

NEAR-EARTH ASTEROID LIGHTCURVE ANALYSIS AT CS3-PALMER DIVIDE STATION: 2014 MARCH-JUNE

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Lightcurves for 38 near-Earth asteroids (NEAs) were obtained at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2014 March through June.

CCD photometric observations of 38 near-Earth asteroids were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) in 2014 March through June. Table I gives a listing of the telescope/CCD camera combinations used for the observations. All the cameras use the same CCD chip from the Kodak 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
PDS-1-12N	0.30-m f/6.3 Schmidt-Cass	ML-1001E
PDS-1-14S	0.35-m f/9.1 Schmidt-Cass	FLI-1001E
PDS-2-14N	0.35-m f/9.1 Schmidt-Cass	STL-1001E
PDS-2-14S	0.35-m f/9.1 Schmidt-Cass	STL-1001E
PDS-20	0.50-m f/8.1 Ritchey-Chretien	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. Guiding was done on a field star, which sometimes resulted in a trailed image for the asteroid. The exposure duration varied depending on the asteroid's brightness and sky motion.

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* finds up to five comparison stars of near solar-color to be used in differential photometry. Catalog magnitudes are 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 magnitude 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).

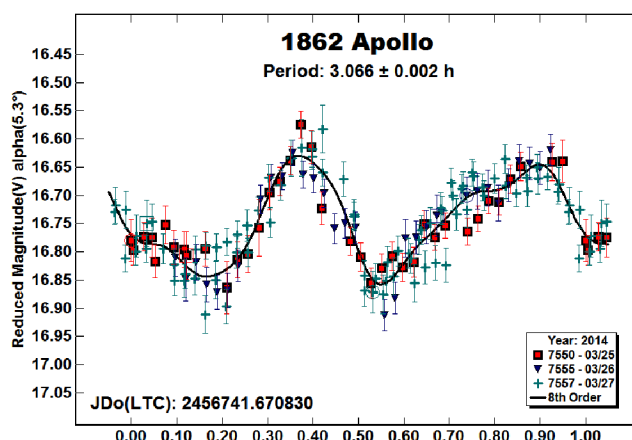
In the plots below, the "Reduced Magnitude" is Johnson V (or Cousins R) as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distance by applying $-5 \cdot \log(r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid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

stated. The horizontal axis is the rotational phase and ranges from -0.05 to 1.05 .

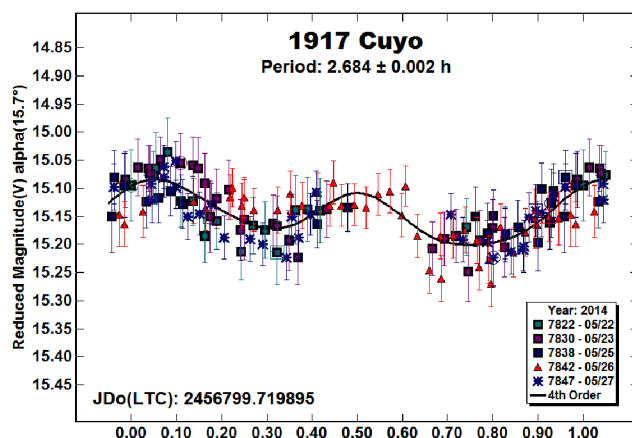
For the sake of brevity, only some of the previously reported results may be referenced in the discussions on specific asteroids. For a more complete listing, the reader is directed to the asteroid lightcurve database (LCDB; Warner *et al.*, 2009). The on-line version at <http://www.minorplanet.info/lightcurvedatabase.html> 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. When possible, researchers are strongly to obtain the original references listed in the LCDB for their work.

Individual Results

1862 Apollo. This is the namesake for the group of near-Earth asteroids that have semi-major axes greater than 1 AU but perihelion distances < 1.017 AU (the aphelion distance of the Earth). The author worked the asteroid in 2006 November (Warner, 2006) when the amplitude went from 1.15 mag to 0.26 over the course about two weeks. The 2014 apparition showed a more stable magnitude range, though the observations covered only three consecutive nights. Numerous other results have been reported, including a shape model by Kaasalainen *et al.* (2007). That paper demonstrated the slow acceleration of the asteroid's spin rate induced on the asteroid by the YORP (Yarkovsky-O'Keefe-Radzievskii-Paddack) effect.



1912 Cuyo. The period of 2.684 h found at CS3-PDS is in good agreement with previous results, e.g., Wisniewski (1997; 2.6905 h) and Behrend (2008; 2.6890 h).

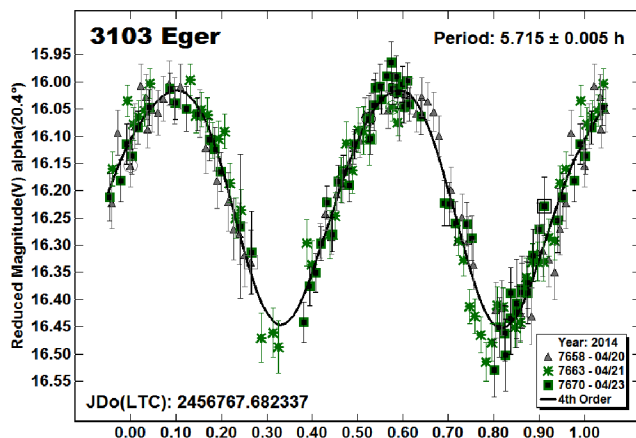


Number	Name	2014 mm/dd	Pts	Phase	L_{PAB}	B_{PAB}	Period	P.E.	Amp	A.E.
1862	Apollo	03/25-03/27	150	5.3, 6.5	181	6	3.066	0.002	0.22	0.02
1917	Cuyo	05/22-05/26	133	15.7, 15.5	255	29	2.684	0.002	0.12	0.02
3103	Eger	04/20-04/23	168	20.4, 20.6	210	31	5.715	0.005	0.49	0.03
21374	1997 WS22	04/08-04/17	183	54.6, 53.2	232	31	3.405	0.005	0.07	0.01
24445	2000 PM8	04/24-04/29	129	24.7, 25.3	169	-12	6.76	0.02	0.19	0.02
25916	2001 CP44	03/16-03/20	67	37.3, 37.9	246	14	4.208 ^A	0.003	0.37	0.03
85628	1998 KV2	04/24-04/30	193	16.6, 11.9	228	10	2.819	0.002	0.16	0.02
85989	1999 JD6	05/20-05/22	109	36.0, 34.8	260	30	7.667	0.006	1.12	0.03
86039	1999 NC43	03/15-03/22	93	65.0, 57.4	128	-7	34.1	0.5	0.75	0.1
86829	2000 GR146	05/31-06/04	97	56.9, 54.3	193	15	2.917	0.002	0.14	0.02
86878	2000 HD24	05/05-05/15	123	31.7, 33.0	200	-5	23.1	0.5	0.35	0.05
143649	2003 QQ47	03/31-04/03	184	84.6, 81.3	141	-9	3.679	0.005	0.19	0.02
153002	2000 JG5	04/25-04/28	178	39.7, 32.9	238	18	6.051	0.005	0.91	0.03
153957	2002 AB29	06/04-06/05	49	45.9, 42.9	283	18	2.545	0.005	0.24	0.03
162181	1999 LF6	05/22-05/28	203	22.2, 26.4	236	22	14.77	0.04	0.17	0.03
188174	2002 JC	05/12-05/15	89	89.8, 94.5	280	37	2.746 ^A	0.002	0.26	0.03
222869	2002 FB6	03/22-03/24	109	30.9, 31.7	205	14	8.98	0.04	0.28	0.03
267337	2001 VK5	04/24-05/02	379	47.4, 0.0, 58.3	158	21	39.05	0.04	0.92	0.05
274138	2008 FU6	03/29-04/04	233	6.0, 12.7	182	-3	2.852	0.005	0.07	0.01
303174	2004 FH11	04/29-05/01	153	13.1, 0.0, 14.8	136	3	2.523	0.003	0.18	0.02
363599	2004 FG11	04/07-04/08	427	47.5, 54.5	214	24	22.0 ^C	0.5	0.37	0.03
387733	2003 GS	04/12-04/13	226	14.9, 16.6	203	9	2.467	0.002	0.14	0.01
388468	2007 DB83	03/27-03/29	125	35.0, 34.5	209	18	5.411	0.003	0.69	0.03
388838	2008 EZ5	03/27-04/03	103	18.2, 17.8, 18.2	202	1	8.4	0.02	0.29	0.03
392211	2009 TG10	05/06-05/14	294	58.8, 59.1	248	48	13.87	0.02	1.34	0.05
395289	2011 BJ2	05/04-05/06	216	55.7, 54.7	184	9	7.03	0.02	0.48	0.03
	2005 GP128	05/31-06/04	63	51.3, 52.9	289	14	3.266	0.005	0.7	0.05
	2010 NG3	05/22-05/26	85	52.4, 54.1	193	22	4.229	0.005	0.33	0.03
	2010 LJ14	03/27-04/15	404	23.9, 12.7	208	10	113	2	0.82	0.05
	2011 JR13	05/19-05/22	674	54.0, 96.8	258	36	3.77 ^A	0.02	0.05	0.38
	2013 WF108	05/28-05/30	556	72.5, 64.8	239	37	7.37	0.02	0.21	0.03
	2014 HM2	05/03-05/12	229	8.0, 15.9	227	7	13.96	0.02	0.37	0.03
	2014 EQ12	03/23-03/31	914	8.5, 43.0	187	11	8.49 ^A	0.01	0.11	0.02
	2014 FH33	04/23-04/25	130	19.6, 21.8	198	14	6.73	0.02	0.35	0.03
	2014 EZ48	03/21-03/23	131	1.7, 4.3	179	2	5.96	0.02	0.53	0.03
	2014 GY48	04/28-05/02	347	85.6, 0.0, 93.8	129	17	6.82 ^A	0.01	0.24	0.02
	2014 HO132	05/03-05/03	472	15.3, 15.3	215	3	4.08	0.05	0.23	0.03
	2014 HS184	05/29-06/02	390	20.9, 24.3	252	12	1.9557 ^B	0.0004	0.89	0.05

Table II. Observing circumstances. ^A Favored period in ambiguous solution. ^B Dominant period of a tumbler. ^C Orbital period of satellite.

