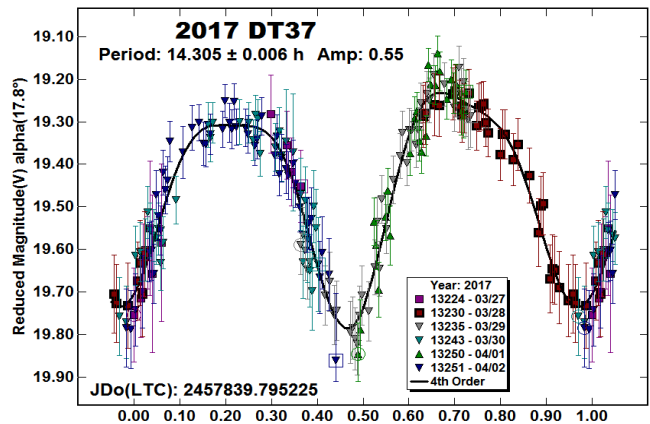
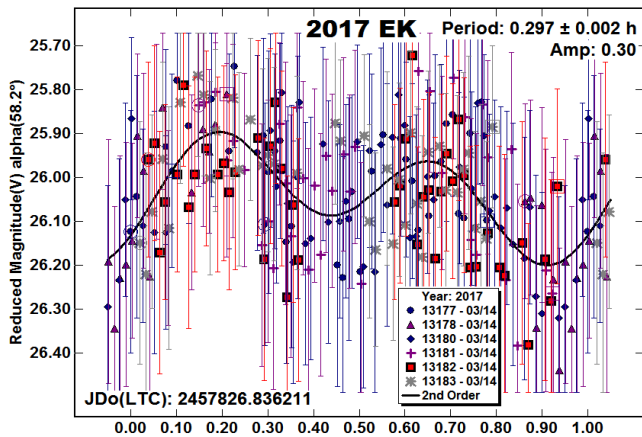
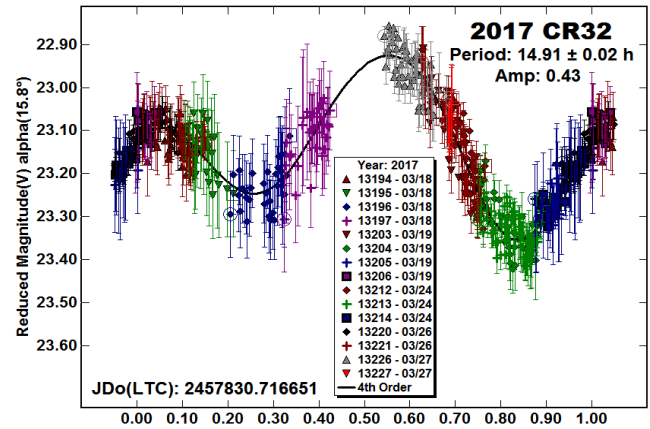
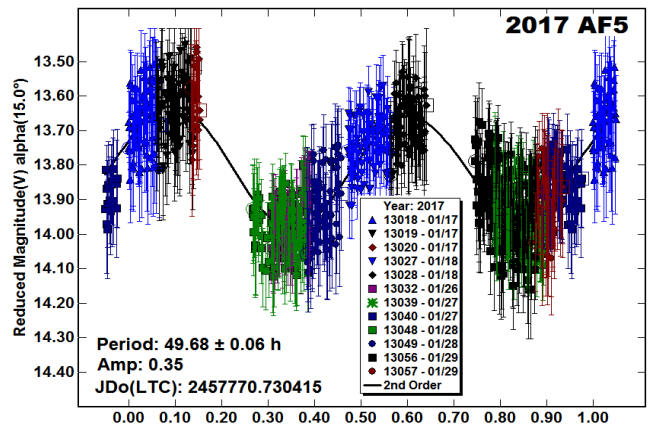
Pravec et al. (2000) showed that exposures must be kept to

$$E < 0.187P$$

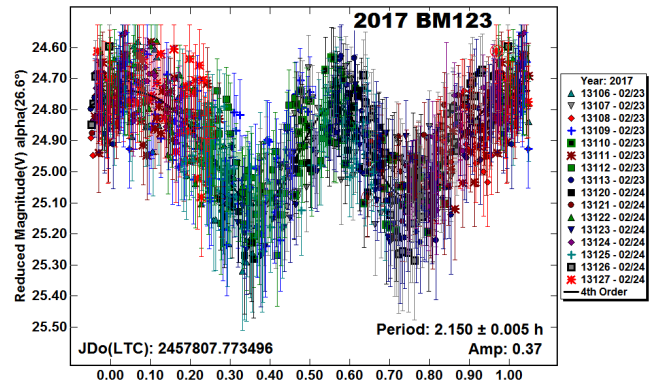
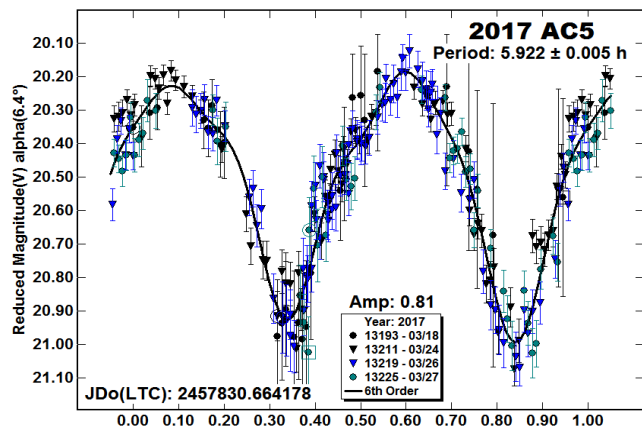
where  $P$  is the rotation period and  $E$  is the exposure in the same units as  $P$ . If the exposures are longer than the above would allow, rotation information is “smeared.” As the exposure increases over the limit, it becomes more difficult and, eventually, impossible to find the period.

The issue of exposure time aside, the lightcurve based on the PDS data is almost of no value given the low amplitude in relation to the error bars and random scatter. This was the least of problems. Radar observations (Patrick Taylor, private communications) showed that the rotation period was on the order of 30 seconds. The 10-second exposures were  $\sim 0.33P$ , or almost double the limit given by Pravec et al.

The result given here is almost certainly wrong. This case is being presented as precautionary tale about the many considerations involved in asteroid lightcurve photometry.



2017 AC5, 2017 AF5, 2017 CR32, 2017 DT37, and 2017 BM123. These appear to be the first reported periods for the five NEAs.



Number	Name	2016 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period	P.E.	Amp	A.E.	Grp
2102	Tantalus	01/06-01/18	297	75.0,81.1	62	28	2.383	0.001	0.07	0.01	NEA
2329	Orthos	02/25-03/03	109	18.6,17.1	195	10	6.178	0.005	0.67	0.05	NEA
3103	Eger	02/15-02/16	396	11.2,11.4	147	12	5.710	0.002	0.60	0.02	NEA
4055	Magellan	03/07-03/09	133	1.2,1.0,1.2	168	2	7.52	0.01	0.38	0.03	NEA
5604	1992 FE	03/23-03/26	122	38.5,39.3	160	-12	5.337	0.004	0.21	0.02	NEA
5626	1991 FE	01/30-03/02	407	21.0,6.9	175	0	133.5	0.4	0.13	0.02	NEA
5693	1993 EA	01/27-01/29	605	6.7,7.6	126	6	2.496	0.002	0.05	0.01	NEA
10636	1998 QK56	03/17-03/19	442	29.2,28.9	157	-2	9.876	0.004	0.53	0.03	NEA
11398	1998 YP11	01/29-02/24	417	12.6,5.4,16.7	141	-2	38.59	0.01	0.20	0.02	NEA
22771	1999 CU3	02/23-03/02	123	24.6,21.8	181	-4	3.781	0.002	0.23	0.02	NEA
40267	1999 GJ4	02/05-02/08	245	21.6,16.4	157	-1	4.9582	0.0005	1.00	0.03	NEA
90075	2002 VU94	03/30-04/05	216	36.3,42.6	160	-15	7.878	0.002	0.55	0.02	NEA
137158	1999 FB	03/28-03/29	130	11.2,10.7	191	11	6.074	0.005	1.18	0.03	NEA
138155	2000 ES70	03/28-04/02	130	18.8,21.8	168	0	5.131	0.002	0.16	0.02	NEA
138359	2000 GX127	03/30-04/03	155	25.0,21.7	204	19	3.685	0.003	0.06	0.01	NEA
143404	2003 BD44	02/25-03/17	409	18.1,3.3	177	-1	29.71	0.01	0.42	0.02	NEA
153951	2002 AC3	01/30-02/01	235	21.8,20.9	148	-2	7.072	0.002	1.09	0.03	NEA
203471	2002 AU4	01/16-01/18	428	27.9,28.2	122	19	13.26	0.02	1.32	0.04	NEA
252091	2000 UP30	03/30-04/03	111	1.7,5.2	188	-1	5.44	0.01	0.22	0.02	NEA
370307	2002 RH52	03/07-03/09	183	24.2,21.9	188	3	4.219	0.002	0.36	0.03	NEA
405427	2004 ST9	04/04-04/06	91	11.8,13.4	182	-3	5.203	0.003	0.74	0.05	NEA
483508	2003 CR1	01/27-02/05	680	52.5,32.7	159	-5	26.32	0.03	1.35	0.10	NEA
484795	2009 DE47	03/24-03/29	182	43.2,35.1	205	21	5.997	0.005	0.24	0.02	NEA
485652	2011 WO41	01/26-01/28	130	11.3,11.0	135	12	4.609	0.008	0.14	0.02	NEA
	2006 EC1	02/23-02/24	231	53.5,50.9	171	34	5.15	0.02	0.25	0.03	NEA
	2013 GL8	01/28-02/16	1027	36.5,1.9	154	3	64.6	0.5	0.68	0.05	NEA
	2013 YK148	02/25-03/03	456	45.0,31.9	158	29	16.3	0.1	0.30	0.03	NEA
	2014 AD17	01/16-01/18	135	4.3,5.1	118	-3	8.48	0.02	0.22	0.03	NEA
	2015 BN509	01/26-01/27	169	37.5,38.2	151	4	5.683	0.004	1.01	0.03	NEA
	2016 PR8	12/29-01/18	123	51.3,27.6	134	15	16.17	0.01	0.39	0.04	NEA
	2017 EK	03/14-03/14	228	57.8,57.8	194	22	0.297	0.002	0.30	0.05	NEA
	2017 AC5	03/18-03/27	243	6.5,14.6	176	4	5.922	0.005	0.81	0.03	NEA
	2017 AF5	01/16-01/29	892	24.4,8.5	132	11	49.68	0.06	0.35	0.04	NEA
	2017 CR32	03/18-03/27	506	15.6,0.2,8.0	183	2	14.91	0.02	0.41	0.03	NEA
	2017 DT37	03/27-04/02	199	17.8,13.8	203	6	14.605	0.006	0.55	0.03	NEA
	2017 BM123	02/23-02/24	921	26.8,31.9	168	9	2.15	0.005	0.37	0.05	NEA

Table II. Observing circumstances. Pts is the number of data points used in the analysis. The phase angle ( $\alpha$ ) is given at the start and end of each date range, unless it reached a minimum, which is then the second of three values. If a single value is given, the phase angle did not change significantly and the average value is given. L<sub>PAB</sub> and B<sub>PAB</sub> are, respectively the average phase angle bisector longitude and latitude, unless two values are given (first/last date in range). Grp is the orbital group of the asteroid. See Warner *et al.* (LCDB; 2009; *Icarus* **202**, 134-146.).

### Spin Axis and Shape Models

To model the shape and spin axis of an asteroid usually requires data from multiple apparitions at different phase angle bisector longitudes (viewing aspect). The inversion code uses the information about the changes in the lightcurve versus the viewing aspect to construct a 3-D model that reproduces the original lightcurves as closely as possible.

A wide range of data, over many years is best, allows finding a more accurate sidereal rotation period, which is the foundation upon which all subsequent modeling is done. If the period is wrong, then the model will likely be not just a little, but significantly wrong.

Following the 2017 observations, there were sufficient data to attempt finding a spin axis and shape model for four of the NEAs discussed earlier. They are listed in Table III, which gives the number of dense lightcurves, e.g., those used in this paper, and the number of data sparse points from the Catalina Sky Survey. Table IV gives observing circumstances for each data set for each asteroid. Table V gives the final results. One asteroid, 4055 Magellan, did not have a single, unambiguous solution. The first pole solution is the one that had the lowest  $\chi^2$  value.

*MPO LCInvert* was used for the inversion work. This is a Windows-based wrapper around the original C/FORTRAN code

developed first by Kaasalainen *et al.* (2001a; 2001b). The reader is referred to the paper by Warner *et al.* (2017b) elsewhere in this issue for details about the inversion process and approach taken to derive the spin axis and shape models. That paper also discusses certain features of derived models, specifically flat zones on the model and their physical interpretation.

The results of the modeling are presented at the end of this paper. There are several plots for each asteroid that were generated by *MPO LCInvert*. For each group of plots, the left-hand plot on the first line shows the L<sub>PAB</sub> distribution. Green circles represent the mid-point of each dense lightcurve. Red squares represent each sparse data point. The right-hand plot of the first line shows the period search  $\chi^2$  values versus period. The horizontal green line is at 1.1x the lowest  $\chi^2$  value, i.e., the so-called “10% rule” discussed in Warner *et al.* (2017b).

On the second line, the left-hand image is the 10% pole search plot. Each small region represents a 15x15° area of the sky in ecliptic coordinates. Deep blue represents the area with the lowest  $\chi^2$ . The colors move towards bright red, which represents the 10% cutoff. Anything more than 10% is dark red. The perfect solution is a single deep blue island in a sea of dark red. The additional image(s) on the second line show profiles of the asteroid model as viewed from over the north and south poles and in the asteroid’s equatorial plane at Z = 0° and Z = +90° rotation.

Asteroid	N <sub>dense</sub>	N <sub>sparse</sub>
3103	19	177
4055	21	139
40267	16	189
90075	14	95

Table III. N<sub>dense</sub> is the number of dense lightcurves used in the modeling. The sparse data are considered a single lightcurve, so the N<sub>sparse</sub> column gives the number of sparse data points.

Number	Name	Dates	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period	P.E.	Amp	A.E.	Src
3103	Eger	1987 01/26-02/02	77	20.5, 13.8	145	5	5.709	0.001	0.72	0.02	WS91
3103	Eger	1991 07/07-07/17	33	41.9, 42.1	318	13	5.707	0.001	0.8	0.1	V92
3103	Eger	2007 02/10-02/17	201	9.4, 11.5	143	10	5.711	0.001	0.58	0.02	RS07
3103	Eger	2014 04/20-04/23	167	20.3, 20.5	210	31	5.714	0.002	0.45	0.02	W14b
3103	Eger	2016 05/31-06/04	158	43.5, 43.9	297	20	5.711	0.002	0.72	0.02	W16b
3103	Eger	2017 02/15-02/16	396	11.1, 11.3	147	12	5.710	0.002	0.59	0.02	this
4055	Magellan	2014 01/26-02/01	74	13.4, 14.5	113	-23	6.384	0.005	0.76	0.02	W14a
4055	Magellan	2015 04/12-04/17	108	38.7, 39.2	255	31	7.496	0.005	0.62	0.04	W15e
4055	Magellan	2017 03/07-03/09	133	1.3, 1.0	168	2	7.52	0.01	0.38	0.03	this
40267	1999 GJ4	2013 03/17-04/22	21	15.0, 14.9, 22.2	181	29	4.958	0.004	0.67	0.03	AW15
40267	1999 GJ4	2014 01/18-01/23	152	34.8, 31.4	168	3	4.959	0.002	0.94	0.03	W14a
40267	1999 GJ4	2014 02/24-02/26	237	7.3, 6.9	159	10	4.956	0.002	0.86	0.02	W14a
40267	1999 GJ4	2017 02/05-02/08	245	21.6, 16.4	157	-1	4.9582	0.0005	1.00	0.03	this
90075	2002 VU94	2014 08/05-08/16	207	42.5, 37.5	15	10	7.88	0.01	0.62	0.03	W15a
90075	2002 VU94	2014 10/13-10/14	151	4.1, 4.2	18	6	7.90	0.01	0.31	0.02	W15c
90075	2002 VU94	2017 03/30-04/05	216	36.3, 42.6	160	-15	7.878	0.002	0.55	0.02	this

Table IV. Observing circumstances and synodic period results. Pts is the number of data points used in the analysis. The phase angle ( $\alpha$ ) is given for the first and last date (0h UT); a third, middle value indicates the asteroid reached a minimum during the period. L<sub>PAB</sub> and B<sub>PAB</sub> are, respectively, the phase angle bisector longitudes and latitudes for the first and last date (0h UT). The Src column gives the reference paper where the original data were used. WS = Wisniewski; V = Velichko; RS = Stephens; AW = Wasczack; W = Warner.

Number	Name	L <sub>1</sub>	B <sub>1</sub>	P <sub>1</sub>	a/b	a/c	L <sub>2</sub>	B <sub>2</sub>	P <sub>2</sub>	a/b	a/c
3103	Eger	211	-76	5.710138	0.75	1.03					
4055	Magellan	81	33	7.477559	1.08	1.38	146	87	7.477580	1.20	1.11
40267	1999 GJ4	63	37	4.957067	1.46	2.28					
90075	2002 VU94	73	-50	7.878512	1.25	1.76					

Table V. Pole solutions. L = ecliptic longitude; B = ecliptic latitude; P = sidereal period. The longitude and latitude errors are on the order of  $\pm 10^\circ$ . The period error is approximately 2 units of the last decimal place. The a/b column gives the ratio of the two longest axes (X/Y) of the model. The a/c column gives the ratio of the longest axis (X or Y) versus the Z-axis.

Since the inversion algorithms used here find only a convex hull, concavities appear as large flat areas on the asteroid. A good analogy is to imagine wrapping the asteroid with paper without punching holes in the paper to fill depressions. This creates flat areas in the wrapping that are covering concavities.

The remaining plots compare the dense data with the model curve at specific times. The red dots represent the dense data while the solid black line is the model lightcurve. The main test is if the dense lightcurve has the same amplitude and shape as the model lightcurve. If there are multiple pole solutions, then the one that gives the best fits for all the dense lightcurves is the more likely solution – assuming it has a realistic shape. If the rotation rate is being affected by YORP, then the model lightcurves will slowly become out of phase with the data, e.g., maximums not quite aligning in rotation phase.

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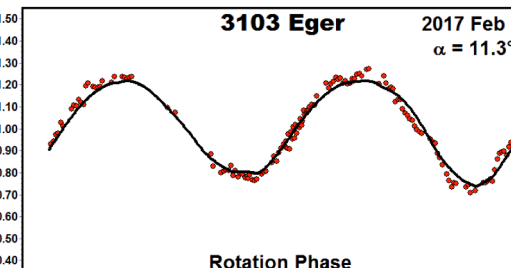
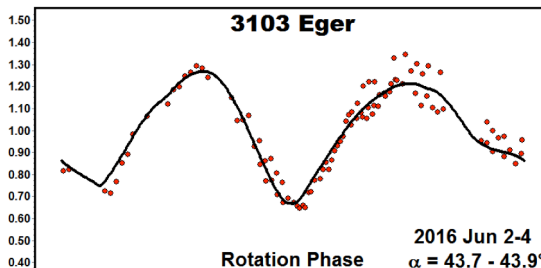
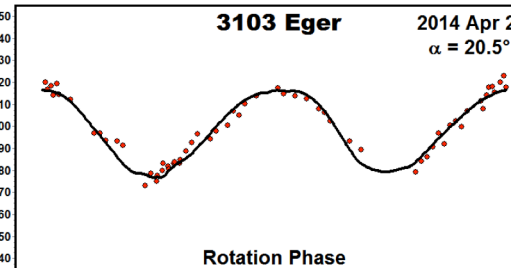
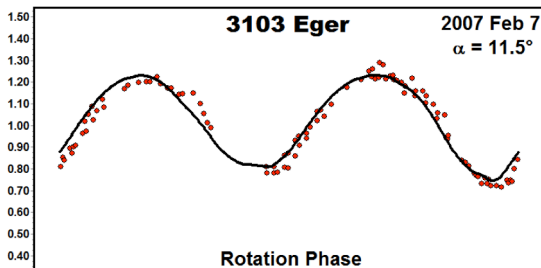
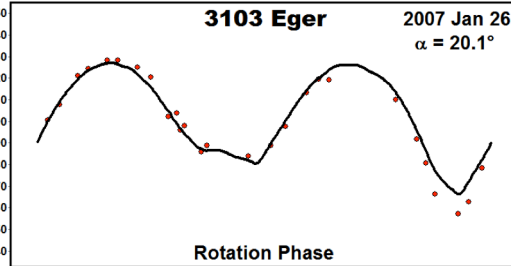
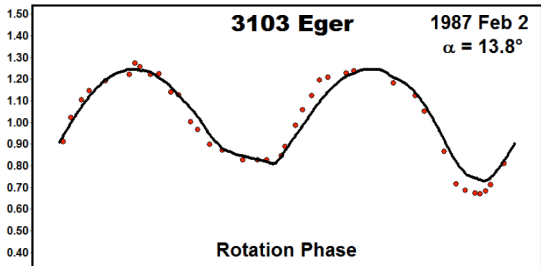
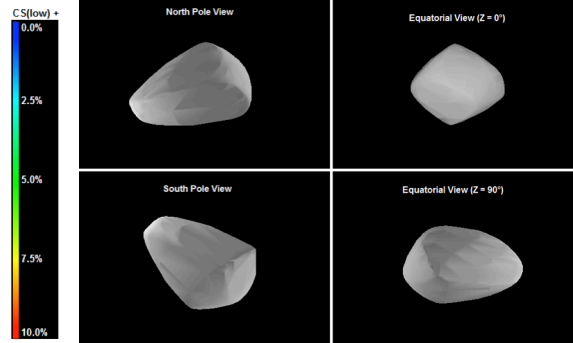
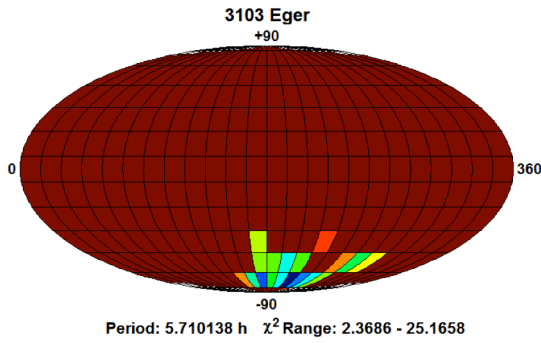
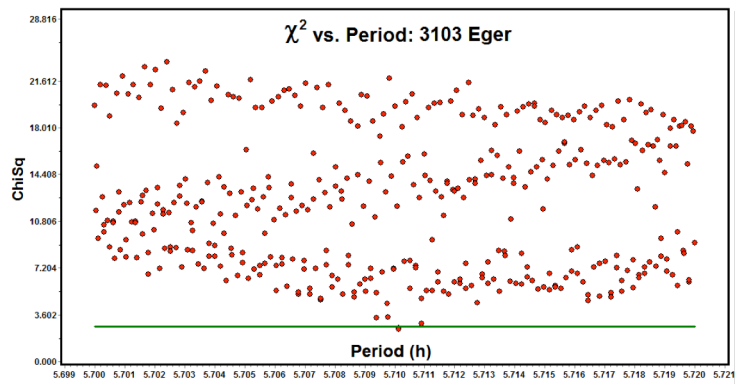
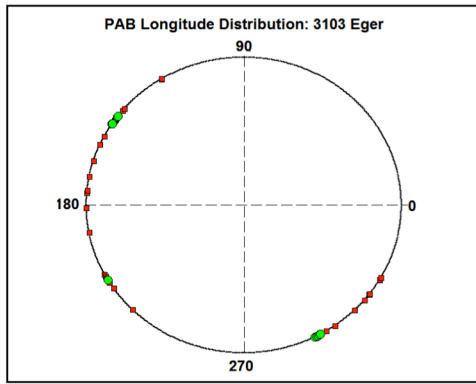


Figure 1: 3103 Eger. The pole solution is unambiguous with regards to the negative latitude, which indicates a retrograde rotation. The fit of the models to the data is surprisingly good since Durech et al. (2012) established that the sidereal rotation period is slowly increasing over time. See the text for an explanation of the plots.

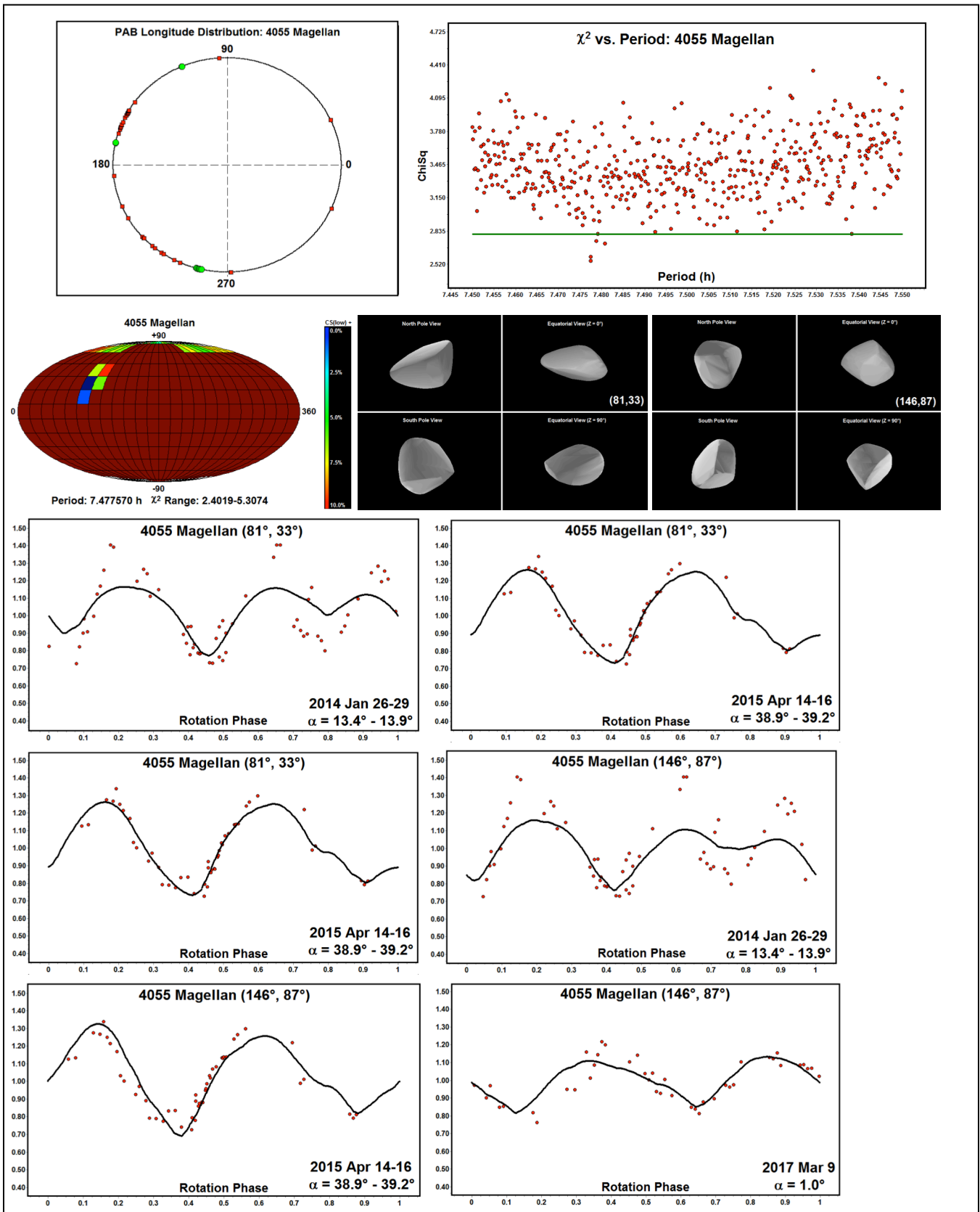


Figure 2: 4055 Magellan. The favored pole is (81°, 33°). The alternate solution, with an obliquity of nearly 0°, cannot be formally excluded. When the latitude is very near one of the ecliptic poles, the uncertainty in the longitude is significantly higher. The poor fit of the models lightcurves to the actual data, especially in 2014 January, reflect the uncertainty of both the period and pole solution. See the text for an explanation of the plots.

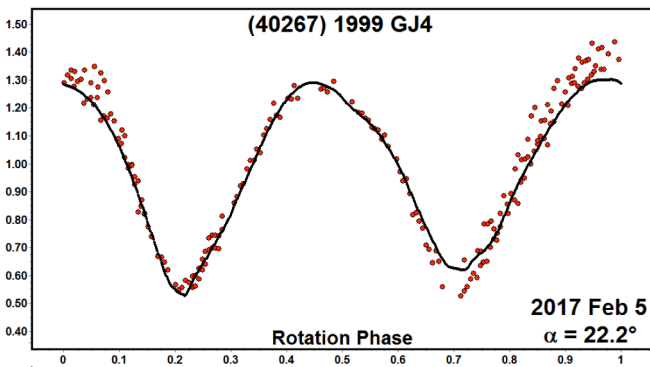
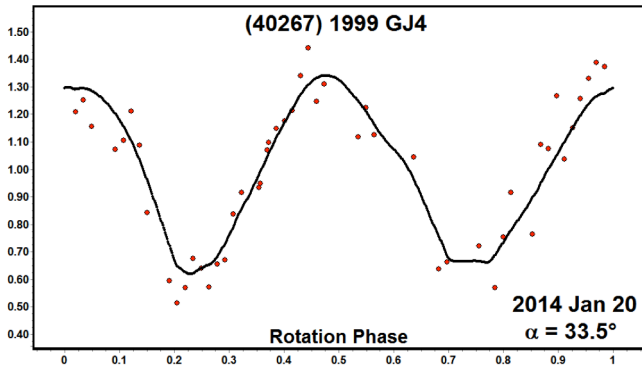
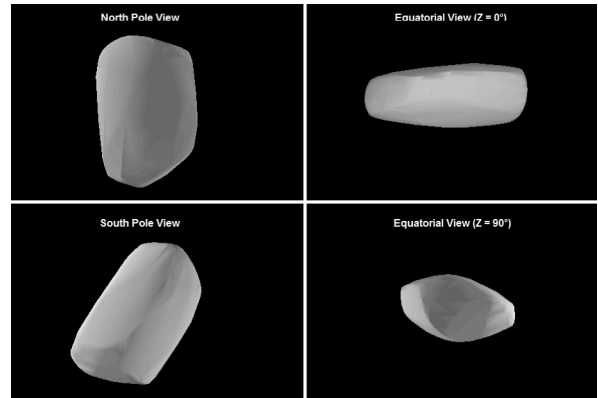
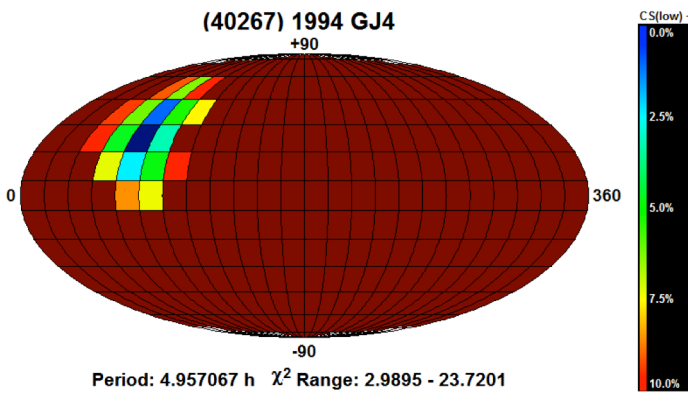
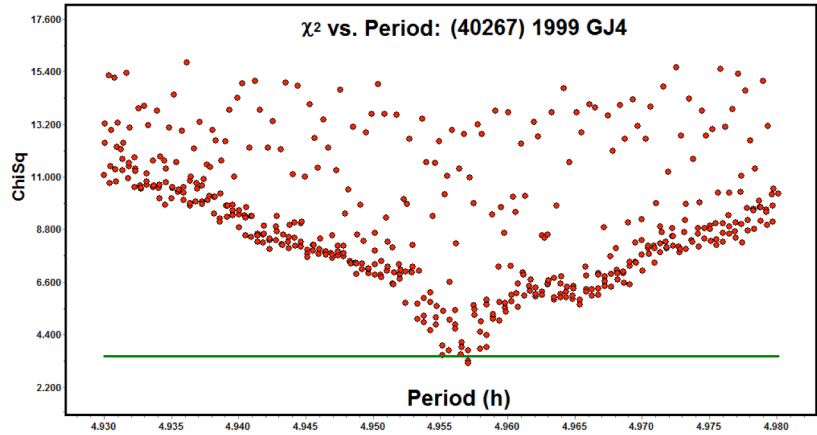
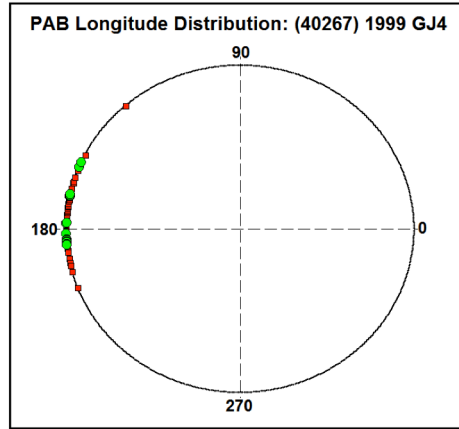
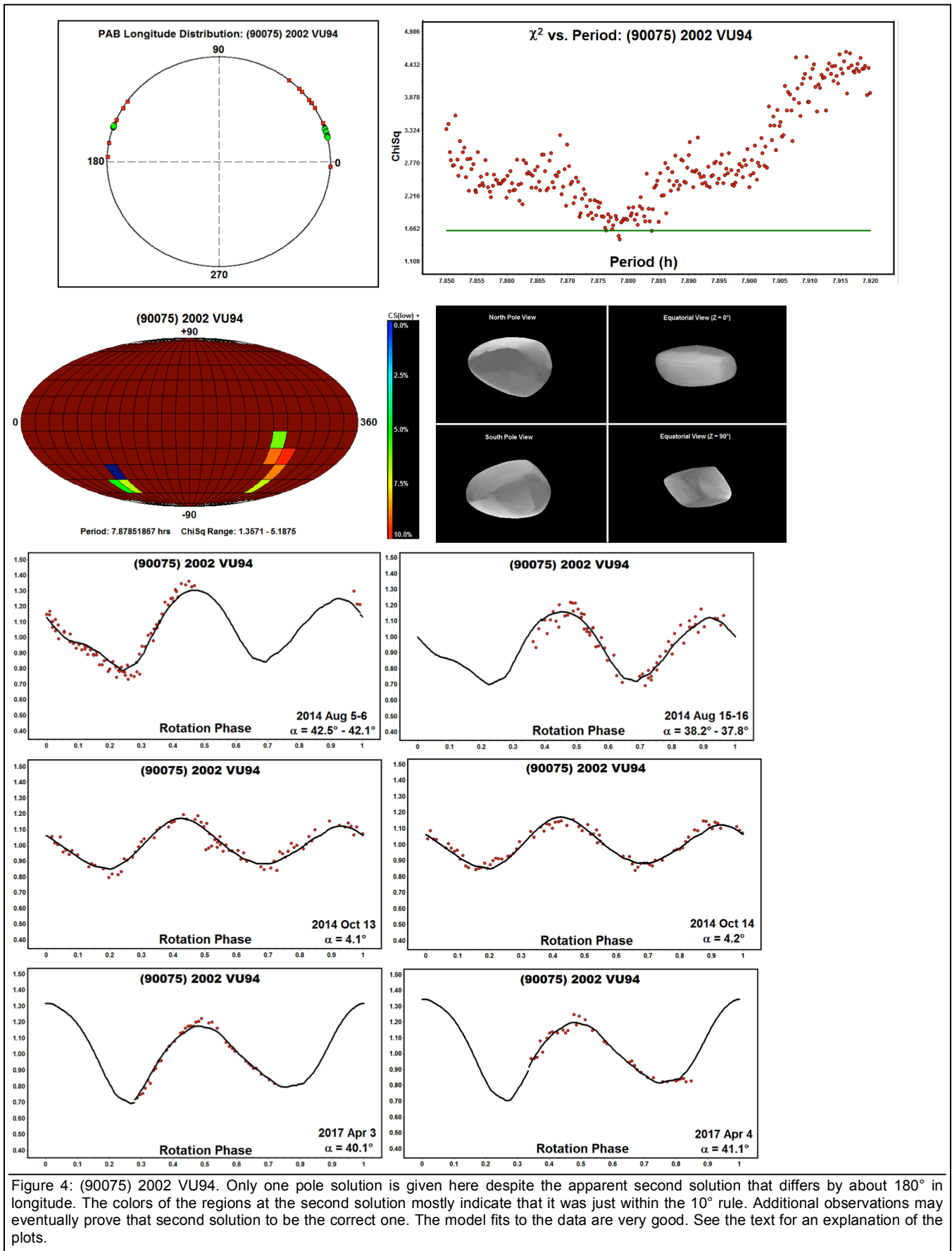


Figure 3: (40267) 1999 GJ4. Dense data were available from only two apparitions. The data set from Waszczak et al. (2015) had fewer than 25 data points spread over several weeks. They were treated as dense data since they were all from the same apparition. Regardless of their status, the data confined the pole solution to a smaller area than when not being used. The larger amplitude of the actual data and the large flat areas in the model may indicate that this is a highly bifurcated body. See the text for an explanation of the plots.



