THE MINOR PLANET BULLETIN

1.

NIR MINOR PLANET PHOTOMETRY FROM BURLEITH OBSERVATORY: 2014 FEBRUARY – JUNE

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Rotation periods were obtained for ten minor planets based on near-IR CCD observations made in 2014 at the urban Burleith Observatory, Washington, DC.

In the city of Washington, DC, increasing light pollution brought on by the installation of "decorative" street lights has severely limited opportunities for minor planet photometry. In 2014 a test selection of bright minor planets of both high and low amplitude were chosen to study the feasibility of differential photometry in the near-infrared (NIR, 700-900nm).

A *PlaneWave* 0.32-m f/8 CDK astrograph was equipped with an SBIG STL-1001E CCD camera and an *Astrodon* Cousins I-band filter (Ic). Image scale was 1.95 arc-seconds per pixel, unbinned, which is well-matched to the typical 3 to 4 arc-second seeing. All observations were bias and sky flat-field corrected using *CCDSoft* version 5.00.217. Photometry and period analysis was performed using *MPO Canopus* version 10.4.3.17. (Warner, 2011). The Comp Star Selector (CSS) in *MPO Canopus* was used to select comparison stars with solar-like spectra.

359 Georgia. The observed rotation is in close agreement with Lagerkvist (1978).

462 Eriphyla. The observing sessions of duration 3.5 hours on 2014 Feb 22 and 3.3 hours on 2014 March 16 appear to indicate that the true rotation period is twice that found by Behrend (2006).

595 Polyxena. The observed rotation is in close agreement with Piironen *et al.* (1998).

616 Elly. Alvarez-Candal *et al.*(2004) found a period of 5.301 h.

782 Montefiore. These observations confirm the period of Wisniewski *et al.* (1997).

953 Painleva. At $M_v = 14$ and amplitude 0.05 mag, a low confidence in these results should be assumed. Ditteon and Hawkins (2007) found no period over two nights.

1019 Strackea. A member of the high-inclination ($i = 27°$) Hungaria group, Strackea has been an object of much interest of late. The rotation period of Warner (2011) is confirmed.

2014 Vasilevskis. Holliday (1995) found a period of 36.25 h, or 7/3 of the period reported here.

2995 Taratuta. Shor (2013) lists a period of 6.6 hours, which is 3/5 of the period given here.

3523 Arina. Folberth *et al.* (2012) reported an amplitude of 0.10 but no period determination. The new results for this $M_v = 14$ object of low amplitude and small phase angle should be treated with appropriate skepticism.

Number	Name	Date Range (mm/dd)	Points	Phase	Period (h)	P.E. (h)	Amp Ic mag	A E Ic mag
359	Georgia	02/25 - 03/14	468	12.8-16.4	5.5341	0.0004	0.23	0.04
462	Eriphyla	02/22 - 04/24	177	12.3-19.2	17.3700	0.0009	0.28	0.02
595	Polyxena	02/12 - 04/03	510	6.2-14.7	11.79280	0.00015	0.75	0.04
616	Elly	03/01 - 03/28	128	5.3-15.5	5.19280	0.00003	0.35	0.02
782	Montefiore	05/19 - 05/20	73	6.2-6.8	4.0756	0.0019	0.40	0.04
953	Painleva	04/17 - 05/07	119	1.8-10.9	7.389	0.004	0.05	0.04
1019	Strackea	04/09 - 04/13	119	22.9-24.3	4.0473	0.0013	0.29	0.06
2014	Vasilevskis	06/15 - 06/18	97	22.3-23.3	15.63299	-	0.31	0.03
2995	Taratuta	03/23 - 04/02	155	14.9-18.5	11.141299	-	0.38	0.13
3523	Arina	04/21 - 05/04	110	4.1-6.2	2.671299	-	0.07	0.03

Table I. Observing circumstances.

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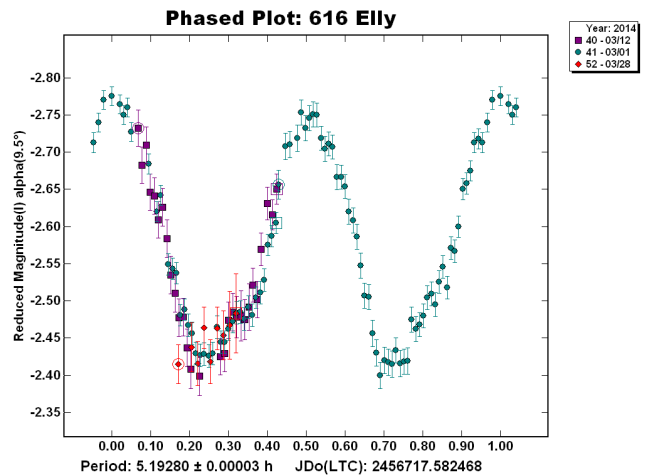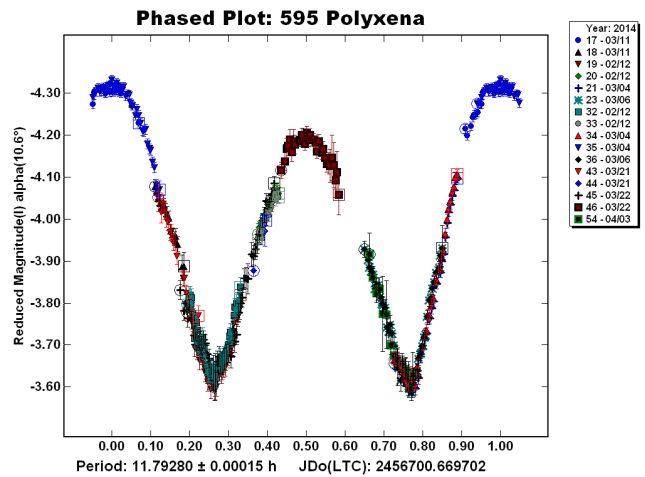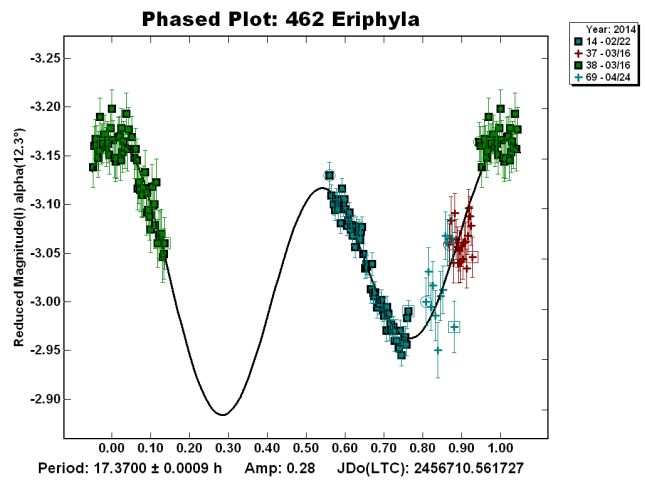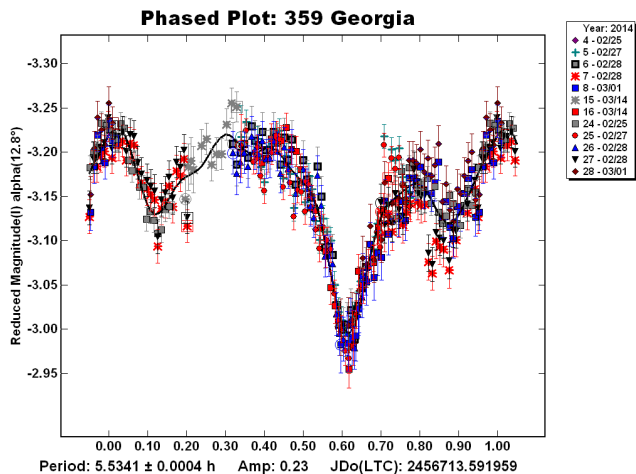
Lagerkvist, C.-I. (1978). "Photographic photometry of 110 main-belt asteroids." *Astron. Astrophys. Suppl. Ser.* **31**, 361-381.

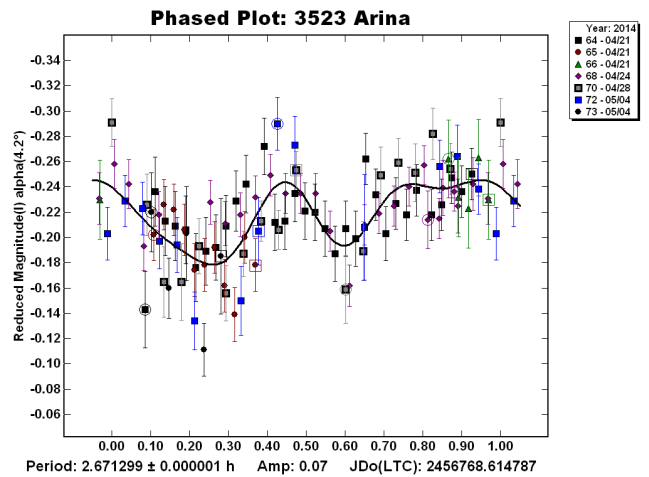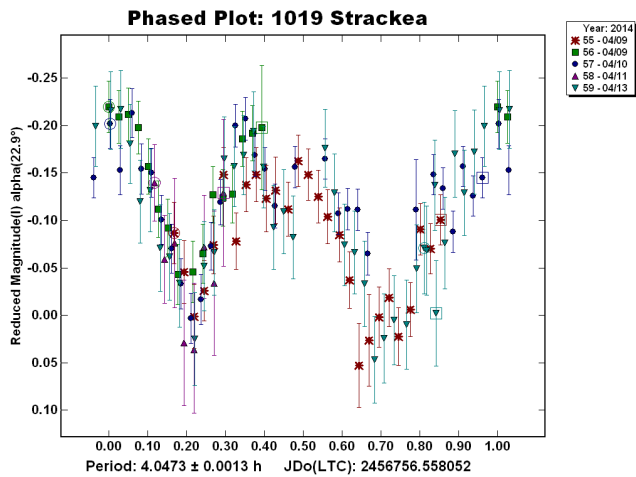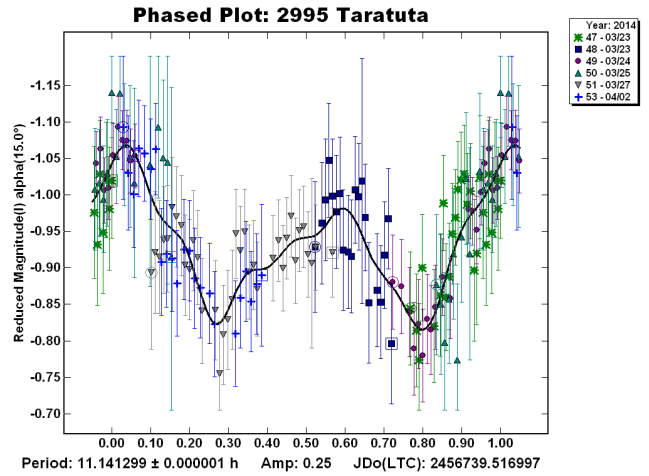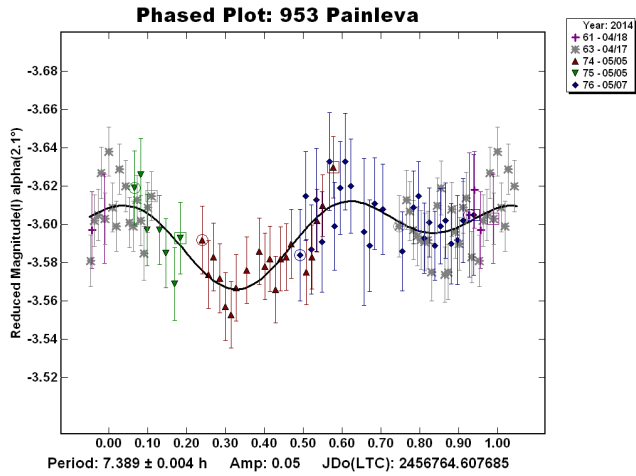Piironen, J., Lagerkvist, C.-I., Erikson, A., Oja, T., Magnusson, P., Festin, L., Nathues, A., Gaul, M., and Velichko, F. (1998). "Physical studies of asteroids. XXXII. Rotation periods and UBVRI-colours for selected asteroids." *Astron. Astrophys. Suppl. Ser.* **128**, 525-540.

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Phased Plot: 462 Eriphyla
Period: 17.3700 ± 0.0009 h   Amp: 0.28   JDo(LTC): 2456710.561727

Phased Plot: 595 Polyxena
Period: 11.79280 ± 0.00015 h   JDo(LTC): 2456700.669702

Phased Plot: 616 Elly
Period: 5.19280 ± 0.00003 h   JDo(LTC): 2456717.582468

Phased Plot: 359 Georgia
Period: 5.5341 ± 0.0004 h   Amp: 0.23   JDo(LTC): 2456713.591959

Phased Plot: 782 Montefiore

Year: 2014
78 - 05/19
79 - 05/20

Reduced Magnitude(I) alpha(6.2°)

Period: 4.0756 ± 0.0019 h   JDo(LTC): 2456796.569618

Phased Plot: 2014 Vasilevski

Year: 2014
81 - 06/15
82 - 06/15
83 - 06/16
84 - 06/18

Reduced Magnitude(I) alpha(22.4°)

Period: 15.63299 ± 0.00001 h   Amp: 0.31   JDo(LTC): 2456823.553018

Phased Plot: 953 Painleva

Year: 2014
61 - 04/18
63 - 04/17
74 - 05/05
75 - 05/05
76 - 05/07

Reduced Magnitude(I) alpha(2.1°)

Period: 7.389 ± 0.004 h   Amp: 0.05   JDo(LTC): 2456764.607685

Phased Plot: 2995 Taratuta

Year: 2014
47 - 03/23
48 - 03/23
49 - 03/24
50 - 03/25
51 - 03/27
53 - 04/02

Reduced Magnitude(I) alpha(15.0°)

Period: 11.141299 ± 0.000001 h   Amp: 0.25   JDo(LTC): 2456739.516997

Phased Plot: 1019 Strackea

Year: 2014
55 - 04/09
56 - 04/09
57 - 04/10
58 - 04/11
59 - 04/13

Reduced Magnitude(I) alpha(22.9°)

Period: 4.0473 ± 0.0013 h   JDo(LTC): 2456756.558052

Phased Plot: 3523 Arina

Year: 2014
64 - 04/21
65 - 04/21
66 - 04/21
68 - 04/24
70 - 04/28
72 - 05/04
73 - 05/04

Reduced Magnitude(I) alpha(4.2°)

Period: 2.671299 ± 0.000001 h   Amp: 0.07   JDo(LTC): 2456768.614787

ROTATION PERIOD OF 584 SEMIRAMIS

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Photometric observations of main-belt asteroid 584 Semiramis were made at the Mark Evans Observatory (MPC W04) between 2014 July 29 and August 4. The measured period of 5.0689 ± 0.0001 is in good agreement with previous values.

A survey of the literature reveals that several period determinations have been made of 584 Semiramis, but the amount of data points used in the lightcurves has been sparse. These lightcurves were used to determine the pole positions of this asteroid. A journal search indicates that the most recent pole determination, by Michalowski (1996), still had a sizable uncertainty. Adding data from an additional phase angle should help to reduce this uncertainty.

All observations were taken at the Mark Evans Observatory using a Celestron CGE Pro 1100 Schmidt-Cassegrain telescope with a 0.28-m aperture. The CCD camera used to capture the images was a Quantum Scientific Imaging model 583C camera. All images were taken at −10°C, binned 2x2, and had 45 second exposures. In addition, the images were unfiltered and unguided. All images were taken between the nights of July 29 and August 4; however, not all the data from each night were used due to losing sufficiently bright solar comparison stars for accurate photometry. The images were corrected using darks and flats, and subsequently analyzed using *MPO Canopus*.

Period analysis was completed using the Fourier feature on *MPO Canopus,* which calculated a period of 5.0689 ± 0.0001 h when using a fit of four orders. The period compares well with previous reported values: 5.068 h (Weidenschilling *et al.,* 1987), 5.069 h (Weidenschilling *et al.,* 1990), 5.0689 h (Drummond *et al.,* 1991), 5.0683 h (Harris *et al.,* 1992), and 5.0689 h (Michalowski, 1993). The extensive coverage of this asteroid at lower phase angles than most previous papers should help further constrain the pole position during future studies.

584 Semiramis
Period: 5.0689 ± 0.0001 h

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ASTEROID LIGHTCURVE ANALYSIS AT ISAAC AZNAR OBSERVATORY ARAS DE LOS OLMOS, VALENCIA SPAIN

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The Isaac Aznar Observatory conducts astrometric and photometric studies of asteroids. This paper contains the photometric results of four asteroids obtained from 2014 April to August. These asteroids were selected from the Collaborative Asteroid Lightcurve Link (CALL) web site: 1088 Mitaka, 2956 Yeomans, 3894 Williamcooke, and (4555) 1974QL.

The observations reported here were all obtained using a 0.35-m *f*/10 Schmidt-Cassegrain telescope and SBIG STL-1001E CCD camera. All images were unfiltered, dark and flat field corrected, and had an image scale of 1.45 arc seconds per pixel. Differential photometry measurements were made in *MPO Canopus* (Bdw Publishing). The asteroid lightcurve database (LCDB; Warner *et al.*, 2009) contains previously reported results for 1088 Mitaka and (4555) 1987QL, but those results are from few years ago. So the results we offer in this paper could be an update for LCDB database because they are slightly different.

1088 Mitaka is a main-belt asteroid of 16.2 km size. This asteroid of 0.15 albedo was discovered by Okuro Oikawa in 1927 and since then has been well analyzed, including a shape model derived from lightcurve inversion. The LCDB and DAMIT (Database of Asteroid Models from Inversion Techniques; Durech, 2014) offers a wealth of information about this minor planet.
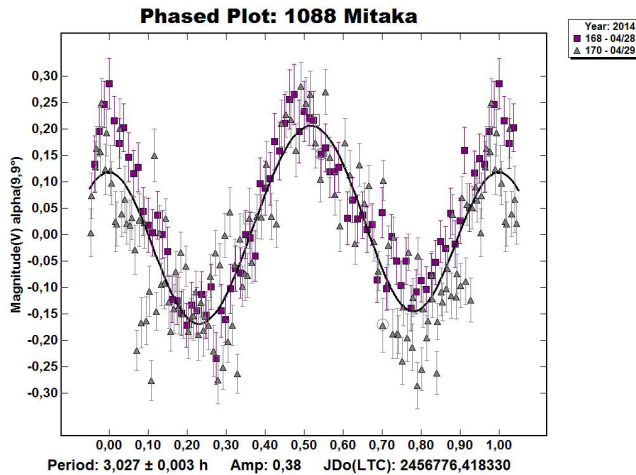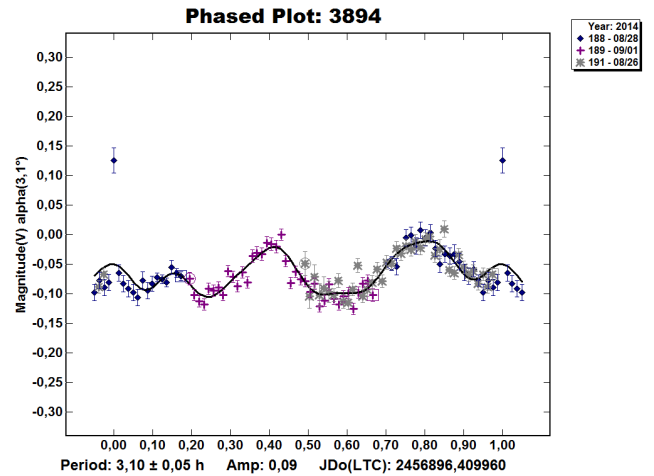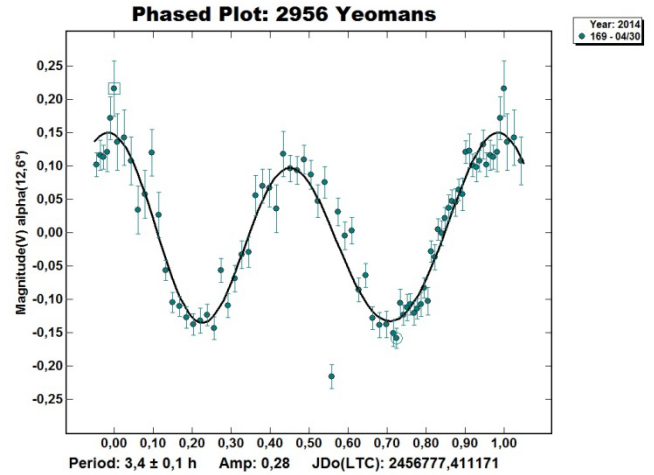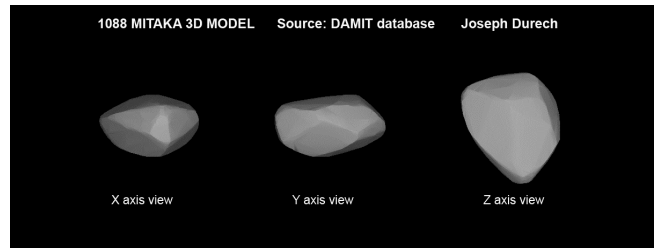
The asteroid was observed on two nights, 2014 April 28 and 29. The solar phase angle was +9.9° and magnitude V ~ 15.2 on the first night and +10.2° and 15.3 magnitude on the second night. A total of 168 points were used to build the lightcurve, which was found to have a period of 3.027 ± 0.003 h and an amplitude of 0.38 mag. The LCDB offers many periods, ranging from 3.035 h to 3.049 h. These are within 1-sigma of the period reported here.

A 3D model of this asteroid was found in the DAMIT database (Durech, 2014). The model reveals an elongated and flat shape from the side view and rounded ellipsoidal shape from the north pole. The elongated shape of this asteroid produces a bimodal lightcurve when observed at relatively low phase angles and if the view is more equatorial than polar.

2956 Yeomans is a main-belt asteroid discovered by E. Bowell at the Anderson Mesa Station of the Lowell Observatory. Its size is unknown. 82 points were obtained over 1 night during 2014 April. The solar phase angle was +15.3°. The asteroid's magnitude was about 18.2 at the time. The lightcurve shows a period of 3.4 ± 0.1 h and an amplitude of 0.28 mag.

3894 Williamcooke is a main belt asteroid discovered in 1980 by P. Jekabson and M.P. Candy at the Perth Observatory. There is no information about this body in the LCDB or DAMIT files. During the span of observations, the asteroid magnitude varied slightly, from 14.5 on August 26 to 14.6 on September 1. The solar phase angle went from +2.6° in first work session to +4.8° in last work session. The lightcurve shows a period of 3.10 ± 0.05 h with an amplitude of 0.1 mag.

(4555) 1974 QL is a main-belt asteroid of 3.2 km discovered by S. Singer-Brewster in 1987. A total of 111 data points were obtained over 2 nights, 2014 July 21 and 22. The solar phase angle was +9.0° and +8.4°, respectively. The magnitude was 15.3 on both nights. The lightcurve shows a period of 2.872 ± 0.011 h and amplitude of 0.23 mag. Chirony *et al.* (2011) reported a period of 2.8847 h and amplitude of 0.21 mag. This is within 1-sigma of the period reported here and so, statistically, the two are the same.
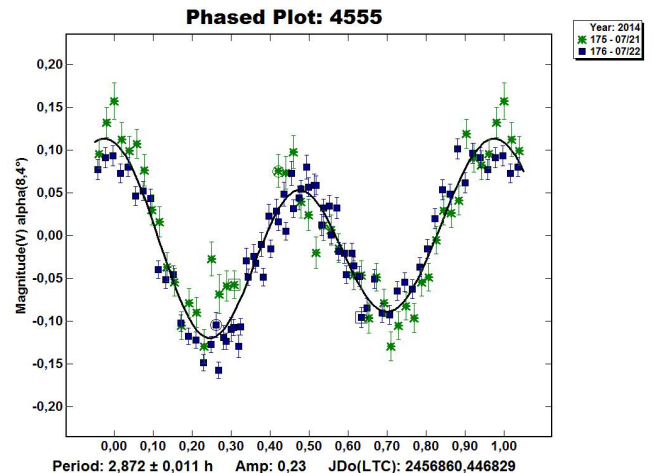
1088 MITAKA 3D MODEL   Source: DAMIT database   Joseph Durech

X axis view   Y axis view   Z axis view

Phased Plot: 2956 Yeomans

Period: 3,4 ± 0,1 h   Amp: 0,28   JDo(LTC): 2456777,411171

Phased Plot: 3894

Period: 3,10 ± 0,05 h   Amp: 0,09   JDo(LTC): 2456896,409960

Phased Plot: 1088 Mitaka

Period: 3,027 ± 0,003 h   Amp: 0,38   JDo(LTC): 2456776,418330

Phased Plot: 4555

Period: 2,872 ± 0,011 h   Amp: 0,23   JDo(LTC): 2456860,446829

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A NINE MONTH PHOTOMETRIC STUDY OF THE VERY SLOWLY ROTATING ASTEROID 288 GLAUKE

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Fifteen images of the extremely slowly rotating 288 Glauke were obtained every clear night except when the target was very close to the Moon in the interval 2013 Nov. 5 - 2014 July 27 during which the object was more than 60 degrees from the Sun, a total of 187 nights. Tumbling behavior was found, with possible periods near 1170 hours and 740 hours, respectively, and uncertainties probably no larger than 2%. The reliability of tumbling behavior was assessed as PAR=-2. The color index was also determined as V-R=0.48. Magnitude parameters in the V photometric system H=9.99 ± 0.04 and G=0.24 ± 0.02 were found

Minor Planet 288 Glauke was the first minor planet ever to be found to have an extremely long rotation period. Harris et al. (1999) found on the basis of observations in 1982 a period between 1110 and 1210 hours with a value dependent upon an assumed value of G between 0.12 and 0.34. Binzel (1987) obtained a period near 1150 hours that Harris et al. (1999) reanalyzed to 1296 hours. Kryszczynska et al. (2003) found an irregular lightcurve which

they suggested as indicative of NPA rotation (tumbling). A stated equivalent single period of 77 days cannot be considered reliable. Ostro et al. (2001) made radar observations of the bandwidth of the echo. Due to uncertainties in the effective diameter of the asteroid, the orientation of its rotation axis relative to the line of sight, and noisy data, the rotation period could only be established as less than 2100 hours.

An ephemeris of 288 Glauke between 2013 November and 2014 August shows that it was consistently farther than 60 degrees from the Sun and brighter than magnitude 15 during this interval, approximately five rotational cycles. The goal of the new observations was to obtain a reliable and fairly accurate rotation period and look for possible tumbling behavior. The observational strategy was to obtain fifteen 60 second exposures every clear night except when the Moon was close during this time frame and establish the R magnitude within a few x 0.01 on each night. A mean magnitude for each night would constitute an effective single data point. On some nights one or more of these fifteen exposures was defective and could not be reliably measured, and on a few nights unusual circumstances recommended obtaining more than fifteen exposures. This observational procedure was made on a total of 187 nights from 2013 Nov. 5 through 2014 July 27, an interval of nearly 9 months.

Author FP made all the observations at the Organ Mesa Observatory with a 0.35-meter Meade LX200 GPS Schmidt-Cassegrain (SCT) and SBIG STL-1001E CCD. All exposures were 60 seconds, unguided, with a clear filter. Photometric measurement calibrated in the Cousins R magnitude system by stars with near solar colors was with *MPO Canopus* software. The Comparison Star Selector in this software identifies stars with near solar colors in the range B-V = 0.54 to 0.9 and V-R = 0.31 to 0.57 computed from the 2MASS catalog by formulas developed by Warner (2007). A further improvement in the R magnitudes of these stars is achieved by the method of Dymock and Miles (2009) and CMC14 (Carlsbad Meridian Circle) catalog as presented by the VizieR Service (2014). The magnitudes of stars in the CMC14 catalog, and in the CMC15 catalog which became available on line 2014 March from VizieR (2014), have a much better internal consistency than those in the MPOSC3 catalog. The Sloan r' magnitudes of the calibration stars in these catalogs are converted to the R magnitude system by R = r' - 0.22, and then substituted for their MPOSC3 values. The *MPO Canopus* software constructs the lightcurve by further adjusting these calibrated R magnitudes to changes in the heliocentric and geocentric distances and an assumed G = 0.15. A raw lightcurve based on these values with no adjustments of instrumental magnitudes has a night to night behavior smooth within a few x 0.01 magnitudes which we interpret as the internal consistency of the calibration star R magnitudes for all of the 187 sessions. The raw lightcurve is however quite irregular on a time scale of 10 to 20 days, which suggests large amplitude tumbling.

Color indices were found on two nights, 2013 Dec. 18 at phase angle 25 degrees, and 2014 April 8 at phase angle 3.6 degrees. Fifteen 60 second exposure images were made in with the R filter and converted from CMC14 r' magnitudes to Cousins R magnitudes by R = r' - 0.22. An additional fifteen 60 second exposure images were made with the V filter and converted from CMC15 r', J, and K magnitudes to Johnson V magnitudes by V = 0.9947*r' + 0.6278*(J-K). Both magnitude conversion procedures are from Dymock and Miles (2009). At 25 degrees phase angle R=13.97, V=14.47, V-R=0.50. At 3.6 degrees phase angle R=11.68, V=12.14, V-R=0.46. I consider the difference between these values of V-R to be within reasonable observational error and

not definitive of a change of color index with phase angle. Hence I adopt the mean V-R = 0.48.

We present the raw lightcurve of all data points as prepared with *MPO Canopus* software, in which the calibrated magnitudes are adjusted to changing heliocentric and distances and assumed G = 0.240 (Figure 1). The lightcurve of each rotational cycle is presented separately in Figures 2-7.

With strong evidence of tumbling indicated in the raw lightcurves, we first used the dual period procedure in *MPO Canopus* software (Warner, 2012). The dual period procedure removes the Fourier average of the lightcurve for each period from the combined lightcurve to produce that part of the variation due to each period separately. A primary period 1169 ± 1.5 hours, amplitude 0.38 magnitudes, and secondary period 737 ± 0.5 hours, amplitude 0.22 magnitudes, are clearly shown in Figures 8 and 9, respectively. The scatter is, however, greater than can reasonably be explained by errors of a few x 0.01 magnitude in the CMC14 and CMC15 catalogs and changes in aspect and solar phase angle through the nine-month interval of observation. The largest source of error arises from the dual period procedure of *MPO Canopus*, which does not model a tumbler's lightcurve fully. There are missing terms with linear combinations of the two tumbling frequencies. See Pravec et al. (2005) for details. The commonly-used technique of adjusting instrumental magnitudes of different sessions for best fit cannot be applied to this data set. In Figure 10 we separately plot the curves of Fourier components of primary and secondary periods, their sum, and include a single data point for each night so that a direct comparison with the data can be made.

If P1 and P2 are, respectively, the primary and secondary periods as found by the dual period procedure above, let the corresponding rotational frequencies be f_1=1/P1 and f_2=1/P2. A 3rd order 2-period Fourier procedure, containing all terms with frequencies (i*f_1+j*f_2) where i, j are integers between -3 and 3, and described by Pravec et al. (2005), was applied to all the data ignoring, however, effects of changing aspect and solar phase. The largest amplitudes are for f_1, 2*f_1, 2*f_2, and 2*f_2-2*f_1. A primary period 1174 hours and secondary period 747 hours are suggested. Unfortunately the data are not quite sufficient to determine a secure second period by this method. The two evaluations of the primary period agree within 0.5%, and those of the secondary period within 2%. Tumbling behavior is clearly shown, with reliability assessed at PAR=-2. Pravec et al. (2005) define the reliability PAR=-2 as "Non principal axis rotation detected based on deviations from the single periodicity but the second period is not resolved." Figure 11 illustrates the sum of the Fourier components of all of the periodic terms listed above and compares with the data.

The dual period complicated the analysis of the absolute magnitude H and slope parameter G with the H-G calculator tool of *MPO Canopus* version 10. The calculations were performed in the Cousins R magnitude system of the calibrated data. Values of H = 9.51 ± 0.03 (R magnitude) and G = 0.24 ± 0.02 have been obtained. Given the directly observed V-R = 0.48, the value of H as conventionally defined in the V magnitude system is 9.99 ± 0.03. This agrees closely with the value of 10.00 quoted in Harris et al. (1999). The H-G plot, in the V magnitude system, is presented in Figure 12.

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EDITOR'S NOTE: The enormity of the effort required to fully reveal Glauke's long period lightcurve cannot be understated. To commemorate this accomplishment, two invited commentaries follow. The first is by long-time *MPB* advisor Dr. Alan W. Harris who gives a perspective on the history of asteroid lightcurve work as recorded on the pages of the *MPB*. The second is a more personal tribute to Dr. Frederick Pilcher by long-time ALPO Minor Planet Section member Frank J. Melillo, who gives a thirty year perspective on Professor Pilcher's broad role in encouraging and promoting amateur astronomers toward minor planet research.
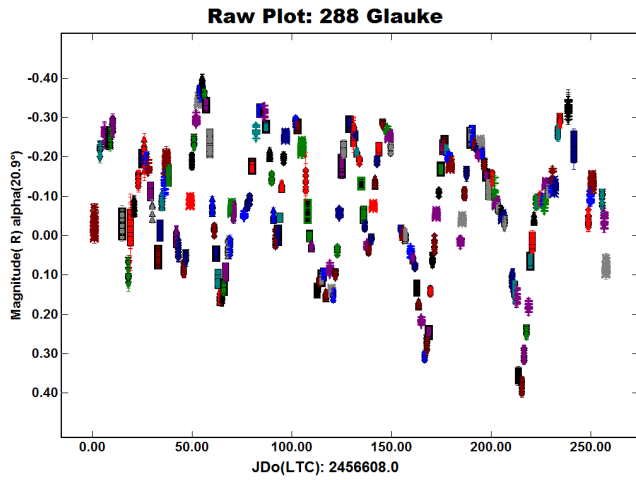
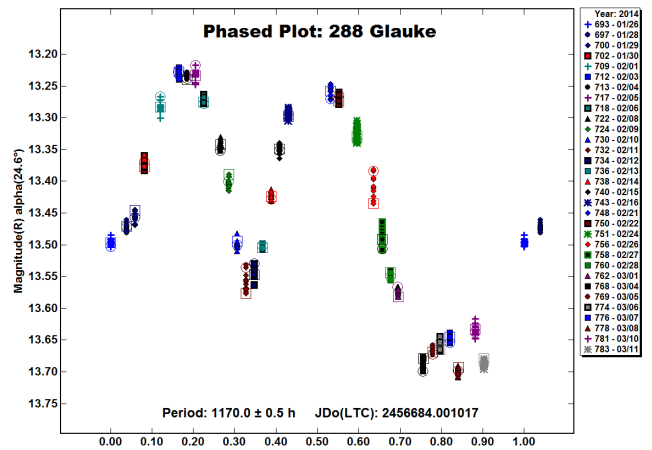Figure 1. Raw lightcurve of 288 Glauke 2013 Nov. 12 - 2014 July 27.

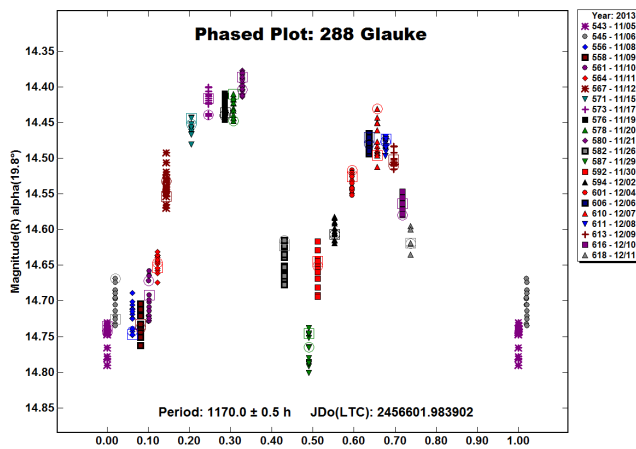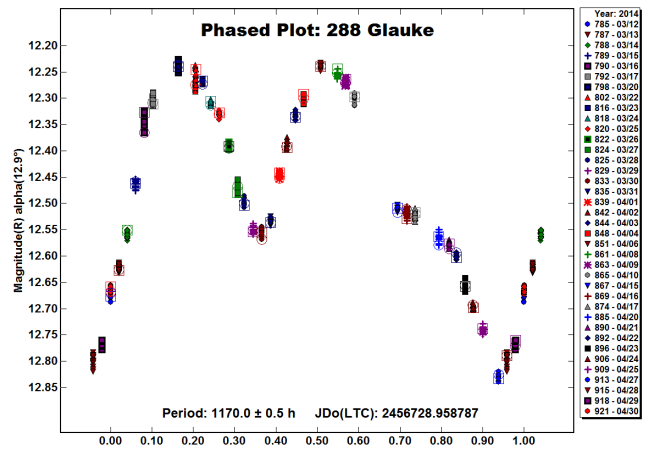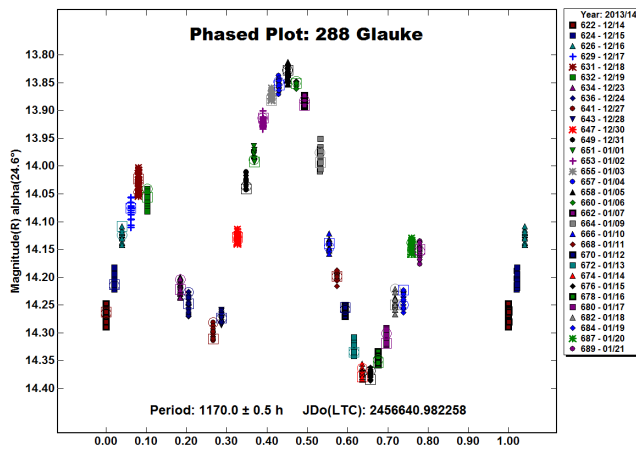Figure 2. One cycle lightcurve of 288 Glauke 2013 Nov. 5 - Dec. 11.

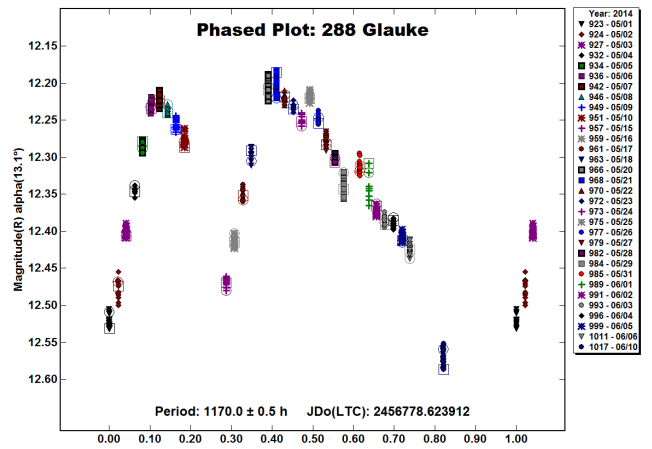Figure 3. One cycle lightcurve of 288 Glauke 2013 Dec. 14 - 2014 Jan. 21.

Figure 4. One cycle lightcurve of 288 Glauke 2014 Jan. 26 - Mar. 11.
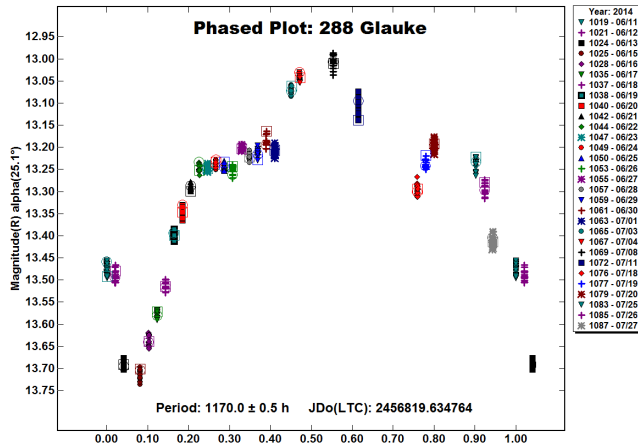

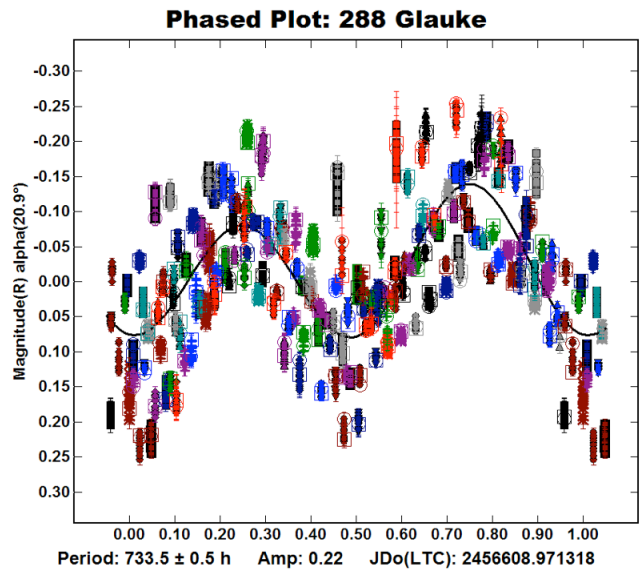Figure 5. One cycle lightcurve of 288 Glauke 2014 Mar. 12 - Apr. 30.

Figure 6. One cycle lightcurve of 288 Glauke 2014 May 1 - June 10.

Figure 7. One cycle lightcurve of 288 Glauke 2014 June 11 - July 27.

Figure 8. Lightcurve of 288 Glauke phased to the primary period 1169.0 hours with the contribution of the secondary period subtracted out.

Figure 9. Lightcurve of 288 Glauke phased to the secondary period 733.5 hours with the contribution of the primary period subtracted out.
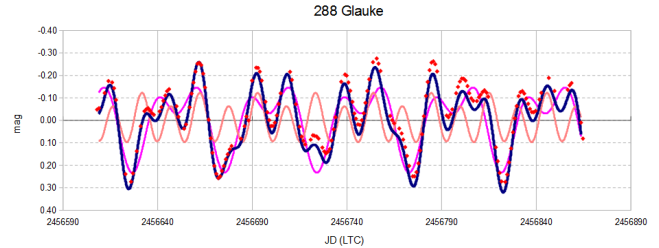
Figure 10. Graphs of second order Fourier coefficients of the primary 1169 hour period (pink), the secondary 733.5 hour period (orange), and their sum (blue). A single data point representing the mean for each night is shown in red for comparison.
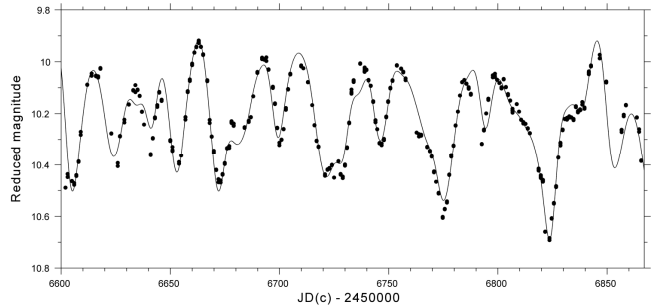
Figure 11. Graph of the third order Fourier components of primary 1174 hour period, secondary 747 hour period, and all other terms as explained in the text, with data points superimposed, all converted to R(1, 15 deg) using G=0.24.
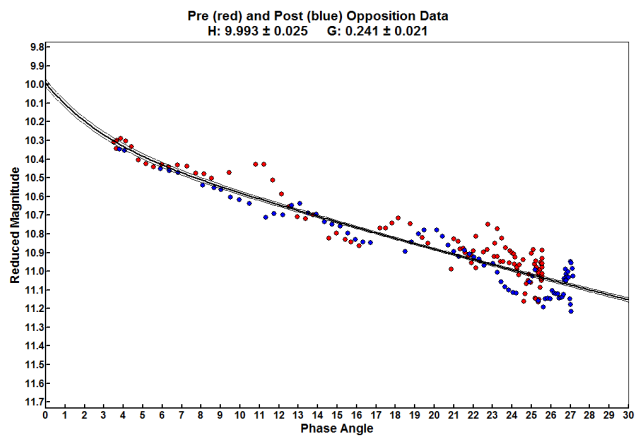
Figure 12. H-G plot for 288 Glauke, with pre-opposition data in red and post-opposition data in blue.

A PERSPECTIVE ON HOW FAR ASTEROID PHOTOMETRY HAS COME IN THE PAST FORTY YEARS

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One of the first papers in the *Minor Planet Bulletin* reporting photometric lightcurve observations appeared forty years ago – and the contrast of what can be achieved by modern amateur astronomers is beautifully put into perspective by the gargantuan accomplishment on asteroid 288 Glauke published by Pilcher *et al.* (this issue, page 6). The contrast is with those first *MPB* asteroid lightcurve observations published by Welch, Binzel and Patterson (*MPB* **2**, 20-21, 1974), reporting photoelectric observations of 18 Melpomene, correcting a previously reported period by professional astronomers. A note following the article from Joseph Patterson, Director of Camp Uraniborg (and recently honored by naming asteroid 8794 Joepatterson), pointed out that the two observers, Douglas Welch and Richard Binzel, were 15 year old high school students when they made the observations. In addition to these familiar names, it can be noted that another, Frederick Pilcher, was a Corresponding Editor of *MPB* at that time. Now, 40 years later, much has changed, yet much remains the same. All the individuals named are still active and accomplished astronomers, Welch, Binzel and Patterson are full professors of astronomy in their respective universities, and Pilcher is a retired professor who is now a very active amateur observer, as demonstrated by the current paper. Binzel, of course, is the current Editor of *MPB*, so roles are a bit reversed 40 years on, but the enthusiasm for research and learning is undiminished.

But much has changed, most dramatically the volume of asteroid lightcurve data nowadays, the methods of observation, and the highly computerized methods of analysis. Figure 1 well illustrates this dramatic growth and reveals the key role played by Brian D. Warner in opening a new gateway to the field. Prior to 1974, there were "known" rotation periods for 64 asteroids, and some of those initially published (18 Melpomene, for example) were wrong; today we have fairly reliable periods for more than 5000 asteroids. In the 1974 paper, Welch *et al.* described taking data by

reading the needle position (in the dark) on a microammeter coming from the output of a 1000 volt 1P21 photomultiplier tube. And that was high-tech; Frederick Pilcher at that time was actively doing asteroid photometry – visually! Today, observations are often taken with robotically, sometimes remotely, controlled telescopes, with highly sensitive CCD cameras that allow a "backyard" telescope of modest aperture (0.3-0.4 m) to work targets as faint as could be reached only with major observatory telescopes (~2 m aperture) using a photoelectric photometer. In 1974, data analysis was done by plotting the few preciously derived data points from each night on graph paper and overlaying them on a light table to estimate the cycle period. Welch *et al.* describe a crude estimation of the pole orientation of Melpomene based on the differences in amplitude of variation at two different longitude aspects in the sky. They were roughly right, not bad for just two observing aspects. The computational power that is now brought to bear on lightcurve analysis, both hardware and software, is truly remarkable and advanced. It is now possible to do "lightcurve inversion" to obtain detailed shape models of asteroids from their lightcurves. The amount of computation to run such solutions boggles the mind and would be impossible with the computing power available even a couple decades ago, now it can be done on a home computer or even a laptop. The *Minor Planet Bulletin* itself has experienced a similar explosion of volume. In 1974, *MPB* Volume 2 consisted of 46 pages, for all four issues. The most recent *MPB* ran 106 pages, the most recent volume (41) concluded with 308 pages. With smaller type and more efficient page layout, the published volume is at least ten times greater. Along with its growth in volume, the *MPB* has become *the* journal for publication of asteroid lightcurve results, by both amateurs and professionals and combinations of both, as in the present publication. With its editorial review practices well established, the *MPB* is recognized as a professional level refereed journal, with articles indexed in the SAO/NASA Astrophysics Data System.

Lastly, it can be noted that with the vast improvement in technology has come greater challenges in observation. We have now discovered asteroids with rotation periods from under a
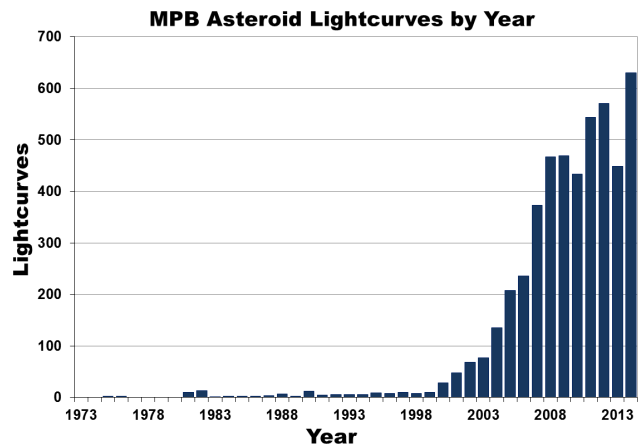

Figure 1. The growth in the number of lightcurves published in *The Minor Planet Bulletin* over the past 40 years. Notable growth spurts commencing in 1999 and 2003, respectively, coincide with the release of the popular *Canopus* software by Brian D. Warner and the subsequent publication of Warner's first edition *A Practical Guide to Lightcurve Photometry*. An even more popular second edition of Warner's book published in 2006 has certainly helped fuel the ongoing growth and what appear to be sustaining numbers of lightcurve measurements.

minute to approaching 2 months for 288 Glauke, the subject of the current paper. In addition, some have satellites, leading to multiple periods of variation and mutual eclipse events to complicate analysis and require more extensive observations. And perhaps most difficult to observe, some very slowly rotating asteroids are "tumbling" in a non-principal axis rotation state, like a badly passed American football. Glauke is exactly such a case, suspected given its extremely long rotation period, but very difficult to confirm since it takes nearly two months for a single rotation cycle. The non-repetitive nature due to "tumbling" requires a minimum of two cycles to compare, and three or more is better. This represents a truly heroic effort to do right, and the Pilcher *et al.* paper in this issue is an example of such heroism on the part of the observers, and also illustrates the elaborate computer analysis needed to make sense of the data. It is an example of collaboration between the amateur and professional communities at its best – and a measure of how far the field has come over the past forty years.

MY THIRTY YEARS' EXPERIENCE
WITH THE ALPO MINOR PLANET SECTION

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This paper describes the author's early experience with asteroids and thirty years with the ALPO Minor Planets Section.

This year will mark the 30th anniversary of my first paper in the *Minor Planet Bulletin*, even though I started my astronomy interest on a different path. When I was growing up, I was attracted by the beauty of the universe. But planetary observing was my true passion. I had seen most of the planets, including Comet Kouhotek. But only one part of the solar system wasn't yet observed for me: the asteroids. I had little experience in observing asteroids before I knew about the ALPO Minor Planets Section and its journal *The Minor Planet Bulletin*.

During the 1970s, I subscribed to *Sky & Telescope* magazine, which I still receive. The December 1974 issue mentioned a very unusual asteroid that was coming near Earth. The asteroid 433 Eros made headlines. I was excited about it and Eros was going to be 'the closest' to Earth since 1931! I had a 4½ - inch Tasco reflector, which was big enough to observe Eros. One of my first observations of an asteroid was on December 6, 1974, when I spotted Eros. I followed Eros until February 1975. I observed and sketched Eros each time and I made notes to describe how it looked through the eyepiece. January 23, 1975 was a night to remember. Eros passed very close to the bright star Kappa Geminorum and I saw real-time motion every 15 minutes through the eyepiece. Also, I noticed Eros change its brightness. Its movement was apparently easy to see due to the close proximity to Earth. In fact, it was around opposition when it moved from north to south in Gemini. I revisited Eros again in 2012 after 37 years!

There was another moment in asteroid observation as I was participating where I witnessed a possible occultation of a star 1 Vulpecula by an asteroid 2 Pallas. On the morning of May 29, 1983, Pallas was predicted to occult this star, which was quite close to the shadow's path. Unfortunately, I did not see anything, but I did see Pallas very close to the occulting star. Also, in 1983, I became involved in photoelectric photometry and I purchased a photometer SSP-3 OPTEC, which I still have today! I became a member of American Association of Variable Star Observers (AAVSO) and started working on variable stars. But the following year I became a member of the Association of Lunar and Planetary Observers (ALPO) to pursue further interest in planetary observing.

Asteroid photometry didn't inspire me until I read the book 'A Complete Manual of Amateur Astronomy' (1981 edition) by Dr. Clay Sherrod. There is a chapter on 'Visual Photometry of the Minor Planets' on page 192. Having a photometer, I knew I could go forward and do more meaningful work on asteroids. But I needed a good start. While I was fairly new to ALPO, I received some quarterly issues of *The Minor Planet Bulletin* from 1983-84. I read that Richard G. Hodgson was no longer a recorder for the Minor Planets section. I understand that he was a founder for that section, but he moved his title position over to the Remote Planets section. A new Minor Planets Recorder, Dr. Frederick Pilcher, took over the section, and he is still holding his position as of today! It was Dr. Pilcher who got me interested in doing asteroid photometry and other related fields.

Dr. Pilcher was actually the first person I corresponded with to do serious astronomical work. He gave me a good start. In April 1985, I was free to choose one asteroid that could be suitable for my equipment. Asteroid 4 Vesta came to opposition at that time and was a perfect target for a start. I monitored Vesta with my SSP-3 OPTEC photometer on a Celestron 8-inch telescope for two nights and I produced some interesting lightcurves. Dr. Pilcher told me that I was doing first-class astronomical work, and I was quite excited about that. He encouraged me to write a paper and get it published in *The Minor Planet Bulletin*. That part got me nervous because I had never published a scientific paper before. Later that year in Volume 12 of the *MPB*, I was completely overwhelmed by seeing my paper on Vesta published for the very first time!

I continued to do more photometry work on asteroids and got my observations published regularly in the *MPB* following the next ten years. Also, I corresponded with Richard Binzel, who was a graduate student at the University of Texas at the time, and he edited my papers for the *MPB*. I met him personally at the 40th Division of Planetary Science (DPS) meeting in 2008. Also, I corresponded with Dr. Alan Harris (JPL; now retired) as well for his advice on asteroid photometry, and I also met him at the 40th DPS meeting. In later years, I pursued other astronomical interests but I never really abandoned my work in minor planet photometry. Then, in 2012, I got around to revisit 'my old friend' 433 Eros to do CCD photometry work. Again, with Dr. Pilcher's encouragement, I monitored Eros for four nights and I published those results in the *MPB* issue 40-2 (2013) - the first time to publish in 17 years!

In 1994, I had a chance to apply for observations with the Hubble Space Telescope (HST). At that time, the top program officers allowed amateur astronomers to participate in some observing time with the HST. My plan with the HST was to observe Vesta near opposition in May 1996 when it was possible to resolve the tiny 0.6 arc second disk diameter. No matter what, it was impossible to discern any details on Vesta from the ground-based observatories. I

asked Dr. Pilcher to be my co-investigator. He accepted it and I wrote a proposal with his help. I turned it in to the amateur working group for the HST project. Unfortunately, I didn't get picked, as only a few amateurs were selected. The reason why my proposal was turned down was because it was then possible that Vesta's disk could be resolved using the adaptive optics on larger telescopes, which could compensate the atmospheric turbulence to discern tiny details.

I'm glad I had a chance to meet Dr. Fred Pilcher at the 2003 ALPO meeting in Boardsman, Ohio. I didn't realize back then, but I do now, how much he helped spark my interest in first-class work in planetary science and other related fields. With Dr. Pilcher's encouragement, I hope other amateurs went through the same experience as I did. I learned a lot from Professor Pilcher. He's a great man and has certainly enriched many people who study minor planets. Without his encouragement, I wouldn't be sitting here and writing this perspective, thirty years later!

ASTEROIDS AT ETSCORN:
490 VERITAS, 3039 YANGEL, 5492 THOMA

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We present lightcurves and synodic periods for 3 asteroids. 490 Veritas is an inversion model candidate, while 3039 Yangel and 5492 Thoma are new determinations of synodic periods.

The observations of asteroid lightcurves were obtained at the Etscorn Campus Observatory (ECO, 2014) in Socorro, New Mexico. We used 3 Celestron 0.35-m SCT telescopes on Software Bisque Parmount ME mounts (SB, 2013). Two of the telescopes used SBIG STL 1001E CCDs that have 1024 x 1024 with 24 micron pixels. The third C-14 used a SBIG ST10xme with an Optic 0.5x focal reducer. The SBIG ST-10XME is binned 2x2 providing an image of 1092 by 736 13.6 with 13.6 micron pixels. The pixel size for the STL 1001E cameras is 1.25 arc seconds/pixel. This provides a 22 x 22 arc minute field of view. The ST-10 XME pixel size is 1.28 arc seconds/pixel. This provides a 20 x 16 arc minute field of view. The asteroid images were obtained through a clear filter. Exposure times varied between 3 and 5 minutes depending on the brightness of the object. Each evening a series of 11 dome flats were obtained and combined into a master flat with a median filter. The telescopes were controlled with Software Bisque's TheSky6 (SB, 2014) and the CCDs were controlled with CCDsoft V5 (SB, 2014). The images were dark subtracted and flat field corrected using image processing tools within MPO Canopus version 10.4.1.9 Warner (2014). The multi-night data sets for each asteroid were combined with the FALC routine (Harris et. al., 1989) within Canopus to provide synodic periods for each asteroid.
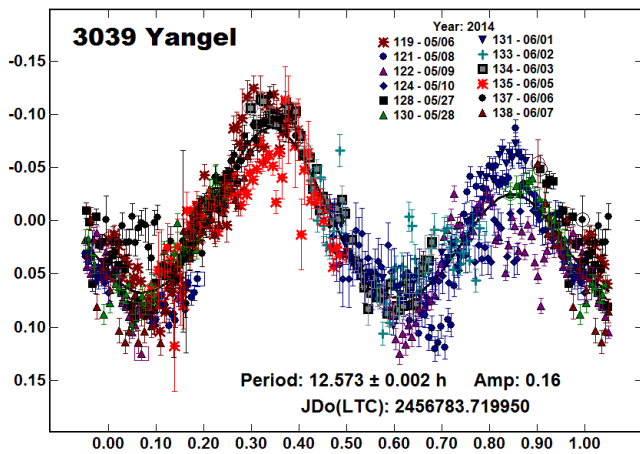
Observed Asteroids

490 Veritas is listed as Inversion Model Candidate by Warner et. el. (2014). Our efforts provide another solar bisector than previously observed. The second two asteroids, 3039 Yangel and 5492 Thoma were observed because they have no known synodic periods. Information about asteroid discovery dates and names were obtained for the JPL small bodies Database, JPLSDB (2014). The previously observed solar bisector phase angles were obtained from the lightcurve data base, LCDB, (Warner *et.al.* 2009).
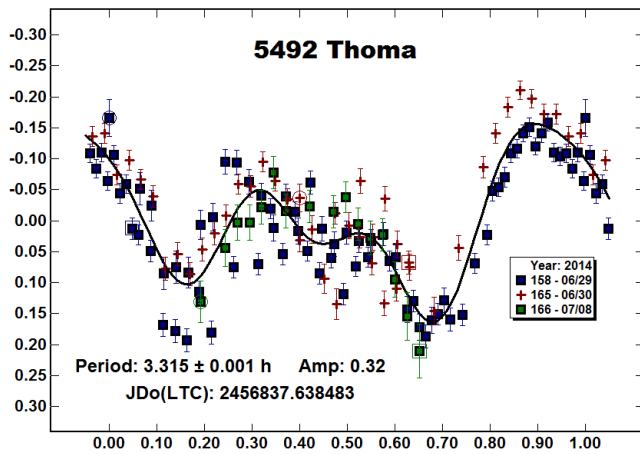
490 Veritas is a main-belt asteroid discovered by M. Wolf at Heidelberg on 1902 Sep 03. It is also known as 1902 JP. The LCDB (Warner et. al., 2009) reports 3 period determinations. Koff and Brincat, (2001) determined a period of 7.30 ± 0.005 h with an amplitude 0.33 mag. from data taken in February and March of 2001. The solar bisector angles (PABL, PABB) were 147.6 and -5.4. Behrend (2007) reported observations of Pierre Antonini which provide a period determination of 7.927 ± 0.002 h with an amplitude of 0.33 mag. form data taken in March 2007. The solar bisector angles (PABL, PABB) were 170.5 and -1.5. Gil-Hutton and Canada (2004) estimated the period to be 9.962 ± 0.004 h with an amplitude of 0.577 mag. There observation were obtained on only 3 nights and do not provide complete phase coverage. Their PABL, PABB were 188.3 and 2.5. We observed 490 Veritas on 9 nights between 2014 Jun 06 and 2014 Jun 25 and obtained a period of 7.927 ± 0.001 h with an amplitude of 0.21 mag. The solar bisector angles (PABL, PABB) were 256.7 and 11.1.
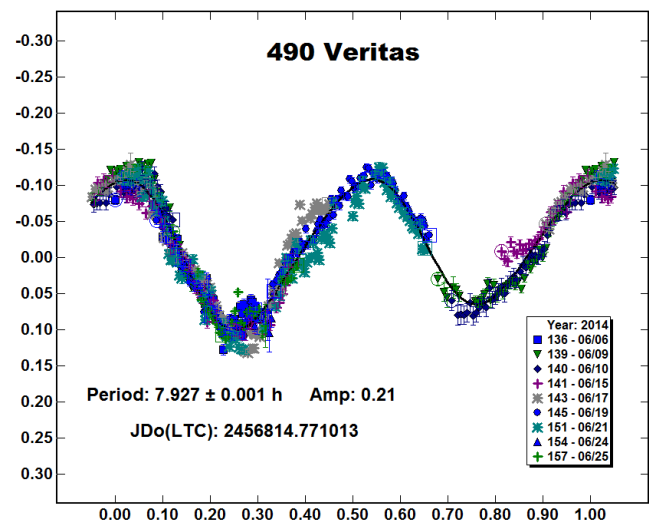
3039 Yangel is a main-belt asteroid discovered by L. Zhuravela at Nauchnyj on 1978 Sep 26. It is also known as 1978 SP2 and 1981 EP17. We observed 3039 Yangel on 12 nights between 2014 May 06 and 2014 Jun 07. While there is a fair amount of noise in the data we determined a period of 12.753 ± 0.002 h with an amplitude of 0.16 ± 0.07 mag.