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).

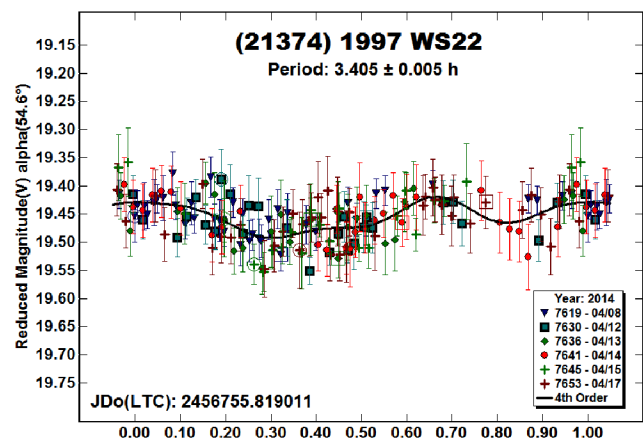
3103 Eger. This asteroid shows a considerable amplitude range over different viewing aspects (see references in the LCDB). The 2014 observations showed the lowest amplitude recorded to date, only 0.49 mag.



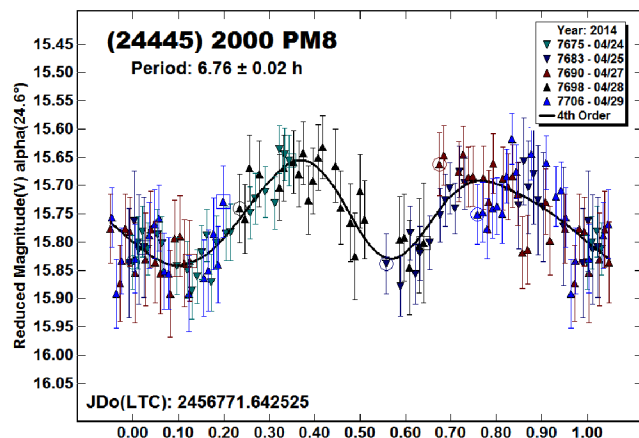
The phase angle bisector longitude (L_{PAB} ; see Harris *et al.*, 1984) in 2014 was about 210°. Combined with the unusually low

amplitude, this would favor the spin axis pole being near 210° (or 30°). This agrees with the pole of (226°, 70°) found by Durech *et al.* (2012).

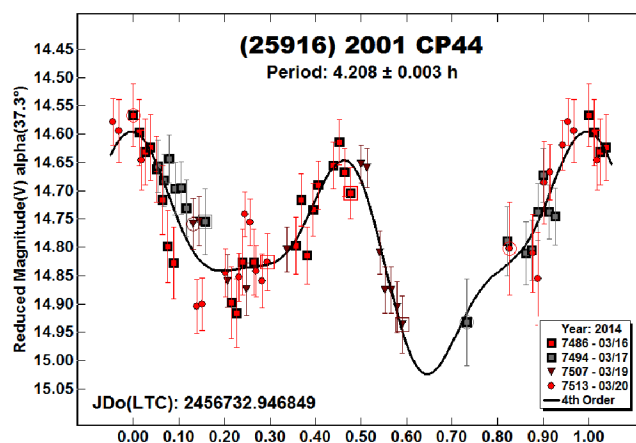
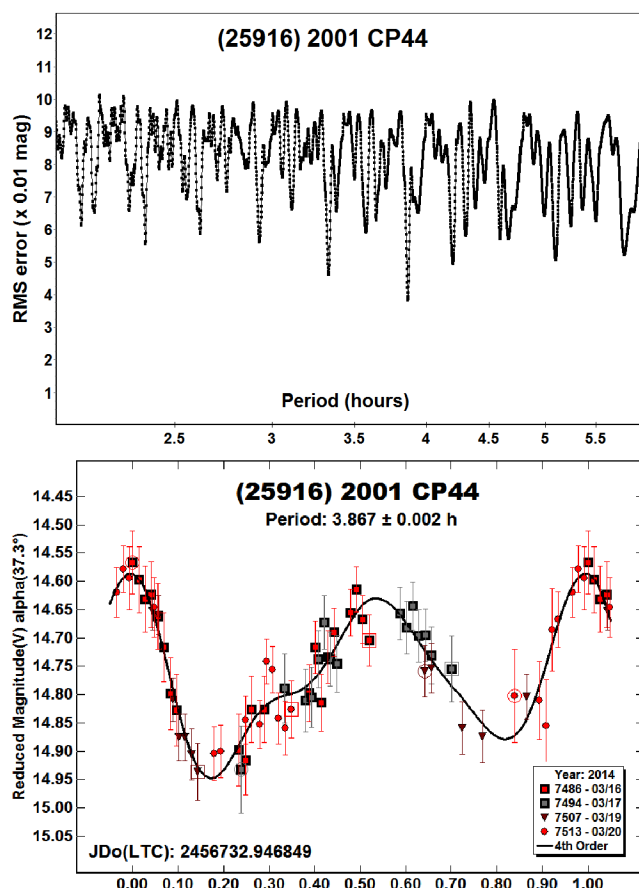
(21374) 1997 WS22. No previous period result was found in the literature for this asteroid. The low amplitude reduces the certainty of the result.



(24445) 2000 PM8. Warner (2014) found a period of 6.811 h based on data obtained in 2013 August. The amplitude was 0.25 mag at $L_{PAB} \sim 5^\circ$. Jahn *et al.* (2014) found a similar period a month later, but an amplitude ranging from 0.65 to 0.95 mag near $L_{PAB} 47^\circ$. The most recent observations from CS3-PDS were at $L_{PAB} 169^\circ$, or close to 180° from the earlier observations. As might be expected, the amplitude was also relatively low, 0.19 mag. This leads to the conclusion that the spin axis longitude is near 0° (or 180°) and that the latitude is somewhat away from the ecliptic pole.



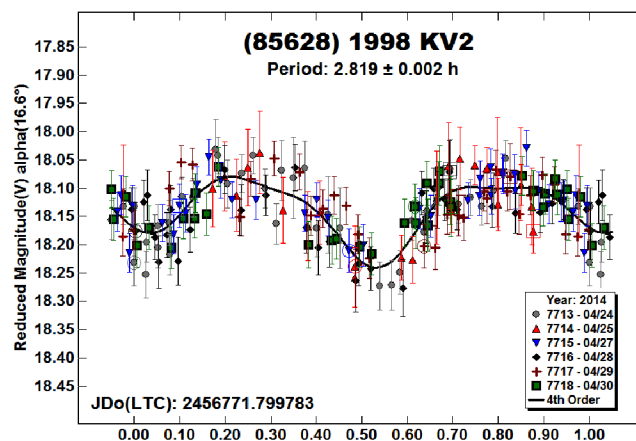
(25916) 2001 CP44. Elenin *et al.* (2012) found a period of 4.19 h based on an extensive data set covering three consecutive nights in 2010. The PDS 2014 data set did not favor that solution, but one of 3.867 hours. However, it was not as dense, although it did cover a range of four nights in two sets of two consecutive nights.



The period spectrum shows the Elenin *et al.* solution, but it is not even the second best fit in terms of RMS. The two lightcurves show the PDS data phased to the favored period and to one near the Elenin *et al.* value. Visually, the curve of the shorter period is more symmetrical and the fit to the model curve noticeably better. The data could not be manipulated, i.e., zero point adjustments, so that the longer period was favored.

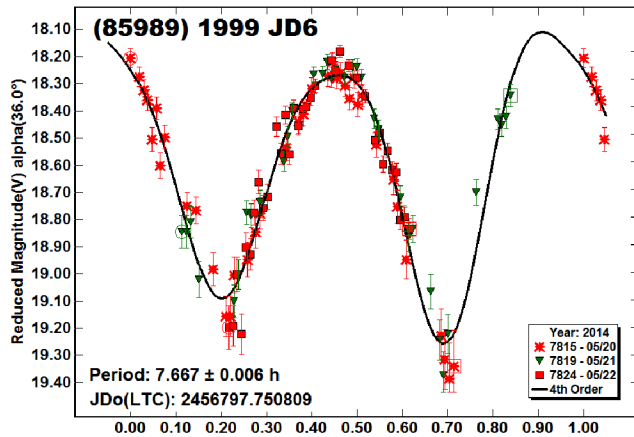
The difference between the two periods is almost exactly one-half rotation over 24 hours. This could lead to a *rotational alias*, where – in this case – the halves of a symmetrical curve are not properly matched. The PDS lightcurves are not very symmetrical; however, the Elenin *et al.* curve was highly symmetrical, which raised some doubts. Elenin (private communications) made his data available for additional analysis. They can be made to fit to the shorter period, but only by ignoring about ten data points in one night's run, for which there is no sound justification, and a noticeably poorer overall fit. In the end, the longer period is probably the correct one but follow-up work is encouraged.

