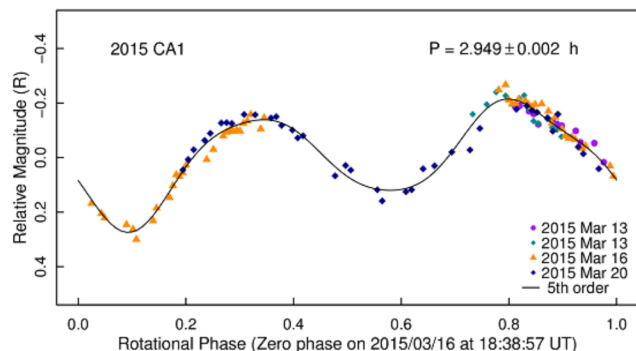
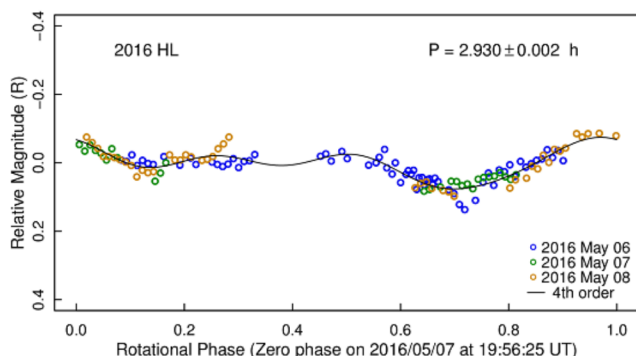


well-covered and presents a low dispersion of the data. It is asymmetric and the amplitude of 0.49 ± 0.02 mag implies $a/b \geq 1.57$, suggesting an elongated object.



2016 HL. The Apollo class and potentially hazardous asteroid (PHA) 2016 HL was discovered at SONEAR Observatory, Oliveira-Brazil, on 2016 April 19. An extremely close approach to the Earth (0.05 AU) occurred on April 12. We observed this asteroid after its close approach for about 8.5 hours on three nights, 2016 May 6 to 8. The derived synodic period is $P = 2.930 \pm 0.002$ h with a small amplitude of $A = 0.15 \pm 0.02$ mag.



Acknowledgements

The authors acknowledge CAPES for the fellowships and FAPERJ for the support to D.L., through project number E-26-102.967/2011. Finally, we are gratefully to the IMPACTON team, in particular, A. Santiago, for the technical support at OASI.

References

- Burns, J.A., Tedesco, E.F. (1979). "Asteroid Lightcurves – Results for Rotations and Shapes." in *Asteroids* (T. Gehrels, editor), pp 494-527. Univ. Arizona Press, Tucson.
- Harris, A.W., Young, J.W. (1983). "Asteroids rotation. IV." *Icarus* **54**, 59-109.
- Harris, A.W., Young, J.W., Bowell, E., Martin, L.J., Millis, R.L., Poutanen, M., Scaltriti, F., Zappala, V., Schober, H.J., Debehogne, H., Zeigler, K. (1989). "Photoelectric Observations of Asteroids 3, 24, 60, 261, and 863." *Icarus* **77**, 171-186.
- Pravec, P., Harris, A.W., Michalowski, T. (2002). "Asteroid Rotations." in *Asteroids III* (W.F. Bottke, A. Cellino, P. Paolicchi, R.P. Binzel, eds.) pp 113-122. Univ. Arizona Press, Tucson.

Warner, B.D., Harris, A.W., Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2016 Sept. <http://www.minorplanet.info/lightcurvedatabase.html>

NEAR-EARTH ASTEROID LIGHTCURVE ANALYSIS AT CS3-PALMER DIVIDE STATION: 2016 JULY-SEPTEMBER

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Lightcurves for 46 near-Earth asteroids (NEAs) obtained at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2016 July-September were analyzed for rotation period and signs of satellites or tumbling.

CCD photometric observations of 46 near-Earth asteroids (NEAs) were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2016 July-September. Table I lists the telescope/CCD camera combinations used for the observations. All the cameras use CCD chips from the KAF blue-enhanced family and so have essentially the same response. The pixel scales for the combinations range from 1.24-1.60 arcsec/pixel.