3039 Yangel


```
Year: 2014
119 - 05/06    131 - 06/01
121 - 05/08    133 - 06/02
122 - 05/09    134 - 06/03
124 - 05/10    135 - 06/05
128 - 05/27    137 - 06/06
130 - 05/28    138 - 06/07
```

Period: 12.573 ± 0.002 h   Amp: 0.16
JDo(LTC): 2456783.719950

5492 Thoma is a main-belt asteroid discovered by van Houten and Gehrels at Mt. Palomar on 1971 Mar 26. It is also known as 3227 T-1, 1959 TK, 1987 SM27 and 1987 UM8. We observed 5492 Thoma on 3 nights between 2014 Jun 29 and 2014 Jul 08. We estimate the period to be 3.315 ± 0.001 h with an amplitude of 0.32 ± 0.05 mag.

5492 Thoma


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Year: 2014
158 - 06/29
165 - 06/30
166 - 07/08
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Period: 3.315 ± 0.001 h   Amp: 0.32
JDo(LTC): 2456837.638483

Acknowledgments

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A LIGHTCURVE FOR 788 HOHENSTEINA

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A lightcurve of 788 Hohenstenia was obtained from the Center for Solar System Studies during July and August 2014.

In late July 2014, a request for observations of 788 Hohenstenia was announced by Raoul Behrend. A group of European observers had been observing Hohenstenia and described several eclipse events. Their lightcurve (Behrend, 2014) was phased to a rotational period of 47.856 h and showed two "events" where the magnitude of the asteroid dropped 0.2 mag. over the course of a few minutes. These observing sessions each ended with the event and did not show a corresponding brightening of the asteroid.

Coley started observations on 25 July using a 0.35-m SCT with a SBIG ST-9XE CCD camera. When that telescope was taken offline for maintenance, Stephens continued observations starting on August 1 with a 0.4-m SCT and an FLI-1001E CCD camera. All images were unbinned with no filter and had master flats and darks applied to the science frames prior to measurement. Measurements were made using *MPO Canopus*, 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). Night-to-night calibration of the data (generally < ±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.

Our observations produced a lightcurve with an amplitude of ~0.10 to 0.15 mag. Harris *et al.* (2014) showed that with an amplitude in this range, it is possible that the lightcurve could have only a single extrema, or three or more extrema. With small zero point adjustments within the comparison star catalog error (~0.05 mag.), our data could be phased to periods of 29.94 h or 40.87 h. A period spectrum also shows possible periods of more than 50 h and 60 h, but these solutions increasingly become a fit-by-exclusion result, i.e., the RMS error is minimized by reducing the number of overlapping data points in the phased data set. There was a single night (Aug 5) which shows an unexplained brightening at the start of the run. There were no background stars or observed defects on the CCD chip that would explain this anomaly. However, since this was seen only once, we initially assume it to be an observational error.

Oey *et al.* (2008) observed Hohensteina in 2008 April – May. Their observations spanned 5 weeks resulting in an asymmetric lightcurve with a rotational period of 37.176 h and an amplitude of about 0.2 mag. These observations were uploaded to the ALCDEF database maintained at the Minor Planet Center (Warner *et al.*, 2011) and were not calibrated to an internal standard. Arbitrary night-to-night zero point adjustments were applied to create a best fit in the lightcurve.

We downloaded the Oey observations from ALCDEF and reanalyzed their lightcurve. We found possible fits at 29.14 h and 43.02 h. These were close to, but could not be reconciled with, our 29.94 h and 40.87 h periods. The Behrend period of ~48 h is synchronized with the Earth's rotational period and can be ruled out by the combination of the Stephens-Coley and Oey *et al.* observations. The eclipse events, with a 24 hour periodicity and occurring at the end of the observing sessions are possibly an observing artifact.

This object remains a mystery for the moment and begs to be reobserved at a future opposition when longer observing runs can be obtained. Hohenstenia reaches opposition again in 2015 September, 2016 November, and 2018 January.

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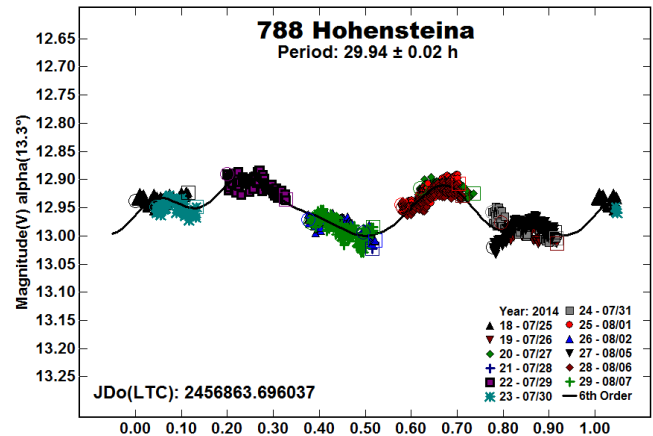
Figure 1. Stephens-Coley 2014 observations phased to a rotational period of 29.94 h.
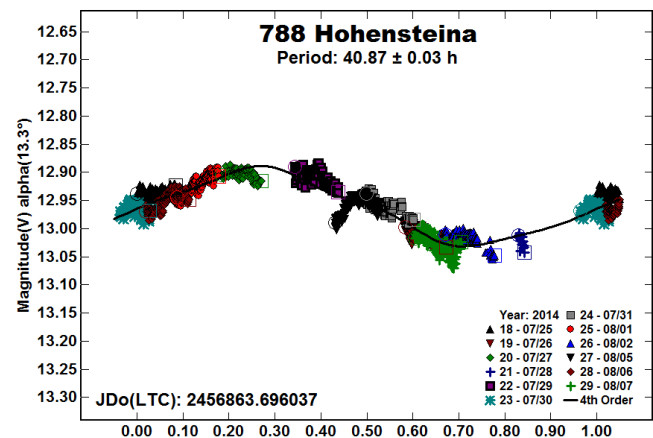

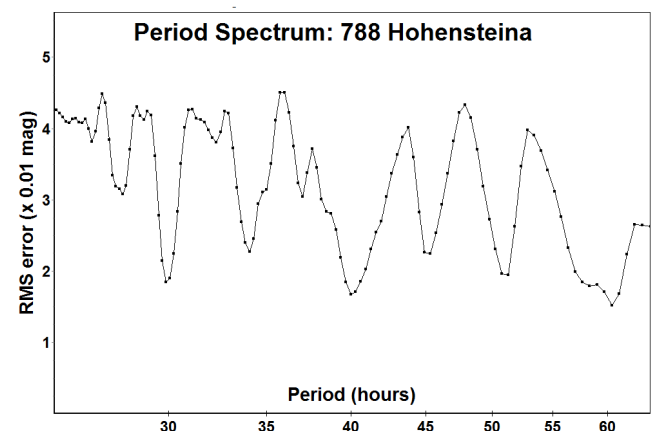Figure 2. Stephens-Coley 2014 observations phased to a rotational period of 40.87 h.

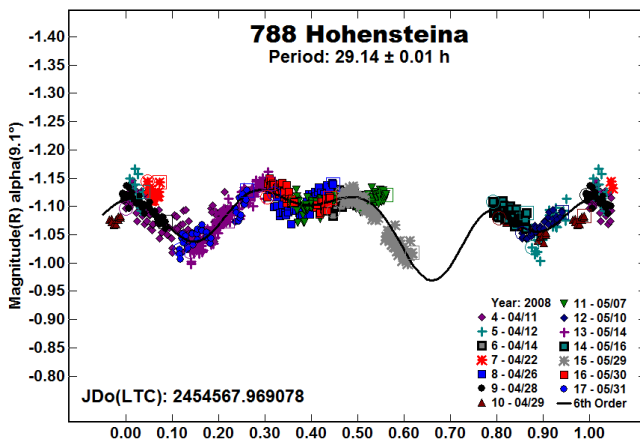Figure 3. Period spectrum for the 2014 data.

Figure 4. Oey *et al.* 2008 data phased to a rotational period of 29.14 h. Arbitrary zero point adjustments were applied to obtain a best fit.
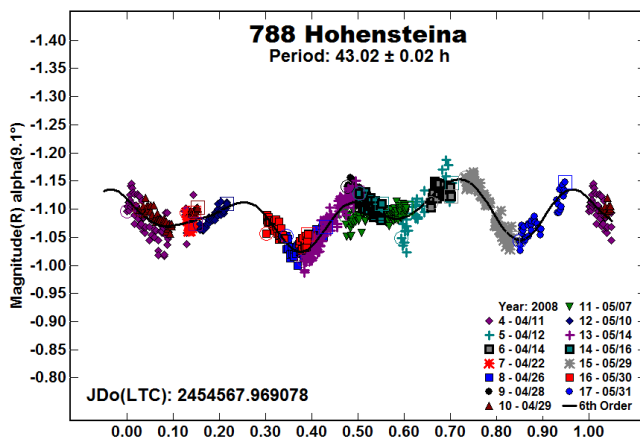

Figure 5. Oey *et al.* 2008 data phased to a rotational period of 43.02 h. Arbitrary zero point adjustments were applied to obtain a best fit.

ASTEROID PHOTOMETRY FROM THE PRESTON GOTT OBSERVATORY

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Asteroid period and amplitude results obtained during 2014 at the Preston Gott Observatory in Texas and the Chiron Observatory in Western Australia are presented.

The Preston Gott Observatory is the main astronomical facility of the Texas Tech University. Located about 20 km north of Lubbock, the main instrument is a 0.5-m *f*/6.8 Dall-Kirkam Cassegrain. An SBIG STL-1001E CCD camera was used with this telescope. Other telescopes used were 0.35-m and 0.3-m Schmidt-Cassegrains (SCT), and 13-cm refractors. SBIG ST9XE CCD cameras were used with the SCTs and SBIG ST10XE CCD

cameras were used with the refractors. All images were unfiltered and reduced with dark frames and twilight flats.

Chiro Observatory is a private observatory owned by Akira Fuji near Yerecion in Western Australia. (MPC 320). The main instrument is a 0.3-m *f*/6 Newtonian. An SBIG STL-1001E CCD was used with this telescope. All images were unfiltered and were reduced with dark frames and twilight flats.

Image analysis was accomplished using differential aperture photometry with *MPO Canopus*. Period analysis was also done in *MPO Canopus*, which implements the algorithm developed by Alan Harris (Harris *et al.*, 1989). Differential magnitudes were calculated using reference stars from the USNO-A 2.0 catalog and the UCAC3 catalog.

Results are summarized in the table where column 3 gives the range of dates of observations and column 4 gives the number of nights on which observations were undertaken. The lightcurve plots are presented at the end of the paper. The data and curves are presented without additional comment except were circumstances warrant.

1132 Hollandia. Observations of this asteroid were made on 3 nights, when it was in the field of another asteroid being observed. The derived period was 5.360 hours. This agrees closely with the 5.568 hour period obtained by Behrend (2003) and the 5.326 hour period derived by Saupe *et al.* (2007). As was observed by these other observers, the lightcurve was not a simple bimodal curve, but had a small secondary rise during the fading portions of the lightcurve. More observations of this asteroid at future oppositions would be useful for modeling its shape.

1967 Menzel. Observations of this asteroid were made on 3 nights, when it was in the field of another asteroid being observed. The derived period was 2.8364 hours. This agrees closely with previously reported periods of 2.834 h (Behrend, 2005), 2.834 hour (Lecrone *et al.*, 2006), and 2.8346 h (Higgins, 2007).

3015 Candy. Observations of this asteroid were previously made by the author in 2005 December (Clark, 2007) and 2011 November (Clark, 2011). The latest observations were made in order to gather data for modeling the asteroid's shape. The period determined from these latest observations matches that found previously but with a slightly smaller amplitude.

3089 Oujianquan. Observations of this asteroid were previously made by the author in 2004 June (Clark, 2007). A period of 11.198 hours was derived at the time, however this result was uncertain. The latest observations rule that result out completely, leading to a period of 14.328 hours.

(14501) 1995 YY1. This asteroid was observed on one night when it was in the field of another asteroid. Although the full period was not covered, the results indicated a period of 5.538 hours.

15609 Kosmaczewski. This asteroid was observed on one night when it was in the field of another asteroid. A period of 5.22 hours was derived from the data, however this result is uncertain and more observations are required.

(21486) 1998 HA148. This asteroid was observed on three nights. However, no reliable period could be derived since the data seemed to show the same portion of the lightcurve. This would indicate a period close to a simple fraction of a day. More observations are needed to confirm this. This asteroid would benefit from international collaboration.

#	Name	Date Range	Sess	Per (h)	Error (h)	Amp	Error
1132	Hollandia	2013 Dec 11 – 2014 Jan 27	3	5.360	0.001	0.30	0.03
1967	Menzel	2014 June 14-16	3	2.8364	0.0005	0.39	0.03
2704	Julian Loewe	2014 Feb 23 – Mar 30	3	2.091	0.001	0.35	0.1
2882	Tedesco	2014 June 14-22	5	19.8046	0.0075	0.76	0.02
3015	Candy	2013 Nov 29 – 2014 Mar 9	5	13.003	0.008	0.09	0.05
3089	Oujianquan	2014 June 23-25	3	14.328	0.008	0.52	0.02
4716	Urey	2014 Mar 9 – May 4	4	5.9260	0.0001	0.59	0.05
4909	Couteau	2014 Aug 3-19	4	5.0505	0.0001	1.04	0.03
4910	Kawasato	2014 June 14-16	3	4.651	0.004	0.22	0.1
9182	1991 NB4	2014 Mar 9-30	3	5.416	0.001	0.40	0.1
9837	Jerryhorow	2014 June 23-25	3	17.397	0.027	0.70	0.05
9854	Karlheinz	2014 Aug 31 – Sept 1	2	4.688	0.006	0.56	0.1
11048	1990 QZ5	2014 July 27 – Aug 24	7	5.9830	0.0004	0.24	0.1
13903	1975 ST	2014 Aug 3 – Sept 1	5	12.933	0.002	0.64	0.1
14051	1995 YY1	2014 June 25	1	5.538	0.022	0.59	0.05
14299	3162 T-2	2014 July 27 – Sept 1	8	17.424	0.002	0.38	0.05
15609	Kosmaczewski	Aug 18, 2014	1			0.15	0.05
18219	6260 P-L	Mar 3 – May 4, 2014	5	4.710	0.002	0.16	0.05
21486	1998 HA148	June 15 – June 18, 2014	3	12.3?		1.3?	
30770	1984 SL4	July 27, 2014	1	5.0?		0.42?	
33684	1999 JW119	June 23 – June 24, 2014	2	5.87	0.01	0.66	0.1
38268	Zenkert	Aug 3, 2014	1	12?		0.7?	
74338	1998 VK15	Aug 20 – Sept 1, 2014	3	7.480	0.001	1.02	0.05

(30770) 1984 SL4. This asteroid was observed on one night when it was in the field of another asteroid. Only a portion of the lightcurve was obtained and the result has been included here as a guide for future observers.

(33864) 1999 JW119. This asteroid was observed on two nights when it was in the field of another asteroid. The data were quite noisy and difficult to analyze. The result presented here is the best that could be obtained. More observations are required to confirm the reality of this result.

38268 Zenkert. This asteroid was observed on one night when it was in the field of another asteroid. Only a portion of the lightcurve was obtained and the result has been included here as a guide for future observers.

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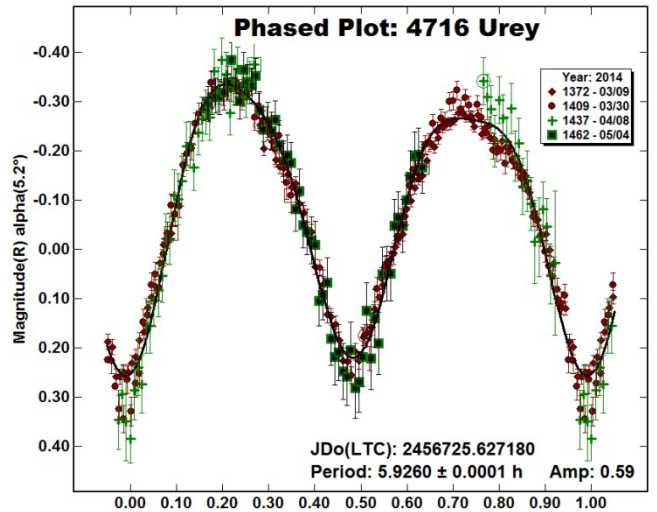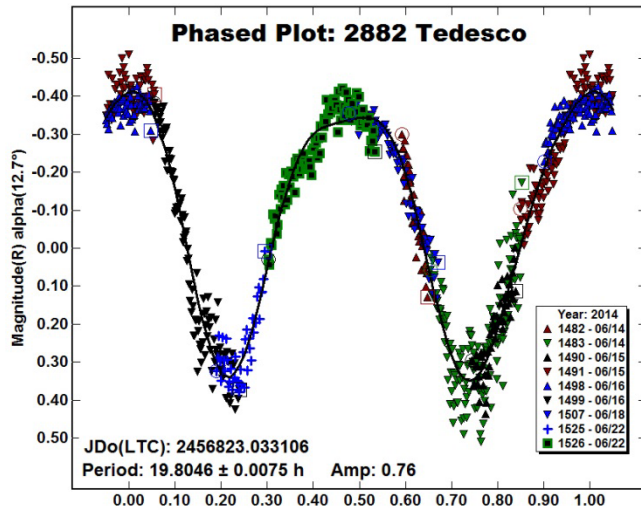Clark, M. (2007). "Asteroid Lightcurves from the Preston Gott Observatory." *Minor Planet Bul.* **39**, 63-65.
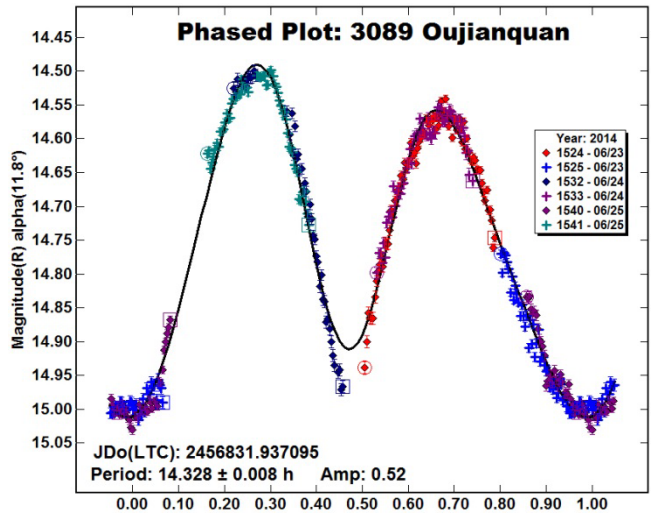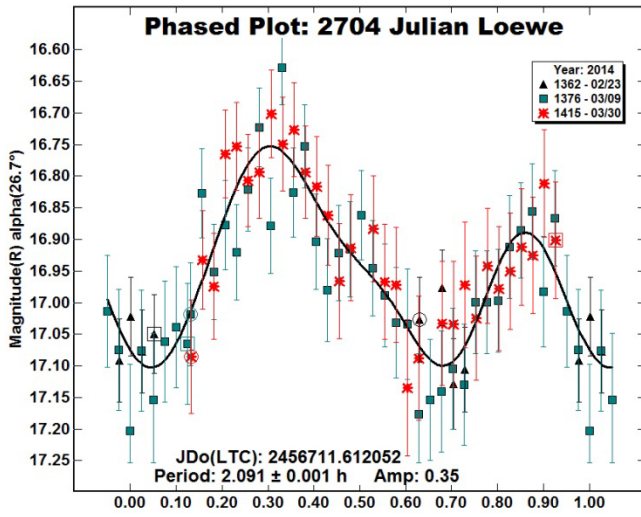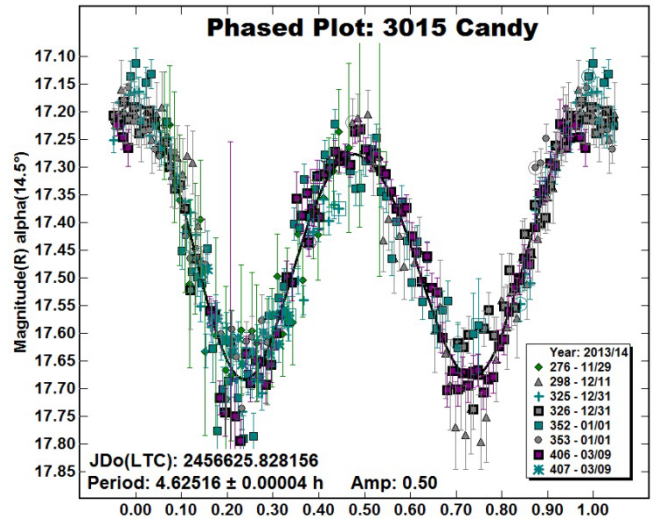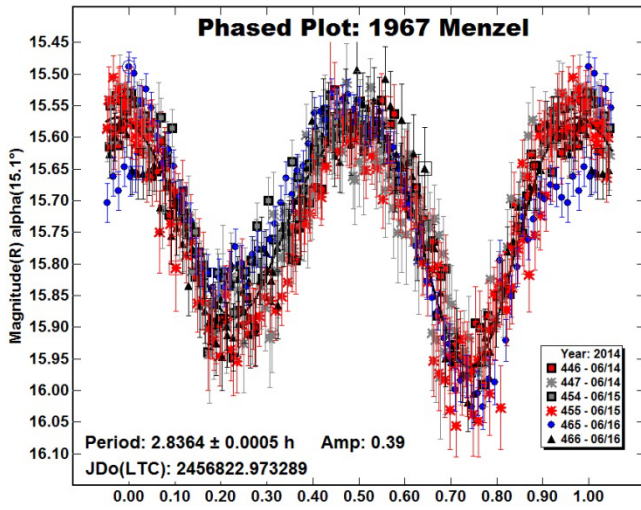
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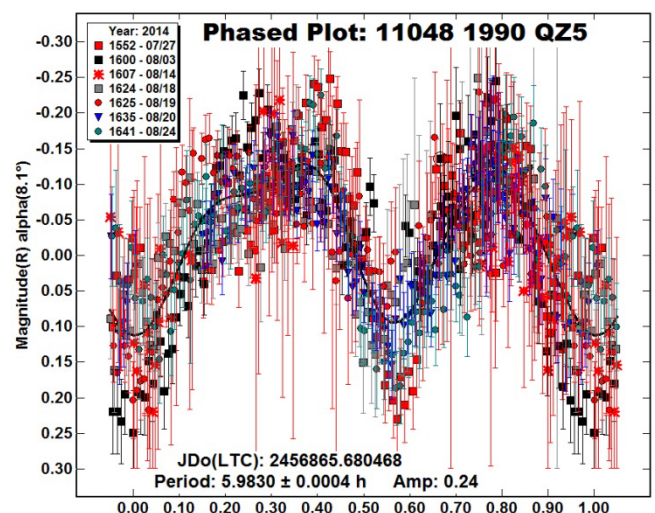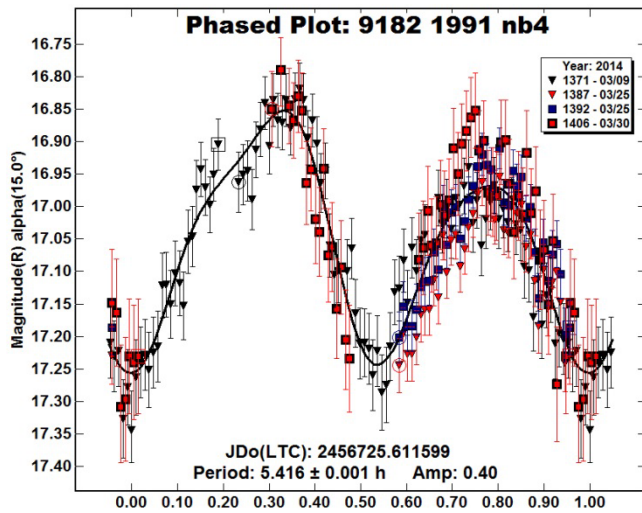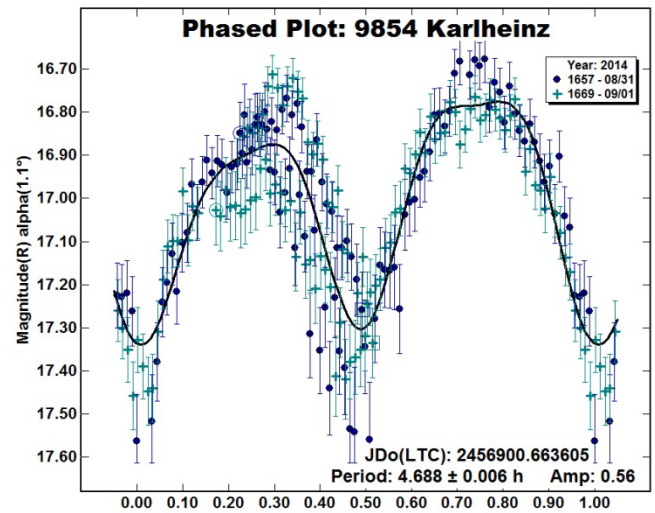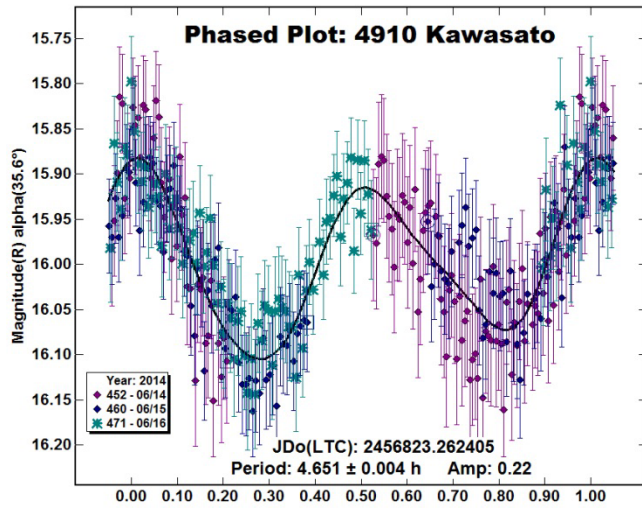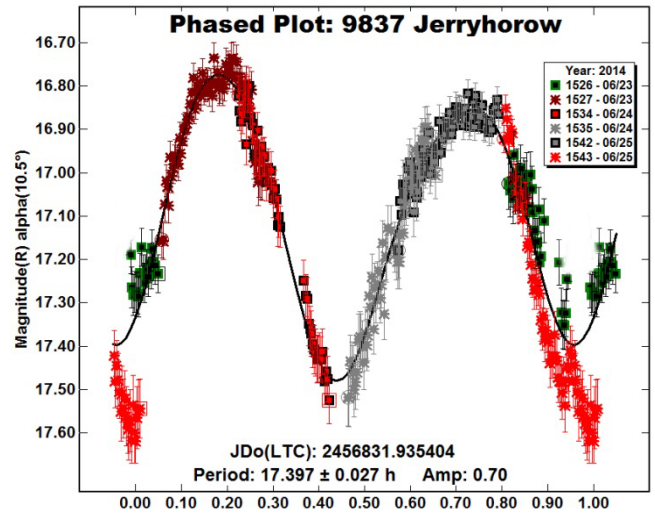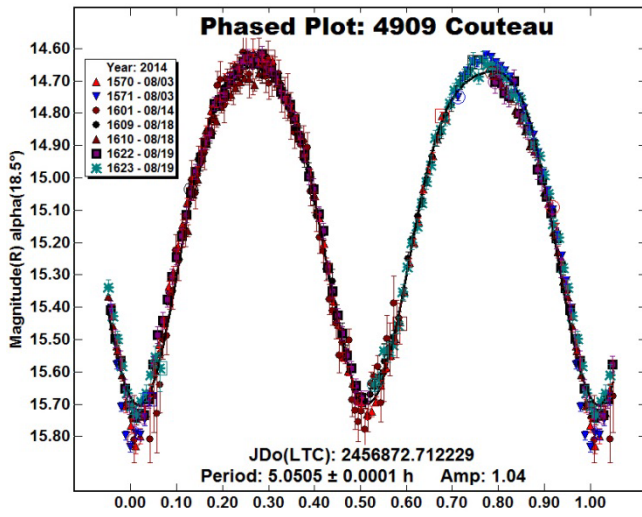
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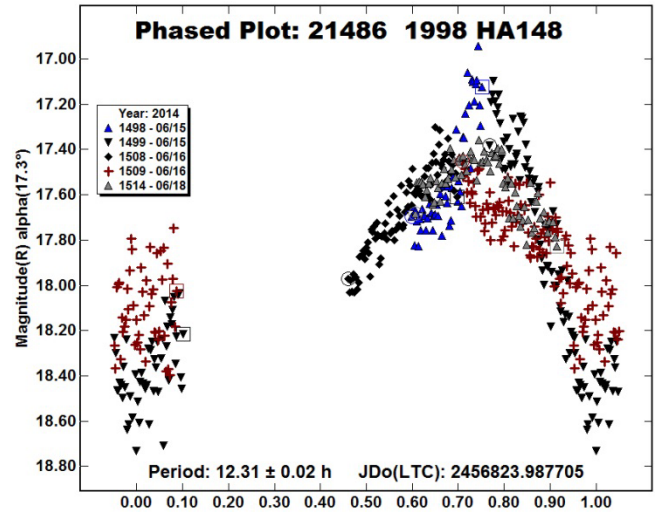
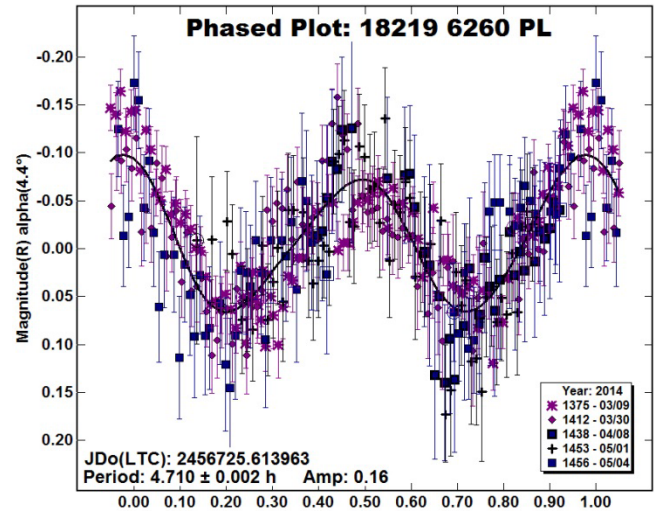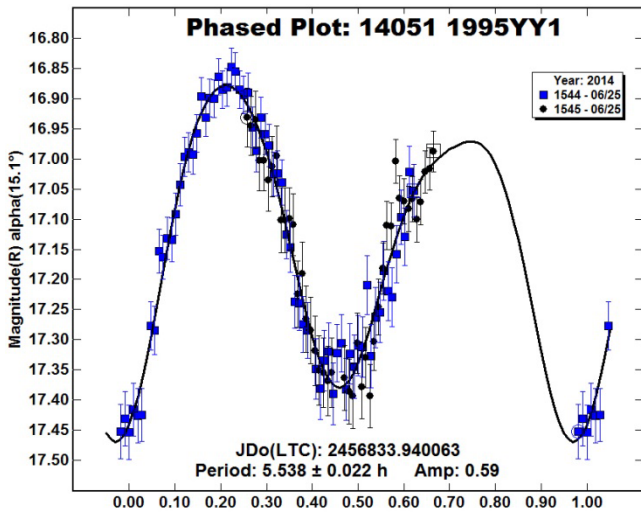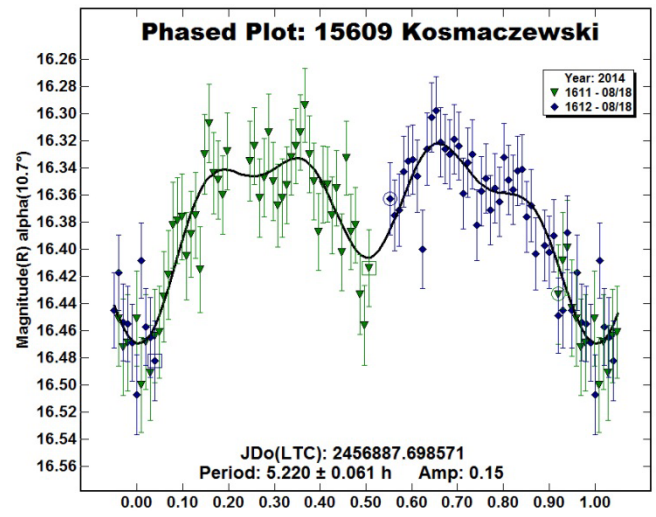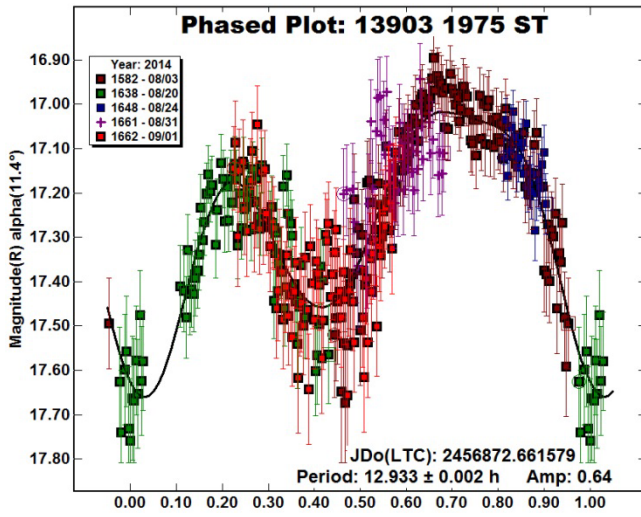Saupe, J., Torno, S., Lemki-Oliver, R., and Ditteon, R. (2007). "Asteroid Lightcurve Analysis at the Oakley Observatory – March/May 2007." *Minor Planet Bul.* **34**, 119-122.
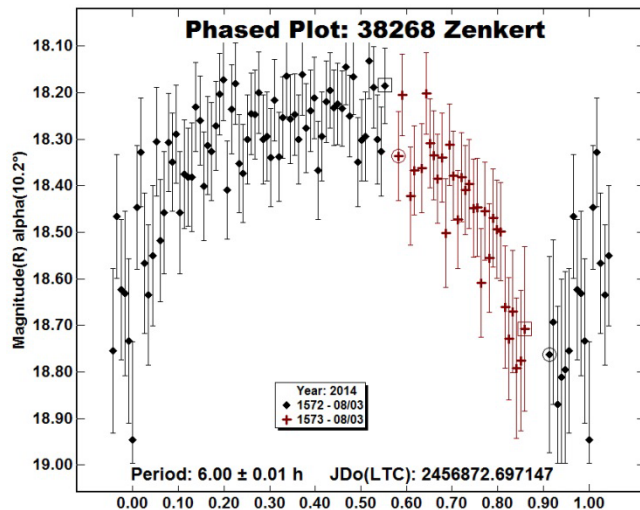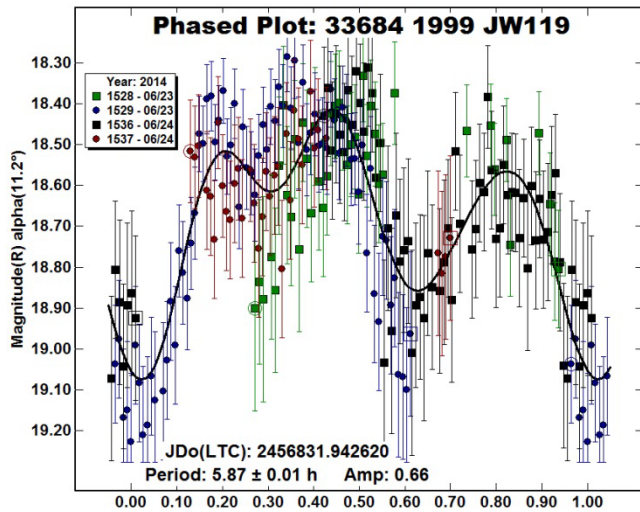
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Phased Plot: 1132 Hollandia

Phased Plot: 1967 Menzel

Magnitude(R) alpha(15.1°)

Year: 2014
446 - 06/14
447 - 06/14
454 - 06/15
455 - 06/15
465 - 06/16
466 - 06/16

Period: 2.8364 ± 0.0005 h   Amp: 0.39
JDo(LTC): 2456822.973289

Phased Plot: 3015 Candy

Magnitude(R) alpha(14.5°)

Year: 2013/14
276 - 11/29
298 - 12/11
325 - 12/31
326 - 12/31
352 - 01/01
353 - 01/01
406 - 03/09
407 - 03/09

JDo(LTC): 2456625.828156
Period: 4.62516 ± 0.00004 h   Amp: 0.50

Phased Plot: 2704 Julian Loewe

Magnitude(R) alpha(26.7°)

Year: 2014
1362 - 02/23
1376 - 03/09
1415 - 03/30

JDo(LTC): 2456711.612052
Period: 2.091 ± 0.001 h   Amp: 0.35

Phased Plot: 3089 Oujianquan

Magnitude(R) alpha(11.8°)

Year: 2014
1524 - 06/23
1525 - 06/23
1532 - 06/24
1533 - 06/24
1540 - 06/25
1541 - 06/25

JDo(LTC): 2456831.937095
Period: 14.328 ± 0.008 h   Amp: 0.52

Phased Plot: 2882 Tedesco

Magnitude(R) alpha(12.7°)

Year: 2014
1482 - 06/14
1483 - 06/14
1490 - 06/15
1491 - 06/15
1498 - 06/16
1499 - 06/16
1507 - 06/18
1525 - 06/22
1526 - 06/22

JDo(LTC): 2456823.033106
Period: 19.8046 ± 0.0075 h   Amp: 0.76

Phased Plot: 4716 Urey

Magnitude(R) alpha(5.2°)

Year: 2014
1372 - 03/09
1409 - 03/30
1437 - 04/08
1462 - 05/04

JDo(LTC): 2456725.627180
Period: 5.9260 ± 0.0001 h   Amp: 0.59

Phased Plot: 4909 Couteau

Year: 2014
- 1570 - 08/03
- 1571 - 08/03
- 1601 - 08/14
- 1609 - 08/18
- 1610 - 08/18
- 1622 - 08/19
- 1623 - 08/19

JDo(LTC): 2456872.712229
Period: 5.0505 ± 0.0001 h   Amp: 1.04

Phased Plot: 9837 Jerryhorow

Year: 2014
- 1526 - 06/23
- 1527 - 06/23
- 1534 - 06/24
- 1535 - 06/24
- 1542 - 06/25
- 1543 - 06/25

JDo(LTC): 2456831.935404
Period: 17.397 ± 0.027 h   Amp: 0.70

Phased Plot: 4910 Kawasato

Year: 2014
- 452 - 06/14
- 460 - 06/15
- 471 - 06/16

JDo(LTC): 2456823.262405
Period: 4.651 ± 0.004 h   Amp: 0.22

Phased Plot: 9854 Karlheinz

Year: 2014
- 1657 - 08/31
- 1669 - 09/01

JDo(LTC): 2456900.663605
Period: 4.688 ± 0.006 h   Amp: 0.56

Phased Plot: 9182 1991 nb4

Year: 2014
- 1371 - 03/09
- 1387 - 03/25
- 1392 - 03/25
- 1406 - 03/30

JDo(LTC): 2456725.611599
Period: 5.416 ± 0.001 h   Amp: 0.40

Phased Plot: 11048 1990 QZ5

Year: 2014
- 1552 - 07/27
- 1600 - 08/03
- 1607 - 08/14
- 1624 - 08/18
- 1625 - 08/19
- 1635 - 08/20
- 1641 - 08/24

JDo(LTC): 2456865.680468
Period: 5.9830 ± 0.0004 h   Amp: 0.24

Phased Plot: 30770 1984 SL4

Year: 2014
1553 - 07/27

JDo(LTC): 2456865.744899
Period: 5.00 ± 0.01 h   Amp: 0.42

Phased Plot: 33684 1999 JW119

Year: 2014
1528 - 06/23
1529 - 06/23
1536 - 06/24
1537 - 06/24

JDo(LTC): 2456831.942620
Period: 5.87 ± 0.01 h   Amp: 0.66

Phased Plot: 38268 Zenkert

Year: 2014
1572 - 08/03
1573 - 08/03

Period: 6.00 ± 0.01 h   JDo(LTC): 2456872.697147

Phased Plot: 74338 1998 VK15

Year: 2014
1643 - 08/20
1644 - 08/20
1652 - 08/31
1653 - 08/31
1674 - 09/01
1679 - 09/01

JDo(LTC): 2456889.676942
Period: 7.480 ± 0.001 h   Amp: 1.02

ROTATIONAL PERIOD OF 1938 LAUSANNA

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We report photometric observations of the main-belt asteroid 1938 Lausanna obtained on five nights in 2014 March and April. We determined a synodic rotation period 2.748 ± 0.001 h and an amplitude of 0.12 ± 0.02 mag.

1938 Lausanna is a main-belt asteroid discovered by P. Wild at Zimmerwald Observatory, Bern, on 1975 April 19. It is a typical main-belt asteroid in an orbit with semi-major axis of 2.24 AU, eccentricity 0.16, and orbital period of 3.34 years. The diameter is unknown but based on an absolute magnitude H = 12.6, the likely diameter is in the range 6-19 km (Minor Planet Center, 2013).

Observations were made on five nights between 2014 March 11 and April 5. At Lindby Observatory (K60) in southernmost Sweden, data were obtained with a 0.25-m f/10 Schmidt-Cassegrain (SCT) operating at f/4.6, Starlight Xpress SXV-H9 CCD camera, and clear imaging filter. The pixel scale was 2.3 arcsec/pixel, and the exposure time was 45 seconds. At Carpione Observatory (K49), near Florence, Italy, data were obtained using a 0.25-m f/10 SCT, SBIG ST9-XE CCD camera, and clear filter. The pixel scale was 1.6 arcsec/pixel, and the exposure time was 210 seconds. Lausanna culminated at an altitude of 34° at Lindby and 46° at Carpione.

Images were calibrated with bias, flats and darks. Photometric reduction to the R filter band was made with *MPO Canopus* software using the MPOSC3 star catalog and the Photometry Magnitude Method (Warner 2014).

In the analysis, 526 observations were used, reduced to 4.6° phase angle. The resulting light curve is double-peaked and quite symmetric. The phased light curve period is 2.748 ± 0.001 h and the amplitude is 0.12 ± 0.02 mag. Very similar results were obtained by Skiff (2014) at Lowell Observatory during the same observing period. The MPC Asteroid Lightcurve Data File (2014) and LCDB (Warner *et al.*, 2009) did not have any entries for this asteroid.

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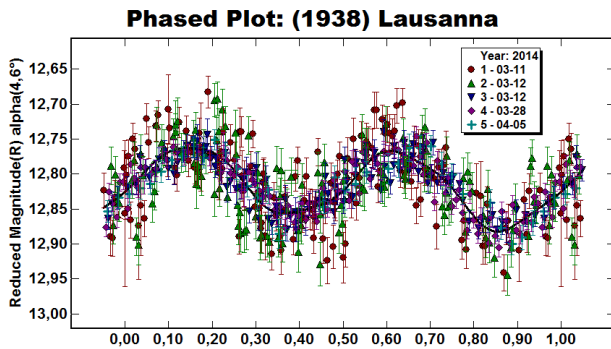
Fig. 1. Phased plot of 1938 Lausanna with 6th order fit, obtained from observations on 2014 March 11 (red circles) and 12 (green up triangles) at Lindby, and March 12 (blue down triangles), 28 (purple diamonds) and April 5 (cyan plusses) at Carpione. Zero phase occurred at JD 2456728.2988 (light-time corrected).

LIGHTCURVE OBSERVATIONS OF 1614 GOLDSCHMIDT

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Photometric observations of the main-belt asteroid 1614 Goldschmidt were obtained on five nights in 2014 March and April. The lightcurve shows only small variations in amplitude, approximately 0.10 mag, and a best-fit rotation period of 7.74 ± 0.02 h. The period determination is uncertain and more observations of higher photometric precision are needed to verify the result.

Minor planet 1614 Goldschmidt was discovered by Alfred Schmitt at Uccle Observatory, Belgium, on 1952 April 18. It is a main-belt asteroid in an orbit with semi-major axis of 3.00 AU, eccentricity 0.07, inclination 14.1°, and orbital period of 5.19 years. The diameter has been determined to about 46 km from IRAS measurements; the absolute magnitude is $H = 10.7$ and the geometric albedo 0.043 (JPL Small Body Database Browser 2014).

Observations were made on five nights between 2014 March 11 and April 5 at Lindby Observatory (K60) in southernmost Sweden. Data were obtained with a 0.25-m *f*/10 Schmidt-Cassegrain (SCT) operating at *f*/4.6, a Starlight Xpress SXV-H9 CCD camera, and a clear imaging filter. The pixel scale was 2.3 arcsec/pixel and individual exposure times were 45 seconds. Goldschmidt culminated at an altitude of 39°.

Images were calibrated with bias, flats and darks. Photometric reduction to the R filter band was made with the *MPO Canopus* software using the MPOSC3 star catalog and the Photometry Magnitude Method (Warner 2014). In the analysis, 394 observations were used, reduced to 4.7° phase angle. A search of the MPC Asteroid Lightcurve data file (MPC 2014), LCDB (Warner *et al.*, 2009) and CALL web site (2014) did not find any previously reported light curve observations of this object.

The period spectrum of the observations is quite flat with no pronounced RMS minimum, but many small fluctuations. The best fit period for the range of 2-20.5 h is found at 7.74 ± 0.02 h (Figure 1). The resulting phased light curve is slowly undulating with two indistinct maxima and minima and an amplitude of 0.10 ± 0.02 mag (Figure 2). In the case of the next best solution, 11.64 h, the observations do not cover the full period length and the fit is partially unconstrained. Observations with higher photometric precision seem necessary to resolve if this is the correct period or if another, perhaps longer, rotation period is hiding in the data.

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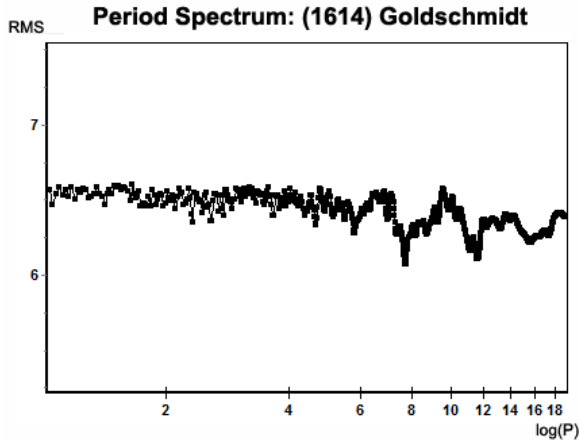
Figure 1. Period spectrum (logarithm of period in hours vs. RMS) for 1614 Goldschmidt.
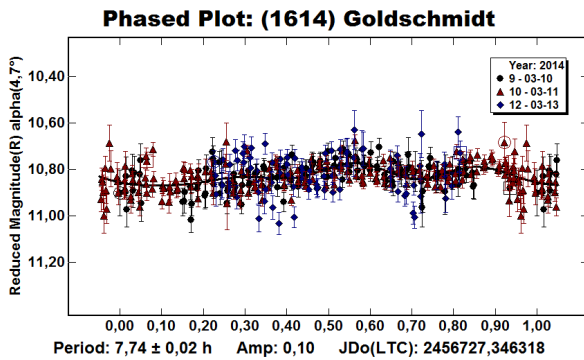
Fig. 2. Phased plot for 1614 Goldschmidt with 4th order fit, obtained from observations on 2014 March 10 (black circles), 11 (red up triangles) and 13 (blue diamonds) at Lindby, based on a best fit rotation period of 7.74 h. Zero phase occurred at JD 2456727.3463 (light-time corrected).

MINOR PLANETS AT UNUSUALLY FAVORABLE ELONGATIONS IN 2015

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A list is presented of minor planets which are much brighter than usual at their 2015 apparitions.

The minor planets in the lists that follow will be much brighter at their 2015 apparitions than at their average distances at maximum elongation. Many years may pass before these planets will be again as bright as in 2015. Observers are encouraged to give special attention to those which lie near the limit of their equipment.

These lists have been prepared by an examination of the maximum elongation circumstances of minor planets computed by the author for all years through 2060 with a full perturbation program written by Dr. John Reed, and to whom he expresses his thanks. They were prepared in the years 2009 and earlier, and recently numbered Earth approachers are not included. Planetary positions are from the JPL DE-200 ephemeris, courtesy of Dr. E. Myles Standish.

Any planets whose brightest magnitudes near the time of maximum elongation vary by at least 2.0 in this interval and in 2015 will be within 0.3 of the brightest occuring, or vary by at least 3.0 and in 2015 will be within 0.5 of the brightest occuring; and which are visual magnitude 14.5 or brighter, are included. For planets brighter than visual magnitude 13.5, which are within the range of a large number of observers, these standards have been relaxed somewhat to include a larger number of planets. Magnitudes have been computed from the updated magnitude parameters published prior to the year 2009, and recent changes incorporated into the Minor Planet Center's catalogs have not been used. The magnitudes should be considered as only approximate.

Oppositions may be in right ascension or in celestial longitude. Here still a third representation is used, maximum elongation from the Sun, instead of opposition. Though unconventional, it has the advantage that many close approaches do not involve actual opposition to the Sun near the time of minimum distance and greatest brightness and are missed by an opposition-based program. Other data are also provided according to the following tabular listings: Minor planet number, date of maximum elongation from the Sun in format yyyy/mm/dd, maximum elongation in degrees, right ascension on date of maximum elongation, declination on date of maximum elongation, both in J2000 coordinates, date of brightest magnitude in format yyyy/mm/dd, brightest magnitude, date of minimum distance in format yyyy/mm/dd, and minimum distance in AU.

Eight numbered minor planets are predicted to make close approaches to Earth at magnitudes brighter than 14.5. A special table of these is provided at the end of this paper.

Users should note that when the maximum elongation is about 177° or greater, the brightest magnitude is sharply peaked due to enhanced brightening near zero phase angle. Even as near as 10 days before or after minimum magnitude the magnitude is generally about 0.4 greater. This effect takes place in greater time

interval for smaller maximum elongations. There is some interest in very small minimum phase angles. For maximum elongations E near 180° at Earth distance Δ, an approximate formula for the minimum phase angle φ is φ=(180°-E)/(Δ +1).