(85628) 1998 KV2. There were no previous results found in the literature for 1998 KV2. The period and shape are consistent with the primaries of small binary asteroids. However, there was no evidence of a satellite, i.e., occultations and/or eclipses. Observations at future apparitions are encouraged. For those who can wait, the asteroid will be as bright as 13.7 in 2037 November. Otherwise, the magnitude near opposition is only 17.2 in 2016 and gradually increases towards the 2037 culmination.

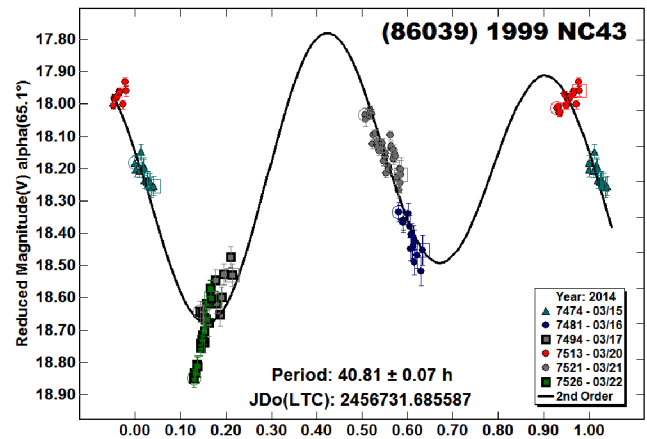
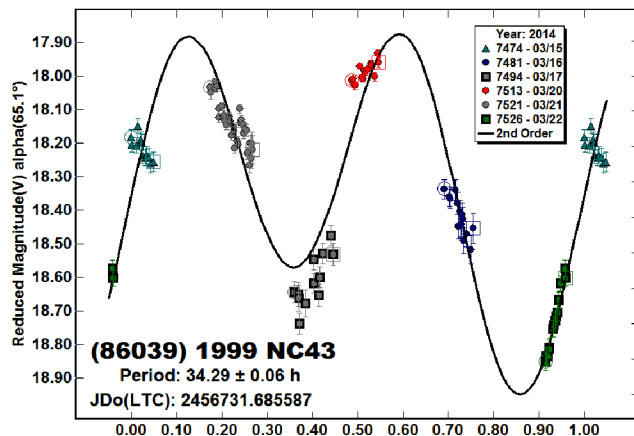
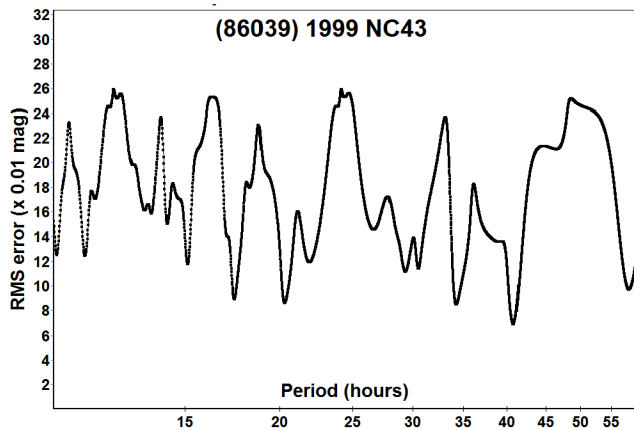


(85989) 1999 JD6. Polishook (2005, 2008) found a period of about 7.66 h for 1999 JD6, a result also supported by Pravec *et al.* (1999, 2000) and by the PDS observations in 2014. All the

lightcurves obtained so far were at similar phase angle bisector longitudes and so the amplitudes have not varied much. The lack of observations at different longitudes makes modeling from dense lightcurves alone more difficult. Since the average amplitude is somewhat large, sparse data from the surveys may be useful in spin axis modeling.

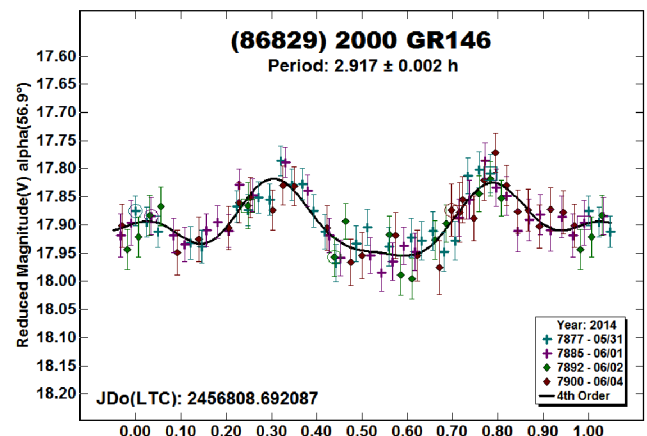
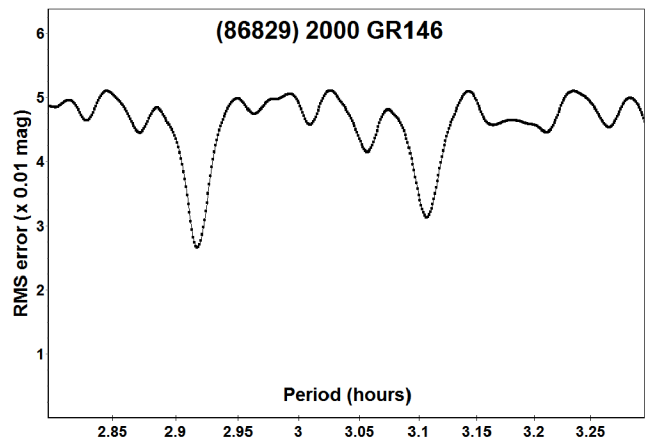


(86039) 1999 NC43. Pravec *et al.* (2000) found a period of 34.49 h and amplitude of 1.1 mag based on observations in 2000 March. They also reported a possible alternative period of 122 h. The PDS data from almost exactly 14 years later roughly confirmed the shorter period but the result is ambiguous. Part of the problem was that the asteroid was located in rich star fields and so most data points had to be eliminated due to star contamination. This left a fairly sparse data set for analysis.



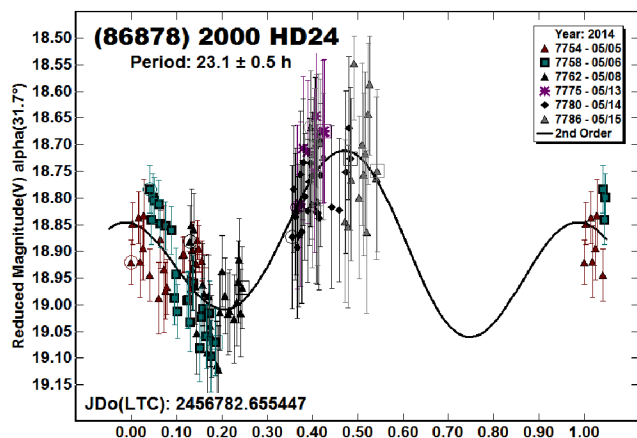
The period spectrum shows a number of possible solutions, with the one near 34 hours being a possibility, but not the most favored. A scan over a larger range of periods did not show a solution near 122 hours. However, given the sparse amount of data, this is not too surprising. The two lightcurves show the PDS data phased first to the shorter period of about 34.3 hours and then to the favored period in the spectrum of about 40 hours. In both cases, the data from at least one night has a slope that is contrary to the model lightcurve. This is often a sign that the asteroid might be in non-principal axis rotation (NPAR) or *tumbling* (see Pravec *et al.*, 2005, for a detailed study of tumbling asteroids).

(86829) 2000 GR146. Previous results for this asteroid include Pravec *et al.* (2007; 3.0996 h) and Polishook (2012; 3.5 h). The PDS result of 2.917 h is outside the error bars of the Pravec *et al.* solution.

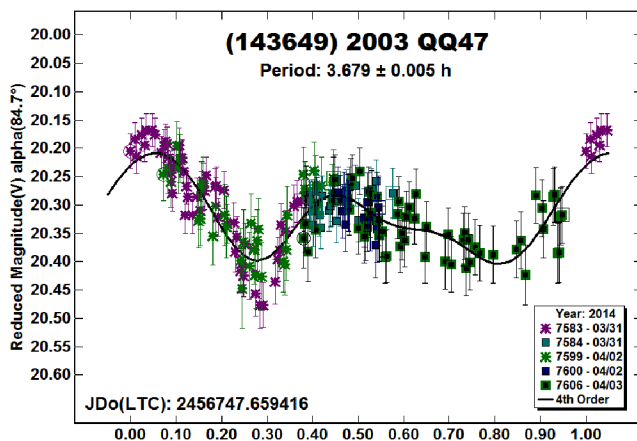


The period spectrum does show a solution near 3.1 hours. However, when the PDS data are forced to the longer period, the fit is not just noticeably worse, but cannot be made better by small zero point adjustments. Additional observations are encouraged.