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

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

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

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

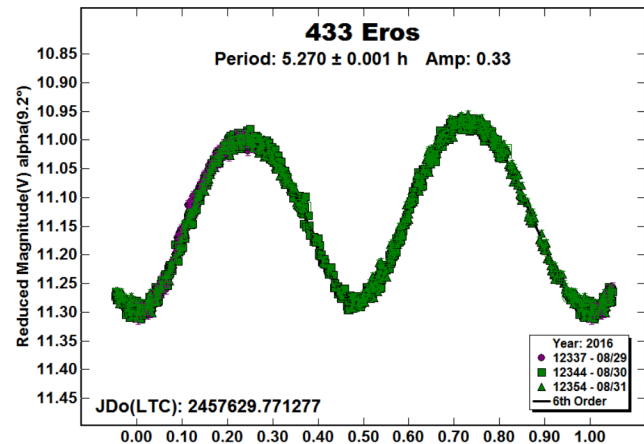
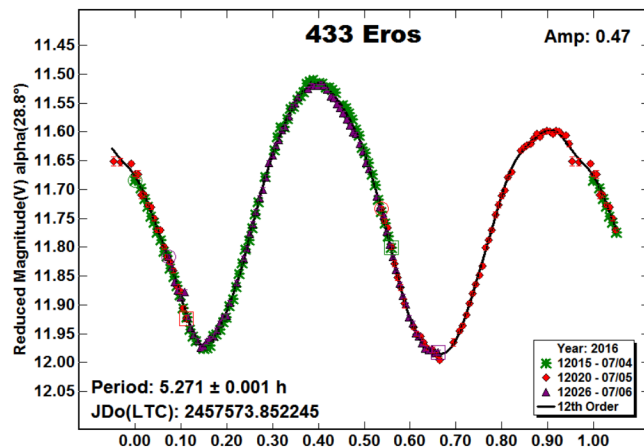
In the plots below, the "Reduced Magnitude" is Johnson V as indicated in the Y-axis title. These are values that have been

converted from sky magnitudes to unity distance by applying $-5 \cdot \log(r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and Earth-asteroid distances in AU. The magnitudes were normalized to the given phase angle, *e.g.*, $\alpha(6.5^\circ)$, using $G = 0.15$, unless otherwise stated. The X-axis is the rotational phase, ranging from -0.05 to $+1.05$.

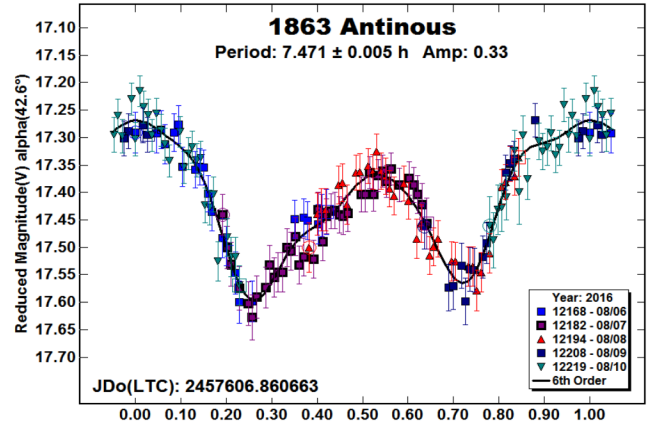
For the sake of brevity, only some of the previously reported results may be referenced in the discussions on a specific asteroid. For a more complete listing, the reader is directed to the asteroid lightcurve database (LCDB; Warner *et al.*, 2009). The on-line version at <http://www.minorplanet.info/lightcurvedatabase.html>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

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

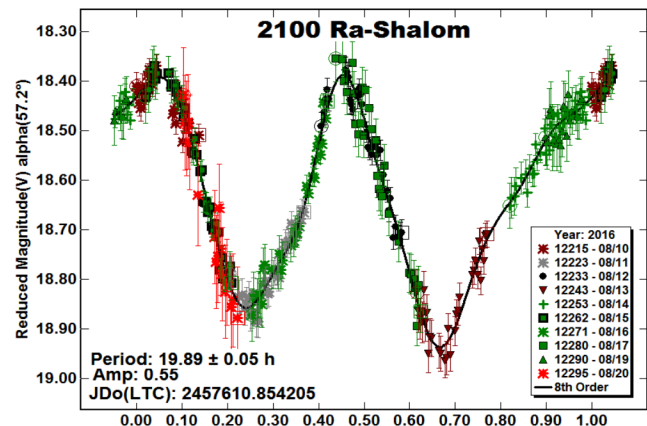
433 Eros. This well-known and extensively studied NEA was observed twice at PDS in 2016, first in July and then in late August. During the approximately six-week interval between data sets, the lightcurve shape and amplitude evolved significantly as the asteroid went from phase angle 28° to 10° . The lower amplitude at a lower phase angle is a well-established trait of most asteroid lightcurves (Zappala *et al.*, 1990).