## ROTATION PERIOD DETERMINATION FOR 393 LAMPETIA

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CCD photometry of minor planet 393 Lampetia shows that it has a synodic rotation period of  $38.455 \pm 0.004$  h, amplitude  $0.08 \pm 0.01$  mag.

Because 393 Lampetia has exhibited a long rotation period and small amplitude, previous period determinations are based on incomplete phase coverage and are therefore less reliable. The published periods are by Scaltriti et al. (1979), 38.7 h; Holliday, 38.47 h; and Behrend (2004), 19.2 h. The three authors of this study agreed to collaborate to obtain a much more dense observation set and complete phase coverage.

Observer Pilcher at the Organ Mesa Observatory used a 0.35-meter Meade LX200 GPS Schmidt-Cassegrain (SCT), SBIG STL-1001E CCD, and clear filter. Oey at Blue Mountain Observatory used a 35-cm SCT operating at  $f/5.9$ , SBIG ST-8XME CCD, and clear filter. Marciniak used a 0.8 m  $f/9.6$  JTO telescope and MEIA 2 CCD by E2V, and Cousins R filter at Montsec Observatory (OAdM) in the Spanish Pyrenees. Photometric measurement and lightcurve construction were done with *MPO Canopus* software. To reduce the number of points on the lightcurves and make them easier to read, data points have been binned in sets of 3 with a maximum time difference of 5 minutes.

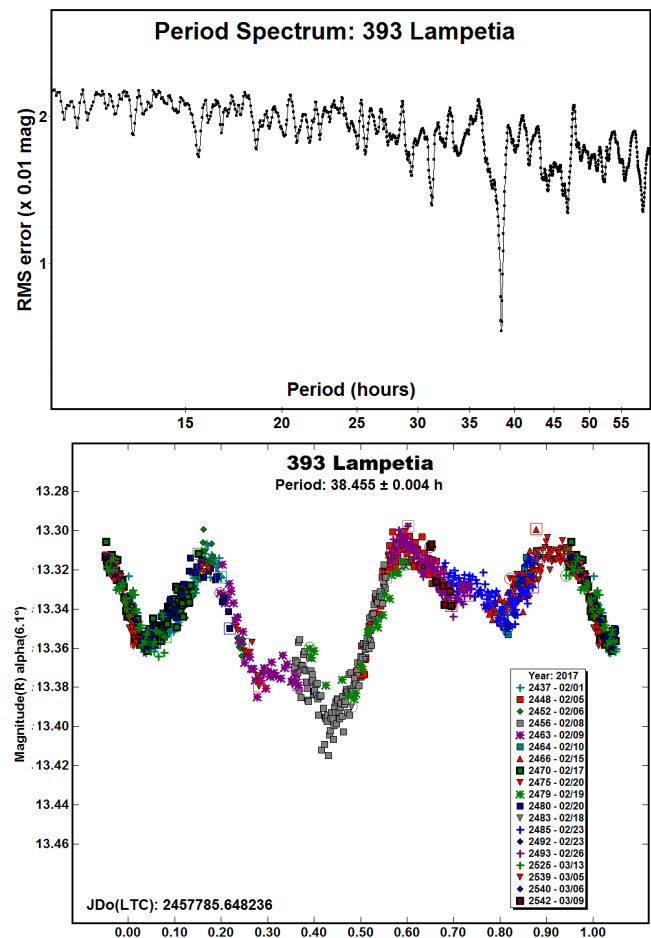
Analysis of observations on 19 nights from 2017 Feb 1 to Mar 13 provides a good fit to an irregular lightcurve with period  $38.455 \pm 0.004$  h, amplitude  $0.08 \pm 0.01$  mag. This is consistent with 38.7 hours by Scaltriti et al. and 38.47 hours by Holliday but rules out the 19.2 hour period by Behrend. We also present the period spectrum between 10 hours and 60 hours, which illustrates no deep minima other than the one near 38.45 hours.

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Number	Name	2017/mm/dd	Pts	Phase	LPAB	BPAB	Period(h)	P.E.	Amp	A.E.
393	Lampetia	02/01-03/13	3108	6.1, 5.2, 10.2	142	-16	38.455	0.004	0.08	0.01

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first date, minimum (second) value reached, and last date. LPAB and BPAB are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris et al., 1984).

**RESULTS OF THE 2016  
MEXICAN ASTEROID PHOTOMETRY CAMPAIGN**

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(Received: 2017 March 31)

We report the results of the 2016 Mexican Asteroid Photometry Campaign. This year observers from seven different research institutions carried out 34 nights of observations at three Mexican observatories. An uncertain, but long, period of  $\sim 115.108 \pm 0.014$  h was estimated for 703 Noëmi from sparse data. A nearly-complete lightcurve was obtained for 1305 Pongola ( $P = 8.0585 \pm 0.0003$  h). Asteroid 2535 Hämeenlinna turned out to be a binary system where the primary exhibits a rotation period of  $3.2311 \pm 0.0001$  h and the secondary shows an orbital period of  $21.20 \pm 0.004$  h. Asteroid 4775 Hansen ( $P = 3.1186 \pm 0.0001$  h) was well observed and showed variations of its lightcurve between two sets of observations separated by about six weeks.

After the successful start of the Mexican Asteroid Photometry Campaign in 2015 with the coordinated observation of three asteroids from three different Mexican observatories (Sada et al., 2016), it was decided to seek increasing the collaboration during 2016. The eventual goal of this effort is to develop teams of coordinated observers in México capable of characterizing not

only main-belt asteroids, but NEOs as well. We report here the results of the 2016 Mexican Asteroid Photometry Campaign.

On this occasion, we collected 34 nights of observations from three different observatories by researchers from seven different institutions. On three of those nights, the observing session was carried out simultaneously from two separate observatories, providing a basis for photometric comparison between them and prolonging the observing period for the target since the observatories were separated by more than  $10^\circ$  in longitude.

At the Universidad de Monterrey (UdeM) Observatory (MPC 720) we observed four asteroids on 17 different nights using a Meade 0.36-m  $f/8$  LX600-ACF telescope and SBIG STL-1301E CCD. The camera uses a  $1280 \times 1024$ - $16 \mu\text{m}$  KAF-1301E/LE chip which covers a  $\sim 26.3 \times 21.1$  arcmin field-of-view (FOV) with an image scale of about 1.24 arcsec/pix. All asteroids were observed unfiltered for maximum SNR and the CCD images were read in  $2 \times 2$  binned format for faster download time and improved observing efficiency. The FOV was maintained fixed on the chip by using an on-axis guide star at all times. Exposure times varied between 60 s and 210 s for each night depending on the target's brightness; sometimes a slight defocus was applied to the telescope to spread the images over a few binned pixels allowing for slightly longer exposure times.

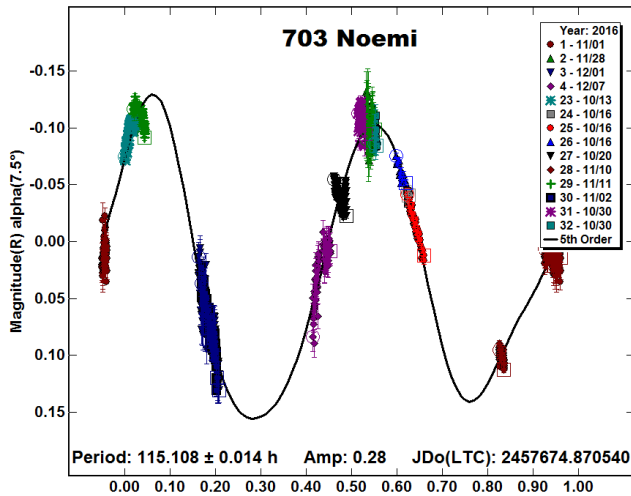
Three one-week observing runs were scheduled throughout the year with the 0.84-m  $f/15$  Ritchey-Chretien telescope at the Observatorio Astronómico Nacional on the Sierra de San Pedro Mártir (OAN-SPM; MPC 679) in Baja California for this program. On top of that, a few additional partial nights of observations were attained on an availability basis from other observing runs. This telescope uses a  $2048 \times 2048$ - $13.4 \mu\text{m}$  Spectral Instruments CCD for regular imaging. This combination yields a FOV of  $\sim 6.3 \times 6.3$  arcmin with an approximate image scale of 0.185 arcsec/pix. All images were obtained using an off-axis guide star for stability (although the field drifted a little during the observing sessions due to telescope sag), were obtained unfiltered, and were also binned  $2 \times 2$  for efficiency. Exposure times also varied for each asteroid between 20s and 480s, depending on the target brightness.

Five observing nights were also recorded at the Carl Sagan Observatory belonging to the Universidad de Sonora (UNISON) in Hermosillo. This observatory operates a Meade LX-200GPS 0.41-m  $f/10$  telescope equipped with a  $3056 \times 3056 \times 12 \mu\text{m}$  Apogee Alta F9000 CCD for imaging. The image frame was trimmed to a subframe of  $2000 \times 2000$  pixels and then binned  $2 \times 2$  yielding an effective  $\sim 20 \times 20$  arcmin FOV with an image scale of about 1.2 arcsec/pix. The images at this site were obtained unguided and unfiltered. Exposure times varied between 70 s and 240 s.

Images from these observatories were processed in the standard manner using nightly dark current and flat-field files. Photometric measurements and lightcurve analysis were performed using *MPO Canopus* (version 10.7.3.0). Although all observations were unfiltered, differential magnitudes were calculated based on R-band stellar magnitudes.

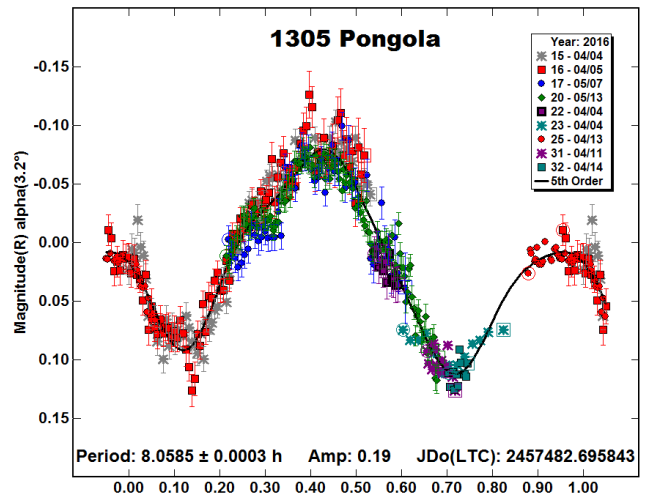
703 Noëmi was discovered by Johann Palisa on 1910 October 3 and named for Baroness Valentine Noëmi von Rothschild (Schmadel, 2003). This S-class asteroid from the Flora Family was observed on five nights from the OAN-SPM Observatory (2016 Oct 13, 16, 20 & Nov 10, 11), four nights from the UDEM Observatory (2016 Nov 1, 28 & Dec 1, 7) and two nights at the UNISON Observatory (2016 Oct 30 & Nov 2). The 2016 Oct 16 observations were treated as three separate sessions because of

differences in exposure times. The 2016 Oct 30 observations were treated as two separate sessions because the FOV was slightly rotated partway through the night. Initial results showed that the asteroid brightness varied a small amount during each night, suggesting either a long rotation period and/or low amplitude. We derived a tentative long rotation period of  $115.108 \pm 0.014$  h by matching the observations from 2016 Nov 2 and Dec 1 in the phased lightcurve, because they exhibited almost identical behavior, and then looking for other possible matches using whole fractions of that time-span and assuming a simple two-maxima and two minima lightcurve. The fact that differential photometry was performed on the unfiltered images, which meant that we could also shift the nightly observations in the brightness axis, added too many degrees of freedom in the search of a solution. Thus, we can only state that the rotation period for this asteroid is long, in the realm of tens of hours, and that our derived tentative value is only one possible solution. Our sparse observations are insufficient to cover an entire lightcurve. No other reports of the rotation period were found in the literature for this asteroid. However, A. Noschese reports on the Collaborative Asteroid Lightcurve Link website (CALL; [minorplanet.info/call.html](http://minorplanet.info/call.html)) a larger set of observations from his group that indicates a longer period of  $\sim 201.9 \pm 0.8$  h, also with larger amplitude. Most of our observations predate his earliest observing date and there is little overlap, so this would be a good opportunity to join both data sets in an effort to obtain a more reliable solution to the rotation period of 703 Noëmi.

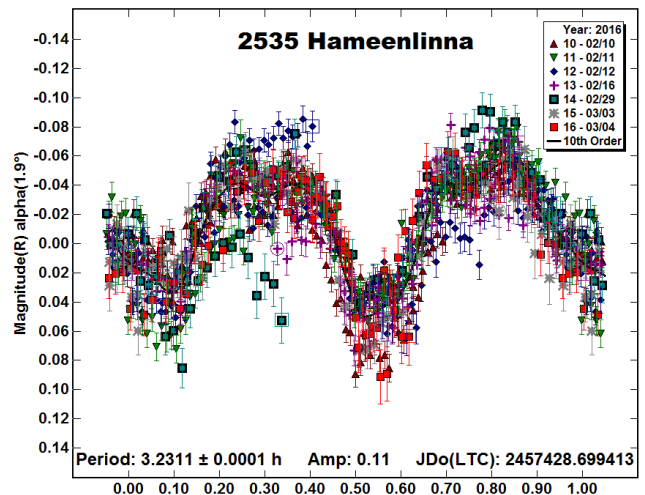


**1305 Pongola.** Was discovered on 1928 July 19 by H. E. Wood at Johannesburg and named for a river in South Africa (Schmadel, 2003). This C-class outer main-belt asteroid was observed at the UdeM Observatory on three nights (2016 Apr 4, 5 & May 7) and at OAN-SPM Observatory on five (2016 April 4, 11, 13, 14 & May 13). During analysis, the 2016 April 4 observations were treated as three separate sessions because of differences in exposure times of the image sets and because they were obtained at two separate observatories. The April 11, 13, and 14 observing sessions were short, obtained during time gaps of other assigned projects, but still provided useful data to complement the lightcurve. A total of 457 data points was used to find a period of  $8.0585 \pm 0.0003$  h with an amplitude of  $\sim 0.19$  mag. Initial rotation period determinations were made by Binzel (1987;  $8.03 \pm 0.10$  h) and Dittion et al. (2012;  $8.06 \pm 0.02$  h). More recently, Waszczak et al. (2015) reported a rotation period of  $8.0586 \pm 0.0015$  h with an amplitude of 0.17 mag, while Mansego et al. (2016) reported a period of  $8.335 \pm 0.002$  h with an amplitude of 0.16 mag. Our

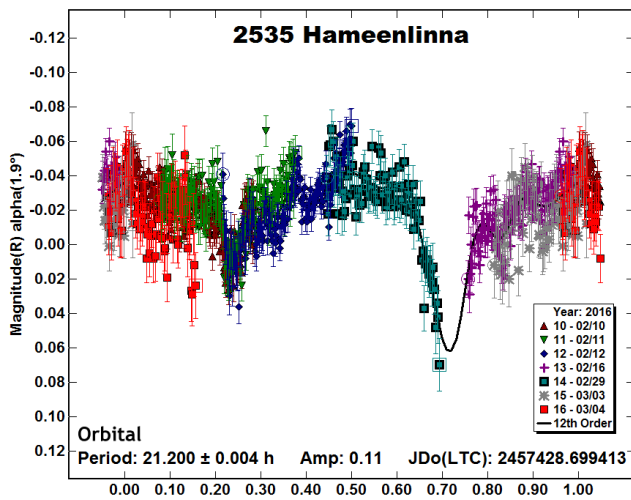
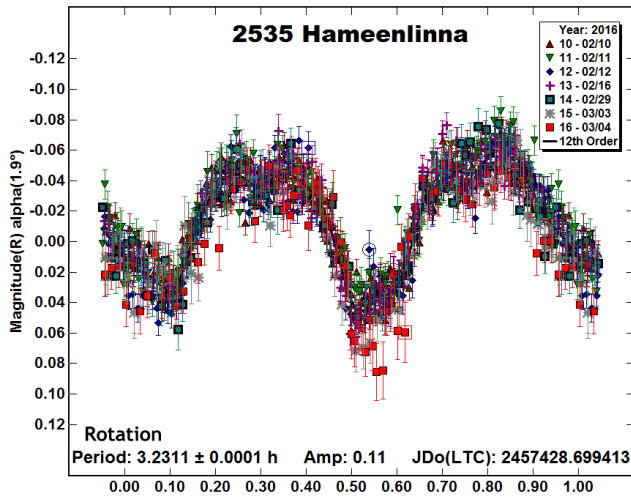
resulting period and amplitude are in better agreement with those obtained by Waszczak et al. (2015).



**2535 Hämeenlinna** was discovered in 1939 February 17 by Y. Väisälä at Turku and named for an old town in the province of Häme (Schmadel, 2003). This S-class asteroid from the Flora family was observed at the UdeM Observatory on eight nights (2016 Feb 10, 11, 12, 16, 29 & Mar 3, 4, 13). On two of these nights (2016 Feb 11 and Mar 3), the asteroid was also observed from the UNISON Observatory, extending the nightly observing period because of its location further west. For the final analysis, the night of 2016 Mar 13 was not included since it was much noisier than the rest. From the onset, this asteroid exhibited a clear  $\sim 3.23$  h period. However, each night the asteroid also exhibited a different overall trend in the data with each successive period not quite matching the previous ones. This was particularly evident in the two extended observing sessions from both observatories. The asteroid was thus suspected as having two periods and further observations were programmed until it was too faint to follow. The following figure below shows the best-fit single period obtained for the data. It confirms a  $3.2311 \pm 0.0001$  h rotation period, but also exhibits larger than usual scatter.

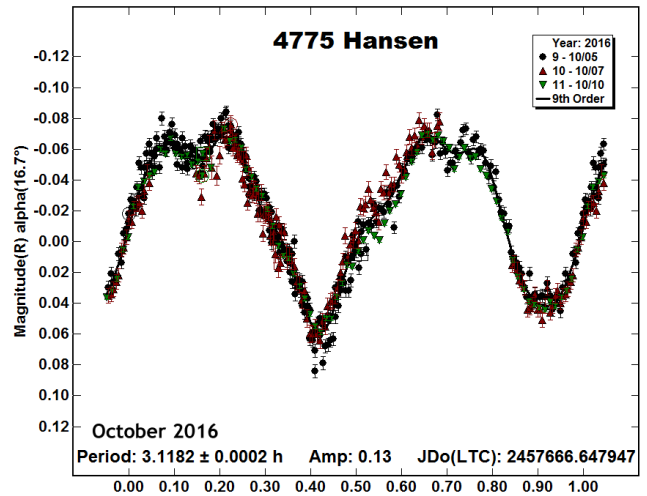
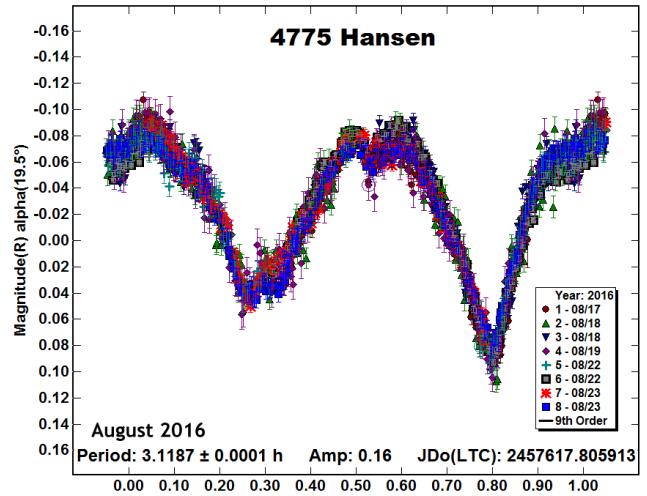


It was decided to use the dual period option included in *MPO Canopus* to attempt to disentangle the possibility of two periods. The results are shown in the next two figures.



They also register eclipse/occultation events with depths of 0.05-0.10 mag. Our data independently confirms this preliminary report from Benishek et al. (2016).

4775 Hansen was discovered in 1927 Oct 3 by Maximilian Franz Wolf at Heidelberg and named after the German astronomer Peter Andreas Hansen (Schmadel, 2003). This is a C-class asteroid that crosses the orbit of Mars. It was observed on six nights at the OAN-SPM Observatory (2016 Aug 17, 18, 19, 22, 23 & Oct 10) and two nights at the UDEM Observatory (2016 Oct 5, 7). During analysis, the 2016 Aug 22 and 23 observations were treated as two separate sessions.



Our initial short rotation period of  $3.2311 \pm 0.0001$  h with an amplitude of 0.11 mag was maintained and the scatter was considerably reduced. An additional period of  $21.20 \pm 0.004$  h with an amplitude of 0.11 mag is also extracted from the data. This second lightcurve exhibits what appear to be primary and secondary attenuations due to the possible presence of a small companion orbiting the asteroid. The secondary attenuation was well sampled by our data, but not the primary. This renders the derived possible orbital period of the companion as tentative since other nearby periods could also fit the data, which has an overall scatter similar to the derived amplitude. The only other report about 2535 Hämeenlinna found in the literature is from Benishek et al. (2016) in which they report that this asteroid is a binary system where the primary exhibits a rotation period of  $3.23106 \pm 0.00006$  h, the secondary shows a synchronous orbital period of  $21.23 \pm 0.01$  h, and the reported lightcurve amplitude is 0.10 mag.

Using the combined data set, we derived a period of  $3.1186 \pm 0.0001$  h with an amplitude of 0.15 mag. This is in general agreement with the results of  $P = 3.1185 \pm 0.0001$  h and amplitude of 0.18 mag obtained by Pravec et al. (2016), but in slight disagreement with the results of  $P = 3.124 \pm 0.001$  h and

Number	Name	2016 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.	Grp
703	Noemi	10/13-12/07	1104	18.4, 15.0	50	-1	*115.108	0.014	0.28	0.05	FLO
1305	Pongola	04/04-05/13	457	3.2, 12.4	202	2	8.0585	0.0003	0.19	0.02	MBO
2535	Hämeenlinna	02/10-03/04	940	1.9, 12.3	143	-2	2.2311	0.0001	0.11	0.02	FLO
4775	Hansen	08/17-08/23	1511	19.5, 16.4	342	-1	3.1187	0.0001	0.16	0.02	MC
4775	Hansen	10/05-10/10	507	16.7, 18.8	5	12	3.1182	0.0002	0.13	0.02	MC

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009).

\* The rotation period of 703 Noemi is not secured and additional observations are needed to derive its real value.

amplitude of 0.12 mag obtained by Warner (2017). We note that the lightcurve did show some variation in shape and amplitude between the observations performed the third week of August vs. those performed the first week of October. The October data exhibits a noticeable decrease in amplitude, from 0.16 mag to 0.13 mag, suggesting a more pole-on view, as outlined by Warner (2017) from his 2016 November observations.

#### Acknowledgements

The results presented in this report were partially based on observations acquired at the Observatorio Astronómico Nacional on the Sierra de San Pedro Mártir, Baja California, México. Laura Cantú-Sánchez is working on her Master's Degree at the Planetary Astrophysics Program of the Universidad Autónoma de Nuevo León.

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## ASTEROID 4296 VAN WOERKOM: A NEWLY DISCOVERED ASYNCHRONOUS BINARY

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We report that asteroid 4296 van Woerkom is a binary asteroid. Lightcurve analysis for images taken from 2016 November through December reveals a primary rotational period of  $2.80868 \pm 0.00005$  h and a secondary orbital period of  $26.22 \pm 0.01$  h.

Photometric observations of asteroid 4296 van Woerkom were initiated as a part of an astronomy research class taught at Phillips Academy, a high school in Andover, Massachusetts. Students used the CALL website (<http://minorplanet.info/call.html>) to identify asteroids with previously unmeasured periods and favored candidates with high declinations, apparent visual magnitudes between 15 and 17, and appealing names.

The first night of imaging 4296 van Woerkom revealed a short rotation period. Attenuations were noted on Dec 3 and 9. Suspecting a binary asteroid, Odden contacted Brian Warner, who agreed that the asteroid was likely a binary (*private communications*). Pilcher, Klinglesmith, and Benishek joined the observing campaign, and Petr Pravec kindly offered to use his method to analyze the combined observations of 4296 van Woerkom.

Once the approximate orbital period was established, observation windows were selected to correspond with eclipse events. Table 1 lists the equipment used by the various observers.

Observer	Telescope (m)	CCD Camera
Pilcher	0.35 f/10 SCT	STL-1001E
Benishek	0.35 f/6.3 SCT	ST-8XME
Klinglesmith	0.35 f/11 SCT	STL-1001E, ST-10
Odden	0.40 f/8 R-C	Andor Tech iKon DW 436 C

Table 1. Observers and equipment. SCT: Schmidt-Cassegrain Telescope; R-C: Ritchey-Chrétien

Number	Name	2016 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.	TxC
4296	van Woerkom	11/29-12/28	514	20.4,28.7	39.6	5.2	2.80868	0.00005	0.20	0.01	S
	P <sub>ORB</sub>						26.23	0.01	0.12-0.17		

Table II. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984). TxC is the taxonomic class as found in the LCDB (Warner *et al.*, 2009). The second line gives the orbital period and mutual events lightcurve amplitudes.

Images were measured using *MPO Canopus* (Warner, 2010) using a differential photometry technique. Comparison stars were chosen to have near solar color using the Comp Selector tool in *MPO Canopus*. All data were sent to Petr Pravec, who assembled the plots included in this paper using his own method, which solves for the primary and secondary period simultaneously. Students in Odden's research class used the Dual Period search function in *MPO Canopus* to obtain results consistent with Pravec's.

The primary rotation period was determined to be  $2.80868 \pm 0.00005$  h, with amplitude 0.20 mag. The secondary synodic period was determined to be  $26.23 \pm 0.01$  h with amplitudes ranging from 0.12 to 0.17 mag. The sidereal orbital period may be different from the estimated value by about  $\pm 0.02$  h, depending on the system's eclipse/occultation geometry and its evolution during the observational interval. The ratio between the satellite's diameter to the diameter of the primary asteroid is estimated by

$$D_s/D_p = \sqrt{10^{0.4\Delta m} - 1.0}$$

where  $\Delta m$  is the depth of the shallower event. In this case,  $\Delta m$  is approximately 0.12 mag, so  $D_s/D_p = 0.34 \pm 0.02$ . The authors announced this discovery through the CBET 4243 (Odden *et al.*, 2016), published on 2017 Jan 8.

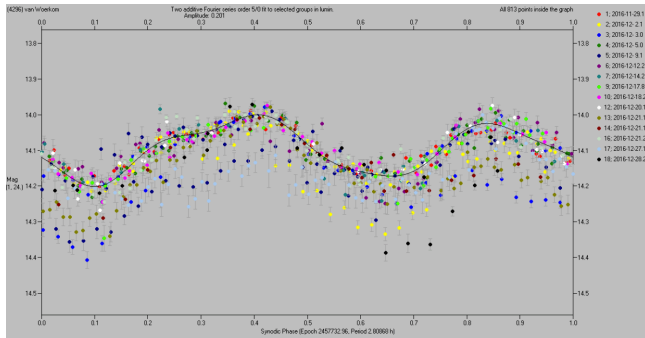


Figure 1. Fifteen sessions folded to the primary rotation period of  $2.80868 \pm 0.00005$  h. Note that several sessions exhibit attenuations, indicating occultations and/or eclipses.

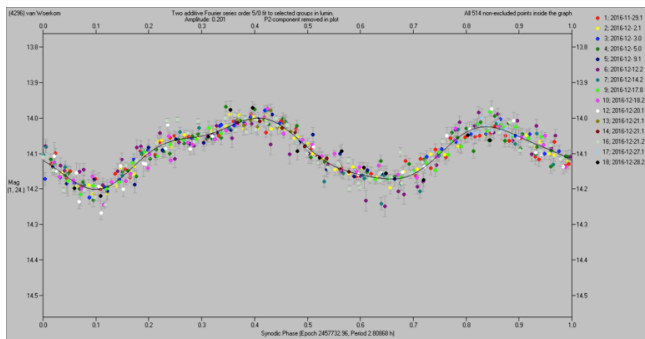


Figure 2. Plot showing the primary rotation curve with period  $2.80868 \pm 0.00005$  h. The secondary period has been removed.

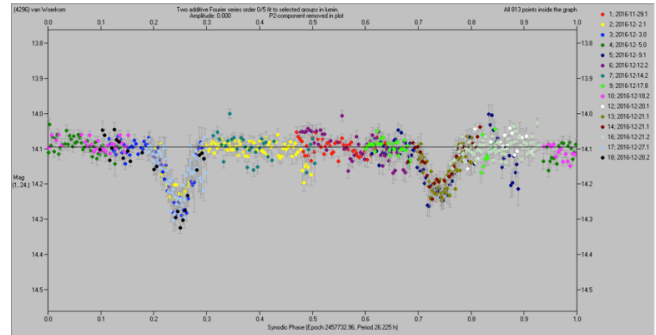


Figure 3. Plot showing the secondary lightcurve with orbital period 26.225 h. The primary period has been removed, making the mutual events evident.

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**CCD ASTEROID PHOTOMETRY  
FROM ETS CORN OBSERVATORY**

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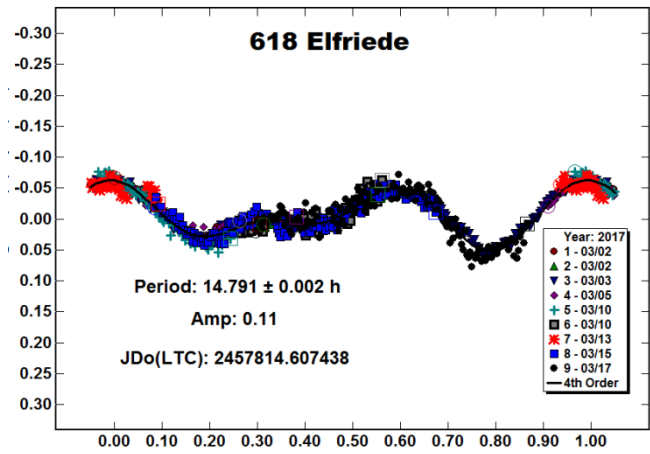
We provide lightcurves for six asteroids from the Spin/Shape Modeling Opportunities listed in the “Lightcurve Photometry Opportunities: 2017 January-March” article by Warner et al. (2017)

The asteroids for which we report results were selected from the list of shape/spin modeling (SSMO) opportunities given by Warner et al. (2017). We selected photometry opportunities based on asteroid brightness.

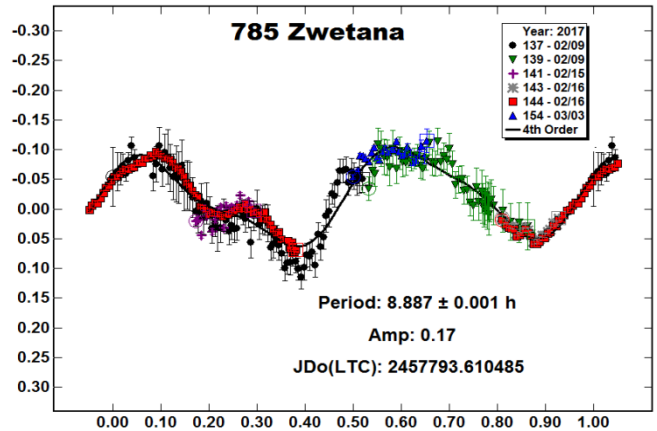
Our observations were obtained with three Celestron 0.35-m telescopes and SBIG CCD cameras at Ets corn Campus Observatory (Klinglesmith and Franco, 2016). The images were processed and calibrated using *MPO Canopus* 10.4.7.6 (Warner, 2015). The exposures were between 180 and 420 seconds through clear filters depending on the brightness of the asteroids. The multi-night data sets for each asteroid were combined with the FALC algorithm (Harris et al., 1989) within *MPO Canopus* to provide synodic periods for each asteroid.

Discovery information was obtained from the JPL small bodies node (JPL, 2017). The six asteroids were suggested as possible targets in order to derive their spin / shape models (Warner et al. 2017). Table I contains the observation circumstances and results. Table II is a compilation of the previously obtained lightcurves with their references.

618 Elfriede is a main-belt asteroid discovered by K. Lohnert at Heidelberg on 1906 Oct 17. It is also known as 1906 VZ. We observed it on seven nights between 2017 Mar 2-17 and obtained a synodic period of  $14.791 \pm 0.002$  h and amplitude of  $0.11 \pm 0.03$  mag.



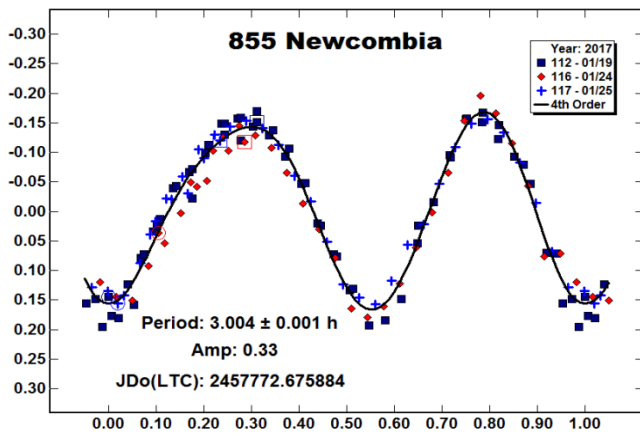
785 Zwetana is a main-belt asteroid discovered by A. Massinger at Heidelberg on 1914 Mar 30. It is also known as 1914 UN. We observed it on four nights between 2017 Feb 9 and Mar 3. We obtained a synodic period of  $8.887 \pm 0.001$  h and amplitude of  $0.17 \pm 0.05$  mag.



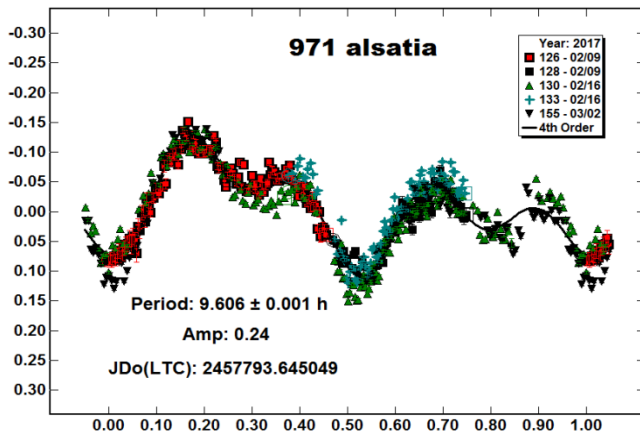
855 Newcombia is a main-belt asteroid discovered by S. Belyavskij on 1916 Apr 3. An independent discovery by 1916 Apr 28 by M. Wolf at Heidelberg was announced first. It is also known as 1916 ZP, 1935 SJ1, and 1938 KB. We observed it on three nights between 2017 Jan 19-25. We obtained a synodic period of  $3.004 \pm 0.001$  h and amplitude of  $0.33 \pm 0.03$  mag.

Number	Name	2017 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.	Grp
618	Elfriede	03/02-03/17	962	5.2, 8.2	156	15	14.791	0.002	0.11	0.03	MB-O
785	Zwetana	02/09-03/03	309	9.0, 16.0	136	16	8.887	0.001	0.17	0.05	EUN
855	Newcombia	01/19-01/25	131	6.8, 8.3	112	14	3.004	0.001	0.33	0.05	MB-I
971	Alsatia	02/09-03/02	971	8.3, 12.2	142	16	9.606	0.001	0.24	0.05	EUN
1152	Pawona	01/08-02/01	1152	8.4, 2.8, 4.3	124	3	3.425	0.001	0.19	0.05	V
1602	Indiana	12/26-02/01	239	24.0, 8.8	143	5	2.601	0.001	0.15	0.03	FLOR

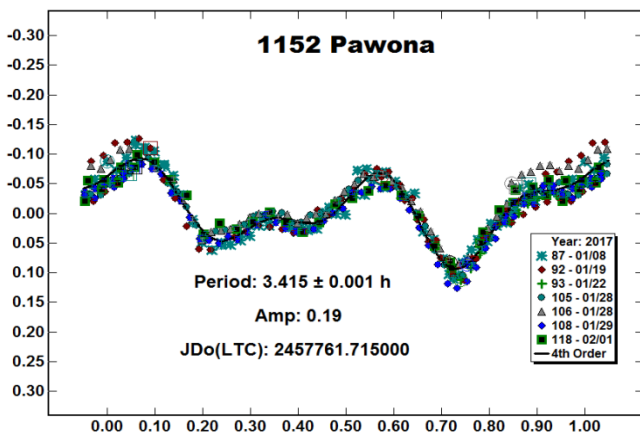
Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009). The initial observations for 1602 were in 2016 December.