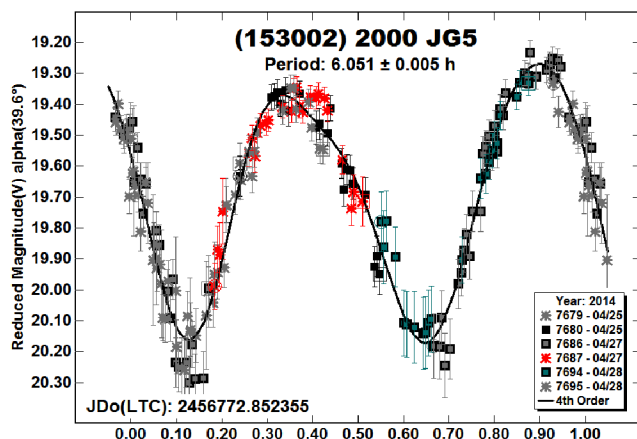
(86878) 2000 HD24. This was a case of working an asteroid too close to the sky background. The data were extremely noisy and, worse, what period could be found was nearly commensurate with an Earth day. Eventually the asteroid was abandoned.



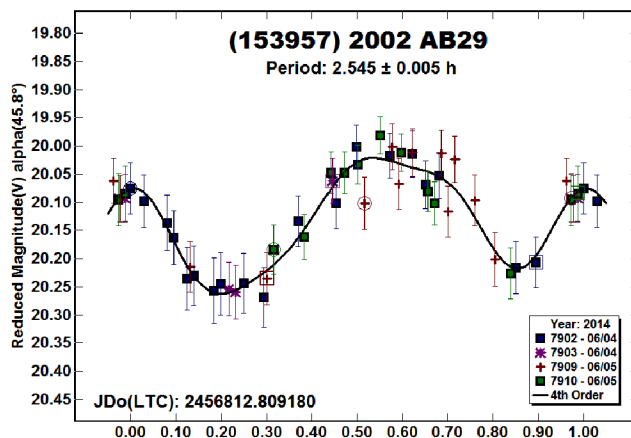
(143649) 2003 QQ47. No previous results were found in the literature for this asteroid. The solution should not be considered definitive and so needs confirmation.



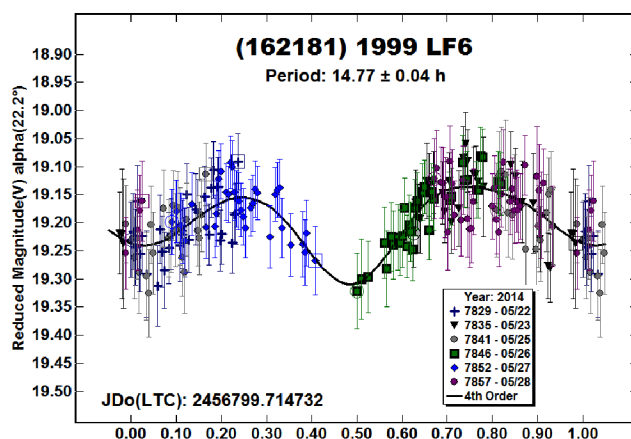
(153002) 2000 JG5. The PDS period agrees with that from Pravec *et al.* (2000).



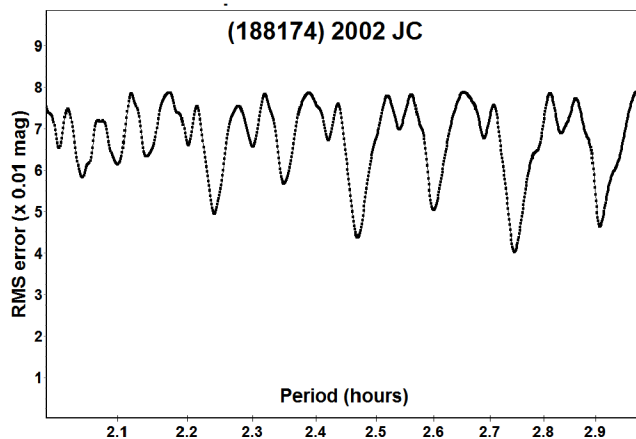
(153957) 2002 AB29. Despite the relatively few data points, the period seems well-determined.

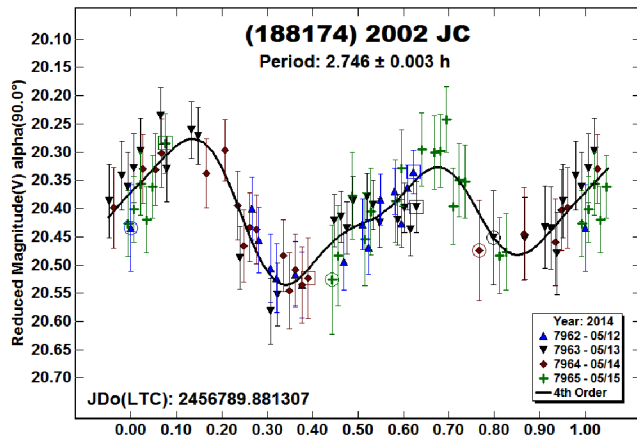
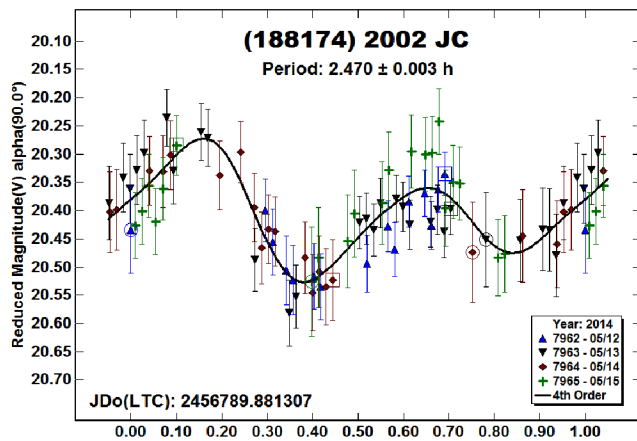


(162181) 1999 LF6. Pravec *et al.* (1999) found a period of 16.007 h. The period spectrum using the PDS data from 2014 shows a significantly weaker solution near 16 hours while a lightcurve forced to that period shows a very poor fit. The difference between the two solutions is unexplained.

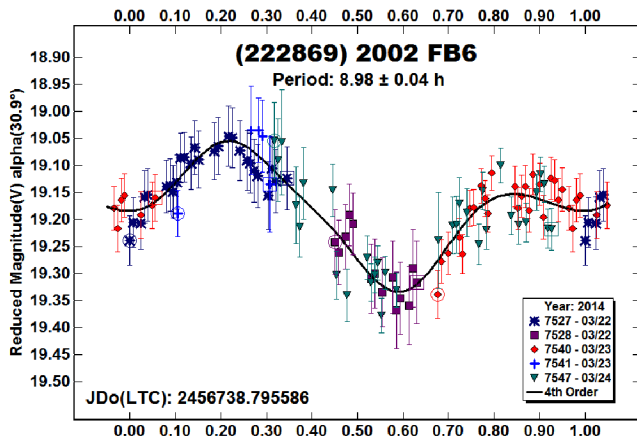


(188174) 2002 JC. Previous results for this asteroid by Polishook (2005, 2008), Skiff (2011), and Behrend (2011) are in the range of 2.47 to 2.49 hours. The period spectrum using the PDS data from 2014 shows that a period of 2.47 h is possible, but that one at 2.75 h is slightly favored. The difference between the two is almost exactly one rotation over 24 hours, presenting another possible case of *rotational aliasing*.