Table I. Numerical Sequence of Favorable Elongations

Planet	Max Elon D	Max E	RA	Dec	Br Mag D	Br Mag	Min Dist D	Min Dist
15	2015/10/03	159.1°	0h 0m	+22°	2015/10/04	7.9	2015/10/04	1.206
21	2015/08/15	174.7°	21h45m	-19°	2015/08/15	9.3	2015/08/15	1.027
27	2015/12/25	179.6°	6h12m	+23°	2015/12/25	8.4	2015/12/24	0.959
49	2015/11/25	176.3°	4h 0m	+24°	2015/11/25	10.7	2015/11/21	1.450
62	2015/12/02	177.0°	4h35m	+19°	2015/12/02	12.1	2015/11/29	1.659
68	2015/07/30	166.2°	20h52m	-31°	2015/07/31	9.8	2015/08/04	1.356
69	2015/01/16	166.7°	7h42m	+ 7°	2015/01/16	10.3	2015/01/17	1.502
74	2015/10/01	178.7°	0h27m	+ 4°	2015/10/01	10.6	2015/10/01	1.111
77	2015/11/28	176.2°	4h13m	+25°	2015/11/28	11.2	2015/11/27	1.336
100	2015/08/02	179.2°	20h51m	-18°	2015/08/02	10.8	2015/08/02	1.555
106	2015/10/31	176.9°	2h24m	+11°	2015/10/31	10.8	2015/10/29	1.655
118	2015/11/24	176.2°	3h58m	+24°	2015/11/25	11.1	2015/11/26	1.068
121	2015/11/04	174.1°	2h44m	+ 9°	2015/11/04	11.5	2015/11/01	2.046
129	2015/06/24	164.8°	18h 6m	- 8°	2015/06/23	9.9	2015/06/21	1.302
135	2015/07/11	176.1°	19h24m	-25°	2015/07/12	9.9	2015/07/17	0.966
177	2015/09/02	179.4°	22h42m	- 8°	2015/09/02	11.8	2015/09/08	1.232
199	2015/07/20	167.5°	20h13m	-32°	2015/07/19	11.9	2015/07/16	1.651
201	2015/09/10	178.1°	23h14m	- 6°	2015/09/10	10.6	2015/09/07	1.189
221	2015/09/02	174.6°	22h54m	-12°	2015/09/02	11.2	2015/09/01	1.691
227	2015/04/30	165.6°	14h 9m	-28°	2015/05/01	12.2	2015/05/03	1.582
229	2015/10/16	179.7°	1h23m	+ 8°	2015/10/16	13.1	2015/10/12	2.047
240	2015/11/24	176.8°	4h 0m	+17°	2015/11/24	11.1	2015/11/22	1.133
273	2015/08/25	174.2°	22h 1m	- 6°	2015/08/24	12.4	2015/08/19	1.104
290	2015/03/13	162.8°	11h44m	+19°	2015/03/10	13.3	2015/03/05	0.911
306	2015/07/11	171.9°	19h13m	-12°	2015/07/11	10.9	2015/07/14	1.008
352	2015/10/01	173.8°	0h19m	+ 8°	2015/10/02	11.5	2015/10/03	0.888
353	2015/01/06	179.1°	7h10m	+23°	2015/01/06	12.5	2014/12/28	0.975
354	2015/03/04	167.3°	11h24m	+17°	2015/03/04	9.6	2015/03/03	1.514
356	2015/10/13	173.8°	1h 4m	+13°	2015/10/14	10.8	2015/10/20	1.279
364	2015/01/01	178.7°	6h42m	+21°	2015/01/01	11.4	2014/12/27	0.967
396	2015/06/11	179.2°	17h17m	-22°	2015/06/11	12.4	2015/06/13	1.296
405	2015/05/28	176.2°	16h13m	-24°	2015/05/27	10.4	2015/05/21	1.045
413	2015/11/04	143.5°	2h55m	-20°	2015/10/24	12.2	2015/10/17	0.884
449	2015/02/03	175.7°	9h10m	+20°	2015/02/03	11.6	2015/02/03	1.124
454	2015/04/02	176.2°	12h49m	- 1°	2015/04/02	11.9	2015/04/04	1.352
471	2015/10/14	156.0°	1h47m	-14°	2015/10/15	9.6	2015/10/16	1.293
517	2015/11/16	176.6°	3h19m	+21°	2015/11/16	12.6	2015/11/15	1.597
523	2015/12/01	178.5°	4h27m	+23°	2015/12/01	12.5	2015/12/03	1.491
532	2015/05/19	158.4°	15h54m	+ 1°	2015/05/17	9.1	2015/05/14	1.453
573	2015/10/03	172.8°	0h25m	+10°	2015/10/03	13.1	2015/10/02	1.673
678	2015/11/28	173.1°	4h10m	+28°	2015/11/28	11.0	2015/11/24	1.058
690	2015/10/02	163.4°	0h 3m	+18°	2015/10/02	11.6	2015/10/01	1.598
697	2015/09/09	166.8°	23h25m	-18°	2015/09/09	10.8	2015/09/08	1.439
747	2015/12/14	153.2°	5h15m	- 3°	2015/12/09	10.3	2015/12/04	1.125
769	2015/09/02	170.0°	23h 0m	-17°	2015/09/02	11.6	2015/08/27	1.713
783	2015/08/15	180.0°	21h38m	-14°	2015/08/15	11.5	2015/08/09	0.820
789	2015/05/12	179.4°	15h13m	-18°	2015/05/12	13.5	2015/05/17	1.370
846	2015/09/10	179.5°	23h13m	- 4°	2015/09/10	13.5	2015/09/14	1.659
849	2015/08/01	148.8°	20h14m	+12°	2015/07/30	11.9	2015/07/29	1.616
854	2015/08/16	171.0°	21h26m	- 5°	2015/08/15	14.2	2015/08/09	1.043
885	2015/09/30	176.6°	0h29m	- 7°	2015/09/30	13.8	2015/09/27	1.523
888	2015/12/19	164.6°	5h43m	+ 8°	2015/12/18	12.2	2015/12/16	1.255
893	2015/08/18	179.6°	21h50m	-13°	2015/08/18	12.8	2015/08/21	1.673
910	2015/05/08	179.2°	14h59m	-16°	2015/05/08	13.3	2015/05/12	1.515
914	2015/05/31	173.7°	16h22m	-27°	2015/06/01	10.9	2015/06/08	1.077
947	2015/10/20	175.2°	1h46m	+ 5°	2015/10/20	11.8	2015/10/19	1.070
949	2015/05/01	162.2°	14h10m	-32°	2015/05/01	13.0	2015/05/01	1.453
953	2015/09/16	169.7°	23h47m	-12°	2015/09/14	13.4	2015/09/08	1.423
956	2015/08/11	169.0°	21h 5m	- 5°	2015/08/10	14.0	2015/08/10	0.821
970	2015/09/06	174.8°	22h51m	- 1°	2015/09/07	14.5	2015/09/16	1.086
981	2015/08/30	176.7°	22h36m	-12°	2015/08/30	13.5	2015/08/30	1.460
1052	2015/09/18	170.8°	23h59m	-10°	2015/09/19	13.8	2015/09/22	0.978
1056	2015/08/15	172.5°	21h50m	-21°	2015/08/15	13.0	2015/08/13	0.824
1059	2015/06/16	162.9°	17h44m	- 6°	2015/06/18	13.3	2015/06/20	1.179
1082	2015/08/26	179.4°	22h21m	-10°	2015/08/26	13.5	2015/08/26	1.547
1088	2015/09/12	164.3°	23h41m	-19°	2015/09/13	12.8	2015/09/15	0.807
1090	2015/02/26	171.3°	10h57m	+15°	2015/02/25	14.1	2015/02/22	0.910
1126	2015/03/22	179.5°	12h 2m	- 0°	2015/03/22	13.7	2015/03/18	1.012
1136	2015/09/24	170.7°	23h44m	+ 8°	2015/09/24	12.6	2015/09/24	0.912
1151	2015/11/15	178.4°	3h22m	+16°	2015/11/15	14.3	2015/11/02	0.978
1153	2015/08/17	174.9°	21h40m	- 8°	2015/08/17	13.4	2015/08/14	0.839
1242	2015/10/22	168.4°	1h31m	+22°	2015/10/22	12.7	2015/10/23	1.242
1247	2015/07/10	177.6°	19h15m	-13°	2015/07/10	13.7	2015/07/11	1.581
1275	2015/09/28	178.4°	0h14m	+ 3°	2015/09/28	13.1	2015/09/29	1.247
1312	2015/09/09	156.9°	23h58m	-25°	2015/09/11	14.4	2015/09/14	1.575
1325	2015/08/14	167.6°	21h48m	-26°	2015/08/15	13.3	2015/08/20	0.941
1331	2015/08/14	178.1°	21h38m	-15°	2015/08/14	13.2	2015/08/12	1.512
1383	2015/08/27	179.8°	22h21m	-10°	2015/08/27	14.5	2015/08/29	1.518
1386	2015/07/31	163.0°	20h13m	- 2°	2015/08/01	13.6	2015/08/02	0.692
1397	2015/06/23	178.2°	18h 8m	-25°	2015/06/23	13.1	2015/06/23	0.990
1427	2015/08/20	163.8°	22h21m	-27°	2015/08/19	13.3	2015/08/18	1.179
1430	2015/08/19	179.9°	21h53m	-17°	2015/08/19	14.5	2015/08/17	1.042
1459	2015/10/01	163.2°	0h48m	-12°	2015/10/01	13.8	2015/10/01	1.437
1537	2015/11/25	178.5°	4h 5m	+19°	2015/11/25	14.4	2015/11/16	1.288
1547	2015/02/02	171.4°	8h57m	+ 8°	2015/02/01	13.0	2015/01/26	1.127

Planet	Max Elon D	Max E	RA	Dec	Br Mag D	Br Mag	Min Dist D	Min Dist
1566	2015/06/28	130.3°	14h55m	-17°	2015/06/18	13.5	2015/06/16	0.054
1572	2015/10/14	174.0°	1h10m	+13°	2015/10/14	13.1	2015/10/11	1.493
1576	2015/12/09	178.5°	5h 2m	+21°	2015/12/09	14.4	2015/12/06	1.673
1584	2015/02/09	162.2°	9h27m	- 2°	2015/02/09	12.6	2015/02/08	0.956
1607	2015/08/02	177.6°	20h52m	-19°	2015/08/02	13.0	2015/08/13	0.895
1613	2015/01/22	175.1°	8h21m	+24°	2015/01/22	13.5	2015/01/17	1.106
1625	2015/06/11	157.0°	16h59m	-45°	2015/06/10	13.8	2015/06/10	1.503
1648	2015/07/23	178.1°	20h 5m	-18°	2015/07/23	13.6	2015/07/16	0.810
1664	2015/04/07	174.1°	13h10m	- 1°	2015/04/06	13.6	2015/03/31	0.913
1672	2015/01/02	178.2°	6h48m	+21°	2015/01/02	13.8	2014/12/28	1.366
1693	2015/08/02	159.6°	21h20m	-37°	2015/08/01	13.3	2015/07/31	1.052
1708	2015/01/29	170.1°	8h32m	+ 8°	2015/01/27	14.3	2015/01/20	1.195
1710	2015/08/22	170.0°	22h14m	-21°	2015/08/22	14.1	2015/08/22	0.692
1730	2015/11/08	165.8°	3h11m	+ 3°	2015/11/08	14.1	2015/11/06	1.194
1768	2015/10/29	177.5°	2h 9m	+15°	2015/10/29	14.4	2015/10/27	1.019
1795	2015/06/01	168.5°	16h41m	-10°	2015/06/01	14.5	2015/06/04	1.277
1815	2015/12/31	179.1°	6h41m	+22°	2015/12/31	14.5	2016/01/01	1.588
1819	2015/08/05	171.4°	21h17m	-24°	2015/08/05	13.3	2015/08/01	1.460
2019	2015/05/28	179.2°	16h18m	-22°	2015/05/28	13.2	2015/06/02	0.893
2081	2015/05/25	179.5°	16h 8m	-20°	2015/05/25	14.1	2015/05/31	1.129
2105	2015/12/17	169.4°	5h27m	+33°	2015/12/17	13.4	2015/12/16	1.061
2167	2015/02/01	170.3°	8h50m	+ 7°	2015/02/02	14.4	2015/02/06	1.149
2243	2015/08/16	166.6°	21h56m	-26°	2015/08/16	14.2	2015/08/16	0.805
2343	2015/10/28	179.4°	2h10m	+13°	2015/10/28	14.2	2015/10/22	0.766
2379	2015/09/05	179.8°	22h55m	- 7°	2015/09/05	13.3	2015/09/01	1.296
2389	2015/07/20	169.6°	20h 0m	-31°	2015/07/20	14.4	2015/07/23	0.873
2433	2015/06/22	159.8°	18h 3m	- 3°	2015/06/21	14.1	2015/06/20	1.052
2569	2015/12/21	175.6°	5h55m	+27°	2015/12/20	14.0	2015/12/15	1.377
2839	2015/11/22	177.4°	3h48m	+22°	2015/11/22	13.6	2015/11/20	0.900
2892	2015/10/15	157.3°	0h47m	+29°	2015/10/17	13.9	2015/10/18	1.648
3000	2015/10/19	179.3°	1h33m	+ 9°	2015/10/18	14.4	2015/10/16	0.933
3018	2015/07/08	171.6°	19h 6m	-14°	2015/07/09	14.5	2015/07/11	0.924
3054	2015/09/10	178.7°	23h13m	- 6°	2015/09/10	14.2	2015/09/07	1.445
3080	2015/09/20	159.0°	0h15m	-21°	2015/09/20	14.2	2015/09/19	1.132
3084	2015/09/09	176.9°	23h 2m	- 2°	2015/09/08	14.5	2015/09/04	0.881
3093	2015/08/16	162.7°	21h24m	+ 2°	2015/08/17	14.0	2015/08/18	1.148
3628	2015/08/28	179.2°	22h23m	- 9°	2015/08/28	13.4	2015/08/29	0.775
3679	2015/10/06	171.7°	0h36m	+12°	2015/10/06	14.5	2015/10/05	0.716
3682	2015/11/25	174.0°	3h55m	+26°	2015/11/24	13.5	2015/11/14	1.066
3824	2015/01/26	177.5°	8h34m	+21°	2015/01/25	14.4	2015/01/17	0.846
3858	2015/07/27	166.2°	20h31m	-33°	2015/07/28	14.5	2015/08/01	0.671
3958	2015/09/24	178.0°	0h 4m	- 1°	2015/09/24	14.1	2015/09/29	1.029
3982	2015/08/16	168.5°	21h26m	- 2°	2015/08/15	14.4	2015/08/10	0.776
4055	2015/09/07	176.4°	22h48m	- 5°	2015/09/07	12.5	2015/08/31	0.239
4212	2015/10/30	173.4°	2h11m	+20°	2015/10/30	14.4	2015/10/25	1.444
4287	2015/07/03	170.8°	18h52m	-32°	2015/07/04	14.5	2015/07/08	0.819
4603	2015/05/20	156.1°	15h24m	-43°	2015/05/23	14.3	2015/05/27	1.081
4919	2015/09/06	178.6°	23h 1m	- 7°	2015/09/06	14.5	2015/08/30	0.739
5231	2015/11/19	164.3°	3h45m	+ 3°	2015/11/19	14.5	2015/11/18	1.258
5381	2015/05/20	145.0°	17h14m	-50°	2015/05/18	14.2	2015/05/17	0.161
5392	2015/04/22	153.0°	13h59m	+14°	2015/04/14	14.1	2015/04/07	0.739
5518	2015/08/01	178.8°	20h46m	-19°	2015/08/01	14.2	2015/07/25	0.917
5567	2015/09/24	175.9°	0h 9m	- 3°	2015/09/24	13.7	2015/09/17	1.402
6146	2015/07/05	172.8°	18h59m	-30°	2015/07/05	13.8	2015/07/09	0.697
6518	2015/03/28	151.8°	13h17m	+22°	2015/03/25	14.2	2015/03/24	0.876
6649	2015/07/30	175.0°	20h42m	-23°	2015/07/30	14.3	2015/08/01	0.876
6905	2015/08/19	155.3°	22h29m	-36°	2015/08/21	14.1	2015/08/23	1.189
8270	2015/07/13	170.6°	19h33m	-31°	2015/07/13	14.3	2015/07/17	0.802
9773	2015/07/20	165.4°	20h 1m	- 6°	2015/07/19	14.3	2015/07/17	0.638
11780	2015/09/01	177.0°	22h48m	-10°	2015/09/02	14.3	2015/09/08	0.904
14276	2015/09/22	172.4°	0h 7m	- 2°	2015/09/22	14.3	2015/09/23	0.860
18487	2015/08/07	179.6°	21h 8m	-16°	2015/08/07	13.8	2015/08/08	1.161
20826	2015/11/30	119.5°	5h50m	+81°	2016/03/22	14.4	2016/04/06	0.337
23120	2015/08/28	163.7°	22h 7m	+ 5°	2015/08/29	14.4	2015/08/31	1.111
33342	2015/12/10	157.5°	4h36m	+ 1°	2015/12/10	11.3	2015/12/11	0.028
85989	2015/07/08	125.5°	21h28m	+20°	2015/07/21	13.8	2015/07/25	0.049
141527	2015/03/24	167.9°	11h25m	- 4°	2015/03/16	14.1	2015/03/13	0.044
206378	2015/08/07	171.1°	21h44m	-16°	2015/08/15	13.8	2015/08/22	0.053

Table II. Temporal Sequence of Favorable Elongations

Planet	Max Elon D	Max E	RA	Dec	Br Mag D	Br Mag	Min Dist D	Min Dist
364	2015/01/01	178.7°	6h42m	+21°	2015/01/01	11.4	2014/12/27	0.967
1672	2015/01/02	178.2°	6h48m	+21°	2015/01/02	13.8	2014/12/28	1.366
353	2015/01/06	179.1°	7h10m	+23°	2015/01/06	12.5	2014/12/28	0.975
69	2015/01/16	166.7°	7h42m	+ 7°	2015/01/16	10.3	2015/01/17	1.502
1613	2015/01/22	175.1°	8h21m	+24°	2015/01/22	13.5	2015/01/17	1.106
3824	2015/01/26	177.5°	8h34m	+21°	2015/01/25	14.4	2015/01/17	0.846
1708	2015/01/29	170.1°	8h32m	+ 8°	2015/01/27	14.3	2015/01/20	1.195
2167	2015/02/01	170.3°	8h50m	+ 7°	2015/02/02	14.4	2015/02/06	1.149
1547	2015/02/02	171.4°	8h57m	+ 8°	2015/02/01	13.0	2015/01/26	1.127
449	2015/02/03	175.7°	9h10m	+20°	2015/02/03	11.6	2015/02/03	1.124
1584	2015/02/09	162.2°	9h27m	- 2°	2015/02/09	12.6	2015/02/08	0.956
1090	2015/02/26	171.3°	10h57m	+15°	2015/02/25	14.1	2015/02/22	0.910
354	2015/03/04	167.3°	11h24m	+17°	2015/03/04	9.6	2015/03/03	1.514
290	2015/03/13	162.8°	11h44m	+19°	2015/03/10	13.3	2015/03/05	0.911
1126	2015/03/22	179.5°	12h 2m	- 0°	2015/03/22	13.7	2015/03/18	1.012
141527	2015/03/24	167.9°	11h25m	- 4°	2015/03/16	14.1	2015/03/13	0.044
6518	2015/03/28	151.8°	13h17m	+22°	2015/03/25	14.2	2015/03/24	0.876
454	2015/04/02	176.2°	12h49m	- 1°	2015/04/02	11.9	2015/04/04	1.352
1664	2015/04/07	174.1°	13h10m	- 1°	2015/04/06	13.6	2015/03/31	0.913
5392	2015/04/22	153.0°	13h59m	+14°	2015/04/14	14.1	2015/04/07	0.739

Planet	Max Elon D	Max E	RA	Dec	Br Mag D	Br Mag	Min Dist D	Min Dist
227	2015/04/30	165.6°	14h 9m	-28°	2015/05/01	12.2	2015/05/03	1.582
949	2015/05/01	162.2°	14h10m	-32°	2015/05/01	13.0	2015/05/01	1.453
910	2015/05/08	179.2°	14h59m	-16°	2015/05/08	13.3	2015/05/12	1.515
789	2015/05/12	179.4°	15h13m	-18°	2015/05/12	13.5	2015/05/17	1.370
532	2015/05/19	158.4°	15h54m	+ 1°	2015/05/17	9.1	2015/05/14	1.453
4603	2015/05/20	156.1°	15h24m	-43°	2015/05/23	14.3	2015/05/27	1.081
5381	2015/05/20	145.0°	17h14m	-50°	2015/05/18	14.2	2015/05/17	0.161
2081	2015/05/25	179.5°	16h 8m	-20°	2015/05/25	14.1	2015/05/31	1.129
405	2015/05/28	176.2°	16h13m	-24°	2015/05/27	10.4	2015/05/21	1.045
2019	2015/05/28	179.2°	16h18m	-22°	2015/05/28	13.2	2015/06/02	0.893
914	2015/05/31	173.7°	16h22m	-27°	2015/06/01	10.9	2015/06/08	1.077
1795	2015/06/01	168.5°	16h41m	-10°	2015/06/04	14.5	2015/06/04	1.277
396	2015/06/11	179.2°	17h17m	-22°	2015/06/11	12.4	2015/06/13	1.296
1625	2015/06/11	157.0°	16h59m	-45°	2015/06/10	13.8	2015/06/10	1.503
1059	2015/06/16	162.9°	17h44m	- 6°	2015/06/18	13.3	2015/06/20	1.179
2433	2015/06/22	159.8°	18h 3m	- 3°	2015/06/21	14.1	2015/06/20	1.052
1397	2015/06/23	178.2°	18h 8m	-25°	2015/06/23	13.1	2015/06/26	0.990
129	2015/06/24	164.8°	18h 6m	- 8°	2015/06/23	9.9	2015/06/21	1.302
1566	2015/06/28	130.3°	14h55m	-17°	2015/06/18	13.5	2015/06/16	0.054
4287	2015/07/03	170.8°	18h52m	-32°	2015/07/04	14.5	2015/07/08	0.819
6146	2015/07/05	172.8°	18h59m	-30°	2015/07/05	13.8	2015/07/09	0.697
3018	2015/07/08	171.6°	19h 6m	-14°	2015/07/09	14.5	2015/07/11	0.924
85989	2015/07/08	125.5°	21h28m	+20°	2015/07/21	13.8	2015/07/25	0.049
1247	2015/07/10	177.6°	19h15m	-19°	2015/07/10	13.7	2015/07/11	1.581
135	2015/07/11	176.1°	19h24m	-25°	2015/07/12	9.9	2015/07/17	0.966
306	2015/07/11	171.9°	19h13m	-14°	2015/07/11	10.9	2015/07/14	1.008
8270	2015/07/13	170.6°	19h35m	-31°	2015/07/14	13.2	2015/07/12	0.802
199	2015/07/20	167.5°	20h13m	-32°	2015/07/19	11.9	2015/07/16	1.651
2389	2015/07/20	169.6°	20h 0m	-31°	2015/07/20	14.4	2015/07/23	0.873
9773	2015/07/20	165.4°	20h 1m	- 6°	2015/07/19	14.3	2015/07/17	0.638
1648	2015/07/23	178.1°	20h 5m	-18°	2015/07/23	13.6	2015/07/16	0.810
3858	2015/07/27	166.2°	20h31m	-33°	2015/07/28	14.5	2015/08/01	0.671
68	2015/07/30	166.2°	20h52m	-31°	2015/07/31	9.8	2015/08/04	1.356
6649	2015/07/30	175.0°	20h42m	-23°	2015/07/30	14.3	2015/08/01	0.876
1386	2015/07/31	163.0°	20h13m	- 2°	2015/08/01	13.6	2015/08/02	0.692
849	2015/08/01	148.8°	20h14m	+12°	2015/07/30	11.9	2015/07/29	1.616
5518	2015/08/01	178.8°	20h46m	-19°	2015/08/01	14.2	2015/07/25	0.917
100	2015/08/02	179.2°	20h51m	-18°	2015/08/02	10.8	2015/08/02	1.555
1607	2015/08/02	177.6°	20h52m	-19°	2015/08/02	13.0	2015/08/13	0.895
1693	2015/08/02	159.6°	21h20m	-37°	2015/08/01	13.3	2015/07/31	1.052
1819	2015/08/05	171.4°	21h17m	-24°	2015/08/05	13.3	2015/08/01	1.460
18487	2015/08/07	179.6°	21h 8m	-16°	2015/08/07	13.8	2015/08/08	1.161
206378	2015/08/07	171.1°	21h44m	-16°	2015/08/15	13.8	2015/08/22	0.053
956	2015/08/11	169.0°	21h 5m	- 5°	2015/08/10	14.0	2015/08/10	0.821
1325	2015/08/14	167.6°	21h48m	-26°	2015/08/15	13.3	2015/08/20	0.941
1331	2015/08/14	178.1°	21h38m	-15°	2015/08/14	13.2	2015/08/12	1.512
21	2015/08/15	174.7°	21h45m	-19°	2015/08/15	9.3	2015/08/15	1.027
783	2015/08/15	180.0°	21h38m	-14°	2015/08/15	11.5	2015/08/09	0.820
1056	2015/08/15	172.5°	21h50m	-21°	2015/08/15	13.0	2015/08/13	0.824
854	2015/08/16	171.0°	21h26m	- 5°	2015/08/15	14.2	2015/08/09	1.043
2243	2015/08/16	166.6°	21h56m	-26°	2015/08/16	14.2	2015/08/16	0.805
3093	2015/08/16	162.7°	21h24m	+ 2°	2015/08/17	14.0	2015/08/18	1.148
3982	2015/08/16	168.5°	21h26m	- 2°	2015/08/15	14.4	2015/08/10	0.776
1153	2015/08/17	174.9°	21h40m	- 8°	2015/08/17	13.4	2015/08/14	0.839
893	2015/08/18	179.6°	21h50m	-13°	2015/08/18	12.8	2015/08/21	1.673
1430	2015/08/19	179.9°	21h53m	-12°	2015/08/19	14.5	2015/08/17	1.042
6905	2015/08/19	155.3°	22h29m	-36°	2015/08/21	14.1	2015/08/23	1.189
1427	2015/08/20	163.8°	22h21m	-27°	2015/08/20	13.3	2015/08/18	1.179
1710	2015/08/22	170.0°	22h14m	-21°	2015/08/22	14.1	2015/08/22	0.692
273	2015/08/25	174.2°	22h 1m	- 6°	2015/08/24	12.4	2015/08/19	1.104
1082	2015/08/26	179.4°	22h21m	-10°	2015/08/26	13.5	2015/08/26	1.547
1383	2015/08/27	179.8°	22h21m	-10°	2015/08/27	14.5	2015/08/29	1.518
3628	2015/08/28	179.2°	22h23m	- 9°	2015/08/28	13.4	2015/08/29	0.775
23120	2015/08/28	163.7°	22h 7m	+ 5°	2015/08/29	14.4	2015/08/31	1.111
981	2015/08/30	176.7°	22h36m	-12°	2015/08/30	13.5	2015/08/30	1.460
11780	2015/09/01	177.0°	22h48m	-10°	2015/09/02	14.3	2015/09/08	0.904
177	2015/09/01	179.4°	22h42m	- 8°	2015/09/02	11.8	2015/09/08	1.232
221	2015/09/02	174.6°	22h54m	-12°	2015/09/02	11.2	2015/09/01	1.691
769	2015/09/02	170.0°	23h 0m	-17°	2015/09/02	12.6	2015/08/27	1.713
2379	2015/09/05	179.8°	22h55m	- 7°	2015/09/05	13.3	2015/09/01	1.296
970	2015/09/06	174.8°	22h51m	- 1°	2015/09/07	14.5	2015/09/16	1.086
4919	2015/09/06	178.6°	23h 1m	- 7°	2015/09/06	14.5	2015/08/30	0.739
4055	2015/09/07	176.4°	22h48m	- 5°	2015/09/07	12.5	2015/08/31	0.239
697	2015/09/09	166.8°	23h25m	-18°	2015/09/09	12.8	2015/09/08	1.439
1312	2015/09/09	156.9°	23h58m	-25°	2015/09/11	14.4	2015/09/14	1.575
3084	2015/09/09	176.9°	23h 2m	- 2°	2015/09/08	14.5	2015/09/04	0.881
201	2015/09/10	178.1°	23h14m	- 6°	2015/09/10	10.6	2015/09/07	1.189
846	2015/09/10	179.5°	23h13m	- 4°	2015/09/10	13.8	2015/09/14	1.659
3054	2015/09/10	178.7°	23h13m	- 6°	2015/09/10	14.2	2015/09/07	1.445
1088	2015/09/12	164.3°	23h41m	-19°	2015/09/13	12.8	2015/09/15	0.807
953	2015/09/16	169.7°	23h47m	-12°	2015/09/16	13.4	2015/09/08	1.423
1052	2015/09/18	170.8°	23h59m	-10°	2015/09/19	13.8	2015/09/22	0.978
3080	2015/09/20	159.0°	0h15m	-21°	2015/09/20	14.2	2015/09/19	1.132
14276	2015/09/22	172.4°	0h 5m	- 7°	2015/09/22	14.3	2015/09/23	0.860
3958	2015/09/23	178.0°	0h 4m	- 1°	2015/09/24	14.1	2015/09/29	1.029
1136	2015/09/24	170.7°	23h44m	+ 8°	2015/09/24	13.7	2015/09/22	0.912
5567	2015/09/24	175.9°	0h 9m	- 3°	2015/09/24	13.7	2015/09/17	1.402
1275	2015/09/28	178.4°	0h14m	+ 3°	2015/09/28	13.1	2015/09/29	1.247
885	2015/09/30	176.6°	0h29m	- 0°	2015/09/30	13.8	2015/09/27	1.523
74	2015/10/01	178.7°	0h27m	+ 4°	2015/10/01	10.6	2015/10/01	1.111
352	2015/10/01	173.8°	0h19m	+ 8°	2015/10/02	11.5	2015/10/03	0.888
1459	2015/10/01	163.2°	0h48m	-12°	2015/10/01	13.8	2015/10/01	1.437
690	2015/10/02	163.4°	0h 3m	+18°	2015/10/02	11.6	2015/10/01	1.598
15	2015/10/03	159.1°	0h 0m	+22°	2015/10/04	7.9	2015/10/04	1.206
573	2015/10/03	172.8°	0h25m	+10°	2015/10/03	13.1	2015/10/02	1.673
3679	2015/10/06	171.7°	0h36m	+12°	2015/10/06	14.5	2015/10/05	0.716
356	2015/10/13	173.8°	1h 4m	+13°	2015/10/14	10.8	2015/10/20	1.279
471	2015/10/14	156.0°	1h47m	-14°	2015/10/15	9.6	2015/10/16	1.293
1572	2015/10/14	174.0°	1h19m	+13°	2015/10/14	13.1	2015/10/11	1.493
2892	2015/10/15	157.3°	0h47m	+29°	2015/10/17	13.9	2015/10/18	1.648
229	2015/10/16	179.7°	1h23m	+ 8°	2015/10/16	13.1	2015/10/12	2.047
3000	2015/10/19	179.3°	1h33m	+ 9°	2015/10/18	14.4	2015/10/16	0.933
947	2015/10/20	175.2°	1h46m	+ 5°	2015/10/20	11.8	2015/10/19	1.070
1242	2015/10/22	168.4°	1h31m	+22°	2015/10/22	12.7	2015/10/23	1.242
2343	2015/10/28	179.4°	2h10m	+13°	2015/10/28	14.1	2015/10/22	0.766
1768	2015/10/29	177.5°	2h 9m	+15°	2015/10/29	14.4	2015/10/27	1.019
4212	2015/10/30	173.4°	2h11m	+20°	2015/10/30	14.4	2015/10/30	1.444
106	2015/10/31	176.9°	2h24m	+11°	2015/10/31	10.8	2015/10/29	1.655
121	2015/11/04	174.1°	2h44m	+ 9°	2015/11/04	11.5	2015/11/01	2.046
413	2015/11/04	143.5°	2h55m	-22°	2015/10/24	12.2	2015/10/17	0.884
1730	2015/11/08	165.8°	3h11m	+ 3°	2015/11/08	14.1	2015/11/06	1.194
1151	2015/11/15	178.4°	3h22m	+16°	2015/11/15	14.3	2015/11/02	0.978
517	2015/11/16	176.6°	3h19m	+21°	2015/11/16	12.6	2015/11/15	1.597
5231	2015/11/19	164.3°	3h45m	+ 3°	2015/11/19	14.5	2015/11/18	1.258
2839	2015/11/22	177.4°	3h48m	+22°	2015/11/22	13.6	2015/11/20	0.900
118	2015/11/24	176.2°	3h58m	+24°	2015/11/25	11.1	2015/11/26	1.068
240	2015/11/25	176.8°	4h 0m	+17°	2015/11/24	11.1	2015/11/22	1.133
49	2015/11/25	176.3°	4h 0m	+24°	2015/11/25	10.7	2015/11/21	1.450
1537	2015/11/25	178.5°	4h 5m	+19°	2015/11/25	11.6	2015/11/16	1.288
3682	2015/11/25	174.0°	3h55m	+26°	2015/11/24	13.5	2015/11/14	1.066
77	2015/11/28	176.2°	4h13m	+25°	2015/11/28	11.2	2015/11/27	1.336
678	2015/11/28	173.1°	4h10m	+28°	2015/11/28	11.0	2015/11/24	1.058
20826	2015/11/30	119.5°	5h50m	+81°	2016/03/22	14.4	2016/04/06	0.337
523	2015/12/01	178.5°	4h27m	+23°	2015/12/01	12.5	2015/12/03	1.491
62	2015/12/02	177.0°	4h35m	+19°	2015/12/02	12.1	2015/11/29	1.659
1576	2015/12/09	178.5°	5h 2m	+21°	2015/12/09	14.4	2015/12/06	1.673
33342	2015/12/10	157.5°	4h36m	+ 1°	2015/12/10	11.3	2015/12/11	0.028
747	2015/12/10	153.2°	5h15m	- 3°	2015/12/09	10.3	2015/12/04	1.125
2105	2015/12/17	169.4°	5h27m	+33°	2015/12/17	13.4	2015/12/16	1.061
888	2015/12/19	164.6°	5h43m	+ 8°	2015/12/18	12.2	2015/12/16	1.255
2569	2015/12/21	175.6°	5h55m	+27°	2015/12/20	14.0	2015/12/15	1.377
27	2015/12/25	179.6°	6h12m	+23°	2015/12/25	8.4	2015/12/24	0.959
1815	2015/12/31	179.1°	6h41m	+22°	2015/12/31	14.5	2016/01/01	1.588

Table III. Numerical Sequence of Close Approaches

Planet	Max Elon D	Max E	RA	Dec	Br Mag D	Br Mag	Min Dist D	Min Dist
1566	2015/06/28	130.3°	14h55m	-17°	2015/06/18	13.5	2015/06/16	0.054
4055	2015/09/07	176.4°	22h48m	- 5°	2015/09/07	12.5	2015/08/31	0.239
5381	2015/05/20	145.0°	17h14m	-50°	2015/05/18	14.2	2015/05/17	0.161
20826	2015/11/30	119.5°	5h50m	+81°	2016/03/22	14.4	2016/04/06	0.337
33342	2015/12/10	157.5°	4h36m	+ 1°	2015/12/10	11.3	2015/12/11	0.028
85989	2015/07/08	125.5°	21h28m	+20°	2015/07/21	13.8	2015/07/25	0.049
141527	2015/03/24	167.9°	11h25m	- 4°	2015/03/16	14.1	2015/03/13	0.044
206378	2015/08/07	171.1°	21h44m	-16°	2015/08/15	13.8	2015/08/22	0.053

USING THE PARALLAX METHOD TO DETERMINE THE DISTANCE TO AN ASTEROID

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By simultaneously imaging an asteroid from two separate telescopes on Earth, it is possible to use the parallax method to determine its distance. This study outlines the steps necessary and results obtained from using the method on asteroid 166 Rhodope.

The purpose of this project was to measure the distance to an asteroid using its parallax angle as determined by taking synchronized images of it from two different locations on earth.

Telescope time was obtained at the two SARA (Southeastern Association for Research in Astronomy) telescopes, one at Kitt Peak National Observatory in Arizona the other at Cerro Tololo Inter-American Observatory in Chile on the night of 2014 January 2 UT.

Asteroid 166 Rhodope was chosen for this study because it was fairly bright at 9th magnitude, its location in the sky was optimal for both telescopes, and its proximity to earth allowed a large enough parallax angle for an accurate measurement (Figure 1).
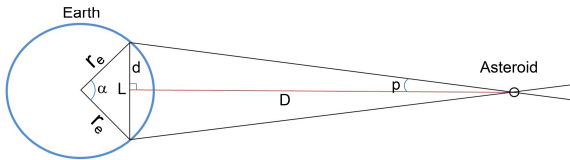
Figure 1. Finding the distance to an asteroid using parallax.

Asteroid 166 Rhodope was discovered in 1876 by C.H.F. Peters (JPL). It is an S-type main belt asteroid with an orbital inclination of 12°. The eccentricity of its orbit is 0.21 with a semi-major axis of 2.68 AU. At the time of the observations Rhodope was at a solar distance of 2.199 AU and an earth distance of 1.460 AU (Figures 2 and 3). These distances were determined using the *MPO Canopus* software program and Rhodope's known orbital elements. (JPL and Warner, 2011)
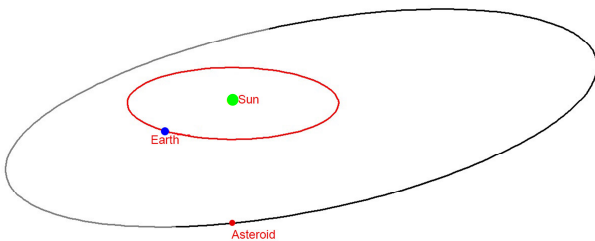
Figure 2. Side view of 166 Rhodope's Orbit
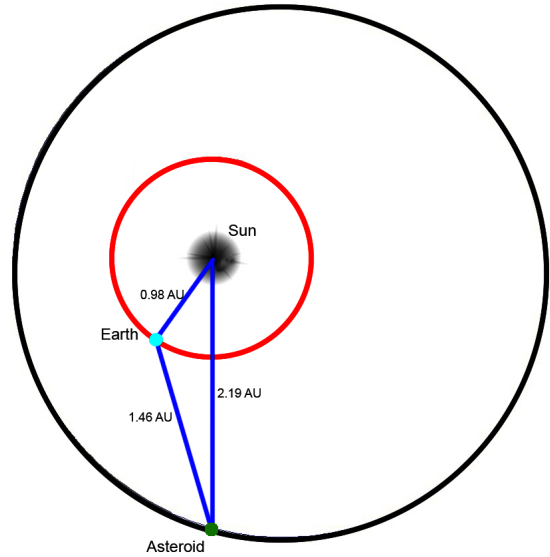
Figure 3. Top view of 166 Rhodope's orbit.

The Parallax Method

The method used to determine the distance to the asteroid using its parallax angle is outlined here. It required determining the parallax angle by operating two telescopes separated by as large a distance as possible. By using images taken simultaneously from both telescopes of the same asteroid and the known physical distance between the telescopes, the distance to the asteroid can then be determined.

The chord length equation was used to find the distance between the two telescopes, see Eq. 1. The known radius of the Earth is r_e and angle α was found by using the difference between the longitude and latitude of the two telescopes (see Figure 1).

$$L = 2 r_e \cdot \sin\left(\frac{\alpha}{2}\right) \qquad (1)$$

From Eq. 1, L was then used to find d. The value d is necessary in order to complete the triangle of which D, the distance to the asteroid, is one side.

$$d = \frac{L}{2} \qquad (2)$$

The angle p was found using the difference in positions of the asteroid on simultaneous images from the two telescopes. Then using trigonometric functions, the distance (D) is found by using equation 3.

$$D = \frac{d}{\tan(p)} \qquad (3)$$

Data and Analysis

On 2014 January 2 UT, the Southeastern Association for Research in Astronomy (SARA) telescopes were used for observations of 166 Rhodope. The SARA northern telescope (SARA-N) is located at Kitt Peak National Observatory at a longitude of 111° 35' 59.4" W and latitude of 31° 57' 36.0" N. The SARA southern telescope (SARA-S) located at Cerro Tololo International Observatory is at a longitude of 70° 47' 57.0" W and a latitude of 30° 10' 19.6" S. The SARA-N has a 0.9-m objective mirror and the SARA-S has a 0.6-m objective mirror.

Both telescopes used Apogee Alta E6-1105 CCD cameras cooled with liquid nitrogen to a temperature of -110° C. Images were binned 2x2 pixels which produced effective pixels of 12x12 microns. Images from SARA-S were shot through a luminance 5 filter and the images from SARA-N were taken through an IR-blocking filter. Five images from each telescope were taken. Typical images from both telescopes are shown in Figures 4 and 5.

After reducing the images using calibrated flat fields and biases, it was found that astrometry measurements were unaffected by the reduction process. Thus raw images were actually used to determine the asteroid position in order to measure the right ascension (RA) and declination (Dec). Each image was opened in the software program *MPO Canopus* and the fields matched to the catalog of stars from the MPOSC3 Catalog, which is a combination of data from the Carlsberg Meridian Catalog 14 (CMC-14) and the Sloan Digital Sky Survey (SDSS). The values measured can be found in Table 1. Since there were no significant differences in the right ascension, the difference in declination of each pair of synchronized images was found in arcseconds and averaged. This number was then converted from arcseconds to degrees and divided by two in order to find the parallax angle, *p*.

Using a known value of the radius of the earth, 6378.1370 km, (NASA) and Eq. 1, the distance between the telescopes was determined.

$$L = 2(6378388\,m)\sin\left(\frac{62.13211111^{\circ}}{2}\right)$$
$$L = 6582827\,m$$

Equation 2 was then used to find *d*, the half-distance of the chord length, *L*.

$$d = \frac{6582827.4}{2}$$
$$d = 3291415\,m$$

Equation 3 applies *d* and the angle *p* to find the distance between Earth and the asteroid, *D*.

$$D = \frac{3291415}{\tan 8.5 \times 10^{-4}}$$
$$D = 2.21854934 \times 10^{11}\,m$$

The final distance measured (*D)* was then converted into 1.48 AU. using 1 AU = 149,597,871,000 m (Astronomical Unit). The known distance from orbital elements was 1.460 AU as given by *MPO Canopus* (Warner, 2011). The difference in methods gives results similar to within <2%.
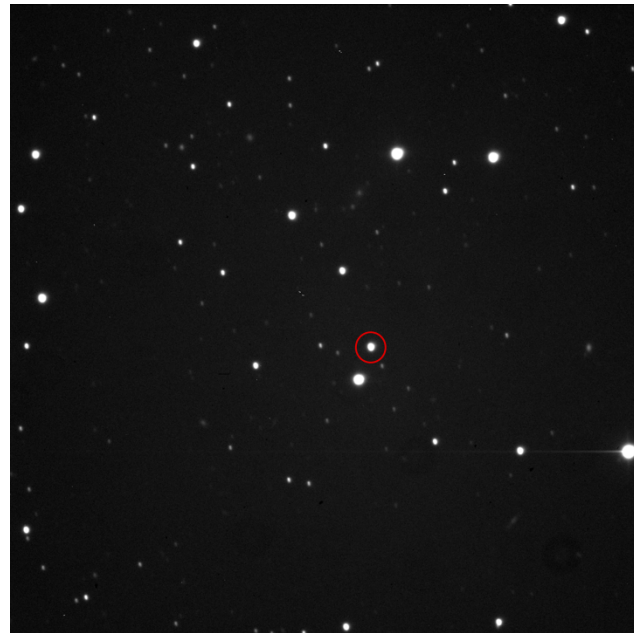
Figure 4. Image taken by SARA North telescope with asteroid position shown.
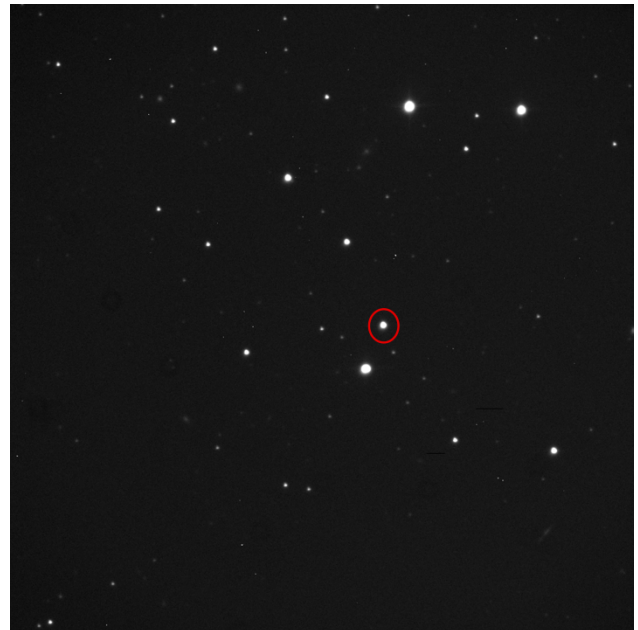
Figure 5. Image taken by SARA South telescope with asteroid position shown.

Image Number	R.A. SARA (S) h min sec	Dec SARA (S) $^{\circ}$ ′ ″	R.A. SARA (N) h min sec	Dec SARA (N) $^{\circ}$ ′ ″	Difference arcsec
1	$3^{h}\ 28^{m}\ 39.81^{s}$	$2^{\circ}\ 53'\ 41.2''$	$3^{h}\ 28^{m}\ 40.05^{s}$	$2^{\circ}\ 53'\ 35.1''$	6.1″
2	$3^{h}\ 28^{m}\ 39.81^{s}$	$2^{\circ}\ 53'\ 42.2''$	$3^{h}\ 28^{m}\ 40.05^{s}$	$2^{\circ}\ 53'\ 36.0''$	6.2″
3	$3^{h}\ 28^{m}\ 39.81^{s}$	$2^{\circ}\ 53'\ 43.0''$	$3^{h}\ 28^{m}\ 40.05^{s}$	$2^{\circ}\ 53'\ 36.9''$	6.1″
4	$3^{h}\ 28^{m}\ 39.81^{s}$	$2^{\circ}\ 53'\ 44.1''$	$3^{h}\ 28^{m}\ 40.05^{s}$	$2^{\circ}\ 53'\ 38.0''$	6.1″
5	$3^{h}\ 28^{m}\ 39.81^{s}$	$2^{\circ}\ 53'\ 44.6''$	$3^{h}\ 28^{m}\ 40.04^{s}$	$2^{\circ}\ 53'\ 38.5''$	6.1″
					Avg: 6.12″

Table 1. Measured RA and Declination of the asteroid from two locations and the difference due to parallax.

Conclusion

The purpose of the project was to test the feasibility of determining the distance to an asteroid using the parallax method with two telescopes and simultaneously imaging it. As this paper shows, it can be done with fairly high precession.

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JPL Small Body Database Search Engine.
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FIRST PHOTOMETRIC OBSERVATIONS OF NEAR-EARTH ASTEROIDS AT TIEN-SHAN ASTRONOMICAL OBSERVATORY

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In this paper, we present results of our first photometric observations of near-Earth asteroids at high-mountain Tien-Shan Astronomical Observatory (TShAO) of Fesenkov Astrophysical Institute (Republic of Kazakhstan). All observations were carried out on the recently modernized 1-meter Zeiss-1000 telescope. For the first target, we chose near-Earth asteroid (387733) 2003 GS, which did not have a known rotation period at the time. Based on the data, we conclude a rotational period of $P = 2.46 \pm 0.02$ h with the amplitude $A = 0.1$ mag.

Tien-Shan Astronomical Observatory was founded in 1957. It is located 30 km south of Almaty, Republic of Kazakhstan, at 2,750 meters above sea level. The observatory is equipped with several optical telescopes, including two Zeiss-1000 (1-m *f*/13) in the east and west cupolas. These telescopes were upgraded in 2011-2014. During this work, a new telescope control system was installed along with new CCD cameras and a 5-element focal reducer designed by A. Yudin (KIAM, ISON) for the east Zeiss-1000. In this configuration, the telescope has 19x19 arcmin field-of-view. Both telescopes are equipped with Johnson B, V, R filters by *Astrodon Photometrics*. Analysis of images and possible rotation period was carried out using the *MPO Canopus* package (Bdw Publishing).

(387733) 2003 GS. Asteroid (387733) 2003 GS is a near-Earth asteroid (Aten family, $q = 0.6977$ AU, $a = 0.8926$ AU, $e = 0.2184$, $i = 12.032°$), discovered by LONEOS on 2003 Apr. 4 (Marsden, 2003). The asteroid was well-observed during the 2014 apparition, with the rotation period independently defined by several observers: $P = 2.467$ h (Benishek, 2014c; Warner, 2014k) and $P = 2.469$ h (Hicks, 2014e). Observations at TShAO were carried out a week later, 2014 Apr. 18, with a Johnson R filter and 30-sec exposures in orbital tracking mode. Detailed information about the observational runs is shown in Table 1.

t, UT	Δ, AU	r, AU	Θ, deg	mag.
2014-04-18T16:17:41	0.093	1.084	29.6	15.2
2014-04-18T21:38:10	0.093	1.083	30.2	15.2

Table 1. Photometric observations of (387733) 2003 GS.

Based on our analysis, we found a rotation period of $P = 2.46 \pm 0.02$ h with a relatively low amplitude $A = 0.1$ mag. This estimate is comparable with the above values.
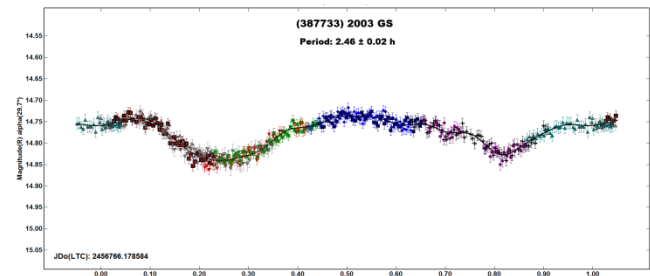
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ROTATION PERIOD DETERMINATION FOR 978 AIDAMINA

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For 978 Aidamina we find a synodic rotation period 10.098 ± 0.001 hours and amplitude 0.24 ± 0.02 magnitudes.

The two authors started observing 978 Aidamina separately and when they learned of each other's observations agreed to share their data and write a collaborative paper. Observations by F. Pilcher were obtained with a Meade 35 cm LX 200 GPS S-C, SBIG STL 1001-E CCD, clear filter, unguided exposures. Those by A. Ferrero were with a 30 cm f/8 Ritchey-Chretien and SBIG ST9 CCD. Image measurement, lightcurve analysis, and sharing of data were done with *MPO Canopus* software.

Previous period determinations are by Behrend (2003), 10.100 hours; LeCrone et al. (2004), 10.099 hours; and Clark (2006), a very uncertain 9.5 hours. From the new observations on ten nights 2014 June 11 - July 24 the authors find a synodic rotation period 10.098 ± 0.001 hours, amplitude 0.24 ± 0.02 magnitudes, with a somewhat asymmetric bimodal lightcurve. This is consistent with previous studies.

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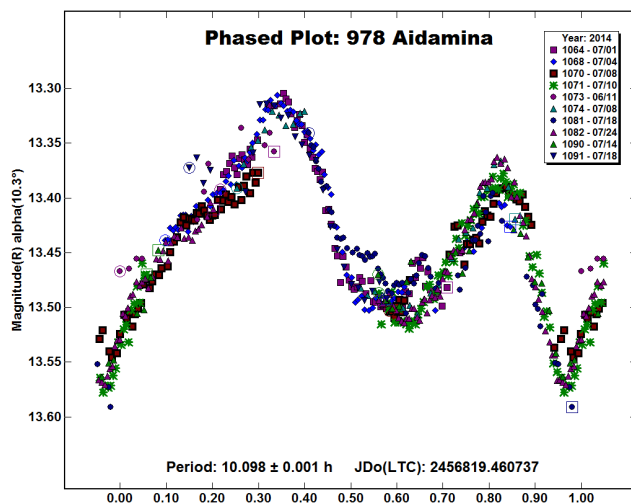
LIGHTCURVES OF ASTEROIDS 2007 MCCUSKEY, 2669 SHOSTAKOVICH, 3544 BORODINO, AND 7749 JACKSCHMITT

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Lightcurves were determined for the following four asteroids: 2007 McCuskey, 2669 Shostakovich, 3544 Borodino, and 7749 Jackschmitt. From these curves periods of 8.611 ± 0.003, 4.914 ± 0.004, 5.437 ± 0.001, and 5.337 ± 0.008 hours were found for 2007 McCuskey, 2669 Shostakovich, 3544 Borodino, and 7749 Jackschmitt, respectively.

Introduction

The purpose of this research was to obtain lightcuves of the chosen asteroids in order to get their rotational periods. The asteroids used in this study were chosen because they fit the following criteria: declination, apparent magnitude, and opposition date. The optimal declination was between 5º and -30º, putting the asteroids in the field of view of the telescopes used for the majority of the night. Ideal magnitudes were brighter than 16. Asteroids near opposition allowed the maximum number of images each night. The asteroids which met the above criteria, were 2007 McCuskey, 2669 Shostakovich, 3544 Borodino, and 7749 Jackschmitt.

Asteroid 2007 McCuskey was discovered in 1963 by the Indiana Asteroid Program. It has an orbital eccentricity of 0.115 and its semi-major axis is 2.384 AU (JPL). Asteroid 2669 Shostakovich was discovered on December 16, 1976 by Chernykh, L. and has an eccentricity of 0.219. Its semi-major axis is 2.780 AU (JPL). Asteroid 3544 Borodino was discovered on September 7, 1977 by Chernykh, N. (JPL). It has an eccentricity of 0.221 and a semi-major axis of 2.401 AU (JPL). Asteroid 7749 Jackschmitt was discovered on May 12, 1988 by Carolyn and Eugene Shoemaker and has an orbital eccentricity of 0.360 (JPL). Its semi-major axis is 2.632 AU (JPL).

Method

The telescopes used to study these asteroids were from the Southeastern Association for Research in Astronomy (SARA) consortium and the Texas A&M-University Commerce Observatory (A&M-Commerce). The SARA-North facility houses a 0.9-m telescope at Kitt Peak National Observatory in Arizona. The SARA-South facility has a 0.6-m telescope at Cerro Tololo Inter-American Observatory in La Serena, Chile. Both of the cameras, used with these telescopes, are Apogee CCD cameras. The telescope at the A&M-Commerce observatory, in Commerce, Texas, is a 0.4-m telescope with a SBIG-STX 16803 CCD camera.

The images obtained were reduced and aligned using the program Maxim DL. This reduction was done with flats, biases, and dark frames taken for each night of observation. These were twilight flats for the images taken with SARA equipment and dome flats for the images taken at the A&M-Commerce observatory. The dark

frames were exposed for three minutes on SARA telescopes and for five minutes at the A&M-Commerce telescope. These exposure times correspond to the asteroid image exposure times.

After calibration, differential photometry was used to determine the brightness of the asteroid using MPO Canopus v10.2.1.0 (Warner, 2011). Five comparison stars and the asteroid were measured on each image. The difference in magnitude between the comparison stars and the asteroid was averaged for each image. Lightcurves were then created using the differentiated magnitudes plotted versus time. A Fourier transform method was applied to determine the rotation period of the asteroid as well as the error of the period.

Results

2007 McCuskey. Images were taken of asteroid 2007 McCuskey using the SARA-South telescope. It was imaged 161 times on 2014 August 3rd and 163 times on 2014 August 4th. The period was found to be 8.611 ± 0.003 hours with an amplitude variation of 0.2 magnitudes. A previous study had found the period to be 8.603 ± 0.001 hours, (Klinglesmith and Franco, 2013).

2669 Shostakovich. Images were taken of asteroid 2269 Shostakovich using the SARA-North telescope. It was imaged 81 times on 2014 January 20th, 108 times on 2014 January 21st, and 24 times on 2014 January 30th using the A&M-Commerce telescope. The period was found to be 4.914 ± 0.004 hours with an amplitude variation of 0.2 magnitudes. A previous study, with very limited coverage, found a period of 6.24 ± 1.44 hours, (Behrend, 2005).

3544 Borodino. Images were taken of asteroid 3544 Borodino using the SARA-South telescope. It was imaged 149 times on 2014 June 23rd and 163 times on 2014 June 24th. The data from one of these nights was split into two sets because the asteroid needed to be re-centered in the field of view. The period was found to be 5.437 ± 0.001 hours with an amplitude variation of 0.35 magnitudes. A previous study found a period of 5.44 ± 0.01 hours, (Torno et al., 2008).

7749 Jackschmitt. Images were taken of asteroid 7749 Jackschmitt using the SARA-South telescope. It was imaged 148 times on 2014 June 25th and 137 times on 2014 June 29th. Asteroid 7749 Jackschmitt has a period of 5.337 ± 0.008 hours. A search of the Astrophysics Data System and the Asteroid Lightcurve Database did not find any previously reported results.

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Phased Plot: 2007 McCuskey

Phased Plot: 2669 Shostakovich

Phased Plot: 3544 Borodino

Phased Plot: 7749 Jack Schmitt
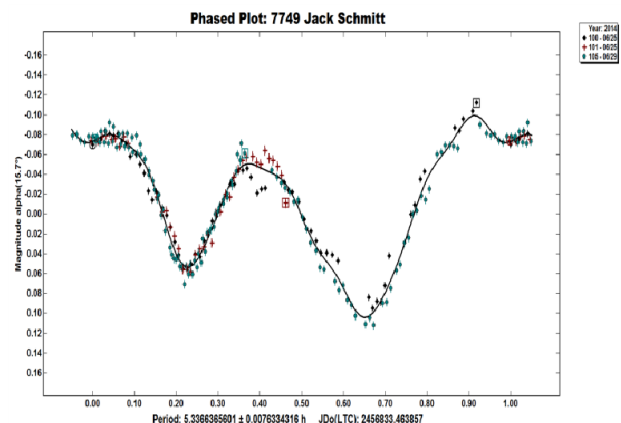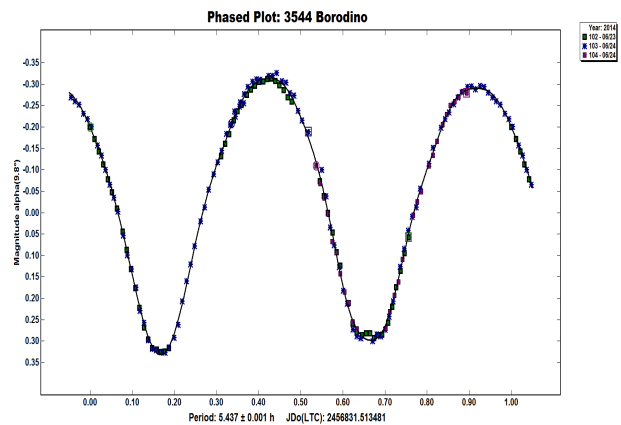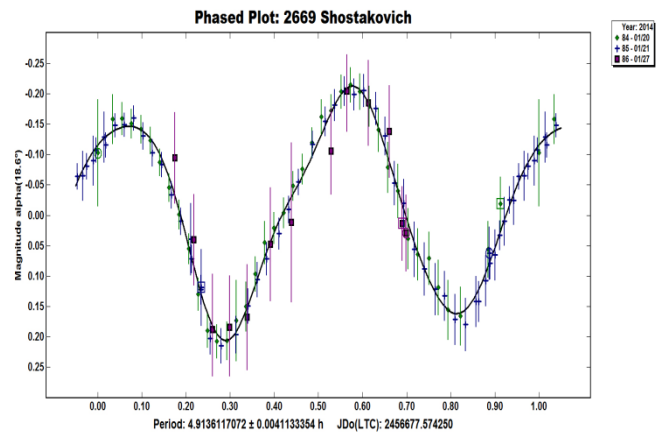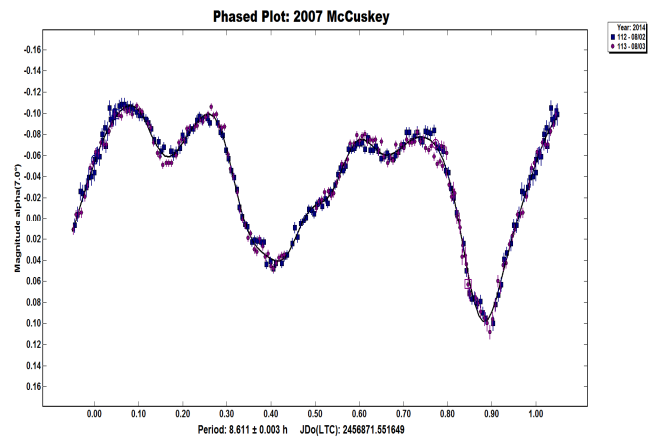
PERIOD DETERMINATION FOR 457 ALLEGHENIA: LOW NUMBERED ASTEROID WITH NO PREVIOUSLY KNOWN PERIOD

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Lightcurve analysis for 457 Alleghenia was performed using observations during its 2014 opposition. The synodic rotation period was found to be 21.953 ± 0.001 h and the lightcurve amplitude was 0.20 ± 0.02 mag.

457 Alleghenia is a main-belt asteroid discovered in 1900 by M.F. Wolf and A. Schwassmann at Heidelberg (Germany); it was named in honor of the Allegheny Observatory, currently an integral part of the University of Pittsburgh (USA). It appeared on the CALL web site as an asteroid photometry opportunity due to it reaching a favorable apparition in 2014 and having no defined lightcurve parameters.

Observations by Álvarez were made at Observatorio Los Algarrobos, Salto, Uruguay (OLASU, MPC Code I38) with a 0.30-m *f*/6.9 Meade LX-200R telescope and QSI 516wsg NABG CCD camera that was off-axis guided and set to 2x2 binning. A clear filter with no infrared blocker was used for the 150-second exposures. Observations by Pilcher were made at the Organ Mesa Observatory (MPC Code G50) with a 0.35-m *f*/10 Meade LX-200 GPS telescope and SBIG STL-1001E CCD camera that was unguided. A clear filter with infrared blocker was used for the 60-second exposures.

Our computers were synchronized with atomic clock time via Internet NTP servers at the beginning of each session. All images were dark and flat-field corrected and then measured using *MPO Canopus* (Bdw Publishing) version 10.4.3.16 with a differential photometry technique. The data were light-time corrected. Night-to-night zero point calibration was accomplished by selecting up to five comparison stars with near solar colors according to recommendations by Warner (2007) and Stephens (2008). Period analysis was also done with *MPO Canopus*, which incorporates the Fourier analysis algorithm developed by Harris (Harris *et al*., 1989).

Observations obtained on 14 nights from 2014 July 27 to September 25 are summarized in Table I. On one of these nights (Aug 24), both observers happened to image the target simultaneously for more than four hours, thus allowing a precise comparison of calibrated magnitudes of the two data sets by means of using the same calibration stars. Pilcher's data were found to be 0.15 magnitudes brighter than the extrapolation of Álvarez's data, which we attributed to different responses of the CCD sensors and to the clear filters, Pilcher's being IR-blocked and Álvarez being non IR-blocked.

More than 80 hours of effective observations and about 3,200 data points were required in order to solve the lightcurve (Figure 1).

Over the span of observations, the phase angle varied from 17.9° to 7.7° to 9.3°, the phase angle bisector ecliptic longitude from 346.1° to 349.7°, and the phase angle bisector ecliptic latitude from 15.6° to 16.6° to 16.3°. The rotation period for 457 Alleghenia was determined to be 21.953 ± 0.001 h with a lightcurve peak-to-peak amplitude of 0.20 ± 0.02 mag. No clear evidence of tumbling or binary companion was seen.

At the time of this study, 457 Alleghenia was the lowest numbered asteroid for which no rotation parameters were found in the literature. There are now rotation periods for all of the first 500 asteroids, although not all of these periods are reliable (i.e., many still have U < 3; see Warner *et al.*, 2009), so that ongoing investigations to verify, refine, or revise their values remains an important and pending endeavor.

```
Session Data
Sess   Observ   2014           UT Data       Pts
1      FP       Jul 27         09:04 - 11:30  128
2      FP       Aug 21         03:15 - 11:28  438
3      EMA      Aug 23         01:44 - 05:53  96
4      EMA      Aug 24         01:34 - 07:24  142
5      FP       Aug 24         03:09 - 11:45  456
6      FP       Aug 25         05:44 - 11:45  320
7      FP       Aug 28         03:34 - 11:51  440
8      FP       Aug 29         02:41 - 06:28  200
9      EMA      Aug 30         01:09 - 06:39  127
10     FP       Sep 11         02:05 - 10:32  397
11     EMA      Sep 15-16      23:36 - 04:37  116
12     EMA      Sep 19-20      23:25 - 04:36  122
13     EMA      Sep 21-22      23:22 - 04:25  119
14     EMA      Sep 24-25      23:01 - 04:27  120
```

Table I. Observing circumstances. In the Observer column, EMA is Álvarez at OLASU, and FP is Pilcher at Organ Mesa.

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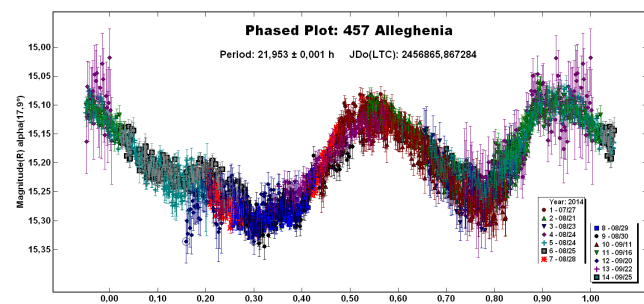
Figure 1. Composite lightcurve of 457 Alleghenia.

A TRIO OF BINARY ASTEROIDS

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CCD observations of three asteroids were made at the Center for Solar System Studies in mid-2014. The Hungaria member 1727 Mette is a known binary system. We saw no evidence of the satellite in 2014, which – assuming the satellite's orbit is nearly in the primary's equatorial rotational plane – leads to an estimate for the primary's spin axis orientation. The near-Earth asteroid (NEA) (68063) 2000 YJ66 has a primary spin period just at the spin barrier of 2.2 hours. Another NEA, 2014 PL51, looks to be one of a small number of wide binary candidates, which are characterized by a large amplitude lightcurve with a period of hundreds of hours superimposed by a short period, low amplitude lightcurve.

The near-Earth asteroid (NEA) program at the Center for Solar System Studies, located in Landers, CA, is primarily dedicated to finding the rotation period of as many NEAs as possible. This includes checking for and confirming satellites and non-principal axis rotation (NPAR, or *tumbling*). The results are added to the growing number of rotational statistics for NEAs, which are important to understanding NEA evolution, overall characteristics, and – to some degree – estimation of impact hazards. The program also monitors members of the Hungarias. These inner main-belt asteroids, which are not subject to planetary tidal encounters, serve as a control group to compare and contrast their rotation, binary, and tumbling statistics against those for the NEAs.