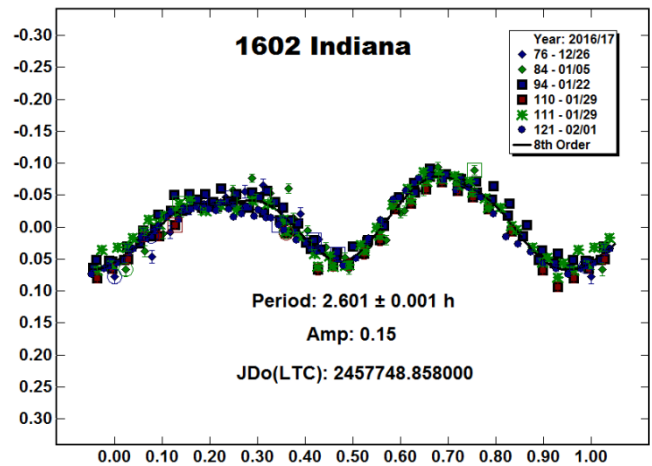
971 Alsatia is a main-belt asteroid discovered by A. Schaumasse at Nice on 1921 Nov 23. It is also known as 1921 LF, 1961 AA, and A908 UE. We observed it on three nights between 2017 Feb 9 and Mar 3. We obtained a synodic period of  $9.906 \pm 0.001$  h and amplitude of  $0.24 \pm 0.05$  mag.



1152 Powona is a main-belt asteroid discovered by K. Reinmuth at Heidelberg on 1930 Jan 8. It is also known as 1930 AD, 1926 AK, 1942 GE1, 1942 GY, 1969 MD, and A924 QA. We observed it on six nights between 2017 Jan 8 and Feb 1. We obtained a synodic period of  $3.415 \pm 0.001$  h and amplitude of  $0.19 \pm 0.05$  mag.



1602 Indiana is a main-belt asteroid discovered by the Indiana Asteroid Program on 1950 Mar 14 at Goethe Link Observatory. It is also known as 1950 GF. We observed it on five nights between 2016 Dec 26 and 2017 Feb 1 and obtained a synodic period of  $2.601 \pm 0.001$  h and amplitude of  $0.15 \pm 0.03$  mag.



#### Acknowledgements

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Number	Name	References	Date	L <sub>PAB</sub>	B <sub>PAB</sub>	Phase	Period	Amp
618	Elfriede	This paper	2017 Mar 10	156	15	6.6	14.7910	0.11
		Warner 2006	2006 May 22	183	19	15.9	14.8010	0.15
		Behrend 2004	2004 Dec 08	119	0	12.8	14.7500	0.17
		Carbo 2009	2008 Sep 09	340	-17	7.1	14.8500	0.12
		Marciniak 2015	2014 Oct 11	9	-21	8.6	14.8000	
		Aznar Macias 2016	2015 Dec 06	92	-8	7.1	14.7950	0.14
785	Zwetana	This paper	2017 Mar 20	139	16	21.7	8.8870	0.17
		Behrend 2005	2005 Apr 23	11	13	8.4	8.8882	0.18
		Shepard 2008	2005 May 11	211	14	18.0	8.8882	0.2
		Warner 2013	2013 Mar 04	156	18	3.5	8.8850	0.18
		Behrend 2015	2015 Oct 31	40	-9	3.5	8.8900	0.16
855	Newcambia	This paper	2017 Jan 22	112	14	7.5	3.0040	0.33
		Cooney 2007	2004 Oct 14	9	-1	5.9	3.0030	0.35
		Klinglesmith 2014	2014 Apr 01	198	0	4.3	3.0030	0.33
		Stephens 2014	2014 Mar 16	197	2	12.9	3.0020	0.41
		Klinglesmith 2016	2015 Nov 09	21	2	11.2	3.0040	0.41
971	Alsatia	This paper	2017 Mar 20	145	16	17.6	9.6060	0.24
		Stephens 2000	2000 Apr 03	167	18	14.3	6.8100	0.17
		Behrend 2005	2005 May 06	237	8	5.8	9.6000	0.21
		Warner 2012	2011 Dec 10	34	-11	20.3	9.6140	0.29
		Melton 2012	2011 Nov 04	31	-14	9.1	9.6100	0.21
1152	Pawona	This paper	2017 Jan 15	124	3	5.1	3.4150	0.19
		Koff 2002	2002 Nov 13	220	-4	3.7	3.4180	0.16
		Behrend 2006	2006 Apr 01	172	-3	10.0	3.4154	0.26
		Behrend 2011	2011 Sep 13	337	1	6.4	3.4150	0.24
1602	Indiana	This paper	2017 Jan 13	142	5	22.1	2.6010	0.15
		Fleenor 2007	2007 Mar 06	165	6	4.0	2.6100	0.12
		Pietschnig 2011web	2007 Apr 02	167	6	15.6	2.5700	0.19
		Vander Haagen 2007	2007 Apr 06	168	6	17.4	2.6010	0.17

Table II: Summation of solar bisector angles, phase angles, periods and amplitudes for the asteroids discussed in this paper.

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## PERIOD DETERMINATION FOR 703 NOEMI

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(Received: 2017 Apr 5)

Collaborative lightcurve photometry observations of main-belt asteroid 703 Noemi were made over 16 nights in 2016 November thru 2017 January. The resulting synodic rotation period is  $200 \pm 1$  h, amplitude  $0.62 \pm 0.10$  mag,  $H_R = 12.24 \pm 0.12$  and  $G_R = 0.16 \pm 0.10$ .

The main-belt asteroid 703 Noemi was discovered on 1910 October 3 by J. Palisa at Vienna. The primary orbital elements are  $a = 2.175$  AU,  $e = 0.138$ , and  $i = 2.46^\circ$ . Its absolute magnitude is  $H = 12.5$  (JPL, 2017). The NEOWISE survey (Nugent et al., 2016) used a value of 12.70 to find a diameter of  $D = 9.85 \pm 1.42$  km. This gives an optical albedo of  $p_V = 0.19 \pm 0.10$ .

CCD photometric observations were made over 16 nights from 2016 November 15 to 2017 January 29 at the Balzaretto Observatory (A81), Fuligni Observatory, and the DSFTA Observatory (DSFTA, 2017) using the instrumentation described in Table I.

Observatory	Telescope, CCD	Exp (s)
Balzaretto (A81)	0.20-m f/5.5 SCT SBIG ST7xme	420
Fuligni (D06)	0.35-m f/10 SCT SBIG ST8-xe	120
DSFTA (K54)	0.30-m f/5.6 MCT SBIG STL-6303e (2x2)	300

Table II. Observing Instrumentation. SCT: Schmidt-Cassegrain Telescope, MCT: Maksutov-Cassegrain Telescope.

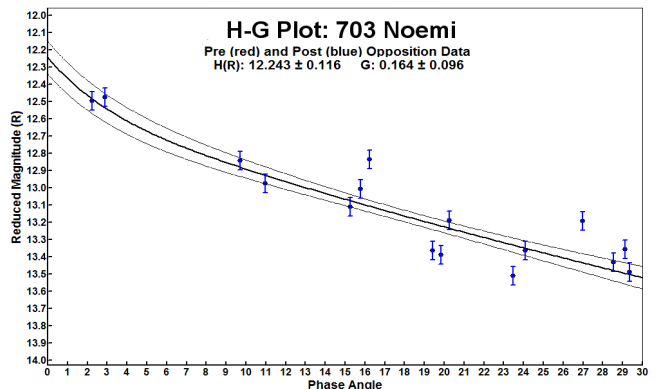
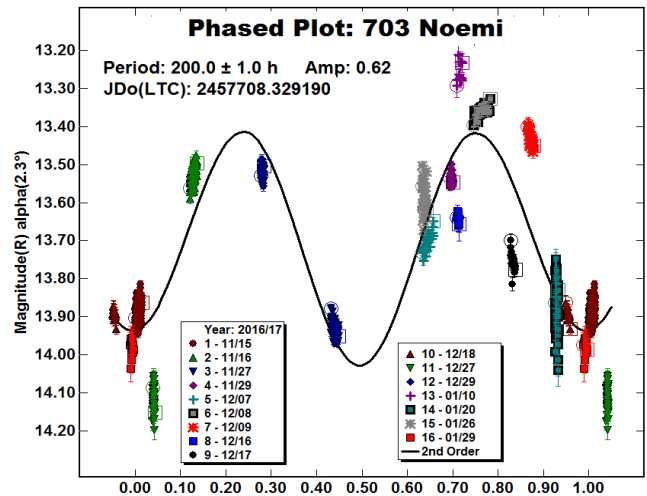
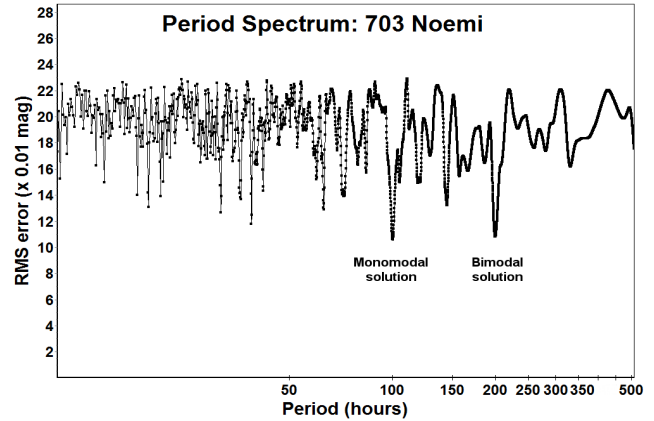
Data processing and analysis were done at the Balzaretto Observatory with *MPO Canopus* (Warner, 2016). All the images, acquired with clear-filter, were calibrated with dark and flat frames and converted to the Cousins-R magnitudes using solar colored field stars from CMC15 catalogue (VizieR, 2014) by the relationship  $R = r' - 0.22$  (Dymock and Miles, 2009). No offset adjustment was applied to the lightcurves. The period analysis shows a bimodal solution for  $P = 200 \pm 1$  hours and amplitude  $A = 0.62 \pm 0.10$  magnitudes.

The absolute magnitude  $H$  (R-band) and slope parameter  $G$  were found using the  $H$ - $G$  Calculator function of *MPO Canopus*. For each lightcurve the average R mag was measured removing the

Number	Name	20xx/mm/dd	Pts	Phase	$L_{PAB}$	$B_{PAB}$	Period(h)	P.E	Amp	A.E.
703	Noemi	16/11/15-17/01/29	724	1.7, 29.3	55	-2	200	1	0.62	0.10

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle values are for the first and last date.  $L_{PAB}$  and  $B_{PAB}$  are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris et al., 1984).

rotational effects, using a Fourier fit model (Buchheim, 2010). We found  $H$  (R-band) =  $12.24 \pm 0.12$  mag,  $G = 0.16 \pm 0.10$ . For 703 Noemi, the taxonomic class and the color index are unknown. We assume it is S-type asteroid, according to SMASSII taxonomic class distribution vs semi-major axis (Bus and Binzel, 2002) with a color index  $V-R = 0.49 \pm 0.05$  (Shevchenko and Lupishko, 1998). We then derive  $H = 12.73 \pm 0.13$ , close to the  $H = 12.7$  listed by Nugent et al. (2016).



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### ROTATION PERIOD DETERMINATION FOR 9671 HEMERA

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(Received: 2017 April 5)

Photometric observations of main-belt asteroid 9671 Hemera were made at the Astronomical Observatory of the University of Siena (Italy) in 2017 March. Analysis of the data revealed a bimodal lightcurve with a synodic period of  $2.532 \pm 0.001$  h as the most likely solution. Some anomalies in the lightcurve suggest that 9671 Hemera could be binary.

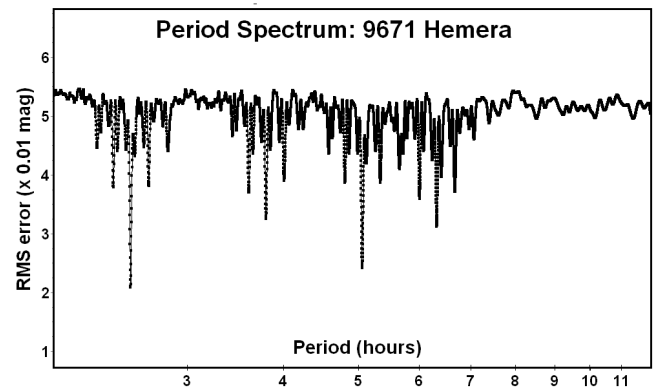
The main-belt asteroid 9671 Hemera was discovered on 1997 October 5 by L. Sarounova at Ondrejov. The Greek goddess of bright day, Hemera, meaning "day" in Greek, gives rise to the word "ephemeris" largely used in astronomy. The primary orbital elements are  $a = 2.691$  AU,  $e = 0.436$ , and  $i = 4.84$  degrees. The absolute magnitude is  $H = 13.9$  (JPL, 2016; MPC, 2016).

CCD photometric observations were carried out in 2017 March at the Astronomical Observatory of the University of Siena (K54) using a 0.30-m  $f/5.6$  Maksutov-Cassegrain telescope, SBIG STL-6303E CCD camera, and clear filter; the pixel scale was 2.30 arcsec in 2x2 binning mode. Exposures were 300 s for all images

(DSFTA, 2016).

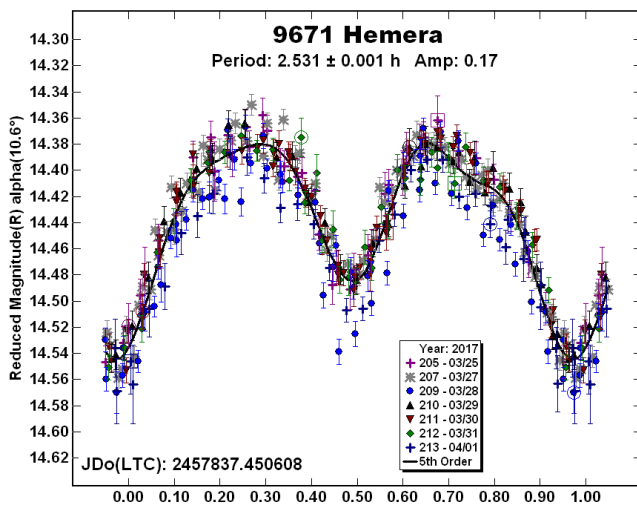
Data processing and analysis were done with *MPO Canopus* (Warner, 2016). All the images were calibrated with dark and flat-field frames and converted to R magnitudes using solar-colored field stars from a version of CMC15 catalogue distributed with *MPO Canopus*. Table I shows the observing circumstances and results. A search of the asteroid lightcurve database (LCDB; Warner et al., 2009) indicates that our results might be the first reported for this object.

Observations of this asteroid were conducted on six nights, collecting a total of 357 data points. The period analysis shows a bimodal solution for  $P = 2.532 \pm 0.001$  h and amplitude  $A = 0.17 \pm 0.01$  mag. During period analysis, we found some attenuation events in the lightcurves that cannot be confirmed with the limited data set. Future observations will be required to verify the possibility of the asteroid being binary.



Number	Name	2016 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E	Amp	A.E.
9671	1997 TU9	03/25-03/31	357	10.5, 6.7	195	-4	2.532	0.001	0.17	0.01

Table I. Observing circumstances. The phase angle ( $\alpha$ ) is given at the start and end of each date range, unless it reached a minimum, which is the second of three values. If a single value is given, the phase angle did not change significantly and the average value is given. L<sub>PAB</sub> and B<sub>PAB</sub> are each the average phase angle bisector longitude and latitude (see Harris *et al.*, 1984).



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Some observing sessions were attended by a group of high school students from Liceo “G. Galilei”, Liceo “E. S. Piccolomini,” and Liceo “Sacro Cuore di Gesù” (Siena) involved in an interesting vocational guidance project about astronomy: A. Anichini, A. Anselmi, G. Artusa, F. Barbucci, M. Bartalini, K. Bartoletti, S. Basili, A. Becchini, M. Brogi, F. Campani, L. Cavaglioni, G. Centini, G. Cessel, T. Corbini, A. Di Cioccio, E. Diciolla, L. Domenichelli, L. Farnetani, F. Faustini, D. Fiorentini, D. Frati, D. Furlani, D. Gabbiai, T. Giorgi, F. Grisanti, C. Hernani, L. Inglesi, S. Lippi, E. Losappio, L. Mannino, A. Palazzolo, M. V. Pennisi, L. Piscitello, G. Polvere, A. Positano, C. Privitera, R. Rossi, M. Salvini, P. Sani, S. Schintu, F. Schwenn, M. Speciale, F. Valentini, C. Venturi, L. Versace, M. Zanda.

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Warner, B.D. (2016). MPO Software, *MPO Canopus* v10.7.7.0. Bdw Publishing. <http://minorplanetobserver.com>

## ROTATION PERIOD DETERMINATIONS FOR 49 PALES, 96 AEGLE, 106 DIONE, 375 URSULA, AND 576 EMANUELA

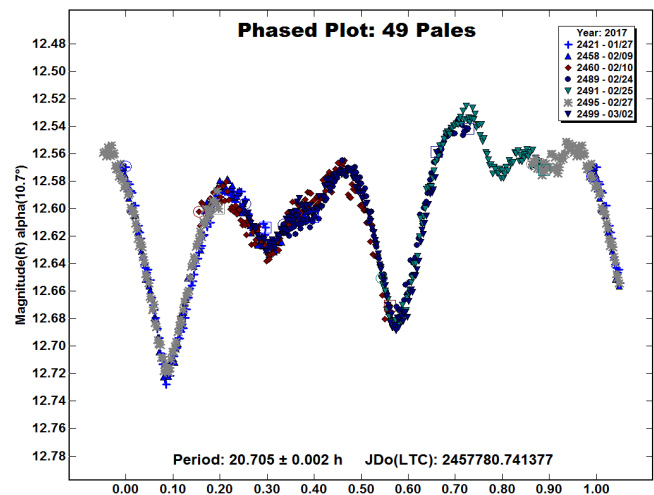
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Synodic rotation periods and amplitudes are found for 49 Pales:  $20.705 \pm 0.002$  h,  $0.18 \pm 0.01$  mag with 4 maxima and minima per cycle; 96 Aegle:  $13.868 \pm 0.001$  h,  $0.11 \pm 0.01$  mag; 106 Dione:  $16.210 \pm 0.001$  h,  $0.18 \pm 0.01$  mag; 375 Ursula:  $16.899 \pm 0.001$  h,  $0.11 \pm 0.01$  mag. All of these objects have irregular lightcurves. For 576 Emanuela the period is  $40.812 \pm 0.004$  h, amplitude is  $0.13 \pm 0.01$  mag with a slightly asymmetric bimodal lightcurve.

Observations to obtain the data used in this paper were made at the Organ Mesa Observatory with a 0.35-meter Meade LX200 GPS Schmidt-Cassegrain (SCT) and SBIG STL-1001E CCD. Exposures were 60 seconds, unguided, with a clear filter. Photometric measurement and lightcurve construction was with *MPO Canopus* software. To reduce the number of points on the lightcurves and make them easier to read, data points were binned in sets of 3 with a maximum time difference of 5 minutes.

**49 Pales.** Two early published rotation periods were by Schober (1979, 10.42 hours) and by Tedesco (1979, 10.3 hours). For many years the period was believed to be near 10.4 hours. Behrend (2013) published a very sparse lightcurve which suggested  $P < 10$  h.



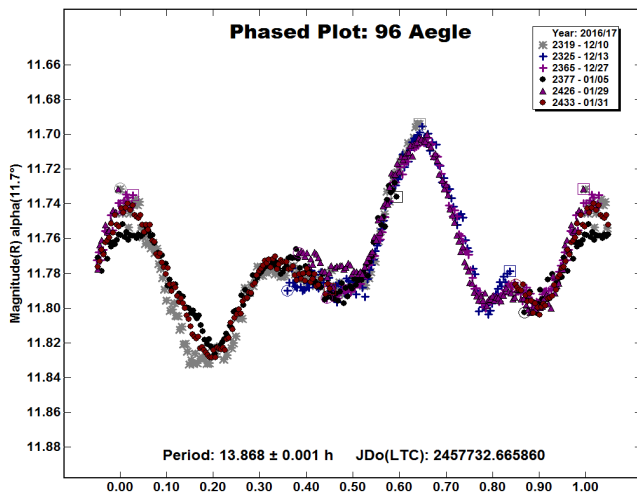
Pilcher et al. (2016) made a comprehensive investigation that found a period 20.704 h with an asymmetric quadramodal lightcurve. Behrend (2016) complemented this study with a period 20.7057 h.

The latest study confirms Pilcher et al. (2016) and Behrend (2016). Observations on seven nights from 2017 Jan 27 to Mar 2 provide a good fit to a period of  $20.705 \pm 0.002$  h, again with an irregular quadramodal lightcurve, and amplitude  $0.18 \pm 0.01$  mag.

Number	Name	20yy/mm/dd	Pts	Phase	LPAB	BPAB	Period(h)	P.E	Amp	A.E.
49	Pales	17/01/27-17/03/02	2533	10.7, 1.2	160	-3	20.705	0.002	0.18	0.01
96	Aegle	16/12/10-17/01/31	2516	11.6, 5.0, 10.8	106	12	13.868	0.001	0.11	0.01
106	Dione	17/01/09-17/02/16	2483	9.3, 4.7, 4.9	135	5	16.210	0.001	0.18	0.02
375	Ursula	16/12/11-17/02/07	2498	11.2, 5.0, 9.0	113	13	16.899	0.001	0.11	0.01
576	Emanuela	17/02/17-17/04/04	3493	11.2, 3.8, 5.3	184	-11	40.812	0.004	0.13	0.01

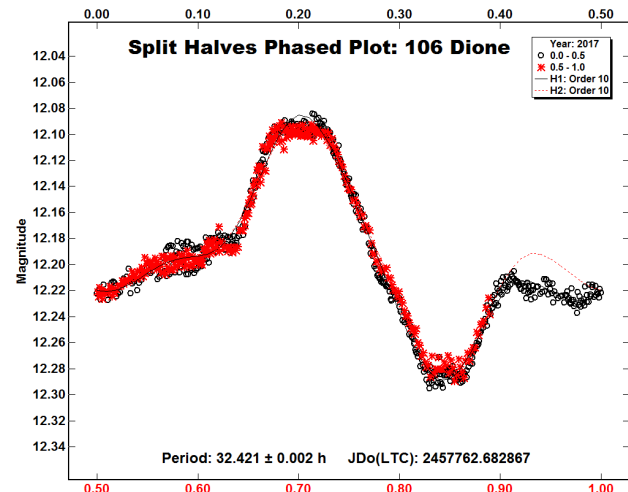
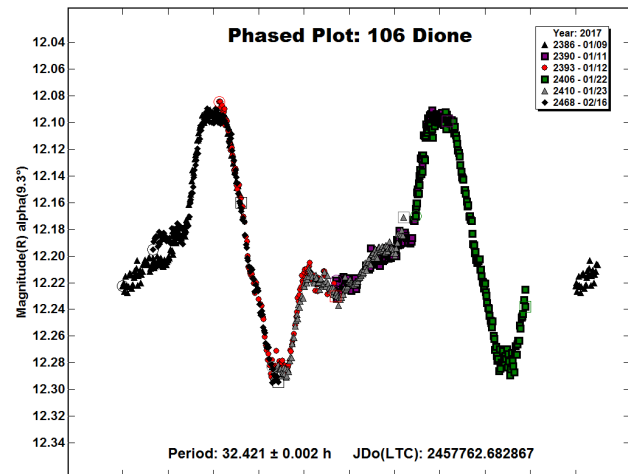
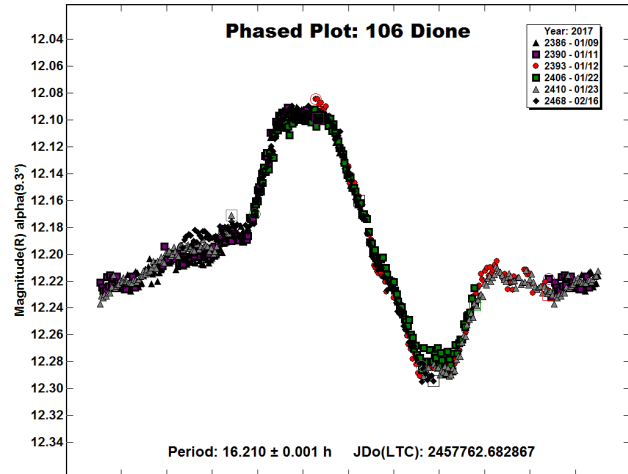
Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date, unless a minimum (second value) was reached. LPAB and BPAB are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984).

**96 Aegle.** Previous rotation period determinations are by Harris and Young (1989, 10 h), Blanco *et al.* (2000, 10.470 h), Slivan and Roller (2001, 26.53 h), Behrend (2004, 13.82 h), Behrend (2005, 13.82 h), and Stephens (2005, 13.82 h). New observations on six nights from 2016 Dec 10 to 2017 Jan 31 provide a good fit to a lightcurve with period  $13.868 \pm 0.001$  h, amplitude  $0.11 \pm 0.01$  mag. This is in good agreement with Behrend (2004, 2005) and Stephens (2005).



Asteroid lightcurves change in shape and amplitude if observations are continued over a considerable range of phase angles. Between phases 0.0 and 0.2 in the lightcurve of 96 Aegle, these changes are especially prominent. The largest amplitude occurs for the session with the largest phase angle (#2319, 2016 Dec 10, 11.9°). The smallest amplitude occurs for the session with the smallest phase angle (#2377, 2017 Jan 6, 5.0°). Session 2433 (2017 Jan 31, 10.8°) has a lightcurve intermediate between the two extremes.

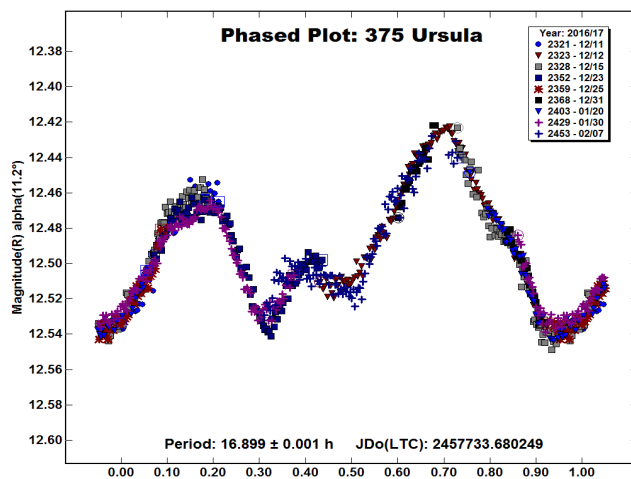
**106 Dione.** Previous period determinations are by Harris *et al.* (1992, 15 h) and by Pray (2005, 16.26 h) with a somewhat asymmetric bimodal lightcurve. New observations on six nights from 2017 Jan 9 to Feb 16 provide a good fit to a lightcurve with period  $16.210 \pm 0.001$  h, amplitude  $0.18 \pm 0.02$  mag, and a very unusual shape.



The lightcurve has a single very high maximum, a single very deep minimum, and half of the lightcurve is nearly flat. When plotted to the double period, a small part of the lightcurve is not covered by the data. However, the two sides of the lightcurve including the maximum and minimum are repeated almost identically and separated by phase 0.50.

The double-period would imply a shape that is both very irregular and is highly symmetric about a 180 degree rotation. Such a shape for a real asteroid is extremely unlikely and so the double-period may be safely rejected. A split halves plot is also included, in which the data points on two sides of the double-period plot precisely overlap. The tenth order Fourier fit curves are identical except for the incomplete segment. Here the difference is a mathematical construct not relevant to the rotational behavior of the target. With these considerations the double-period may be safely rejected. The agreement with Pray (2005) is good.

**375 Ursula.** Previously published period determinations are by Schober (1987, 16.83 h), Harris et al. (1999, 16.900 h), and Hamanowa and Hamanowa (2011, 16.78 h). New observations on nine nights from 2016 Dec 11 to 2017 Feb 7 provide a good fit to a much denser than previously published lightcurve with period of  $16.899 \pm 0.001$  h, amplitude  $0.11 \pm 0.01$  mag. The period is consistent with Harris et al. (1999), and slightly greater than Schober (1987) and Hamanowa and Hamanowa (2011).



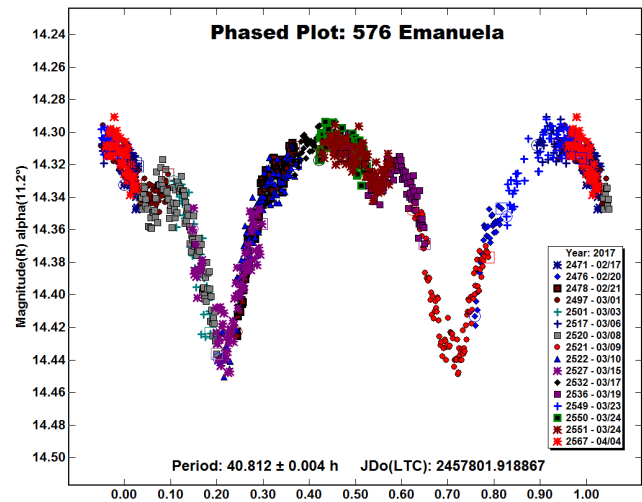
**576 Emanuela.** Previously published periods, all very uncertain and based on fragmentary lightcurves, are by Wetterer et al. (1999, < 26 h), Behrend (2003, 2014; 14 hours), and Pray (2003, 8.192 h). New observations on 16 nights from 2017 Feb 17 to Apr 4 provide a good fit to a dense lightcurve with a period of  $40.812 \pm 0.004$  h, amplitude  $0.13 \pm 0.01$  mag. This result rules out all other published periods.

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**LIGHTCURVE ANALYSIS OF TROJAN ASTEROIDS AT  
THE CENTER FOR SOLAR SYSTEM STUDIES  
2017 JANUARY - MARCH**

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(Received: 2017 April 12)

Lightcurves for 18 Jovian Trojan asteroids were obtained at the Center for Solar System Studies (CS3) from 2017 January to March.

CCD Photometric observations of 18 Trojan asteroids from the L<sub>5</sub> (Trojan) Lagrange point were obtained at the Center for Solar System Studies (CS3, MPC U81). For several years, CS3 has been conducting a study of Jovian Trojan asteroids. This is another in a series of papers reporting data being accumulated for family pole and shape model studies. It is anticipated that for most Jovian Trojans, two to five dense lightcurves per target at oppositions well distributed in ecliptic longitudes will be needed and can be supplemented with reliable sparse data for the brighter Trojan asteroids. For most of these targets, we were able to get preliminary pole positions and create shape models from sparse data and the dense lightcurves obtained to date. These preliminary models will be improved as more data are acquired at future oppositions and will be published at a later date.

Table 1 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.

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). Night-to-night calibration (generally  $\leq \pm 0.05$  mag) was done using field stars from the CMC-15 catalog or APASS (Henden *et al.*, 2009). The Comp Star Selector feature in *MPO Canopus* was used to limit the comparison stars to near solar color.

In the lightcurve plots, the “Reduced Magnitude” is Johnson V corrected to a unity distance by applying  $-5 \cdot \log(r\Delta)$  to the measured sky magnitudes with  $r$  and  $\Delta$  being, respectively, the Sun-asteroid and the Earth-asteroid distances in AU. The magnitudes were normalized to the phase angle given in parentheses using  $G = 0.15$ . The X-axis rotational phase ranges from -0.05 to 1.05.

Telescope	Camera
0.40-m F/10 Schmidt-Cass	FLI Proline 1001E
0.35-m F/11 Schmidt-Cass	FLI Microline 1001E
0.35-m F/10 Schmidt-Cass	FLI Proline 1001E
0.35-m F/10 Schmidt-Cass	SBIG STL-1001E

Table 1. List of telescopes and CCD cameras used at CS3.

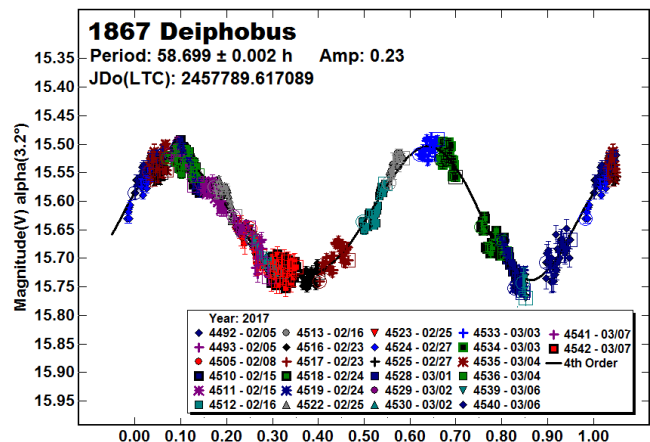
The amplitude indicated in the plots (e.g. Amp. 0.23) is the amplitude of the Fourier model curve and not necessarily the adopted amplitude of the lightcurve.

Targets were selected for this L<sub>5</sub> observing campaign based upon the availability of dense lightcurves acquired in previous years. We obtained 2 to 4 lightcurves for most of these Trojans at previous oppositions, and some data were found from the Palomar Transient Factory, Waszczak *et al.*, (2015).

For brevity, only some of the previously reported rotational periods may be referenced. A complete list is available at the lightcurve database (LCDB; Warner *et al.*, 2009).

To evaluate the quality of the data obtained to determine how much more data might be needed, preliminary pole and shape models were created for all of these targets that will be published at a later date. Sparse data observations were obtained from the Catalina Sky Survey and USNO-Flagstaff survey using the AstDyS-3 site (<http://hamilton.dm.unipi.it/asdys2/>). This sparse data was combined with our dense data as well as any other dense data found in the Asteroid Lightcurve Database (<http://www.alcdef.org/>) using *MPO LCInvert*, (Bdw Publishing) a Windows-based program that incorporates the algorithms developed by Kassalain *et al* (2001a, 2001b) and converted by Josef Durech from the original FORTRAN to C. A period search was made over a sufficiently wide range to assure finding a global minimum in  $\chi^2$  values.

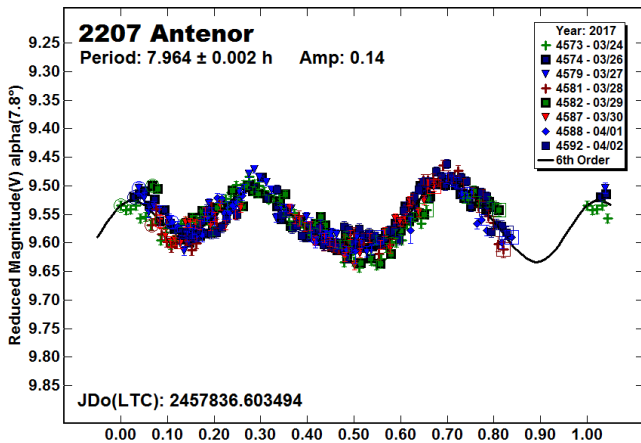
1867 Deiphobus. This large Trojan has been well studied over the years. Mottola *et al.*, (2011), French *et al.*, (1987, 2012), and Stephens *et al.*, (2016b) each found synodic rotational periods near 58.6 h. The result found this year is in good agreement.



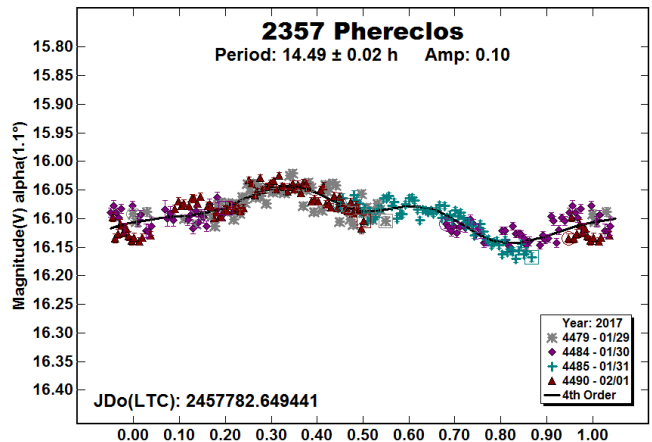
Number	Name	2017 mm/dd	Pts	Phase	LPAB	BPAB	Period	P.E.	Amp	A.E.	Grp
1867	Deiphobus	02/05-03/07	651	3.2, 7.5	128	-14	58.699	0.002	0.23	0.03	TR-J
2207	Antenor	03/24-04/02	373	7.8, 9.0	144	-1	7.964	0.002	0.14	0.02	TR-J
2357	Phereclos	01/29-02/01	266	1.2, 0.6	135	-2	14.49	0.02	0.10	0.02	TR-J
2674	Pandarus	03/28-04/04	272	10.1, 10.7	128	-1	8.47	0.002	0.63	0.02	TR-J
2895	Memnon	01/29-02/01	216	3.0, 2.4	143	5	7.52	0.01	0.14	0.02	TR-J
3317	Paris	01/06-01/17	181	4.6, 2.7	132	-3	7.091	0.002	0.11	0.02	TR-J
3451	Mentor	01/29-02/01	216	5.3, 4.8	154	-13	7.702	0.002	0.46	0.02	TR-J
4348	Poulydamas	02/05-02/16	176	1.8, 1.7, 2	139	-9	9.922	0.002	0.34	0.02	TR-J
4707	Khryses	02/23-03/01	119	0.9, 2.0	151	-3	6.862	0.002	0.41	0.02	TR-J
4709	Ennomos	01/29-03/03	267	6.4, 5.4, 5	151	-27	12.269	0.001	0.43	0.02	TR-J
4715	1989 TS1	02/23-02/25	212	4.5, 28.5	165	8	8.846	0.004	0.5	0.02	TR-J
4867	Polites	01/18-01/28	197	4.7, 3.0	139	10	11.242	0.006	0.14	0.02	TR-J
11089	1994 CS8	02/23-03/27	149	9.5, 11.3	102	-2	7.729	0.001	0.54	0.02	TR-J
15502	1999 NV27	01/17-01/28	340	1.0, 0.8, 1	120	3	15.129	0.002	0.26	0.02	TR-J
16070	1999 RB101	03/12-03/27	343	6.7, 8.5	133	-5	*20.205	0.015	0.13	0.03	TR-J
24451	2000 QS104	03/09-04/06	153	6.0, 8.7	140	21	17.06	0.01	0.17	0.03	TR-J
30705	Idaios	02/27-03/07	149	7.8, 8.7	120	21	15.699	0.002	0.45	0.02	TR-J
76867	2000 YM5	03/12-03/19	192	9.2, 9.7	125	31	9.085	0.005	0.44	0.03	TR-J

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle values are for the first and last date. LPAB and BPAB are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009). \*Persistent low amplitude multi-modal lightcurves over three oppositions suggests an alias could be the true period.