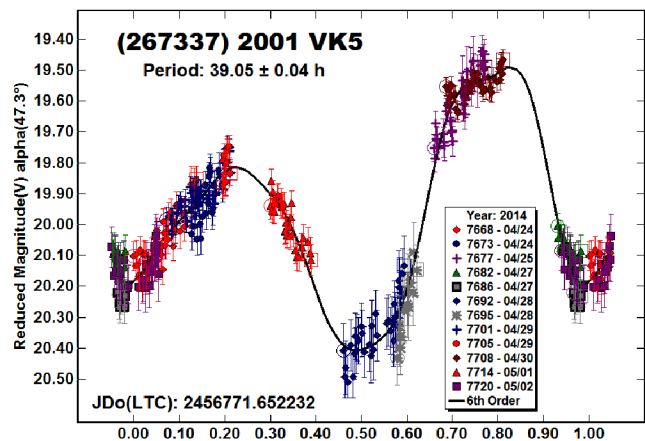




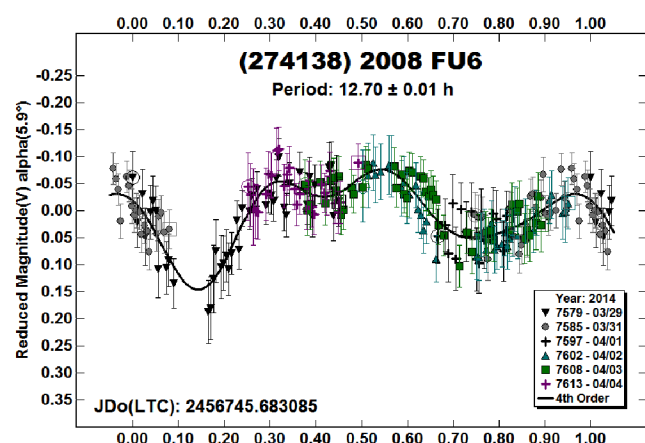
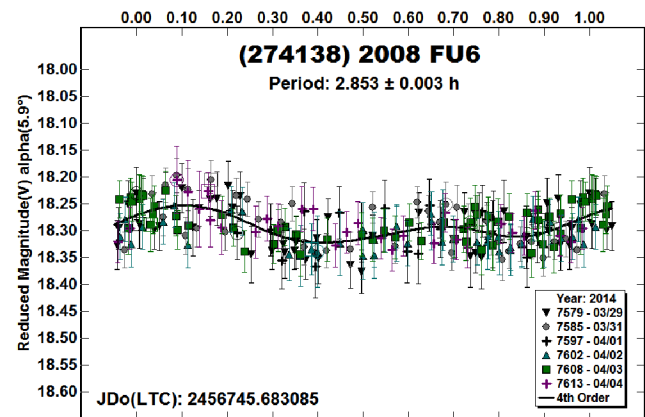
(222869) 2002 FB6. No previous results were found in the literature. The asymmetry of the curve raises at least some doubt about the certainty of the solution. However, the period spectrum showed only integral or half-integral multiples, e.g., $3P/2$ and $2P$.



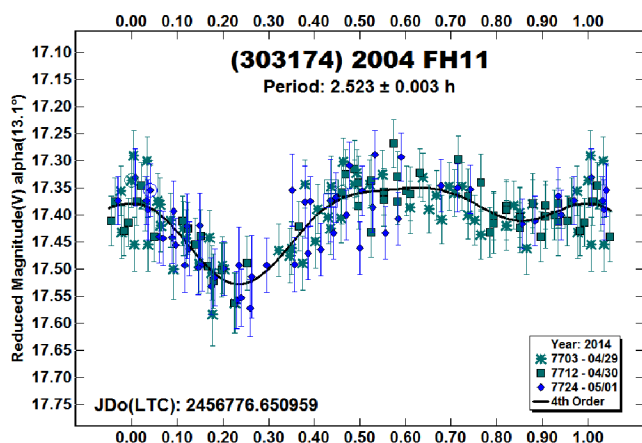
(267337) 2001 VK5. No previous results were found in the literature for 2001 VK5. The derived period of 39.05 hours makes the asteroid a candidate for being a tumbler (see Pravec *et al.*, 2014, and references therein). In fact, there were signs of a low-amplitude secondary period as seen by the unusual shape and how some of the overlapping sessions don't have the same general slope. It is very difficult, if not impossible for a single station to obtain sufficient data to resolve a slow rotator that may or may not be tumbling. Even with stations from different longitudes and an extended campaign of several weeks, a definitive solution may not always be found.



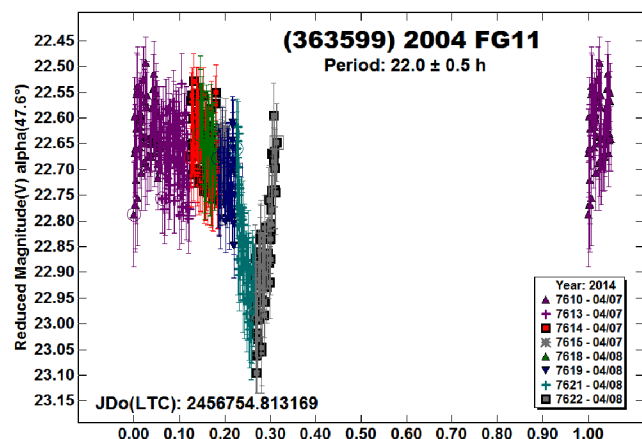
(274138) 2008 FU6. Skiff (2011) previously reported a period of 2.6 hours for this asteroid, but it was rated only $U = 1$ (probably wrong) in the LCDB. The PDS data did find a more reliable period of about the same duration, 2.852 h, but there were also signs of a second period of 12.70 hours. It is possible that this second lightcurve is the result of a satellite and that the two minimums represent occultation and/or eclipse events. The evidence is not sufficient to consider this a *probable* binary but does warrant a *possible* designation. Observations at future apparitions are strongly encouraged.



(303174) 2004 FH11. This appears to be the first reported lightcurve for 2004 FH11. This is another potential binary candidate by virtue of the short period, somewhat low amplitude, and general shape of the lightcurve. A check for signs of a satellite proved negative.

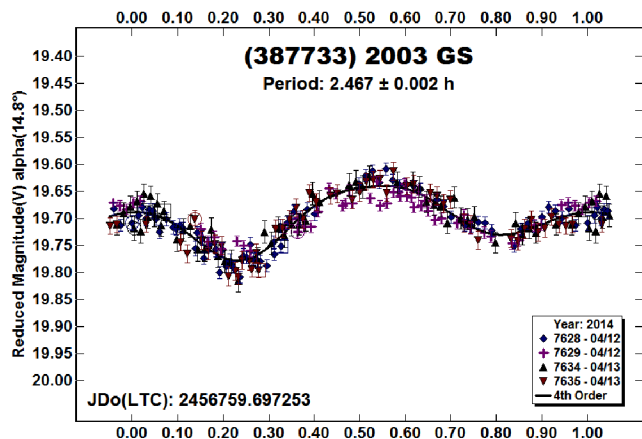


(363599) 2004 FG11. Radar observations by Taylor *et al.* (2012) showed this to be a binary asteroid. The primary's period was set as < 4 h and the orbital period of the satellite at approximately 20 h. Optical observations were not reported at the time to help confirm these results.

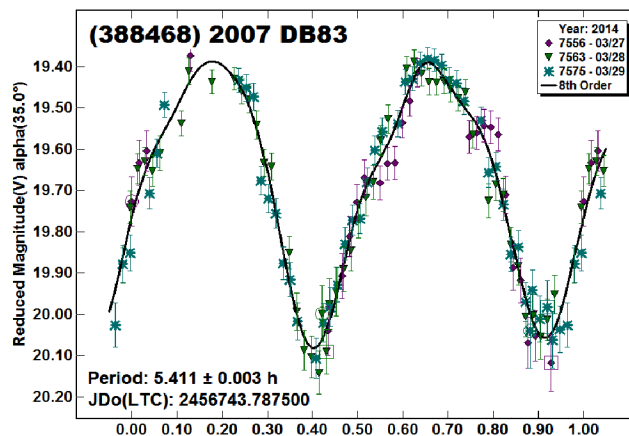


The asteroid was observable for only two days in 2014, April 7 and 8. Data on the second night appeared to have captured a mutual event involving the satellite. The lightcurve is the result of forcing the solution near the 20 h period from the radar observations. The primary rotation period could not be found in the limited data set, probably because of a combination of the noisy data and a low amplitude.

(387733) 2003 GS. Hicks *et al.* (2014) worked this NEA the same time as at PDS. Both efforts found essentially the same period.

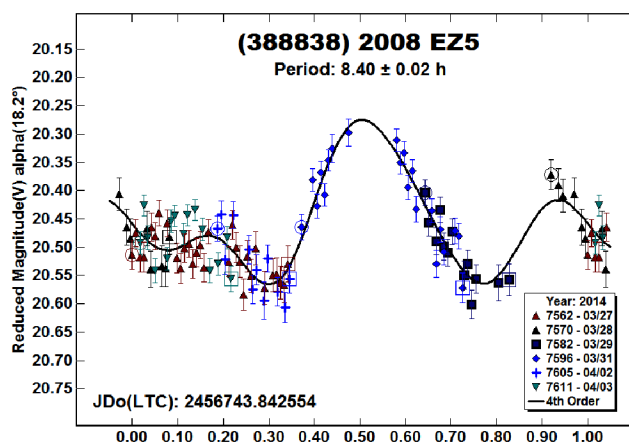


(388468) 2007 DB83. The initial analysis for this asteroid showed that a period of 6.05 h was favored, with another solution near 5.4 h. Pravec *et al.* (2014) subsequently reported a period of 5.414 h and so the PDS data were given a second look.

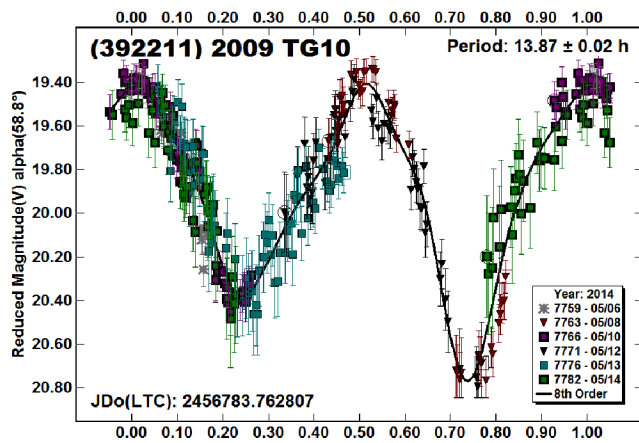


The longer period appears to have been a “fit by exclusion”, meaning that the Fourier analysis incorrectly minimized the number of overlapping data points in order to achieve a lower RMS. Furthermore, the lightcurve for the longer period showed a flat, incomplete minimum near 0.9 rotation phase. This made the solution less likely given the large amplitude: it would have required a large flat spot or concavity on one end of the elongated asteroid. The revised lightcurve completed the second minimum with a smoother outline and matches the Pravec *et al.* result.