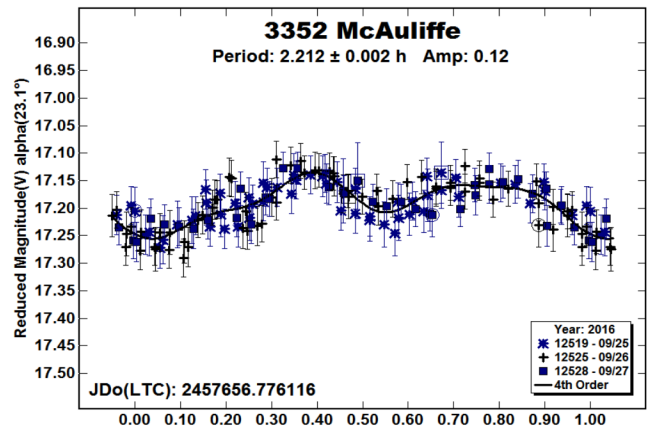
1863 Antinous. Binzel (1987) first reported a period of 4.02 h. Harris *et al.* (1999) observed the asteroid at about the same time in 1982 and found a period of 4.386 h. Observations by Pravec *et al.* (1999w) led to a more reliable solution of 7.4568 h. The NEA was observed at CS3-PDS in early 2016 (Warner, 2016a; 7.453 h). The latest PDS observations made in 2016 August led to a period of 7.471 h, which is consistent with the Pravec *et al.* and earlier PDS results.



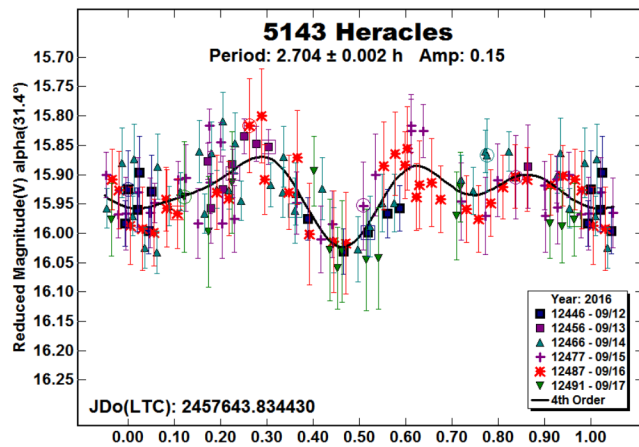
2100 Ra-Shalom. The period for Ra-Shalom was first established at 19.79 h by Ostro *et al.* (1984). The period found from the 2016 PDS data is slightly longer, 19.89 h, but still consistent with earlier results.



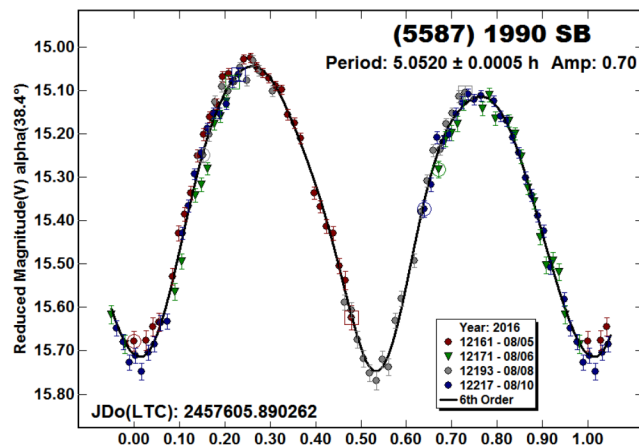
3352 McAuliffe. This is a suspected binary asteroid (Warner, 2012). No signs of the purported satellite were seen at the 2016 apparition.