During the period of 2013 May 25 through 2014 October 3, the CS3 NEA program determined 190 rotation periods for 181 NEAs. Of these, 15 were binaries (rated as *possible*, *probable*, or *confirmed*) and 13 suspected or confirmed tumblers.

As part of the NEA program, we observed three asteroids: one Hungaria, 1727 Mette, and two NEAs, (68063) 2000 YJ66 and 2014 PL51. Mette was a known binary. To our knowledge, the two NEAs had not been observed before, and so their binary status was not known. Table I lists the equipment that was used by the authors for this study. Table II gives the dates of observations.

Observer	Telescope	Camera
Warner	0.50-m f/8.1 Ritchey-Chretien	FLI-1001E
	0.35-m f/9.6 Schmidt-Cass	STL-1001E
Stephens	0.35-m f/10 Schmidt-Cass	STL-1001E
	0.40-m f/10 Schmidt-Cass	FLI-1001E

Table I. List of observers and equipment.

Asteroid	Obs	Date (2014 mmm/dd)
1727 Mette	RDS	Jul 19-22
(68063) 2000 YJ66	BDW	Aug 18-21
	RDS	Aug 28-31; Sep 01-06
2014 PL51	BDW	Aug 31; Sep 02-06, 24
	RDS	Sep 15-18

Table II. Dates of observations for each asteroid. Observations were not necessarily made on every date within a range.

Image processing and measurement were done using *MPO Canopus* (Bdw Publishing). Master flats and darks were applied to the science frames prior to measurements. The *MPO Canopus* export data sets were collected by Warner for period analysis, also in *MPO Canopus,* which incorporates the FALC Fourier analysis algorithm developed by Harris (Harris *et al.,* 1989).

Conversion to an internal standard system with approximately ±0.05 mag zero point precision was accomplished using the Comp Star Selector in *MPO Canopus* and the MPOSC3 catalog provided with that software. The magnitudes in the MPOSC3 are based on the 2MASS catalog converted to the BVRcIc system using formulae developed by Warner (2007). This internal calibration works well within a given telescope-camera system. However, in some cases, there is a nearly constant offset from one system to the next, as in the case of merging the Stephens data with Warner's. For (68063) 2000 YJ66, an offset of approximately 0.2 magnitudes was applied to the Stephens sessions.

In the lightcurve plots presented below, the "Reduced Magnitude" is Johnson V corrected to unity distance by applying $-5*\log (r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and Earth-asteroid distances in AU. The magnitudes were normalized to the phase angle given in parentheses, e.g., alpha(68.5°), using $G = 0.15$. The horizontal axis is the rotation phase, ranging from −0.05 to 1.05.

1727 Mette. This asteroid is a member of the Hungaria *orbital group*, not of the *collisional family.* Tholen (1984) listed it as a type S asteroid; members of the Hungaria collisional family are type E. Its rotation period was well established (see references in the asteroid lightcurve database; LCDB; Warner *et al.*, 2009) before being discovered as a binary (Warner and Stephens, 2013). The 2014 observations were made as follow-up to confirm, if possible, the satellite's lightcurve and orbital period.
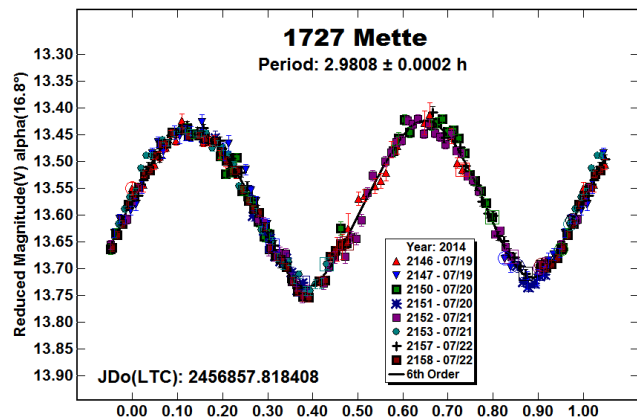
Figure 1. The lightcurve for 1727 Mette showed no obvious signs of the satellite discovered by the authors in 2013.

Analysis of the observations by Stephens from 2014 Jul 19-22 yielded a period of 2.9808 ± 0.0002 h and lightcurve amplitude of 0.31 ± 0.02 mag. The period is in excellent agreement with earlier

results. The total time of observations was about 16 hours (4 hours per night). This should have been enough to capture at least one event in the 21-hour orbital period. However, there were no obvious signs of deviations on the order of 0.05 mag, the level seen in 2013. Events of much less deviation would have been too small to observe reliably.

The satellite discovery observations were made in 2013 January, when the phase angle was about 10° and the phase angle bisector longitude (L$_{PAB}$) was 114° (see the appendix in Harris *et al.*, 1984, for the derivation of the phase angle bisector). The amplitude of the primary was 0.33 mag. Over the years, the amplitude has stayed within the range of 0.22-0.35 mag (Warner *et al.*, 2009). In 2014, the phase angle was 17° and L$_{PAB}$ was 322° (the opposing angle being 142°). This is about 30° from the longitude in 2013. Usually, this is not enough of a difference to go from seeing to not seeing events. An exception would be if the 2013 observations were just within the boundaries for *event seasons*.

Assuming that the satellite's orbital plane is near the primary's equatorial rotational plane, the lack of events in 2014 would imply that the primary's spin axis ecliptic longitude is near 320°, or 140°. This is supported by the fact that lower amplitudes are expected when viewing the asteroid more pole-on and that the lowest amplitudes in the LCDB were made near a L$_{PAB}$ of 140°. Observations at future apparitions are encouraged to help model the binary system and primary spin axis.

<u>(68063) 2000 YJ66</u>. By general definition, an NEA is an asteroid with a perihelion distance of $q < 1.3$ AU. As such, 2000 YJ66 is just within the group with a $q \sim 1.27$ AU. Warner did the initial observations in the middle of 2014 August. Because of observatory structural limitations, the asteroid moved too far north to continue with the available telescopes. Stephens continued the observations, starting in late August and going into early September.
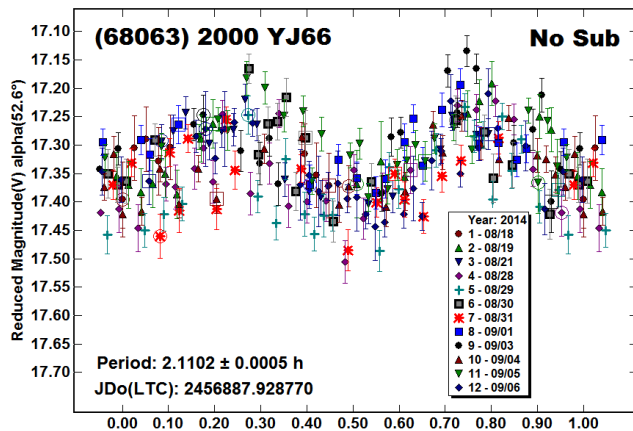
Figure 2. A plot using the full data set for 2000 YJ66 showed a fair amount of scatter that might be periodic instead of random. This prompted a dual period search.

A plot (Fig. 2) using all data phased to an initial best fit in a Fourier analysis shows a large amount of scatter. However, the scatter within the individual data sets was much less, indicating the possibility of a second period. In *MPO Canopus*, the search for a second period can be done two ways. The one we chose was to find a period using all data. The resulting Fourier model curve was subtracted from the data in a second search. Usually, we start on a likely short period, e.g., between 1 and 6 hours, then search for a longer period. In this case, we tried finding the long period first as well as the short to see if it would change the results. It did not.

When and if a second period is found, that Fourier curve is subtracted from the data and a new search for the short period is run. This iterative process continues until both periods stabilize. There is a bit of self-fulfilling prophecy in this method since each solution depends on the other period being correct. It has happened where, after a more extensive data set was obtained and previous periods put aside, an entirely different set of periods was found. In almost all cases, it was the long period that changed the most dramatically.
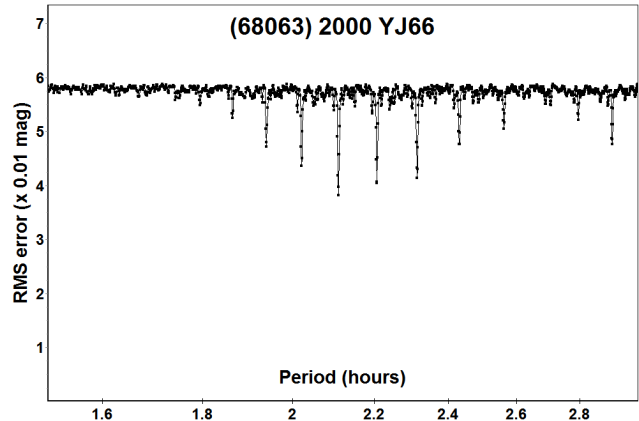
Figure 3. The period spectrum for the shorter period slightly favors a solution of 2.11 hours. The sequence of minima represents successive differences of half a rotation over a 24-hour span.
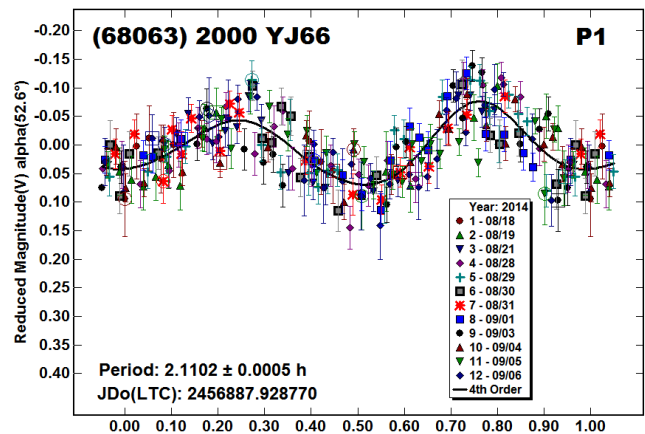
Figure 4. The lightcurve for the primary in the 2000 YJ66 binary system, obtained after subtracting the effects of the satellite.

The primary's period of 2.1102 h is just at or above the so-called *spin barrier* of about 2.2 hours, which separates rubble pile and strength-bound bodies. The fact that the there is a satellite indicates that this is almost certainly a rubble pile asteroid that was spun-up by the YORP effect (Yarkovsky–O'Keefe–Radzievskii–Paddack; Rubincam, 2000) to the point where it shed mass that formed the satellite.

We did try forcing the short period to the other periods on either side of 2.11 hours. Even after subtracting the effects of the satellite, the scatter in the primary lightcurve made it difficult to say that any one of the solutions was unique and so a "more ordinary" value of about 2.2 hours is almost as likely. It is important to note that regardless of which short period we used, the long period solution did not change by more than 0.02 hours.
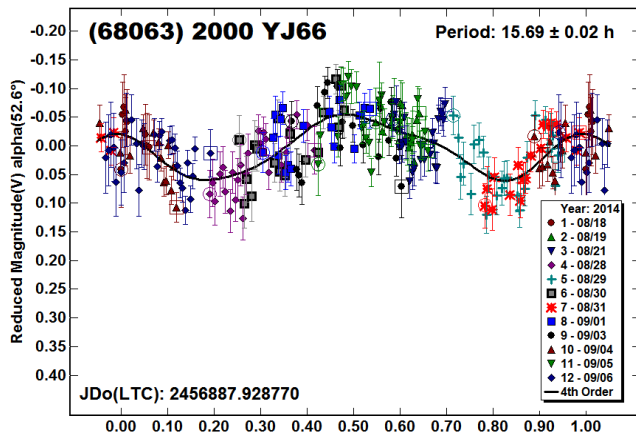
Figure 5. The lightcurve attributed to the tidally-locked satellite of 2000 YJ66.

The secondary lightcurve for 2000 YJ66 does not show any *mutual events*, i.e., occultations or eclipses, which are considered direct evidence of a satellite. It does show a lightcurve of 0.12 mag amplitude with a period of 15.69 ± 0.02 hours. The period is within the expected boundaries given the primary period (Pravec *et al.*, 2010). The shape of the curve fits one for an elongated satellite that is tidally-locked to the orbital period.

2014 PL51. Jacobson and Scheeres (2011) have examined the possibilities for different types of binary asteroid systems. Among them is what are sometimes called *wide binaries*. In this case, the primary has a long period (due to conservation of energy) while the satellite has a short period and is well-removed from the primary. Unless the rarest of circumstances prevail, the period of the orbit cannot be determined from the observations due to the absence of *mutual events*, but it is probably long based on the asynchronous rotation of the two components.

In such a system, the primary has a lightcurve with a period of hundreds of hours and an amplitude $A \geq 0.3$ mag. The satellite's lightcurve amplitude is on the order of $A \leq 0.10$ mag with a period in the range 2-8 hours. In addition to 2014 PL51, there are seven other such binary candidates (Table III).

Number	Name	P1	P2	Ref
1220	Crocus	785	7.97	Icarus 72, 135-208
8026	Johnmckay	372	2.2981	MPB 38, 33-36
15778	1993 NH	113	3.320	MPB, this issue
67175	2000 BA19	275	2.7157	MPB 40, 36-42
119744	2001 YN42	624	7.24	MPB 41, 102-112
190208	2006 AQ	182	2.621	MPB, this issue
218144	2002 RL66	588	2.49	MPB 37, 109-111
	2014 PL51	205	5.384	This work

Table III. List of suspected wide binary asteroids. P1 is the primary's period (hours). P2 is the satellite's, which is not tidally-locked to its orbital period. All references are Warner (et al.) except for 1220 Crocus, which is Binzel and was only recently added to the list.

In most of these, the amplitude of the secondary lightcurve has been weak in comparison to the noise in the data, and so the results were inconclusive. The results for 2014 PL51 make one of the stronger cases to date.

The raw plot of the data for 2014 PL51 shows a very strong, long period component. Because of the possibility for a wide binary, a search is always made for a secondary period by first eliminating

the long period, but with caution to avoid forcing a solution. The period search process described above led to finding a period of 205 ± 5 hours for the primary. The precision is somewhat arbitrary given the gaps in the coverage of the lightcurve. Just as much so, when the data set extends for a month or so, there is the chance that the lightcurve evolves due to changing phase angle or phase angle bisector longitude and latitude.
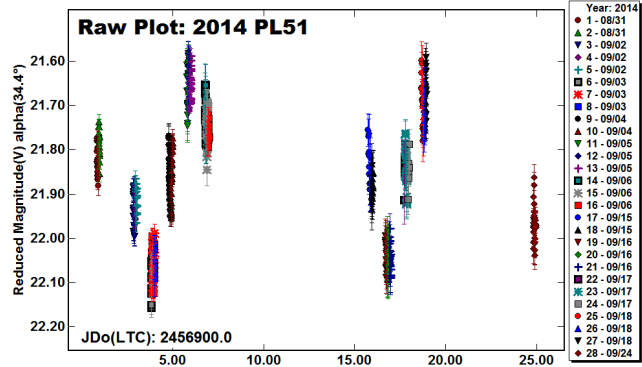
Figure 6. The raw plot of the data obtained for 2014 PL51 clearly shows a long period component.
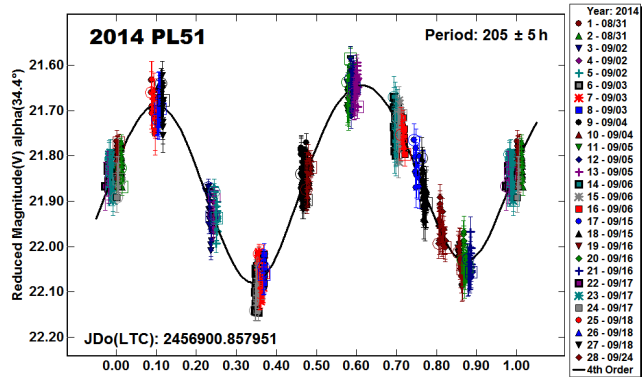
Figure 7. The long period lightcurve for 2014 PL51. The short period component is not obvious at this point.
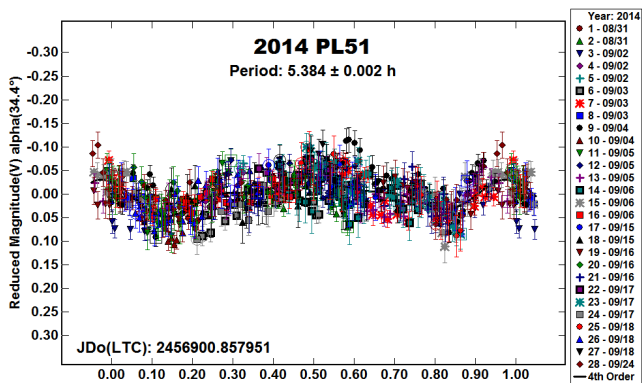
Figure 8. The short period lightcurve is attributed to a satellite that is not tidally-locked to a very long orbital period.

The search for a secondary period found 5.384 h with an amplitude of about 0.09 mag. The shape is somewhat asymmetrical, which is not unexpected for a low amplitude lightcurve. More important is that the minimums cannot be attributed to mutual events since this would indicate that the orbital period is also 5.4 hours. This is far too short if typical densities are presumed for the two bodies.

Acknowledgements

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LOW AMPLITUDE LIGHTCURVE FOR KM-SIZED NEAR-EARTH ASTEROID (285944) 2001 RZ11

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In this paper we present results of photometric observations of near-Earth asteroid (285944) 2001 RZ11. Observations were carried out at two observatories: ISON-NM (Mayhill, NM, USA) and Tien-Shan Astronomical Observatory (TShAO) (Almaty, Republic of Kazakhstan) with 0.4-meter Santel-400AN and 1-meter Zeiss-1000 telescopes, respectively. Based on the combined data set, we found a period of $P = 2.2455h \pm 0.0002$ with a low amplitude $A = 0.07$ mag. Critical bulk density for this object is $\rho \sim 2.3$ g/cm^3. We did not find any previously published data on the rotation period for this object.

The first observation phase for (285944) 2001 RZ11 was carried out on 2014 August 18-21 at ISON-NM Observatory with the Santel-400AN (0.4-m *f*/3) telescope in Johnson R band and 30-60 second exposures. The initial results showed a relatively fast rotation rate for the object with diameter 1.7 km ± a factor of two (NEOWISE). Together with the low amplitude, this led us to conclude that confirming observations were required. Unfortunately, the weather at ISON-NM Observatory turned bad for three weeks and the asteroid was too faint for the 0.4-meter telescope. For confirmation in the second observation phase, we used the 1-meter telescope Zeiss-1000 (East) at TShAO. To increase the signal-to-noise ratio, all observations were carried out in luminance (clear) filter with 300-sec integration time. More details of observations are shown in Table 1. Analysis of images and possible rotation period were made using *MPO Canopus* (Bdw Publishing).

t, UT	Δ, AU	r, AU	Θ, deg	mag.
2014-08-18T08:20:11	0.090	1.010	11.9	12.1
2014-08-21T09:37:04	0.114	1.108	30.8	13.2
2014-09-26T16:43:01	0.657	1.260	52.3	17.9
2014-09-29T17:30:06	0.718	1.283	51.1	18.1

Table 1. Photometric observations of (285944) 2001 RZ11.

Asteroid (285944) 2001 RZ11 follows a highly inclined orbit (Amor family, *q* = 1.079 AU, *a* = 2.191 AU, *e* = 0.5075, *i* = 53.1107°). This object was discovered by LINEAR at 2001 Sept.

10 (Spahr, 2001). (285944) 2001 RZ11 was one of brightest NEAs).

Based on analysis of our data, we found a synodic rotation period of P = 2.2455h ± 0.0002 with very low lightcurve amplitude A = 0.07 mag. Radar echoes received at Goldstone radio observatory, showed a Doppler broadening of about 30 Hz. That suggests rapid rotation of the asteroid (L. Benner, personal communication).
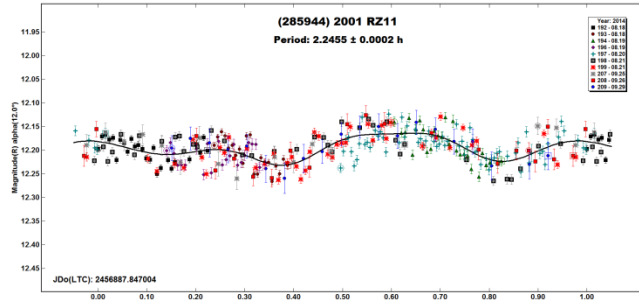
Figure 1. The phased lightcurve for (285944) 2001 RZ11.
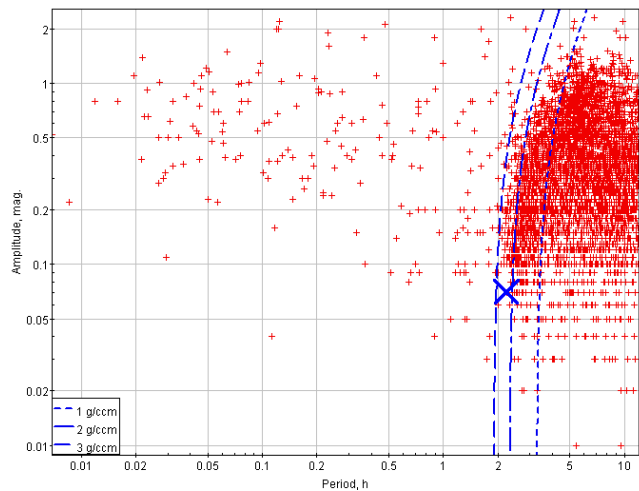
Figure 2. A plot showing amplitude versus period (from Warner et al., 2009) shows the location of 2001 RZ11. See the text for additional details.
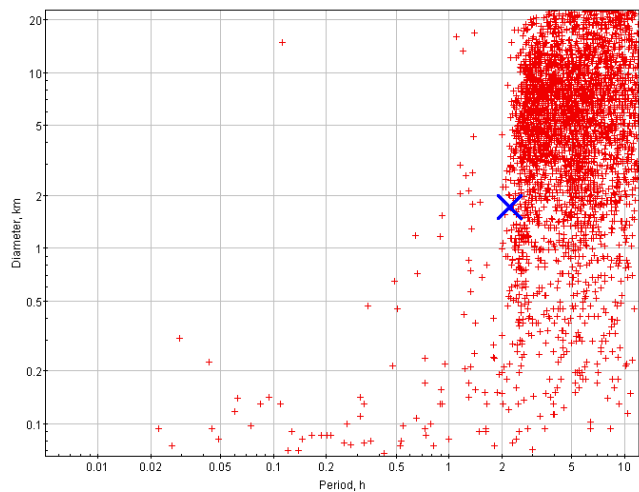
Figure 3. A plot showing diameter versus period. The blue cross represents 2001 RZ11.

Assuming a critical rotation period as $P \sim 3.3\sqrt{1 + \Delta m / \rho}$ (Pravec and Harris, 2000) and a near spherical form of object of study, due to very low lightcurve amplitude, we can calculate critical bulk 3. Although the relatively high density, asteroid (285944) 2001 RZ11 may still be a "rubble-pile" object, because its bulk density 3 (Pravec and Harris, 2000). Fig. 2 shows the rotation periods vs. lightcurve amplitudes; the blue bold cross is (285944) 2001 RZ11. The blue lines represent the estimated spin rate limits for bulk 3. Fig. 3 shows the distribution of rotation periods vs. object diameters (from Warner *et al.*, 2009).

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LIGHTCURVE AND ROTATION PERIOD DETERMINATION FOR MINOR PLANET 4910 KAWASATO

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Collaborative CCD photometric observations of minor planet 4910 Kawasato (1953 PR) were undertaken by the authors in 2014 September. The resulting synodic rotation period of 4.661 ± 0.003 h and amplitude, A = 0.10 ± 0.03 mag was determined from four nights of observations.

Cherryvalley observatory (MPC Code I83) and Saronno Observatory are amateur-owned facilities located in Ireland and Italy respectively. Observations from Cherryvalley Observatory were conducted with a 0.2-m Schmidt-Cassegrain Telescope (SCT) operating at *f*/7.6 using an SBIG STL-1301E CCD camera with a 1280x1024 array of 16-micron pixels fitted with an R-band Bessel photometric filter. The resulting image scale was 2.15 arcsecond per pixel unbinned. Image acquisition was with Software Bisque's *TheSky6* Professional and *CCDSoft* v5. Saronno Observatory employs a 0.24-m *f*/10 SCT using an SBIG ST8-XME CCD

camera with a 1530x1020 array of 9-micron pixels; no photometric filter was used for observations. The resulting image scale was 1.48 arcsecond per pixel (2x2 binning). All light images were aligned, dark and flat field corrected using either *MaxIm DL* v5.03 or *CCDSoft* v5 with mid-exposure times light-time corrected using *MPO Canopus v10.4.3.17* (Bdw Publishing). 162 data points were used in the calculations, which were obtained over four nights of observations spanning eight days.

Data produced in *MPO Canopus* (Bdw Publishing) using differential photometry to facilitate easy exportation. Night-to-night zero point calibration was accomplished by using the "comp star selector" (CSS) feature, which allows selecting up to five near solar colour stars within the field of view for differential photometry. The Cousins R Magnitudes for the comparisons were derived using the 2MASS to BVRI formulae developed by Warner (2007). Period analysis was completed using *MPO Canopus*, which incorporates the Fourier analysis algorithm (FALC) developed by Harris (Harris *et al.*, 1989).

<u>4910 Kawasato.</u> Kawasato is classed as a Mars-crossing asteroid, being constrained by an orbit of 1.3 AU $< q <$ 1.666 AU and $a <$ 3.2 AU where q is the perihelion distance and a is the orbital semi-major axis. The orbital period is approximately 3.81 years and the absolute magnitude is H = 13.3 mag. Discovered 1953 August 11 by K. Reinmuth at Heidelberg, it is named in honour of Nobuhiro Kawasato, who co-discovered 1988 VG2, which was identified with the lost minor planet (724) Hapag. The name was proposed by S. Nakano, who found the identifications involving this object. Bus and Binzel (2002) observed 4910 Kawasato during Phase II of the Small Main Belt Asteroid Spectrographic Survey (SMASS II) with the 2.4-m f/7.5 Hiltner telescope at the MDM Observatory on Kitt Peak in Arizona 1994 April 01 with resulting spectral classification of S-type.

The phased plot for 4910 Kawasato (Figure I) demonstrates a classical if shallow bimodal lightcurve. The period solution of 4.661 ± 0.003 h is in close agreement with earlier work by Stephens (2014) from 147 data points with a quality rating of 3, Warner *et al.* (2009). Observations of 4910 Kawasato were made during the period of 2014 September 20 to 2014 September 28. The solar phase angle varied from +1.70° through to +7.0°, a minimum solar phase angle of 0.6° occurred on September 18. For the first observation on 2014 September 20, 21:47 UT, the phase angle bisector longitude (L_{PAB}) and latitude (B_{PAB}) were 355.6° and +0.6° respectively. For the last observation on 2014 September 28, 21:58 UT, the L_{PAB} and B_{PAB} were 357.2° and –0.1° respectively. 4910 Kawasato's Earth distance was approximately 0.68 AU on average during observation time span, (ephemeris data generated from the asteroid data browser, *MPO Canopus*). See Harris *et al.* (1984) for the derivation of the phase angle bisector.

4910 Kawasato was reported as a lightcurve opportunity in the *Minor Planet Bulletin* (Warner *et al.*, 2014).
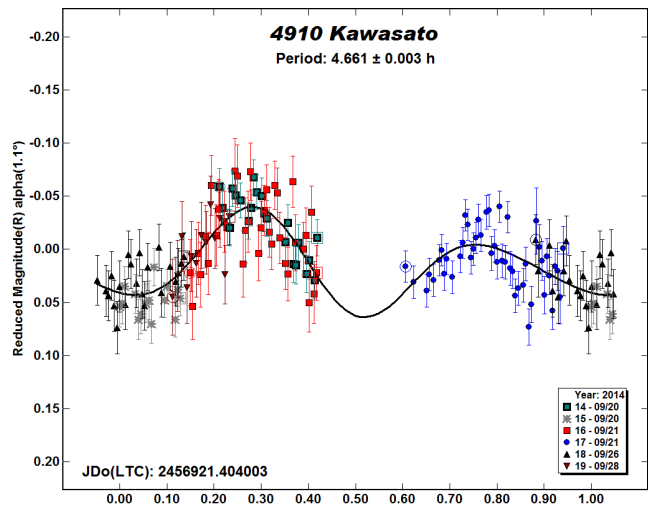
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(399307) 1991 RJ2:
A NEW NEA BINARY DISCOVERY

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Analysis of CCD photometric observations of the near-Earth asteroid (399307) 1991 RJ2 made in 2014 August-September show it to be a binary system with a primary period of 3.4907 ± 0.0002 h and orbital period of 15.917 ± 0.001 h. The depth of the secondary *mutual event* indicates a minimum effective diameter ratio (Ds/Dp) of 0.47 ± 0.02. The lightcurve showing the orbital period and *mutual events* indicates a slightly elongated (a/b ~ 1.07/1.0) satellite that is tidally-locked to the orbital period.

The near-Earth asteroid (NEA) (399307) 1991 RJ2 was observed as part of the ongoing program at Center for Solar System Studies (CS3) to determine the rotation periods and other photometric characteristics of NEAs and to support radar observations with optical lightcurves. The initial observations were made at the Palmer Divide Station at CS3 (CS3-PDS) from 2014 August 27 through September 6. Analysis of the resulting data showed some intriguing possibilities, including that it was a binary system with one period on the order of 24-hours.

This particular result was in question because the attenuations of ~0.3 mag, presumably due to the satellite, were always near the end of a nightly run. "End-of-run" anomalies are often found to be the result of the telescope aiming at least partly into the observatory walls or dome or some other systematic effect. However, the raw plot of the comparison stars showed no indications of systematic problems or obstructions. To check further, a star in the field on two nights was measured as the target and was found to have a flat lightcurve throughout the night. As yet another safety check, a recently observed NEA by Pollock with a well-defined lightcurve was observed at CS3-PDS to see if the new data indicated any systematic problems. None were found. All

this led to the conclusion that the attenuations in the lightcurve were real and due to the asteroid.

The period of the attenuations was found to be 23.87 hours. For a single station, this meant that it would take nearly a week for the observation window to move by only 4% of the period. In the meantime, there was concern that the lightcurve would evolve due to changing phase and phase angle bisector. This made obtaining observations from a significantly different longitude imperative, where even just one or two long runs could prove useful.

Pollock was able to arrange time on Sep 22 to observe from two stations in the Southern Hemisphere: the PROMPT telescope in Chile and the R-COP at Perth Observatory in Western Australia. The combined run covered nearly 13 hours. Tables I and II list the equipment and the dates of observations for the different locations.

OBS	Telescope	Camera
CS3-PDS	0.50-m f/8.1 Ritchey-Chretien 0.35-m f/9.6 Schmidt-Cass	FLI-1001E STL-1001E
PROMPT	0.40-m f/10 Schmidt-Cass	Apogee Alta
R-COP	0.35-0 f/10 Schmidt-Cass	ST-10XME

Table I. Telescope/cameras used at each location.

Location	2014 mmm dd	Phase	L_{PAB}	B_{PAB}
CS3-PDS	Aug 27-31 Sep 01-06 Sep 28	21, 18 17, 12 6	349, 351 351, 354 1	6, 4 4, 2 -4
PROMPT	Sep 22 Sep 28	3 6	359 1	-3 -4
R-COP	Sep 22	3	359	-3

Table II. Observing circumstances for each location. Phase is the phase angle, in degrees. LPAB and BPAB are, respectively, the phase angle bisector longitude and latitude, also in degrees. For rows with a range of dates, the values are for the first and last date in the range. All values are computed for 0 h UT.

Analysis and Results: A New Binary

The data from the Sep 22 run provided the critical evidence needed to establish the true nature of the asteroid: a binary system with a relatively large satellite that is tidally locked to its orbital period. Follow-up observations at PROMPT on Sep 28, also overlapped in part at CS3, helped further refine the orbital solution and shape of the mutual events
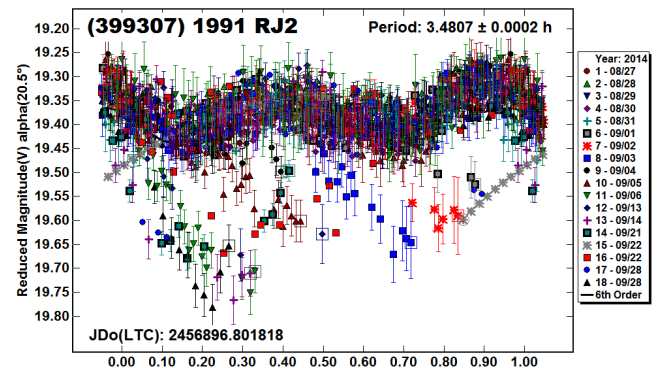
Figure 1. The lightcurve of 1991 RJ1 when using the full data set and forcing the period to that of the primary. The attenuations due to the mutual events are very apparent.

Figure 1 shows the complete data set of more than 1400 observations when forced to the primary's period. The attenuations

due to the satellite are clearly seen. For our analysis, we used the dual period tool in *MPO Canopus*, which is based on the FALC algorithm developed by Harris (Harris *et al.*, 1989). The search proceeded by first finding a period between 2 and 10 hours using all data with no subtraction. The resulting Fourier model curve was subtracted in the subsequent search for a long period, one in the range of 5-35 hours. The Fourier curve for this period was subtracted when looking again for the short period. The processing of swapping back and forth continued until both solutions stabilized. The initial results still favored one of 12 or 24 hours. However, there was a strong third candidate in the period spectrum at approximately 16 hours.

Sometimes the Fourier analysis will find a "best" fit that is the result of a *fit by exclusion*, meaning that the RMS fit is minimized by finding a period that also minimizes the number of overlapping data points. The lightcurves at 12 and 24 hours did not seem to represent something that was physically probable. In the off-chance that the two periods were the result of a *fit by exclusion*, the second period search was limited to the range of 14-18 hours. The results are shown in Figures 2 and 3.
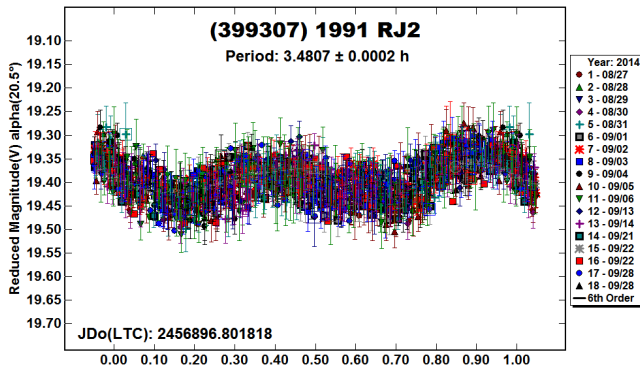
Figure 2. The lightcurve for the primary body of 1991 RJ2. The low amplitude and symmetry indicate a nearly spheroidal body.

Figure 2 shows the data set phased to a period of 3.4807 h after removing the effects due to the satellite, mostly the *mutual events* due to occultations and/or eclipses. The amplitude of only 0.09 mag and nearly symmetrical shape indicate a nearly spheroidal body. This is very common among small binary systems.
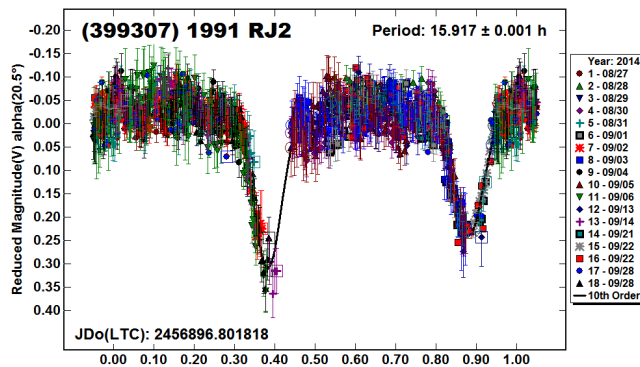
Figure 3. The lightcurve due to the satellite of 1991 RJ2. The deep attenuations are due to occultations and/or eclipses.

In Figure 3, the mutual events are clearly indicated, with drops of 0.35 mag and 0.27 mag. The shallower of the two events allows finding a minimum effective diameter ratio of the two bodies of Ds/Dp ≥ 0.47 ± 0.02. The event was not total, as would be indicated by a flat instead of rounded minimum, therefore the ratio

is a minimum and could be larger. Figure 3 also shows a slight upward bowing of about 0.07 mag between events. This indicates that the satellite is slightly elongated, a/b ~ 1.07:1. The overall shape of the lightcurve, discounting the *mutual events*, indicates that the satellite's rotation period matches the orbital period, i.e., it is tidally-locked to the orbital period.

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ROTATION PERIOD DETERMINATIONS FOR 275 SAPIENTIA, 309 FRATERNITAS, AND 924 TONI

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Synodic rotation periods and amplitudes are reported for three asteroids: 275 Sapientia 14.931 ± 0.001 hours, amplitude 0.12 ± 0.01 magnitudes with an irregular lightcurve; 309 Fraternitas 22.398 ± 0.001 hours, 0.12 ± 0.01 magnitudes; 924 Toni 19.437 ± 0.001 hours, 0.24 ± 0.02 magnitudes.

Observations to produce these determinations have been made at the Organ Mesa Observatory with a 35.4 cm Meade LX200 GPS S-C and SBIG STL 1001-E CCD. Photometric measurement and lightcurve construction are with *MPO Canopus* software. All exposures are 60 second exposure time, unguided, clear filter. 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 maximum time difference 5 minutes.

275 Sapientia. Previous rotation period determinations have been made by Denchev (2000), >20 hours; Behrend (2006), 24.07 hours; and Warner (2007), 14.766 hours. New observations on 8 nights 2014 July 25 - Sept. 10 provides a good fit to an irregular lightcurve with period 14.931 ± 0.001 hours and amplitude 0.12 ± 0.01 magnitudes. It is noted that segments of the lightcurve between phase 0.95 and 0.10 for the sessions on July 25 and 26 at phase angle near 11 degrees lie about 0.02 magnitudes higher than the for the corresponding phases on Sept. 1 and 4 near phase angle 3 degrees. These phase angle dependent misfits also appear at the same phase on a lightcurve phased to the double period of 29.862 hours. The change can therefore be attributed to the change in phase angle and does not provide evidence in favor of the double period. An irregular lightcurve indicates an irregular shape. The double period lightcurve is not only irregular, segments separated by rotational phase 0.5 are identical within errors of observation.

The probability of a real asteroid having irregular shape symmetric over a 180 degree rotation required by such a lightcurve is extremely small and may be safely rejected. Hence I claim the 14.931 hour period is secure. This period is fairly close to the period by Warner (2007) and disagrees completely with all other previous determinations.

309 Fraternitas. Previous rotation period determinations for 309 Fraternitas have been made by Robinson (2002), 13.2 hours; Shevchenko et al. (2005), 22.39 hours with no published lightcurve, and Shevchenko et al. (2008), 11.205 hours. New observations on 9 nights 2014 Aug. 30 - Oct. 4 provide a good fit to an asymmetric bimodal lightcurve with period 22.398 ± 0.001 hours, amplitude 0.12 ± 0.01 magnitudes. The new observations rule out the 13.2 hour period by Robinson (2002). They are consistent with the 22.39 hour period stated by Shevchenko et al. (2005), but the lightcurve that they later published (Shevchenko et al. 2008), was the half period lightcurve that features one maximum and minimum per cycle.
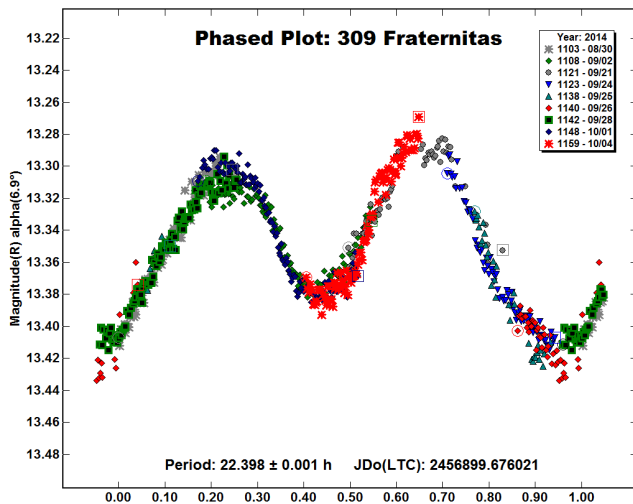
924 Toni. Previous rotation period determinations for 924 Toni have been made by Behrend (2006), 21.1 hours; and Behrend (2007), 21.12 hours. New observations on 12 nights 2014 June 12 - July 27 provide a good fit to a slightly asymmetric bimodal lightcurve with period 19.437 ± 0.001 hours, amplitude 0.24 ± 0.02 magnitudes. This is not in agreement with earlier determinations based on much less dense lightcurves.
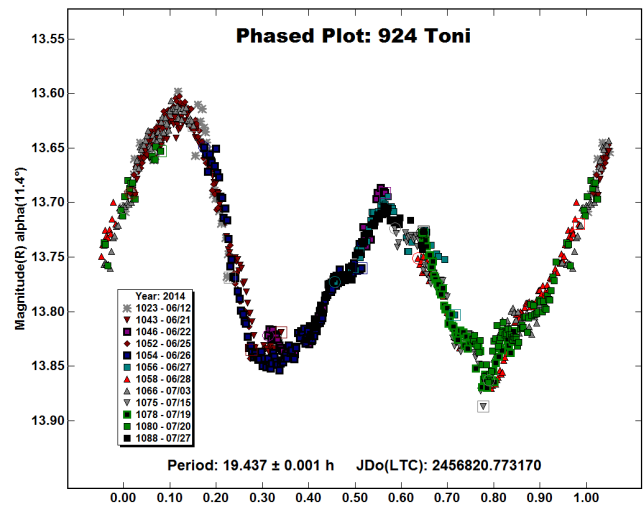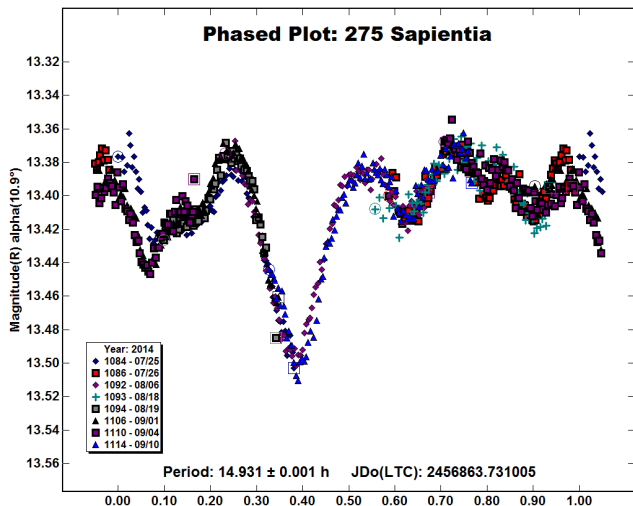
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ROTATION PERIOD DETERMINATION FOR 2484 PARENAGO

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Photometric observations of the main-belt asteroid 2484 Parenago performed by the authors in Italy in 2014 September revealed the bimodal light curve phased to 3.433 ± 0.001 hours as the most likely solution representing the synodic rotation rate for this asteroid.

2484 Parenago is a main-belt asteroid discovered on 1928 October 7 by Grigory Neujmin at Simeis and named for the Russian astronomer Pavel Petrovich Parenago (1906-1960). It is a typical main-belt asteroid in an orbit with a semi-major axis of about 2.34 AU, eccentricity 0.25, and orbital period of 3.59 years. According to the WISE satellite infrared radiometry (Mainzer *et al.*, 2011), the diameter is 6.266 ± 0.249 km and has an absolute magnitude $H = 14.0$. A search of the asteroid lightcurve database (LCDB; Warner *et al.*, 2009) indicates that these constitute the first reported lightcurve observations of this object.

Observations were made on five nights between 2014 September 15-23. During the interval of 9 days, the phase angle ranged from 7.1° to 0.8° pre-opposition. At the Astronomical Observatory of the University of Siena, data were obtained with a 0.30-m *f*/5.6 Maksutov-Cassegrain telescope, SBIG STL-6303E NABG CCD camera and clear filter; the pixel scale was 2.20 arcsec in binning 2x2. Exposures were 180 seconds. At Saronno, Salvaggio's data were obtained with a 0.23-m *f*/10 telescope, SBIG ST8-XME NABG CCD camera, unfiltered; the pixel scale was 1.6 arcsec in binning 2x2. Exposure were 150 seconds. The collaborative observations resulted in 6 sessions with a total of 347 data points.

Images were calibrated with bias, flats, and darks. Data processing, including reduction to R band, and period analysis were performed using *MPO Canopus* (BDW Publishing, 2012) by Papini. Differential photometry measurements were performed using the Comp Star Selector (CSS) procedure in *MPO Canopus* that allows selecting of up to five comparison stars of near solar color. Additional adjustments of the nightly zero-points were made in order to achieve the best alignment as determined by minimizing the Fourier RMS residual.

The period analysis yielded several possible solutions that clearly stand out in the period spectrum (Fig. 1) with nearly comparable RMS errors; only some of these have a valid physical justification. The complex lightcurve solutions with multiple minima and maxima phased to periods of over 8 hours were immediately ruled out as physically unreasonable, leaving three solutions that were taken into further consideration: a bimodal light curve phased to 3.433 ± 0.001 hours (Fig. 2), the double value of this period, i.e. a quadramodal solution of about 6.8 hours, and a trimodal lightcurve

phased to 5.1 hours. A closer examination of the Fourier series coefficients favors 3.433 hours over its double value due to larger values for the even term coefficients with respect to the odd term coefficients in the longer period case. The bimodal solution shows significantly better uniformity between the even and odd term coefficients, which is an indication of its greater adequacy.

We conclude that the most likely value of the synodic period for 2484 Parenago is associated with a bimodal lightcurve phased to 3.433 ± 0.001 hours with an amplitude of 0.29 ± 0.01 mag. There is a faint possibility of trimodal light curve and period of 5.1 hours; this could be confirmed or rejected by a more thorough analysis of additional data that would be collected at some future apparitions.
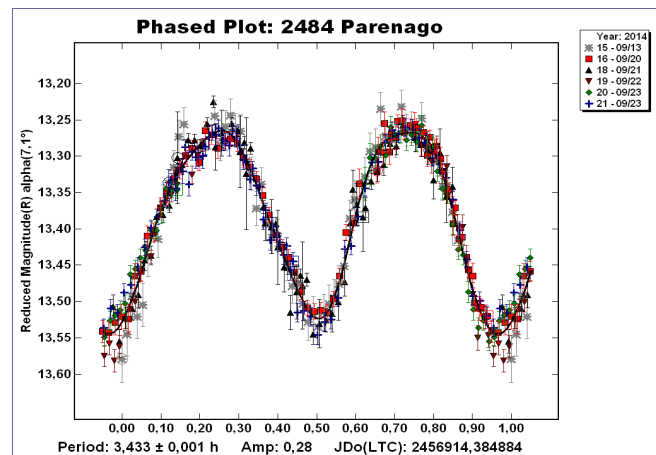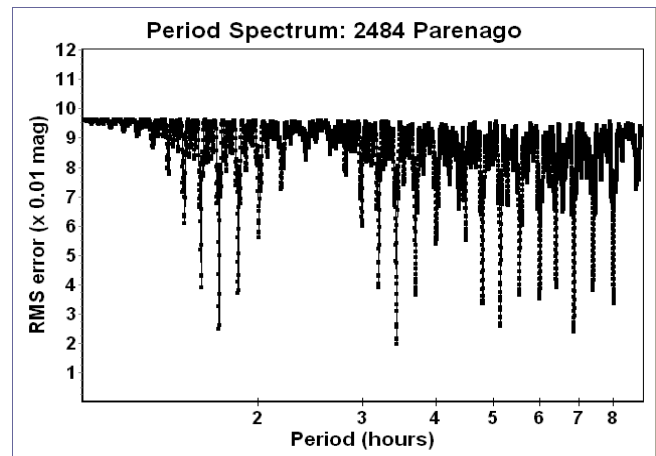
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NEAR-EARTH ASTEROID LIGHTCURVE ANALYSIS AT CS3-PALMER DIVIDE STATION: 2014 JUNE-OCTOBER

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Lightcurves for 45 near-Earth asteroids (NEAs) were obtained at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2014 June through October. Periods and lightcurve amplitudes were determined for 44 of the objects. No period or amplitude could be found for 2014 SZ144.

CCD photometric observations of 45 asteroids were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) in 2014 June through October. 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 done using *MPO Canopus*. If necessary, an elliptical aperture with the long axis parallel to the asteroid's path was used. 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 MPOSC3 catalog, which is based on the 2MASS catalog (*http://www.ipac.caltech.edu/2mass*) but with magnitudes converted from J-K to BVRI using formulae developed by Warner (2007b). When possible, magnitudes are taken from the APASS catalog (Henden *et al.,* 2009) since these are derived directly from reductions based on Landolt standard fields. Using either catalog, the nightly zero points have been found to be consistent to about ± 0.05 mag or better, but on occasion are as large as 0.1 mag. This consistency is critical to analysis of long period and/or tumbling asteroids. Period analysis is also done using *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 $-5*\log (r\Delta)$ to the measured sky magnitudes with r and Δ 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°), 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 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.

Individual Results

1917 Cuyo. Some previous results for Cuyo include Wisniewski *et al.* (1997; 2.6905 h), Behrend *et al*. (2008; 2.6890 h), and Warner (2014b; 2.684 h) from data in 2014 May. The observations at PDS two months later led to a period of 2.720 h, beyond the statistical errors and any allowance for sidereal-synodic period offset. The period spectrum for the 2014 July data (shown here) shows only a very weak solution around the earlier results while the spectrum based on the May data shows a weak solution at 2.72 h. More work on this asteroid is planned.
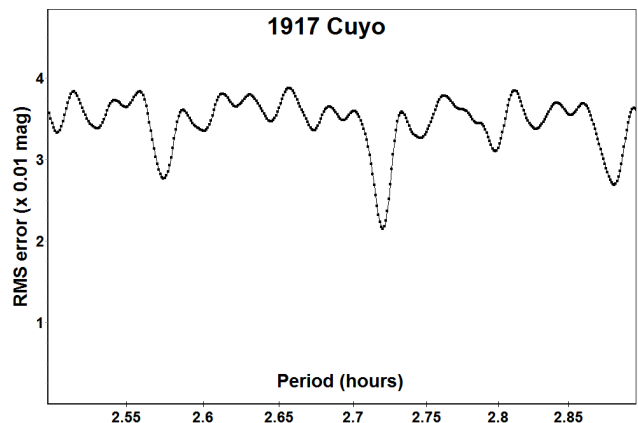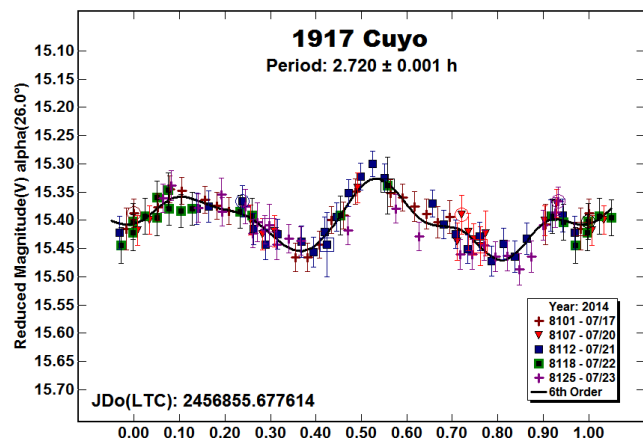
1943 Anteros. Anteros was observed as an early-evening target while waiting for another to rise. This made for short runs that were also in rich star fields, which mean that a good portion of the images were skipped to avoid field stars. As a result, the data set included only 51 observations. This is rarely enough to establish a period with certainty. The original analysis found a period of 4.49 h, significantly different from previous results, e.g., Pravec *et*

al. (1998; 2.8695 h) and Warner (2014a; 2.867 h). With some manipulation of zero points, a solution of 2.735 h was found, also significantly different from the previous results. The period adopted here should not be considered reliable.
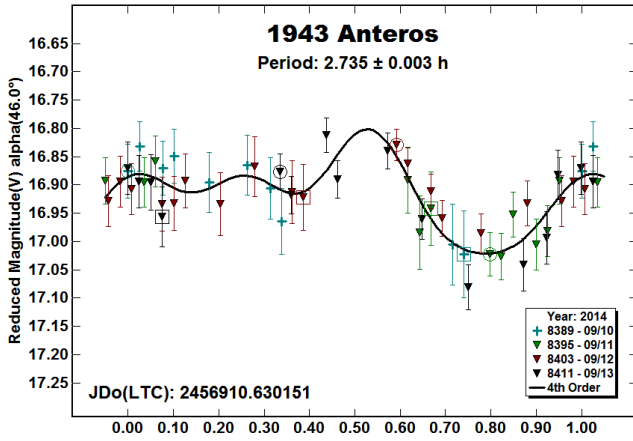
4401 Aditi. There were no previous results found in the literature for this NEA. The period is considered secure.
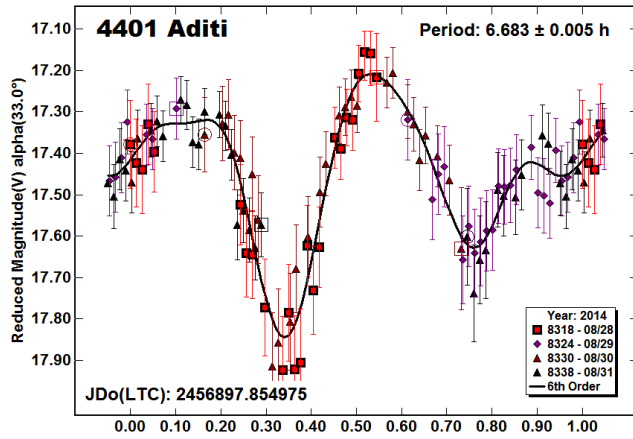
6050 Miwablock. Pravec *et al.* (2001) reported a period of 5.7566 hours. The CS3-PDS results are in good agreement.
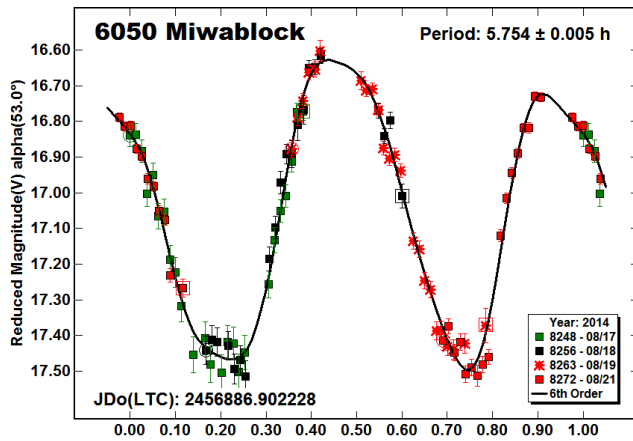
(16636) 1993 QP. A period spectrum covering the range of 5 to 30 hours strongly favored the adopted period of 19.01 hours. However, there was a weaker solution at the half-period of about 9.5 hours that warranted further investigation, especially given the

near symmetry of the 19-hour lightcurve. A *split-halves* plot (see Harris *et al.*, 2014) proves to be a good tool under these circumstances. In the *split-halves* plot, the data are phased to the adopted period but the second half of the cycle is superimposed over the first half.
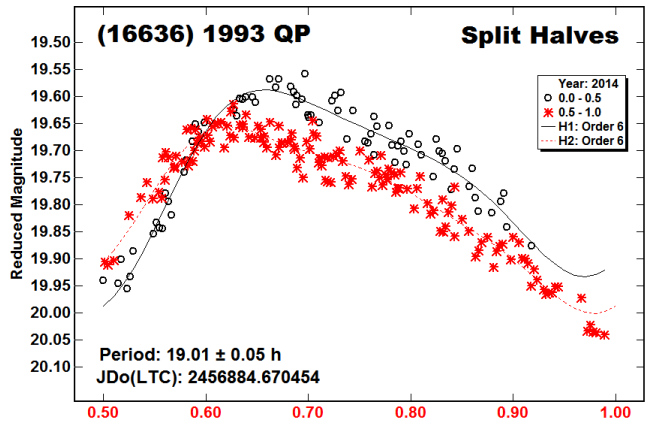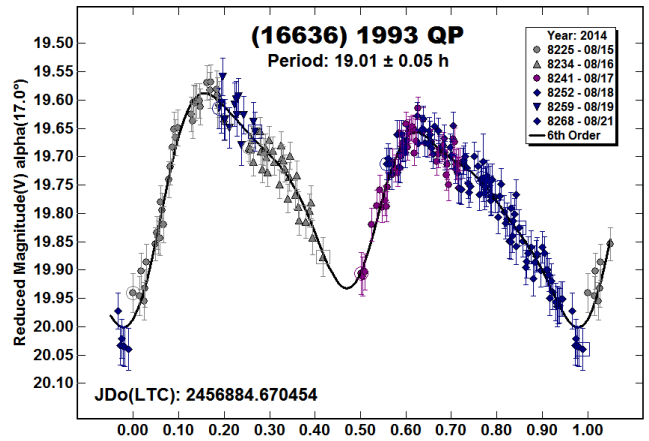
The red data in the plot indicate the second half of the lightcurve. If the two halves are nearly identical, then it is *possible but not certain* that the half-period solution is valid. In this case, the two halves are sufficiently different so that, combined with the difference in RMS fit in the period spectrum, the half-period was safely rejected.

(24443) 2000 OG. The period spectrum for 2000 OG shows a number of nearly equal solutions, the stronger ones being in the range of 4-5 hours. The two lightcurves, phased to those stronger results, show how either solution might be considered correct.

the problem. The result should not be considered likely but not secure and serve as a reference point for future observations.

(54686) 2001 DU8. The large amplitude and low noise make the result of 12.552 h secure.

(85713) 1998 SS49. The period spectrum for 1998 SS49 shows numerous nearly equal solutions. This is another case where a *rotational alias* comes into play.
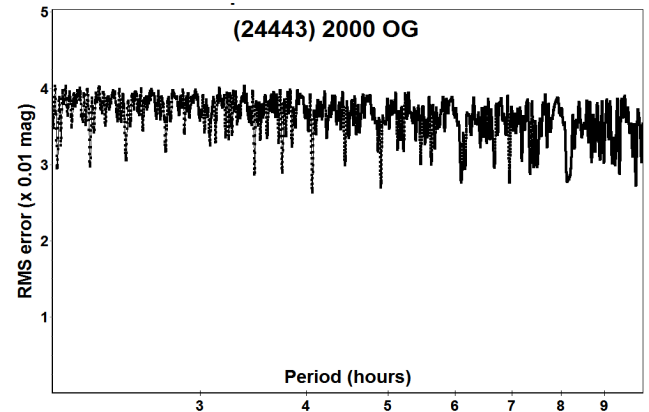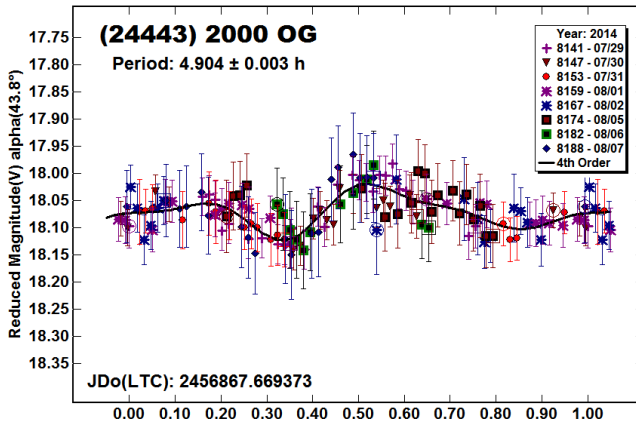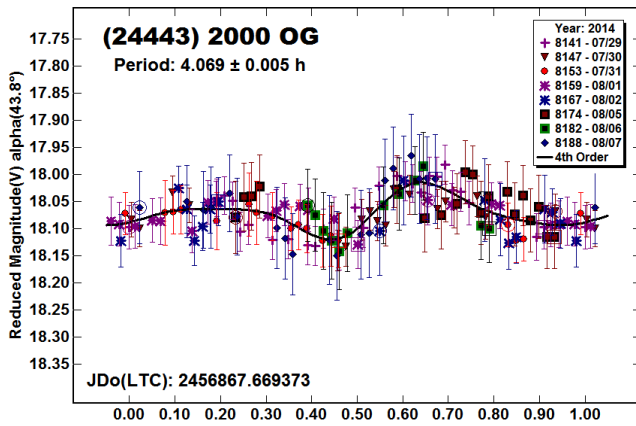
Note that the periods differ by one rotation over a 24-hour cycle. This is sometimes called a *rotational alias*, meaning that there is an uncertainty in the number of rotations over the range of observations. These can often be resolved if the individual observing sessions extend for 1.5 to 2 times the suspected period, or by adding observations from a sufficiently different longitude. In this case, the observing runs were a little less than 4 hours, and thus the rotational alias seen here.