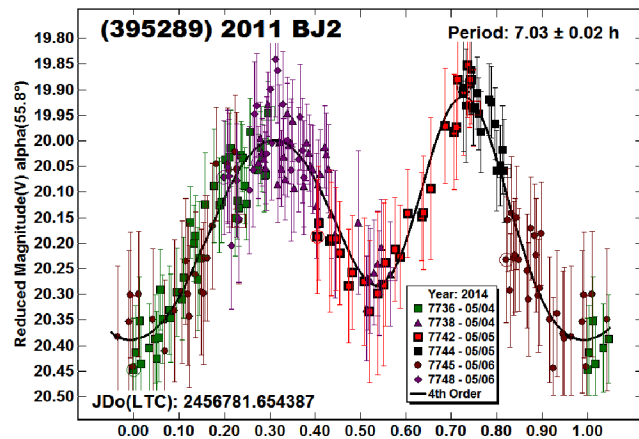
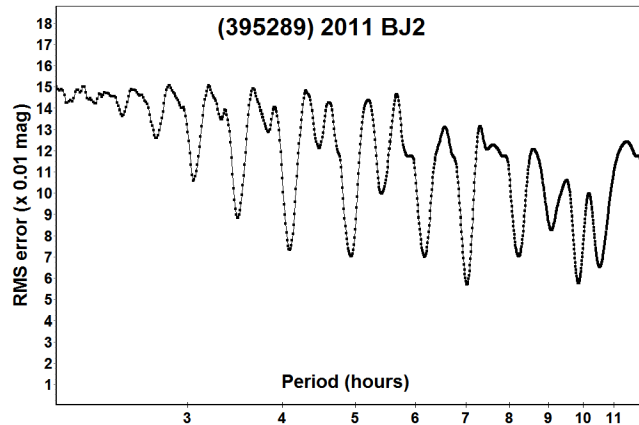
(388838) 2008 EZ5. The unusual shape of the lightcurve and data from only two sessions supporting the maximum near 0.5 rotation phase make the period of 8.4 hours somewhat suspicious. However, a scan of the period spectrum from 2 to 30 hours found no other solution save those with up to 6 minimum/maximum pairs per cycle.



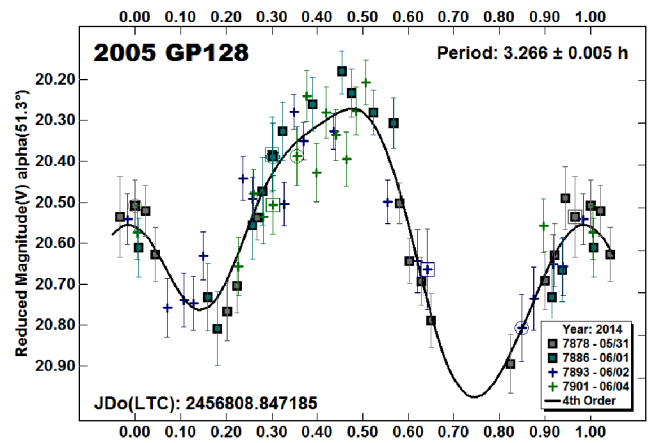
(392211) 2009 TG10. Despite the noisy data, the result of $P = 13.87$ h seems reasonably secure, mostly based on the large amplitude of 1.34 mag. At low phase angles, such an amplitude physically demands a bimodal lightcurve (see Harris *et al.*, 2014). However, at high phase angles, such as nearly 60° in the case of the 2014 observations, lightcurves can take on “unexpected” shaped due to shadowing effects. For example, a nearly spherical object, which would have a low amplitude at small phase angles, can have a large amplitude at large phase angles because of a concavity causing deep shadows.



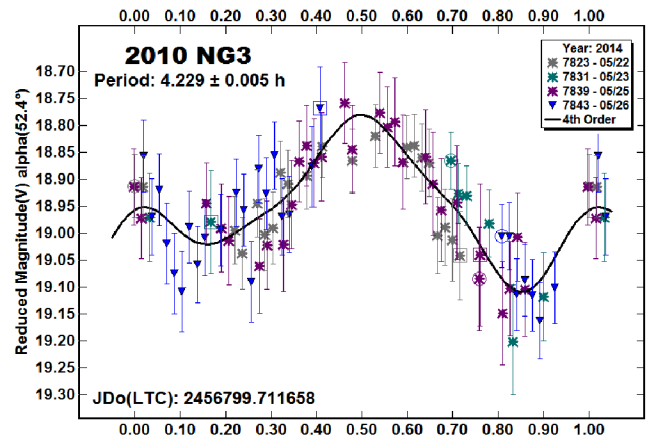
(395289) 2011 BJ2. The period spectrum for 2011 BJ2 favors a period of 7.03 h, which produces a typical bimodal lightcurve. However, as mentioned previously, lightcurves obtained at high phase angles don't always follow the basic rule of thumb tying amplitude and modality. There were no other results found in the literature.



2005 GP128. Observations of this NEA were made in late May and early June 2014. The period of 3.266 h and 0.70 mag amplitude are reliable but, here again, because of the high phase angle observations and the potential for deep shadowing effects, it cannot be rated higher than $U = 2+$ on the reliability scale in the LCDB. These appear to be the first results reported for this asteroid.

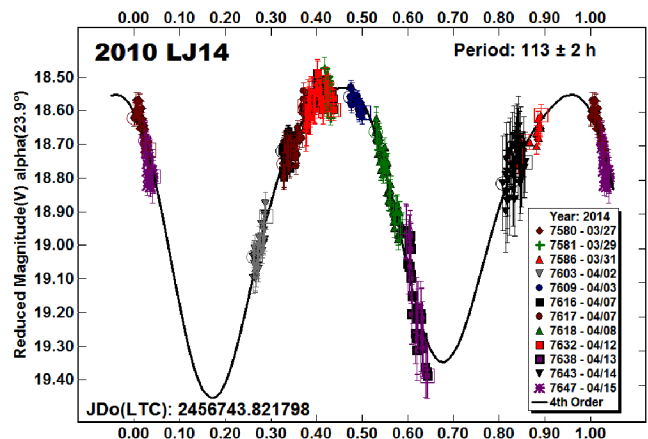


2010 NG3. There were no other results found in the literature for 2010 NG3. The asymmetrical lightcurve may be due to shadowing effects at high phase angles.



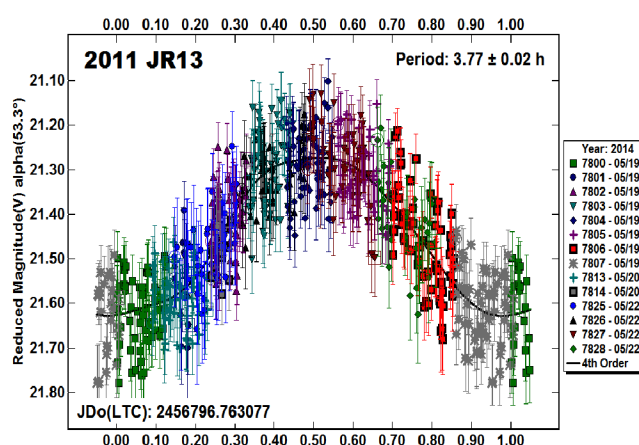
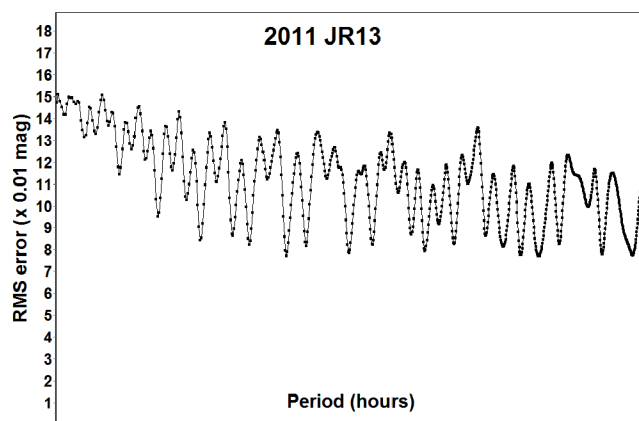
2010 LJ14. The long period of 113 hours makes this a good candidate for being a tumbler. There were no obvious signs of such, at least within the uncertainties of the zero point calibrations.

It should be noted that Pravec *et al.* (2014) adopted a different formulae for tumbling damping time, i.e., the time it takes for an asteroid to stabilize into single axis rotation after reaching its maximum tumbling state (see Pravec *et al.*, 2005). For a given damping time, e.g., the age of the Solar System, and diameter, the new formula reduces the expected rotation period by about half that under the old formula. In other words, tumbling asteroids "settle down" faster than previously expected.