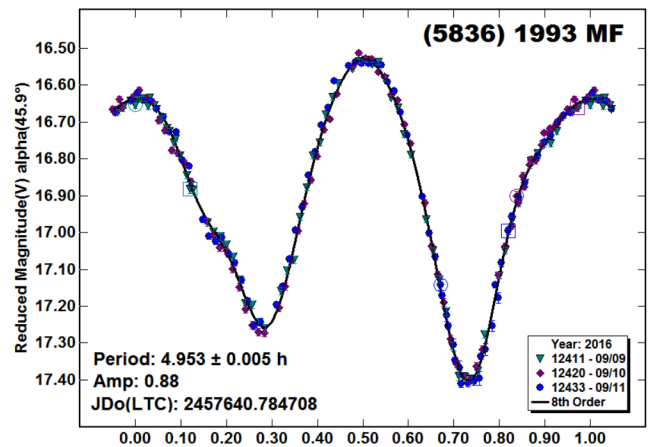
5143 Heracles. This is a known binary (Taylor *et al.*, 2012b) based on radar observations. The estimated effective diameter ratio is about 0.16 and the orbital period in the range of 14-17 hours. The small size ratio is on the edge of being detectable with photometry observations alone, so it is not too surprising that the satellite had not been discovered before the radar observations.



(5587) 1990 SB. Koff *et al.* (2002) did an extensive study of 1990 SB that included observations from before and after opposition. This allowed showing the evolution of the lightcurve shape and synodic period over several months. The period found from the 2016 PDS data is consistent with the average period from Koff *et al.* and other previous results.



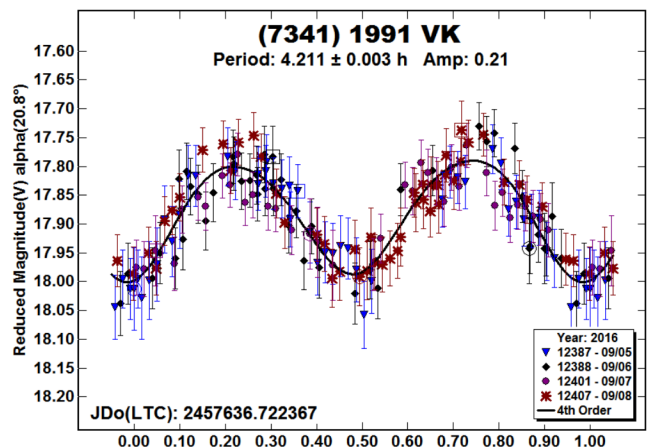
(5836) 1993 MF. The period of 4.953 h found from the PDS data is consistent with earlier results such as Mottola *et al.* (1995; 4.959 h) and Pravec *et al.* (1997w; 4.9543 h). The NEA was observed in 2016 June (Warner, 2016c; 4.948 h) when the amplitude was 0.82 mag. The 0.88 mag found in September is the largest found in the LCDB for 1993 MF.



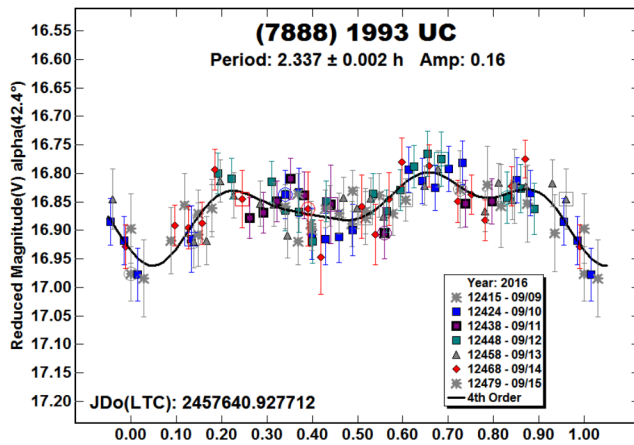
(7341) 1991 VK. Pravec *et al.* (1998) found a period of 4.2096 h. The period of 4.211 h derived from the 2016 PDS data is consistent with that earlier result.

It's of some note that the AKARI survey (Usui *et al.*, 2011) reported a very high albedo, $p_V = 0.625$, which is somewhat unusual within the NEA population. Even if using a different absolute magnitude, $H = 16.95$ (Pravec *et al.*, 2012), and the correcting algorithm of Harris and Harris (1997), the albedo is still 0.49 ± 0.10 . This is more consistent with type E (possibly type M) asteroids (Warner *et al.*, 2009a) rather than the more typical S-complex or, to a lesser extent, C-complex types seen among the NEA population.