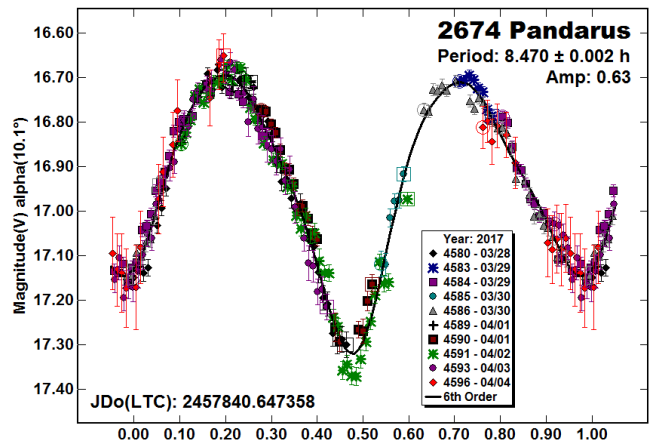
2207 Antenor. The synodic period found using CS3 data from 2017 for this large Trojan is in good agreement with previous results (Mottola et al., 2011, Stephens et al., 2016b, Waszczak et al., (2015).



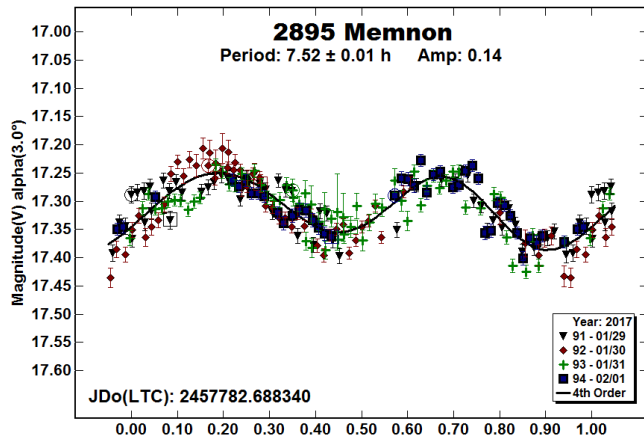
2357 Phereclos. The synodic period found this year produced a low amplitude, single extrema lightcurve with a similar rotational period to those found in previous years (Mottola et al., Stephens et al., 2016b).



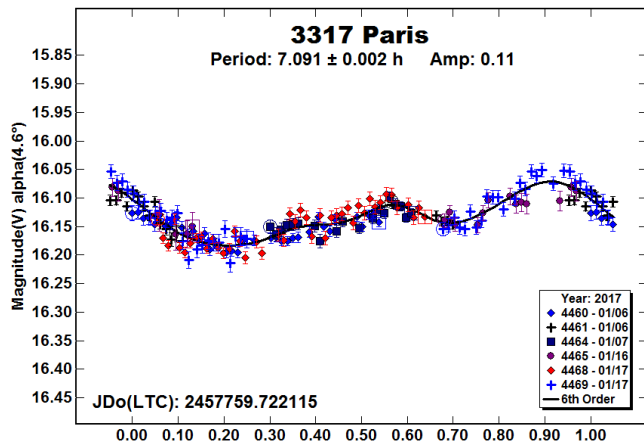
2674 Pandarus. We previously found the synodic period to be about 8.48 h (French 1987, Stephens et al., 2016b), in good agreement with this result.



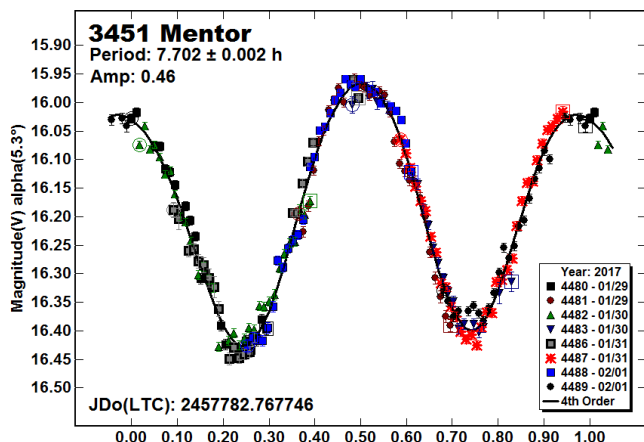
2895 Memnon. The synodic period we found this year agrees with previous synodic results (Benzel *et al.*, 1992, Mottola *et al.*, 2011, French 2011a, Stephens *et al.*, 2015, 2016a).



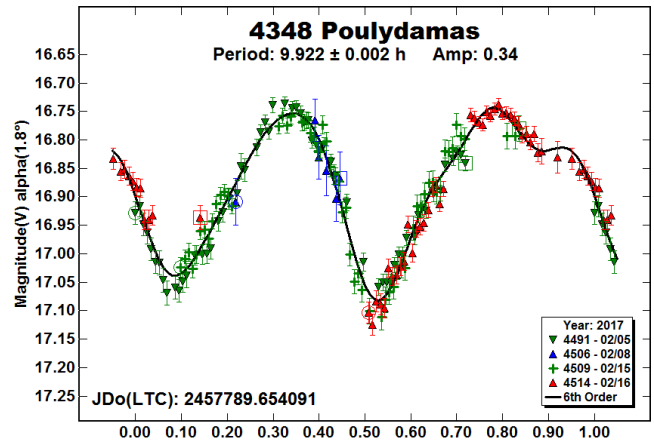
3317 Paris. Mottola *et al.*, (2011) and Behrend (2008 and 2009) each found a synodic rotational period of 7.082 h. We observed it last year (Stephens *et al* 2016b) finding a synodic rotational period of 7.048 h. The result this year showed a low amplitude lightcurve in good agreement with those prior results.



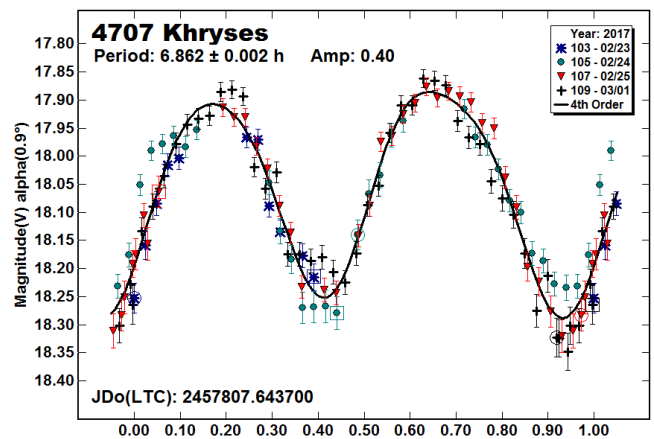
3451 Mentor. Mentor has been observed many times in the past (Behrend 2006, 2008, 2009, 2010, Mottola *et al.*, 2011, French *et al.*, 2011, Stephens *et al.*, 2014 and 2016b, and Waszczak *et al.*, 2015) each time finding a rotational period near 7.7 h. This year's result is in good agreement with those previous findings.



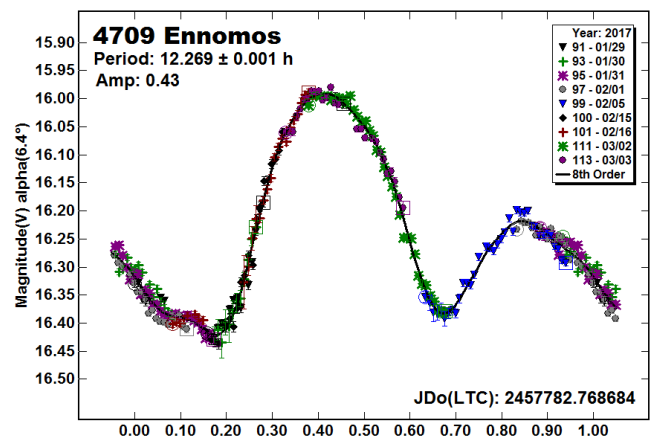
4348 Poulydamas. Rotational periods have been determined four times in the past (Mottola *et al.*, 2011, Stephens *et al.*, 2015 and 2016b, and Waszczak *et al.*, 2015) each time finding a synodic period near 9.9 h. This year's result is in good agreement.



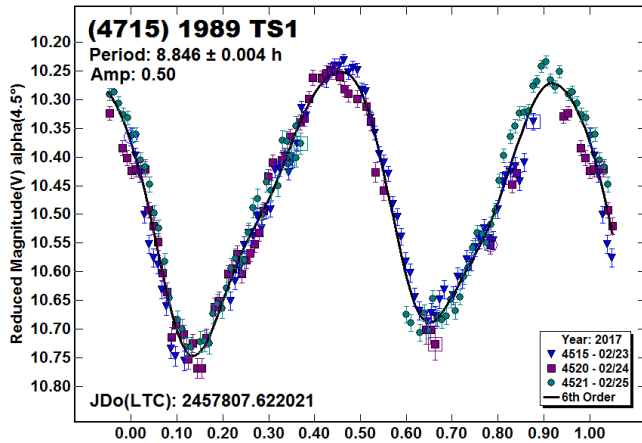
4707 Khryses. We observed this Trojan three times in the past (Stephens *et al.*, 2014 and 2015), each time finding a synodic rotational period near 6.86 h. The results this year are similar to those prior periods.



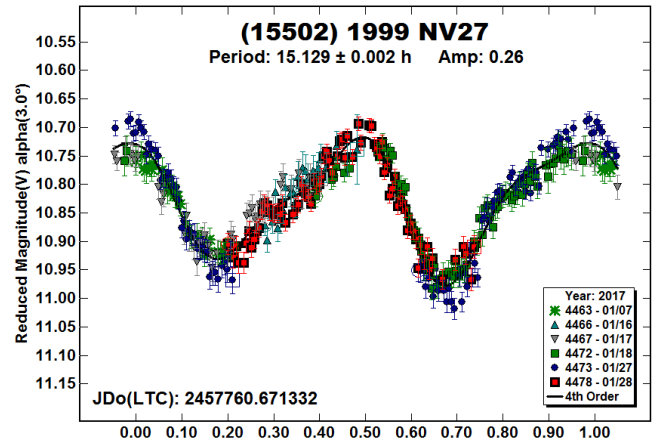
4709 Ennomos. This member of the L<sub>5</sub> Trojan cloud has been observed several times in past (French *et al.*, 2012, Mottola *et al.*, Stephens *et al.*, 2016a, 2016b) with each result near 12.27 h. The period found at this opposition agreed with those results.



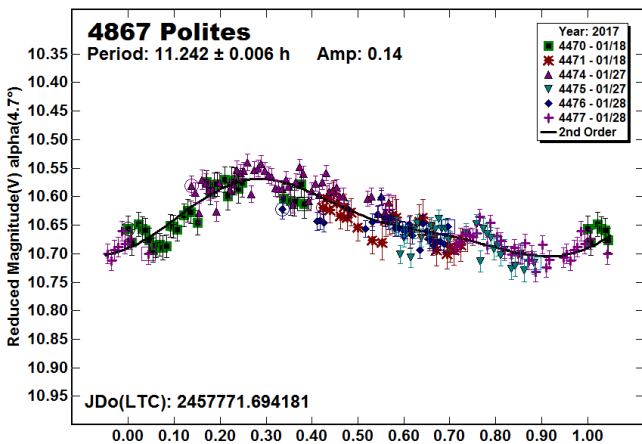
(4715) 1989 TS1. This Trojan previously had its rotational period measured four times (Mottola *et al.*, 2011, Stephens *et al.*, 2015 and 2016b, and Waszczak *et al.*, 2015) with all synodic periods near 8.8 h. This year's synodic rotational period is a little longer, but in good agreement with those prior findings.



15502 1999 NV27. We determine the synodic rotational period of this L<sub>5</sub> Trojan four times in the past (French *et al.*, 2013, Stephens *et al.*, 2014, 2015, 2016a) all with synodic periods near 15.1 h. The lightcurve created this year has the classic bimodal shape with a 15.129 h synodic period.

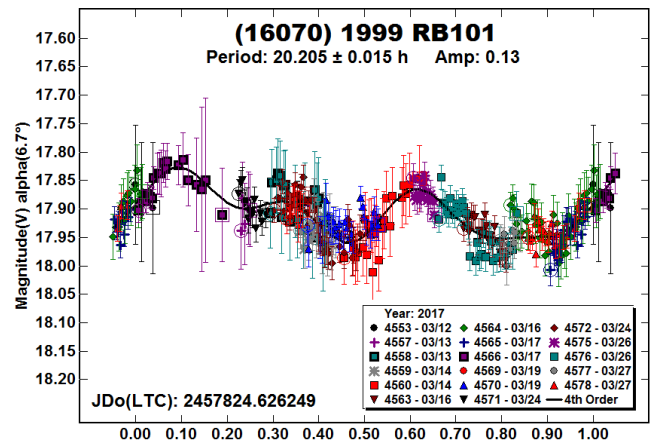
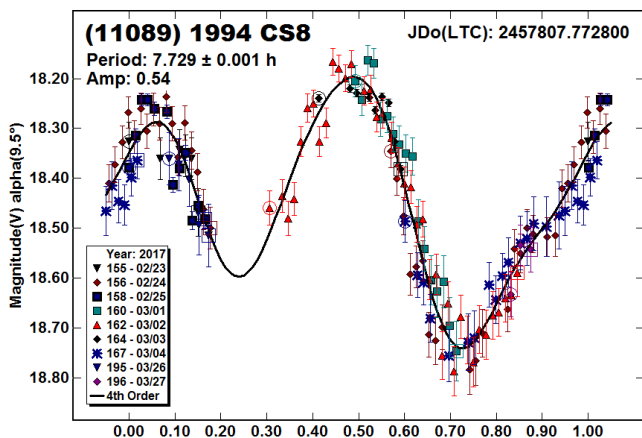


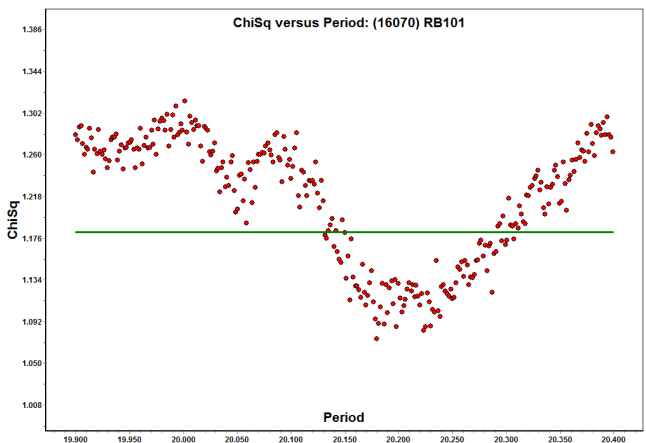
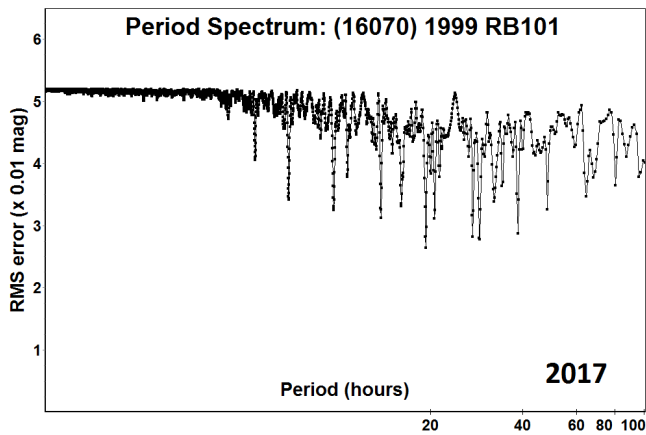
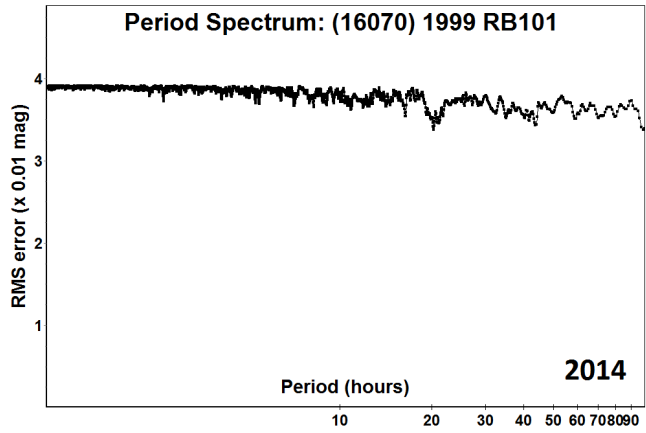
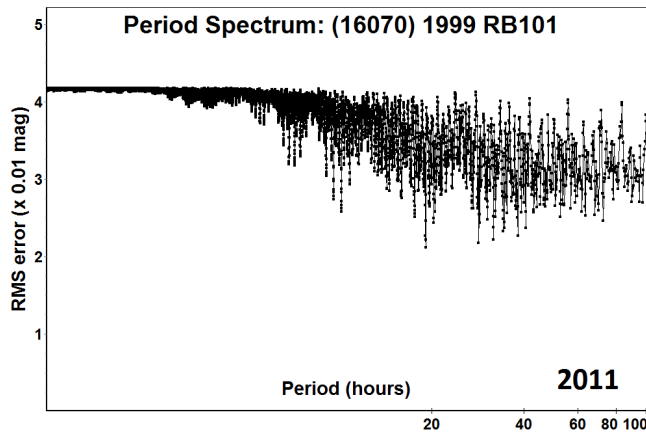
4867 Polites. We observed Polites four times in the past (French *et al.*, 2011, Stephens *et al.*, 2014, 2015, 2016b) finding synodic periods near 11.24 h. This year's observations resulted in a low amplitude single extrema lightcurve which was a good match for the rotational frequency we previously found.



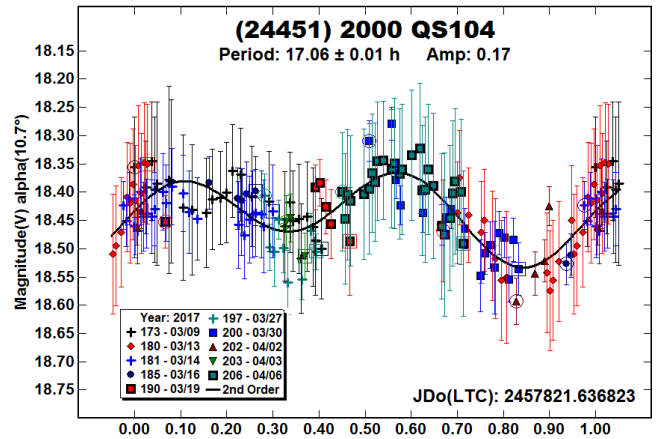
(16070) 1999 RB101. This Trojan has been a difficult case over the years as it always seems to be low amplitude. We observed it twice in the past, first in 2011 (French *et al.*, 2012) finding a synodic period of 31.74 h. In 2015, we observed it again finding a synodic period of 20.27 h while creating a low amplitude single-modal lightcurve (Stephens *et al.*, 2016a). At that time, we were able to determine that the 2011 data would fit a synodic rotational period of 20.24 h which was an alias of the original result. In 2017, we again found a low amplitude lightcurve with a best fit synodic period of 20.205 h. However, the short runs each night and shape of the lightcurve does not by itself present a convincing case. While examining the Period Spectrum for each year suggests that 20.2 h is the most likely period, there are several aliases present and minor zero point adjustments could make a difference. Likewise, combining the data from these oppositions with available sparse data did not produce a convincing sidereal period. The range used to find a global minimum in  $\chi^2$  values was 0.5 hours. Experience suggests that future effort should be made to acquire better quality data rather than allocating computing time to expand the period range covering nearby possible aliases.

(11089) 1994 CS8. We observed this Trojan three times before (Stephens *et al.*, 2014, 2015, 2016a) each time finding a synodic rotational period of 7.72 h. This year's result was in agreement.

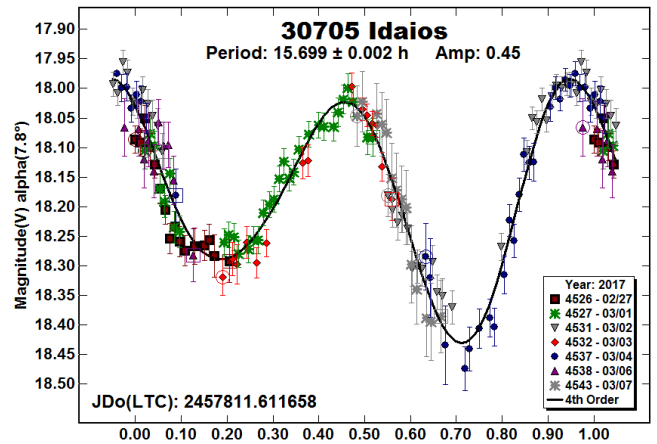




(24451) 2000 QS104. Determining the rotational of this Trojan also proved to be a difficult case. We observed it twice before (French *et al.*, 2012, Stephens *et al.*, 2014). In 2012, we initially found a synodic period of 40.68 h which proved to be a fit-by-exclusion. There was almost no overlap of data for the six nights of observations. In 2013, we observed it again finding a rotational period of 17.18 h with a classic bimodal lightcurve with an amplitude of 0.16 mag. Rephasing the 2012 data to that period created a single modal lightcurve with an amplitude of just 0.05 magnitude. Our 2017 observations had a larger amplitude of 0.17 mag. but the data was noisier than the data acquired in 2013 and resulted in a synodic rotational period of 17.06 h.



30705 Idaios. This L<sub>5</sub> Trojan was observed three times in the past (Stephens *et al.*, 2014 and 2015, and Waszczak *et al.*, 2015) each time reporting a synodic rotational period near 15.7 h. Our result this year is in good agreement with past results.



Acknowledgements

This research was supported by NASA grant NNX13AP56G. Work on the asteroid lightcurve database (LCDB) was also funded in part by National Science Foundation grants AST-1210099 and AST-1507535. This research was made possible in part based on data from CMC15 Data Access Service at CAB (INTA-CSIC) (<http://svo2.cab.inta-csic.es/vocats/cmc15/>) and through the use of the AAVSO Photometric All-Sky Survey (APASS), funded by the Robert Martin Ayers Sciences Fund. The purchase of two FLI-1001E CCD cameras was made possible by 2013 and 2015 Gene Shoemaker NEO Grants from the Planetary Society.

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**ASTEROIDS OBSERVED FROM CS3:  
2017 JANUARY - MARCH**

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(Received: 2017 April 12)

CCD photometric observations of two Hungaria asteroids were obtained from the Center for Solar System Studies from 2017 January to March.

The Center for Solar System Studies "Trojan Station" (CS3, MPC U81) has two telescopes that are normally used in a of program asteroid family studies. When those targets are too dim to continue observations during bright moon times, brighter targets suitable for future shape modeling studies are selected to keep the telescopes operating. Two asteroids with known short rotational periods were selected for observations in the week nearest the full moon.

All images were made with a 0.4-m or a 0.35-m SCT using an FLI ML-Proline 1001E or FLI ML-Microline 1001E CCD camera. Images were unbinned with no filter and had master flats and darks applied. 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). Night-to-night calibration (generally  $< \pm 0.05$  mag) was done using field stars from the CMC-15 catalog or APASS (Henden et al., 2009) The Comp Star Selector feature in *MPO Canopus* was used to limit the comparison stars to near solar color.

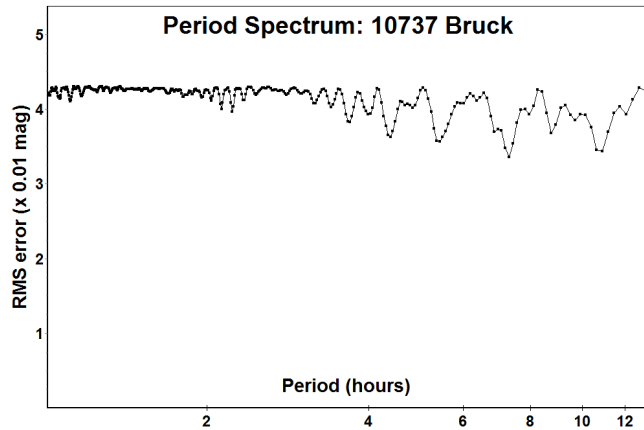
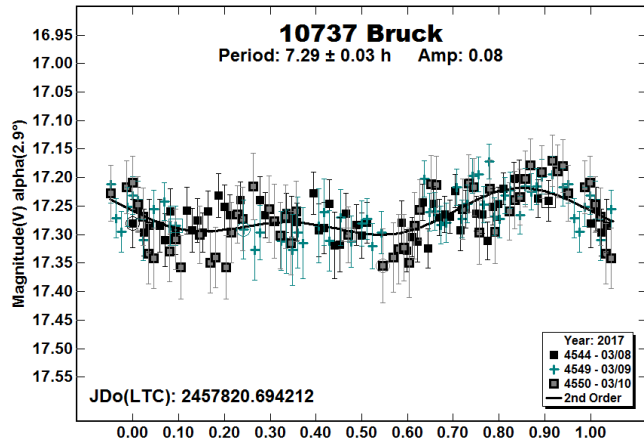
In the lightcurve plots, the "Reduced Magnitude" is Johnson V corrected to a unity distance by applying  $-5 \cdot \log(r\Delta)$  to the measured sky magnitudes with  $r$  and  $\Delta$  being, respectively, the Sun-asteroid and the Earth-asteroid distances in AU. The magnitudes were normalized to the phase angle given in parentheses using  $G = 0.15$ . The X-axis ranges from  $-0.05$  to  $1.05$  rotation phase. The amplitude indicated in the plots is the amplitude of the Fourier model curve and not necessarily the adopted amplitude of the lightcurve.

10737 Bruck, Warner (2016) reported a rotational period of 3.22 h for this Hungaria with a shallow amplitude of 0.08 mag. The result found this year could not be made to agree with the Warner period, possibly as a result of the noisiness of the data acquired at the time of the full moon. Adding further complexity, with an

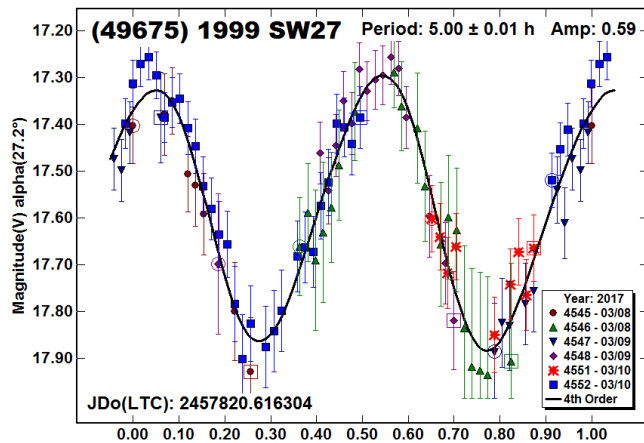
Number	Name	2017 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.	Grp
10737	Bruck	03/08-03/10	155	2.9,2.2	170	-3	7.29	0.03	0.08	0.03	H
49675	1999 SW27	03/08-03/10	95	38.2,38.5	167	49	5.00	0.01	0.59	0.03	H

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984). Grp is the asteroid family/group (Warner *et al.*, 2009); H = Hungaria.

amplitude of around 0.08 magnitudes, it is possible that the lightcurve could have only a single extremum, or three or more extrema (Harris *et al.*, 2014). This asteroid will not be well placed again for Northern Hemisphere observers until 2020 June.



(49675) 1999 SW27. We have studied this Hungaria in the past as part of a Hungaria family pole position study. Warner (2011;2014) and Waszczak *et al.*, (2015) previously found periods of about 5.0 h. The result this year is in agreement with the earlier findings.



Acknowledgements

This research was supported by NASA grant NNX13AP56G and was made possible in part based on data from CMC15 Data Access Service at CAB (INTA-CSIC) (<http://svo2.cab.inta-csic.es/vocacs/cmcl5/>). The purchase of a FLI-1001E CCD cameras was made possible by a 2013 Gene Shoemaker NEO Grants from the Planetary Society.

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**PHOTOMETRIC OBSERVATIONS OF ASTEROIDS  
4742 CALIUMI, 5267 ZEGMOTT, (18429) 1994 AO1,  
(26421) 1999 XP113, AND (27675) 1981 CH**

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(Received: 2017 April 10)

CCD photometric observations conducted from the George West ISD Mobile Observatory of asteroids 4742 Caliumi, 5267 Zegmott, (18429) 1994 AO1, (26421) 1999 XP113, and (27675) 1981 CH are described. This represents the research results for the 2016-17 school year. Analysis of our data found the synodic period and lightcurve amplitudes for each asteroid: 4742 Caliumi,  $5.475 \pm 0.005$  h, 0.80 mag; 5267 Zegmott  $5.209$  h  $\pm$  0.002 h, 0.32 mag; (18429) 1994 AO1,  $3.911 \pm 0.002$  h, 0.23 mag; (26421) 1999 XP113,  $4.320 \pm 0.005$  h, 0.23 mag; and (27675) 1981 CH,  $3.085 \pm 0.002$  h, 0.13 mag.

The photometric observations described in this paper were conducted from the George West ISD Mobile Observatory, which is located at a dark sky site 19 kilometers south of George West, Texas. This research was conducted as part of an educational program of the George West Independent School District.

The research was conducted using a Meade 0.35-m LX600 Schmidt-Cassegrain telescope (SCT) fitted with an SBIG STF-402M thermoelectrically cooled CCD camera. The telescope is housed within a converted eight by sixteen foot Wells Cargo trailer with a hinged roof that sits upon concrete blocks supported by a thick concrete slab to minimize vibrations. The photometric exposures ranged from 60 to 90 seconds. The raw science images were dark subtracted and flat fielded. To obtain the highest possible SNR, no filters were used during the observations.

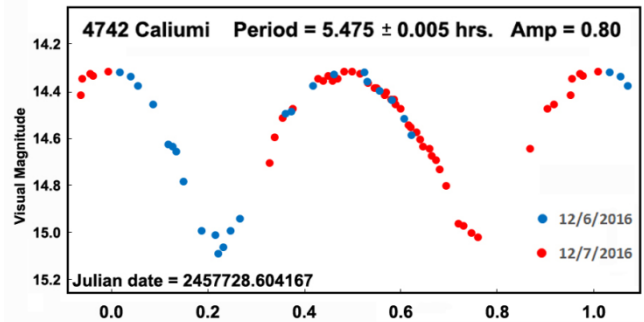
The brightness of the asteroid was compared to that of a comparison star in the same CCD frame. Two additional stars were also measured in each frame to act as check stars to assess the precision of the observations and confirm that the comparison star was not variable. The brightness of the comparison star, check star, and asteroid were determined by measuring a 7x7 pixel sample surrounding the object in question. This corresponds to a 13.65x13.65 arcsec box centered on the object. When possible, the same comparison and check star were used during consecutive nights of observation. The coordinates of the asteroid were obtained from the online Lowell Asteroid Services. When constructing the lightcurve, we vertically shifted the individual nights using Eq. 1 to calculate and offset the asteroid's brightness due to changing Earth and Sun distances:

$$\Delta m = -2.5 \log_{10} \left( \frac{e_2^2}{e_1^2} \left( \frac{r_2^2}{r_1^2} \right) \right) \quad (1)$$

$\Delta m$	magnitude correction between night 1 and 2
$e_1$	earth-asteroid distance on night 1
$e_2$	earth-asteroid distance on night 2
$r_1$	sun-asteroid distance on night 1
$r_2$	sun-asteroid distance on night 2

4742 Caliumi is a mid main-belt asteroid that was discovered on 1986 November 6 at the San Vittore Observatory near Bologna, Italy. Its orbit ranges from a perihelion distance of 263 million kilometers to an aphelion distance of 458 million kilometers, with an average distance of 361 million kilometers. This allows the asteroid to cross the orbit of Mars as times.

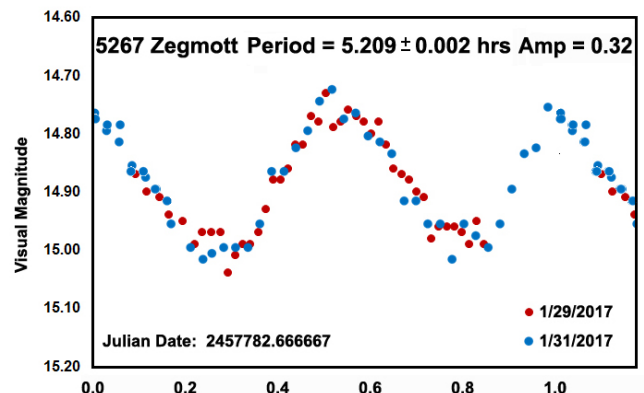
We observed Caliumi on 2016 December 6 and 7. This was a very favorable opposition, with the asteroid being 0.972 AU from Earth on December 7. Weather conditions were particularly favorable. A composite lightcurve with a period of  $5.475 \pm 0.005$  h best fit the available data. The lightcurve has an amplitude of 0.80 mag and displays two maxima and two minima per rotational cycle.



The two maxima appear to be of equal magnitude as do the two minima. A search of the asteroid lightcurve database (LCDB; Warner et al., 2009) revealed that this asteroid was observed by two other observers at about the same time. Both reported a rotation period very similar to the one given here.

5267 Zegmott was discovered on 1966 February 13 in Nanking, China, at the Purple Mountain Observatory. Its orbit has a semi-major axis of 2.37 AU, an eccentricity of 0.09, and an inclination of  $9.0^\circ$ .

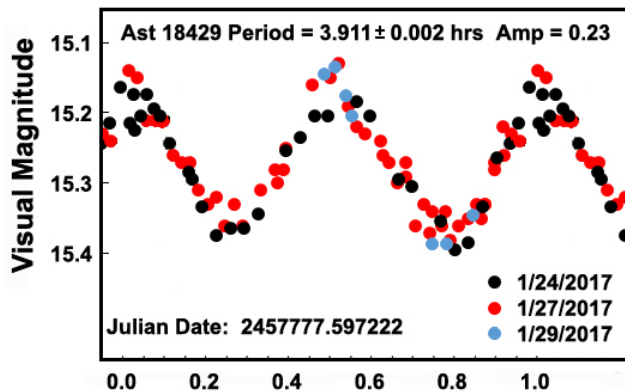
We observed the asteroid on the nights of 2017 January 29 and 31, when it was near perihelion. The asteroid's lightcurve is characterized by a pair of essentially identical maxima. The minima are also nearly identical.



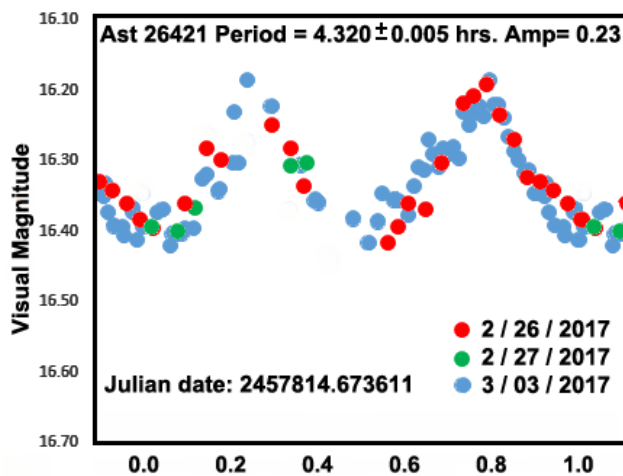
One somewhat unusual aspect to the lightcurve is that the rise in brightness between the minimum and the following maximum is nearly linear and displays a greater slope than the nearly linear decline from that maximum to the following minimum. According to the LCDB, this asteroid was observed by Waszczak et al. (2015), who reported a rotation period of 5.212 h, very close to our period of 5.209 h.

(18429) 1994 AO1 was discovered on 1994 January 8 at Dync Observatory in Kyoto, Japan, and orbits the sun in the inner part of the main-belt. It has a relatively low orbital eccentricity of 0.107, bringing it as close to the sun as 2.188 AU. At its opposition in late January 2017, it was just three weeks past its perihelion.