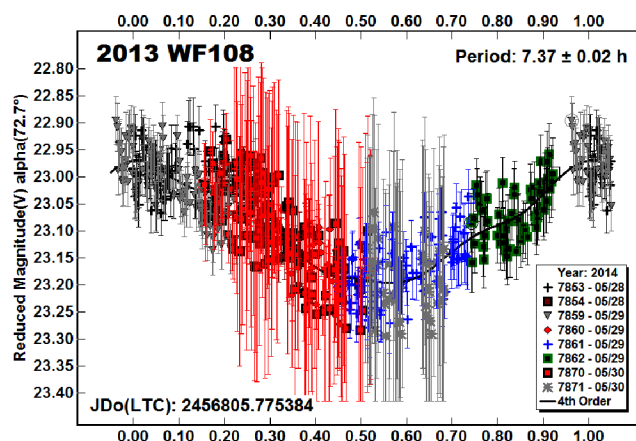
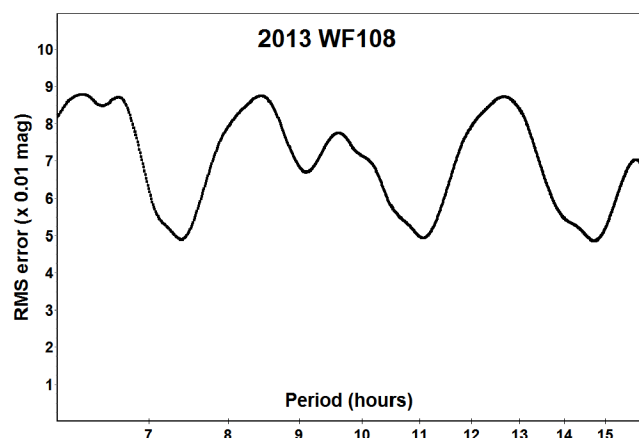


2011 JR13. Radar observations (Ellen Howell, private communications) showed that the rotation period of this asteroid was approximately 4 hours. The initial analysis of the optical data gave entirely different results, mostly because – as shown in the period spectrum – there were a number of potential solutions. The lightcurve shows the PDS photometry data forced to a solution of 3.77 hours, in agreement with the radar period.

Furthermore, the radar observations indicated a nearly spheroidal shape. Given the high phase angle, where shadowing effects can alter the lightcurve significantly, the monomodal, high amplitude lightcurve is not overly surprising. This was a good example of how close coordination between optical and radar observers is highly beneficial and strongly encouraged.

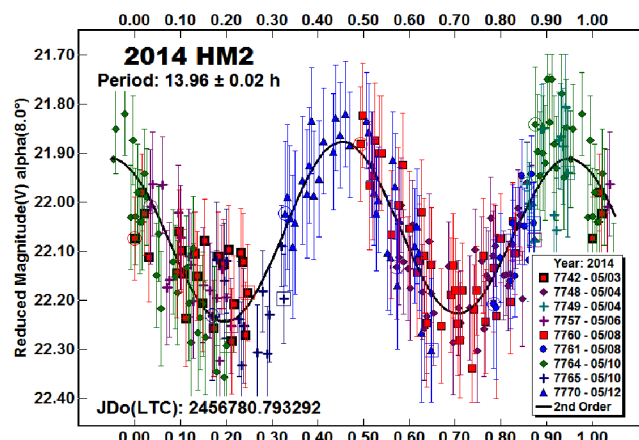


2013 WF108.

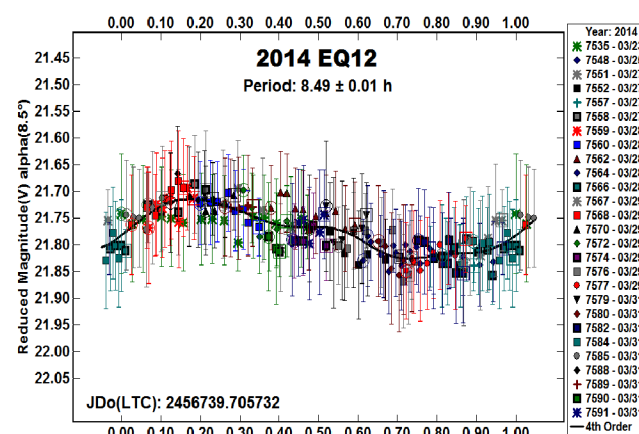


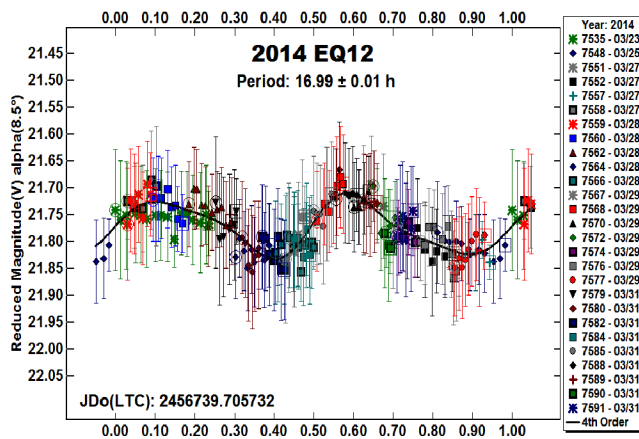
2013 WF108 was a fast moving, faint NEA observed at the end of May 2014. The period spectrum, as in many other cases, showed a number of potential solutions. Taking the results from 2011 JR13 as a guide, i.e., observations at very high phase angles and a monomodal solution, the preferred period is 7.37 h, although a bimodal solution at about 14.7 hours cannot be formally excluded.

2014 HM2. Given the low phase angle of 8° , this was a case where an amplitude of 0.40 would reasonably lead to a bimodal lightcurve (see Harris *et al.*, 2014). While the period spectrum showed a number of other possibilities, the bimodal solution is considered secure.



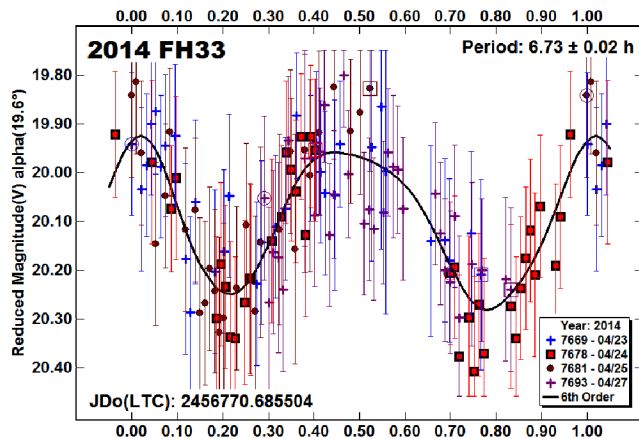
2014 EQ12. The lightcurves below use bins of 5 data points (*not* running average mode), but the analysis used all data points.



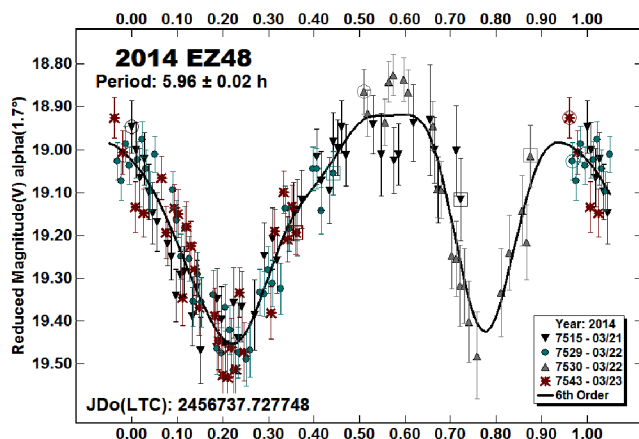


Because of the low amplitude and phase angle, no assumption could be made about the shape of the lightcurve (Harris *et al.*, 2014). The period spectrum, however, favored the two more common solutions, a monomodal lightcurve with a period of 8.49 h and a bimodal shape with a period of 16.99 h. Complicating matters was that radar observations (Ellen Howell, private communications) indicated a rotation period on the order of 4.4 hours. No amount of manipulation of zero points in the photometry data would lead to a period that short. Given the radar analysis, the shorter period, 8.49 h, is adopted for this paper but the solution should be considered ambiguous at best.