(32814) 1990 XZ. The period of 2.849 h reported here agrees well with previous results from Warner (2007a; 2.8509 h) and Stephens *et al.* (2014; 2.84 h).
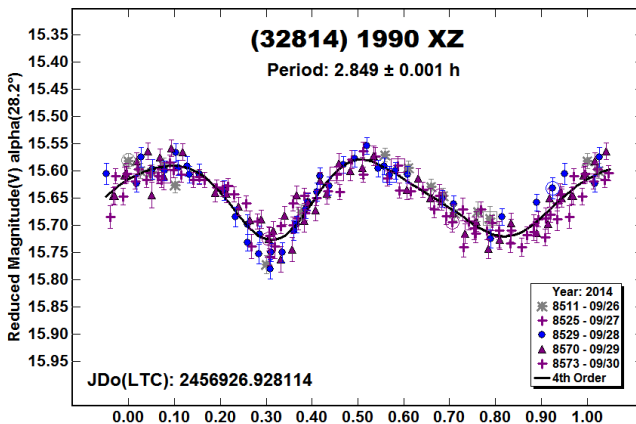
(53110) 1999 AR7. There were no previous results found in the literature for 1999 AR7. The asteroid's magnitude was near the limit of producing usable photometry, as evidenced by the large error bars. However, the amplitude was large enough to overcome

The assumption about a bimodal lightcurve cannot be made in this case for two reasons. First, the amplitude is not so large as to preclude a monomodal shape at smaller phase angles. Second, the relatively high phase angle of about 35° could cause shadowing effects to come into play, thus altering the "normal" lightcurve. See Harris *et al.* (2014) for a discussion of these considerations.

The first lightcurve shows the data phased to a period of 2.686 h. Given the estimated diameter of 1.6 km, this is a reasonable result.

However, since the double period was also possible, the data were forced to a value in the 5-6 hour range, which produced a period of 5.370 hours. A *split-halves* plot for the longer period showed nearly symmetrical halves, meaning that the shorter period is possible, but *not* necessarily certain. There is just enough asymmetry in the split-halves plot that the long period is adopted for this paper, but the short period cannot be excluded.
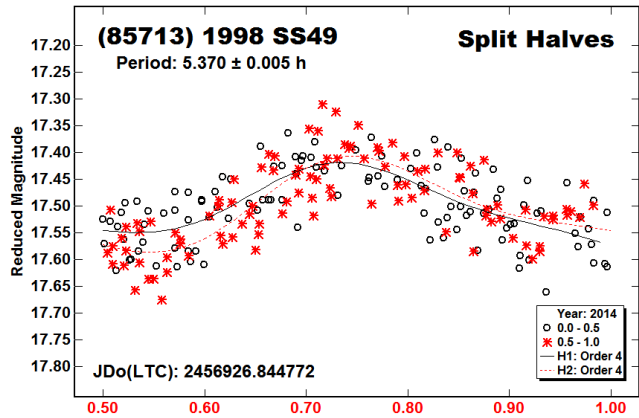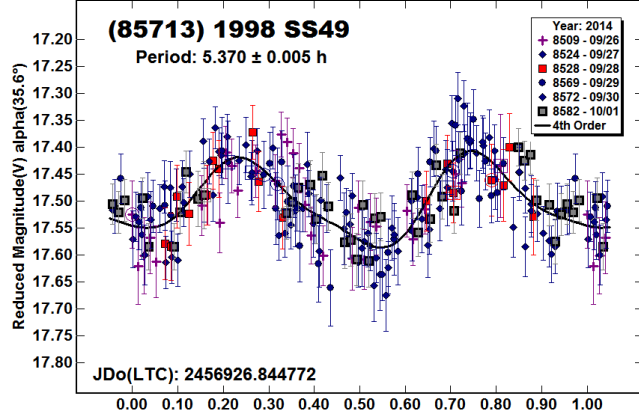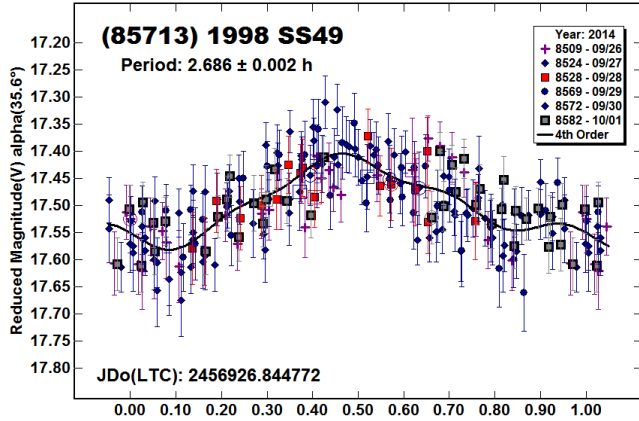
produced the second lightcurve plot, which is far from convincing. It is possible, however, that the longer period is the result of a *fit by exclusion*. This is where the Fourier analysis finds period by minimizing the number of overlapping data points. This is often seen as a gap in the resulting lightcurve. A hint of a gap is seen in the lightcurve for the longer period. It's probable that the short period around 3.02 hours is correct, but other results should not be excluded without the benefit of additional data.
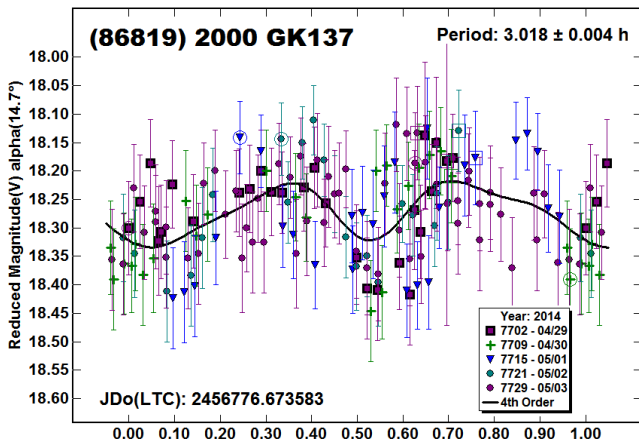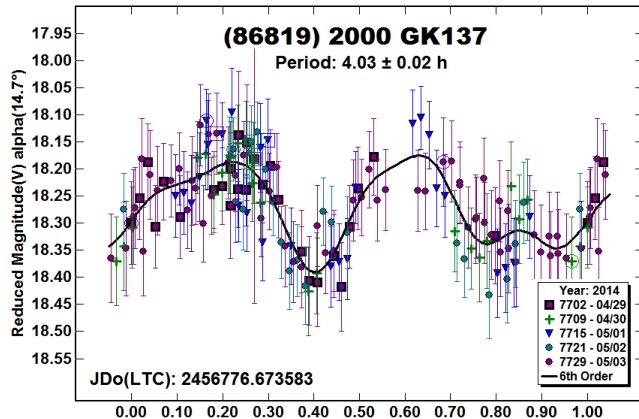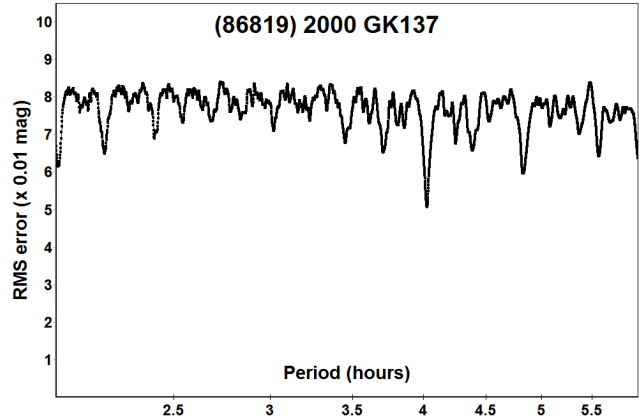
(86819) 2000 GK137. Previous results for this NEA come from Pravec *et al.* (2000) who reported three separate results over a single apparition. From data in 2000 March, they found $P = 3.025$ h, $A = 0.16$ mag, phase angle (α) = 31°. In June, the results were $P = 3.0239$ h, $A = 0.13$ mag, $\alpha = 47°$. In July, they were $P = 3.023$ h, $A = 0.24$ mag, $\alpha = 84°$.

The period spectrum for the 2014 data from CS3-PDS shows a strong solution at 4.03 hours and only a much weaker solution near those earlier results. Attempts to force the period near 3 hours

(87309) 2000 QP. No previous results were found in the literature for 2000 QP. The result is not unique given the low amplitude, slightly unusual shape, and high phase angle where shadowing effects come into play. The period spectrum strongly favors the 2.1 hour period but there is another solution at 2.268 h. Assuming the longer period would make the asteroid a little less "extraordinary" in the sense that the 2.1 hour period is just above the 2.2 hour *spin barrier* separating rubble piles from strength-bound objects, which

is not expected for an object with an estimated size of about 0.9 km. Either period does make the asteroid a good candidate for being a binary, which should be kept in mind at future observations.

(90075) 2002 VU94. This appears to be the first set of lightcurve parameters to be published for 2002 VU94.

(137799) 1999 YB. There are fits for periods of about 8 and 12 hours in the period spectrum for 1990 YB that are not far different from the one for the adopted period of 9.39 hours. A half-period search, with a monomodal lightcurve, for the three periods is dominated by one at 4.7 hours. The 8-hour solution produces a too much of an asymmetrical lightcurve while the 12-hour solution produces a bimodal lightcurve with a large gap. The split-halves plots for 8 and 9.39 hours give even more confidence that the 9.39 hour period is correct.

(143624) 2003 HM16. This NEA was started just before a full moon with the hope that it would have a relatively short period and so could be completed in a few days. The best fit result is a period of 32.1 h and 0.50 mag amplitude.

(154275) 2002 SR41. Benishek (2014) reported a period of 2.75 hours for 2002 SR41. The PDS data cannot be made to fit that period.
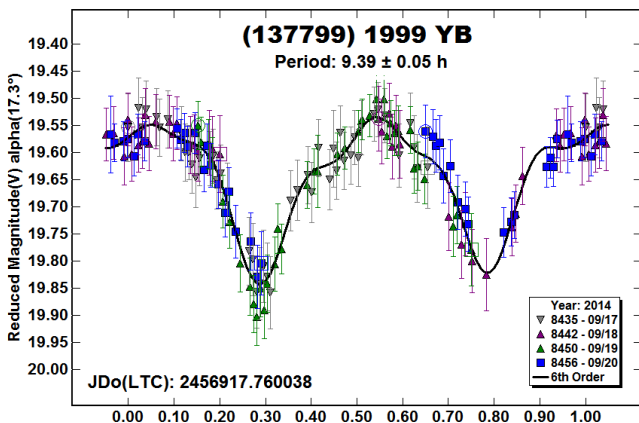
The period spectrum actually favors a period of about 3.4 hours, but this produces an asymmetric trimodal lightcurve.

(159857) 2004 LJ1. Galad et al. (2005) reported a period of 2.7247 h for 2004 LJ1. The PDS data could not be fit to that period and, in fact, the period spectrum slightly favored a period of 3.991 h, which is not considered a likely solution.

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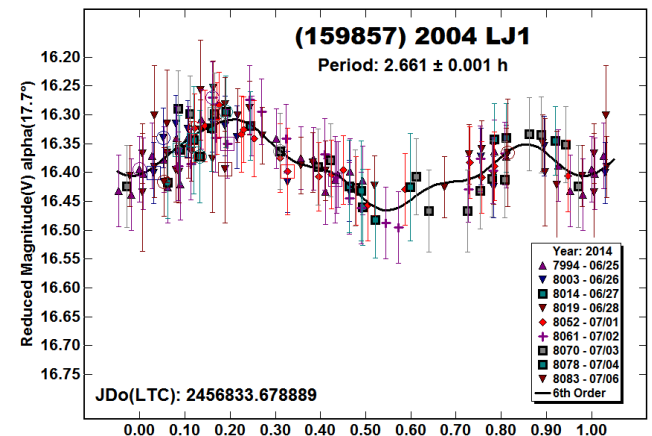
(162980) 2001 RR17. Given the unusual shape of the lightcurve and that the period is nearly commensurate with an Earth day, this period should not be considered secure. If they had been available, data from another longitude might have allowed solving the period with at least some certainty.
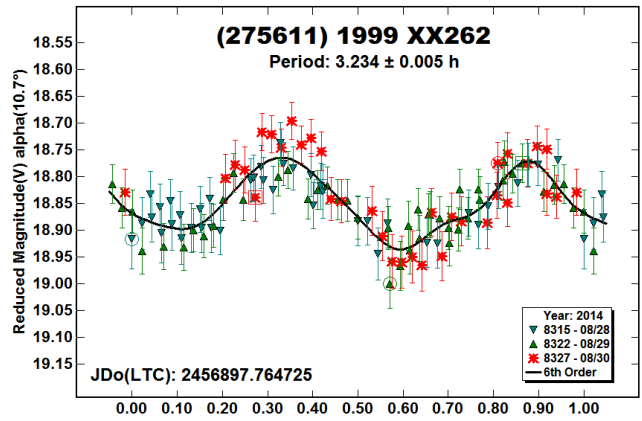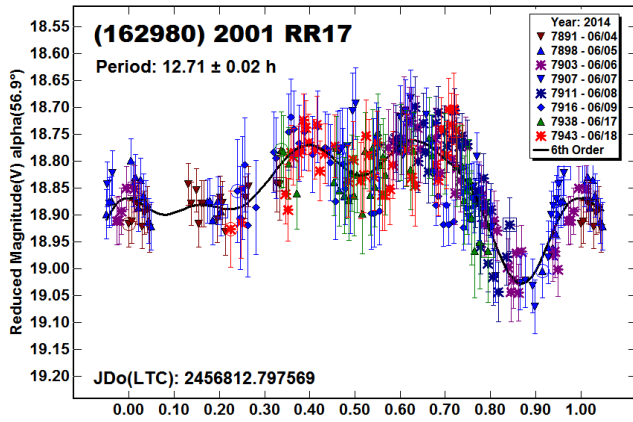
(190166) 2005 UP156. Even though there are gaps in the lightcurve, the four extrema points are at least touched. This makes the solution reasonably secure.

(235086) 2003 HW11. This appears to be the first lightcurve reported in the literature for 2003 HW11.

(275611) 1999 XX262. Two of the nightly runs for 1999 XX263 were longer than the reported period, which made for a relatively quick and secure solution. No previous results could be found in the LCDB.

(277616) 2006 BN6. This NEA was started as it was outbound and fading, meaning that the observing opportunity was short-lived. Unfortunately, the period was close to an integral fraction of an Earth day and so the lightcurve coverage is incomplete and the period solution is less than secure.

(333578) 2006 KM103. This asteroid is an excellent study in lightcurve evolution and for the need to sometimes analyze data sets in parts instead of *en masse*.

The lightcurve above shows the result of a period search using the entire data set. It is a tangled web with several deviations and unusual shape. The results are much different when the data set was divided into two sections, one covering the dates of 2014 Aug 9-14 (α ~ 57°, L_{PAB} ~ 323°, B_{PAB} ~ 34°), and other from Aug 31 - Sep 1 (α ~ 86°, L_{PAB} ~ 14°, B_{PAB} ~ 31°). With such large changes

in the phase angle and phase angle bisector longitude (L_PAB), dramatic changes in the lightcurve were not expected.
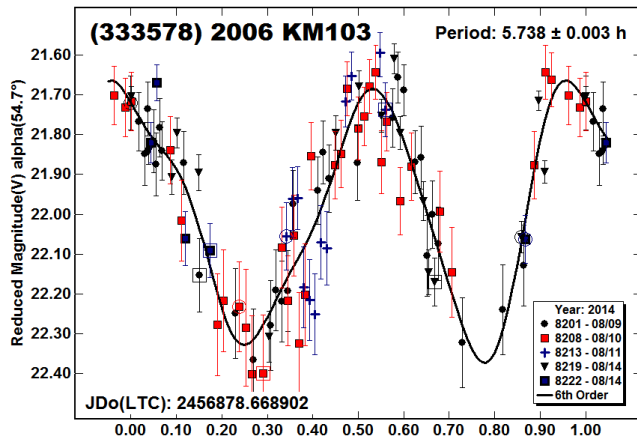
This lightcurve shows the results using the first section of the data set. Here the amplitude is about 0.71 mag and the shape is bimodal.
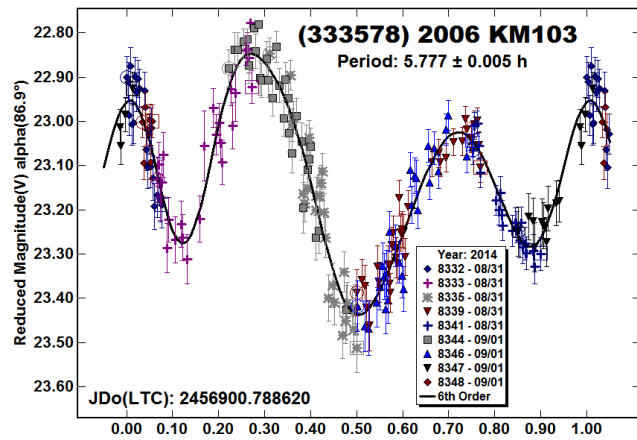
Just two weeks later, at higher phase angles, the lightcurve has evolved into a more complex shape with an amplitude of 0.58 mag. Note that the synodic period has changed. The sidereal-synodic difference from Aug 9 to Aug 20 would be about 0.01 hour, less than seen here. Some of the extra difference might be explained by the shadowing effects at high phase angles and the more complete coverage of the second section lightcurve.

(391033) 2005 TR15.
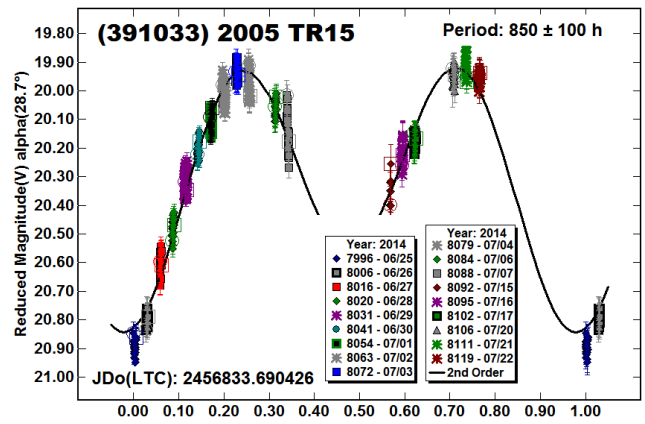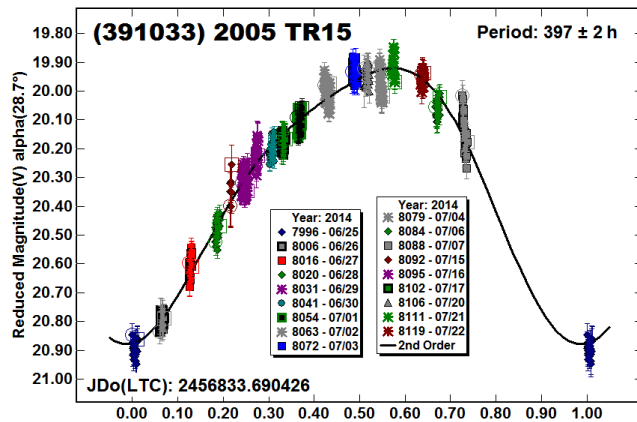
The data set for this asteroid covers almost one month and clearly shows that the asteroid has a long rotation period. The first plot shows an estimated half period solution of about 400 hours. When the solution is forced to something near the double period, the result is 850 ± 100 hours with an amplitude of about 1.0 mag. Since the phase angle is not too large, that and the amplitude make a bimodal solution fairly certain. The period and size of about 0.5 km make this a good candidate for tumbling. However there are no obvious signs of such since the slopes of the individual sessions seem to be in-line with the slopes of the Fourier curve.

(398188) 2010 LE15.
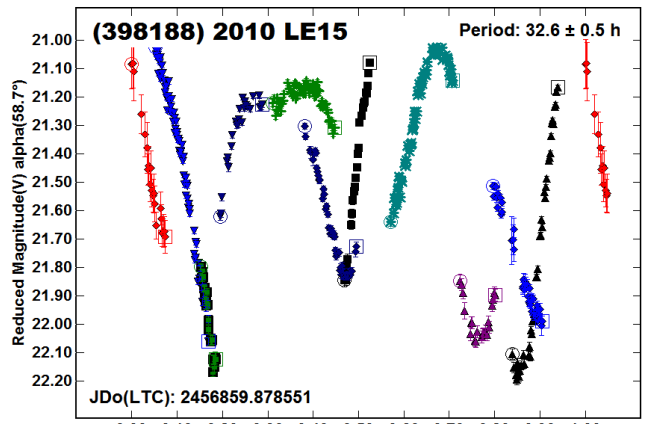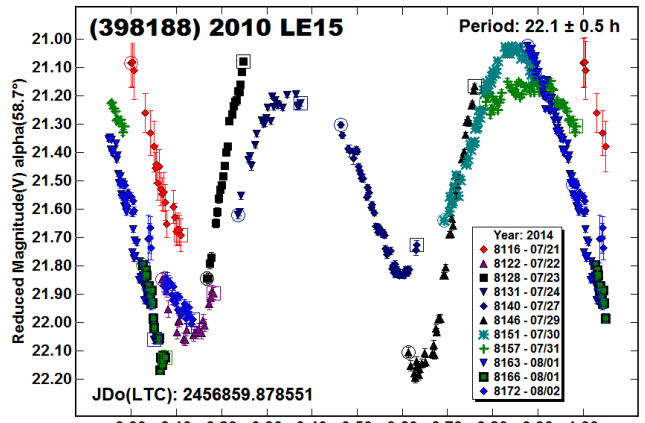
These lightcurves for 2010 LE represent the *MPO Canopus* rendering of the data using two possible periods found by Petr Pravec (personal communications) for a tumbling asteroid. It is

rated as PAR = –2 on the scale developed by Pravec *et al.* (2005). The solution is not unique, with several other linear combinations of integral multiples of the rotation and precession *frequencies* being possible. See the Pravec *et al.* paper for a detailed discussion.

(401998) 2003 MO**.** There were two solutions that stood out in the period spectrum. The longer one of 50 h is adopted here.
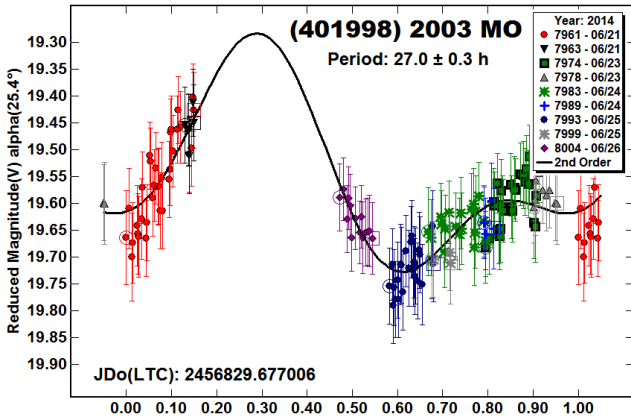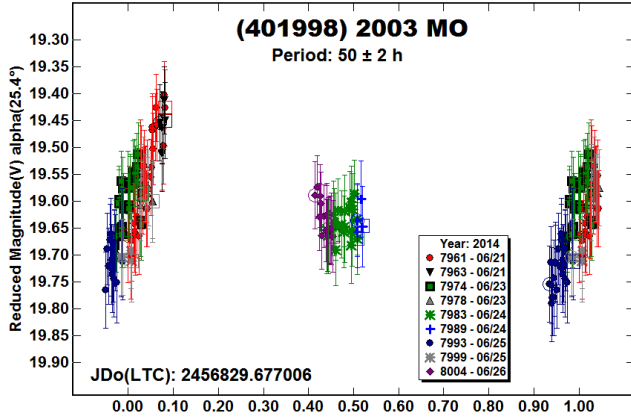
1987 SF3. There were two likely periods for 1987 SF3. A monomodal solution had a period of 21.0 ± 0.5 hours while the bimodal solution was 42.0 ± 0.5 hours. The *split-halves* plot for the longer period is very symmetrical, making the shorter period possible. The amplitude is not quite large enough to assume a bimodal solution (Harris *et al.*, 2014). The shorter period is adopted for this paper but the longer period cannot be excluded.
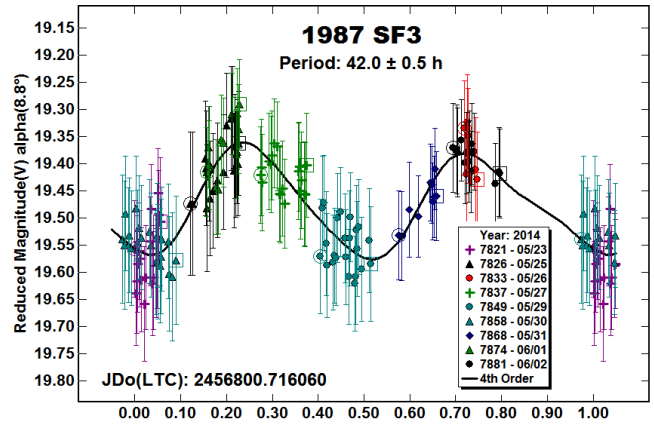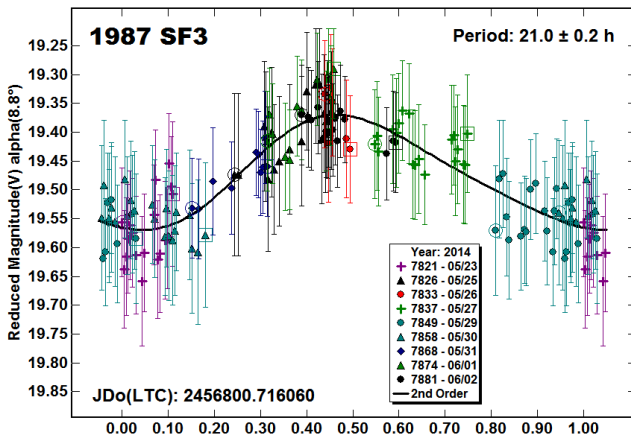
1994 CJ1. Radar observations (Patrick Taylor, personal communications) determined that this is a binary asteroid consisting of two closely-separated bodies. The circumstances were not good to observe the asteroid, but an effort was made nonetheless. The lightcurve shows the data forced to the synchronous system's estimated period of 30 hours. It appears that one of the expected deep events as one body eclipses the other was captured on 2014 July 3. All other observations were when both bodies were visible. Still, the other sessions do fit with the Fourier model lightcurve, e.g., showing the end of the first eclipse event and the start of the second.
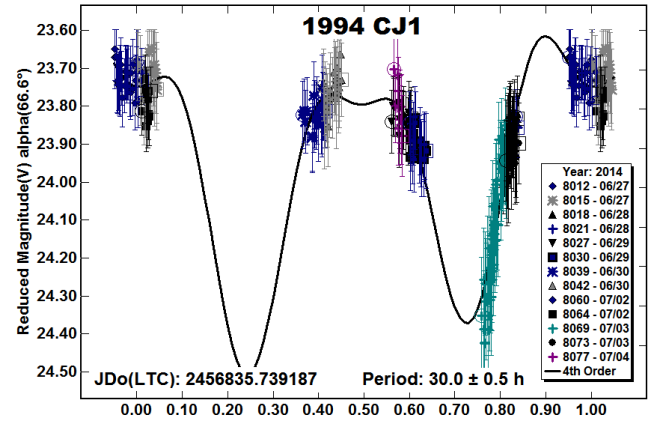
2001 MF1. Previous results for 2001 MF1 include Krugly *et al.* (2002; 6.572 h) and Pravec *et al.* (2001; 6.569 h). The results from PDS in 2014 are in good agreement with those results.
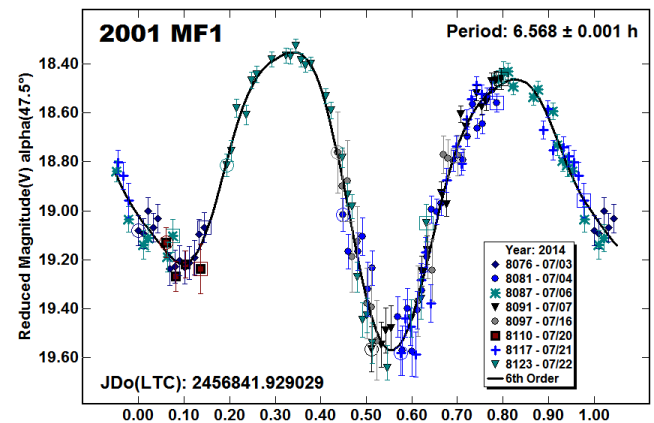
2002 RB126. The period spectrum for 2002 RB126 shows several nearly likely solutions, one of 8.08 hours and the other at 16.21 hours. The split-halves plot for the longer period shows nearly symmetrical halves, so the 8 hour solution is possible. Even so, the longer period is adopted for this paper while noting that the short period cannot be excluded.

changing the zero point values for both sessions by an equal amount in the same direction. While the noise was significant, it was still possible to determine a period of 42.5 ± 0.5 h for the lightcurve.

2012 TS. The period for this NEA makes it a good binary candidate. No indications of a satellite were seen. High-precision observations in the future are encouraged.
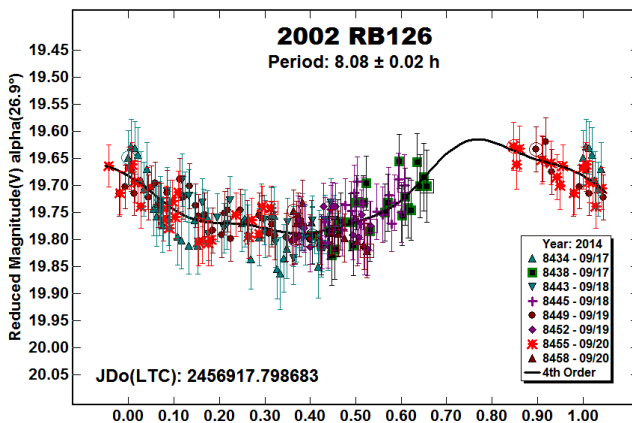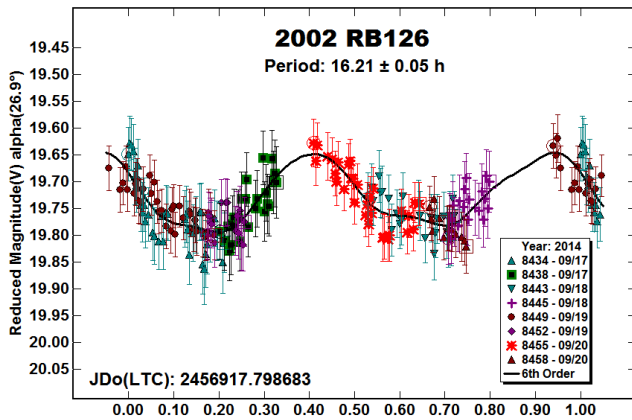
2003 EG16. This appears to be the first published set of lightcurve parameters for 2003 EG16.
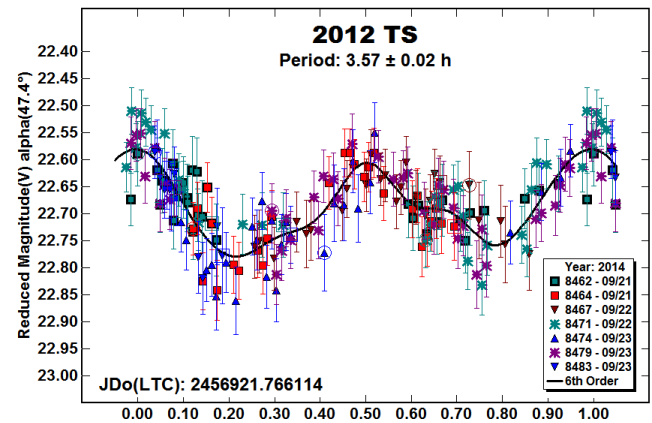
2013 XM24. The raw lightcurve for 2013 XM24 shows a chaotic path that is often seen with a *tumbler*, i.e., the lightcurve tries to be singly-periodic but doesn't quite manage to do so.

2008 OB9. The sky motion for 2008 OB9 in mid-September 2014 was large enough so that it was necessary to split each night of observing into two sessions. To facilitate zero point adjustments under such circumstances, the last five images in the first session were measured again for the start of the second session. These five anchor points were used to set the zero point of the second session to match that of the first. Any subsequent adjustments involved

Petr Pravec (personal communications) analyzed the data set and found several solutions sets, i.e., a period of rotation for the body and the period of precession of the spin axis. With data from only one station and the long periods, it is not possible to reach a definitive solution. The true results may be different linear combinations of the integral multiples of entirely different *frequencies* for the rotation and precession. The plots from *MPO*

Canopus show the data forced to the periods found by Pravec. It is not possible to say which is the one due to rotation and the one due to precession of the spin axis.
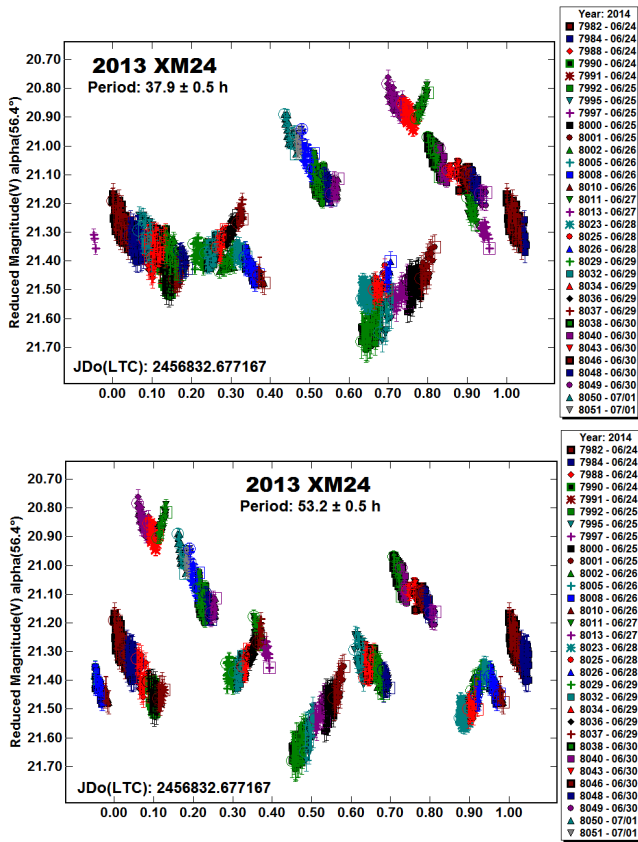
2013 WT67. This was another case where the Fates conspired against the observer. This was started as an early-evening object while waiting for another asteroid to rise. As such, the runs were 3 hours or less. Given that each session showed a slight rise or fall, the likelihood of a short period was discounted. There is always the danger, however, of a modest period, P < 48 hours, and that what is seen in a phased plot as steadily rising data on a long period solution may actually be of seeing just a little to the left or right along the rotation phase axis of a shorter period. With enough data, the true period comes to light.
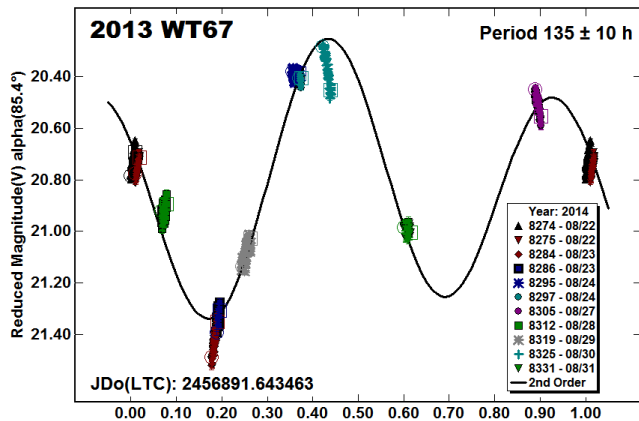
Even when taking this possibility into account, any solution that was found showed the tell-tale signs of a tumbling asteroid in that the slope of one or more sessions was contrary to the Fourier

model curve at that point. Petr Pravec (personal communications) found a main period of about 70 hours with possible signs of tumbling. However, it could not be ruled out that the deviations were due to the natural evolution of the lightcurve due to rapidly changing viewing aspect. The period shown here happens to be about double the period found by Pravec; it should not be considered definitive.

2014 SS1. The asymmetrical shape of the lightcurve for 2014 SS1 was of some concern. In the end, no other period, with or without zero point adjustments of reasonable amounts, found a solution that was worth noting.
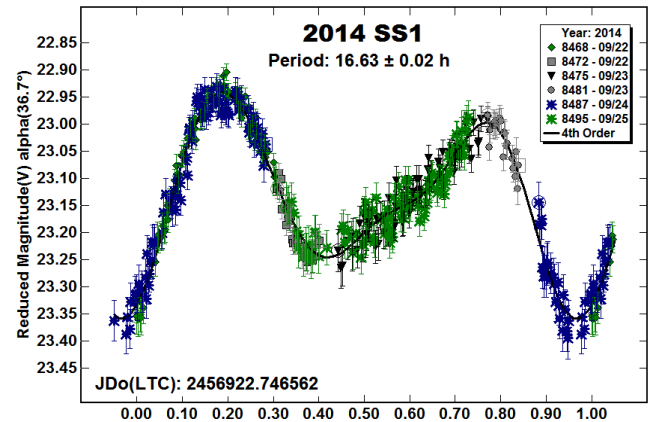
2014 QO33. No previously reported lightcurve was found in the literature for 2014 QO33.
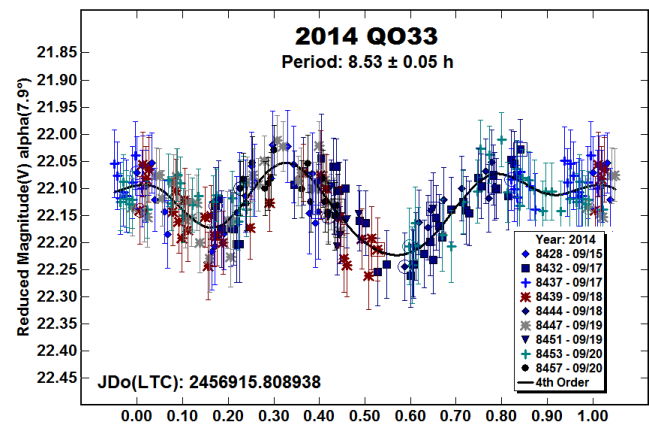
The period spectrum showed a few other significantly weaker solutions. The results to plot the data to those periods were entirely unconvincing.

2014 PR62. At first glance, the plot with a period 16.42 hours seems fairly symmetrical, which would raise the possibility that the half-period of about 8.2 hours was possible. The *split-halves* plot shows that this is not likely. On the other hand, the period spectrum covering from 5 to 30 hours found an almost equally likely solution at about 18.1 hours. The spectrum shown here covers the range from 10-20 hours to show the two solutions more clearly. Very minor adjustments of the zero points, 0.01-0.03 mag, changed the preferred solution from the shorter to the longer or vice versa. The shorter period of 16.42 h is adopted for this paper despite the small gaps in coverage and the fact that a bimodal solution is not certain singe the amplitude is only 0.17 mag (Harris *et al.*, 2014).

2014 PR62

2014 PR62
Period: 16.42 ± 0.04 h

2014 PR62
Period: 18.08 ± 0.03 h
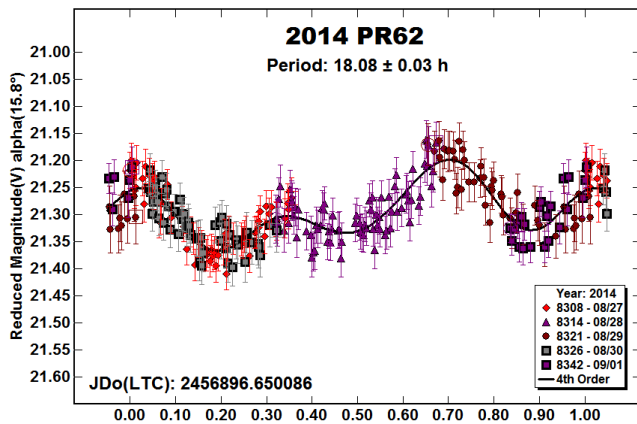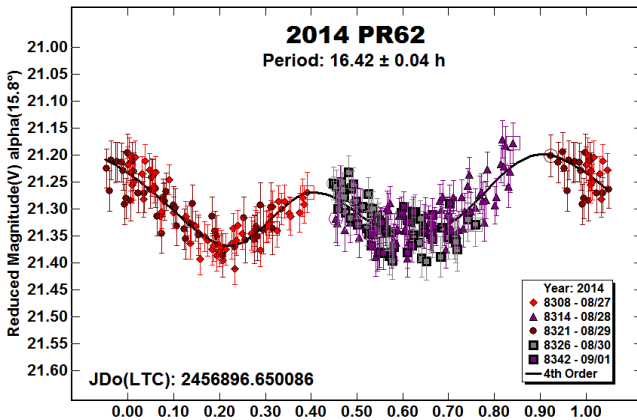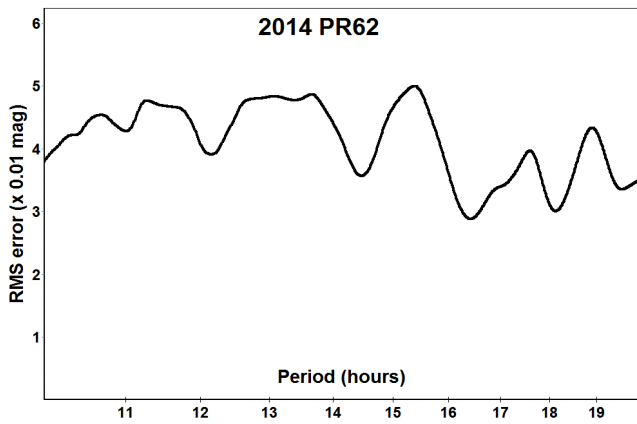
2014 NE63. This appears to be the first published lightcurve.

2014 NE63
Period: 4.11 ± 0.05 h
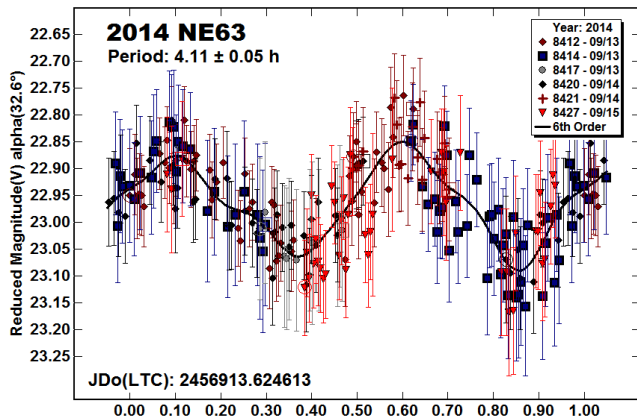
2014 OT111. This is another case where the period spectrum showed a number of possible solutions. The two most likely are plotted in the lightcurves with the longer period of 19.41 h adopted for this work. This is based on the relatively low phase angle and the amplitude of 0.23 mag. While not quite to the level where a bimodal solution is almost certain, the longer solution seems the better choice. However, the half-period at 9.71 h cannot be formally excluded.

2014 OT111
Period: 19.41 ± 0.03 h

2014 OT111
Period: 9.71 ± 0.05 h
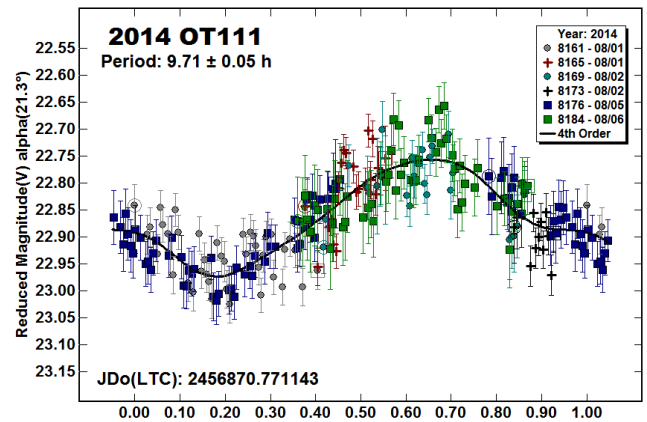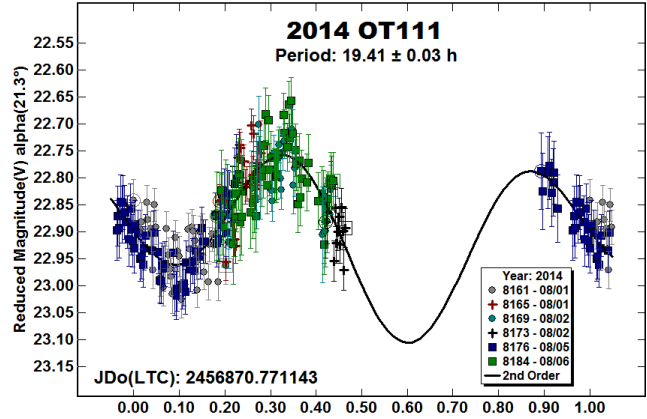
2014 SZ144. Exposures of 10 sec were used for 2014 SZ144 to avoid excessive trailing. Unfortunately, this resulted in a very low SNR for the asteroid. Despite all efforts, it was not possible to find a period for 2014 SZ. The raw plot of the data shows no obvious signs of periodic behavior. The period spectrum covering a range of 0.001 to 10 hours is essentially flat.

2014 SZ144   **Raw Plot**
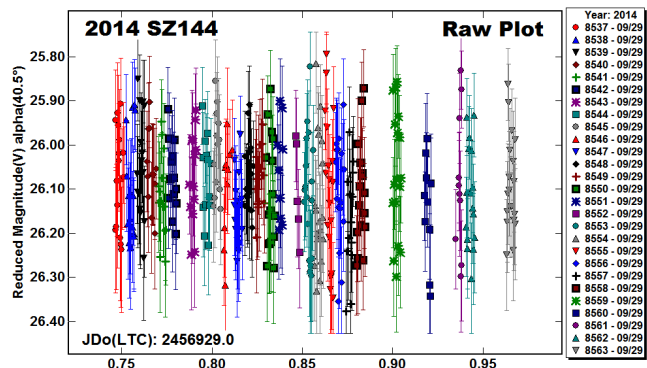
In the case of potentially super-fast rotators, a possible explanation for the lack of results is that the exposures were too long and so the rotation data were "smeared" beyond recognition. This concept

Number	Name	2014 mm/dd	Pts	Phase	L_PAB	B_PAB	Period	P.E.	Amp	A.E.
1917	Cuyo	07/17-07/22	104	26.0,27.4	254	31	2.72	0.001	0.11	0.02
1943	Anteros	09/10-09/13	51	46.0,45.6	296	13	2.735	0.003	0.22	0.02
4401	Aditi	08/28-08/31	109	33.0,32.9	24	-11	6.683	0.005	0.64	0.05
6050	Miwablock	08/17-08/21	98	53.0,53.3	23	-10	5.754	0.005	0.87	0.03
16636	1993 QP	08/15-08/21	230	17.1,21.3	313	9	19.01	0.05	0.41	0.03
24443	2000 OG	07/29-08/07	149	43.8,51.3	267	40	4.069	0.005	0.11	0.02
32814	1990 XZ	09/26-09/30	172	28.2,26.8	45	-13	2.849	0.001	0.15	0.02
53110	1999 AR7	06/04-06/20	235	33.0,32.7,33.0	230	29	50.4	0.3	0.37	0.03
54686	2001 DU8	07/29-08/16	203	25.5,16.0	337	14	12.552	0.005	0.9	0.05
85713	1998 SS49	09/26-10/01	220	35.6,35.9	49	-3	5.370	0.005	0.18	0.03
86819	2000 GK137	04/29-05/03	157	14.7,17.6	206	13	4.03	0.02	0.24	0.02
87309	2000 QP	07/04-07/16	159	43.2,30.1	315	6	2.1651	0.0002	0.1	0.01
90075	2002 VU94	08/05-08/15	168	42.4,38.1	14	10	7.88	0.01	0.62	0.03
137799	1999 YB	09/17-09/20	157	17.4,14.7	8	-8	9.39	0.05	0.31	0.03
143624	2003 HM16	09/02-09/06	172	59.9,57.1	306	53	32.1	0.5	0.5	0.03
154275	2002 SR41	06/21-06/24	165	44.7,41.8	253	20	2.283	0.002	0.1	0.01
159857	2004 LJ1	06/26-07/06	138	18.3,23.3	244	10	2.661	0.001	0.15	0.02
162980	2001 RR17	06/04-06/18	266	56.9,49.5	276	56	12.71	0.02	0.23	0.02
190166	2005 UP156	08/09-08/22	269	47.5,39.3	6	4	40.5	0.1	0.79	0.03
235086	2003 HW11	09/25-09/27	135	18.4,17.0	20	-9	6.385	0.003	0.8	0.03
275611	1999 XX262	08/28-08/30	119	10.7,9.1	346	2	3.234	0.005	0.16	0.02
277616	2006 BN6	08/17-08/21	94	50.5,47.2	295	35	5.45	0.03	0.31	0.03
333578	2006 KM103	08/09-08/14	101	54.7,59.1	323	34	5.737	0.003	0.71	0.03
333578	2006 KM103	08/31-09/01	217	87.1,89.5	14	31	5.777	0.005	0.58	0.03
391033	2005 TR15	06/26-07/22	508	29.1,32.3	266	12	850	100	1.0	0.1
398188	2010 LE15	07/21-08/02	454	58.7,57.4,57.9	336	9	21.99	0.05	1.12	0.05
401998	2003 MO	06/21-06/26	139	25.5,34.7	253	19	50	2	0.4	0.05
	1987 SF3	05/23-06/02	143	8.8,17.8	235	6	21	0.2	0.2	0.02
	1994 CJ1	06/27-07/04	232	66.6,53.5	248	16	30	0.5	0.8	0.05
	2001 MF1	07/04-07/22	136	47.9,54.8	341	20	6.568	0.001	1.22	0.03
	2002 RB126	09/17-09/20	205	27.0,21.1	16	-2	16.21	0.05	0.14	0.02
	2003 EG16	08/22-08/24	321	66.5,58.6	7	-10	7.079	0.005	1.38	0.05
	2008 OB9	09/10-09/15	537	43.7,48.6	24	13	42.5	0.5	0.34	0.05
	2012 TS	09/21-09/23	193	47.4,43.8	24	12	3.57	0.02	0.2	0.03
	2013 XM24	06/24-07/03	1325	55.9,23.2	267	18	37.9	0.5	0.8	0.05
	2013 WT67	08/22-08/31	752	85.7,102.1	293	35	135	10	1.1	0.1
	2014 SS1	09/22-09/25	399	36.7,36.9	21	1	16.63	0.02	0.43	0.02
	2014 QO33	09/15-09/20	219	7.8,11.0	352	5	8.53	0.05	0.17	0.03
	2014 PR62	08/27-09/01	255	15.8,18.3	329	8	A16.42	0.04	0.17	0.05
	2014 NE63	09/10-09/15	250	30.1,0.0,34.5	282	13	4.11	0.05	0.2	0.05
	2014 OT111	08/01-08/06	226	21.3,19.8	322	5	19.41	0.03	0.3	0.05
	2014 SZ144	09/29-09/29	388	43.7,43.7	28	0	ND		ND	
	2014 SX261	09/29-09/30	328	27.3,25.4	21	-4	2.804	0.005	0.33	0.05
	2014 OX299	08/05-08/07	76	18.2,23.7	304	10	40.5	2	0.37	0.05
	2014 OZ337	08/05-08/08	149	18.9,16.8	324	0	85	5	0.43	0.05

Table II. Observing circumstances. APreferred period for an ambiguous solution. Pts is the number of data points used in the analysis. The phase angle (α) 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_PAB and B_PAB are, respectively the average phase angle bisector longitude and latitude, unless two values are given (first/last date in range). In the period and amplitude columns, "ND" means "not determined".

was explored in detail by Pravec et al. (2000) where they determined that to avoid smearing the data, the exposure must be $E < 0.187P$, where P is the period in the same units of the exposure. Using the Pravec et al. rule of thumb, the 10-second exposures required the rotation period to be about 60 seconds or more.

There are asteroids with periods shorter than 1-minute, but they are rare: the LCDB lists only 8 objects with $P < 1$ minute. The estimated diameter of 2014 SZ144 is 30 meters, which makes it highly probable that it is a super-fast rotator and, so it's possible, but considered not likely, that *rotational smearing* could explain the lack of periodic behavior in the data.

2014 SX261. The period of 2.804 hours is considered secure and makes the asteroid a good binary candidate should the opportunity for photometry arise again. The amplitude of 0.33 mag for a binary's primary is not common but possible, e.g., 1727 Mette (Warner et al., 2013)

2014 SX261 — Period: 2.804 ± 0.005 h
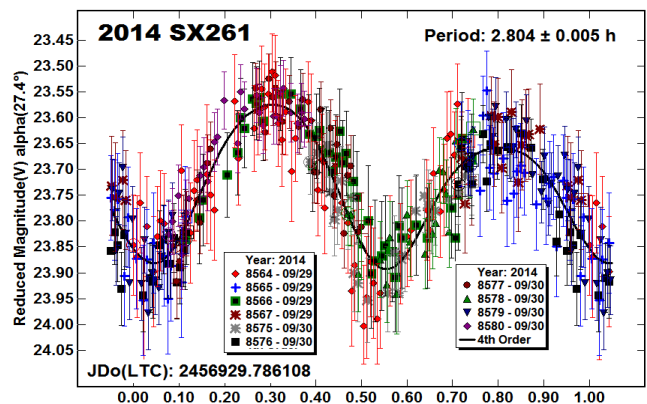
__2014 OX299, 2014 OZ337.__ Both of these asteroids were within reach of the PDS telescopes for only a few days. Obviously, this was not enough time to find a reliable period for either one.
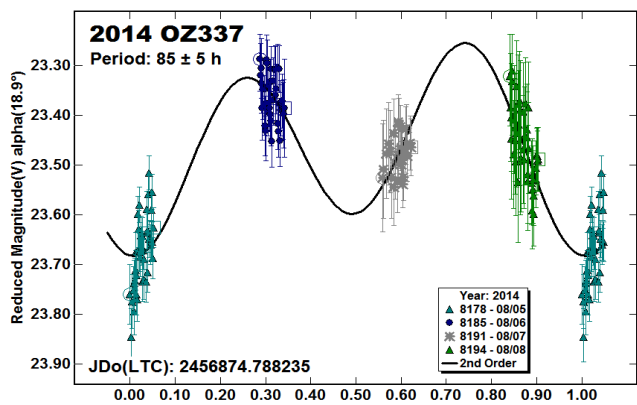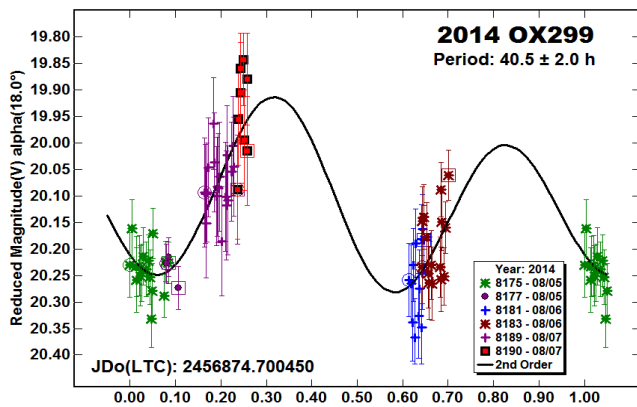
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ASTEROID LIGHTCURVE ANALYSIS AT CS3-PALMER DIVIDE STATION: 2014 JUNE-OCTOBER

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Lightcurves for 24 main-belt asteroids were obtained at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2014 June through October. Some objects were members of the Hungaria orbital group or collisional family, observed as follow-up to previous apparitions to check for undiscovered satellites, to improve previous binary discovery parameters, or to obtain data for spin axis and shape modeling.

CCD photometric observations of 24 main-belt asteroids were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) in 2014 June through October. 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 done using *MPO Canopus*. If necessary, an elliptical aperture with the long axis parallel to the asteroid's path was used. 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 MPOSC3 catalog, which is based on the 2MASS catalog (*http://www.ipac.caltech.edu/2mass*) but with magnitudes converted from J-K to BVRI using formulae developed by Warner (2007). When possible, magnitudes are taken from the APASS catalog (Henden *et al.*, 2009) since these are derived directly from reductions based on Landolt standard fields. Using either catalog, the nightly zero points have been found to be consistent to about ± 0.05 mag or better, but on occasion are as large as 0.1 mag. This consistency is critical to analysis of long period and/or tumbling asteroids. Period analysis is also done using *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*log (rΔ) to the measured sky magnitudes with r and Δ 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°), 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 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.

Individual Results

1103 Sequoia. There are numerous entries for this Hungaria asteroid in the LCDB. The period reported here is in good agreement with the previous results. The data from the 2014 apparition were combined with those from 2011 (Warner, 2012) and sparse data from the Catalina Sky Survey and USNO-Flagstaff to generate a spin axis model (Warner, in preparation). The result indicates retrograde rotation, which agrees with the finding by Hanus *et al.* (2011).
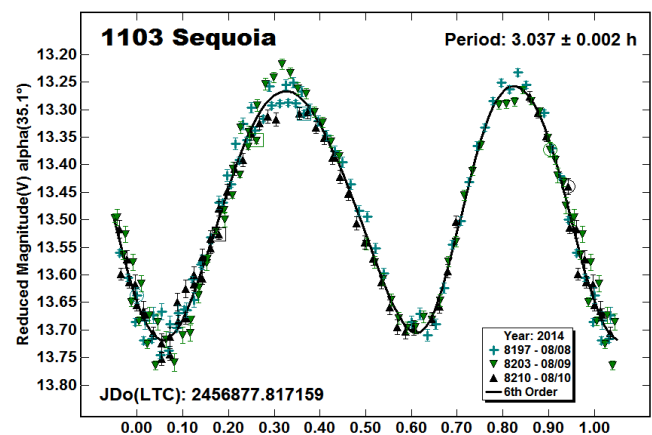
1823 Gliese. Gliese was observed at CS3 as part of a test of one of the CS3 telescope/camera systems and reduction methods. The results were compared to those reported by Pravec *et al.* (2014) and found to be in close agreement, enough so to confirm that there were no significant systematic problems with the CS3 system or methods.