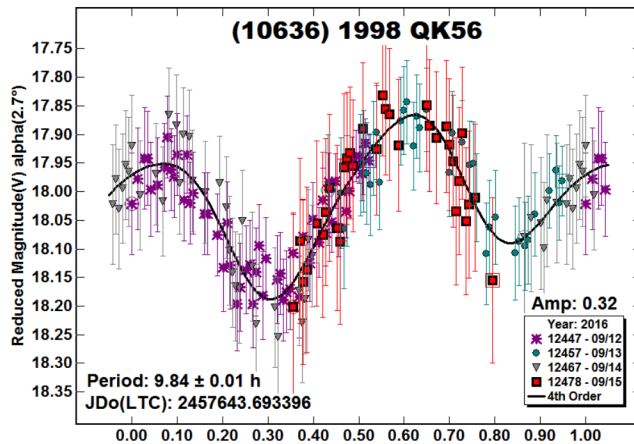
The asteroid has a very favorable apparition in 2017 February, at which time it will be a strong radar target. Supporting photometric observations are encouraged. The close encounter may also allow spectroscopic observations of the asteroid that will help determine its true taxonomic class.



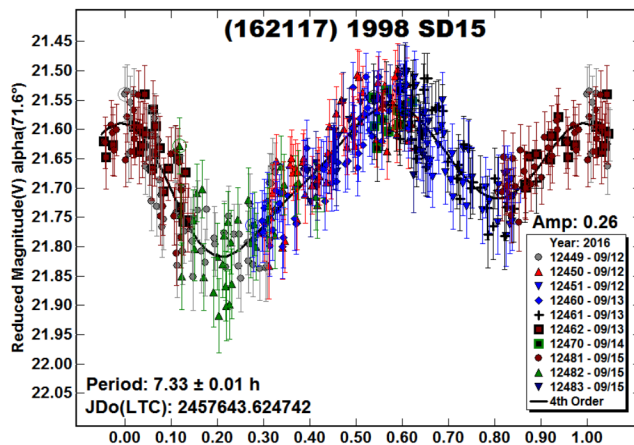
(7888) 1993 UC. The PDS observations in 2016 led to a period of 2.337 h, which is consistent with the 2.340 h found by Pravec *et al.* (1996). Unfortunately, there appears to be no results between these two, making it difficult – if not impossible – to determine if the rotation period is being affected by YORP.



(10636) 1998 QK56. The results from PDS appear the first to be reported for this NEA. The asteroid has a favorable apparition in 2017 March, when it will reach $V \sim 15.2$ mag. Follow-up observations at PDS are planned. Other observations are encouraged.

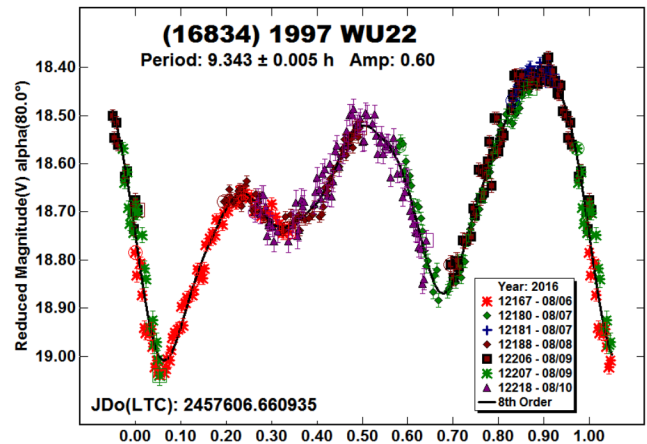


(162117) 1998 SD15. There were no previously reported periods in the LCDB for 1998 SD15. The 2016 apparition was the last good chance for photometric observations until 2025 September, when the asteroid will reach $V \sim 17.0$. Before then, it is mostly below 20th magnitude.

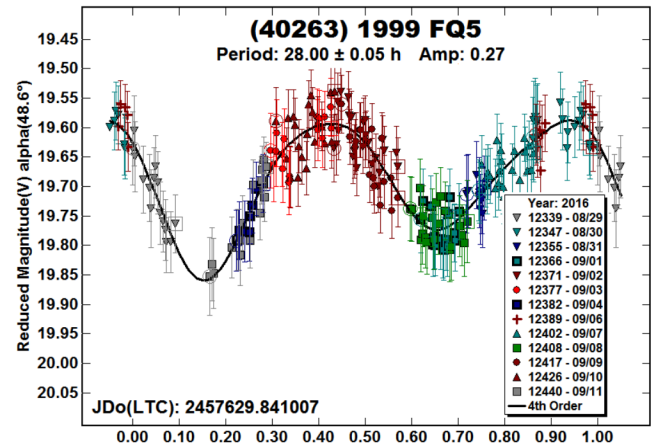


(16834) 1997 WU22. The usual lightcurve shape for 1997 WU22 may have been due in good part to the high phase angle, when