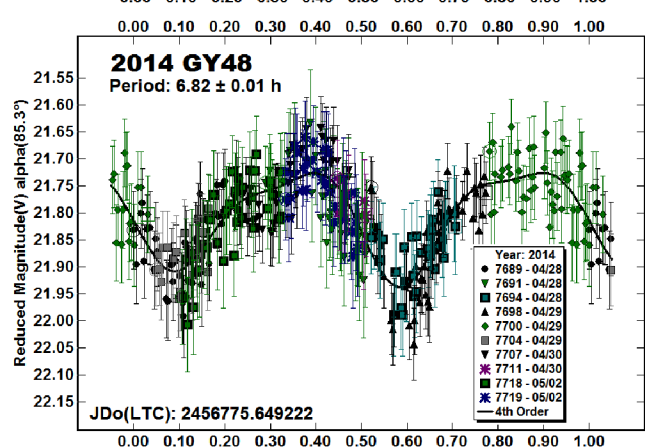
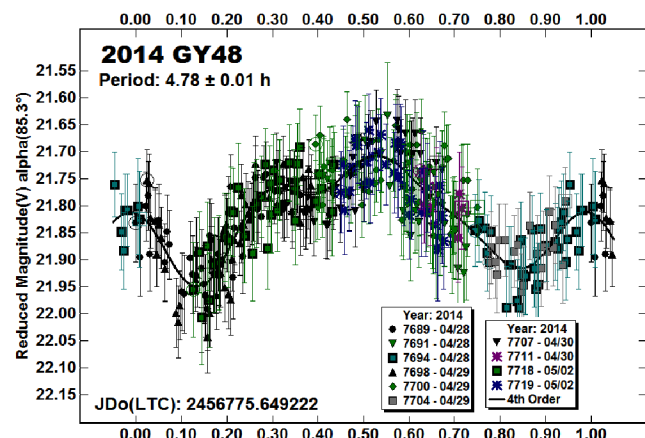
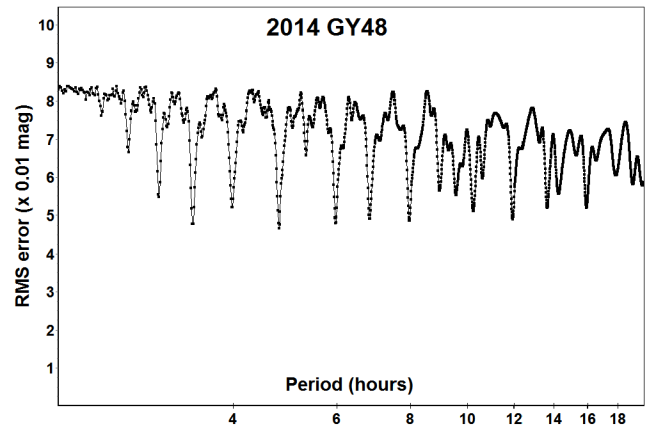
2014 FH33. No previous results for 2014 FH33 were found.



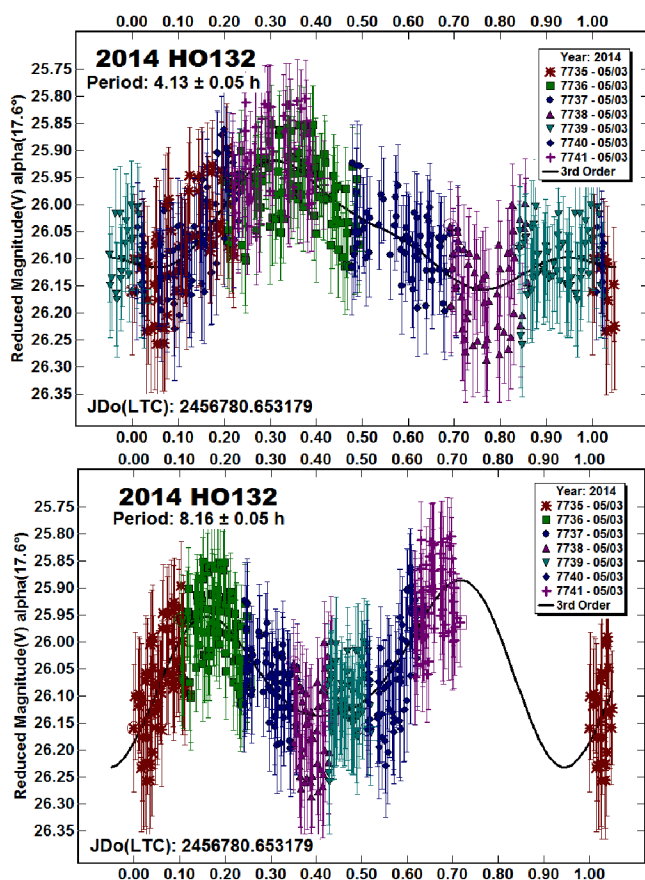
2014 EZ48. This appears to be the first reported lightcurve for 2014 EZ48. It was too far away and small for radar observations.



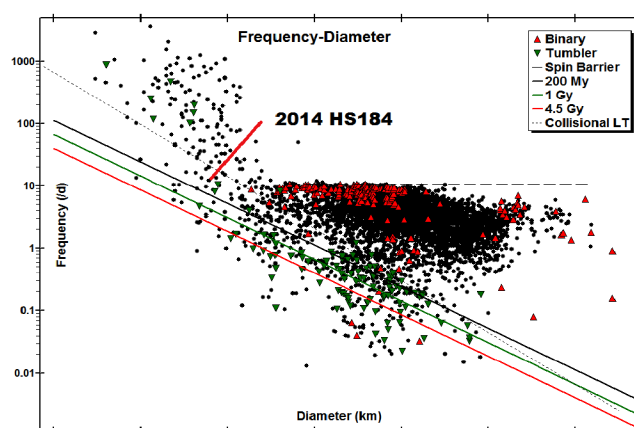
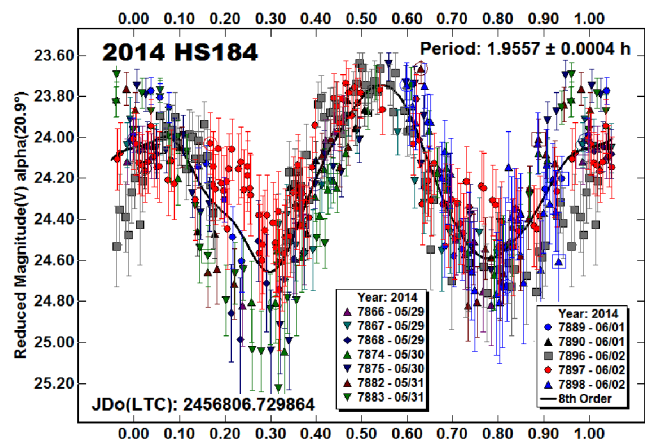
2014 GY48. The period spectrum for 2014 GY48 shows a number of equally possible solutions. The slightly favored result was for 4.78 hours and produced an asymmetrical bimodal lightcurve. On the other hand, the second most likely result produced a more symmetrical bimodal shape with a period 6.82 hours. Looking at the period spectrum RMS fits for the half-periods of the two possibilities, the one for the longer period, i.e., about 3.4 hours, is nearly equal to the fit for the full period solution while the half-period for 4.8 h (2.4 h) is considerably weaker. Because of this and the better symmetry in the lightcurve, the 6.82 h period is believed to be more likely correct, but the half-period cannot be formally excluded, especially in light of the high phase angle.



2014 HO132. Photometry analysis provided two possible solutions, a monomodal lightcurve at 4.13 h and a bimodal lightcurve at 8.16 h. Radar observations (Marina Brozovic, private communications) tend to support the shorter period and so it is the one adopted for this work.



2014 HS184. Analysis of photometric observations found a bimodal lightcurve with a period of 1.9557 h. This lies a little above the so-called *spin barrier* that divides objects with $D > \sim 0.2$ km between rubble piles and strength-bound bodies. At first, this made the solution a bit suspicious but, when noting that the estimated diameter is only 0.06 km, the solution was more plausible. The frequency-diameter plot from the LCDB shows the location of 2014 HS184, near the bottom-left of the *ascending branch* that is populated by small, super-fast rotators that are almost certainly strength-bound objects. It is also near the 0.2 Gy tumbling damping line (see Pravec *et al.*, 2014) and close to two known tumblers. Analysis by Petr Pravec (private communications) indicated signs that the asteroid is a tumbler but the data set was insufficient to confirm this.



Acknowledgements

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LIGHTCURVE ANALYSIS OF THE NEA BINARY ASTEROID 5381 SEKHMET

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Radar observations in 2003 (Nolan *et al.*, 2003) showed that the near-Earth asteroid (NEA) 5381 Sekhmet was a binary. CCD photometry observations made from the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) during the 2014 apparition confirmed the discovery and found the first precise values for the primary rotation period, $P_1 = 2.8233 \pm 0.0001$ h, and the orbital period of the satellite, $P_{ORB} = 12.379 \pm 0.004$ h. The estimated effective size ratio of the two bodies is $D_s/D_p \geq 0.25 \pm 0.02$, which is in good agreement with the sizes estimated by radar.

Using the Arecibo radar facility in 2003 May, Nolan *et al.* (2003) discovered that the near-Earth asteroid (NEA) 5381 Sekhmet was a binary object. Their analysis indicated sizes of 1 km and 0.3 km for the primary body and satellite, respectively. They also estimated the orbital period to be on the order of 12 hours, with 24 hours being less probable.

The NEA was favorably placed for optical observations in 2014 May and June, at which time CCD photometry was conducted at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS). A 0.3-m $f/9.4$ Schmidt-Cassegrain was used along with a Finger Lakes Instrumentations MicroLine-1001E operating at -30° C. The 1024x1024 array of 24-micron pixels provided a field of view of about 29.5x29.5 arcminutes and a plate scale of 1.7 arcsec/pixel. All images were guided and taken with no filter. Exposures were 120 seconds in late May and decreased to 90 seconds in June as the asteroid's sky motion increased. Dark frames and flat fields were applied in *MPO Canopus*.

Measurements were done using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* finds up to five comparison stars of near solar-color to be used in differential photometry. Catalog magnitudes were taken from the APASS catalog (Henden *et al.*, 2009) since these are derived directly from reductions based on Landolt standard fields. Period analysis was also done using *MPO Canopus*, which implements the FALC algorithm developed by Harris (Harris *et al.*, 1989).

In the lightcurve 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 phase angle given in parentheses, e.g., $\alpha(6.5^\circ)$, using $G = 0.15$, unless otherwise stated. The horizontal axis is the rotational phase, ranging from -0.05 to 1.05 .