5841 Stone. This is another multiple-apparition Hungaria for the author, 2014 being the fourth set of observations. The period in all four cases was found to be close to 2.890 hours. Even with a number of dense lightcurves and sparse data, the spin axis modeling produced highly ambiguous results (Warner, in preparation).
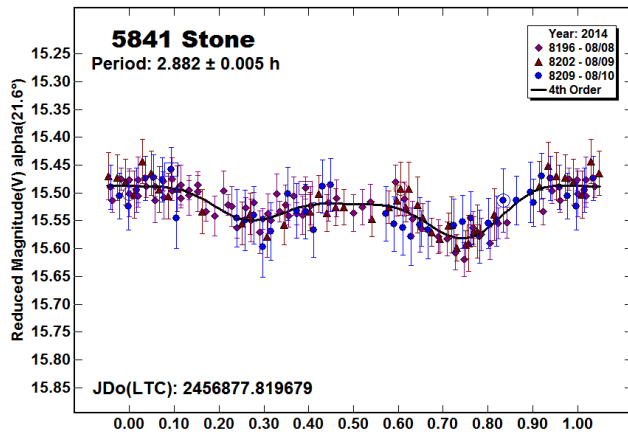
(6394) 1990 QM2. The period of 3.686 h reported here is in good agreement with previous findings by the author (e.g., Warner, 2013a). Spin axis modeling reliably establishes retrograde rotation (Warner, in preparation).
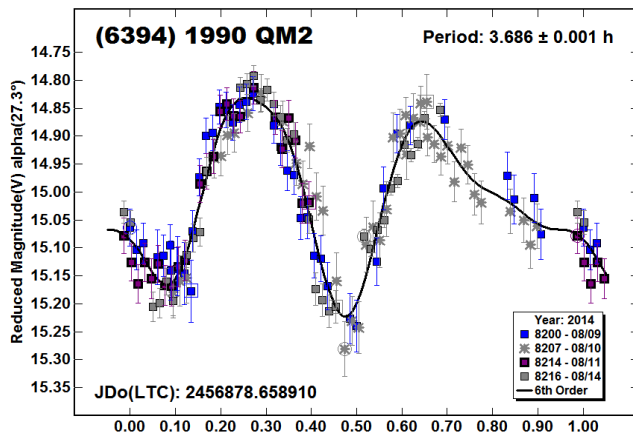
(7660) 1993 VM1. Spin axis modeling (Warner, in preparation) using data from 2014 and two previous apparitions (Warner, 2012; Stephens *et al.*, 2014) establishes a retrograde rotation for this Hungaria.
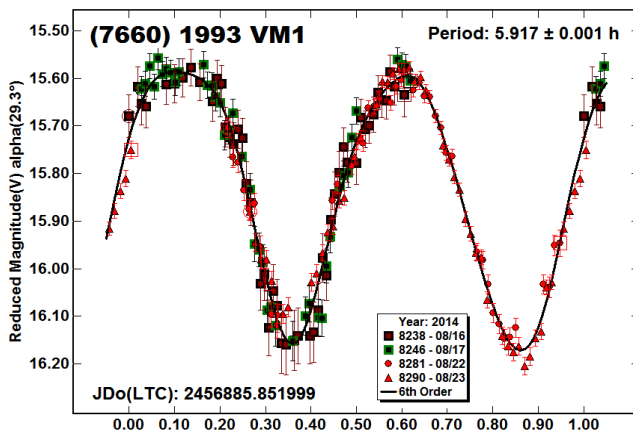
8024 Robertwhite. The period previously reported by the author (Warner, 2013b; 7.067 h) and the one here are in close agreement.
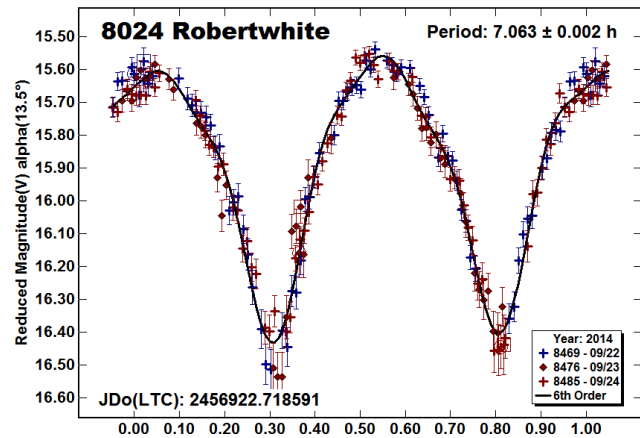
16641 Esteban. While the lightcurve coverage is not complete, the four extrema were well-defined for this Phocaea member, thus making for a secure period of 79.62 h.
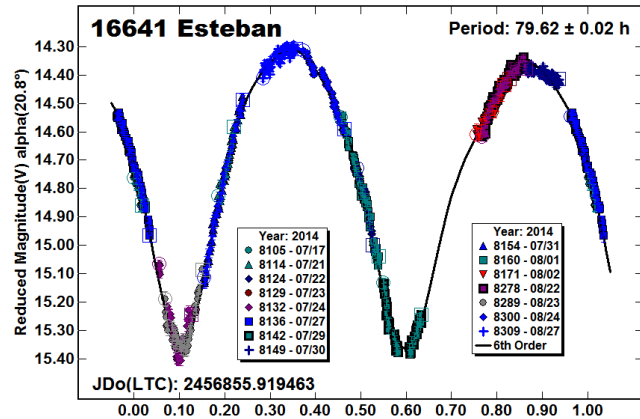
(27713) 1989 AA. With a period of almost exactly 4 hours, combined with short northern summer nights, it took several sessions to secure a period of 4.002 h. This is in close agreement with the previous result of 3.999 h (Warner, 2013a). Spin axis modeling (Warner, in preparation) was able to establish that the pole is close to the ecliptic plane. Not unexpectedly, this meant that the pole longitude was ambiguous, being close to 0° or 180°.
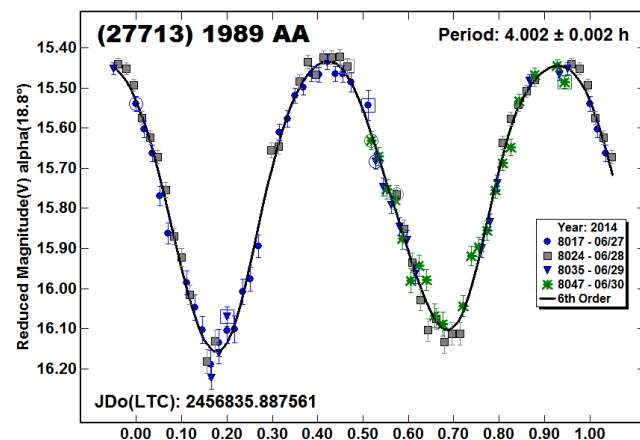
(29242) 1992 HB4. The period found using the 2014 data is in good agreement with that found at three previous apparitions (e.g., Warner, 2013a).
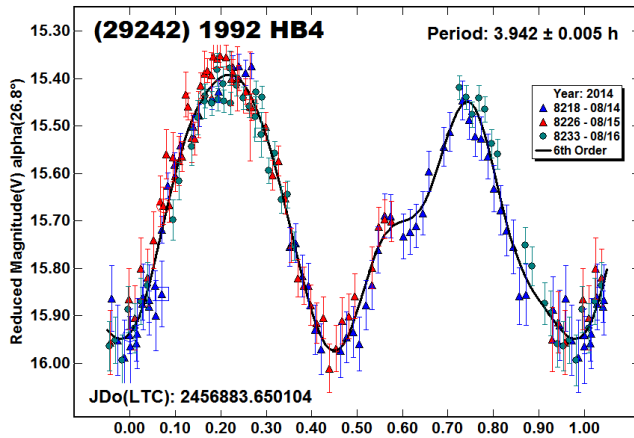
(33324) 1998 QE56. The previous result (Warner, 2011) and that from 2014 are in good agreement. Given the high albedo, p_V = 0.635 (Masiero *et al.*, 2011), 1998 QE56 is very likely a member of the Hungaria *collisional family* and not just the *orbital group*.
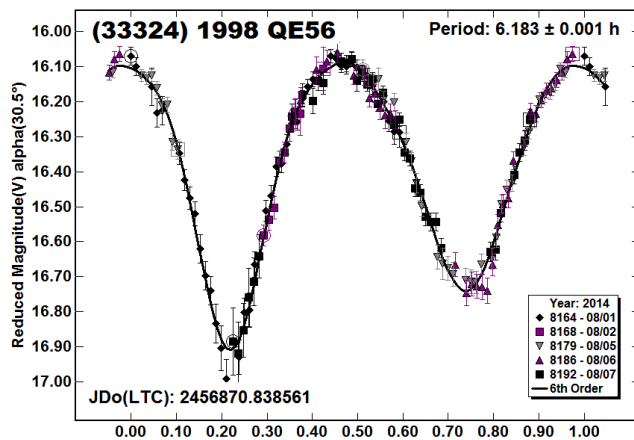
35087 von Sydow. This was the first apparition at which this Hungaria was observed by the author. The period of 36.1 h is somewhat uncertain because of the incomplete coverage, including none at the second minimum near 0.65 rotation phase. Follow-up observations are planned for the next favorable apparition.
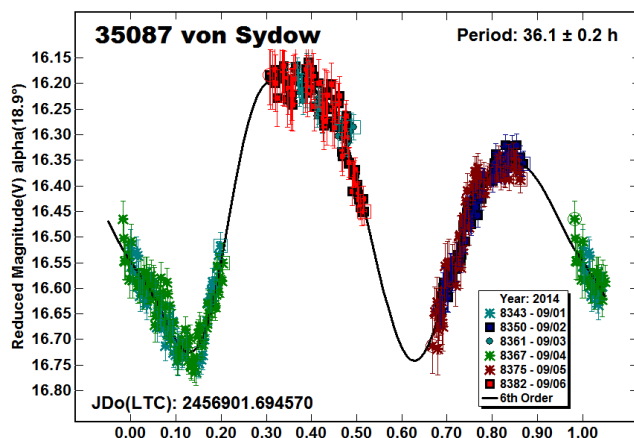
(38047) 1998 TC3. The period agrees with earlier results (e.g., Warner, 2011). This was the author's fourth apparition for this Hungaria.
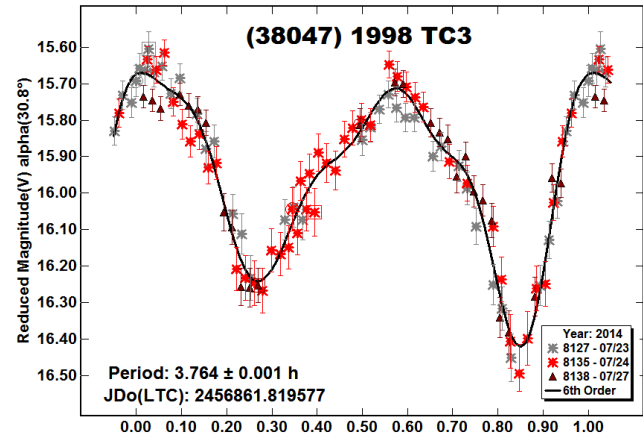
Spin axis modeling (Warner, in preparation) found a retrograde pole of about –80°. As might be expected with such a low obliquity, the pole longitude is highly ambiguous, i.e., nearly equal solutions were found from 0° to 360°.

(53424) 1999 SC3. There were no previously reported periods found in the LCDB for this Hungaria. The low amplitude makes the solution somewhat uncertain. With luck, a future apparition will show a larger amplitude and result in a secure period.
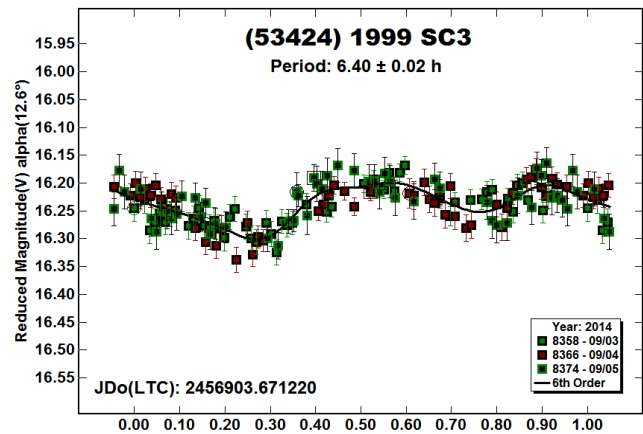
(64107) 2001 TK8. There is a chance that this Hungaria is in non-principal axis rotation (NPAR; see Pravec *et al.*, 2005). This is indicated by the way the slopes of individual sessions don't always match the outline of the Fourier model.
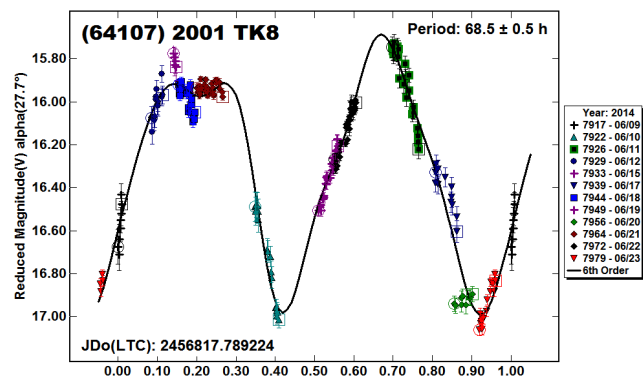
(67404) 2000 PG26. The results from 2014 agree almost exactly with those found in 2011 (Warner, 2012).
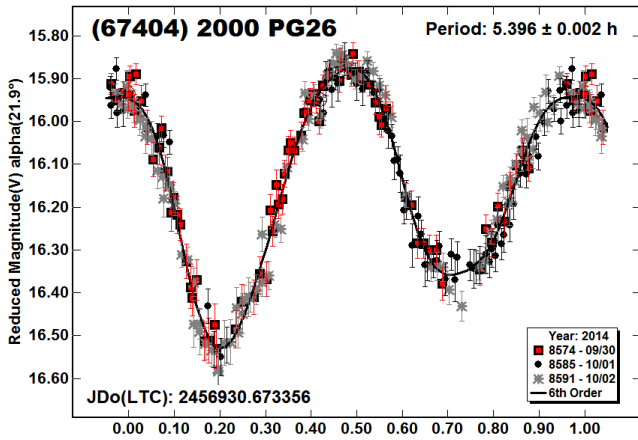
(68537) 2001 VC123. This asteroid is also a likely member of the Hungaria *collisional family* based on the reported albedo (Masiero *et al.*, 2011). The results are nearly identical to those previously found by the author (Warner, 2013a).
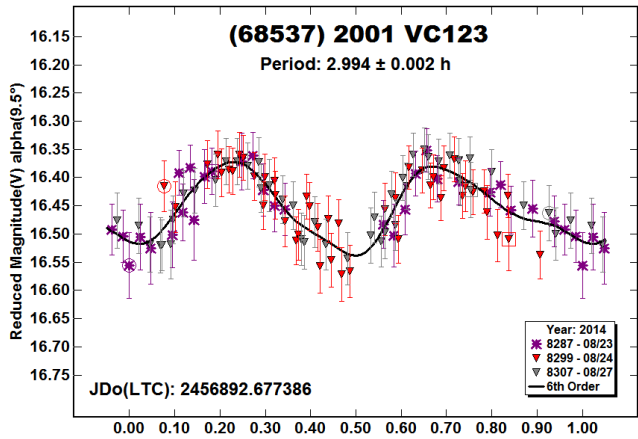
96327 Ullmann. When first observed by the author (Warner, 2011), a period of 7.78 hours was reported. Analysis of the 2014 data favored a period of 3.639 hours.
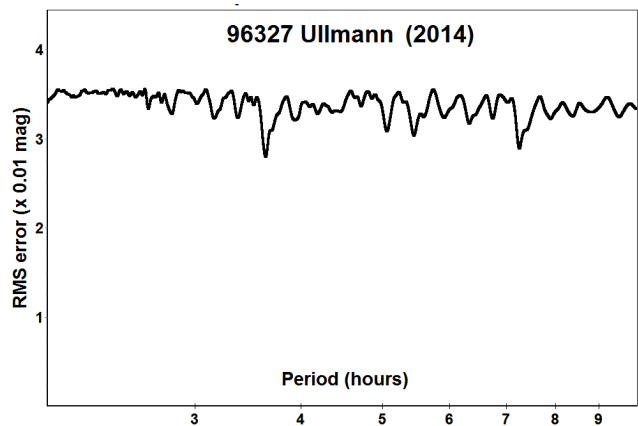
The 2011 data were re-examined and found to support a solution of 3.625 h. The low amplitude at both apparitions as well as the relatively low signal-to-noise (SNR) in 2014 makes any of the solutions ambiguous.
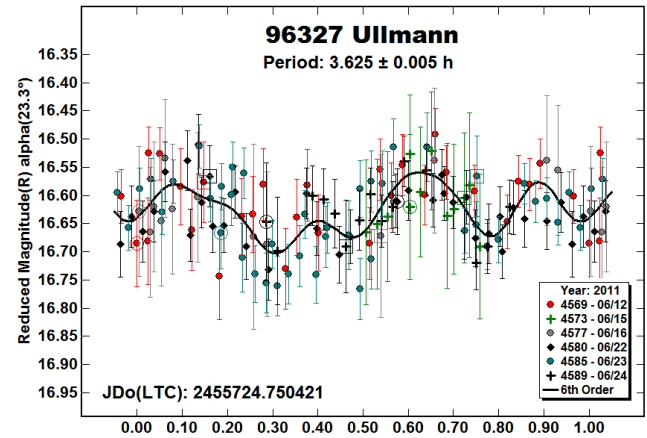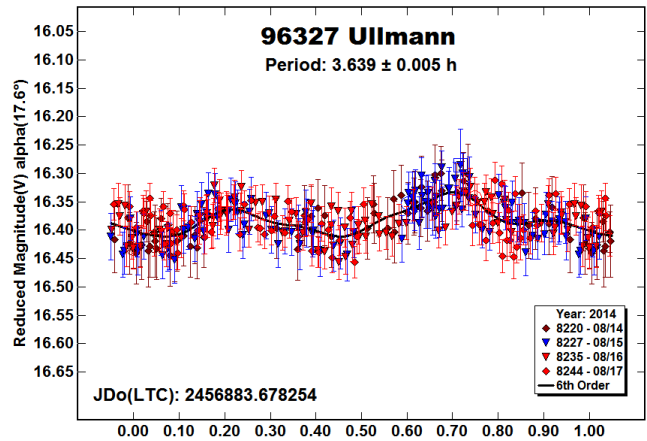
(134422) 1998 QM3. This is a clear case of a tumbling asteroid. However, the periods reported here are not unique. This is often the case when the two periods, that of rotation and that of the spin axis precession, are long and the data come from a single station. For a detailed discussion of non-principal axis rotation (NPAR) and the methods for analysis, see Pravec *et al.* (2005).

The first two plots were generated by *MPO Canopus* with the data forced to the two periods found by Pravec (personal communications). Based on the one for 25.4 h, one might suspect that it would be possible to find a single period solution by manipulating the zero point adjustments. This was tried, but it required unreasonable offsets and still showed the data from some sessions to have a slope opposite that of the Fourier model curve.
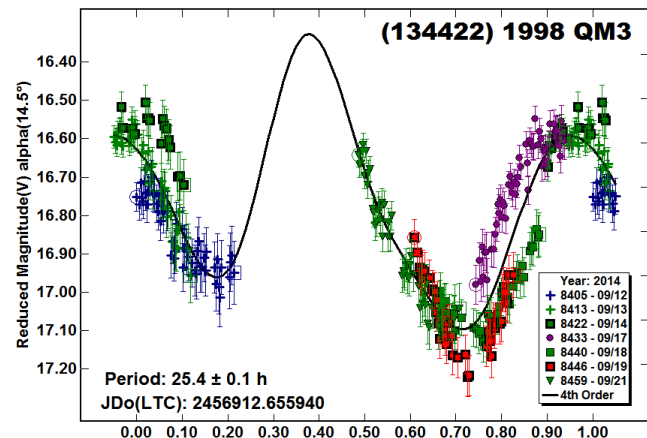
Number	Name	2014 mm/dd	Pts	Phase	L$_{PAB}$	B$_{PAB}$	Period	P.E.	Amp	A.E.
1103	Sequoia	08/08-08/10	195	35.1,35.1	23	21	3.037	0.002	0.46	0.03
1823	Gliese	09/10-09/11	212	9.1,9.6	332	2	4.488	0.003	0.23	0.02
2078	Nanking	07/15-07/22	183	36.9,37.2	353	20	6.459	0.001	1.19	0.03
2150	Nyctimene	08/09-08/14	144	31.6,31.1	17	11	6.13	0.002	0.76	0.03
3401	Vanphilos	08/15-08/17	126	29.1,28.9	10	17	4.227	0.005	0.62	0.03
4388	Jurgenstock	07/16-07/22	158	25.8,25.2	339	29	2.81	0.001	0.1	0.01
4531	Asaro	09/10-09/12	105	29.8,29.5	43	7	4.16	0.01	0.27	0.02
5841	Stone	08/08-08/10	100	21.7,20.7	345	-5	2.882	0.005	0.1	0.01
6394	1990 QM2	08/09-08/14	144	27.3,28.3	281	24	3.686	0.001	0.39	0.03
7660	1993 VM1	08/16-08/23	183	29.3,27.6	11	-4	5.917	0.001	0.59	0.03
8024	Robertwhite	09/22-09/24	198	13.5,12.5	21	3	7.063	0.002	0.9	0.03
16641	Esteban	07/17-08/27	735	20.8,15.3,15.9	325	21	79.62	0.02	1.08	0.05
27713	1989 AA	06/27-06/30	97	18.8,17.7	304	13	4.002	0.002	0.72	0.03
29242	1992 HB4	08/14-08/16	160	26.9,27.2	285	29	3.942	0.005	0.58	0.03
33324	1998 QE56	08/01-08/07	192	30.5,28.8	357	10	6.183	0.001	0.86	0.03
35087	von Sydow	09/01-09/06	375	18.9,16.6	356	18	36.1	0.2	0.55	0.05
38047	1998 TC3	07/23-07/27	112	30.8,30.5	5	20	3.764	0.001	0.78	0.03
53424	1999 SC3	09/03-09/05	153	12.6,13.8	330	12	6.4	0.02	0.1	0.01
64107	2001 TK8	06/09-06/23	228	27.7,25.1	296	23	68.5	0.5	1.31	0.05
67404	2000 PG26	09/30-10/02	237	21.9,21.3	35	23	5.396	0.002	0.66	0.03
68537	2001 VC123	08/23-08/27	118	9.5,10.5	327	15	2.994	0.002	0.16	0.02
96327	Ullmann	08/14-08/17	308	17.6,16.2	337	18	3.639	0.005	0.08	0.02
134422	1998 QM3	09/13-09/21	307	15.1,19.4	336	14	25.4[A]	0.1	0.65	0.05
306790	2001 KB1	08/09-08/22	357	33.0,36.1	287	34	71	5	0.85	0.1

Table II. Observing circumstances. [A]P_1 for a two-period tumbling (NPAR solution); P_2 is 34.2 ± 0.1 h. See text for details. The phase angle (α) 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$_{PAB}$ and B$_{PAB}$ are each the average phase angle bisector longitude and latitude, unless two values are given (first/last date in range).

(134422) 1998 QM3 — Period: 34.2 ± 0.5 h

(13442) 1998 QM3 (by P. Pravec)

The last plot was produced by Pravec, whose software is capable of analyzing the complex nature of a tumbling asteroid. Such plots don't show simple, overlapping curves, but do indicate the shapes of the curves for the two periods and the residuals after subtracting both curves from the data set. As noted above, the two periods here are not necessarily the true periods. Pravec found other solution sets involving different linear combinations of integral multiples of two *frequencies* that produced similar residuals.
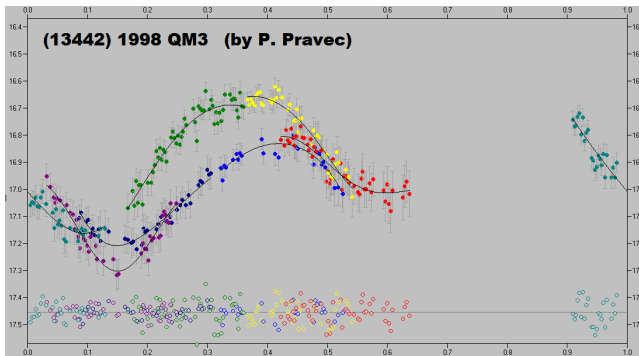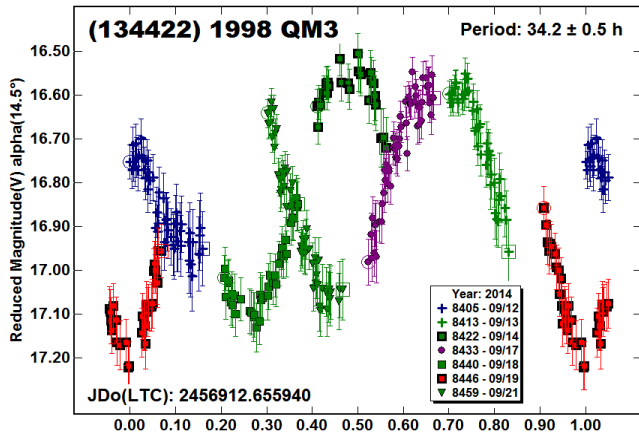
(306790) 2001 KB1. There were no previous reports of a period in the LCDB for this Mars-crosser. The solution is the best fit to the data, which are strongly suggestive of tumbling.
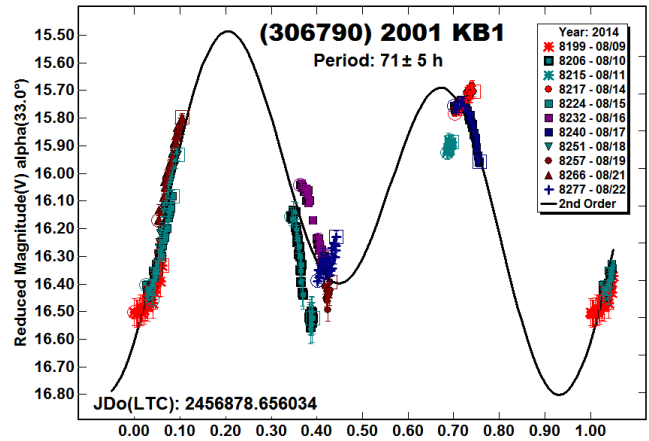
(306790) 2001 KB1 — Period: 71 ± 5 h

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A SEXTET OF MAIN-BELT BINARY ASTEROID CANDIDATES

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Analysis of CCD photometry observations at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) made in 2014 June-October found six main-belt binary candidates. 1355 Magoeba (Hungaria) is a *possible* binary, showing indications of a secondary period. 2131 Mayall is a known binary. The rotation period of the primary was confirmed. (15778) 1993 NH is a *possible* member of the subclass of *wide binaries* that are characterized by a large amplitude, long period lightcurve superimposed by a low amplitude, short period component. (18890) 2000 EV26 is a *confirmed* new binary, showing *mutual events* in the satellite's lightcurve. Analysis of data from 2011 shows, at best, only weak evidence of the satellite. (27568) 2000 PT6 is a *probable* binary with strong evidence of a second period but no confirming *mutual events*. (30535) 2001 OR5 is a *possible* binary that shows a secondary period but it may be a harmonic artifact of Fourier analysis.

CCD photometric observations of six main-belt asteroids made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) in 2014 June through October showed them to be binary candidates. Table I lists the telescope/CCD camera combinations used for the observations. The cameras all use KAF blue-enhanced CCD chips 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 observations were unfiltered since a clear filter can result in a 0.1-0.3 magnitude loss. The exposure duration depended on the asteroid's brightness and sky motion. Guiding was on a field star, which sometimes caused the asteroid image to trail.

Measurements were done using *MPO Canopus*. If necessary, an elliptical aperture with the long axis parallel to the asteroid's path was used. 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 MPOSC3 catalog, which is based on the 2MASS catalog (*http://www.ipac.caltech.edu/2mass*) but with magnitudes converted from J-K to BVRI using formulae developed by Warner (2007). When possible, magnitudes are taken from the APASS catalog (Henden *et al.,* 2009) since these are derived directly from reductions based on Landolt standard fields. Using either catalog, the nightly zero points have been found to be consistent to about ± 0.05 mag or better, but on occasion are as large as 0.1 mag. This consistency is critical to analysis of long period and/or tumbling asteroids. Period analysis is also done using *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 $-5*\log (r\Delta)$ to the measured sky magnitudes with r and Δ 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°), 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 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.

Individual Results

1355 Magoeba. The 2014 apparition was the fifth one observed by the author. Previous results have varied considerably, e.g., 31.65 h (Warner, 2010), 5.99 h (Warner, 2011), and 2.975 h (Warner, 2013) with a possible solution at 5.95 h. Analysis of the 2014 data, which indicated two periods in the data, may help explain some of the disparate solutions.

Figure 1 shows the unsubtracted data from 2014 after a period search covering a range of 2-17 hours. The small deviations at the minimum near 0.2 rotational phase prompted a search for a second period.
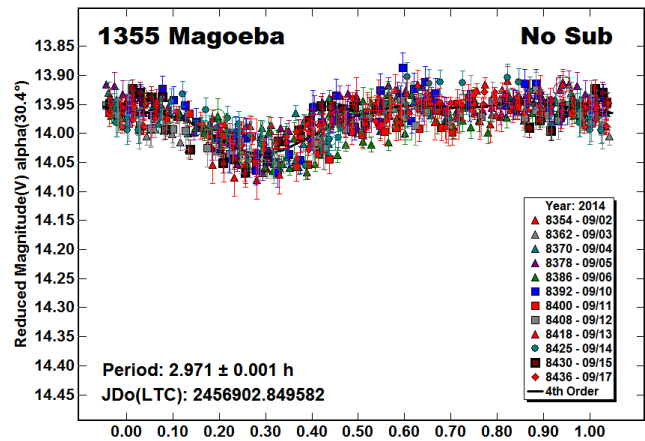
Figure 1. The data from the 2014 apparition for 1355 Magoeba are plotted without subtracting any effects due a possible second period. The period is close to the final result for P1
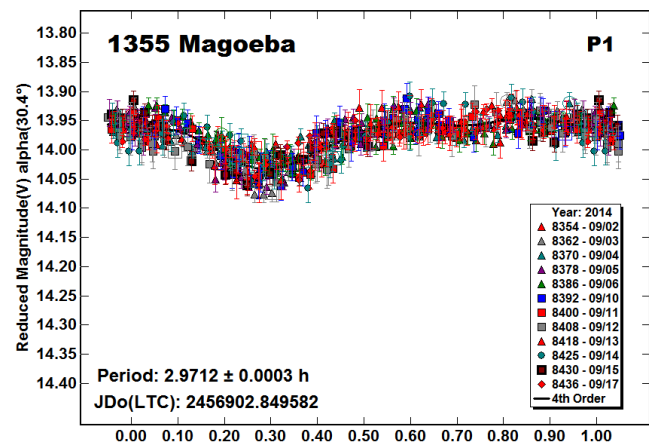
Figure 2. The short period for 1355 after subtracting a second period of 15.05 hours.

Number	Name	2014 mm/dd	Pts	Phase	L_{PAB}	B_{PAB}	Period	P.E.	Amp	A.E.
1355	Magoeba	09/02-09/17	569	30.4,27.8	42	9	2.9712	0.0003	0.09	0.01
2131	Mayall	07/23-07/31	248	37.2,37.0	8	30	2.5907	0.0005	0.07	0.01
15778	1993 NH	08/15-08/28	235	34.5,36.9	282	26	3.32	0.001	0.04	0.01
18890	2000 EV26	07/23-08/02	297	22.0,18.9	330	23	3.8216	0.0005	0.11	0.01
18890	2000 EV26	[12]06/28-07/04	73	20.1,20.9	264	32	3.882	0.003	0.09	0.02
27568	2000 PT6	08/19-09/06	403	24.9,17.8	10	-3	3.499	0.001	0.11	0.02
30535	2001 OR5	06/18-07/03	323	23.6,25.2	255	34	2.9697	0.0002	0.12	0.01

Table II. Observing circumstances. [12]Dates are in 2012. The period and amplitude are for the primary of the binary system. The phase angle (α) 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_{PAB} and B_{PAB} are each the average phase angle bisector longitude and latitude, unless two values are given (first/last date in range).
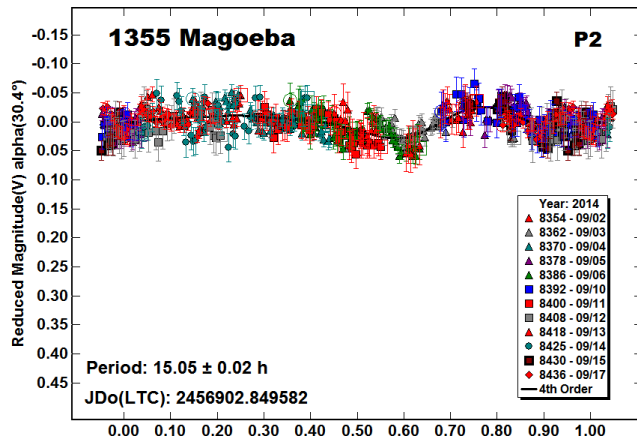
Figure 3. The lightcurve for the second period of 15.05 h does not show any obvious mutual events but may indicate a satellite with a rotation period locked to its orbital period.

The dual period search feature in *MPO Canopus* was used to determine if there was a second period present in the data. The process started by finding a best fit period of all data without subtraction that was restricted to a range of 2-7 hours, the range of the more likely previous results. The resulting Fourier model curve was subtracted from the data when conducting a search for a second period, this time with a range of 2 to 25 hours. This covers typical rotation periods of a fully-asynchronous satellite or the orbital period and rotation period of a tidally-locked satellite. The resulting Fourier model was subtracted from the data for another search of the short period. The process of going back-and-forth was repeated until both periods stabilized.

The result was a short period of 2.9712 h (Figure 2), which shows somewhat less scatter overall compared to Figure 1 as well as near the minimum at 0.2 rotation phase. Figure 2 shows the lightcurve for the second period, 15.05 hours. There are no obvious signs of *mutual events*, i.e., occultations and/or eclipses, but the lightcurve period is in the proper range for a satellite (see Pravec *et al*., 2010) and can be reasonably interpreted to be due to an elongated satellite that is tidally-locked to its orbital period. Given the lack of mutual events and the asymmetrical shape of the second period lightcurve, this is listed as a *possible* instead of *probable* binary.

2131 Mayall. This Hungaria is likely a member of the *orbital group* but not the *collisional family*. Observations by Masiero *et al.* (2011) show an albedo of about 0.2, which is more typical of a type S asteroid. The collisional family members are type E. The asteroid was discovered to be a binary in 2009 (Warner *et al.*, 2010) fulfilling the adage of "the third time is a charm" since observations in 2005 (Warner, 2005) and 2006 (Warner *et al.*, 2007a) did not show any signs of a satellite, even with additional analysis after the binary discovery.
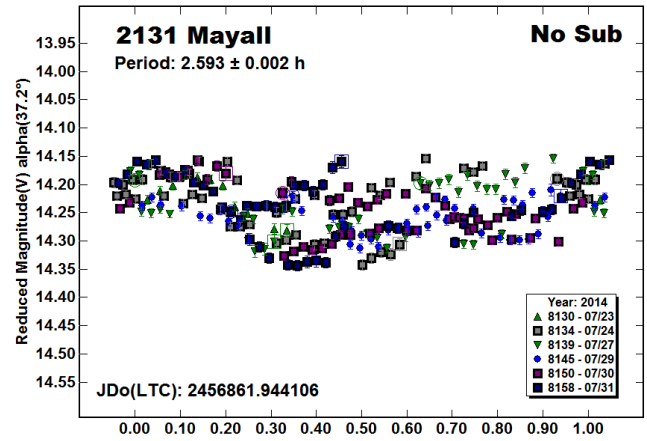
Figure 4. The data for 2131 after the initial search for a short period. The result is chaotic at best.
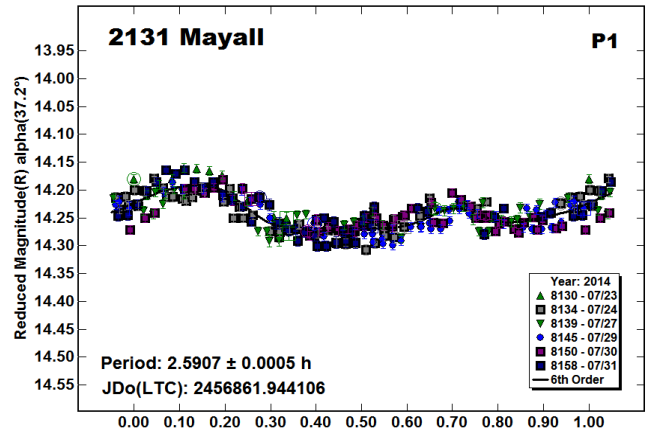
Figure 5. The lightcurve for the primary body of 2131 Mayall.
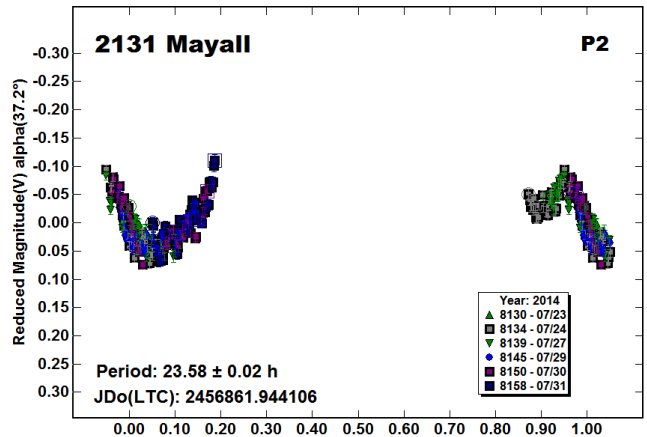
Figure 6. The lightcurve for 2131 Mayall after subtracting the effects of the primary's rotation. This is hardly a conclusive result but subtracting the Fourier curve produces a good solution for the primary.

Figure 4 shows the data for the asteroid after a preliminary search for a short period in the range of 2-17 hours. Either the data were very bad or there is a second period involved. Figure 5 shows the lightcurve for the primary after the dual period search. To find this, the period for the satellite was assumed to be within a small range around the one found in 2010, i.e., 23.48 hours. Since this is nearly commensurate with an Earth day, no one station could hope to

cover the entire secondary lightcurve and so it was expected that there would be large gaps in the long period lightcurve.

Since data from another location were not available, the best that could be done was to subtract the result of the search, despite the Fourier model having very large gyrations, when searching for the short period. Once this was found, the search for the second period was "refined". The lightcurve appears to show a deep event near rotation phase 0, but that was not confirmed. Were it not known that this is a binary system, the best that could be said based on the 2014 data is that Mayall is a *probable* binary.

(15778) 1993 NH. In the past few years, there has been growing evidence for a subset of binary asteroids known as *wide binaries*. These are discussed in detail by Jacobson and Scheeres (2011). The photometric observations of such objects show a lightcurve with a long period ($P > 100$ hours) and relatively large amplitude (Figure 8) superimposed by a short period, low amplitude lightcurve (Figure 7).
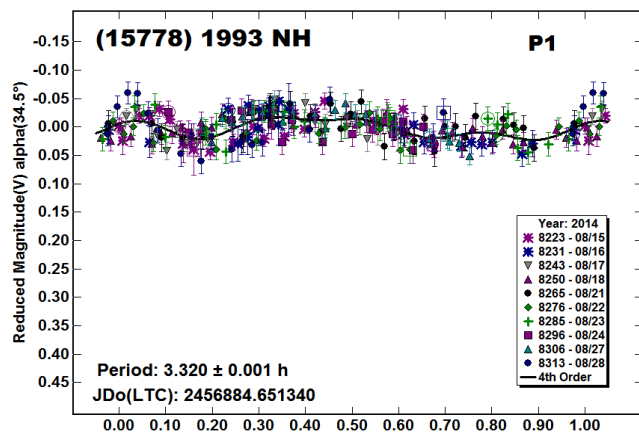
Figure 7. The short period lightcurve for 1993 NH.
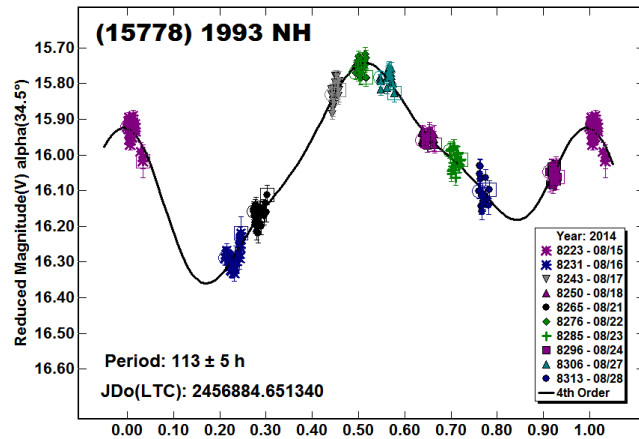
Figure 8. The long period component for 1993 NH. At this scale, the low amplitude, short period lightcurve cannot be seen.

Since the long period lightcurve dominates the data, the search for its period is done first. Once an approximate period is found, often using only a 2nd order Fourier fit, the resulting model lightcurve is subtracted in the search for the short period. Quite often, that lightcurve has a low amplitude and so it is difficult to determine if the Fourier analysis is finding a true period or locking onto noise. In this case, it's believed that the short period is real, especially since it is appropriate for a fully-asynchronous satellite, i.e., one

not tidally-locked to its orbit. Still, this is listed only as a *possible* binary.

The long period component is *not* due to the satellite but to the primary, which has a slow rotation period due to conservation of rotational energy. The chances for seeing mutual events and so confirming the orbital period of the satellite, which will be very long, are exceedingly remote.

(18890) 2000 EV26. This Hungaria was first reported to have a period of 10.53 h (Warner, 2012). Analysis of the 2014 data indicated that this is a *confirmed* binary system with the secondary period showing *mutual events* (occultations and/or eclipses) that allow determining the orbital period.
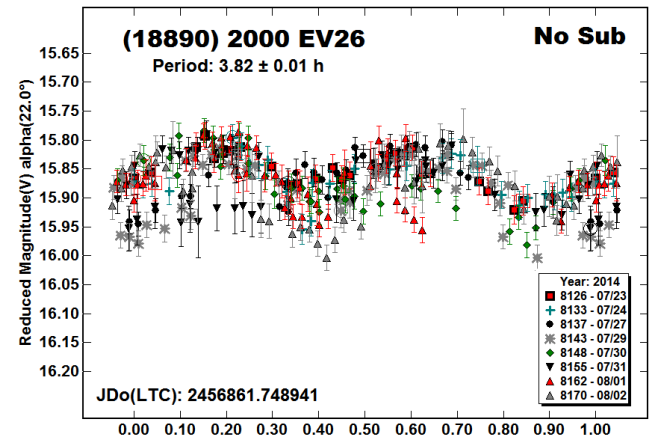
Figure 9. The unsubtracted lightcurve of 2000 EV2 after an initial search for a period shows obvious signs of a second period.

Figure 9 shows the 2014 data set when finding a period with no more than a bimodal lightcurve. Searching out to 15 hours found solutions of up to 6 extrema pairs. The deviations from the main curve prompted a second period search.
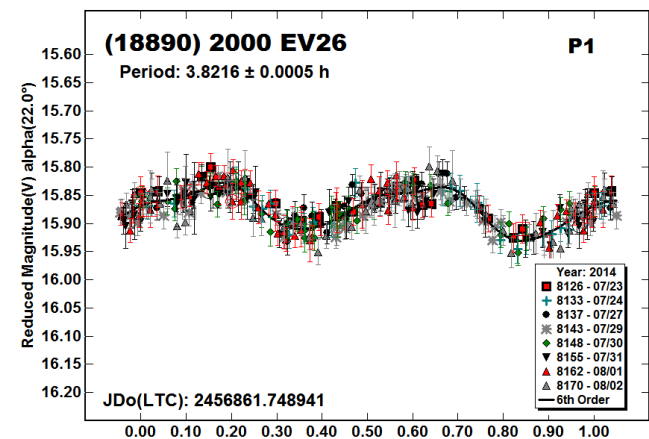
Figure 10. The lightcurve for 2000 EV26 after subtracting the effects of the satellite. The scatter is considerably less than in Figure 9.
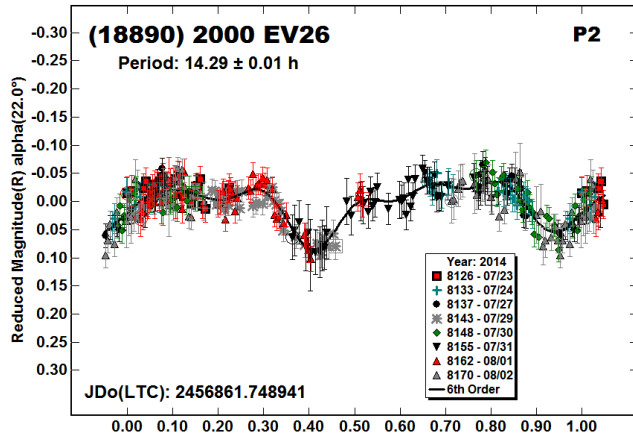
Figure 11. The lightcurve for P2 clearly shows the mutual events and defines the orbital period of the proposed satellite.
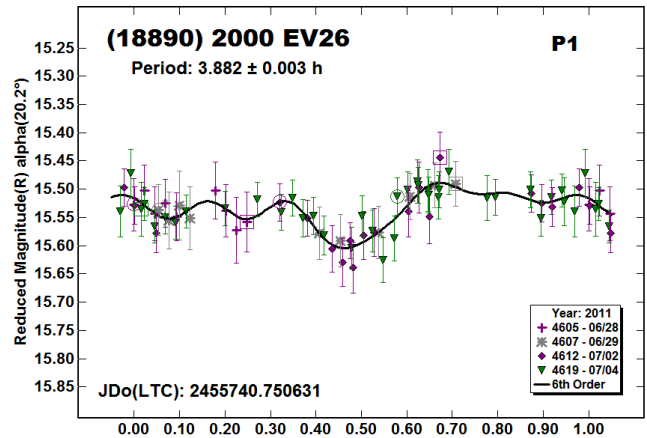

Figure 12. The 2011 data for 2000 EV2 were searched for evidence of the satellite found in 2014. This plot shows the primary lightcurve after forcing the P1 and P2 values near those found in 2014.
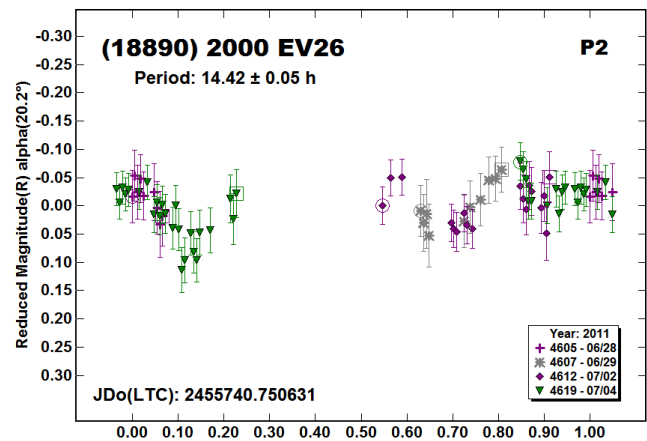

Figure 13. The P2 lightcurve from the 2011 data shows what may be a hint of events at 0.1 and 0.6 rotation phase. With no follow-up to support that claim, this could easily be attributed to "bad data."

Figures 10 and 11 give the final results of the dual period search. The former shows the rotation due to the primary. The low amplitude and symmetrical shape indicate a nearly spheroidal body, which is typical among small binary asteroids. Figure 11 shows the lightcurve due to the satellite with the mutual events at 0.4 and 0.9 rotation phase. The latter event allows giving an effective diameter ratio of the satellite to the primary as $D_s/D_p \geq 0.27 \pm 0.02$. Since the secondary event is not total (it is not flat at the minimum point), this makes the estimate a minimum and so the satellite could be larger.

Given the findings from 2014, the data from 2011 were re-examined to see if they also showed signs of the satellite. Unfortunately, that data set had considerably fewer data points per night and, because a satellite was not suspected at that time, it did not have as many nights. This reinforces the advice that when preliminary results for an asteroid show a period of 2-5 hours and – in most, but not all cases – a low amplitude, some extra observation time should be allowed to make sure that evidence of a satellite is not overlooked.

Figure 12 shows the 2011 lightcurve for the shorter period after a dual period search where the solutions were forced near those found for 2014. The fit in Figure 12 is within reason and so a new period of 3.882 h has been adopted for the 2011 data. On the other hand, given the sparse data, the solution for the satellite is far from conclusive. If the search were being done without knowledge of the 2014 results, it's highly unlikely that this would be accepted as evidence for even a *possible* satellite. At best, subtracting the P2 model lightcurve did improve the fit of the P1 lightcurve, but that could also be due to a fit to random noise.

(27568) 2000 PT6. The author first observed this asteroid in 2011 (Warner, 2012) when a period of 3.624 h was reported. Observations in 2013 (Warner and Stephens, 2013) with five sessions from March 11-19 found a period of 3.4885 h and indicated the possibility of a satellite with an orbital period of 16.356 h. The 2011 data were re-examined but no indications of a satellite were found. The asteroid was observed again in 2014 August and September with the aim of confirming, if possible, the satellite and the orbital period.

The initial search without subtracting the effects due a satellite found a period of 3.499 h. Figure 14 shows that result. The dual period search feature of *MPO Canopus* found a primary period, also of 3.499 hours (Figure 15). This is good agreement with 2013 results. That is where the similarities ended.

The 2014 data set that consisted of 10 individual nights from August 19 through September 6 led to a secondary period of 11.73 h, or almost a 2:3 ratio of the longer period found in 2013. This might indicate that a *rotational alias* (i.e., uncertainty about the number of rotations over a given period) had been found with one set or the other since both answers cannot be right. The dual period search was applied to the 2013 and 2014 data sets but forcing the search for P2 for one data set to be near the value from the other data set, e.g., the search for P2 using the 2014 data was limited to the range of 15-17 hours. For the 2013 data, the closest

fit was to 12.2 h with a gap of about 0.3 rotation phase. The 2014 data could be forced to a period of 15.73 hours and a bimodal lightcurve. Both of these follow-up solutions are significantly off the original periods.
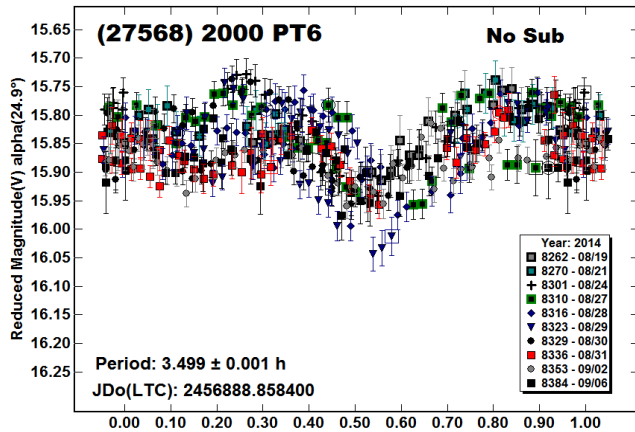

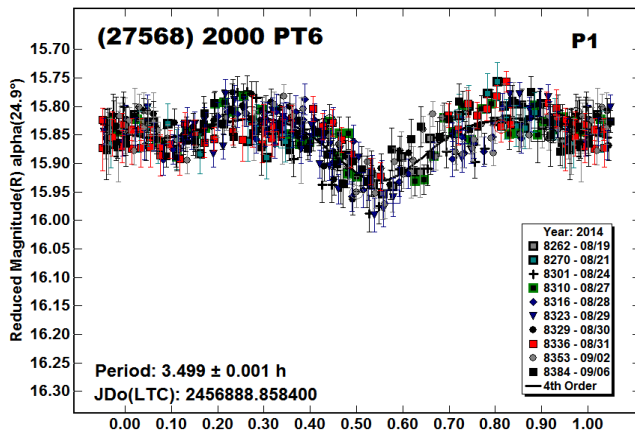Figure 14. The unsubtracted lightcurve of 2000 PT6.

Figure 15. The lightcurve of 2000 PT6 after subtracting the effects of a second period. This is much cleaner than in Figure 14.
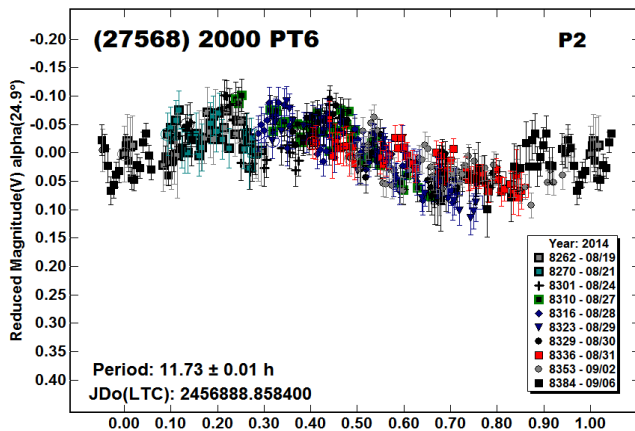

Figure 16. The adopted period for P2. This suggests a tidally-locked satellite with an orbital period of 11.73 h.

An explanation for the different results may be due to what's called a *fit by exclusion*. This is where the Fourier analysis finds a false best-fit period by minimizing the number of overlapping data points. This result is often seen as a gap in the lightcurve. Such a gap was in the 2013 data when fit to its original period of 16.356 hours. Even though there were parts of the lightcurve that were

covered more than once, a *fit by exclusion* may explain why the latest data do not support that result.

This brings up another argument for the 2014 results: the 2014 data set covered more nights over a longer period of time. Since the two suspect periods are nearly commensurate with an Earth day, it would be difficult to avoid finding a *rotational alias*. If the period is just enough off from an integral ratio with a 24-hour cycle and the range of observations eventually allows seeing more of the lightcurve, the number of rotational aliases can be reduced. The 2014 data may have succeeded in that effort while the 2013 data did not.

It is very likely that 2000 PT6 is a binary asteroid, i.e., it is listed as *probable*, since subtracting P2 significantly improves the P1 lightcurve. However, the question of the orbital period of the satellite remains very much in question and so follow-up observations are encouraged at future apparitions.

(30535) 2001 OR5. There were no previous results in the LCDB against which to compare the results from the 2014 observations. The difference between a lightcurve with no subtraction and one with the eventual second period removed is very small.
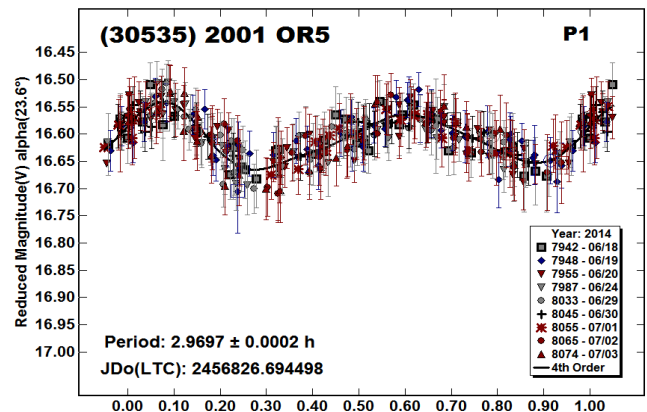
Figure 17. The lightcurve for 2001 OR5 after subtracting the effects of a secondary period is almost the same as with no subtraction.
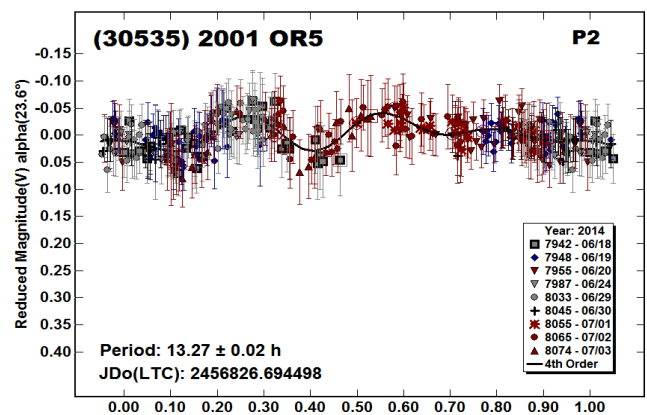

Figure 18. The lightcurve for P2 is marginally convincing, if that.

Figure 17 shows the subtracted lightcurve for 2001 OR5. Even without subtraction, the solution is unique and so not in question. The dual period process described previously eventually found a second period of 13.27 hours (Figure 18) with an irregular lightcurve that wouldn't seem to have a reasonable physical counterpart. A telling clue that this may be a false secondary period is that P2:P1 is almost an integral ratio, i.e., 9:2. This is the

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result of what is sometimes called a *harmonic alias*, which is where the Fourier analysis locks onto higher orders of noise in a lightcurve when a suspect period is subtracted from the data. The true difference is 8.937:2.0, but this is close enough so that when combined with the unconvincing shape of the P2 lightcurve, the best that can be said at this point is this is a *possible* binary and so additional observations of higher-precision are encouraged.

Acknowledgements

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ROTATION PERIOD AND LIGHTCURVE OF 1762 RUSSELL

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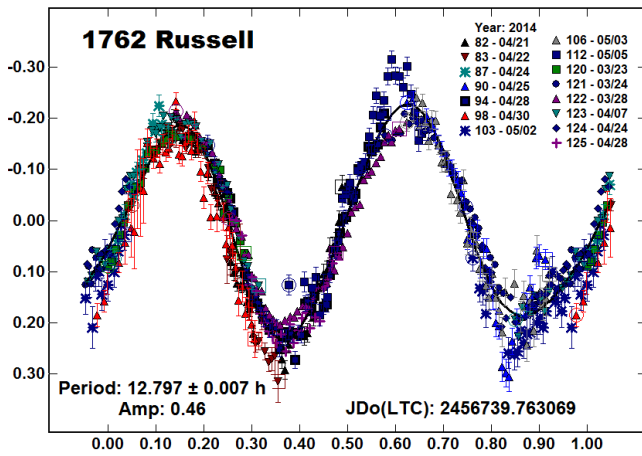Socorro, NM USA 87801

Unfiltered photometry of 1762 Russell at Sonoita Research Observatory and Etscorn Campus Observatory yields a period of 12.797 ± 0.007 hours and amplitude of 0.46 magnitudes.

Unfiltered photometry of 1762 Russell was carried out at Sonoita Research Observatory and at Etscorn Campus Observatory on thirteen nights from 2014 March 23 to May 5. Nine nights of data were taken at Sonoita Research Observatory and six at Etscorn Campus Observatory. There was dual coverage from both observatories on two of the nights.

Sonoita Research Observatory employed a 0.51-m *f*/4 folded Newtonian and an SBIG STL-6303E on a Paramount ME. Images were 5 minutes unfiltered integrations and photometric reduction was carried out in *MIRA*. Estcorn Campus Observatory employed 0.35-m Celestron Schmidt-Cassegrains on Paramount ME's with several cameras. Details can be found in Klinglesmith *et al.* (2014). Images were 5 minutes unfiltered integrations and photometric reduction was carried out in *MPO Canopus*.

Period analysis and phasing of the combined data was carried out in *MPO Canopus*. The phased light curve has a period of 12.797 ± 0.007 hours and amplitude of 0.46 magnitudes. No previous period or lightcurve determinations for 1762 Russell have been reported.