We observed during the nights of 2017 January 24, 27, and 29. A synodic rotation period of  $3.911 \pm 0.002$  h best fits the data. The amplitude was approximately 0.23 mag. The lightcurve displays two identical maxima and two identical minima per rotation. Based on a review of the literature, it would appear that this is the first determination of the asteroid's rotation period.



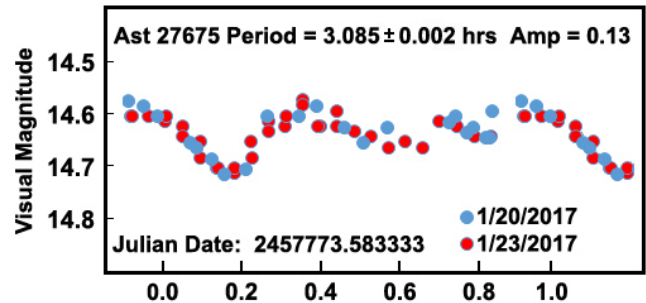
(26421) 1999 XP113 was discovered on 1999 December 11 by LINEAR in Socorro, New Mexico. We observed it during the nights of 2017 February 26 and 27, and March 2. This is the faintest asteroid observed as a part of this research program to date, with an average magnitude of 16.3.



A rotation period of  $4.320 \pm 0.005$  h with an amplitude of 0.23 mag best fits the data. This lightcurve displays two essentially identical maxima and minima per rotational cycle. A search of the

LCDB revealed no previously published lightcurves for this asteroid.

(27675) 1981 CH was discovered on 1981 February 2 at the Klet Observatory. We observed it on the nights of 2017 January 20 and 23. A synodic rotation period of  $3.085 \pm 0.002$  h with a relatively low amplitude of 0.13 mag was determined. The lightcurve appears to display one deeper minimum and two shallower minima per rotational cycle. It also displays three maxima. Two of the maxima appear to be about the same brightness, while the third is about 0.02 magnitudes fainter.



An examination of LCDB revealed one other observation of this asteroid during this same opposition. Pray et al. (2017) reported a rotation period of 2.9661 h, with a lightcurve amplitude of 0.11 mag. This measurement is relatively close to our result. Pray et al. also determined that the asteroid is binary, with an orbital period of 120.1 h. With only two observing runs, it was unlikely that we were going to observe the mutual events that proved the existence of the satellite.

#### Acknowledgments

This research effort represents an effort to introduce high school level students to real astronomical research. Our thanks go to the McCarthy Dressman Educational Foundation and the George West Education Foundation for their continuing support.

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**FOLLOW-UP OBSERVATIONS OF 788 HOHENSTEINA**

References

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(Received: 2017 April 14)

CCD photometric observations were made in 2016 November and December of the suspected tumbler and Hungaria group member 788 Hohensteina . The goal was to find a definitive rotation period, which would presumably match one of several reported periods.

Observations of 788 Hohensteina were first started at the end of 2014 July. However, due to equipment failure, it was not possible to complete the work. Luck was kinder the second time around with successful observations made on 21 nights from 2016 Nov 7 to Dec 4.

The observations were made using a Meade 0.35-m ACF OTA mounted on a Mathis Instruments MI-500 and an FLI Proline PL-1001 CCD camera. All images were unbinned with no filter and had flats and darks applied to the images prior to measurement. All measurements were made using *MPO Canopus*, which employs differential aperture photometry to produce the raw data. Period analysis was also performed using *MPO Canopus*, which incorporates the Fourier analysis algorithm (FALC) developed by Harris (Harris *et al.*, 1989). Night-to-night calibration of the data (generally  $< \pm 0.05$ mag) was done using field stars converted to approximate Cousins V magnitudes based on 2MASS J-K colors (Warner, 2007). The Comp Star Selector feature in *MPO Canopus* was used to limit the comparison stars to near solar color.

This year’s observations produced a lightcurve with an amplitude of 0.11 mag. Harris *et al.* (2014) showed that with an amplitude in this range, it is possible that a lightcurve could have only a single extrema or three or more extrema, as demonstrated in this case. After a few small zero point night-to-night adjustments ( $\sim 0.05$  mag), the data could be easily analyzed to reflect a period of  $37.137 \pm 0.005$  h, which is very close to the period of 37.176 h found by Oey et al. (2008).

It’s still uncertain if this asteroid is tumbling since it was not possible to reconcile data from Oey et al. (2014), Stephens et al. (2014), and sessions from unknown (2006) to match these most recent results, so further evaluation during the next opposition would be suggested.

**Acknowledgements**

I would like to thank The Planetary Society for awarding me with the 2015 Shoemaker NEO Grant, which allowed me to replace a failing CCD camera with the one that was used for these observations.

This research was made possible through the use of the AAVSO Photometric All-Sky Survey (APASS), funded by the Robert Martin Ayers Sciences Fund.

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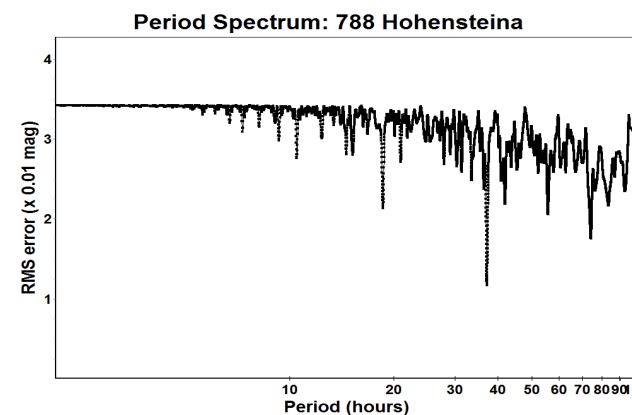
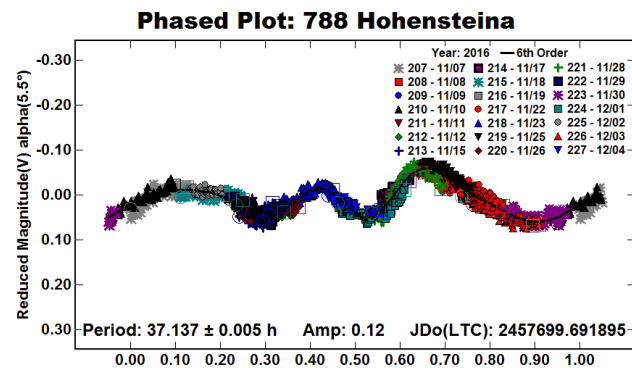
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Number	Name	2016 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.	Grp
788	Hohensteina	11/07-12/04	1390	5.46,7.23	54.4	-14.4	37.137	0.005	0.12	0.01	H

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984). Grp is the asteroid family/group (Warner *et al.*, 2009); H = Hungaria.

**LIGHTCURVE AND ROTATION PERIOD DETERMINATION FOR 1773 RUMPELSTILZ**

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Photometric observations from two locations in Europe and North America in 2017 February-April revealed that the main-belt asteroid 1773 Rumpelstilz was a slow rotator with a synodic period of  $105.49 \pm 0.01$  h.

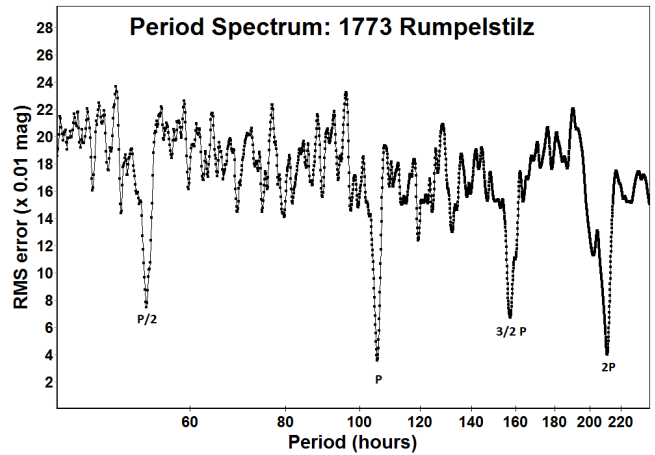
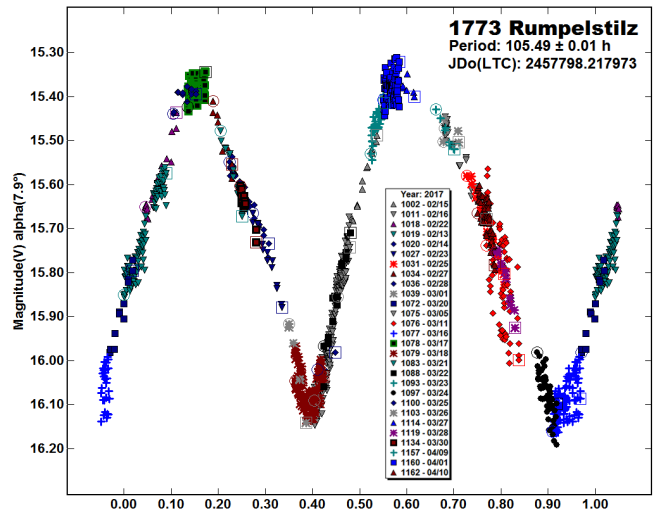
The main-belt asteroid 1773 Tumpelstiz was discovered by P. Wild on 1968 April 17 at Zimmerwald. Given that there was no previously reported rotation period, photometric observations were started on 2017 February 13 at Sopot Astronomical Observatory (SAO) by Benishek. Even the initial data clearly suggested slow rotation, which was unambiguously confirmed by the additional data collected in 2017 February. To achieve more efficient data gathering, a collaboration was formed Pilcher at Organ Mesa Observatory (New Mexico, USA) in early March. The first observations by Pilcher were taken on 2017 March 5.

The equipment used at the SAO consists of a 0.35-m *f*/6.3 Schmidt-Cassegrain telescope (SCT) and SBIG ST-8XME CCD in 2x2 binning mode. Pilcher at Organ Mesa Observatory used a 0.35-m *f*/10 SCT and a SBIG STL 1001-E CCD. The exposures for both observers were unfiltered and unguided.

As of 2017 April 10 a total of 28 data sets (*sessions*) were obtained, of which 22 were by Benishek and 6 were by Pilcher.

*MPO Canopus* software (Warner, 2016) was used by both authors for photometric reduction, data sharing and period analysis. Differential photometry with up to five comparison stars of near solar color ( $0.5 \leq B-V \leq 0.9$ ) was performed using the Comparison Star Selector (CSS) utility within *MPO Canopus*. To calibrate field comparison stars we used the Johnson V magnitudes from the AAVSO Photometric All-Sky Survey catalog (APASS DR9; Henden *et al.*, 2009). By this we hoped to minimize nightly zero point adjustments and merge data sets with near zero offsets. However, in some cases, considerable zero point adjustments, up to several tenths of a magnitude, were required to achieve the best fit, which was determined by minimizing the RMS residual of a Fourier analysis. Some of this could be attributed to catalog errors but the evolution of the lightcurve over the two months of observations may have also been a factor.

The period analysis of the combined data set found the most plausible solution to be a bimodal lightcurve with  $P = 105.49 \pm 0.01$  h. Given the large amplitude (0.76 mag) and the fact that the data were obtained at fairly low phase angles, there is little doubt that the bimodal solution is correct (Harris *et al.*, 2014).



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Warner, B.D. (2016). *MPO Canopus* software version 10.7.7.0. <http://www.bdwpublishing.com>

Number	Name	2017 mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period (h)	P.E.	Amp	A.E.	Grp
1773	Rumpelstilz	02/13-04/10	1055	6.9,23.6	135	6	105.49	0.01	0.76	0.02	MB-I

Table I. Observing circumstances and results. The phase angle ( $\alpha$ ) is given at the start and end of the date range. L<sub>PAB</sub> and B<sub>PAB</sub> are the average phase angle bisector longitude and latitude. Grp is the asteroid family/group (Warner *et al.*, 2009).

**GENERAL REPORT OF POSITION OBSERVATIONS  
BY THE ALPO MINOR PLANETS SECTION  
FOR THE YEAR 2016**

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Observations of positions of minor planets by members of the Minor Planets Section in calendar year 2016 are summarized.

During the year 2016 a total of 2565 observations of 141 different minor planets were reported by members of the Minor Planets Section. Of these, 715 are approximate visual positions denoted V, and 1827 are CCD images denoted C not measured at the time of writing.

The summary lists minor planets in numerical order, the observer and telescope aperture (in cm), UT dates of the observations, and the total number of observations in that period. When a significant departure from the predicted magnitude was noted, it is stated following the column for the number of positions. The year is 2016 in each case.

Positional observations were contributed by the following observers:

Observer, Instrument	Location	Planets	Positions
Bookamer, Richard E. 41 cm f/4.5 Newtonian	Sebastian, Florida USA	5	21V
Faure, Gerard 9 cm Celestron at Carro 35 cm Meade S-C at Arlezier Olympus E-M10 CCD	Col d'Arlezier, Carro, France	6	15V, 1683 C
Harvey, G. Roger 73 cm Newtonian, 35 cm Celestron SC	Concord, North Carolina, USA	50	174V
Pryal, Jim 20 cm f/10 S-C	Ellensburg, WA USA	31	81V
Rayon, Jean-michel 20 cm Vixen R200SS 35 cm Orion XX14G Sony A6000 CCD	Meylan and Aspres-sur-Buech, France	4	167C
Werner, Robert 20 cm Celestron	Pasadena, CA USA	60	424V

PLANET	OBSERVER & APERTURE (cm)	OBSERVING PERIOD (2016) (V unless otherwise stated)	NO. OBS.
1 Ceres	Werner, 20	Nov 19-Dec 2	7
2 Pallas	Werner, 20	Jul 7-8	2
3 Juno	Faure, 9 Rayon, 20 Werner, 20	May 3-4 May 4 May 27-Jun 7	12 (2V, 10C) 1C 6
5 Astraea	Werner, 20	Mar 27-Apr 13	5
6 Hebe	Werner, 20	Mar 27-Apr 14	6
7 Iris	Werner, 20	Jun 3-Jul 8	7
8 Flora	Werner, 20	Jun 3-Jul 8	7
10 Hygiea	Faure, 9 Rayon, 20 Werner, 20	May 2-4 May 4 Mar 27-Apr 14	17 (2V, 15C) 1C 6

PLANET	OBSERVER & APERTURE (cm)	OBSERVING PERIOD (2016) (V unless otherwise stated)	NO. OBS.
17 Thetis	Werner, 20	Jul 27-Sep 9	6
18 Melpomene	Werner, 20	Nov 2-Dec 2	8
19 Fortuna	Werner, 20	Jul 7-Sep 9	19
20 Massalia	Werner, 20	Jul 7-Oct 1	23
22 Kalliope	Werner, 20	Dec 19-29	4
23 Thalia	Werner, 20	May 27-Jun 7	5
28 Bellona	Werner, 20	Mar 27-Apr 14	6
31 Euphrosyne	Werner, 20	Sep 24-Oct 1	2
37 Fides	Werner, 20	Mar 27-Apr 14	6
40 Harmonia	Werner, 20	Mar 27-Apr 3	2
42 Isis	Werner, 20	May 27-Jun 7	6
44 Nysa	Werner, 20	Jul 7-Sep 6	10
45 Eugenia	Werner, 20	Dec 19-29	3
48 Doris	Werner, 20	Jul 25-Sep 2	6
51 Nemausa	Werner, 20	Nov 18-Dec 1	3
52 Europa	Werner, 20	Mar 27-Apr 13	4
56 Melete	Pryal, 20 Werner, 20	Aug 12-13 Jul 7-Sep 9	2 19
57 Mnemosyne	Werner, 20	Oct 2-Dec 2	13
59 Elpis	Werner, 20	Jul 8-Sep 4	11
60 Echo	Werner, 20	Nov 19-Dec 29	10
67 Asia	Pryal, 20 Werner, 20	Sep 5 Aug 30-Oct 9	2 12
68 Leto	Werner, 20	Dec 19-29	4
69 Hesperia	Werner, 20	May 27-Jun 6	4
79 Eurynome	Werner, 20	Oct 26-Dec 2	10
85 Io	Pryal, 20 Werner, 20	Aug 12-13 Jul 7-Sep 9	3 16
97 Klotho	Werner, 20	Mar 27-Apr 13	4
110 Lydia	Werner, 20	Aug 12-Oct 4	8
114 Cassandra	Pryal, 20	Sep 26-27	3
124 Alkestes	Werner, 20	Apr 5-13	2
133 Cyrene	Pryal, 20	Mar 11	2
138 Tolosa	Werner, 20	Jul 25-Aug 7	3
173 Ino	Harvey, 73	Mar 7	3
174 Phaedra	Pryal, 20	Apr 2-3	2
185 Eunike	Pryal, 20 Werner, 20	Sep 4-5 Jul 27-Oct 4	3 11
193 Ambrosia	Werner, 20	Nov 19-Dec 19	4
194 Prokne	Werner, 20	Nov 19-30	3
196 Philomela	Werner, 20	Mar 27-Apr 13	5
226 Weringia	Pryal, 20	Aug 5-6	2
284 Amalia	Werner, 20	Jul 4-8	4
287 Nephthys	Werner, 20	Nov 19-Dec 1	4
322 Phaeo	Pryal, 20 Werner, 20	Aug 27 Sep 6-Oct 9	2 9
323 Brucia	Pryal, 20 Werner, 20	Dec 31 Dec 28-29	2 2
335 Roberta	Werner, 20	Jun 3-Jul 8	6
338 Budrosa	Pryal, 20	Sep 4	2
344 Desiderata	Pryal, 20	Mar 11	2

PLANET	OBSERVER & APERTURE (cm)	OBSERVING PERIOD (2016) (V unless otherwise stated)	NO. OBS.	PLANET	OBSERVER & APERTURE (cm)	OBSERVING PERIOD (2016) (V unless otherwise stated)	NO. OBS.
345 Tercidina	Werner, 20	Oct 9-Nov 3	4	4146 Rudolfinum	Harvey, 73	Feb 28	3
346 Hermentaria	Werner, 20	Apr 2-13	4	4493 Naitomitsu	Harvey, 73	Jan 3	3
349 Dembowska	Werner, 20	Jul 25-Oct 5	16	4601 Ludkewycz	Harvey, 73	Feb 28	3
354 Eleonora	Werner, 20	Jun 3-Jul 8	6	4617 Zadunaisky	Harvey, 73	Jan 11 .5b@15.4	3
404 Arsince	Pryal, 20 Werner, 20	Jun 6-7 Jun 3-7	2 3	4637 Odorico	Harvey, 73	Apr 4 .4f@16.1	3
423 Diotima	Harvey, 73	Jan 30-31	6	4775 Hansen	Pryal, 20	Sep 3-10	9
432 Pythia	Pryal, 20 Werner, 20	Jun 6-7 May 27-Jun 7	2 5	4968 Suzamur	Harvey, 73	Jan 4	3
433 Eros	Pryal, 20	Aug 25-26	3	4996 Veisberg	Harvey, 73	Jan 11 .5b@15.4	3
437 Rhodia	Pryal, 20	Aug 26	2	5143 Heracles	Bookamer, 41	Nov 22	6
444 Gyptis	Werner, 20	Oct 26-Dec 2	9	5315 Bal'mont	Faure, 35	Sep 28-30	62C
451 Patientia	Werner, 20	Sep 7-Oct 4	4	5423 Horahorejs	Harvey, 73	Feb 6	3
476 Hedwig	Pryal, 20	Mar 11	2	5874 1989 XB	Harvey, 73	Jan 18	3
487 Venetia	Pryal, 20	Sep 27	2	5961 Watt	Harvey, 73	Jan 11	3
511 Davida	Pryal, 20 Werner, 20	Jun 6-7 May 27-Jun 7	2 5	5974 1991 UZ2	Harvey, 73	Apr 3	3
532 Herculina	Werner, 20	Jul 27-Oct 4	11	5993 Tammydickenson	Harvey, 73	Jan 18	3
563 Suleika	Pryal, 20	Mar 11	2	6138 1991 JH1	Harvey, 73	Apr 3	3
582 Olympia	Pryal, 20	Apr 1-2	2	6363 Doggett	Harvey, 73	Jan 11	3
585 Bilkis	Pryal, 20	Apr 2-3	2	7084 1991 BR	Harvey, 73	Apr 4	3
670 Ottegebe	Pryal, 20	Sep 5	2	7350 1993 VA	Harvey, 73	Mar 29	6
696 Leonora	Pryal, 20	Aug 25-26	3	7402 1987 YH	Harvey, 73	Feb 6	3
699 Hela	Bookamer, 41	Nov 20	3	7462 Grenoble	Harvey, 73	Jan 11	3
704 Interamnia	Werner, 20	Jul 4-Aug 10	7	7572 Znokai	Harvey, 73	Feb 14	3
718 Erida	Pryal, 20	Apr 1-2	2	7594 Shotaro	Harvey, 73	Apr 4	3
753 Tiflis	Rayon, 20	May 4	1C	7595 Vaxjo	Harvey, 73	Feb 6	3
779 Nina	Pryal, 20 Werner, 20	Aug 11-12 Jul 7-Sep 9	3 19	7717 Tabeisshi	Harvey, 73	Jan 11	3
814 Tauris	Werner, 20	Nov 19-Dec 2	4	7822 1991 CS	Harvey, 73	Feb 27	6
887 Alinda	Faure, 35	Sep 7	6 (4V, 2C)	10294 1988 AA2	Harvey, 73	Jan 11	3
980 Anacostia	Werner, 20	Jul 25-Aug 7	4	10566 Zabadak	Harvey, 73	Jan 18	3
984 Gretia	Pryal, 20	Sep 10-11	3	11093 1994 HD	Harvey, 73	Apr 3	3
1195 Orangia	Harvey, 35	Jul 10	6	12867 JoeLoic	Faure, 35	Aug 3-Nov 1 (5V, 1156C)	1161
1204 Renzia	Pryal, 20	Aug 5-6	2	Rayon, 20, 35		Aug 4-Oct 1	164C
1414 Jerome	Harvey, 73	Feb 6	3	14831 Gentileschi	Harvey, 73	Jan 11	3
1665 Gaby	Bookamer, 41	Jan 16	3	15776 1998 KO	Harvey, 73	Apr 3	3
1685 Toro	Pryal, 20	Feb 8	3	16993 1999 CC10	Harvey, 73	Jan 18	3
1963 Bezovec	Bookamer, 41	Jan 1	4	19774 2000 OS51	Harvey, 73	Feb 14 .5f@16.0	3
2103 Laverna	Harvey, 73	Feb 28	3	20826 2000 UV13	Harvey, 73	Feb 27	6
2457 Rublyov	Harvey, 73	Mar 7	3	31013 1996 DR	Harvey, 73	Mar 29	3
2710 Veverka	Harvey, 73	Apr 3	3	31354 1998 TR3	Harvey, 73	Apr 3	3
2914 Glarnish	Faure, 35	Aug 24-Sep 30 (2V, 438C)	440	32248 2000 OV44	Harvey, 73	Feb 14	3
2925 Beatty	Harvey, 73	Jan 4	3	85990 1999 JV6	Harvey, 73	Jan 11	6
3334 Somov	Harvey, 73	Jan 18	3	96590 1988 XB	Bookamer, 41	Nov 25	5
3371 Giacomoni	Harvey, 73	Feb 11	3	154244 2002 KL6	Harvey, 35	Jul 10	6
3417 Tambyn	Harvey, 73	Feb 28	3	164121 2003 YT1	Pryal, 20	Oct 28	4
3949 Mach	Harvey, 73	Jan 4	3	294739 2008 CM	Harvey, 73	Jan 3	6
				2016 DV1	Harvey, 73	Mar 3	3

## MEASUREMENTS OF 100 ‘CRITICAL’ MINOR PLANETS FROM NEAT ARCHIVE

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Uncertainties associated with the orbits of minor planets can be reduced by analyzing archival imagery as attempted in the current investigation. Archival images from NEAT and NASA’s *Skymorph* database were analyzed using standard software to identify the minor planets listed in the critical list. Findings of each minor planet were submitted to Minor Planet Center (MPC) to offer better orbital solutions.

The Minor Planet Center (MPC) publishes a ‘critical’ list of numbered minor planets. Published observations of these minor planets are not sufficient to reduce the uncertainty associated with their orbits. In other words, more observations are sought so as to offer better orbital solutions and thereby reduce the uncertainty. Generally, minor planets are brightest when they are at opposition and hence provide best opportunity for observation.

Additional observations will offer better solutions; any shortfall in the available observations can be complemented by analysis of archival imagery, which will be beneficial in resolving associated uncertainty.

### Observations of Minor Planets

Many sky surveys were in operation during 1990s. Some of these were especially designed to find minor planets. Regions on either side of the ecliptic were scanned using automated telescopes. Temporal (hourly or half-hourly) observations of the same part of the sky were taken in order to discern the displacement of moving objects. Additionally, repeated observations of the same areas were carried out after a few months. This resulted in the rise of the number of discoveries of minor planets in the last two decades.

### Minor Planets Hunting Programs

The solid state charged-coupled device (CCD) based detection systems and computer processing of data were first demonstrated by Spacewatch ([spacewatch.lpl.arizona.edu/index.html](http://spacewatch.lpl.arizona.edu/index.html)) search system in 1984. The CCD’s were almost twice sensitive as that of film based detectors, therefore a fainter limiting magnitude ( $V > 21.0$ ) was achieved. As a result, a rise in the number of discoveries was observed and Spacewatch remained as leading minor planet hunter for several years.

In 1995, NASA’s Jet Propulsion Laboratory (JPL) and the U.S. Air Force joined hands to launch the Near Earth Asteroids Tracking (NEAT) program ([neat.jpl.nasa.gov](http://neat.jpl.nasa.gov)). With its larger angular pixel scale, the NEAT system was able to cover wider area but with lesser depth of search.

The Lincoln Near-Earth Asteroid Research (LINEAR; Evans et al., 2003) program developed for the U.S. Air Force commenced in 1998. Within five years of its operation, LINEAR contributed over half of the total number of observations worldwide.

The Lowell Observatory Near-Earth Object (LONEOS; [asteroid.lowell.edu/asteroid/loneos/loneos1.html](http://asteroid.lowell.edu/asteroid/loneos/loneos1.html)) located in Flagstaff, Arizona, is yet another program that was dedicated to search for asteroids and comets. LONEOS has submitted millions of observations to MPC.

These are only some of the major projects dedicated to minor planet searches; other successful programs include Mt. Lemmon Survey, Catalina Sky Survey, etc.

In this investigation, the archival images of NEAT program are used for measurements of critical list numbered minor planets.

### Skymorph

*Skymorph* is an archive of visible images of the sky and information associated with these images. It can be accessed at [skyview.gsfc.nasa.gov/skymorph/obs.html](http://skyview.gsfc.nasa.gov/skymorph/obs.html)

All the measurements under this investigation were made using this archive.

### Procedure Overview

A list of images containing a selected minor planet was fetched using *Skymorph*. Observations that had already submitted to Minor Planet Center (MPC) were ignored and only the dates with no observations in MPC’s database were considered. In most of the cases, a triplet having an estimated magnitude of  $< 20.5$  was selected to download images. The data reduction of these images was done using Herbert Raab’s *Astrometrica* (Version 4.6.5.390; [astrometrica.at/](http://astrometrica.at/)). Depending on the source of the image, respective telescope was selected from settings, so as to ensure error free data reduction.

Measurements were made only if the fit order for all the images in the set was 4 (Haleakala-NEAT/GEODSS, Haleakala-AMOS) and 3 (Palomar/NEAT). If the fit order for a particular image was found to be less than the values, that image was discarded and the remaining images were used for measurements. The fit order for those images was verified and if it was found to be below the threshold, then the entire data set was rejected. Using the ‘blink images’ option, images were flickered to differentiate any moving object. To ensure the correct identification of the minor planets in the field of view, the *Asteroid Plot* (ASTPLOT, Version 1.5; [asteroid.lowell.edu/cgi-bin/astplot](http://asteroid.lowell.edu/cgi-bin/astplot)) utility of Lowell Observatory was used.

After selecting appropriate Observatory parameters (code, date, time and positions) in *Asteroid Plot*, all minor planets brighter than mag. 21.5 were sought on the chart. Identification of the particular minor planet on the background star was performed, followed by careful measurement. Despite utmost care, a few observations were rejected and were omitted from this discussion. There are two exceptions to this, some of the measurements for minor planets 307934 and 217837 were rejected. However, the same were published subsequently by MPC and so are included in the discussion.

This procedure was repeated for all the remaining observations. These observations were saved in the format prescribed by MPC and then were submitted to [obs@cfa.harvard.edu](mailto:obs@cfa.harvard.edu)

### Selection of Candidates

The primary goal of this investigation was to provide better orbital solutions based on the observation arc from archival images. Hence, the selection of candidate minor planets was made from ‘critical list’ of numbered minor planets maintained by the MPC. Selection was constrained by the availability of images in NEAT archive as well as the availability of unpublished observations. The estimated magnitude of the object, quality of the images for data reduction, and quality for object detection and measurement were also factors that governed the selection.

Minor planets in the critical list were examined one by one and the process stopped when 100 minor planets were found. Table III gives the list of all candidates measured. Needless to say, the composition of the population is predominantly (80%) of main-belt asteroids (MBA) with remaining 20% being Apollos, Amors, Mars-crossers, etc., including three potentially hazardous asteroids (PHAs). Table IV shows the population distribution.

### Measurements

Since the NEAT project was active from 1995 to 2006, all the measurements were within this range. However, many fruitful observations were made in 2002 from Palomar mountain/NEAT (MPC 644), hence it was the most dominating contributor of the measurements, followed by Haleakala-AMOS (MPC 608) and Haleakala-NEAT/GEODSS (MPC 566).

Table I shows the number of measurements submitted using images taken from these observatories. With constraints of selecting minor planet as described above, measurements were made for maximum possible positions for each candidate. This ranges from just two measurements to seventeen measurements. A frequency distribution of all the measurements is shown in Table II.

### Minor Planets at Oppositions

Apart from orbital elements, the MPC also gives circumstances of measurements, such as observations used for measurements, length of arc observed in days, first and last opposition used, residual RMS, first and last observation date used for computation, etc. As mentioned above, minor planets can best be observed at opposition. Hence, observations from pre-discovery era are useful, such additional observations at or near the time when the minor planet was at opposition can be searched in the archival images. Table V shows the list of minor planets for which new oppositions were added as an outcome of this investigation.

### Results

The prime objective of this investigation was to reduce the uncertainty associated with orbital elements of ‘critical list’ minor planets by providing additional observations. As of 2013 Sep 30, out of 628 observations of 100 minor planets submitted to MPC, 374 observations of 54 minor planets were published. Of these 54 minor planets, observations at new oppositions were provided for 23 minor planets. Out of these 23 minor planets, the uncertainty

Code	Observatory	Count
566	Haleakala-NEAT/GEODSS	14
608	Haleakala-AMOS	138
644	Palomar mountain/NEAT	476
<b>Total measurements</b>		<b>628</b>

Table I. The number of measurements from each observatory.

Observations	Frequency
2	6
3	31
4	1
5	11
6	17
7	5
8	5
9	6
10	1
11	4
12	5
13	1
14	1
15	5
17	1
<b>TOTAL</b>	<b>100</b>

Table II. The frequency of observations.

was reduced for 14 minor planets. It is expected that when the remaining observations are published, more uncertainties will be reduced.

Along with the measurements of critical list numbered minor planets, the investigation also resulted in 413 observations of 134 known minor planets which were submitted to MPC. However, these measurements are beyond the scope of this paper.

### Acknowledgements

I sincerely thank Stefan Kurti for his invaluable guidance during my initial NEAT asteroids hunting that ultimately induced me to delve into this project. Further, I also thank Herbert Raab for his amazing data reduction software, Astrometrica and making it available to me. I also pay my gratitude towards Quan-Zhi Ye, Caltech for his valued guidance along with my fellows in Akash Mitra Mandal, Kalyan, especially, Dr.Amit Kokje and Sunil Vidwans for their suggestions, encouragement and support without which this could not have been completed.

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Sl.No.	Designation	Type	Net Obs.	Code(s)	First Obs. dd.mm.yyyy	Last Obs. dd.mm.yyyy	Arc length
1	(362138) 2009 DY81	MBA	5	644	01.06.2002	02.06.2002	2
2	(361772) 2008 AY29	MBA	10	608/644	11.06.2002	08.08.2002	59
3	(360815) 2005 JT84	MBA	6	644	04.09.2002	14.09.2002	11
4	(360793) 2005 GU58	MBA	6	644	15.10.2002	28.10.2002	14
5	(360234) 2000 BF41	MBA	3	644	11.06.2002	11.06.2002	0.02153
6	(359772) 2011 UH133	MBA	3	644	24.11.2002	24.11.2002	0.12473
7	(359188) 2009 CQ56	MBA	7	644	06.07.2002	15.07.2002	10
8	(358675) 2007 YY1	MBA	9	644	02.06.2002	11.06.2002	10
9	(357408) 2003 WD15	MBA	8	608/644	12.03.2001	18.06.2002	464
10	(356077) 2009 DP97	MBA	5	608	05.04.2001	16.05.2001	42
11	(354675) 2005 NM56	MBA	9	644	29.07.2002	15.09.2002	49
12	(354630) 2005 FR1	MBA	7	608/644	15.03.2001	19.08.2002	523
13	(354059) 2001 TR97	MBA	15	644	12.10.2001	07.03.2003	512
14	(353964) 1999 VY152	MBA	6	644	13.04.2002	07.05.2002	25
15	(352985) 2009 BG95	MBA	3	644	04.06.2002	04.06.2002	0.04578
16	(349691) 2008 WC136	MBA	8	644	04.04.2002	15.04.2002	12
17	(348722) 2006 DS71	MBA	3	644	12.04.2002	14.04.2002	3
18	(348286) 2004 XF26	MBA	6	644	13.04.2002	15.04.2002	3
19	(348124) 2004 BY2	MBA	5	644	12.06.2001	01.07.2001	20
20	(347030) 2010 EX70	MBA	6	644	04.04.2002	15.04.2002	12
21	(347024) 2010 EQ39	MBA	3	644	25.10.2001	25.10.2001	0.04815
22	(344950) 2004 VO52	MBA	6	644	02.04.2002	14.04.2002	13
23	(342183) 2008 SX190	MBA	6	644	03.02.2002	04.02.2002	2
24	(342005) 2008 RS35	MBA	12	644	18.12.2001	04.03.2002	18
25	(340294) 2006 CO5	MBA	3	644	08.01.2002	08.01.2002	1
26	(339212) 2004 TN274	MBA	3	644	20.03.2002	20.03.2002	1
27	(339185) 2004 TN159	MBA	3	644	11.03.2002	11.03.2002	0.0209
28	(338292) 2002 UA31	Aten (NEO)	6	608/644	03.11.2002	17.11.2002	15
29	(337990) 2002 CR253	MBA	9	644	07.01.2002	05.02.2002	30
30	(337050) 1996 VD16	MBA	12	608/644	03.02.2002	11.03.2002	37
31	(337046) 1996 TM12	MBA	5	644	04.04.2002	14.04.2002	11
32	(329247) 1995 OY9	MBA	3	644	02.09.2002	02.09.2002	0.04399
33	(326307) 1998 XE10	MBA	3	644	05.12.2002	05.12.2002	0.12978
34	(324554) 2006 WM82	MBA	2	644	11.12.2002	11.12.2002	0.02154
35	(324553) 2006 WL80	MBA	5	644	13.11.2002	24.11.2002	12
36	(323453) 2004 HQ53	MBA	3	644	22.09.2001	22.09.2001	0.04617
37	(323428) 2004 FR54	MBA	3	644	09.08.2001	09.08.2001	0.02228
38	(320829) 2008 FY43	MBA	5	608/644	04.10.2002	30.11.2002	58
39	(320713) 2008 DR56	MBA	9	644	20.10.2002	12.12.2002	53
40	(319741) 2006 UP135	MBA	3	644	12.08.2002	12.08.2002	0.02054
41	(319719) 2006 UX60	MBA	13	644	01.11.2002	27.12.2002	57
42	(316958) 2001 FG1	MBA	17	608/644	26.03.2001	30.06.2002	461
43	(316849) 2000 GH47	MBA	5	644	25.08.2001	25.08.2001	0.04142
44	(312329) 2008 CE162	MBA	3	644	12.07.2002	12.07.2002	0.02142
45	(312227) 2007 XQ40	MBA	8	644	11.05.2002	05.06.2002	26
46	(309683) 2008 ET147	MBA	6	644	24.11.2002	24.11.2002	0.15757
47	(309125) 2006 WY203	MBA	2	644	08.10.2001	08.10.2001	0.02117
48	(308895) 2006 ST176	MBA	9	644	14.09.2002	28.09.2002	15
49	(308621) 2005 WV193	MBA	3	644	17.12.2001	17.12.2001	0.12827
50	(308604) 2005 VX112	Mars Crosser	7	644	29.10.2002	12.11.2002	14
51	(308545) 2005 UE232	MBA	7	644	18.10.2001	22.11.2001	35
52	(308412) 2005 ST103	MBA	15	644	19.09.2001	26.10.2001	38
53	(308184) 2005 CP41	MBA	8	644	06.07.2002	15.07.2002	10
54	(308113) 2004 XV23	MBA	5	644	24.02.2002	03.04.2002	8
55	(307934) 2004 EG65	MBA	11	608/644	11.04.2000	14.10.2001	552
56	(307901) 2004 CR61	MBA	3	644	26.09.2002	26.09.2002	0.12813
57	(307881) 2004 BV86	MBA	15	608/644	13.09.2002	24.02.2004	531
58	(307736) 2003 UC227	MBA	8	644	30.05.2002	13.06.2002	15
59	(307484) 2002 XL55	MBA	5	644	27.01.2003	03.02.2003	7
60	(307473) 2002 XV11	MBA	15	644	22.06.2001	22.01.2003	580
61	(307457) 2002 VE66	Mars Crosser	3	608	09.10.2002	09.10.2002	0.02168
62	(307099) 2002 BV29	MBA	14	566/644	25.12.1997	03.02.2002	1502
63	(307057) 2001 YN83	MBA	11	608/644	09.01.2002	05.02.2002	28
64	(306952) 2001 UL176	MBA	6	644	23.03.2003	30.03.2003	8
65	(306945) 2001 UM135	MBA	9	566/644	26.11.1997	19.12.2002	1850
66	(306598) 2000 GE176	MBA	6	566/644	01.09.1997	15.11.2002	1902
67	(306569) 2000 CA138	MBA	3	566	17.03.1996	17.03.1996	0.042
68	(306536) 1999 XU222	MBA	4	608 & 644	15.06.2001	16.08.2002	428
69	(306456) 1999 CW6	MBA	3	644	23.09.2001	23.09.2001	1
70	(305543) 2008 QY40	Centaur	2	644	12.08.2001	18.08.2001	7

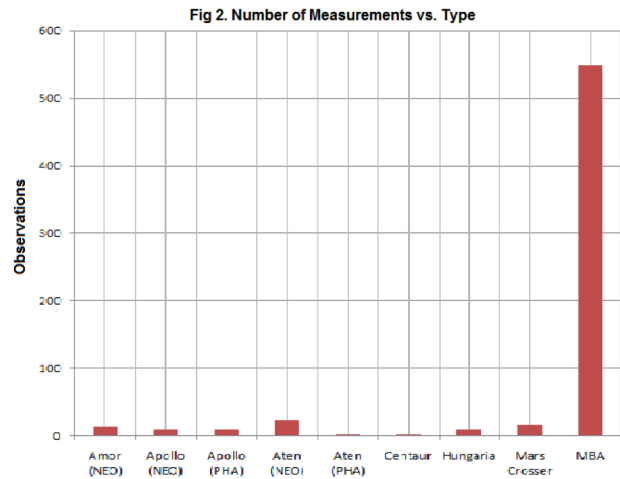
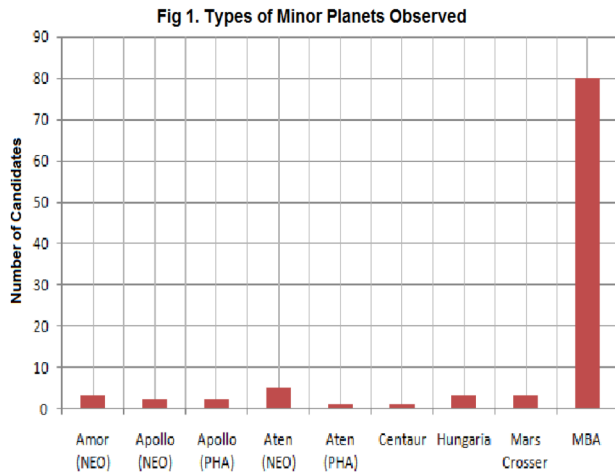
Table III. List of critical list numbered minor planets measured from NEAT archives.