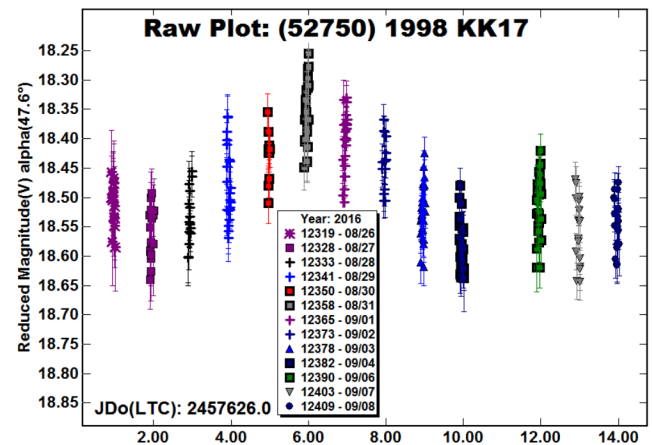
shadowing effects can come into play. The period agrees with Pravec *et al.* (2000w; 9.345h) and Stephens (2013w; 9.374 h).



(40263) 1999 FQ5. There were no other periods in the LCDB for 1999 FQ5. The next favorable apparition is not until 2036.

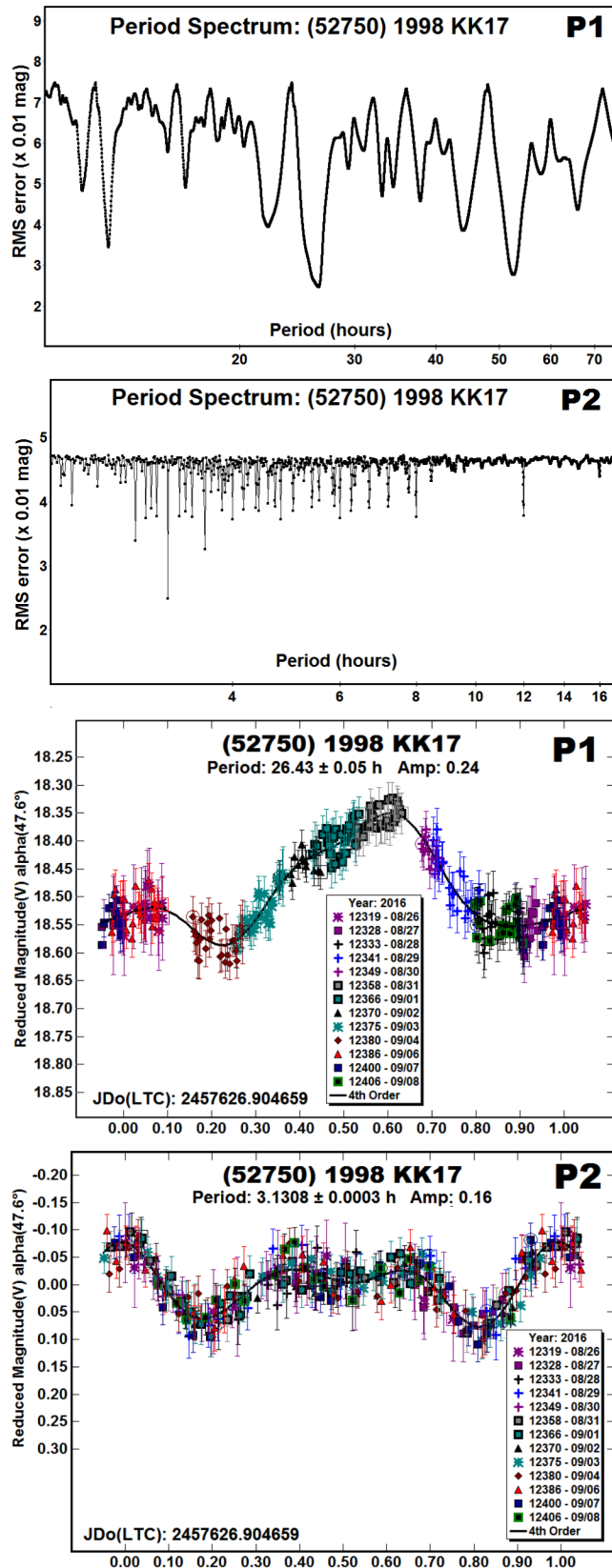


(52750) 1998 KK17. Higgins (2005) reported a period of 3.124 h for this NEA while the author (Warner, 2015) reported 2.28 h. Neither of these fit the single period analysis of the data.