1762 Russell
Period: 12.797 ± 0.007 h
Amp: 0.46
JDo(LTC): 2456739.763069

Year: 2014

▲ 82 - 04/21		△ 106 - 05/03	
▼ 83 - 04/22		■ 112 - 05/05	
✳ 87 - 04/24		■ 120 - 03/23	
✳ 90 - 04/25		◆ 121 - 03/24	
■ 94 - 04/28		▲ 122 - 03/28	
▲ 98 - 04/30		▼ 123 - 04/07	
✳ 103 - 05/02		◆ 124 - 04/24	
		✛ 125 - 04/28	

Acknowledgments

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LIGHTCURVE ANALYSIS OF NEA 2009 FG19

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MoreData!
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CCD photometric observations of the near-Earth asteroid 2009 FG19 were made in 2014 September and October to supplement radar observations made at the same time. Analysis of the CCD data from September only found several possible periods, all commensurate with an Earth day. The most likely period was 8.00 ± 0.02 h with an amplitude of 0.80 ± 0.05 mag with an alternate solution of 9.61 ± 0.02 h being possible. The addition of data from October, even though the lightcurve had evolved noticeably, removed the 9.6 hour alias and confirmed the 8-hour solution. There were no obvious signs of non-principle axis rotation (NAPR; *tumbling*) but that cannot be formally excluded.

CCD photometric observations of the near-Earth asteroid (NEA) 2009 FG19 were made at the request of Lance Benner (private communications) to supplement radar observations being made in 2014 September. The initial observations were made at the Palmer Divide Station at CS3 (CS3-PDS) from 2014 September 21-26. Analysis of the resulting data showed that the period was nearly commensurate with an Earth day. Since the individual observing runs from a single station were too short to resolve the rotational ambiguities, observations were requested of and made by Pray at Sugarloaf Mountain Observatory (SMO). The additional data helped remove some of the alias periods, but not all. It was not until data from early October were added by Pollock *et al.* using the PROMPT telescope in Chile and the R-COP telescope in Perth, Australia, that a final result was found. Tables I and II give the equipment and observation details.

Obs	Telescope	Camera
CS3-PDS	0.35-m f/9.6 Schmidt-Cass	SBIG STL-1001E
SMO	0.50-m f/4 Newtonian	SBIG ST-10XME
PROMPT	0.40-m f/10 Schmidt-Cass	Apogee Alta
R-COP	0.35-0 f/10 Schmidt-Cass	ST-10XME

Table I. Telescope/cameras used at each location.

Location	2014 mmm dd	Phase	L_PAB	B_PAB
CS3-PDS	Sep 21-28	93,57	47,37	29,-12
SMO	Sep 27-28	66,60	41,37	-6,-12
R-COP	Oct 6	47	16	-32
PROMPT	Oct 7	47	15	-33

Table II. Dates of observations from each location. Phase is the phase angle, in degrees, on the first and last dates in the range. The PAB columns are, respectively, the longitude and latitude, also in degrees and on the first and last dates in the range.

Image processing and measurement by Warner and Pray were done using *MPO Canopus* (Bdw Publishing). Pollock used *Mira* for his images. Master flats and darks were applied to the science frames prior to measurements. The *MPO Canopus* export data sets and raw text from *Mira* were collected by Warner for period analysis in *MPO Canopus,* which incorporates the FALC Fourier analysis algorithm developed by Harris (Harris *et al.,* 1989).

For Warner and Pray, conversion to an internal standard system with approximately ±0.05 mag zero point precision was accomplished using the Comp Star Selector in *MPO Canopus* and the MPOSC3 catalog provided with that software. The magnitudes in the MPOSC3 are based on the 2MASS catalog converted to the BVRcIc system using formulae developed by Warner (2007). This internal calibration works well within a given telescope-camera system. In some cases, a nearly constant offset is required to merge data from one system to another. This was not necessary in this case. The data from Pollock were differential magnitudes only. His two data sets were first aligned to produce a best fit (lowest RMS) in a period search from 5 to 20 hours. The zero point for the combined data set was then adjusted as needed to obtain a minimum RMS when merging with the data from Warner and Pray.
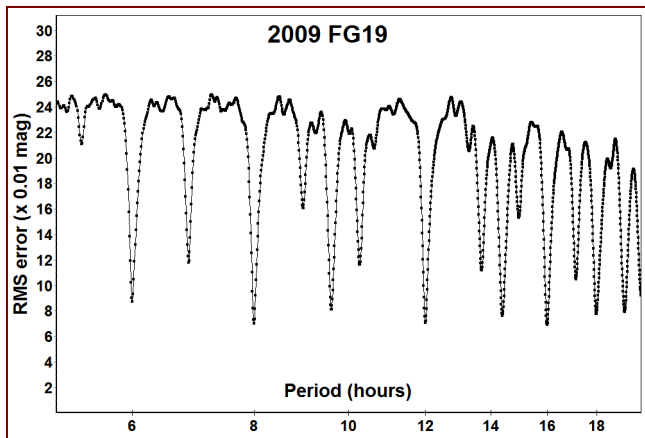
The Initial Campaign

Figure 1. The period spectrum from 4 to 20 hours for 2009 FG19 using data from Warner and Pray shows several almost equally likely solutions.

Figure 1 shows a period spectrum produced by the Fourier analysis ranging from 4 to 20 hours when using only the data from Warner

and Pray. There are several almost equally likely solutions (minimum RMS value), several of which differ by an integral of half-integral number of rotation over 24 hours. The CS3-PDS data alone could not resolve which of the periods was most likely. The two runs by both stations on Sep 27 and 28 extended the total span of observation by about 3 hours and helped reduce the ambiguities down to two probable periods.
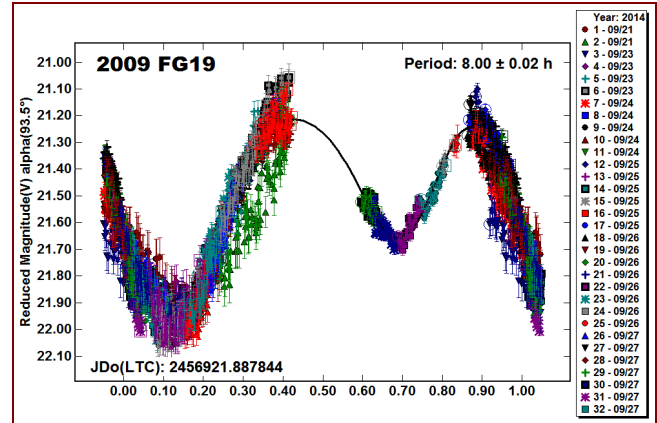

Figure 2. The data for 2009 FG19 phased to the favored period of 8.00 hours.

Figure 2 shows the favored solution of 8.00 hours. The amplitude of the lightcurve, 0.80 ± 0.05 mag, is made a little more uncertain by the lightcurve not being complete at the first maximum at 0.4 rotation phase. Evidence of the changing shape of the lightcurve is seen around rotation phase 0.3.
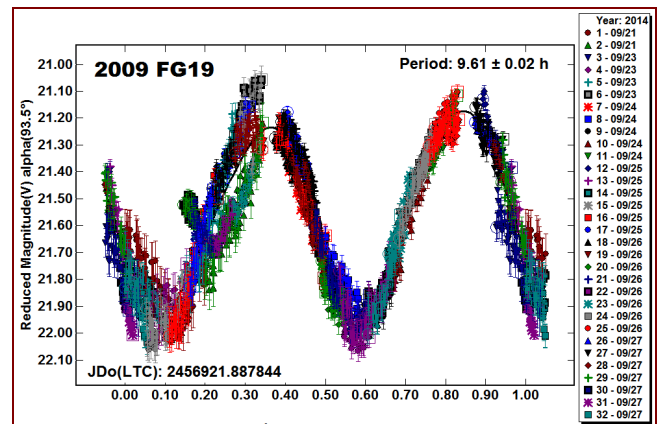

Figure 3. The data for 2009 FG19 phased to an alternate solution of 9.61 hours.

Figure 3 shows the alternate solution of 9.60 hours, also with a 0.80 mag amplitude. The two periods have an integral ratio of 6:5. Even though Figure 2 shows a significant gap in the lightcurve, it is considered the more likely solution because of the misalignment of the data in Figure 3 near 0.2 rotation phase.

At the time, Petr Pravec (personal communications) reviewed the data set for indications of *tumbling*. While nothing certain was found, the possibility could not be formally excluded without having data from stations at other longitudes and/or not showing any significant changes in the lightcurve due to changing viewing aspects.

If nothing else, the initial observations indicating a period of several hours helped the radar team plan their observations, which

is a vital service that is easily provided by the backyard astronomy community in addition to astrometry to reduce position uncertainties.

The Second Campaign

The asteroid moved too far south at the end of September for Warner and Pray to try filling in the lightcurve and solving the rotational alias. Pollock had been contacted in September but, due to the northerly location of the asteroid and other circumstances, could not observe the asteroid until early October, when he arranged runs on Oct 6 UT for R-COP in Perth, Australia, and Oct 7 for the PROMPT telescope in Chile.

Using only his data, a period search strongly favored a solution near 8 hours (Figure 4). Since the lightcurve did evolve so much, we used a combined data set that included the observations from Sep 25 through Oct 7. This excluded the observations at the more extreme phase angles of $\alpha > 80°$, although the range of angles in the subset still exceeded 30 degrees. Figure 5 shows the resulting period spectrum from 4 to 20 hours. The 9.6 hour solution has been completely eliminated, leaving three solutions, each commensurate with an Earth day and differing by one rotation over a 24-hour period.
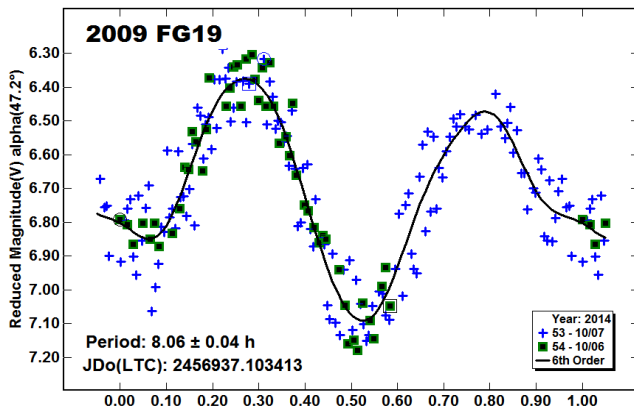
Figure 4. The lightcurve for 2009 FG19 using only the data from Pollock *et al.* and phased to the best fit period of 8.06 hours. The reduced magnitudes are differential values added to an arbitrary constant.
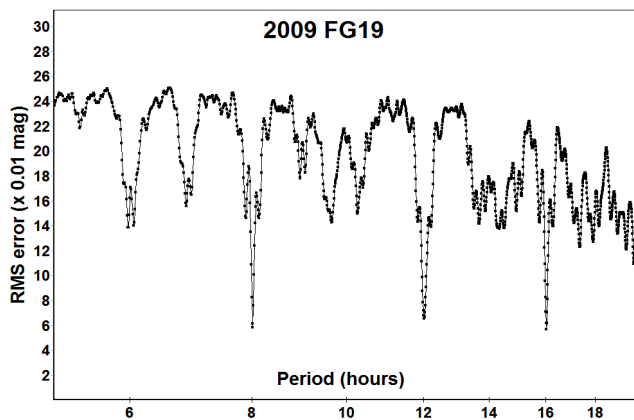

Figure 5. The period spectrum using a subset of the data ranging from 2014 Sep 25 through Oct 7. The 9.6 hour period is eliminated.
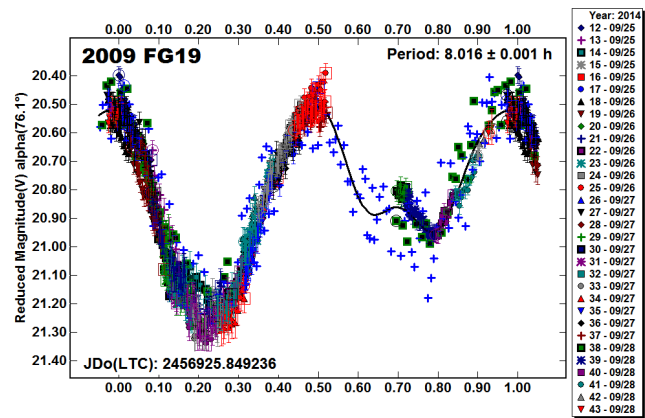

Figure 6. The lightcurve for 2009 FG19 using the subset of data described in the text and phased to the most likely period of 8.016 hours.

The lightcurves in Figures 4 and 6 used data binned 2x10, meaning any given bin used the average of up to 2 unique data points separated by no more than 10 minutes. No data point was used in more than one bin. Figure 6 appears to verify the lower amplitude of the secondary minimum at about 0.8 rotational phase that was suspected during the initial analysis.

We have adopted the period of 8.016 hours for this paper. The lightcurves for the longer periods are either trimodal (12 hours) or quadramodal (16 hours). The latter is highly symmetrical over the first and second half, which is physically improbable and so represents the double period.

Photometry observations and analysis of near-Earth asteroids are fraught with difficulties. This campaign showed that even some of the more challenging of circumstances – short-lived campaigns and longer, Earth-day commensurate periods – can be overcome through timely response and coordinated efforts.

Acknowledgements

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ASTEROIDS OBSERVED FROM CS3:
2014 JULY - SEPTEMBER

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CCD photometric observations of 16 asteroids were obtained from the Center for Solar System Studies from 2014 July to September.

During this calendar quarter, the Center for Solar System Studies (CS3, MPC U81) focused on studying asteroids in near Earth space; NEAs, Mars Crossers, Inner Main-belt asteroids, and members of the Hungaria, Vesta and Phocaea families. Some of these targets were selected from the 'Shape/Spin Modeling Opportunities' list in the back of each Minor Planet Bulletin. These are targets with at least one high quality lightcurve which are not in the Database of Asteroid Models from Inversion Techniques (DAMIT).

All images were made with a 0.4-m or a 0.35-m SCT with an FLI-1001E or a SBIG STL-1001E CCD camera. Images were unbinned with no filter and had master flats and darks applied to the science frames prior to measurement. Measurements were made using *MPO Canopus*, 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). Night-to-night calibration of the data (generally < ±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.

474 Prudentia. Behrend (Behrend 2014) reported a period of 8.57 h in 2006 and 8.58 h in 2009. This result is in good agreement with those periods.

654 Zelinda. Zelinda has been a difficult observational target over the years due to its low amplitude. Behrend (Behrend 2014) reported a period of 34.080 h in 2007. Schober (Schober 1975) reported a period of 31.9 h. Warner and Higgins (Warner *et al*

2008) reported a period of 32.0 h. Finally, the author (Stephens 2009) calculated a period of 31.735 h. Observations were obtained this year to obtain data for a future shape model. Marchis (Marchis et al 2006) observed Zelinda with Keck adaptive optics determining that the D=131 km and that it was roughly circular or perhaps triangular.

1341 Edmee. Because its rotational period is nearly commensurate with the Earth's, Edmee is a very difficult object to obtain a complete phased rotational period. The author (Stephens 2010) observed Edmee in 2004 and 2009 and reported a period of 23.745 h. For 2014, long runs could not be obtained because of the short summer nights. Only a partial lightcurve was created which was consistent with the prior results.

1589 Fanatica. This member of the Vesta Family has a rotational period determined by Warner (Warner 2004) of 2.58 h. 2014 had a favorable opposition so observations were obtained to assist in a future shape model. The 2014 rotational period is in good agreement with the previous result.

1747 Wright. Hanus (Hanus *et al* 2011) previously determined pole-latitude and a shape model for Wright. Its sidereal rotational period was found to be 5.2896 h. Since there was a favorable opposition in 2014, more observations were obtained to improve the shape model. The synodic period of 5.290 h is in good agreement with the previous result.

3332 Raksha. This Main Belt asteroid has been observed twice in the past by Behrend (Behrend 2014) and Klinglesmith (Klinglesmith *et al*, 2013). Both reported periods within a few thousandths of an hour of this result.

4002 Shinagawa. Shinagawa has never had a period reported in the Asteroid lightcurve database (LCDB; Warner *et al*., 2009). It is probable that because of its 175 h period, data yet resides in 'dusty file cabinets.'

4910 Kawasato. Unlike Shinagawa it is surprising that no previous period is reported for this Mars crosser (LCDB; Warner *et al*., 2009). With an amplitude of only 0.11 mag., it is possible that the lightcurve could have only a single extrema, or three or more extrema (Harris *et al* 2014). However, the extrema on this high quality lightcurve are not symmetrical favoring the 4.662 hour period.

Number	Name	2014 mm\dd	Pts	Phase	L_{PAB}	B_{PAB}	Period	P.E.	Amp	A.E.
474	Prudentia	08/11-08/23	328	28.7,26.7	22	-5	8.57	0.001	0.9	0.02
654	Zelinda	08/08-08/18	3162	10.3,8.5	332	18	32.012	0.006	0.08	0.02
1341	Edmee	07/11-07/30	295	9.6,3.2	263	-3	23.75	0.01		
1589	Fanatica	08/17-08/18	207	20.1,19.8	2	-7	2.582	0.001	0.18	0.02
1747	Wright	07/16-07/17	185	19.7,20.4	276	11	5.29	0.001	0.55	0.02
3332	Raksha	07/16-07/18	194	16.2,16.7	255	15	4.8	0.003	0.27	0.02
4002	Shinagawa	06/24-07/13	679	10.9,17.0	255	11	175	0.2	0.97	0.03
4910	Kawasato	08/24-08/27	333	14.9, 16.7	351	2	4.662	0.001	0.11	0.01
7330	Annelemaitre	08/19-08/23	218	25.0,24.2	14	5	4.438	0.001	0.32	0.02
9387	Tweedledee	08/08-08/16	561	15.9,11.0	337	-1	3.534	0.001	0.12	0.02
9739	Powell	07/24-08/07	1048	28.7,25.1	344	19	109	1	0.4	0.1
14764	Kilauea	07/19-07/23	109	17.4,17.6	299	29	19.59	0.05	0.5	0.05
31351	1998 SD24	09/20-09/21	161	14.2,13.6	13	-11	4.259	0.006	0.18	0.02
38063	1999 FH	08/24-10/12	3896	15.0,6.3,17.8	349	7	990	50	0.5	0.1
159493	2000 UA	09/22-09/25	388	16.2,17.9	342	15	14.517	0.005	0.36	0.02
285944	2001 RZ11	09/10-09/14	291	55.7,55.2	322	43	4.804	0.004	0.11	0.02

7330 Annelemaitre. It is also surprising that no previous period is reported in the Asteroid lightcurve database (LCDB; Warner *et al*., 2009) . The short period of 4.438 h makes this Phocaea family member a candidate to be a binary, but no evidence was detected over three nights.

9387 Tweedledee. Warner (Warner 2007) observed Tweedledee in 2006 and 2013, finding periods of 3.543 and 3.535 respectively. A primary period of 3.534 h was found in good agreement with those results. There is a hint of a secondary period of 15.15 h which cannot be definitively separated from the noise.

9739 Powell. Warner (Warner 2009) observed this Hungaria family asteroid in 2006 and again in 2009. In 2006, an 18.2 h period was reported with a 0.09 mag. amplitude. This period was updated to a 16.7 signal modal period with an alternate 33.5 h bimodal period, both with an amplitude of 0.11 mag. Since any number of extrema are possible with such a low amplitude, there was a possibility that the actual period is something far different. This year's observations had a far greater amplitude of about 0.4 mag. which should provide for a definitive solution. However, a definitive solution yet remains elusive, with the best fit at 109 h. Powell exhibits signs of 'tumbling' (nonprinciple axis of rotation) which can explain the difficulties in determining a rotational period in three attempts. A half-period plot and period spectrum for the 2014 data are included. Warner attempted to replot the 2009 data using these periods, but that data was too sparse to allow any further conclusions.

14764 Kilauea. Warner (Warner *et al*, 2012) observed this Hungaria family member in 2011 resulting in a three extrema 28.59 h rotational period. He reasoned that the asteroid must be tumbling because the phase angle was relatively low (~17°) and the amplitude of the curve was a high 0.8 magnitude, resulting in an impossible physical shape for a low phase angle. This year the phase angle was similar, but the amplitude was only 0.5 mag. A Period Spectrum reveled two possible periods for the 2014 observations, 13.91 h and 19.59 h. Both of those periods could be aliases to the three extrema period found in 2011. Upon reinvestigating the 2011 observations, it was found that observations from Brian Skiff of Lowell Observatory were in the ALCDEF database (Warner *et al* 2011) and were obtained a few nights after Warner's run concluded. These observations were combined with Warner's to see if a better solution could be created. The three extrema solution is still present and is an even poorer fit with the Skiff data. The 19 h fit of the Warner-Skiff data produces the best fit, although the asteroid is obviously tumbling. The best fit to the much sparser 2014 data is 19.59 h, but there is not enough observations to revel a secondary period.

(38063) 1999 FH. This Mars Crosser has never had a period reported in the Asteroid lightcurve database (LCDB; Warner *et al*., 2009). Its near 1000 h period is suggestive that it should have a nonprincipal axis of rotation (tumbling). However, as is typical of these long period asteroids, it could not be observed long enough to prove the case.

(159493) 2000 UA. This Mars Crosser has never had a period reported in the Asteroid lightcurve database (LCDB; Warner *et al*., 2009).

(285944) 2001 RZ11. Follow up of this Mars Crossing asteroid was requested by Vladimir Benishek (private communication). He had observed 2001 RZ11 from 18 August to 28 August. However, due to the change of phase angle over this time span and the relatively low amplitude, he could not derive a satisfactory rotational period, finally settling on 9.6 h derived from the last 5 nights of his observing run. The 5 nights in this observing run were at a higher phase angle which did not change much. We found two possible periods of 4.002 h and 4.804 h representing 5 and 6 rotations per Earth day. We slightly favor the 4.804 h period, representing a half period of the Benishek result which assumed a bimodal lightcurve. With an amplitude of only 0.11 mag., Harris (Harris *et al* 2014) demonstrated the lightcurve could have a single or three or more extrema.

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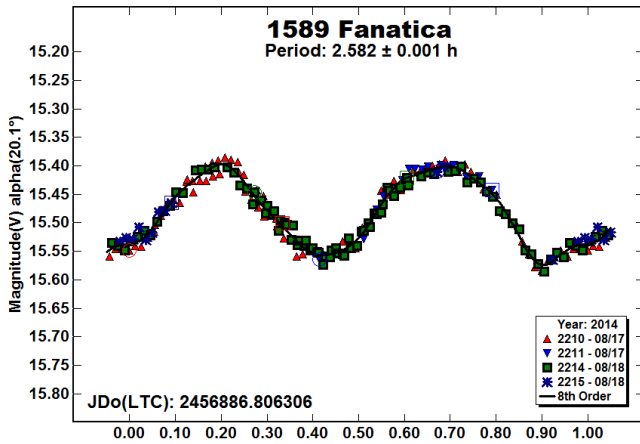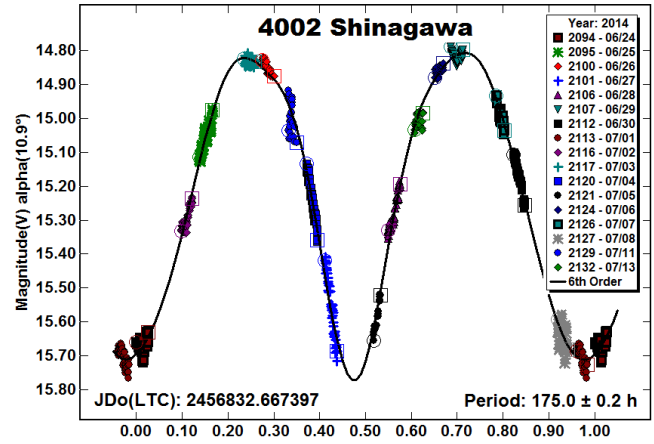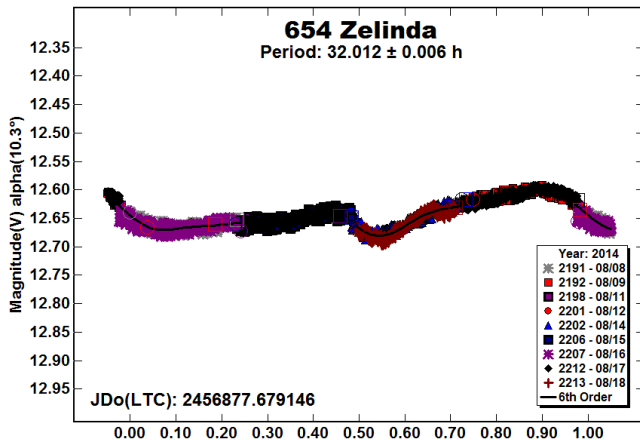Warner, B.D. and Higgins, D. (2008). "Lightcurve Analysis of 654 Zelinda." *Minor Planet Bul*. **35**, 32-33.
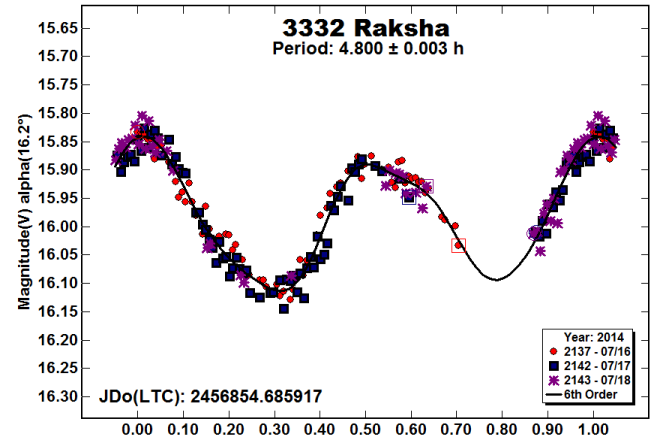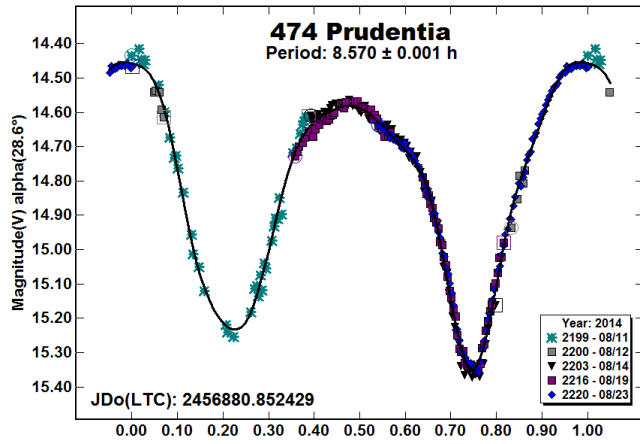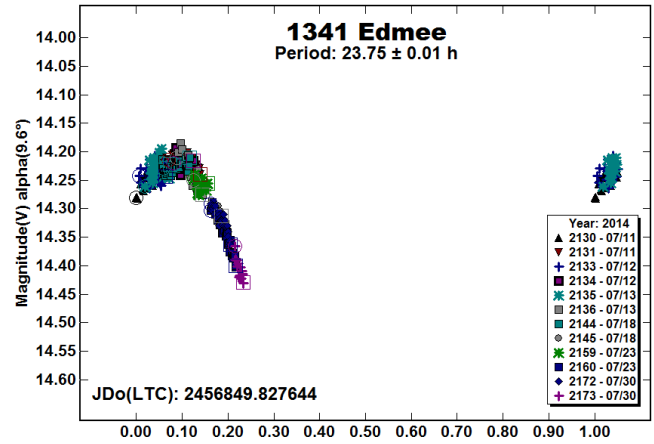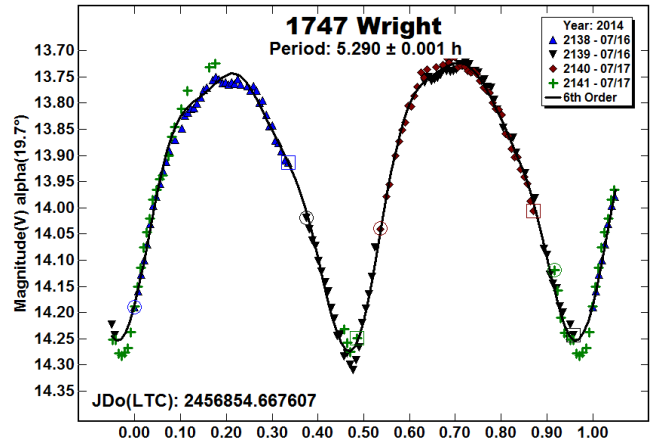
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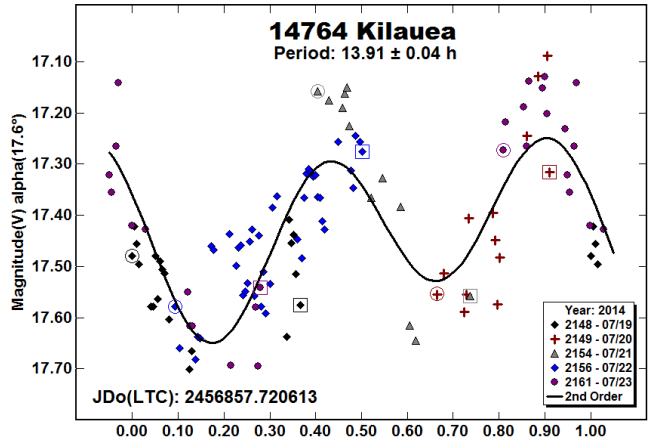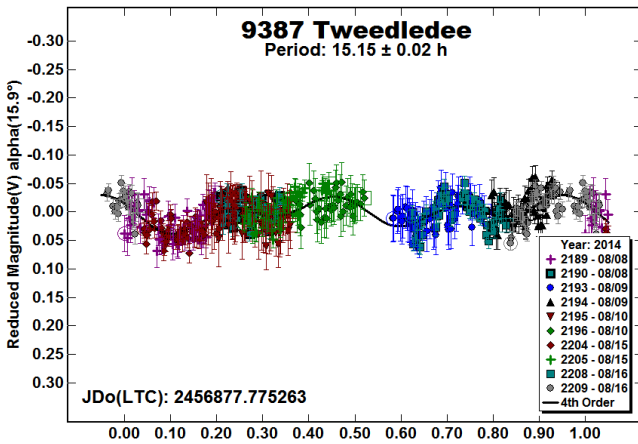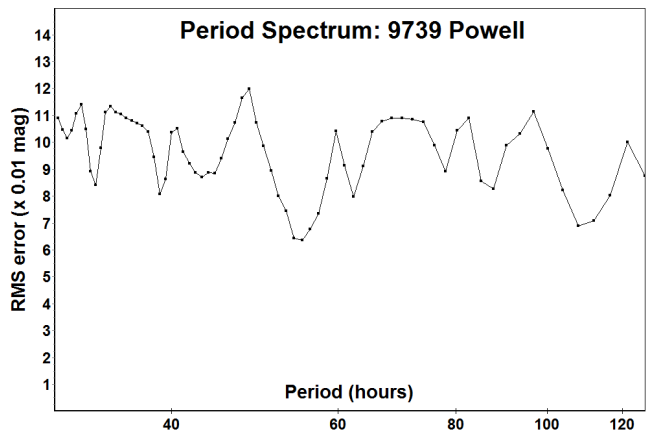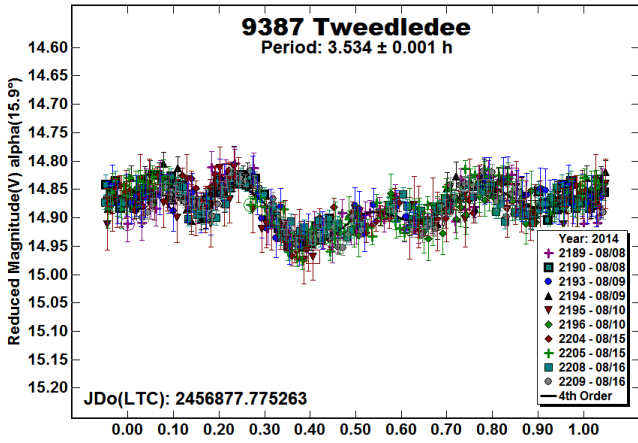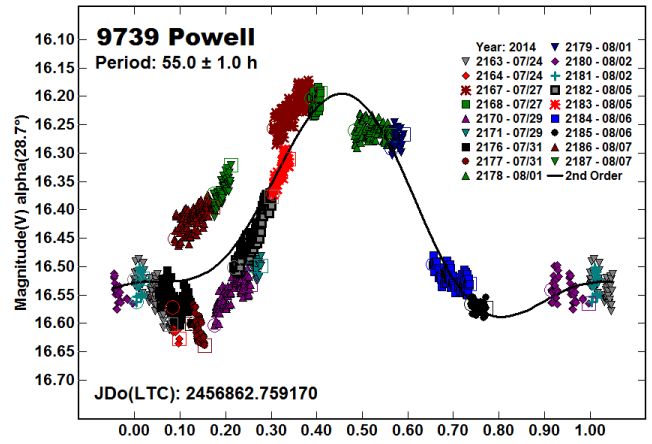Warner, B.D., Harris, A.W., and Pravec, P. (2009). *Icarus* **202**, 134-146. Updated 2014 February 28. *http://www.minorplanet.info/lightcurvedatabase.html.*

Acknowledgements

1747 Wright
Period: 5.290 ± 0.001 h

474 Prudentia
Period: 8.570 ± 0.001 h

1341 Edmee
Period: 23.75 ± 0.01 h

654 Zelinda
Period: 32.012 ± 0.006 h

3332 Raksha
Period: 4.800 ± 0.003 h

1589 Fanatica
Period: 2.582 ± 0.001 h

4002 Shinagawa
Period: 175.0 ± 0.2 h

4910 Kawasato
Period: 4.662 ± 0.001 h

9739 Powell
Period: 109.0 ± 1.0 h

7330 Annelemaitre
Period: 4.438 ± 0.001 h

9739 Powell
Period: 55.0 ± 1.0 h

9387 Tweedledee
Period: 3.534 ± 0.001 h

Period Spectrum: 9739 Powell

9387 Tweedledee
Period: 15.15 ± 0.02 h

14764 Kilauea
Period: 13.91 ± 0.04 h

14764 Kilauea
Period: 19.59 ± 0.05 h

(159493) 2000 UA
Period: 14.517 ± 0.005 h

(14764) 7072 P-L
Period: 15.74 ± 0.01 h

(285944) 2001 RZ11
Period: 4.002 ± 0.003 h

(14764) 7072 P-L
Period: 19.00 ± 0.02

(285944) 2001 RZ11
Period: 4.804 ± 0.004 h

(38063) 1999 FH
Period: 990.0 ± 50.0 h

Period Spectrum: (285944) 2001 RZ11
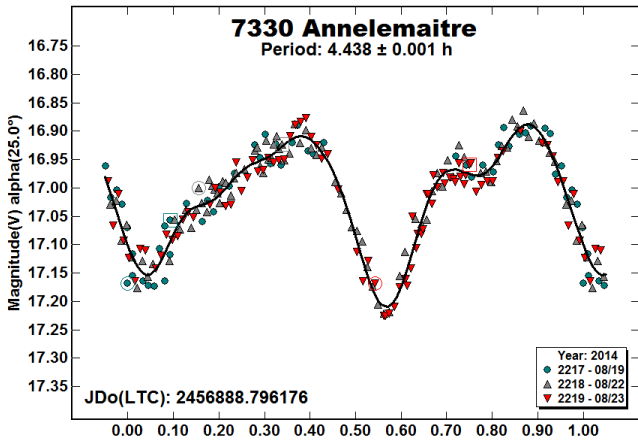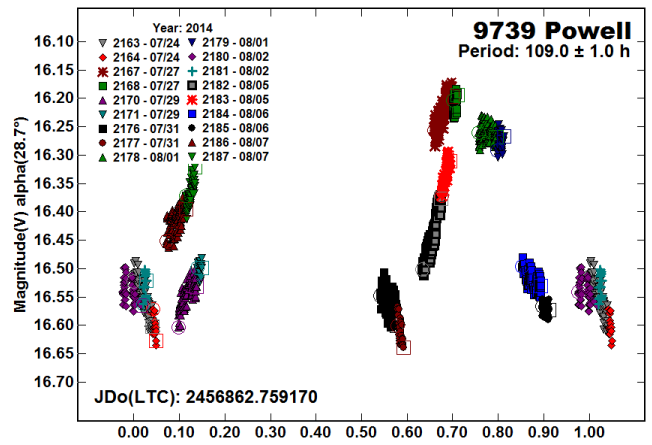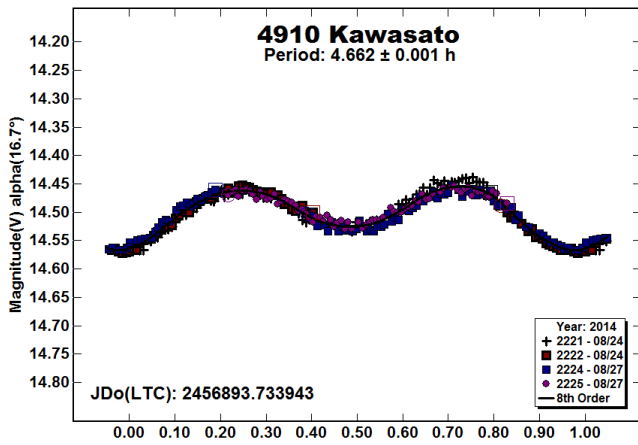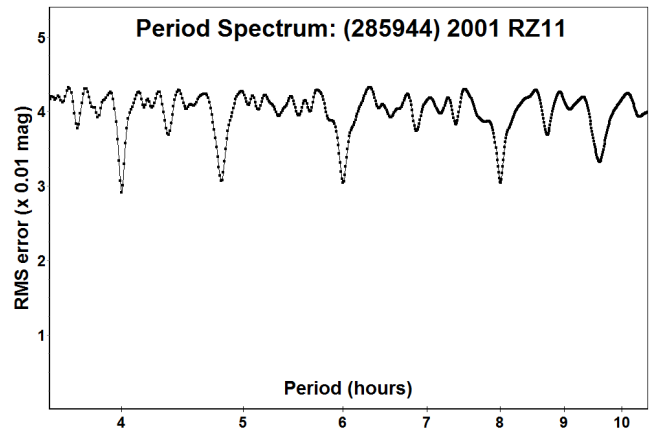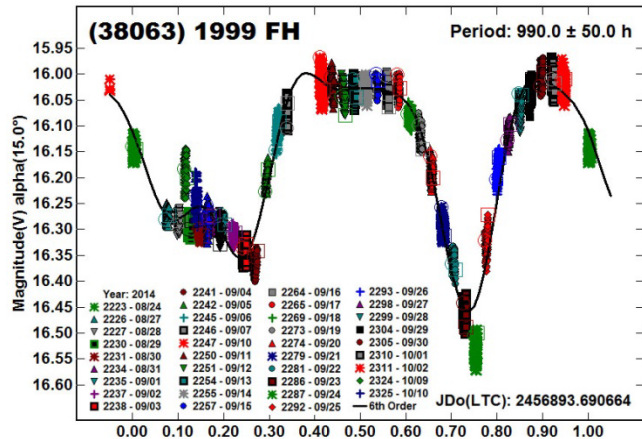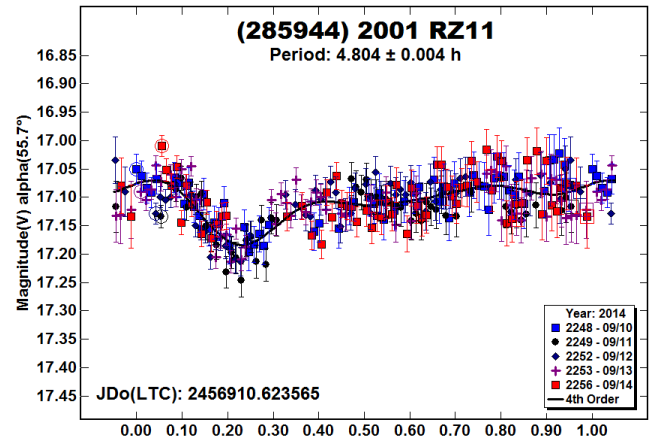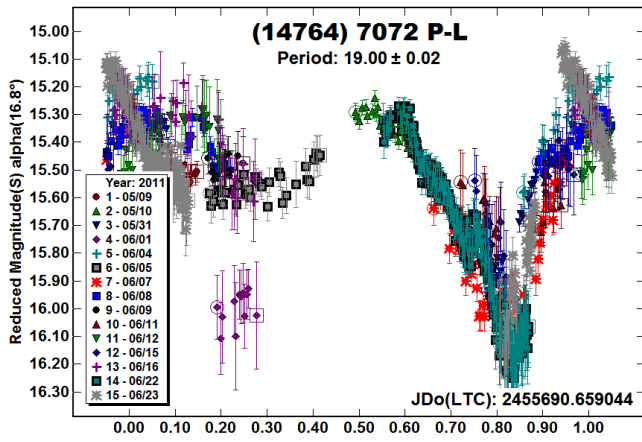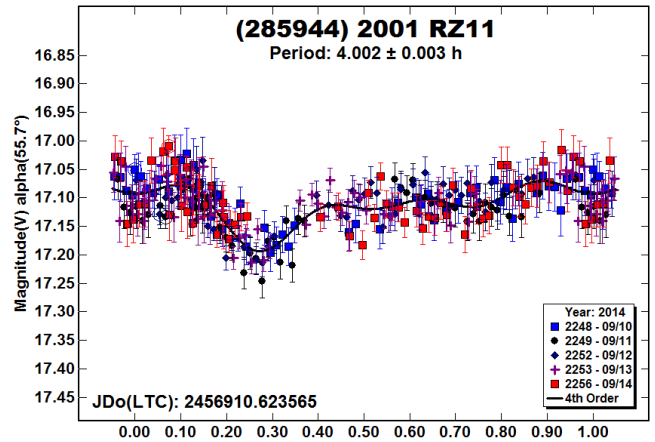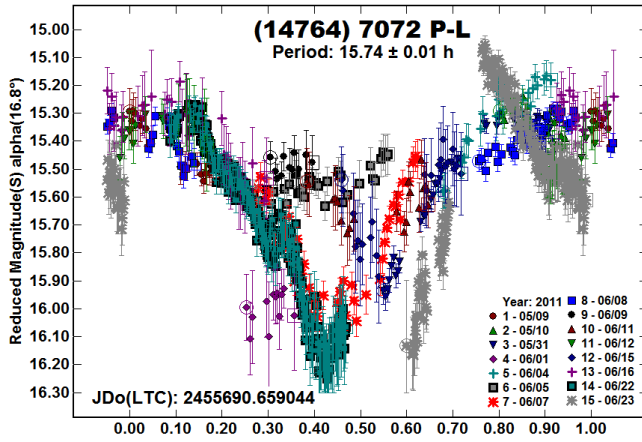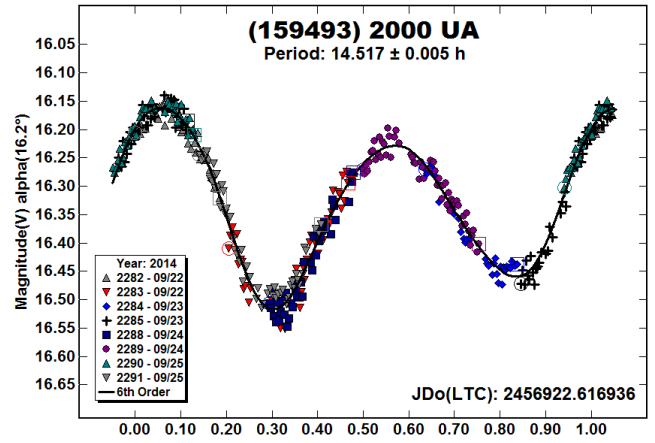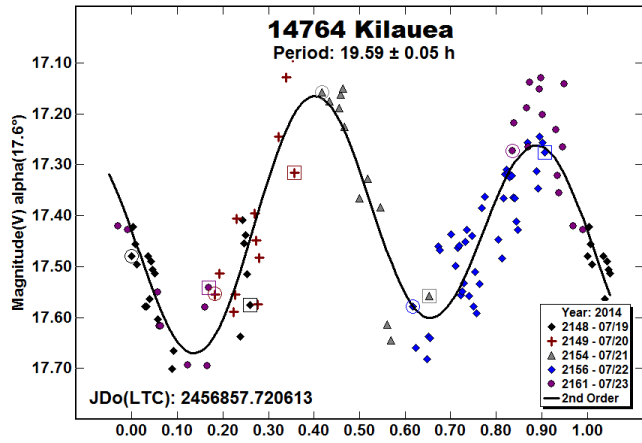
ROTATION PERIOD DETERMINATIONS FOR 1095 TULIPA, 1626 SADEYA, 2132 ZHUKOV, AND 7173 SEPKOSKI

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Observations from 2013 October to 2014 March produced synodic rotation periods and lightcurve amplitudes for the minor planets 1095 Tulipa, 1626 Sadeya, 2132 Zhukov, and 7173 Sepkoski.

Photometric observations of four asteroids were carried out at the Sopot Astronomical Observatory (SAO) from 2013 October through 2014 March employing a 0.35-m f/6.3 Meade LX200GPS Schmidt-Cassegrain (SCT) and SBIG ST-8 XME CCD camera. The camera was operated in 2x2 binning mode in order to increase signal-to-noise ratio. All observations were unfiltered and unguided. Prior to measurements, all images were corrected using dark and flat field frames. Differential photometry with up to five comparison stars, lightcurve construction, and period analysis were performed using *MPO Canopus* software (Warner, 2012). Only the instrumental magnitudes were used for all period determinations. To produce best lightcurve fit, the zero-point of each individual data set was adjusted until a minimum Fourier residual was reached. All targets have been selected using the CALL website maintained by Warner (2014a). The individual results for each target are shown below.

1095 Tulipa. This target was previously observed by Benishek during its apparition in 2006 July (Benishek, 2008). The observations at that time, conducted over 5 nights, led to a synodic rotation period of 2.7879 hours. Other authors have also reported quite close values for a period: 2.77 h (Binzel, 1987), 2.78721 h (Behrend, 2005), and 2.787 h (Husarik, 2011). Regardless of many previous rotation period determinations, this target was still listed as a potential lightcurve target on the CALL website in 2013 December. Guided by the idea that new photometric observations may be useful for future shape/spin modeling, the author decided to observe 1095 Tulipa again. The observations were started on 2013 December 03. As of 2014 January 03, a total number of 536 data points in 4 individual data sets were obtained. As expected, the period analysis confirmed the previously found rotation period results. A bimodal lightcurve (Fig. 1) phased to 2.7873 ± 0.0001 hours and with an amplitude of 0.21 ± 0.02 magnitudes was obtained as the most favorable solution.

1626 Sadeya. The observations of this target were launched as a by-product of a systematic photometric follow-up of the slow rotator 3345 Tarkovskij in 2013 December, Sadeya being in the same field-of-view with 3345 Tarkovskij on 2013 December 21. The asteroid was also listed as a potential lightcurve target for 2013 December on the CALL website. The observations started on 2013 December 21 and lasted until 2014 February 15, encompassing a fairly large range of phase angle of 18.4 to 32.6 degrees. The lightcurve showed a pronounced shape change and increase in amplitude with increasing phase angle due to the changing viewing geometry. For this reason, the overall data were divided into two groups, which were analyzed separately. The first group of data obtained at relatively low phase angles (18.4 - 21.1

degrees) yielded the bimodal lightcurve phased to 3.418 ± 0.001 h with a fairly low amplitude of 0.08 ± 0.01 magnitudes (Fig. 2). The analysis of the second group of data obtained at higher phase angles (31.4 - 32.6 degrees) led to a period of 3.419 ± 0.001 hours (which is consistent with the low phase angle result) and significantly larger amplitude of the lightcurve (0.14 ± 0.02 mag; Fig. 3). These period values are also in accordance with the period results previously found by other authors: 3.438 h (Florczak, 1997), 3.420 h (Behrend, 2007), 3.42048 h (Behrend, 2009), 3.4200 h (Oey, 2008), 3.414 h (Warner, 2010), and 3.420 h (Warner, 2014b).

2132 Zhukov. No previous period determinations were found for this asteroid. It was listed as a potential lightcurve target on the CALL website in 2014 January (Warner, 2014). Period analysis of the data obtained from 2014 January 12 through March 20 gives a bimodal lightcurve solution phased to 6.836 ± 0.001 h and amplitude of 0.45 ± 0.01 mag (Fig. 4). Such a large amplitude value at fairly low phase angles (8.3 - 17.7 degrees) virtually assures a bimodal solution.

7173 Sepkoski. A search for previous reports on period determinations for this Hungaria asteroid found Warner (2011, 2.50 h; 2014c, 2.5006 h), Han (2013, 2.44 h). Warner (2014c) also points to the possibility of a binary nature for this asteroid. Photometric observations carried out at the SAO over 7 nights from 2013 October 27 through November 08 produce a low amplitude (0.11 mag.) bimodal lightcurve phased to a period of 2.5002 h (Fig. 5), which is highly consistent with the value recently obtained by Warner (2014c).

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Warner, B.D. (2014b). "Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2014 January-March." *Minor Planet Bul.* **41**, 144-155.

Warner, B.D. (2014c). "Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2013 September-December." *Minor Planet Bul.* **41**, 102-112.
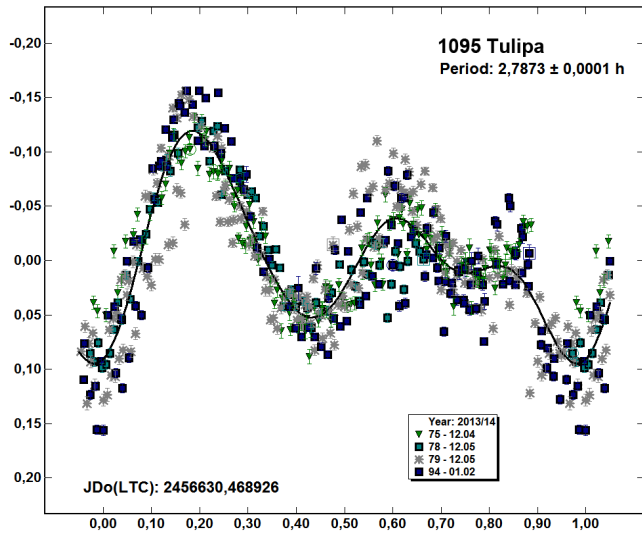
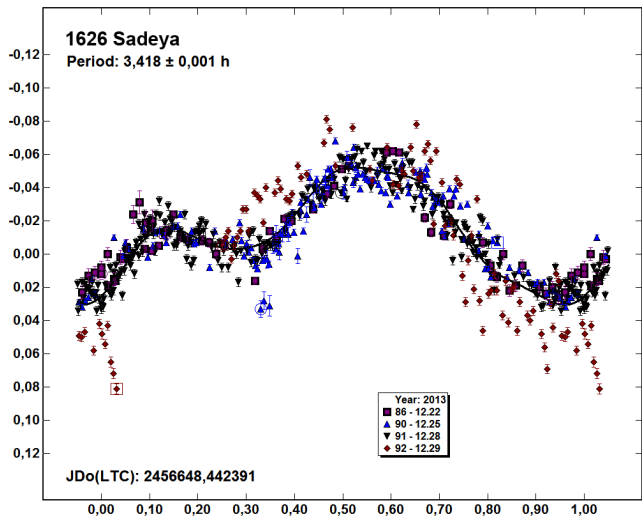Figure 1. The composite lightcurve plot for 1095 Tulipa.

Figure 2. The composite lightcurve plot for 1626 Sadeya using data from 2013 December.
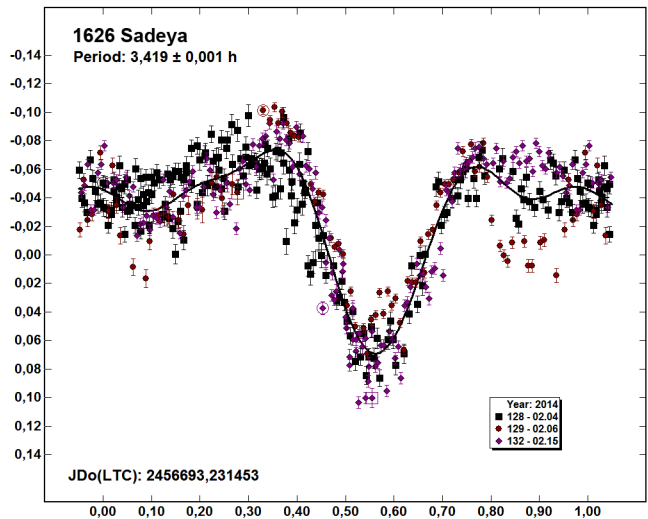

Figure 3. The composite lightcurve plot for 1626 Sadeya using data from 2014 February.
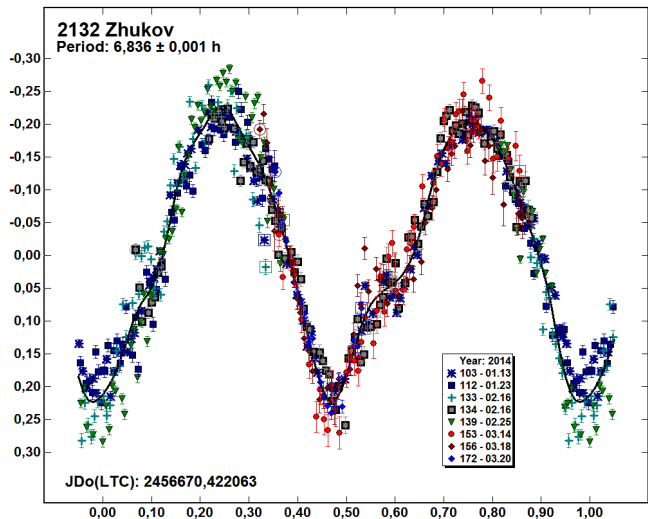

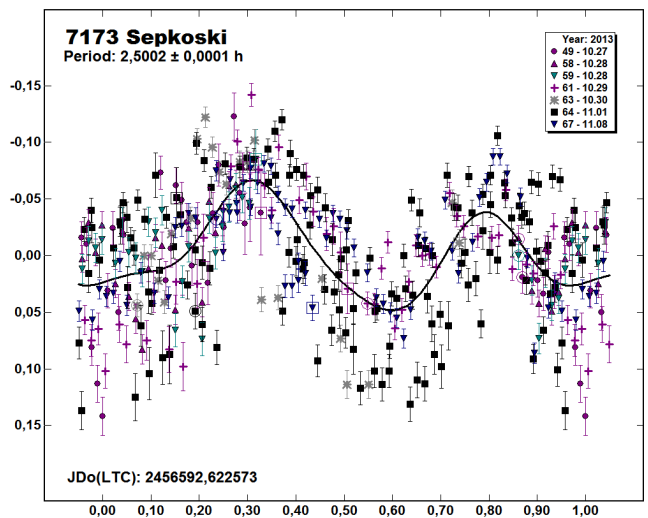Figure 4. The composite lightcurve plot for 2132 Zhukov.

Figure 5. The composite lightcurve plot for 7173 Sepkoski.

TARGET ASTEROIDS! OBSERVING CAMPAIGNS FOR JANUARY THROUGH MARCH 2015

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Asteroid campaigns to be conducted by the *Target Asteroids!* program during the period of January through March 2015 are described. In addition to asteroids on the original *Target Asteroids!* list of easily accessible spacecraft targets, an effort has been made to identify other asteroids that are 1) brighter and easier to observe for small telescope users and 2) analogous to (101955) Bennu, the target asteroid of the OSIRIS-REx sample return mission.

Introduction

The *Target Asteroids!* program strives to engage telescope users of all skill levels and telescope apertures to observe asteroids that are viable targets for robotic sample return. The program also focuses on the study of asteroids that are analogous to (101955) Bennu and (162173) 1999 JU3, the target asteroids of the NASA OSIRIS-REx and JAXA Hayabusa-2 sample return missions respectively. Most target asteroids are near-Earth asteroids (NEA) though observations of relevant Main Belt asteroids (MBA) are also requested.

Even though many of the observable objects in this program are faint, acquiring a large number of low S/N observations allows many important parameters to be determined. For example, an asteroid's phase function can be measured by obtaining photometry taken over a wide range of phase angles. The albedo can be constrained from the phase angle observations, as there is a direct correlation between phase function and albedo (Belskaya and Shevchenko (2000). The absolute magnitude can be estimated by extrapolating the phase function to a phase angle of 0°. By combining the albedo and absolute magnitude, the size of the object can be estimated.

An overview of the *Target Asteroids!* program can be found at Hergenrother and Hill (2013).

Current Campaigns

Target Asteroids! plans to conduct a number of dedicated campaigns on select NEAs and analog carbonaceous MBAs during the quarter. These campaigns have a primary goal of conducting photometric measurements over a large range of phase angles.

Target Asteroids! objects brighter than V = 18.0 are presented in detail. A short summary of our knowledge of each asteroid and 10-day (shorter intervals for objects that warrant it) ephemerides are presented. The ephemerides include rough RA and Dec positions, distance from the Sun in AU (r), distance from Earth in AU (Δ), V magnitude, phase angle in degrees (PH) and elongation from the Sun in degrees (Elong).

We ask observers with access to large telescopes to attempt observations of spacecraft accessible asteroids that are between V magnitude ~18.0 and ~20.0 during the quarter (contained in the table below).

Asteroid Number	Name	Peak V Mag	Time of Peak Brightness
(89136)	2001 US16	19.2	mid Feb
(136635)	1994 VA1	18.8	mid Jan
(303450)	2005 BY2	18.5	early Jan
	2002 TD60	18.7	late Mar

The campaign targets are split up into two sections: 1) carbonaceous MBA that are analogous to Bennu and 1999 JU3 and 4) NEAs analogous to the Bennu and 1999 JU3 or provide an opportunity to fill some of the gaps in our knowledge of these spacecraft targets (examples include very low and high phase angle observations, phase functions in different filters and color changes with phase angle).

The ephemerides listed below are just for planning purposes. In order to produce ephemerides for your observing location, date and time, please use the Minor Planet Center's Minor Planet and Comet Ephemeris Service:

http://www.minorplanetcenter.net/iau/MPEph/MPEph.html

or the *Target Asteroids!* specific site created by Tomas Vorobjov and Sergio Foglia of the International Astronomical Search Collaboration (IASC) at

http://iasc.scibuff.com/osiris-rex.php

Analog Carbonaceous Main Belt Asteroid Campaigns

(19) Fortuna (a=2.44 AU, e=0.16, i=1.6°, H = 7.1)

Fortuna is one of the larger asteroids in the Main Belt with a diameter of ~220 km. Taxonomically it is classified as a Ch-type or hydrated carbonaceous asteroid. It rotates once every 7.44 hours with a lightcurve amplitude of 0.2-0.3 magnitudes. Though an inner Main Belt carbonaceous asteroid, it does not appear to belong to any obvious collisional family. Such 'background' objects may still be related to objects like Bennu.

From February through April, we have an opportunity to measure the phase function of Fortuna from a maximum phase angle of 20° to an extremely low 0.02° on April 23. We request lightcurve and phase function photometry of this object as well as color photometry and low-resolution spectroscopy.

DATE	RA	DEC	Δ	r	V	PH	Elong
02/10	14 25.1	-14 48	2.43	2.81	12.4	20	101
02/20	14 28.9	-15 04	2.30	2.81	12.2	19	111
03/02	14 30.5	-15 08	2.18	2.82	12.1	17	120
03/12	14 29.5	-15 00	2.06	2.82	11.9	15	131
03/22	14 25.9	-14 39	1.97	2.82	11.7	12	141
04/01	14 19.9	-14 05	1.89	2.82	11.4	9	153

(335) Roberta (a=2.47 AU, e=0.17, i=5.1°, H = 8.9)

Roberta may be a member of the Eulalia family with a B-type taxonomy and a low albedo of 0.058 (Walsh et al. 2013). Lightcurve observations found a period of ~12 hours and low amplitude of 0.06-0.17. Phase function observations are possible from 21° (in late April) to a minimum of 0.56° (on Feb 5 UT). As with Fortuna, phase function, lightcurve and color photometry is requested.