Sl.No.	Designation	Type	Net Obs.	Code(s)	First Obs. dd.mm.yyyy	Last Obs. dd.mm.yyyy	Arc length
71	(292860) 2006 VW	MBA	15	608/644	12.07.2002	23.08.2002	43
72	(290964) 2005 WB193	MBA	5	608/644	25.09.2000	18.01.2002	481
73	(289583) 2005 FW2	MBA	11	608/644	12.04.2002	18.05.2002	29
74	(287601) 2003 GN	Hungaria	3	644	11.08.2001	11.08.2001	0.02405
75	(286664) 2002 EN105	MBA	11	644	03.02.2002	03.04.2002	60
76	(286193) 2001 UG64	MBA	6	644	26.10.2001	10.12.2001	17
77	(277533) 2005 YZ3	MBA	12	644	05.01.2002	12.02.2002	39
78	(276451) 2003 FH24	MBA	6	608	30.10.2001	05.04.2003	523
79	(276004) 2001 YF18	MBA	6	608	07.12.2001	25.12.2001	19
80	(275946) 2001 UZ170	MBA	3	608	02.04.2003	02.04.2003	0.02148
81	(267221) 2001 AD2	Apollo (PHA)	3	608	06.01.2002	06.01.2002	0.02915
82	(255071) 2005 UH6	Apollo (PHA)	6	608	26.10.2002	31.10.2002	6
83	(252399) 2001 TX44	Aten (PHA)	2	644	19.09.2001	19.09.2001	0.02116
84	(252373) 2001 SA270	Apollo (NEO)	3	644	05.11.2001	05.11.2001	0.0437
85	(247517) 2002 QY6	Aten (NEO)	3	608	28.08.2005	28.08.2005	0.02164
86	(234341) 2001 FZ57	Aten (NEO)	7	608	21.03.2001	10.05.2001	51
87	(217837) 2001 LC	Apollo (NEO)	6	608	25.06.2001	28.06.2001	4
88	(209215) 2003 WP25	Aten (NEO)	3	644	28.10.2002	28.10.2002	0.0444
89	(185192) 2006 TV1	MBA	2	644	28.07.2002	28.07.2002	0.05783
90	(185108) 2006 SM37	MBA	3	644	14.07.2002	14.07.2002	0.03734
91	(180904) 2005 JG179	MBA	12	608/644	08.09.2002	16.09.2002	40
92	(174540) 2003 EM60	MBA	12	608/644	17.12.2001	10.05.2003	510
93	(172421) 2003 HF	MBA	3	644	22.11.2001	22.11.2001	1
94	(168828) 2000 SY320	Mars Crosser	5	608	22.12.2000	07.08.2003	959
95	(167697) 2004 RO255	Hungaria	2	608	27.05.2006	27.05.2006	0.01074
96	(163678) 2002 XT65	Hungaria	3	644	19.10.2002	19.10.2002	0.02111
97	(163023) 2001 XU1	Aten (NEO)	3	608	23.11.2001	23.11.2001	0.02139
98	(162698) 2000 UN30	Amor (NEO)	3	608	08.05.2003	08.05.2003	0.02173
99	(162273) 1999 VL12	Amor (NEO)	6	608	28.11.1997	02.01.2002	1497
100	(162181) 1999 LF6	Amor (NEO)	3	644	11.02.2002	11.02.2002	0.04194
	<b>TOTAL</b>		<b>628</b>				<b>14377.525</b>

Table III (continued).

Minor Planet type	Count	# of Obs
Amor (NEO)	3	12
Apollo (NEO)	2	9
Apollo (PHA)	2	9
Aten (NEO)	5	22
Aten (PHA)	1	2
Centaur	1	2
Hungaria	3	8
Mars Crosser	3	15
MBA	80	549
<b>Total</b>	<b>100</b>	<b>628</b>

Table IV. Number of each asteroid type and observations for each type.



Sl.No.	Designation	Type	Code(s)	First Obs. dd.mm.yyyy	Last Obs. dd.mm.yyyy	MPS Ref.	Year
1	(360234) 2000 BF41	MBA	644	11.06.2002	11.06.2002	469102	2002
2	(359772) 2011 UH133	MBA	644	24.11.2002	24.11.2002	471170	2002
3	(358675) 2007 YY1	MBA	644	02.06.2002	11.06.2002	468638	2002
4	(354675) 2005 NM56	MBA	644	29.07.2002	15.09.2002	471170	2002
5	(349691) 2008 WC136	MBA	644	04.04.2002	15.04.2002	471170	2002
6	(348286) 2004 XF26	MBA	644	13.04.2002	15.04.2002	471170	2002
7	(347024) 2010 EQ39	MBA	644	25.10.2001	25.10.2001	471169	2001
8	(344950) 2004 VO52	MBA	644	02.04.2002	14.04.2002	471169	2002
9	(342183) 2008 SX190	MBA	644	03.02.2002	04.02.2002	471169	2002
10	(342005) 2008 RS35	MBA	644	18.12.2001	04.03.2002	471169	2001-02
11	(339212) 2004 TN274	MBA	644	20.03.2002	20.03.2002	471169	2002
12	(339185) 2004 TN159	MBA	644	11.03.2002	11.03.2002	471169	2002
13	(337050) 1996 VD16	MBA	608/644	03.02.2002	11.03.2002	471323-4	2002
14	(337046) 1996 TM12	MBA	644	04.04.2002	14.04.2002	471323	2002
15	(324553) 2006 WL80	MBA	644	13.11.2002	24.11.2002	472608	2002
16	(316958) 2001 FG1	MBA	608/44	26.03.2001	30.06.2002	472596	2002
17	(312227) 2007 XQ40	MBA	644	11.05.2002	05.06.2002	472591	2002
18	(307934) 2004 EG65	MBA	608/644	11.04.2000	14.10.2001	472967	2001
19	(307881) 2004 BV86	MBA	608/644	13.09.2002	24.02.2004	472967	2002
20	(307473) 2002 XV11	MBA	644	22.06.2001	22.01.2003	472967	2001
21	(307099) 2002 BV29	MBA	566/644	25.12.1997	03.02.2002	474304	1997
22	(306598) 2000 GE176	MBA	566/644	01.09.1997	15.11.2002	474304	1997
23	(255071) 2005 UH6	Apollo (PHA)	608	26.10.2002	31.10.2002	MPEC R82	2002

Table V. List of minor planets for which new opposition year is added in this investigation. (The Year column gives the year of the new opposition data.)

Sl.No.	Designation	Type	Code(s)	First Obs. dd.mm.yyyy	Last Obs. dd.mm.yyyy	Net Obs.	Arc length	MPS Ref.	U (pre)	U (post)
1	(360234) 2000 BF41	MBA	644	11.06.2002	11.06.2002	3	0.02153	469102	3	1
2	(359772) 2011 UH133	MBA	644	24.11.2002	24.11.2002	3	0.12473	471170	3	2
3	(358675) 2007 YY1	MBA	644	02.06.2002	11.06.2002	9	10	468638	3	1
4	(354675) 2005 NM56	MBA	644	29.07.2002	15.09.2002	9	49	471170	3	1
5	(347030) 2010 EX70	MBA	644	04.04.2002	15.04.2002	6	12	471169-70	3	2
6	(347024) 2010 EQ39	MBA	644	25.10.2001	25.10.2001	3	0.04815	471169	3	1
7	(339185) 2004 TN159	MBA	644	11.03.2002	11.03.2002	3	0.0209	471169	3	2
8	(337050) 1996 VD16	MBA	608/644	03.02.2002	11.03.2002	12	37	471323-4	3	2
9	(337046) 1996 TM12	MBA	644	04.04.2002	14.04.2002	5	11	471323	3	2
10	(329247) 1995 OY9	MBA	644	02.09.2002	02.09.2002	3	0.04399	471779	?	1
11	(319719) 2006 UX60	MBA	644	01.11.2002	27.12.2002	13	57	472600	3	2
12	(316958) 2001 FG1	MBA	608/644	26.03.2001	30.06.2002	17	461	472596	3	1
13	(312227) 2007 XQ40	MBA	644	11.05.2002	05.06.2002	8	26	472591	3	0
14	(307473) 2002 XV11	MBA	644	22.06.2001	22.01.2003	15	580	472967	3	1
<b>TOTAL</b>						<b>109</b>				

Table VI. List of minor planets with reduced uncertainty. The U columns give the orbital uncertainty rating before (pre) and after (post) this work.

**299 THORA AND 496 GRYPHIA:  
TWO MORE VERY SLOWLY ROTATING ASTEROIDS**

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CCD observations of the asteroids 299 Thora and 496 Gryphia were made to determine the synodic rotation periods. For 299 Thora, the period is  $272.9 \pm 0.9$  h with a maximum amplitude 0.47 mag. No evidence of tumbling was found. We measured a color index of  $V-R = 0.52$ . Using average lightcurve magnitude, we found  $H = 11.68 \pm 0.06$ ,  $G = 0.27 \pm 0.06$ . For 496 Gryphia, we found a rotation period near 1072 h and amplitude of 1.25 mag. Tumbling behavior was found but not quantified. The color index is  $V-R = 0.48$ . Using average lightcurve magnitudes, we found  $H = 12.21 \pm 0.05$ ,  $G = 0.18 \pm 0.04$ .

A strategy for observing very slowly rotating asteroids has been described by Pilcher et al. (2017). Briefly, a short session is obtained every clear night for several months using calibrated solar-colored stars from the CMC15 catalog (VizieR web site) to determine the asteroid's brightness. Alternating V and R filter exposures are obtained on at least one night to find a color index  $V-R$  and a search for tumbling is made with simultaneous two-period software.

Observations to obtain the data used in this paper were made at the Organ Mesa Observatory with a 0.35-meter Meade LX200 GPS Schmidt-Cassegrain (SCT) and SBIG STL-1001E CCD. Exposures were 60 to 120 seconds, unguided, with a clear filter. All measurements were calibrated from CMC15 Sloan  $r'$  (SR) values to Cousins R magnitudes for solar-colored field stars. Photometric measurement was done with *MPO Canopus*. To reduce the number of points on the lightcurves and make them easier to read, data points on all lightcurves constructed with *MPO Canopus* were binned in sets of 3 with a maximum time difference of 5 minutes between points in each bin.

To find the  $V-R$  color index, images in both R and V filters were obtained alternately on one night for each object in the study. The same solar-colored comparison stars with SR and 2MASS J and K magnitudes read from the CMC15 catalog (VizieR web site) were

used to measure both image sets. For the R filter images, conversions to Cousins R magnitudes used (Dymock and Miles, 2009)

$$R = r' - 0.22 \quad (1)$$

For the V filter images, conversions to Johnson V magnitudes used Dymock and Miles (2009)

$$V = 0.9947r' + 0.6278(J-K) \quad (2)$$

The converted magnitudes for each color are plotted together. The V magnitude data points can be adjusted upward to obtain the best fit between R magnitude and V magnitude overlapping sessions. The amount of the adjustment is then the color index  $V-R$ . For each session, R magnitudes were estimated at maximum, mid, and minimum light for the rotational cycle. Each measured R magnitude was converted to its corresponding V magnitude by adding the derived  $V-R$ .

The H-G calculator function of *MPO Canopus* was used to find the values for absolute magnitudes ( $H$ ) and phase slope parameter ( $G$ ) based on the V magnitudes at maximum, mid, and minimum light. Using maximum light has a better geometric foundation but the H-G system assumes mid-light, i.e., the average magnitude of a lightcurve at any given time.

299 Thora. The only previously published rotation period and amplitude is by Pilcher et al. (2014), who obtained a period of 274 h and amplitude of 0.39 mag based on numerous dense all-night lightcurves obtained over a two month interval. However, there were calibration problems related to systematic differences between the equipment used by Pilcher and Alvarez that prevented finding whether or not small amplitude tumbling was occurring. Small-amplitude, short-period variations were not definitively observed.

New observations, mostly of 20 minutes to 2 hours duration, were obtained on 73 nights between 2016 Oct 31 and 2017 Mar 26. All images were obtained using the same telescope and CCD camera at Organ Mesa Observatory. A single-period lightcurve constructed from *MPO Canopus* software including all observations in this interval (Fig. 1) provides a good fit to a period of 272.65 h and amplitude 0.47 mag but with considerable scatter among individual sessions.

However, when the data over the intervals of 2016 Oct 31 to 2017 Jan 7 (Fig. 2; 272.2 h, 0.47 mag) and 2017 Jan 8 to March 26 (Fig. 3; 273.2 h, 0.38 mag) are plotted separately, most of the scatter is removed. The scatter over the full interval is attributed to changes in the phase angle between the two data sets.

The split-halves plot for the data set covering 2017 Jan 8 to Mar 26 for the double-period of 548 hours is shown in Fig. 4. The tenth-order Fourier approximations for the two halves are almost identical, which makes the double period extremely unlikely. A split halves plot for the same data set for the 273 hour period (Fig. 5) shows much greater differences for the tenth-order Fourier approximations for the two halves and rules out the half period. An independent analysis by co-author Pravec established a period

Number	Name	yyyy/mm/dd	Pts	Phase	L <sub>PAB</sub>	B <sub>PAB</sub>	Period(h)	P.E.	Amp	A.E.
299	Thora	2016/10/31-2017/03/26	3685	21.4, 1.0, 24.7	127	-2	272.9	0.9	0.47	0.04
496	Gryphia	2016/09/22-2017/02/11	3222	16.3, 0.3, 27.8	33	-1	1072.0	2.0	1.25	0.10

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first date, minimum value, and last date. L<sub>PAB</sub> and B<sub>PAB</sub> are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984).

of  $272.9 \pm 0.9$  h and found no evidence of tumbling. This period is in fairly close agreement with 274 hours found by Pilcher et al. (2014). Using the tumbler rating system from Pravec et al. (2005), the asteroid is rated PAR = +2, tending to +3.

Twenty-five images each in R and V filters were obtained alternately on 2017 Jan 26 and plotted together (Fig. 6) in which the R and V magnitudes are separated by V-R = 0.52. An H-G plot using the data obtained in this investigation (Fig. 7) shows

Maximum light:  $H = 11.53 \pm 0.02, G = 0.29 \pm 0.03$   
 Mean light:  $H = 11.68 \pm 0.06, G = 0.27 \pm 0.06$   
 Minimum light:  $H = 11.82 \pm 0.05, G = 0.25 \pm 0.06$

A parallel study using sparse data from USNO Flagstaff Station (Fig. 8) yields mean light values of  $H = 11.616 \pm 0.046, G = 0.268 \pm 0.050$ , in good agreement with the results of this study. There is also good agreement with JPL (2017),  $H = 11.3$  and with Nugent et al. (2016)  $H = 11.54, G = 0.24$ .

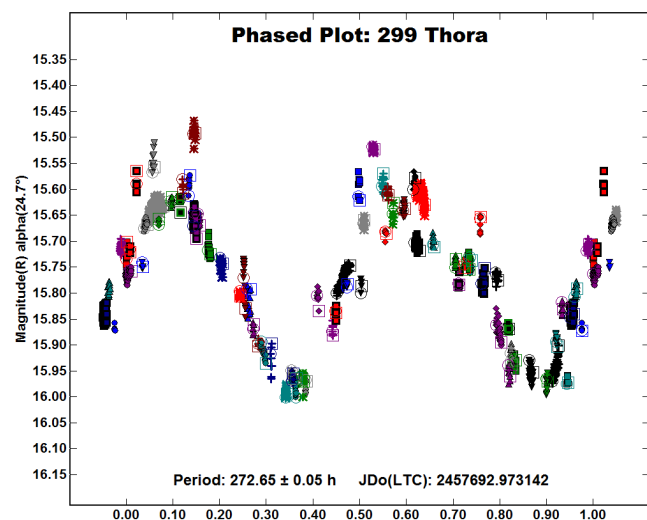


Fig. 1. Phased lightcurve of 299 Thora based on 73 sessions from 2016 Oct 31 to 2017 Mar 26.

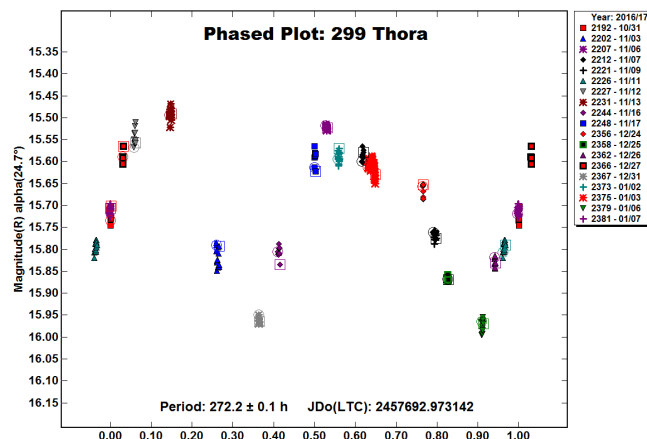


Fig. 2. Phased lightcurve of 299 Thora based on 19 sessions covering 2016 Oct 31 to 2017 Jan 7.

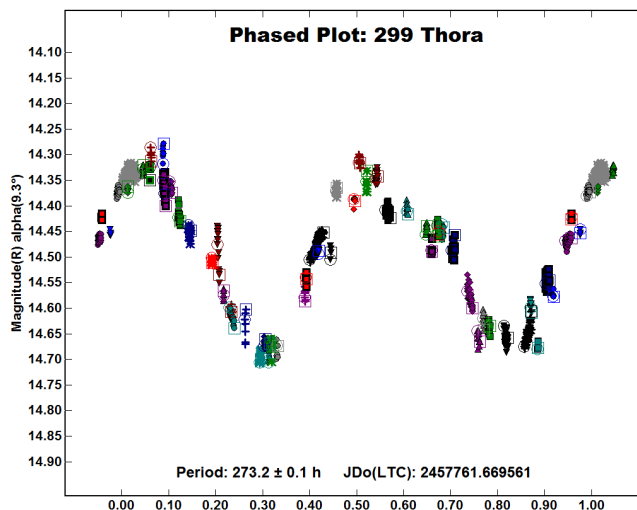


Fig. 3. Phased lightcurve of 299 Thora based on 54 sessions covering 2017 Jan 8 to Mar 26.

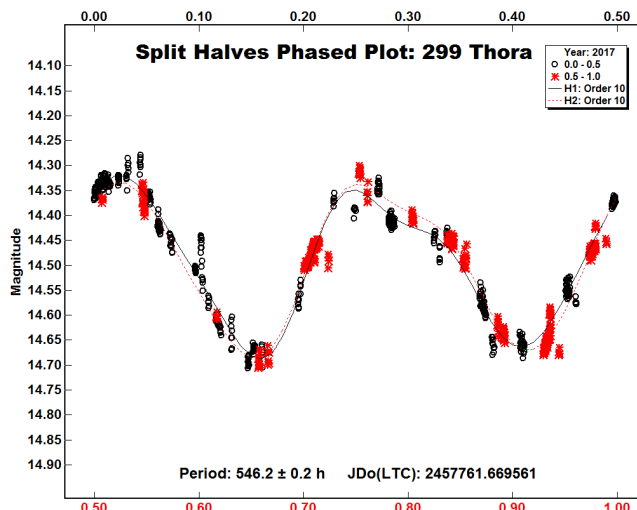


Fig. 4. Split halves lightcurves of 299 Thora over the interval 2017 Jan 8 to Mar 26 for a presumed double period of 546.2 h.

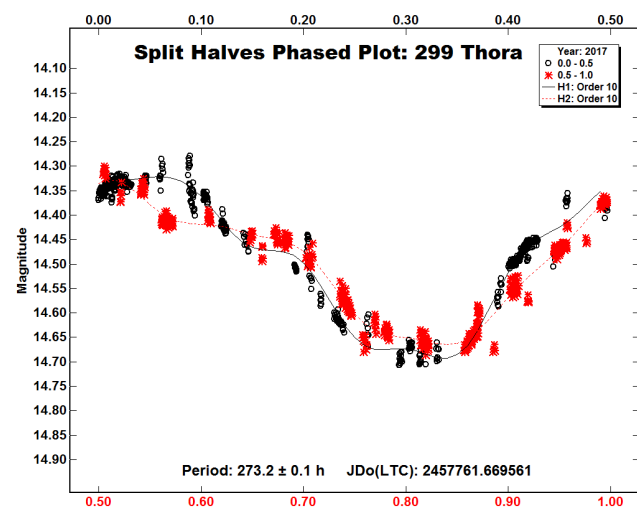


Fig. 5. Split halves lightcurves of 299 Thora over the interval 2017 Jan 8 to Mar 26 for a presumed period of 273.2 h.

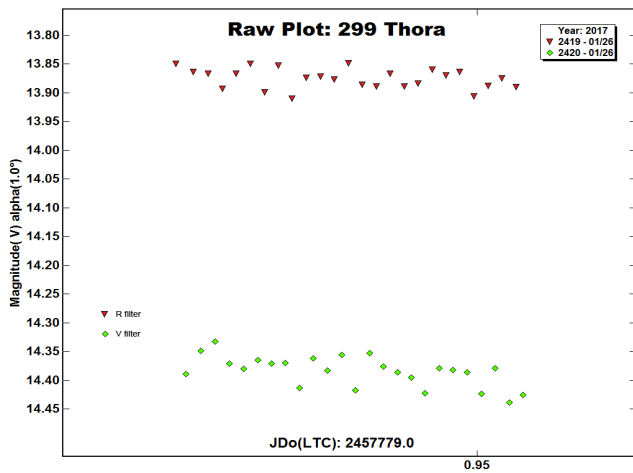


Fig. 6. Observations of 299 Thora 2017 Jan. 26 in R and V magnitudes.

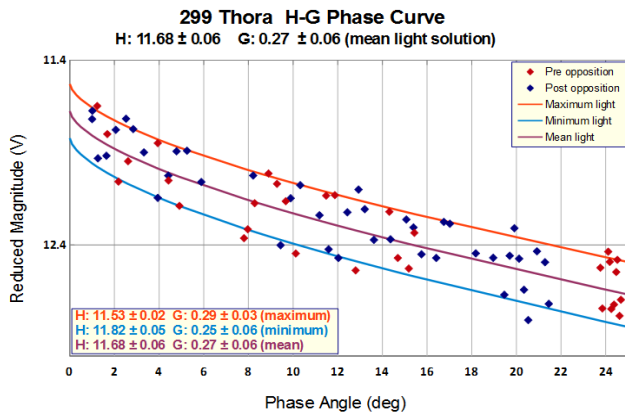


Fig. 7. H-G plots for 299 Thora for maximum, mean, and minimum light data.

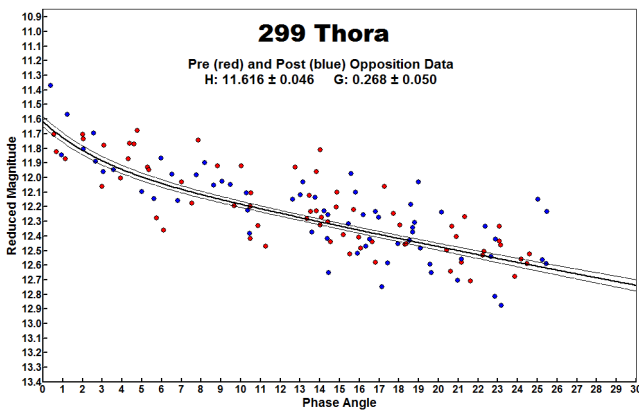


Fig. 8. H-G plot for 299 Thora using USNO Flagstaff Station data.

**496 Gryphia.** The only previously published results are from Behrend (2006;  $P = 18.0$  h,  $A = 0.05$  mag) based on a sparse lightcurve. Pilcher obtained a six-hour lightcurve on 2015 May 15 that showed little variation and is published here for the first time (Fig. 9). The first lightcurve of the next apparition was obtained 2016 Sep 22 and also showed very little variation. On the basis of these results, very slow rotation was suspected.

On subsequent nights, the recommended procedure of obtaining short sessions on every clear night was followed. Fig. 10 is a raw

plot of the first four sessions covering 2016 Sep 22-25 and reveals a very slowly changing lightcurve. Another raw plot (Fig. 11) of the seven-hour session on Oct 11 between short sessions on Oct 10 and 12 shows smooth behavior on the rising part of the lightcurve. From 2016 Sep 22 to 2017 Feb 11, a total of 97 sessions, most of them 15 to 30 minutes, were obtained. All observations were obtained with using the same equipment and camera at Organ Mesa Observatory.

A single-period lightcurve was constructed with *MPO Canopus* with best fit to a period of  $1069.5 \pm 0.5$  h and amplitude 1.25 mag with one minimum much deeper than the other (Fig. 12). Three full rotational cycles are included. While a period of 1069.5 hours is well defined by the data, there are variations up to 0.2 magnitudes between successive cycles, a variation much larger than the internal accuracy of the CMC-15 catalog.

Fig. 13 shows the raw lightcurve using data from 2016 Sep 22 to Dec 1. Fig. 14 shows a raw plot of data from 2016 Dec 1 to 2017 Feb 11. Splitting the full set this way spreads out the data horizontally and displays more clearly both smooth night-to-night variation and considerable variation among the three cycles. This variation among the three cycles strongly suggests tumbling behavior.

For tumbling asteroids, the systematic errors are much larger than the formal error in the single period plot. A simultaneous two-period solution was used to find a principal period of  $1072 \pm 2$  h and confirm tumbling,  $PAR = -2$  (Pravec et al., 2005) but with only three cycles, a second period was indeterminate. Twenty images each in R and V filters were obtained alternately on 2016 Nov 9 and plotted together (Fig 15), in which R and V magnitudes are separated by  $V-R = 0.48$ .

We used the most recent data to find the H-G parameters for the asteroid:

- Maximum light:  $H = 11.79 \pm 0.03, G = 0.34 \pm 0.03$
- Mean light:  $H = 12.21 \pm 0.05, G = 0.18 \pm 0.04$
- Minimum light:  $H = 12.64 \pm 0.04, G = 0.02 \pm 0.03$

These results are shown in Fig. 16. A parallel study with sparse data from USNO Flagstaff Station shows a large scatter due to the large rotational amplitude. Using mean light, we found  $H = 12.062 \pm 0.094, G = 0.204 \pm 0.092$  (Fig. 17), which agree within the expected errors with the mid-light value from the current study.

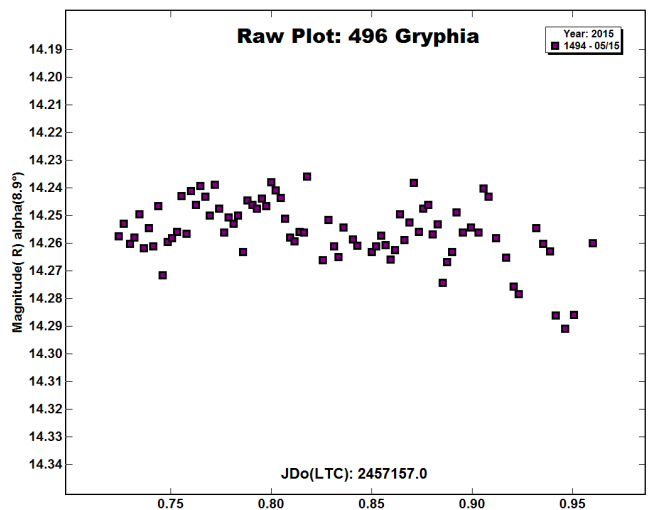


Fig. 9. Raw lightcurve of 496 Gryphia (2015 May 15).

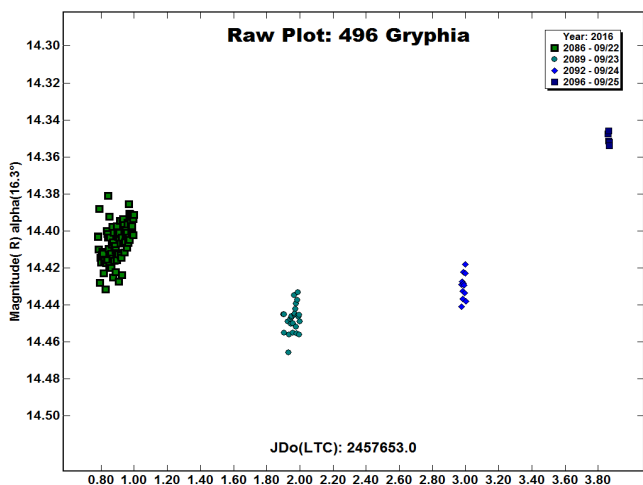


Fig. 10. Raw lightcurve of 496 Gryphia (2016 Sept. 22-25).

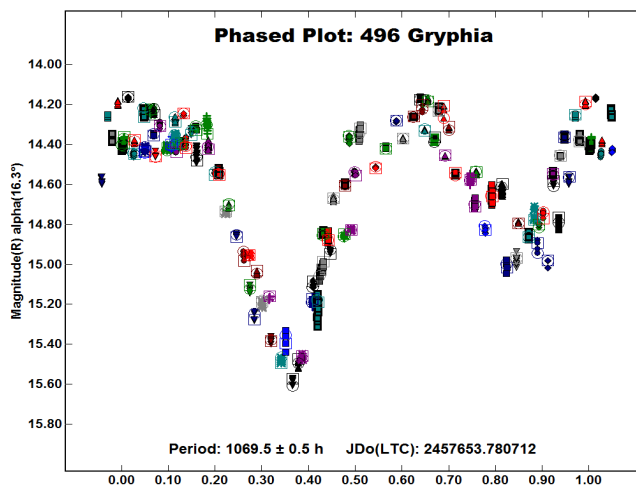


Fig. 12. Single period lightcurve of 496 Gryphia based on 97 sessions 2016 Sep 22 to 2017 Feb 11 in R band magnitudes, corrected for changes in phase angle and geocentric-heliocentric distances using *MPO Canopus*.

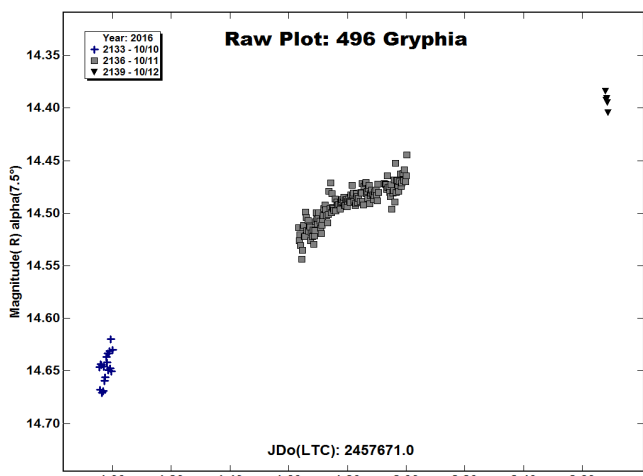


Fig. 11. Raw lightcurve of 496 Gryphia (2016 Oct. 10-12).

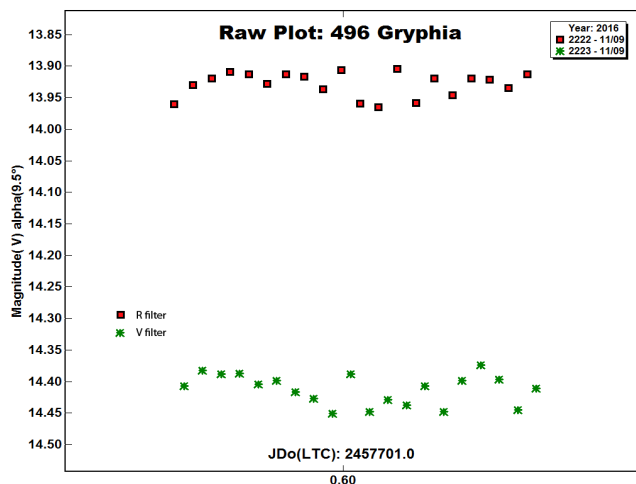


Fig. 15. R and V observations of 496 Gryphia (2016 Nov 9).

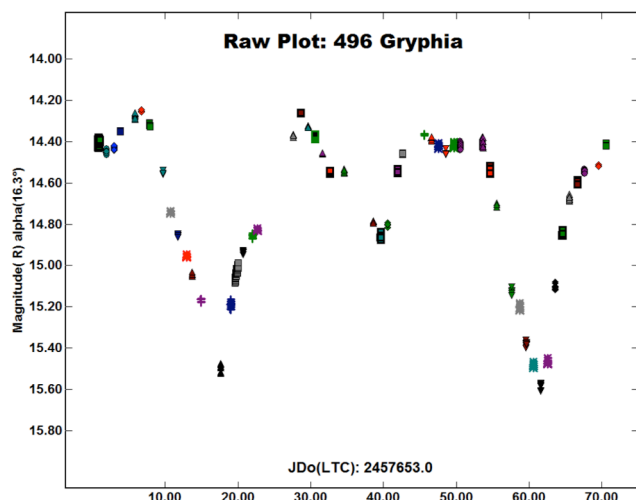


Fig. 13 (left) Raw lightcurve of 496 Gryphia for the interval 2016 Sept. 22 - Dec. 1.