DATE	RA	DEC	Δ	r	V	PH	Elong
01/01	09 40.3	+11 33	2.06	2.86	13.6	13	136
01/11	09 35.4	+12 05	1.97	2.85	13.4	10	147
01/21	09 28.3	+12 50	1.90	2.84	13.1	6	160
01/31	09 19.6	+13 45	1.85	2.83	12.9	2	172
02/10	09 10.2	+14 44	1.84	2.82	12.8	1	174
02/20	09 00.9	+15 41	1.86	2.82	13.0	6	162
03/02	08 53.0	+16 31	1.90	2.80	13.3	10	150
03/12	08 47.2	+17 12	1.97	2.79	13.5	13	138
03/22	08 43.9	+17 42	2.06	2.78	13.6	16	127
04/01	08 43.3	+17 59	2.16	2.77	13.8	18	117

(3064) Zimmer (a=2.45 AU, e=0.12, i=2.9°, H = 13.4)
Many of the Main Belt asteroids observed by *Target Asteroids!* have been large bodies with diameters on the order of 50 to hundreds of kilometers. Zimmer and Nakamura, the next asteroid listed below, are only on the order of 10 km or so in diameter. Zimmer is a member of either the carbonaceous Eulalia or 'Old' Polana families (Walsh et al. 2013) Surprisingly, no lightcurve parameters have been published for this object. Lightcurve photometry is especially requested in addition to color and phase function photometry. Phase function photometry can be obtained over a range of 27° to 1.3°.

DATE	RA	DEC	Δ	r	V	PH	Elong
01/01	12 24.5	-02 29	1.86	2.16	17.6	27	93
01/11	12 35.2	-03 24	1.74	2.15	17.5	26	100
01/21	12 44.0	-04 04	1.63	2.16	17.3	25	108
01/31	12 50.5	-04 26	1.52	2.16	17.1	23	117
02/10	12 54.2	-04 30	1.42	2.16	16.9	21	126
02/20	12 54.9	-04 12	1.33	2.16	16.7	18	136
03/02	12 52.6	-03 34	1.26	2.16	16.4	14	147
03/12	12 47.4	-02 38	1.21	2.17	16.1	9	158
03/22	12 40.1	-01 30	1.18	2.17	15.8	4	170
04/01	12 31.6	-00 18	1.18	2.18	15.7	2	175

(4219) Nakamura (a=2.46 AU, e=0.12, i=3.1°, H = 13.5)
Nakamura is similar to Zimmer in that it is a carbonaceous asteroid and member of either the Eulalia or 'Old' Polana family (Walsh et al. 2013). These families are of interest since they may be the sources of both the OSIRIS-REx and Hayabusa-2 mission targets (Walsh et al. 2013). Nakamura also does not have any published lightcurve data so lightcurves are requested. Lightcurve photometry is especially requested in addition to color and phase function photometry. Phase function photometry is possible this quarter from 22° down to a very low 0.08° on Feb 7.

DATE	RA	DEC	Δ	r	V	PH	Elong
01/01	09 47.7	+12 13	1.56	2.36	17.2	17	135
01/11	09 44.7	+12 39	1.47	2.35	17.0	13	146
01/21	09 38.9	+13 22	1.39	2.33	16.7	9	157
01/31	09 30.8	+14 17	1.35	2.32	16.4	4	170
02/10	09 21.4	+15 18	1.32	2.31	16.1	1	177
02/20	09 11.9	+16 18	1.33	2.30	16.4	6	164
03/02	09 03.9	+17 10	1.36	2.29	16.7	11	152
03/12	08 58.4	+17 48	1.41	2.27	16.9	15	141
03/22	08 55.9	+18 11	1.49	2.26	17.1	19	130
04/01	08 56.8	+18 18	1.57	2.25	17.3	22	120

Near-Earth Asteroid Campaign Targets

(1580) Betulia (a=2.19 AU, e=0.48, i=52.1°, H = 14.5)
Near-Earth asteroid Betulia has been selected as a *Target Asteroids!* campaign object due to its low albedo (0.077) and taxonomy (C-type). During the current quarter it brightens from V = 17.7 to 16.8 as its phase angle increases from 31° to 51°. Observing circumstances improve during the next quarter as Betulia reaches V = 14.7 and a maximum phase angle of 63° in late May/early June.

DATE	RA	DEC	Δ	r	V	PH	Elong
01/01	14 45.3	+74 14	1.30	1.81	17.7	31	104
01/11	16 07.7	+74 11	1.27	1.75	17.6	33	101
01/21	17 16.5	+73 12	1.25	1.69	17.6	35	97
01/31	18 08.8	+71 54	1.23	1.62	17.5	37	93
02/10	18 47.6	+70 45	1.21	1.56	17.4	39	89
02/20	19 15.9	+70 01	1.18	1.49	17.4	41	86
03/02	19 36.1	+69 49	1.14	1.43	17.3	43	84
03/12	19 48.7	+70 11	1.09	1.37	17.1	45	82
03/22	19 53.4	+71 09	1.03	1.32	17.0	48	81
04/01	19 47.4	+72 42	0.95	1.26	16.8	51	80

(3200) Phaethon (a=1.27 AU, e=0.89, i=22.2°, H = 14.6)
Phaethon is well known as the parent object of the Geminid meteor shower. Whether the shower was produced by cometary activity or a series of splitting events, the Geminids are now one of the strongest annual showers. Recently Phaethon has been observed to display comet-like activity around perihelion (Jewitt et al. 2013, Li and Jewitt 2013). It is a B-type asteroid similar to Bennu, the OSIRIS-REx target. Though carbonaceous, it is not as dark as many other carbonaceous asteroids (albedo 0.11). A rotation period of 3.60 h and amplitude of up to 0.34 magnitudes have been measured for this 5 km near-Earth asteroid.

Phaethon peaks in brightness at V ~ 16.1 in early December. Its phase angle ranges from a minimum of 9° in late November to over 100° in early March 2015.

DATE	RA	DEC	Δ	r	V	PH	Elong
01/01	01 48.5	+22 40	0.78	1.47	16.4	37	112
01/11	01 29.8	+17 51	0.82	1.35	16.6	46	97
01/21	01 18.3	+13 50	0.85	1.22	16.7	52	82
01/31	01 11.6	+10 26	0.88	1.07	16.6	59	69
02/10	01 06.6	+07 19	0.89	0.90	16.5	66	57
02/20	00 59.5	+03 55	0.87	0.71	16.2	76	44

(3691) Bede (a=1.77 AU, e=0.28, i=20.3°, H = 14.6)
Bede is a bit of an enigma. Spectra show it to be an Xc or Cgh carbonaceous asteroid. Such objects should be dark and yet its measured albedo is very high at ~0.4. This quarter Bede will peak near magnitude 14.8 in early March. Color phase photometry is possible over phase angles from 12° to 52°.

DATE	RA	DEC	Δ	r	V	PH	Elong
01/01	11 12.1	+32 27	0.98	1.70	17.0	29	120
01/11	11 16.7	+32 22	0.87	1.67	16.6	27	128
01/21	11 15.9	+32 21	0.76	1.63	16.2	24	137
01/31	11 08.3	+32 12	0.67	1.59	15.8	20	146
02/10	10 53.3	+31 34	0.60	1.55	15.3	15	154
02/20	10 31.5	+29 59	0.55	1.51	15.0	12	160
03/02	10 06.1	+27 05	0.51	1.48	14.8	14	157
03/12	09 42.1	+22 50	0.50	1.44	15.0	21	148
03/22	09 23.6	+17 44	0.51	1.41	15.2	28	136
04/01	09 12.6	+12 21	0.53	1.38	15.4	35	126

(141527) 2002 FG7 (a=1.51 AU, e=0.62, i=9.1°, H = 18.9)
Peaking at magnitude 14.2 in mid-March, 2002 FG7 has an excellent apparition for phase function determination as its phase angle ranges from >100° down to 12°. No physical characteristics have yet been published for this object. Phase angle, lightcurve and color photometry are requested.

DATE	RA	DEC	Δ	r	V	PH	Elong
03/09	23 54.1	-56 53	0.06	0.95	18.1	124	52
03/10	00 03.8	-64 10	0.05	0.96	17.2	116	60
03/11	00 27.3	-73 18	0.05	0.97	16.4	107	70
03/12	02 27.0	-83 39	0.04	0.98	15.6	95	81
03/13	09 41.3	-79 53	0.04	0.99	15.0	81	95
03/14	10 44.9	-66 19	0.04	1.01	14.5	67	110
03/15	11 02.1	-53 11	0.04	1.02	14.3	53	123
03/16	11 10.0	-41 57	0.05	1.03	14.2	42	135
03/22	11 23.3	-09 37	0.10	1.09	14.9	12	166
04/01	11 28.9	+03 06	0.21	1.20	16.8	16	160

(357439) 2004 BL86 (a=1.50 AU, e=0.40, i=23.7°, H = 19.1)
The brightest NEA of 2015 will be (357439) 2004 BL86 at V ~ 9.4 making it an easy visual object in small telescopes. Almost nothing is known about the physical properties of 2004 BL86. This will undoubtedly change as its close approach will allow some of the highest resolution radar imaging yet of an asteroid.

Approaching Earth from the south, BL86 is solely a southern object till the day of its close approach on January 26 UT (when it will pass within 0.008 AU of Earth. A day after close approach it will only be visible from the Northern Hemisphere. Southern observers will be able to pick it up at a phase angle of ~108°. All observers should be able to follow it to a minimum phase angle of 1.2°. Phase angle, lightcurve and color photometry are requested. At 9th magnitude, it will be bright enough for small telescope spectroscopy.

DATE	RA	DEC	Δ	r	V	PH	Elong
01/01	23 50.9	-71 24	0.22	0.90	19.4	103	64
01/11	00 22.2	-72 24	0.14	0.93	18.7	107	64
01/21	01 46.5	-74 17	0.05	0.96	16.7	108	69
01/22	02 14.3	-74 26	0.04	0.97	16.2	106	70
01/23	02 56.3	-74 14	0.03	0.97	15.6	104	73
01/24	04 01.2	-72 52	0.02	0.98	14.7	100	78
01/25	05 33.1	-67 17	0.01	0.98	13.5	91	87
01/26	07 12.4	-46 13	0.01	0.98	11.5	67	112
01/27	08 29.6	+08 29	0.01	0.99	9.4	10	169
01/28	09 20.4	+43 01	0.01	0.99	11.1	25	153
01/29	09 53.4	+54 49	0.02	1.00	12.4	38	141
01/31	10 15.6	+59 58	0.03	1.00	13.3	43	135
02/10	11 18.5	+68 10	0.13	1.06	16.7	50	123
02/20	11 21.6	+67 56	0.22	1.12	17.9	48	122
03/02	11 17.8	+66 25	0.31	1.18	18.7	46	120

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A QUARTET OF NEAR-EARTH ASTEROID BINARY CANDIDATES

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Analysis of CCD photometry observations at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) made in 2014 June-October found four main-belt binary candidates. 2012 Tantalus is a *probable* binary that shows a strong second period but no *mutual events*. (68348) 2001 LO7 is a *probable* binary, also showing a strong second period and no confirmed *mutual events*, but P_2 is a close to an integral multiple to P_1, which sometimes indicates a *harmonic alias*. (190208) 2006 AQ appears to be *probable wide binary*, showing a long period lightcurve superimposed by a short period, lower amplitude component. (276049) 2002 CE26 is a known binary (Shepard *et al.*, 2004). Pravec *et al.* (2006) reported P_1 = 3.293 h with no indications of the satellite. The 2014 observations at CS3 initially led to P_1 = 3.088 h. After further analysis and confirmation of the longer period (Pravec, personal communications), a period of P_1 = 3.928 h was adopted. Unlike the earlier results, there were indications of a satellite with P_{orb} = 16.26 h, which agrees with estimates for the orbital period based on the discovery radar observations. The lightcurve data, however, indicate a considerably larger satellite than indicated by radar.

CCD photometric observations of four main-belt asteroids made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) in 2014 June through October showed them to be binary candidates. 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 1.20-1.60 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*. If necessary, an elliptical aperture with the long axis parallel to the asteroid's path was used. 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 MPOSC3 catalog, which is based on the 2MASS catalog (*http://www.ipac.caltech.edu/2mass*) but with magnitudes converted from J-K to BVRI using formulae developed by Warner

Number	Name	2014 mm/dd	Pts	Phase	L_PAB	B_PAB	Period	P.E.	Amp	A.E.
2102	Tantalus	06/19-06/22	490	55.1,52.8	255	46	2.384	0.001	0.12	0.01
68348	2001 LO7	06/22-06/30	176	11.8,14.9	265	20	3.869	0.001	0.1	0.01
190208	2006 AQ	09/18-09/25	264	8.4,15.2	349	4	2.621	0.001	0.08	0.01
276049	2002 CE26	08/18-08/24	245	42.0,39.0	337	31	3.298	0.002	0.07	0.01

Table II. Observing circumstances. The period and amplitude are for the primary of the binary system. The phase angle (α) is given at the start and end of each date range, unless it reached an extremum, 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_{PAB} and B_{PAB} are each the average phase angle bisector longitude and latitude, unless two values are given (first/last date in range).

(2007). When possible, magnitudes are taken from the APASS catalog (Henden *et al.*, 2009) since these are derived directly from reductions based on Landolt standard fields. Using either catalog, the nightly zero points have been found to be consistent to about ±0.05 mag or better, but on occasion are as large as 0.1 mag. This consistency is critical to analysis of long period and/or tumbling asteroids. Period analysis is also done using *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*log (rΔ) to the measured sky magnitudes with r and Δ 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°), using *G* = 0.15, unless otherwise stated. The horizontal 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 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.
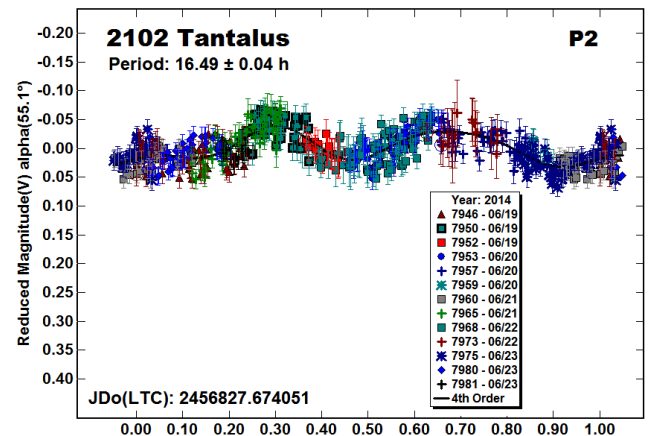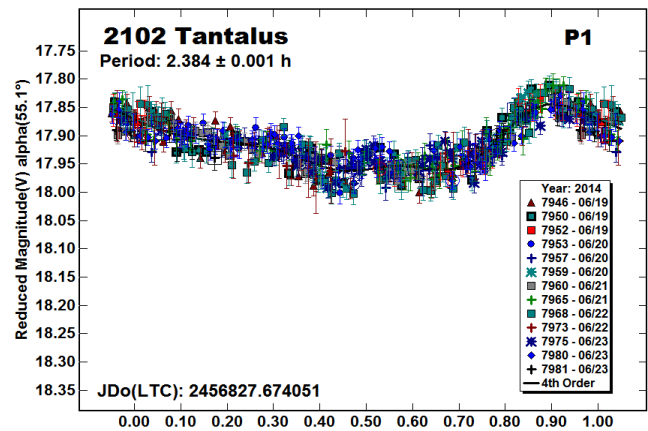
Individual Results

2102 Tantalus. Pravec *et al.* (1997) reported a weighted average period of 2.391 h, although one set of observations found a synodic period of 2.380 h, which is close to the period given here.
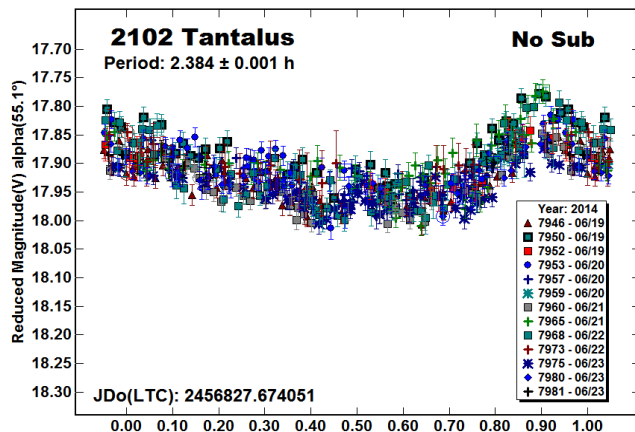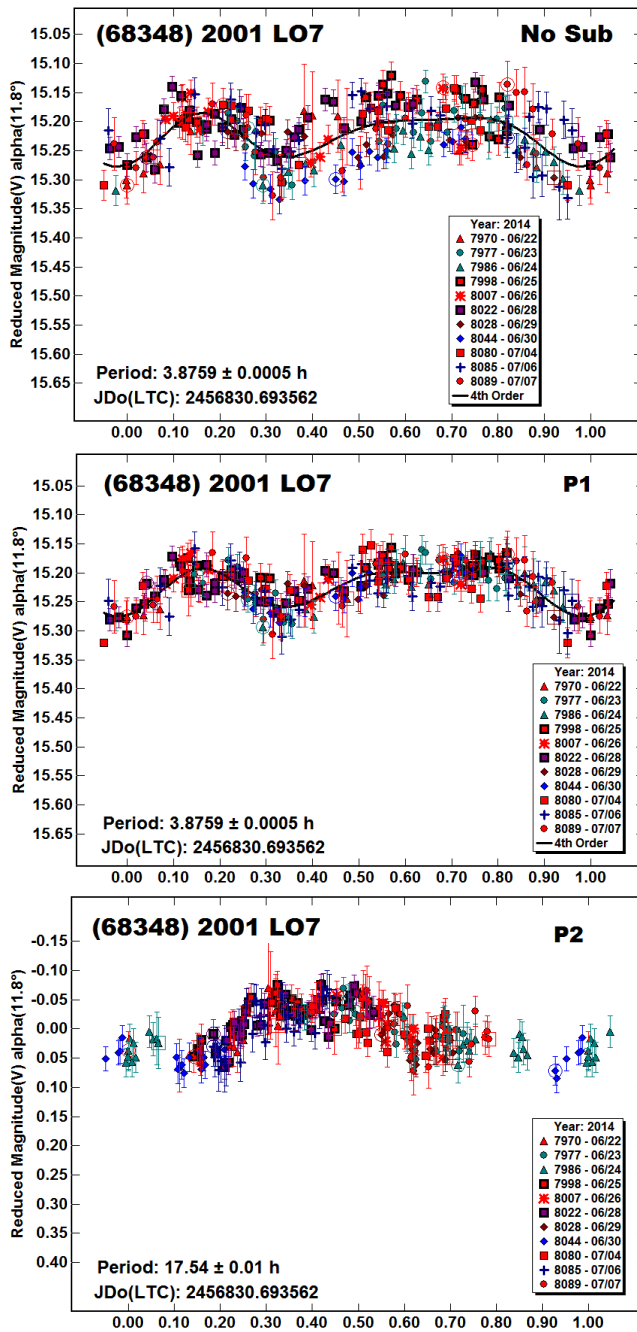

The plot labeled "No Sub" shows the results before using the dual period search feature of *MPO Canopus*. The larger than usual scatter prompted a search for a second period on the off-chance that it was due to something other than systematic or random reasons. The "P1" plot shows the eventual result for the purported primary of a binary system and shows considerably less scatter. The "P2" plot shows the lightcurve for the second period. This can be interpreted as an elongated satellite with a rotation period of 16.49 hours with the viewing geometry not favorable for seeing mutual events (occultations and/or eclipses). A half-period solution is also possible, but that would be too short if assuming typical densities for the two bodies. Since there are no mutual events seen, this is listed as a *probable* binary.

(68348) 2001 LO7. Skiff (2011) reported a period of 3.324 h based on two nights of observations in 2011. He did not report any indications of a satellite based on about 12 hours of observations.
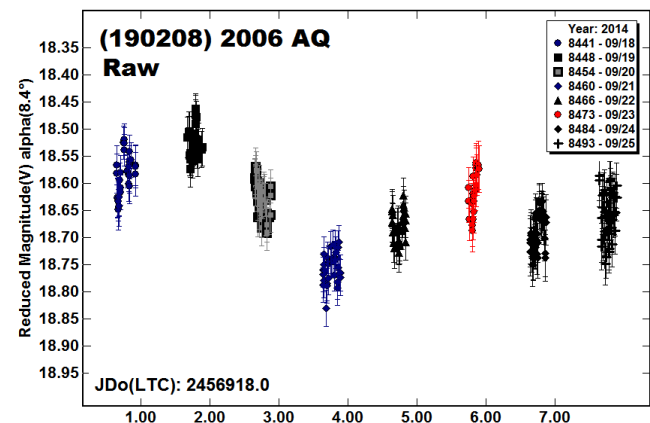
This is sometimes called a *harmonic alias*. Such aliasing is not considered likely in this case given the significant improvement in the P1 lightcurve when subtracting P2 or, put another way, the amplitude of P2 is larger than might be expected due to random or systematic effects.
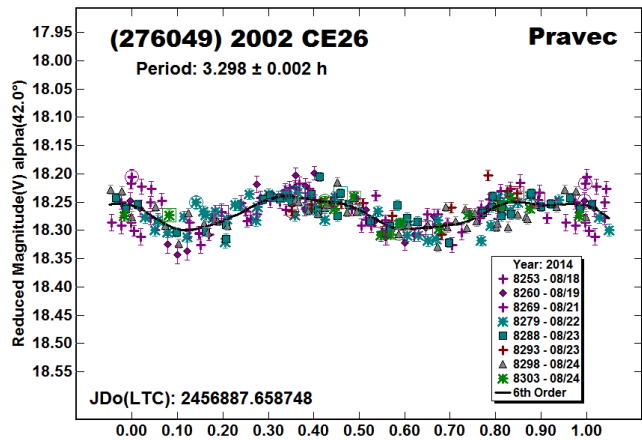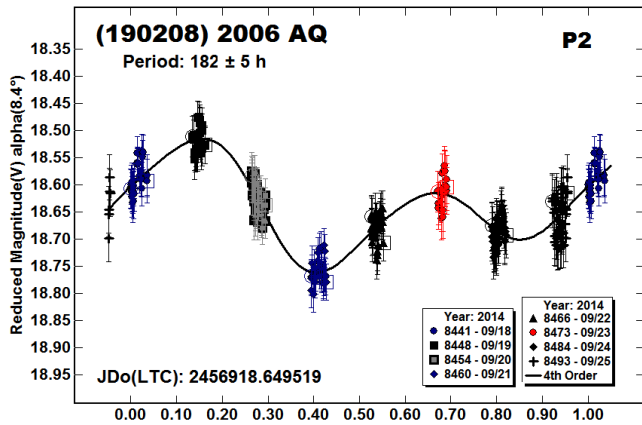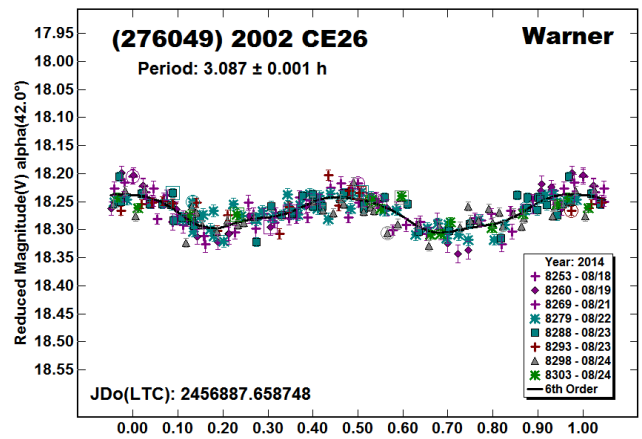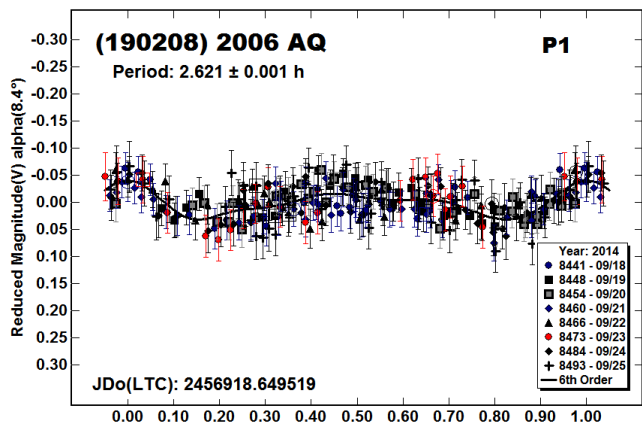
(190208) 2006 AQ. There are three basic types of small binary asteroids. One is the fully synchronous binary, where both bodies have the same rotation period that is also the orbital period. The fully asynchronous binary has both the primary and satellite rotating with different periods and the satellite's period is different from its orbital period. The two asteroids before are examples of the third type, the semi-synchronous binary, which is characterized by the primary and secondary having different rotation periods but the satellite's rotation period is also its orbital period. Jacobson and Scheeres (2011) discuss the different types in detail, how they form, and how they evolve. It is highly recommended reading.

2006 AQ is believed to be a member of the second type, i.e., a fully-asynchronous type and, more specifically, part of the *wide binary* subset. These objects show a long period lightcurve with an amplitude of at least 0.2 mag, often much larger, and periods usually in the hundreds of hours. On top of this is a short period, low amplitude lightcurve that is sometimes hard to distinguish from noise. Due to the conservation of rotational energy, the primary is responsible for the long period lightcurve. The fully-asynchronous satellite produces the short period lightcurve. The orbital period is very long and will likely never be known by photometric means since the odds of seeing mutual events are extremely remote.
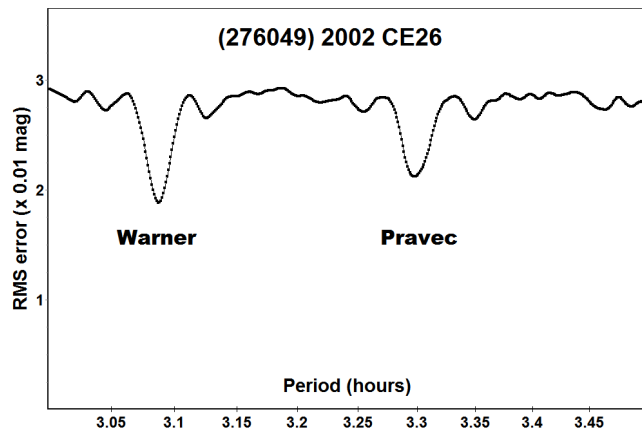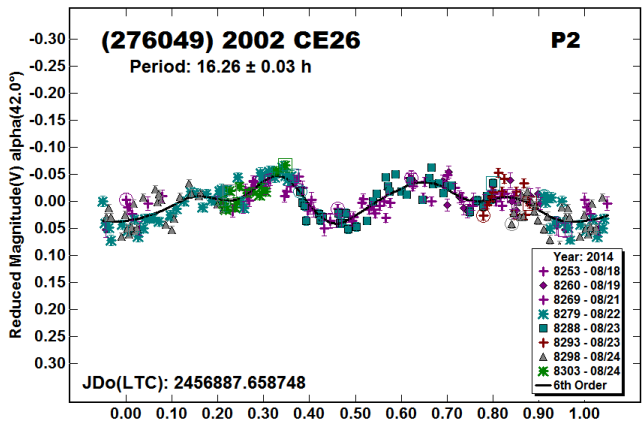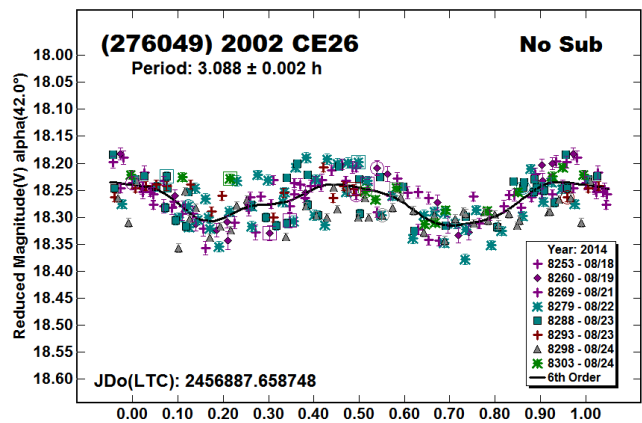
The "Raw" plot shows the data for 2006 AQ before any period analysis. A long period component seems very apparent. There are sometimes hints of the short period on this scale but usually the evidence that prompts a dual period search is found when looking at the individual nights and seeing what appears to be short term periodic behavior beyond random noise. The dual period search in *MPO Canopus* found the results shown in "P1" and "P2". The plot in P1 is one of the clearer cases of a short period component seen to-date. The curve in P2 is seen to have "cleaned up" somewhat from the raw plot after removing the P1 component.

It is important to emphasize that there is not a binary hiding within every long period lightcurve. Considerable care and review must be used to make sure that the short period component is not just the result of the Fourier analysis locking onto random noise. One way to avoid this is to use low-order analysis, e.g., no more than 4th order. Often, because of the relatively sparse coverage of the long period, a 2nd order search is the highest used for that period.

The "No Sub" plot shows some significant deviations, too much in most cases to be due to systematic or random effects. This prompted a dual period search which led to the results shown in the "P1" and "P2" plots. The P1 plot shows considerably less scatter. The period is also with the typical range for a small binary asteroid (Pravec *et al.*, 2010). The P2 plot has a period of 17.54 h, also within range of typical values given the primary period. The lightcurve is not complete but does show the typical bowing due to the rotation of a tidally-locked, elongated satellite. There are no obvious signs of mutual events, and so this must be listed as a *probable* binary candidate.

There is a caveat to the results for 2001 LO7. P2 happens to be very close to an integral ratio of 9:2 with P1. When the two periods have an integral ratio, there is a possibility that they are harmonically related and, therefore, due to the Fourier analysis locking onto noise of the shorter period to find a longer period.

(190208) 2006 AQ P1
Period: 2.621 ± 0.001 h
Reduced Magnitude(V) alpha(8.4°)

Year: 2014
8441 - 09/18
8448 - 09/19
8454 - 09/20
8460 - 09/21
8466 - 09/22
8473 - 09/23
8484 - 09/24
8493 - 09/25
— 6th Order

JDo(LTC): 2456918.649519

(190208) 2006 AQ P2
Period: 182 ± 5 h
Reduced Magnitude(V) alpha(8.4°)

Year: 2014
8441 - 09/18
8448 - 09/19
8454 - 09/20
8460 - 09/21
Year: 2014
8466 - 09/22
8473 - 09/23
8484 - 09/24
8493 - 09/25
— 4th Order

JDo(LTC): 2456918.649519

(276049) 2002 CE26.

(276049) 2002 CE26 No Sub
Period: 3.088 ± 0.002 h
Reduced Magnitude(V) alpha(42.0°)

Year: 2014
8253 - 08/18
8260 - 08/19
8269 - 08/21
8279 - 08/22
8288 - 08/23
8293 - 08/23
8298 - 08/24
8303 - 08/24
— 6th Order

JDo(LTC): 2456887.658748

(276049) 2002 CE26
RMS error (x 0.01 mag)
Warner   Pravec
Period (hours)

(276049) 2002 CE26 Warner
Period: 3.087 ± 0.001 h
Reduced Magnitude(V) alpha(42.0°)

Year: 2014
8253 - 08/18
8260 - 08/19
8269 - 08/21
8279 - 08/22
8288 - 08/23
8293 - 08/23
8298 - 08/24
8303 - 08/24
— 6th Order

JDo(LTC): 2456887.658748

(276049) 2002 CE26 Pravec
Period: 3.298 ± 0.002 h
Reduced Magnitude(V) alpha(42.0°)

Year: 2014
8253 - 08/18
8260 - 08/19
8269 - 08/21
8279 - 08/22
8288 - 08/23
8293 - 08/23
8298 - 08/24
8303 - 08/24
— 6th Order

JDo(LTC): 2456887.658748

(276049) 2002 CE26 P2
Period: 16.26 ± 0.03 h
Reduced Magnitude(V) alpha(42.0°)

Year: 2014
8253 - 08/18
8260 - 08/19
8269 - 08/21
8279 - 08/22
8288 - 08/23
8293 - 08/23
8298 - 08/24
8303 - 08/24
— 6th Order

JDo(LTC): 2456887.658748

This asteroid was discovered to be a binary by radar observations (Shepard *et al.*, 2004). The estimates at the time were for a primary of 3 km and satellite of 0.2 km effective diameters. This gives Ds/Dp ~ 0.07. As such, it would not seem likely that ground-based photometry with small telescopes could detect the satellite since the mutual events would be on the order of 0.01 mag (Pravec *et al.*, 2006). They observed the asteroid in 2004 August and found a period of 3.293 h but no evidence for the satellite, which radar also indicated had an orbital period of about 16 hours. These numbers and results set the background for the analysis of the 2014 data from CS3-PDS.

The "No Sub" plot shows the 2014 data after a period search from 2 to 5 hours without trying to subtract any effects of a satellite. The scatter does not appear to random, which would lead to a dual period search even if a satellite was not known to exist. The period

spectrum shows the results after finding a second period of *P* = 16.26 h, which is in agreement with the estimated period from radar observations, and is shown in the "P2" plot.

The period spectrum shows that two periods are favored, the one from Pravec *et al.* being the lesser of the two over one of 3.088 hours found from the PDS data. The results are labelled as "Warner" and "Pravec" in the lightcurves. *It should be noted that using either short period in the dual period search produced the same value for P2 and an identical lightcurve.*

The difference between the two short periods is one-half cycle over 24 hours, or what is sometimes called a *rotational alias*, which is where the number of rotations over a given period is ambiguous. The data set for PDS and Pravec *et al.* spanned 6 days, which should have been enough to resolve the period. However, the Pravec data were obtained from several stations from different longitudes, which favors their result since rotational aliases are often difficult to break when using data from a single station. In fact, Pravec (personal communications) confirmed that the 3.293 hour period that Pravec *et al.* reported is secure. Their period spectrum shows no indication of a solution near 3.088 hours. Therefore, the longer period found using the PDS data, i.e., 3.298 h, is adopted for this paper.

Just as much of a mystery is the lightcurve for P2. It does not seem to show signs of *mutual events* but, in general, does resemble a tidally-locked, elongated satellite. If the "dip" at about 0.5 rotation phase is due to an event, then this would indicate a Ds/Dp far greater than 0.07, i.e., it would be more on the order of 0.25. This contradicts the radar evidence. Even if not due to an event, the feature is too deep and wide to fit with the estimated size of 0.2 km for the satellite.

Follow-up observations would usually be encouraged. However, except for the 2015 January apparition when the asteroid is V ~ 18.8 at –43° declination, it does not get brighter than V ~ 19.7 until 2024 September. At which time it will range from V ~ 15.6 and +22° at the first of the month to V ~ 16.9 and –70° at the end of the month. Unfortunately, it will be moving through the rich star fields of Cygnus, Aquila, and points south, making it a difficult target. Even so, the next generation of photometrists should make note.

Acknowledgements

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LIGHTCURVE PHOTOMETRY OPPORTUNITIES: 2015 JANUARY-MARCH

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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 2015 January-March.

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 ≤ 18.0 during any month in the current year, e.g., limiting the results by magnitude and declination.

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

We believe this to be the largest publicly available database of raw lightcurve data that contains 1.5 million observations for more than 2300 objects.

Lightcurve/Photometry Opportunities

Objects with 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, d*o 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 asterisk (*) follows the name if the asteroid is reaching a particularly favorable apparition. A hashtag (#) indicates a near-Earth asteroid (NEA).

#	Name	Brightest Date	Mag	Dec	LCDB Data Period	Amp	U
6023	Tsuyashima*	01 01.6	15.5	+18			
7068	Minowa*	01 03.0	15.0	+22			
6141	Durda*	01 03.8	14.2	+24	460.	0.50	2+
2444	Lederle*	01 03.9	14.4	+24	17.85	0.18-0.45	2+
3272	Tillandz*	01 04.1	15.0	+24			
6445	Bellmore*	01 04.2	15.4	+13			
4039	Souseki*	01 04.3	15.3	+22			
5394	Jurgens*	01 04.5	15.1	+23			
2999	Dante*	01 06.8	15.5	+29			
16592	1992 TM1*	01 08.4	14.9	+16			
2663	Miltiades*	01 08.6	15.4	+35		0.5	
3754	Kathleen*	01 09.1	14.2	+24	11.17	0.13-0.18	2
3859	Borngen*	01 10.3	15.4	+21			
8508	1991 CU1*	01 10.8	15.4	+20			
1646	Rosseland*	01 11.3	14.2	+19	69.2	0.13	2
85804	1998 WQ5*#	01 12.0	14.9	+13	3.0089	0.10	2+
1220	Crocus*	01 12.1	15.3	+21	737.	0.15-0.87	2
36619	2000 QE151*	01 16.1	15.4	+22			
2737	Kotka*	01 16.2	14.4	+32	12.157	0.30	2+
2310	Olshaniya*	01 17.3	14.9	+20			
6901	Roybishop*	01 17.4	15.0	+8	4.682	0.04	2
2455	Somville*	01 18.7	14.9	+21			
3711	Ellensburg*	01 19.4	15.5	+25			
1613	Smiley*	01 22.4	13.7	+25	80.61	0.29-0.30	2+
45224	1999 XO209*	01 24.2	15.3	+23			
4703	Kagoshima*	01 24.8	15.2	+17	4.092	0.03	2
2540	Blok*	01 26.9	14.9	+17			

#	Name	Brightest Date	Mag	Dec	LCDB Data Period	Amp	U
357439	2004 BL86*#	01 27.1	9.4	+8			
3446	Combes*	01 29.4	15.3	+32			
2601	Bologna*	02 01.1	15.4	+12		0.10	
52269	1988 CU*	02 02.0	15.4	+10			
11512	1991 AB2*	02 02.6	15.4	+12			
449	Hamburga*	02 03.3	11.6	+21	18.263	0.08-0.17	2+
1911	Schubart*	02 03.6	14.7	+16			
21373	1997 VF6*	02 04.4	15.5	-1			
2864	Soderblom*	02 05.3	15.5	+16			
10111	Fresnel*	02 06.8	15.2	+15			
3395	Jitka*	02 07.9	15.1	+20			
70171	1999 OL2*	02 08.1	15.3	+10			
2136	Jugta*	02 09.2	15.2	+12			
2929	Harris*	02 12.0	15.5	+14	3.112	0.3	2
4670	Yoshinogawa*	02 12.0	15.5	+13			
4364	Shkodrov*	02 12.1	15.4	+14			
68569	2001 YE3*	02 12.6	15.1	-27			
583	Klotilde*	02 13.0	12.7	+2	9.2116	0.18-0.41	2
1389	Onnie*	02 17.4	15.3	+11	22.5	0.34	2
22128	2000 SH242*	02 21.8	15.5	+20			
21690	1999 RA39*	02 22.9	15.0	+14			
1027	Aesculana*	02 23.0	14.3	+12	6.83	0.15	1
1657	Roemera*	02 23.2	15.0	+42	34.	0.09-0.15	2
6880	Hayamiyu*	02 24.0	15.5	+12			
4494	Marimo*	02 27.7	15.3	+5			
44262	1998 QR51*	02 28.1	15.0	+7			
3691	Bede*#	02 28.8	14.8	+27	226.8	0.05- 0.5	2
1511	Dalera*	03 03.3	14.9	+14			
4056	Timwarner*	03 04.3	15.4	+14			
16029	1999 DQ6*	03 04.3	15.4	+2			
70474	1999 TH35*	03 05.8	15.4	+27			
4638	Estens*	03 06.0	15.4	+0	3.029	0.16	2-
5334	Mishima*	03 08.8	15.0	+4			
1907	Rudneva*	03 09.4	14.9	+6	44.	0.1	1+
1238	Predappia*	03 13.3	15.1	+20	8.94	0.03	2-
1194	Aletta*	03 13.7	14.3	-11	20.39	0.28-0.32	2+
141527	2002 FG7*#	03 16.2	14.1	-42			
2879	Shimizu*	03 16.3	14.8	+9	18.72	0.08	2
10143	Kamogawa*	03 16.6	15.4	-20			
2296	Kugultinov*	03 16.7	15.1	+3	10.41	0.03	1
5181	SURF*	03 18.5	15.4	+6			
3940	Larion*	03 22.1	14.4	-11	84.	0.08-0.31	2
5048	Moriarty*	03 22.5	15.4	-2			
16813	1997 UT6*	03 25.6	15.5	-4			
6518	Vernon*	03 25.8	15.0	+22			
4676	Uedaseiji*	03 29.7	15.5	-11			

Low Phase Angle Opportunities

The Low Phase Angle list includes asteroids that reach very low phase angles. The "α" 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."

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 have to 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 tricky. Refer to Harris, *et al.* ("Phase Relations of High Albedo Asteroids." *Icarus* **81**, p365 ff) 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.

#	Name	Date	α	V	Dec	Period	Amp	U
364	Isara	01 01.1	0.58	11.4	+22	9.156	0.30-0.40	3
346	Hermentaria	01 03.7	0.93	10.7	+25	28.43	0.07-0.20	2
408	Fama	01 10.6	0.63	13.1	+24	202.1	0.58	3
431	Nephele	01 18.6	0.12	13.6	+21	18.821	0.03-0.30	2
623	Chimaera	01 29.7	0.23	13.4	+18	14.635	0.12-0.18	3
71	Niobe	02 04.8	0.21	10.6	+17	35.864	0.12-0.22	3

#	Name	Date	α	V	Dec	Period	Amp	U
435	Ella	02 05.2	0.96	13.7	+19	4.623	0.30-0.45	3
89	Julia	02 05.7	0.73	10.4	+14	11.387	0.10-0.25	3
335	Roberta	02 05.9	0.56	12.7	+14	12.054	0.05-0.78	3
222	Lucia	02 11.0	0.81	13.7	+17	7.80	0.25-0.38	3
58	Concordia	02 16.3	0.75	12.1	+11	9.895	0.10-0.15	3
545	Messalina	02 18.8	0.30	13.9	+13	7.2	0.27	3
324	Bamberga	02 19.9	0.25	11.1	+11	29.43	0.07-0.12	3
231	Vindobona	02 20.1	0.85	13.5	+14	14.245	0.20-0.29	3
358	Apollonia	02 26.2	0.50	12.8	+08	50.6	0.04-0.15	3-
76	Freia	02 28.1	0.72	12.1	+06	9.969	0.06-0.33	3
656	Beagle	03 01.8	0.15	13.4	+07	7.035	0.9 -1.2	3
214	Aschera	03 04.1	0.10	12.1	+07	6.835	0.20-0.22	3
755	Quintilla	03 14.3	0.16	13.5	+02	4.552	0.08-0.45	3
120	Lachesis	03 18.0	0.95	11.8	-01	46.551	0.14-0.22	3
190	Ismene	03 20.2	0.14	12.9	+01	6.52	0.10-0.16	3
1126	Otero	03 22.0	0.05	13.4	+00	3.648	0.69-0.70	3
90	Antiope	03 22.4	0.83	13.1	+02	16.509	0.08-0.90	3
365	Corduba	03 25.0	0.15	13.3	-02	6.354	0.05-0.15	2
149	Medusa	03 26.1	0.32	13.2	-01	26.023	0.47-0.56	3
236	Honoria	03 30.0	0.17	12.7	-03	12.333	0.05-0.18	2+
312	Pierretta	03 31.9	0.43	12.1	-05	10.282	0.30-0.32	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

Below is a list of objects reaching brightest this quarter with well-determined periods and for which there is no pole solution in the LCDB. They are further limited to those reaching a favorable apparition. Since they have a high U rating, this means there is at least one dense lightcurve of high quality. 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.

Note that you can compare and combine the results of searches using the ephemeris generator and LCDB query (limited to with or without a pole solution) at the sites listed above to create your own customized list of objects.

			Brightest		LCDB Data		
#	Name	Date	Mag	Dec	Period	Amp	U
1672	Gezelle	01 02.1	14.1	+21	40.72	0.2 -0.56	3
19982	Barbaradoore	01 03.0	15.0	+30	3.3162	0.28	3
2445	Blazhko	01 03.1	13.7	+26	3.6197	0.57	3
2708	Burns	01 03.7	15.1	+22	5.315	0.52	3
138666	2000 RX96	01 04.6	16.0	+19	8.6824	0.80-0.88	3
1670	Minnaert	01 08.0	15.0	+35	3.528	0.23-0.25	3
3065	Sarahill	01 17.9	15.4	+21	7.4525	0.95	3
5036	Tuttle	01 19.8	15.3	+21	3.775	0.30-0.42	3
5931	Zhvanetskij	01 21.0	15.7	-5	12.006	0.63	3-
7829	Jaroff	01 21.3	15.8	-3	4.398	0.50-0.51	3
17738	1998 BS15	01 22.3	14.8	+27	4.235	0.10	3
103067	1999 XA143	01 24.7	15.6	+44	9.849	0.49	3
3824	Brendalee	01 25.9	14.5	+21	4.52	0.18	3
996	Hilaritas	01 26.6	14.2	+19	10.05	0.63-0.70	3
1708	Polit	01 27.6	14.2	+9	7.52	0.30-0.50	3
623	Chimaera	01 29.7	13.4	+18	14.635	0.12-0.18	3
1547	Nele	02 01.9	13.0	+8	7.1	0.18-0.45	3-
6646	Churanta	02 03.3	15.8	+35	5.8711	0.73-0.77	3
1584	Fuji	02 09.3	12.6	-3	14.88	0.13-0.29	3
1845	Helewalda	02 10.0	14.7	+14	7.2786	0.20-0.28	3-
58	Concordia	02 16.3	12.1	+11	9.895	0.10-0.15	3
5481	Kiuchi	02 17.9	15.6	+11	3.6196	0.08-0.10	3
3192	A'Hearn	02 20.6	15.3	+16	3.16	0.20	3
3642	Frieden	02 22.2	14.5	+18	14.491	0.13	3
1090	Sumida	02 25.9	14.1	+16	2.719	0.10-0.28	3
656	Beagle	03 01.8	13.4	+7	7.035	0.9- 1.2	3
2284	San Juan	03 06.9	14.8	+9	9.16	0.60	3
3493	Stepanov	03 07.4	15.0	+13	6.112	0.77-0.80	3
5515	1989 EL1	03 07.6	15.2	+4	5.23	0.58	3
6382	1988 EL	03 07.8	14.5	+9	2.895	0.06-0.08	3
2291	Kevo	03 08.9	14.6	+4	11.971	0.27	3-
546	Herodias	03 09.8	12.7	+18	10.77	0.07-0.18	3
744	Aguntina	03 10.0	14.0	+9	17.47	0.50	3

			Brightest		LCDB Data		
#	Name	Date	Mag	Dec	Period	Amp	U
1095	Tulipa	03 15.4	14.3	+1	2.7872	0.17-0.21	3
120	Lachesis	03 18.0	11.8	-1	46.551	0.14-0.22	3
4375	Kiyomori	03 26.4	15.2	+6	6.4709	0.15-0.16	3
2449	Kenos	03 28.8	15.7	+4	3.8492	0.16-0.23	3
6619	Kolya	03 31.8	15.1	+0	10.5011	0.39	3
7283	1989 TX15	03 31.8	15.9	-3	2.6747	0.19	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

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 using the RSS feeds from the Minor Planet Center

http://www.minorplanetcenter.net/iau/rss/mpc_feeds.html

In particular, monitor the NEA feed 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 if you get data (through Dr. Benner's email listed above). They may not always be observing the target but, in some cases, 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 α 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" in the header 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.

(357439) 2004 BL86 (Jan, H = 18.8, PHA)
This is going to be one of the more spectacular NEA fly-bys in current times. The asteroid will come within 3.7 lunar distances on January 26 and reach a magnitude of about 9.1 about 0 h UT on January 27, making it visible even in binoculars and small telescopes. This is the largest known object to come this close until 2027. Little is known about the physical characteristics of 2004 BL84, i.e., its actual size (estimated to be 0.5 km), its albedo, or its

rotation period. Astrometry in mid-January, before the close fly-by, is strongly encouraged. Otherwise the pointing uncertainty may be so large that radar will miss the object altogether. The best photometry chances are in the hours and few days immediately after closest approach. Plan ahead and be prepared. For more details about the radar campaign, visit *http://echo.jpl.nasa.gov/asteroids/2004BL86/2004BL86_planning.html*

```
DATE      RA       Dec     ED    SD    V       α    SE  ME   MP    GB
-----------------------------------------------------------------------
01/15   00 39.8  -72 59   0.11  0.94  18.2  109.2   65   91  -0.34  -44
01/18   01 01.5  -73 34   0.08  0.95  17.6  109.4   66   78  -0.09  -44
01/21   01 45.8  -74 17   0.05  0.97  16.7  108.0   69   73  +0.00  -42
01/24   04 00.0  -72 55   0.03  0.98  14.7  100.2   78   82  +0.17  -38
01/27   08 29.6  +08 30   0.01  0.99   9.4   10.2  170   93  +0.48  +26
01/30   10 15.9  +60 02   0.03  1.01  13.3   43.7  135   70  +0.78  +48
02/02   10 51.4  +65 31   0.06  1.02  14.8   49.3  128   59  +0.96  +47
02/05   11 07.4  +67 14   0.08  1.04  15.7   50.6  126   59  -0.99  +47
02/08   11 15.6  +67 57   0.11  1.05  16.3   50.6  124   70  -0.86  +47
02/11   11 19.8  +68 15   0.14  1.07  16.8   50.3  124   87  -0.62  +47
```

2007 EC (Jan, H = 22.2)

This NEA spends the vast majority of its time *inside* the Earth's orbit, so opportunities to catch it are not too common. The estimated size is only 100 meters. This makes it a good candidate for being a super-fast rotator, i.e., one with a period of < 2 hours. As far as we can tell, the rotation period has not been reported.

```
DATE      RA       Dec     ED    SD    V       α    SE  ME   MP    GB
-----------------------------------------------------------------------
01/10   19 44.7  +48 01   0.04  0.97  18.9  107.8   70  114  -0.80  +12
01/13   20 57.4  +62 25   0.03  0.98  17.8   92.6   86  108  -0.54  +11
01/16   00 42.2  +71 15   0.03  0.99  17.0   73.6  105  119  -0.25   +8
01/19   03 56.6  +59 34   0.03  1.00  16.6   56.5  122  130  -0.04   +5
01/22   04 58.0  +45 13   0.03  1.01  16.8   46.0  132  113  +0.03   +2
01/25   05 24.2  +34 51   0.04  1.02  17.1   41.5  137   76  +0.26   -1
01/28   05 39.0  +27 47   0.05  1.03  17.5   40.3  138   38  +0.59   -2
01/31   05 48.9  +22 52   0.06  1.03  17.9   40.6  137    4  +0.86   -2
02/03   05 56.4  +19 20   0.08  1.04  18.3   41.7  135   34  +0.99   -3
02/06   06 02.5  +16 42   0.09  1.05  18.7   43.0  134   68  -0.96   -3
```

(90416) 2003 YK118 (Jan-Feb, H = 18.5, PHA)

This potentially hazardous asteroid (PHA) will ride high in the northern sky for several weeks as 2015 begins. There are no known lightcurve parameters for the asteroid, which has an estimated size of 0.6 km.

```
DATE      RA       Dec     ED    SD    V       α    SE  ME   MP    GB
-----------------------------------------------------------------------
01/01   08 06.0  +39 18   0.40  1.35  18.0   17.1  156   67  +0.83  +31
01/06   08 00.3  +40 07   0.35  1.32  17.7   15.5  159   24  -0.99  +30
01/11   07 51.8  +40 54   0.31  1.28  17.3   15.0  160   64  -0.72  +28
01/16   07 40.2  +41 34   0.27  1.24  17.0   16.1  159  122  -0.25  +26
01/21   07 24.9  +41 59   0.24  1.21  16.8   19.3  156  149  +0.00  +24
01/26   07 05.5  +42 01   0.21  1.17  16.6   24.4  151   83  +0.37  +20
01/31   06 41.7  +41 25   0.18  1.13  16.4   31.3  143   26  +0.86  +16
02/05   06 12.7  +39 52   0.15  1.10  16.2   39.9  134   57  -0.99  +10
02/10   05 38.0  +36 51   0.13  1.06  16.0   50.6  124  120  -0.71   +3
02/15   04 56.7  +31 35   0.11  1.03  16.0   64.0  110  160  -0.21   -7
```

2007 EJ (Jan-Feb, H = 17.9)

The estimated size of 2007 EJ is about 0.8 km. The geometry of the approach has the asteroid brightest at very high phase angles, where the usual assumptions about lightcurve modality and shapes often break down. Don't assume the typical bimodal lightcurve even if the amplitude is $A > 0.2$ mag or more.

```
DATE      RA       Dec     ED    SD    V       α    SE  ME   MP    GB
-----------------------------------------------------------------------
01/01   23 15.4  +15 24   0.20  0.96  17.6   91.5   77   58  +0.83  -42
01/06   23 43.1  +25 50   0.18  0.98  17.2   86.4   83  108  -0.99  -35
01/11   00 20.7  +37 08   0.18  1.00  16.9   79.0   91  141  -0.72  -25
01/16   01 13.3  +47 46   0.18  1.03  16.7   70.4  100  137  -0.25  -15
01/21   02 24.6  +55 41   0.19  1.06  16.6   61.7  108  101  +0.00   -5
01/26   03 48.1  +59 32   0.21  1.09  16.7   54.0  116   60  +0.37   +4
01/31   05 05.9  +59 42   0.24  1.13  16.9   47.8  122   42  +0.86  +11
02/05   06 05.6  +57 39   0.28  1.17  17.1   43.0  126   65  -0.99  +17
02/10   06 48.2  +54 45   0.31  1.21  17.4   39.5  129  105  -0.71  +21
02/15   07 18.7  +51 41   0.36  1.25  17.6   36.9  131  144  -0.21  +25
```

2002 RQ25 (Jan-Feb, H = 20.4)

With a diameter of about 250 meters, it's possible that this asteroid might be a super-fast rotator. Given that, keep exposure times to a minimum for the initial runs to see what the data reveal, then proceed accordingly.

```
DATE      RA       Dec     ED    SD    V       α    SE  ME   MP    GB
-----------------------------------------------------------------------
01/25   11 07.8  +37 22   0.16  1.11  18.1   34.1  141  136  +0.26  +66
01/28   11 17.5  +39 21   0.15  1.10  17.9   35.1  140  105  +0.59  +67
01/31   11 29.5  +41 43   0.13  1.08  17.6   36.8  139   75  +0.86  +68
02/03   11 45.2  +44 34   0.11  1.07  17.4   39.5  136   53  +0.99  +68
02/06   12 07.2  +48 02   0.10  1.05  17.1   43.6  133   46  -0.96  +67
02/09   12 40.5  +52 10   0.08  1.04  16.9   49.5  127   58  -0.79  +65
02/12   13 35.1  +56 37   0.07  1.02  16.8   57.9  119   75  -0.52  +60
02/15   15 06.4  +59 40   0.06  1.01  16.7   69.8  107   86  -0.21  +50
02/18   17 09.6  +57 06   0.05  0.99  17.0   85.6   91   84  -0.02  +36
02/21   18 53.2  +46 48   0.05  0.98  17.7  104.0   73   80  +0.06  +19
```

(385186) 1994 AW1 (Feb, H = 17.0, PHA, Binary)

1994 AW1 was first reported as a suspect binary by Mottola *et al.* (1995) and then confirmed as such by Pravec and Hahn (1997). The primary has a rotation period of about 2.52 hours with an amplitude ranging from 0.10-0.17 mag. The orbital period is about 22.4 hours. A campaign involving two stations well-separated in longitude will have the best chance of seeing mutual events (occultations and/or eclipses) well enough to confirm the orbital period and help model the system. This assumes that events will be seen at this apparition.

```
DATE      RA       Dec     ED    SD    V       α    SE  ME   MP    GB
-----------------------------------------------------------------------
12/25   11 45.6  -11 11   0.63  1.18  18.9   56.3   92  132  +0.12  +48
01/04   11 58.8  -20 10   0.58  1.19  18.7   55.8   95   97  +0.98  +41
01/14   12 10.2  -29 45   0.55  1.19  18.6   55.2   97   31  -0.44  +32
01/24   12 19.2  -39 40   0.52  1.19  18.5   54.8   99  137  +0.17  +23
02/03   12 24.8  -49 30   0.51  1.19  18.4   54.7  100   84  +0.99  +13
02/13   12 25.3  -58 52   0.50  1.18  18.4   55.0  101   58  -0.41   +4
02/23   12 16.4  -67 18   0.50  1.18  18.4   55.6  100  120  +0.22   -5
03/05   11 49.2  -74 25   0.50  1.18  18.4   56.4   99   82  +0.99  -12
03/15   10 43.6  -79 39   0.50  1.17  18.4   57.5   98   77  -0.36  -18
03/25   08 42.3  -81 54   0.49  1.16  18.4   58.6   96  104  +0.27  -23
```

2014 EK24 (Feb-Mar, H = 23.2)

The estimated size of 2014 EK24 is only 70 meters. The odds are good that it will be a super-fast rotator.

```
DATE      RA       Dec     ED    SD    V       α    SE  ME   MP    GB
-----------------------------------------------------------------------
02/15   13 26.3  +21 52   0.04  1.02  18.3   49.6  128   79  -0.21  +81
02/18   13 04.9  +18 43   0.04  1.02  18.0   42.4  136  122  -0.02  +81
02/21   12 42.1  +15 12   0.04  1.02  17.8   34.6  144  161  +0.06  +78
02/24   12 18.4  +11 25   0.04  1.03  17.5   26.4  153  135  +0.32  +72
02/27   11 54.8  +07 30   0.04  1.03  17.3   18.2  161   93  +0.63  +66
03/02   11 32.0  +03 41   0.04  1.03  17.1   10.8  169   52  +0.88  +60
03/05   11 10.9  +00 07   0.04  1.04  17.0    6.4  173   13  +0.99  +54
03/08   10 51.8  -03 02   0.05  1.04  17.3    9.2  170   28  -0.95  +48
03/11   10 35.0  -05 45   0.05  1.04  17.6   14.7  165   67  -0.77  +43
03/14   10 20.6  -08 00   0.05  1.05  18.0   20.1  159  107  -0.47  +39
```

(141527) 2002 FG7 (Mar-Apr, H = 18.9, PHA)

There are no known lightcurve parameters for this 0.5 km NEA. It's better placed for southerly observers when at brightest in mid-March. However, it should still be a relatively easy target by the time it moves north enough for those above the equator.

```
DATE      RA       Dec     ED    SD    V       α    SE  ME   MP    GB
-----------------------------------------------------------------------
03/10   00 03.7  -64 08   0.06  0.97  17.2  116.7   60  101  -0.84  -52
03/13   09 40.9  -79 57   0.04  1.00  15.0   81.7   96   75  -0.58  -20
03/16   11 10.0  -42 00   0.05  1.03  14.2   42.5  135  104  -0.26  +17
03/19   11 19.6  -20 22   0.08  1.07  14.5   21.1  157  152  -0.03  +38
03/22   11 23.3  -09 38   0.10  1.10  14.9   12.3  166  149  +0.04  +47
03/25   11 25.5  -03 40   0.14  1.13  15.5   10.8  168  107  +0.27  +53
03/28   11 27.1  +00 01   0.17  1.16  16.1   12.6  165   67  +0.57  +56
03/31   11 28.4  +02 28   0.20  1.19  16.7   15.0  162   31  +0.83  +58
04/03   11 29.7  +04 11   0.24  1.23  17.1   17.3  159    6  +0.98  +60
04/06   11 31.0  +05 24   0.28  1.26  17.6   19.3  155   41  -0.98  +61
```

IN THIS ISSUE

This list gives those asteroids in this issue for which physical observations (excluding astrometric only) were made. This includes lightcurves, color index, and H-G determinations, etc. In some cases, no specific results are reported due to a lack of or poor quality data. The page number is for the first page of the paper mentioning the asteroid. EP is the "go to page" value in the electronic version.

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The deadline for the next issue (42-2) is January 15, 2015. The deadline for issue 42-3 is April 15, 2015.