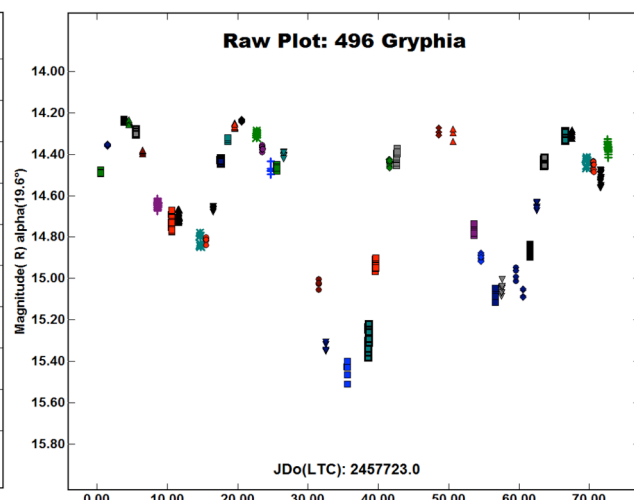


Fig. 14 (right) Raw lightcurve of 496 Gryphia for the interval 2016 Dec. 1 - 2017 Feb. 11

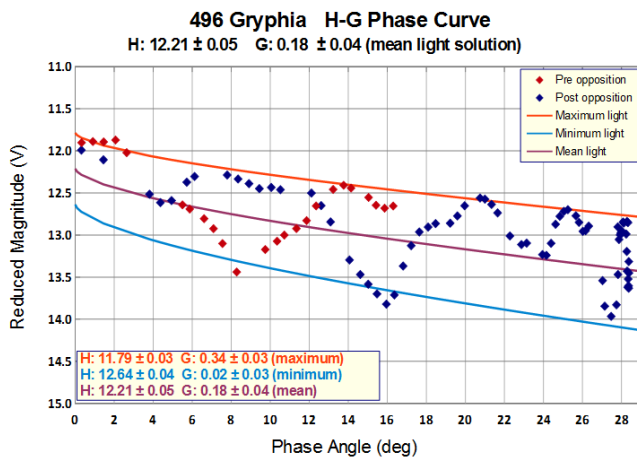


Fig. 16. H-G plots using maximum, mean, and minimum light.

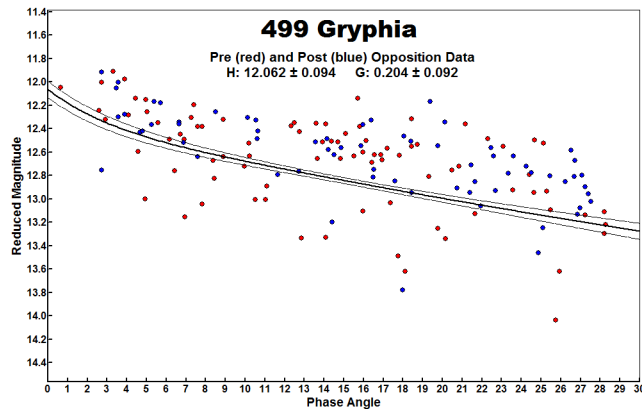


Fig. 17. H-G plot using USNO Flagstaff Station data.

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#### ROTATION PERIOD DETERMINATION FOR 2411 ZELLNER, 5293 BENTENGAHAMA, AND 9148 BORISZAITSEV

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Photometric observations of three main-belt asteroids were made from the Astronomical Observatory of the University of Siena (Italy) in order to determine their synodic rotation periods. For 2411 Zellner, we found a period of  $2.975 \pm 0.002$  h with an amplitude of 0.33 mag. For 5293 Bentengahama, the period was  $15.781 \pm 0.002$  h with an amplitude of 0.18 mag. For 9148 Boriszaitsev, we found  $8.124 \pm 0.02$  h with an amplitude of 0.23 mag.

CCD photometric observations of three main-belt asteroids were carried out in 2017 January-March at the Astronomical Observatory of the University of Siena (K54). We used a 0.30-m  $f/5.6$  Maksutov-Cassegrain telescope, SBIG STL-6303E CCD camera, and clear filter. The pixel scale was 2.30 arcsec when binning 2x2 pixels. All exposures were 300 sec. Data processing and analysis were made with *MPO Canopus* (BDW Publishing, 2017). All the images were calibrated with dark and flat-field frames and converted to R magnitudes using solar-colored field stars from a version of the CMC-15 catalogue distributed with *MPO Canopus*. Table I shows the observing circumstances and results.

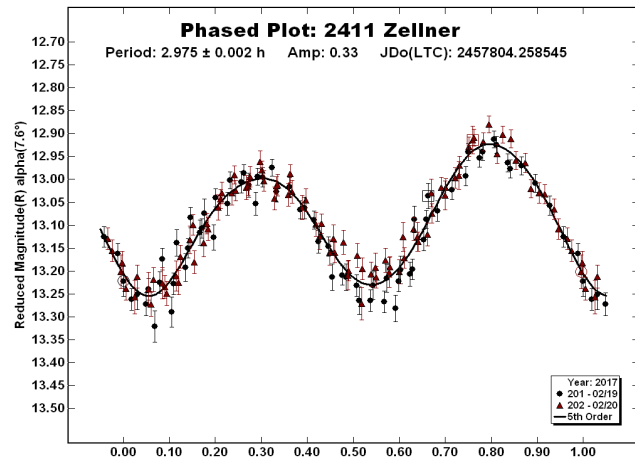
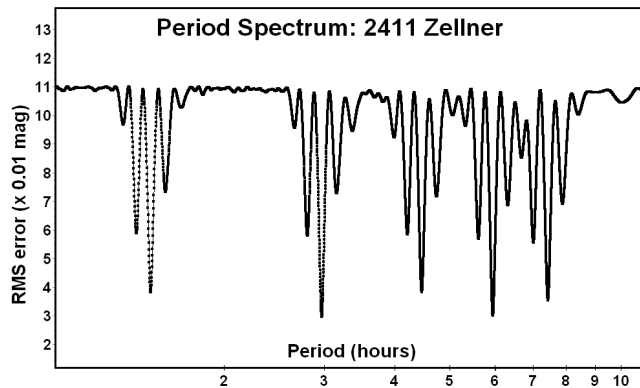
A search of the asteroid lightcurve database (LCDB; Warner et al., 2009) indicates that our results may be the first reported lightcurve observations and results for these objects.

2411 Zellner (1981 JK) was discovered on 1981 January 3 by E. Bowell at Anderson Mesa and is named in honor of Benjamin H. Zellner, an astronomer at the University of Arizona, Tucson. He brought to fruition the polarimetric-photometric method of albedo and diameter determination for asteroids. According to MPC (2017), JPL (2017), and WISE (Masiero et al., 2014), the absolute magnitude is  $H = 12.75$  and  $D = 8.050$  km. This leads to an optical albedo of  $p_V = 0.22 \pm 0.03$ .

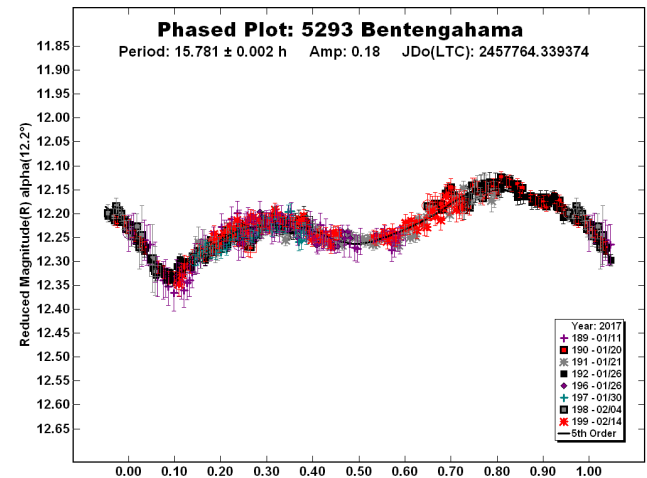
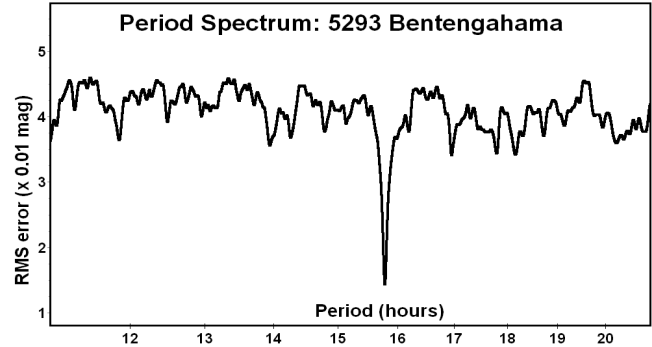
Number	Name	2016 mm/dd	Pts	Phase	$L_{PAB}$	$B_{PAB}$	Period(h)	P.E	Amp	A.E.
2411	1981 JK	02/19-02/20	158	7.1, 7.7	137	0	2.975	0.002	0.33	0.02
5293	1991 BQ2	01/10-02/14	513	12.6, 6.6	135	7	15.781	0.002	0.18	0.03
9148	1977 EL1	03/03-03/17	182	8.5, 0.4	175	1	8.124	0.002	0.23	0.02

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given at the start and end of each date range, unless it reached a minimum, which is the second of three values.  $L_{PAB}$  and  $B_{PAB}$  are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984).

Observations of this asteroid were conducted on two nights, collecting a total of 158 data points. The period analysis shows a clear bimodal solution at  $P = 2.975 \pm 0.002$  h with an amplitude  $A = 0.33 \pm 0.02$  mag.

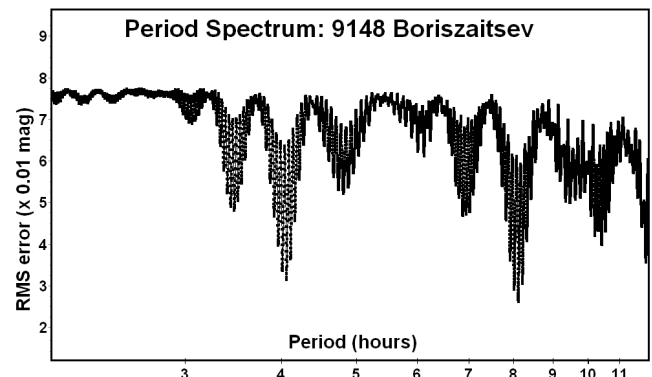


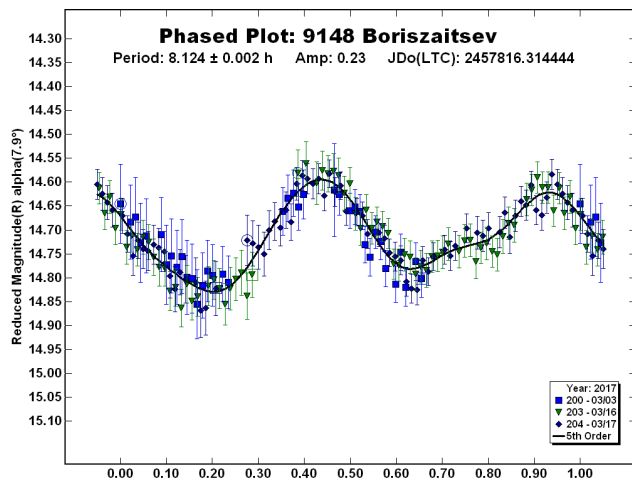
5293 Bentengahama (1991 BQ2) was discovered on 1991 January 23 by M. Matsuyama and K. Watanabe working at Kushiro. It is named for a beautiful sandy beach between Kushirozaki lighthouse and Chiyonoura, in the southern part of Kushiro City. Its absolute magnitude is  $H = 11.8$  (JPL, 2017; MPC, 2017). The WISE survey (Masiero *et al.*, 2011) used  $H = 11.6$  to find  $D = 11.932 \pm 0.308$  km. This gives an optical albedo of  $p_V = 0.284 \pm 0.019$ .



Observations of this asteroid were conducted on eight nights, collecting a total of 513 data points. The period analysis shows a clear bimodal solution with  $P = 15.781 \pm 0.002$  h with an amplitude  $A = 0.18 \pm 0.03$  mag.

9148 Boriszaitsev (1977 EL1) was discovered on 1977 March 13 by N. S. Chernykh at the Crimean Astrophysical Observatory. It is named for Boris Petrovich Zaitsev (1925-2000) who, as a result of an injury in 1945, lost his eyesight and both legs, but was able to graduate from the academy of music and became a leading soloist at the Odessa Philharmonic Society.





According to JPL, the absolute magnitude is  $H = 14.2$  with a diameter of  $3.743 \pm 0.012$  km, which leads to an optical albedo of  $0.190 \pm 0.022$  (JPL, 2017). The WISE survey (Masiero et al., 2011) used  $H = 14.3$  to find  $D = 3.699 \pm 0.073$  km. From this, an optical albedo of  $p_V = 0.247 \pm 0.042$  was derived.

Observations of this asteroid were conducted on three nights, collecting a total of 182 data points. The period analysis shows a clear bimodal solution with  $P = 8.124 \pm 0.002$  h and amplitude  $A = 0.23 \pm 0.02$  mag.

#### Acknowledgements

Some students of the course in Physics and Advanced Technologies at the Department of Physical Sciences, Earth and Environment (DSFTA, 2017) looked in on the observations and the writing of this article during their internship activities at the Astronomical Observatory of the University of Siena, and appear as authors. They want to thank the other students of the same course involved in the observations and in the discussion on the subjects: Cristina Cicali, Marco Lorenzetti, Teodora Palmas and Anna Poggialini.

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## DENSITY AND AXIS-SIZE RELATIONSHIP OF FIVE MAIN-BELT ASTEROIDS: 2017 JANUARY – MARCH

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Despite many decades of minor planet studies focused on external and dynamical properties, there are still hundreds of asteroids that have never been measured. Presented here are the results of photometric analysis applied to five main-belt asteroids. In addition to calculating rotation period, axis ratios assuming a simple ellipsoidal shape and the estimated minimum density of each asteroid are reported.

During the first trimester of 2017, the APT Observatories Group (APTOG onwards) continued with its regular analysis of main-belt asteroids using photometric techniques. During recent years, the group has analyzed more than one hundred main-belt asteroids as well as more than one hundred near-Earth asteroids (NEAs). We have discovered five binary asteroids (see IAU CBET 4272, 4316, 4326, 4345, and 4361). All this work constitutes the APT Asteroid Photometric Survey, which collects lightcurves obtained from APTOG and other observatories, including some within the EURONEAR network.

The APT Observatory Group is made up of two observatories. First is the Isaac Aznar Observatory located in Aras de los Olmos town, Valencia, Spain, under dark skies ( $\sim 21.7$  mag/arcsec<sup>2</sup>). The image scale is 1.44 arcsec/pixel. The second observatory, POP-Punto de Observación de Puçol, Puçol, Spain, is in a semi-urban location equipped with a 0.25-m telescope, SBIG ST-9 CCD, and adaptive optics. The image scale is 1.56 arcsec/pixel.

All images were obtained in 1x1 binning mode and were taken using a clear filter, except for 1106 Cydonia, which was observed using Johnson V and Sloan r' (SR) filters. The SNR for the target assured a lightcurve of sufficient quality and low data dispersion. Dark and bias frames and twilight sky flat-fields were applied to each image.

Table I shows the observation circumstances and period analysis results; Table II shows the derived ellipsoid ratios and densities.

#### Analysis

Data reduction was done with *MPO Canopus*. This software implements the FALC period analysis algorithm developed by Harris (Harris et al., 1989). The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. The comp star magnitudes were

taken from the CMC15 and MPOSC3 catalogs, depending on availability of comparison stars. The APASS catalog was used for 1106 Cydonia SR magnitudes. The nightly zero points for both catalogs have been found to be generally consistent to about  $\pm 0.05$  mag or better.

The StarBGone star subtraction algorithm in *MPO Canopus* was used when needed in order to remove the effect of stars located in the asteroid's path. This is most effective when the star's SNR is equal to or lower than asteroid's SNR. (Aznar, 2013).

When doing period analysis, the period spectrum (RMS vs. period) was reviewed to check for the possibility of other plausible solutions. The number of orders used in the Fourier analysis was dependent on the quality of the lightcurve data (in number and dispersion). A conservative approach was adopted to ensure that using too high of harmonic order did not adversely affect the end result. This becomes important when estimating the shape of the body based on the lightcurve amplitude. For example, a lightcurve with a large amplitude implies an highly elongated shape. If too high a Fourier order is used, the resulting model lightcurve may have an amplitude that is much larger than the shape would actually produce.

Assuming a triaxial body model where  $a > b > c$  (Jacobi ellipsoid) and the object rotates about the  $c$ -axis (Harris and Lupishko 1989) it is possible to determine  $a/b$  axis ratio from the lightcurve amplitude assuming the body has sufficient gravity and low enough rigidity to pull itself into an equilibrium shape. This assumption is likely violated for objects in the size range we discuss here, where the rigid strength of the body (or its constituents if fractured) are likely to dominate the final shape compared to gravitational relaxation into an equilibrium figure. Nevertheless, we proceed with our analysis as an exercise in computing minimal densities for these objects under the equilibrium figure assumption.

When trying to estimate shape information, it is necessary to calibrate the amplitude value  $A(\alpha)$  to the amplitude at zero phase angle  $A(0)$  (Zappala et al., 1990) before trying to estimate the axis ratio. Taking into account the amplitude lightcurve calibrated to zero phase angle, the axis ratios were found for the five asteroids reported here.

It must be said that since the spin axis orientation of the target is unknown, only a lower limit for axis-size relationship can be found. For the values reported here, it was assumed that the observations were made with the center of the optical disc at or near the asteroid equator, i.e., an "equatorial view," and the asteroid is rotating about the  $c$  axis (Binzel et al., 1989).

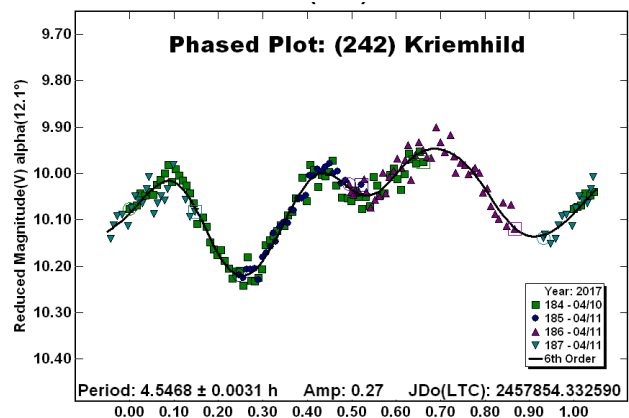
Although density calculations are a subtle task, an attempt was made to calculate the minimum density for each asteroid. The lower limit calculated density for these asteroids was derived by using a criterion for the critical limit of rotation period that depends only on the density of the asteroid.

A rotating sphere will be in a state of hydrostatic equilibrium as long as the rotation frequency does not exceed the surface orbit frequency about the sphere. That assumption means that the centrifugal acceleration at the equator is less than the acceleration of gravity (Pravec and Harris, 2000). Comparing the acceleration of gravity at the surface with the centrifugal acceleration at the equator, it is possible to derive a criterion for the critical limit of rotation period ( $P_c = 2\pi/\omega_c$ ), which depends on the density ( $\rho$ ) of the sphere,

$$Gm/r^2 = \omega_c^2 r \rightarrow P_c = 3.3 \text{ h } \sqrt{\rho}$$

where  $G$  is the gravitational constant,  $m$  is the mass of the sphere, and  $r$  is its radius;  $\rho$  is expressed in  $\text{g/cm}^3$ . There were no previous density estimates against which to compare the results. Since the taxonomic type was not known, it was not possible to compare the results to average values assumed for various taxonomic classes. Regarding the density data interpretation,  $\rho < 1 \text{ gcm}^{-3}$  reveals a porous internal structure while  $\rho > 1 \text{ gcm}^{-3}$  suggests a rocky internal structure (Thirouin et al, 2010).

**242 Kriemhild.** There are eight entries in lightcurve database (LCDB; Warner et al., 2009) that give a period, all of them being about 4.53 h. Analysis of the observations made in 2017 April found  $P = 4.5468 \pm 0.0031$  h, which is similar to the LCDB entries.



**1106 Cydonia.** This is a 12.41 km S-type asteroid. Only one night was required to find the rotation period of  $P = 2.6792 \pm 0.12$  h, which matches Klinglesmith et al. (2016). The lightcurve shows a typical bimodal shape with an amplitude of 0.12 mag, suggesting a nearly spherical shape, or a nearly pole-on viewing aspect.

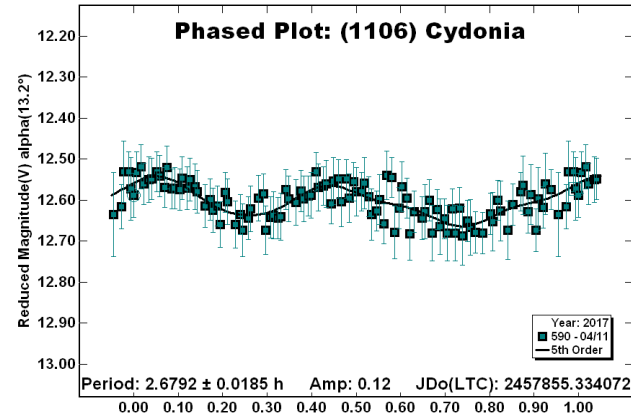
Observations were made Johnson V and Sloan  $r'$  filters in order to calculate the color index. The analysis shows that this main-belt asteroid has a color index  $V-r' = 0.152$ .

Number	Name	2017 mm/dd	Pts	Phase	$L_{PAB}$	$B_{PAB}$	Period	P.E.	Amp	A.E.
242	Kriemhild	04/11-04/12	176	12.1, 12.4	174	-6	4.5468	0.0031	0.27	0.02
1106	Cydonia	04/12-04/12	105	13.6	179	-11	2.6700	0.0181	0.10	0.01
2825	Crosbi	02/20-02/26	79	8.2, 11.3	137	7	2.8131	0.0001	0.09	0.03
18007	Dianeingrao	03/21-03/21	78	6.7	14	-10	4.447	0.089	0.15	0.05
27675	1981 CH	01/17-01/28	245	9.0, 10.0	116	12	2.966	0.01	0.10	0.04

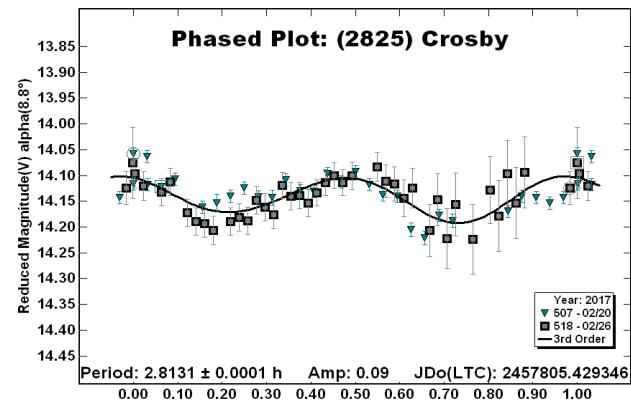
Table I. Observing circumstances and results. Pts is the number of data points used in the analysis. The phase angle values are for the first and last date.  $L_{PAB}$  are the average phase angle bisector latitude. Period is in hours. Amp is peak-to-peak amplitude in magnitudes.

Number	Name	D km	a/b	b/c	$\rho$
242	Kriemhild	40.8	1.234	1.046	0.647
1106	Cydonia	12.4	1.075	1.011	1.636
2825	Crosby	2.8	1.076	1.015	1.485
18007	Dianeingrao	4.6	1.139	1.026	0.628
27675	1981 CH	5.1	1.085	1.016	1.347

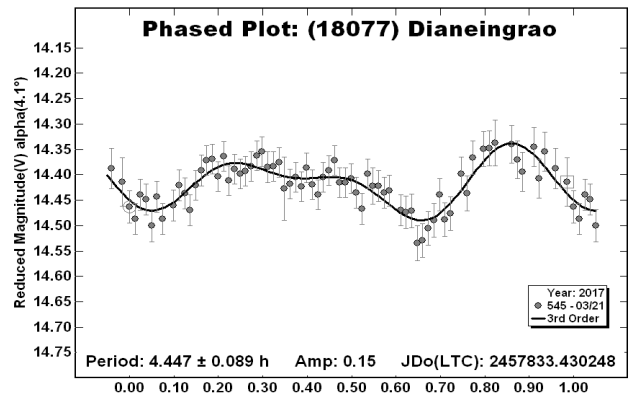
Table II. D is from the JPL Small Bodies Node. Columns 4 and 5 give the a/b and b/c ratios for an assumed triaxial ellipsoid viewed equatorially based on the amplitude.  $\rho$  is the minimum density ( $\text{gcm}^{-3}$ ).



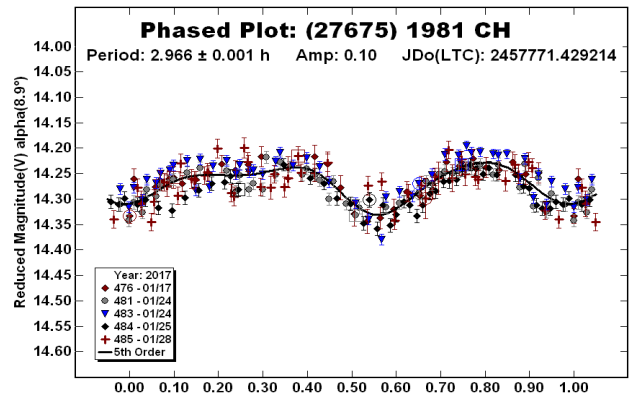
2825 Crosby. This is a binary main-belt asteroid. The satellite was discovered in 2017 February by Pray et al. (2017a). We observed the asteroid for a total of seven hours and our analysis found a period of  $2.8131 \pm 0.0179$  h. This matches the primary period found by Pray et al. (2017a) who assumed a density of  $1.6 \text{ gcm}^{-3}$ . This is similar to  $\rho = 1.6 \text{ gcm}^{-3}$  given here. Again, this value is a minimum since it assumed a full equatorial view of the asteroid when finding the axis ratios.



18077 Dianeingrao. No references with period were found in LCDB for this target. APTOG followed this asteroid for one night. Inclement weather prevented additional observations. The lightcurve has a period of  $P = 4.447 \pm 0.089$  h, but this is not certain. Observations at future oppositions are encouraged.



(27675) 1981 CH. This is a binary main-belt asteroid. The satellite was discovered in 2017 February by Pray et al. (2017b). Members of the APTOG group were among the co-discoverers. The rotation period obtained by APTOG of  $P = 2.966 \pm 0.001$  h matches the period from Pray et al. (2017b).



Acknowledgements

I would like to express my gratitude to Brian Warner for supporting LCDB as main database for study of asteroids and for all suggestions provided.

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## LIGHTCURVE PHOTOMETRY OPPORTUNITIES: 2017 JULY-SEPTEMBER

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We present lists of asteroid photometry opportunities for objects reaching a favorable apparition and have no or poorly-defined lightcurve parameters. Additional data on these objects will help with shape and spin axis modeling via lightcurve inversion. We also include lists of objects that will be the target of radar observations. Lightcurves for these objects can help constrain pole solutions and/or remove rotation period ambiguities that might not come from using radar data alone.

We present several lists of asteroids that are prime targets for photometry during the period 2017 July-September.

In the first three sets of tables, "Dec" is the declination and "U" is the quality code of the lightcurve. See the asteroid lightcurve data base (LCDB; Warner *et al.*, 2009) documentation for an explanation of the U code:

<http://www.minorplanet.info/lightcurvedatabase.html>

The ephemeris generator on the CALL web site allows you to create custom lists for objects reaching  $V \leq 18.5$  during any month in the current year, *e.g.*, limiting the results by magnitude and declination.

[http://www.minorplanet.info/PHP/call\\_OppLCDBQuery.php](http://www.minorplanet.info/PHP/call_OppLCDBQuery.php)

We refer you to past articles, *e.g.*, *Minor Planet Bulletin* **36**, 188, for more detailed discussions about the individual lists and points of advice regarding observations for objects in each list.

Once you've obtained and analyzed your data, it's important to publish your results. Papers appearing in the *Minor Planet Bulletin* are indexed in the Astrophysical Data System (ADS) and so can be referenced by others in subsequent papers. It's also important to make the data available at least on a personal website or upon request. We urge you to consider submitting your raw data to the ALCDEF page on the Minor Planet Center web site:

[http://www.minorplanetcenter.net/light\\_curve](http://www.minorplanetcenter.net/light_curve)

We believe this to be the largest publicly available database of raw lightcurve data that contains 2.5 million observations for more than 11500 objects.

Now that many backyard astronomers and small colleges have access to larger telescopes, we have expanded the photometry opportunities and spin axis lists to include asteroids reaching  $V = 15.3$  and brighter.

### Lightcurve/Photometry Opportunities

Objects with  $U = 3-$  or  $3$  are excluded from this list since they will likely appear in the list below for shape and spin axis modeling. Those asteroids rated  $U = 1$  should be given higher priority over those rated  $U = 2$  or  $2+$ , but not necessarily over those with no period. On the other hand, do *not overlook asteroids with  $U = 2/2+$  on the assumption that the period is sufficiently established.* Regardless, do not let the existing period influence your analysis since even high quality ratings have been proven wrong at times. Note that the lightcurve amplitude in the tables could be more or less than what's given. Use the listing only as a guide.

An entry in bold italics is a near-Earth asteroid (NEA).

Number	Name	Brightest			LCDB Data		
		Date	Mag	Dec	Period	Amp	U
3830	Trelleborg	07 02.3	15.1	-17		0.05	
3927	Feliciaplatt	07 02.7	15.2	-21			
6045	1991 RG9	07 04.7	15.3	-16			
10487	Danpeterson	07 04.9	14.1	-28			
1279	Uganda	07 05.8	14.0	-32	23.2	0.16	1
2728	Yatskiv	07 09.2	14.5	-17			
3652	Soros	07 11.3	14.7	-19			
3961	Arthurcox	07 12.2	14.6	-33			
105127	2000 MH1	07 13.4	14.7	-27			
5933	Kemurdzhan	07 13.9	15.3	-22			
4140	Branham	07 15.0	14.9	-19			
5778	Jurafrance	07 15.3	14.5	-16	4.14	0.27	2-
<b>190166</b>	<b>2005 UP156#</b>	<b>07 15.8</b>	<b>14.4</b>	<b>+14</b>	<b>40.5</b>	<b>0.79</b>	<b>2</b>
9927	Tyutchev	07 16.7	15.3	-10	2.51	0.15	2
6358	Chertok	07 16.9	14.8	-33			
2736	Ops	07 19.0	15.3	-12			
820	Adriana	07 20.9	14.3	-21			
3216	Harrington	07 22.0	14.4	-23			
13538	1991 ST	07 23.2	14.5	-31			
	2017 BS5	07 23.9	15.1	-22			
39235	2000 YH55	07 26.3	14.8	-28			
7832	1993 FA27	07 26.4	15.3	-8	8.295	0.03	2
4976	Choukyongchol	07 26.5	15.3	-10	4.419	0.88	2
14665	1999 CC5	07 26.6	15.1	-27			
2558	Viv	07 26.7	15.1	-30			
31775	1999 JN122	07 27.8	15.3	-12			
2249	Yamamoto	07 28.1	15.1	-17	31.59	0.14	2
31498	1999 CX61	07 28.9	15.1	-7			
6490	1991 NR2	07 29.3	15.1	+0	4.468	0.26	2+
5913	1990 BU	07 30.0	14.6	-26	52.	0.10	1
13989	Murikabushi	07 30.7	15.2	-20			
3802	Dornburg	07 31.2	15.2	-16			
19530	1999 GQ23	07 31.6	15.2	-17			
<b>138925</b>	<b>2001 AU43#</b>	<b>08 02.3</b>	<b>13.5</b>	<b>-11</b>			
3839	Bogaevskij	08 03.1	15.1	-13	129.936	0.44	2
3699	Milbourn	08 03.3	14.5	-24			
4225	Hobart	08 03.5	14.7	-24			
7996	Vedernikov	08 05.1	14.8	+0			
2898	Neuvo	08 05.3	15.0	-23			
11233	1999 JA82	08 05.8	15.3	-29			
6963	1990 OQ3	08 08.4	14.8	-12			
33982	2000 NQ23	08 10.1	14.9	-15	4.227	0.33	2
9865	Akiraohata	08 10.2	15.2	-7	2.96	0.08	2
14375	1989 SU	08 11.6	15.1	-11			
2440	Educatio	08 12.9	14.4	-6			
1551	Argelander	08 13.0	14.5	-18	4.061	0.41	2
20885	2000 WD2	08 13.2	15.3	-9	3.07	0.16	2
31947	2000 GO109	08 13.5	15.0	-7	3.822	0.07	2
11434	Lohnert	08 14.8	15.1	-22			
21893	1999 VL4	08 15.1	14.1	-20			
2718	Handley	08 15.6	15.1	-16			
23621	1996 PA	08 15.8	14.7	-13			
15549	2000 FN	08 16.8	14.8	-18			
30769	1984 ST2	08 17.2	15.1	-17		0.65	
12674	Rybalka	08 18.8	15.0	-12	3.594	0.22	2
9200	1993 FK21	08 19.3	15.0	-10			

(cont'd)		Brightest			LCDB Data		
Number	Name	Date	Mag	Dec	Period	Amp	U
2833	Radishchev	08 22.1	15.1	-12			
6021	1991 TM	08 22.1	15.3	-14			
7604	Kridsadaporn	08 23.0	14.7	-13			
20445	1999 JN77	08 23.0	15.2	-17		0.85	
2865	Laurel	08 24.2	14.4	-7	21.5	0.15	2
6693	1986 CC2	08 24.4	14.9	-6			
11745	1999 NH3	08 25.0	15.2	-8			
1132	Hollandia	08 25.5	13.1	-21	5.36	0.15-0.35	2+
1418	Fayeta	08 27.4	13.2	-16	63.641	0.15-0.24	2+
9462	1998 HC37	08 28.0	15.1	-9	3.432	0.30	2
12377	1994 PP	08 28.2	15.0	+14	9.49	0.23-0.47	2
5945	Roachapproach	08 29.4	14.9	-16			
7198	Montelupo	08 29.4	14.7	-19			
9131	1998 JV	08 31.3	15.3	-6	26.839	0.67	2
1603	Neva	09 01.1	14.1	-15	6.424	0.22-0.25	2
5813	Eizaburo	09 01.6	15.1	+2			
1159	Granada	09 03.1	14.0	-11	31.	0.24-0.28	2
3716	Petzval	09 04.1	15.1	-9			
1215	Boyer	09 06.8	14.0	-23	10.36	0.31-0.50	2
7629	Foros	09 07.7	15.3	-6			
1256	Normannia	09 07.8	14.7	-1	488.063	0.39	2
876	Scott	09 09.1	14.4	-10	11.814	0.25-0.35	2
1604	Tombaugh	09 10.0	14.1	+4	7.047	0.16-0.35	2+
3973	Ogilvie	09 10.0	14.3	-8	21.211	0.29	2
14892	1991 VE5	09 10.2	15.1	-11			
73714	1992 SW14	09 10.4	15.3	-2			
11004	Stenmark	09 11.1	15.2	-6			
8994	Kashkashian	09 11.2	15.1	+2			
10132	Lummelunda	09 11.8	15.1	-1			
8577	Choseikomori	09 12.4	15.3	+3			
29564	1998 ED6	09 12.6	15.1	+14			
6125	1989 CN	09 15.1	15.1	-4			
2021	Poincare	09 15.2	14.5	-6			
2353	Alva	09 15.2	14.7	-7			
24367	2000 AC126	09 15.2	15.3	-15			
3341	Hartmann	09 18.4	15.0	-11			
4911	Rosenzweig	09 18.4	14.5	+11			
2633	Bishop	09 18.6	14.5	-7			
2414	Vibeke	09 18.7	15.2	-2			
5359	Markzakharov	09 19.0	15.2	-5			
6854	1987 UG	09 19.7	15.2	+0	3.64	0.66	2
3863	Gilyarovskij	09 20.1	14.5	-1			
11923	1992 WX	09 21.7	15.2	-8			
4307	Chereshchuk	09 21.9	15.3	-4	2.724	0.24	2
2498	Tsessevich	09 22.6	15.2	+1	3.059	0.15	2
18295	Borispetrov	09 22.6	15.1	-18			
20310	1998 FD117	09 23.7	15.3	+13	5.488	0.07	1
57038	2001 AX39	09 23.7	15.4	+1			
6032	Nobel	09 24.0	14.7	+2			
2944	Peyo	09 24.1	15.2	+5			
3944	Halliday	09 24.5	15.2	-12	5.565	0.32	2
3702	Trubetskaya	09 25.0	13.9	-24			
2585	Irpedita	09 26.4	13.7	-7			
994	Othhild	09 26.6	12.6	+2	5.95	0.09-0.15	2+
7297	1992 UG	09 28.6	15.0	-11			
16024	1999 CT101	09 28.9	15.5	+2	2.804	0.13	2
9755	1990 RR2	09 29.1	15.3	+4			
1004	Belopolskya	09 29.4	14.2	+0	9.44	0.14	2
2902	Westerlund	09 29.7	14.8	+1			
	1989 VB	09 30.0	14.1	-53	16.	0.32	2
4691	Toyen	09 30.8	14.7	-4			
15419	1998 FZ62	09 30.9	15.4	+3			

### Low Phase Angle Opportunities

The Low Phase Angle list includes asteroids that reach very low phase angles. The " $\alpha$ " column is the minimum solar phase angle for the asteroid. Getting accurate, calibrated measurements (usually V band) at or very near the day of opposition can provide important information for those studying the "opposition effect." Use the on-line query form for the LCDB

[http://www.minorplanet.info/PHP/call\\_OppLCDBQuery.php](http://www.minorplanet.info/PHP/call_OppLCDBQuery.php)

to get more details about a specific asteroid.

You will have the best chance of success working objects with low amplitude and periods that allow covering at least half a cycle every night. Objects with large amplitudes and/or long periods are much more difficult for phase angle studies since, for proper analysis, the data must be reduced to the average magnitude of the

asteroid for each night. This reduction requires that you determine the period and the amplitude of the lightcurve; for long period objects that can be difficult. Refer to Harris *et al.* (1989; *Icarus* **81**, 365-374) for the details of the analysis procedure.

As an aside, some use the maximum light to find the phase slope parameter ( $G$ ). However, this can produce a significantly different value for both  $H$  and  $G$  versus when using average light, which is the method used for values listed by the Minor Planet Center.

The International Astronomical Union (IAU) has adopted a new system,  $H-G_{12}$ , introduced by Muinonen *et al.* (2010; *Icarus* **209**, 542-555). However it will be some years before it becomes the general standard and, furthermore, it is still in need of refinement. That can be done mostly through having more data for more asteroids, but only if there are data at very low and moderate phase angles. Therefore, we strongly encourage observers to obtain data for these objects not only at very low phase angles, but to follow them well before and/or after opposition, *i.e.*, out to phase angles of 15-30 degrees.

Num	Name	Date	$\alpha$	V	Dec	Period	Amp	U
476	Hedwig	07 01.8	0.90	11.4	-25	27.33	0.13-0.17	3
548	Kressida	07 02.4	0.36	14.5	-22	11.940	0.44	2
569	Misa	07 07.9	0.19	14.2	-23	13.52	0.25	2
6463	Isoda	07 12.8	0.49	14.3	-21	6.15	0.21	3-
307	Nike	07 15.2	0.60	14.4	-23	7.902	0.16-0.23	3
511	Davida	07 15.8	0.63	11.3	-24	5.1297	0.05-0.25	3
414	Lirioppe	07 19.5	0.40	14.5	-22	7.353	0.13	3-
820	Adriana	07 20.8	0.10	14.3	-21			
1112	Polonia	07 21.7	0.34	14.0	-21	82.5	0.20	2
370	Modestia	07 21.8	0.95	12.9	-18	22.530	0.24-1.39	3
492	Gismonda	07 26.5	0.98	13.2	-22	6.488	0.10	3
1085	Amaryllis	07 27.1	0.91	13.9	-17	18.2	0.20	2
1635	Bohrmann	08 02.0	0.90	14.4	-16	5.864	0.25-0.50	3
717	Wisibada	08 08.6	0.52	14.1	-17			
382	Dodona	08 09.1	0.19	12.8	-15	4.113	0.39-0.42	3
945	Barcelona	08 09.3	0.58	14.2	-18	7.36	0.09-0.13	3
1653	Yakhontovia	08 12.0	0.97	13.7	-13	15.41	0.03	2
1142	Aetolia	08 27.2	0.26	14.5	-11	10.730	0.20-0.22	3-
6091	Mitsuru	08 27.9	0.54	14.2	-11	5.853	0.80	3
1120	Cannonia	09 06.7	0.45	13.3	-07	3.816	0.15-0.16	3
271	Penthesilea	09 08.6	0.38	13.3	-05	18.787	0.33	3
120	Lachesis	09 10.1	0.34	12.1	-04	46.551	0.14-0.22	3
732	Tjilaki	09 11.7	0.61	13.4	-03	12.34	0.19	3-
107	Camilla	09 13.3	0.17	12.0	-03	4.844	0.32-0.53	3
2111	Tselina	09 14.9	0.50	14.1	-04	6.563	0.17	3
3868	Mendoza	09 16.8	0.32	14.4	-03	2.771	0.07-0.20	3
755	Quintilla	09 18.7	0.10	14.5	-02	4.552	0.08-0.45	3
277	Elvira	09 19.9	0.59	13.1	+00	29.69	0.34-0.59	3
3863	Gilyarovskij	09 20.2	0.17	14.5	-01			
337	Devosa	09 23.4	0.51	11.4	+01	4.653	0.08-0.75	3
994	Othhild	09 26.6	0.30	12.6	+02	5.95	0.09-0.15	2+
2251	Tikhov	09 26.8	0.94	14.1	+03	5.67	0.39	3
1004	Belopolskya	09 29.4	0.77	14.2	+00	9.44	0.14	2
291	Alice	09 29.5	0.60	14.0	+01	4.313	0.09-0.55	3

### Shape/Spin Modeling Opportunities

Those doing work for modeling should contact Josef Ďurech at the email address above. If looking to add lightcurves for objects with existing models, visit the Database of Asteroid Models from Inversion Techniques (DAMIT) web site

<http://astro.troja.mff.cuni.cz/projects/asteroids3D>

An additional dense lightcurve, along with sparse data, could lead to the asteroid being added to or improving one in DAMIT, thus increasing the total number of asteroids with spin axis and shape models.

Included in the list below are objects that:

1. Are rated  $U = 3-$  or 3 in the LCDB
2. Do not have reported pole in the LCDB Summary table
3. Have at least three entries in the Details table of the LCDB where the lightcurve is rated  $U \geq 2$ .

The caveat for condition #3 is that no check was made to see if the lightcurves are from the same apparition or if the phase angle bisector longitudes differ significantly from the upcoming apparition. The last check is often not possible because the LCDB does not list the approximate date of observations for all details records. Including that information is an on-going project.

Favorable apparitions are in bold text. NEAs are in italics.

Num	Name	Brightest			LCDB Data		U
		Date	Mag	Dec	Period	Amp	
3873	Roddy	07 02.7	15.3	+5	2.4782	0.05-0.11	3
582	Olympia	07 03.8	14.1	+13	36.312	0.05- 0.6	3
860	Ursina	07 04.8	13.7	-33	9.386	0.22-0.50	3
503	Evelyn	07 08.2	13.7	-27	38.78	0.30- 0.5	3-
734	Benda	07 10.0	14.6	-30	7.11	0.28-0.32	3
721	Tabora	07 10.4	14.4	-33	7.982	0.19-0.30	3
3754	Kathleen	07 12.1	14.8	-22	11.18	0.13-0.20	3-
3223	Forsius	07 13.3	15.5	-9	2.343	0.20-0.28	3
2903	Zhuhai	07 13.9	15.5	-2	5.263	0.32-0.54	3
654	Zelinda	07 14.6	12.3	-14	31.735	0.08- 0.3	3
766	Moguntia	07 16.7	14.9	-35	4.816	0.06-0.23	3
256	Walpurga	07 18.2	14.0	-2	16.664	0.25-0.58	3
78	Diana	07 21.6	12.5	-28	7.299	0.02-0.30	3
205	Martha	07 22.3	13.2	-4	14.911	0.10-0.50	3
<b>839</b>	<b>Valborg</b>	<b>07 23.7</b>	<b>13.3</b>	<b>-34</b>	<b>10.366</b>	<b>0.14-0.19</b>	<b>3</b>
479	Caprera	07 24.4	13.4	-16	9.43	0.10-0.25	3
1717	Arlon	07 24.5	15.3	-26	5.148	0.07-0.12	3
<b>1369</b>	<b>Ostanina</b>	<b>07 26.4</b>	<b>14.0</b>	<b>+0</b>	<b>8.400</b>	<b>0.3 -1.11</b>	<b>3</b>
261	Prymno	07 28.1	12.4	-22	8.002	0.13-0.20	3
<b>913</b>	<b>Otila</b>	<b>07 28.1</b>	<b>13.2</b>	<b>-25</b>	<b>4.872</b>	<b>0.09-0.45</b>	<b>3</b>
<b>1246</b>	<b>Chaka</b>	<b>08 01.4</b>	<b>12.4</b>	<b>-7</b>	<b>25.462</b>	<b>0.18-0.25</b>	<b>3</b>
1845	Helewalda	08 01.7	15.4	-14	7.279	0.15-0.28	3-
583	Klotilde	08 01.9	14.2	-9	9.214	0.17-0.30	3
585	Bilkis	08 03.3	14.1	-9	8.577	0.10-0.41	3
219	Thusnelda	08 05.2	11.2	+3	59.74	0.19-0.24	3
524	Fidelio	08 05.9	13.1	-20	14.198	0.18-0.22	3
195	Eurykleia	08 06.9	13.2	-25	16.521	0.10-0.24	3
453	Tea	08 10.3	12.7	-23	6.812	0.03-0.37	3
834	Burnhamia	08 11.6	12.8	-11	13.875	0.15-0.22	3
<b>545</b>	<b>Messalina</b>	<b>08 12.0</b>	<b>12.3</b>	<b>-19</b>	<b>7.2</b>	<b>0.22-0.27</b>	<b>3</b>
656	Beagle	08 14.2	14.8	-14	7.035	0.57-1.20	3
465	Alekto	08 18.6	14.0	-10	10.936	0.12-0.16	3
<b>20691</b>	<b>1999 VY72</b>	<b>08 21.7</b>	<b>14.8</b>	<b>-42</b>	<b>2.699</b>	<b>0.11-0.18</b>	<b>3</b>
1308	Halleria	08 22.4	14.8	-15	6.028	0.14-0.17	3
267	Tirza	08 22.6	13.6	-20	7.648	0.18- 0.4	3
2460	Mitlincoln	08 24.3	15.4	-9	3.01	0.03-0.20	3
418	Alemannia	08 24.8	12.7	+0	4.671	0.20-0.33	3
124	Alkeste	08 25.0	11.3	-8	9.906	0.08-0.30	3
1562	Gondolatsch	08 25.9	14.5	-14	8.78	0.30- 0.4	3-
<b>3122</b>	<b>Florence</b>	<b>08 31.1</b>	<b>8.6</b>	<b>-11</b>	<b>2.358</b>	<b>0.12-0.27</b>	<b>3</b>
<b>5040</b>	<b>Rabinowitz</b>	<b>09 02.1</b>	<b>14.5</b>	<b>+6</b>	<b>4.690</b>	<b>0.31-0.35</b>	<b>3</b>
<b>8116</b>	<b>Jeanperrin</b>	<b>09 02.6</b>	<b>15.5</b>	<b>-18</b>	<b>3.617</b>	<b>0.09-0.10</b>	<b>3</b>
456	Abnoba	09 04.3	13.4	+13	18.281	0.2 -0.32	3
1453	Fennia	09 05.0	14.4	-30	4.412	0.10-0.20	3
1095	Tulipa	09 06.3	14.6	-3	2.787	0.14-0.23	3
643	Scheherezade	09 08.9	14.9	+12	14.161	0.23-0.36	3
2195	Tengstrom	09 10.2	14.3	-13	2.821	0.17-0.45	3
2653	Principia	09 12.0	15.4	-1	5.523	0.45-0.52	3
<b>6394</b>	<b>1990 QM2</b>	<b>09 12.5</b>	<b>14.9</b>	<b>-11</b>	<b>3.687</b>	<b>0.25-0.39</b>	<b>3</b>
<b>4905</b>	<b>Hiroimi</b>	<b>09 13.8</b>	<b>14.7</b>	<b>+6</b>	<b>6.043</b>	<b>0.40-0.55</b>	<b>3</b>
2648	Owa	09 16.2	14.9	+5	3.564	0.20-0.35	3
<b>3868</b>	<b>Mendoza</b>	<b>09 16.8</b>	<b>14.4</b>	<b>-3</b>	<b>2.771</b>	<b>0.07-0.20</b>	<b>3</b>
755	Quintilla	09 18.8	14.5	-2	4.552	0.08-0.45	3
712	Boliviana	09 18.9	11.3	+14	11.743	0.10-0.12	3
651	Antikleia	09 21.9	13.8	-11	20.299	0.13-0.41	3
<b>46436</b>	<b>2002 LH5</b>	<b>09 23.3</b>	<b>15.0</b>	<b>+30</b>	<b>3.884</b>	<b>0.46-0.62</b>	<b>3</b>
58	Concordia	09 25.8	12.6	-2	9.895	0.09-0.15	3

### Radar-Optical Opportunities

There are several resources to help plan observations in support of radar.

Future radar targets:

<http://echo.jpl.nasa.gov/~lance/future.radar.nea.periods.html>

Past radar targets:

<http://echo.jpl.nasa.gov/~lance/radar.nea.periods.html>

Arecibo targets:

<http://www.naic.edu/~pradar/sched.shtml>

<http://www.naic.edu/~pradar>

Goldstone targets:

[http://echo.jpl.nasa.gov/asteroids/goldstone\\_asteroid\\_schedule.html](http://echo.jpl.nasa.gov/asteroids/goldstone_asteroid_schedule.html)

However, these are based on *known* targets at the time the list was prepared. It is very common for newly discovered objects to move up the list and become radar targets on short notice. We recommend that you keep up with the latest discoveries the Minor Planet Center observing tools

In particular, monitor NEAs and be flexible with your observing program. In some cases, you may have only 1-3 days when the asteroid is within reach of your equipment. Be sure to keep in touch with the radar team (through Dr. Benner's email listed above) if you get data. The team may not always be observing the target but your initial results may change their plans. In all cases, your efforts are greatly appreciated.

Use the ephemerides below as a guide to your best chances for observing, but remember that photometry may be possible before and/or after the ephemerides given below. Note that *geocentric* positions are given. Use these web sites to generate updated and *topocentric* positions:

MPC: <http://www.minorplanetcenter.net/iau/MPEph/MPEph.html>

JPL: <http://ssd.jpl.nasa.gov/?horizons>

In the ephemerides below, ED and SD are, respectively, the Earth and Sun distances (AU), V is the estimated Johnson V magnitude, and  $\alpha$  is the phase angle. SE and ME are the great circles distances (in degrees) of the Sun and Moon from the asteroid. MP is the lunar phase and GB is the galactic latitude. "PHA" indicates that the object is a "potentially hazardous asteroid", meaning that at some (long distant) time, its orbit might take it very close to Earth.

#### About YORP Acceleration

Many, if not all, of the targets in this section are near-Earth asteroids. These objects are particularly sensitive to YORP acceleration. YORP (Yarkovsky–O'Keefe–Radzievskii–Paddack) is the asymmetric thermal re-radiation of sunlight that can cause an asteroid's rotation period to increase or decrease. High precision lightcurves at multiple apparitions can be used to model the asteroid's *sidereal* rotation period and see if it's changing.

It usually takes four apparitions to have sufficient data to determine if the asteroid rotation rate is changing under the influence of YORP. So, while obtaining a lightcurve at the current apparition may not result in immediately seeing a change, the data are still critical in reaching a final determination. This is why observing asteroids that already have well-known periods can still be a valuable use of telescope time. It is even more so when considering BYORP (binary-YORP) among binary asteroids where that effect has stabilized the spin so that acceleration of the

primary body is not the same as if it would be if there were no satellite.

Name	Grp	Period	App	Last	Bin	R	SNR
2005 UP156	NEA	40.5	1	2014	-	474	<b>A</b> 27 G
2004 AF	NEA	-	-	-	-	22	<b>A</b>
2017 BS5	<b>NEA</b>	1 <sup>A</sup>	-	-	-	897	<b>A</b> 510 G
2015 BS5	<b>NEA</b>	0.16 <sup>A</sup>	-	-	-	357	<b>A</b> 204 G
2003 AZ2	NEA	-	-	-	-	39	<b>A</b>
2001 AU43	NEA	-	-	-	-	55	<b>A</b>
2001 QP153	<b>NEA</b>	-	-	-	-	623	<b>A</b> 35 G
1993 BW	NEA	2.57	2	2015	-	53	<b>A</b>
2000 PD3	NEA	-	-	-	-	142	<b>A</b>
<b>Florence</b> <b>PHA</b>	<b>NEA</b>	2.36	7	2016	?	56900	<b>A</b> 3240 G
1990 BG	NEA	37.2	1	2015	-	19	<b>A</b>
2001 QL142 <b>PHA</b>	<b>NEA</b>	-	-	-	-	2510	<b>A</b> 143 G
2007 XJ16 <b>PHA</b>	<b>NEA</b>	-	-	-	-	111	<b>A</b>

Table I. Summary of radar-optical opportunities in 2017 Apr-Jun. Data from the asteroid lightcurve database (Warner *et al.*, 2009; *Icarus* **202**, 134-146). <sup>A</sup> assumed period, hours.

To help focus efforts in YORP detection, Table I gives a quick summary of this quarter's radar-optical targets. Note that 2015 BS5 is included twice. It's period is not known but, given the estimated size of about 5 meters, it's very likely a superfast rotator. The first entry assumes a period of 1 h while the second line assumes a period of 0.16 h, or about 10 minutes.

The Grp column gives the family or group for the asteroid. The period is in hours and, in the case of binary, for the primary. The App columns gives the number of different apparitions at which a lightcurve period was reported while the Last column gives the year for the last reported period. The Bin column is 'Y' if the asteroid has one or more satellites (a '?' indicates a suspected binary). The last column indicates the estimated radar SNR using the tool at

<http://www.naic.edu/~eriverav/scripts/radarscript.php>

The estimate in Table I is based on using the Arecibo (A) or Goldstone (G) radar. Goldstone is the default if a close approach is outside the declination range of Arecibo. The estimate uses the current MPCORB absolute magnitude (*H*), a period of 3.0 hours if it's not known, and the approximate minimum Earth distance during the three-month period covered by this paper.

If the SNR value is in bold text, the object was found on the radar planning pages listed above. Otherwise, the search tool at

[http://www.minorplanet.info/PHP/call\\_OppLCDBQuery.php](http://www.minorplanet.info/PHP/call_OppLCDBQuery.php)

was used to find known NEAs that were  $V < 18.0$  during the quarter. An object was placed on the list only if the estimated radar SNR  $> 10$ . This would produce a very marginal signal, not enough for imaging, but might allow improving orbital parameters.

**(190166) 2005 UP156 (Jul-Sep,  $H = 17.1$ )**

Warner (2015) found a period of 40.5 h for this 1.1 km NEA. There is a chance it could be tumbling, so try to follow it for as long as possible, maybe with a collaborator at a different longitude, and get high-quality data with consistent night-to-night zero points. The radar team is looking for optical photometry and characterization. Opportunities for observations continue every month through about October, though July may not good because the asteroid will be at very low galactic latitudes.

DATE	RA	Dec	ED	SD	V	$\alpha$	SE	ME	MP	GB
07/01	17 31.0	+13 30	0.14	1.12	14.5	35.8	140	74	+0.50	+24
07/11	18 19.1	+14 37	0.13	1.12	14.4	35.4	140	48	-0.97	+14
07/21	19 09.6	+13 17	0.14	1.13	14.4	32.0	144	141	-0.08	+2
07/31	19 55.2	+09 58	0.15	1.15	14.5	26.6	150	80	+0.54	-9
08/10	20 32.0	+05 47	0.18	1.18	14.7	20.8	156	40	-0.95	-19
08/20	21 00.0	+01 41	0.22	1.22	15.1	16.5	160	159	-0.04	-27
08/30	21 21.5	-01 46	0.26	1.26	15.5	15.3	161	68	+0.57	-34
09/09	21 39.1	-04 23	0.32	1.31	16.1	17.1	157	56	-0.91	-39
09/19	21 54.4	-06 10	0.39	1.37	16.8	20.2	152	166	-0.02	-43
09/29	22 08.7	-07 12	0.48	1.42	17.4	23.4	146	46	+0.59	-47

**(143992) 2004 AF (Jul-Sep,  $H = 16.0$ )**

No period was found in the asteroid lightcurve database (LCDB; Warner et al., 2009) for this 2 km NEA. It's best observed in early July, when its solar elongation is highest. With it always being at very high phase angles, assumptions about lightcurve shape should be made with caution.

DATE	RA	Dec	ED	SD	V	$\alpha$	SE	ME	MP	GB
07/01	00 05.1	-28 10	0.45	1.23	16.6	51.8	108	150	+0.50	-80
07/11	00 43.8	-16 10	0.34	1.15	16.1	58.8	104	57	-0.97	-79
07/21	01 32.8	+03 40	0.28	1.08	15.8	69.9	95	62	-0.08	-58
07/31	02 39.5	+29 19	0.26	1.01	16.1	83.6	81	161	+0.54	-28
08/10	04 10.2	+49 03	0.31	0.95	16.6	92.1	70	87	-0.95	-2
08/20	05 54.3	+57 34	0.40	0.91	17.1	92.8	64	48	-0.04	+15
08/30	07 23.6	+58 38	0.50	0.88	17.4	89.1	61	131	+0.57	+27
09/09	08 27.2	+56 22	0.60	0.88	17.5	83.3	60	96	-0.91	+35
09/19	09 11.4	+52 50	0.70	0.90	17.7	77.0	60	48	-0.02	+42
09/29	09 43.4	+48 55	0.78	0.93	17.8	71.0	62	137	+0.59	+48

**2017 BS5 (Jul,  $H = 24.1$ )**

The odds are very good that the period for this 5-meter NEA will be very short, possibly on the order of minutes, if not seconds. There are also good chances for it to be in non-principal axis rotation (tumbling). The MPC ephemeris service gives a sky motion of about 1 arcmin/min on July 24. This will require short exposures to avoid excessive trailing. That's a good thing considering the potential for very fast rotation.

According to Pravec et al. (2000), exposures should be no more than  $0.187 \cdot P$  if there is hope of getting a reliable period; that's 11 seconds for a 1-minute rotation period. Longer exposures will "smear" the data over too large a fraction of the period and so mask the true shape of the lightcurve.

DATE	RA	Dec	ED	SD	V	$\alpha$	SE	ME	MP	GB
07/20	18 10.6	+40 37	0.02	1.02	17.3	65.3	114	118	-0.16	+25
07/21	18 07.6	+32 18	0.01	1.02	16.7	58.7	121	128	-0.08	+23
07/22	18 04.0	+19 47	0.01	1.02	16.0	49.3	130	140	-0.03	+19
07/23	17 59.7	+01 22	0.01	1.02	15.3	37.9	142	148	+0.00	+12
07/24	17 54.3	-21 48	0.01	1.02	15.1	32.0	148	140	+0.01	+2
07/25	17 47.4	-43 35	0.01	1.02	15.5	38.7	141	122	+0.04	-8
07/26	17 38.4	-59 30	0.01	1.02	16.2	48.8	131	106	+0.09	-15
07/27	17 25.7	-70 04	0.01	1.02	16.8	56.6	123	95	+0.16	-19
07/28	17 06.5	-77 05	0.02	1.02	17.4	62.2	117	87	+0.25	-21
07/29	16 34.8	-81 52	0.02	1.02	17.9	66.1	113	82	+0.34	-22

**(232368) 2003 AZ2 (Jul-Aug,  $H = 18.2$ )**

The estimated diameter for 2003 AZ2 is 700 meters. There will be chances to observe the asteroid throughout the third quarter of 2017 during which time the phase angle does not change much. On the other hand, the phase angle bisector longitude increases by

nearly  $40^\circ$  while the latitude goes from about  $+30^\circ$  to  $-40^\circ$ . This dramatic change in viewing aspect may produce some significant changes in the shape and/or synodic period of the lightcurve.

Assuming that the period is not much longer than 4-5 hours, try getting short data sets (2 or 3 consecutive nights) every two or so weeks. Analyze each subset independently so you see how the lightcurve changes as the viewing aspect changes.

DATE	RA	Dec	ED	SD	V	$\alpha$	SE	ME	MP	GB
07/01	21 54.3	+31 55	0.28	1.13	17.8	58.6	108	130	+0.50	-17
07/08	22 24.6	+28 19	0.24	1.12	17.4	58.0	111	77	+0.99	-24
07/15	23 00.0	+22 07	0.20	1.11	17.0	56.5	114	30	-0.69	-34
07/22	23 40.4	+12 20	0.17	1.11	16.6	54.3	118	100	-0.03	-47
07/29	00 24.7	-01 15	0.16	1.10	16.3	52.4	121	168	+0.34	-63
08/05	01 10.3	-16 26	0.16	1.10	16.3	52.6	120	89	+0.93	-78
08/12	01 53.5	-29 42	0.17	1.10	16.6	54.6	117	35	-0.81	-76
08/19	02 31.4	-39 25	0.20	1.11	17.0	56.7	114	89	-0.10	-66
08/26	03 02.0	-46 02	0.23	1.12	17.4	57.9	111	125	+0.20	-58
09/02	03 25.2	-50 31	0.27	1.12	17.7	58.2	109	93	+0.82	-53

**(138925) 2001 AU43 (Jul-Aug,  $H = 15.9$ )**

There were no entries with a period in the LCDB for this NEA. With a diameter of about 2 km, the rotation period will likely be 2 or more hours. That makes it a good candidate for being binary. Unfortunately, the asteroid keeps close to the galactic plane, which will make it more difficult to get accurate photometry.

DATE	RA	Dec	ED	SD	V	$\alpha$	SE	ME	MP	GB
07/01	22 36.6	+55 32	0.66	1.18	17.5	59.2	87	119	+0.50	-2
07/08	22 22.9	+52 17	0.54	1.18	17.0	58.9	94	90	+0.99	-4
07/15	22 02.0	+46 24	0.42	1.19	16.4	55.7	105	56	-0.69	-7
07/22	21 31.6	+34 30	0.30	1.20	15.5	46.2	121	113	-0.03	-12
07/29	20 49.6	+09 37	0.22	1.22	14.2	23.7	151	115	+0.34	-21
08/05	19 57.7	-25 55	0.23	1.23	13.9	13.9	163	17	+0.93	-25
08/12	19 03.2	-49 21	0.31	1.25	15.3	34.9	135	87	-0.81	-22
08/19	18 16.0	-59 57	0.43	1.28	16.3	44.2	119	137	-0.10	-19
08/26	17 41.4	-64 53	0.56	1.30	17.0	47.6	108	73	+0.20	-17
09/02	17 19.4	-67 31	0.70	1.33	17.5	48.3	101	52	+0.82	-17

This additional ephemeris shows a "closeup" of the one above, centering on August 2. Note how the asteroid goes through a large range of phase angles in only a short time. This will provide a good opportunity to find H-G values. The sky motion will reach a maximum of about 14 arcsec/pixel. Given the bright magnitudes, short exposures of 15-30 seconds will still produce good SNRs.

DATE	RA	Dec	ED	SD	V	Ph	SE	ME	MP	GB
07/25	21 14.3	+25 28	0.26	1.21	14.9	38.1	133	140	+0.04	-16
07/27	21 02.0	+17 57	0.24	1.21	14.5	31.3	142	135	+0.17	-18
07/29	20 48.7	+09 01	0.22	1.22	14.2	23.1	152	113	+0.36	-21
07/31	20 34.6	-01 03	0.21	1.22	13.8	14.3	163	86	+0.55	-23
08/02	20 19.8	-11 37	0.21	1.23	13.5	7.7	171	57	+0.73	-25
08/04	20 04.5	-21 47	0.22	1.23	13.7	10.8	167	28	+0.88	-25
08/06	19 48.8	-30 52	0.24	1.24	14.2	18.1	158	12	+0.97	-25
08/08	19 33.0	-38 30	0.26	1.24	14.6	25.0	149	35	-1.00	-24
08/10	19 17.4	-44 42	0.28	1.25	15.0	30.6	141	62	-0.94	-23
08/12	19 02.3	-49 37	0.31	1.25	15.3	35.2	135	89	-0.80	-22

**(153415) 2001 QP153 (Aug-Sep,  $H = 17.0$ )**

This planned radar target has a diameter of about 1.2 km. Its rotation period is not known but it likely 2 or more hours. Unfortunately, it's not very far from the Sun (low elongations) for most of August, but it may still be possible to get observations around new moon. Watch for strange lightcurve behavior at these high phase angles.

DATE	RA	Dec	ED	SD	V	$\alpha$	SE	ME	MP	GB
08/01	05 51.3	-02 09	0.15	0.92	18.0	125.9	47	142	+0.63	-14
08/06	06 11.5	+23 21	0.10	0.94	18.2	134.9	41	159	+0.97	+2
08/11	07 26.6	+63 04	0.10	0.96	17.0	123.4	52	104	-0.89	+28
08/16	13 25.9	+76 54	0.14	0.97	16.4	103.1	69	83	-0.39	+40
08/21	15 46.0	+66 58	0.20	0.99	16.7	91.3	77	79	-0.01	+42
08/26	16 17.3	+60 16	0.26	1.00	17.0	84.4	81	73	+0.20	+42
08/31	16 30.4	+56 03	0.33	1.02	17.4	79.7	82	76	+0.66	+42
09/05	16 37.8	+53 11	0.39	1.03	17.7	76.1	82	94	+0.98	+41
09/10	16 42.9	+51 06	0.45	1.04	17.9	73.3	81	113	-0.84	+41
09/15	16 46.9	+49 30	0.51	1.05	18.1	71.0	80	105	-0.30	+40

**(6053) 1993 BW3 (Jul-Sep,  $H = 14.8$ )**

Pravec et al. (1997) found a period of 2.573 h for 1993 BW. Observations by Warner in 2015 favored a period of about 2.85 h but the solution was ambiguous with the alternate period being 2.55 h. Here's a chance to put all doubt to rest. While no evidence has been found so far, the diameter and period do make the asteroid a good candidate for being binary.

DATE	RA	Dec	ED	SD	V	$\alpha$	SE	ME	MP	GB
07/01	22 54.2	-19 55	0.77	1.56	16.6	33.9	121	147	+0.50	-62
07/11	23 06.0	-15 49	0.63	1.49	16.1	33.3	127	34	-0.97	-63
07/21	23 16.1	-10 07	0.51	1.41	15.5	32.3	132	99	-0.08	-62
07/31	23 24.1	-01 50	0.41	1.34	14.8	31.3	137	129	+0.54	-57
08/10	23 29.5	+10 35	0.32	1.27	14.2	31.9	138	20	-0.95	-47
08/20	23 31.7	+28 35	0.27	1.21	13.8	37.8	133	115	-0.04	-31
08/30	23 29.1	+50 38	0.25	1.15	13.9	50.2	119	109	+0.57	-10
09/09	23 16.1	+71 09	0.26	1.10	14.3	63.2	103	70	-0.91	+10
09/19	21 28.8	+86 07	0.30	1.06	14.8	71.9	92	85	-0.02	+25
09/29	12 42.7	+82 04	0.35	1.03	15.2	76.0	84	110	+0.59	+35

**(422699) 2000 PD3 (Aug-Sep,  $H = 18.3$ )**

In terms of solar elongation and galactic latitude, August will be the best time to catch this 600-700 meter NEA. No previously reported period was found.

DATE	RA	Dec	ED	SD	V	$\alpha$	SE	ME	MP	GB
08/10	22 31.8	+06 44	0.26	1.25	16.9	23.0	151	17	-0.95	-42
08/14	22 33.8	+11 19	0.22	1.21	16.6	24.4	150	57	-0.62	-39
08/18	22 36.1	+17 20	0.19	1.18	16.3	27.6	147	107	-0.18	-35
08/22	22 39.0	+25 26	0.16	1.14	16.0	33.3	142	143	+0.00	-29
08/26	22 43.3	+36 28	0.14	1.11	15.8	42.2	133	129	+0.20	-20
08/30	22 51.6	+51 07	0.12	1.07	15.8	54.9	120	103	+0.57	-7
09/03	23 13.9	+68 49	0.11	1.04	16.1	70.7	103	92	+0.89	+8
09/07	02 33.5	+85 15	0.11	1.01	16.6	86.8	87	92	-0.99	+23
09/11	09 24.8	+75 43	0.13	0.98	17.4	100.1	73	79	-0.75	+35
09/15	09 57.8	+63 36	0.15	0.95	18.1	109.2	63	53	-0.30	+44

**3122 Florence (Jul-Sep,  $H = 14.1$ , PHA)**

Pravec et al. (1998) found a period of 2.358 h. Warner (2016) reported it as a suspected binary after finding a second period of 10.36 h with an amplitude of 0.07 mag. No telltale signs, i.e., mutual events, were seen. If the second period is real, it might also be due to low-level tumbling. The SNRs for the radar teams are going to be extremely large and so they are planning hi-res imaging.

DATE	RA	Dec	ED	SD	V	$\alpha$	SE	ME	MP	GB
07/01	23 01.6	-65 13	0.50	1.35	14.9	40.2	121	112	+0.50	-48
07/11	23 23.7	-66 12	0.42	1.29	14.4	42.0	122	56	-0.97	-49
07/21	23 38.3	-66 49	0.34	1.23	13.9	44.0	123	107	-0.08	-49
07/31	23 41.0	-66 46	0.26	1.18	13.3	45.7	124	96	+0.54	-49
08/10	23 25.0	-65 02	0.18	1.13	12.5	46.2	126	57	-0.95	-50
08/20	22 40.6	-57 34	0.11	1.09	11.1	41.7	134	132	-0.04	-52
08/30	21 22.0	-19 23	0.05	1.06	8.7	19.1	160	63	+0.57	-42
09/09	19 49.4	+51 03	0.08	1.03	10.9	66.8	109	83	-0.91	+12
09/19	18 33.4	+68 02	0.14	1.02	12.7	79.0	93	91	-0.02	+27
09/29	17 42.2	+72 52	0.21	1.02	13.5	78.7	89	93	+0.59	+31

**(5131) 1990 BG (Jul-Sep,  $H = 14.7$ )**

Warner (2016) found a period of 37.2 h. The solar elongations are very small throughout the quarter and looking ahead to the fourth quarter of 2017, the elongation never gets much above 90°. It may not be possible to do useful photometry this time around but it's included for the adventurous and daring and those doing astrometry.

DATE	RA	Dec	ED	SD	V	$\alpha$	SE	ME	MP	GB
07/01	09 23.4	+38 00	1.17	0.73	16.5	59.2	38	59	+0.50	+45
07/11	10 07.5	+34 59	1.01	0.67	16.3	71.4	38	154	-0.97	+54
07/21	10 49.8	+29 06	0.83	0.64	16.4	86.4	39	71	-0.08	+63
07/31	11 26.6	+18 55	0.66	0.65	16.6	101.2	39	57	+0.54	+69
08/10	11 56.1	+02 46	0.53	0.70	16.7	110.1	41	166	-0.95	+62
08/20	12 20.2	-19 10	0.46	0.78	16.4	106.9	48	69	-0.04	+43
08/30	12 43.9	-42 03	0.46	0.87	16.0	93.6	59	58	+0.57	+21
09/09	13 15.6	-60 26	0.52	0.97	16.0	79.2	70	124	-0.91	+2
09/19	14 15.3	-73 16	0.61	1.06	16.1	67.8	78	88	-0.02	-11
09/29	16 41.9	-80 33	0.70	1.16	16.4	59.2	84	63	+0.59	-22

**(310560) 2001 QL142 (Sep-Oct,  $H = 17.8$ , PHA)**

Here's another radar target that should produce very large SNRs and so allow hi-res imaging. The rotation period is unknown. The estimated diameter of 500 meters makes it likely that the period is 2 or more hours. Assume nothing, however.

DATE	RA	Dec	ED	SD	V	$\alpha$	SE	ME	MP	GB
09/15	13 23.1	-52 42	0.06	0.98	16.2	116.3	61	108	-0.30	+10
09/18	16 28.5	-75 50	0.08	1.00	15.3	88.2	88	104	-0.06	-18
09/21	20 49.8	-73 46	0.10	1.03	15.4	72.4	102	99	+0.01	-34
09/24	22 04.9	-67 01	0.13	1.06	15.8	63.6	110	86	+0.15	-43
09/27	22 32.4	-62 09	0.17	1.08	16.2	58.3	113	67	+0.40	-48
09/30	22 46.6	-58 39	0.20	1.10	16.5	54.8	116	51	+0.68	-52
10/03	22 55.4	-56 01	0.24	1.13	16.9	52.4	117	46	+0.91	-54
10/06	23 01.7	-53 54	0.27	1.15	17.2	50.7	117	62	-1.00	-57
10/09	23 06.6	-52 08	0.31	1.17	17.4	49.3	117	91	-0.86	-58
10/12	23 10.6	-50 36	0.35	1.19	17.7	48.3	117	121	-0.56	-60

**2007 XJ16 (Jul-Sep,  $H = 18.6$ , PHA)**

No period was found for the 600-meter 2007 XJ16. The NEA doesn't get particularly bright and stays in or on the edge of the galactic plane for the three month period. Also, the phase angle stretches out towards 90°. This could mean unexpected lightcurve behavior and shapes; be prepared.

DATE	RA	Dec	ED	SD	V	$\alpha$	SE	ME	MP	GB
07/01	15 46.9	-34 15	0.39	1.34	18.4	28.7	141	55	+0.50	+16
07/11	15 33.0	-31 43	0.35	1.27	18.4	38.6	129	72	-0.97	+20
07/21	15 25.9	-28 45	0.32	1.20	18.4	48.5	118	148	-0.08	+23
07/31	15 26.3	-25 29	0.29	1.14	18.3	58.0	108	18	+0.54	+25
08/10	15 34.2	-21 50	0.26	1.09	18.2	67.0	99	107	-0.95	+27
08/20	15 49.1	-17 23	0.23	1.04	18.1	75.4	92	115	-0.04	+28
08/30	16 11.8	-11 20	0.19	1.02	17.9	82.6	87	12	+0.57	+28
09/09	16 44.7	-02 15	0.16	1.00	17.6	87.1	84	129	-0.91	+27
09/19	17 34.7	+11 47	0.13	1.01	17.1	85.8	87	99	-0.02	+22
09/29	18 56.9	+30 20	0.11	1.03	16.5	74.9	99	50	+0.59	+12



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The deadline for the next issue (44-4) is July 15, 2017. The deadline for issue 45-1 is October 15, 2017.