A plot of the raw data from late August to early September showed indications of a long period with, possibly, a short-period component as well. On this presumption, a dual-period search was done using *MPO Canopus* where a solution for a long period was found and then subtracted from the data to determine if there was

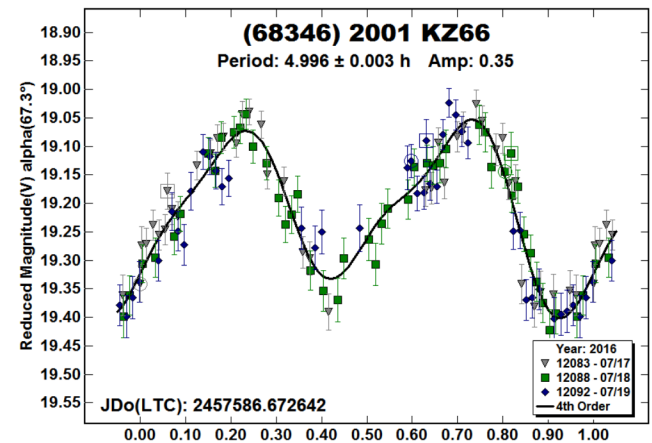
a short period. The short period was subtracted to confirm the long period. The process continued until both periods stabilized. The results are shown in the four plots, two being period spectra and the others the individual components of the combined lightcurve.



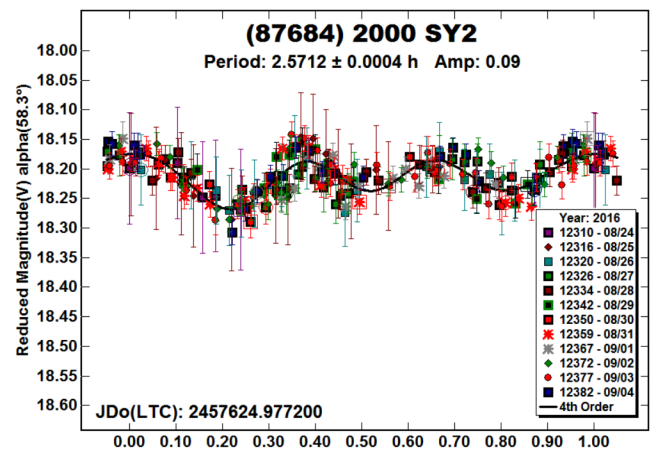
Note that the short period is very close to the one found by Higgins. It's possible that by using arbitrary zero-point adjustments, the long period was unintentionally removed, which serves as a cautionary tale to "let the data fall where they may" until there is good reason to do otherwise.

1998 KK17 may be another example of a so-called very wide binary asteroid. See Warner (2016b) for a discussion of this suspected subclass of binary asteroids.

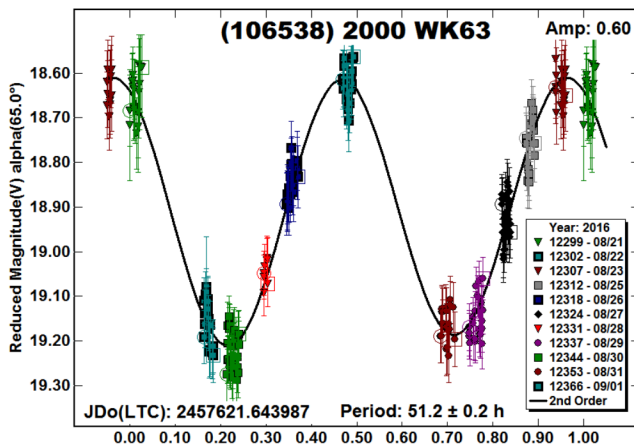
(68346) 2001 KZ66. Based on radar observations, Benner *et al.* (2006) estimated a rotation period of about 2.7 hours. Subsequent photometric observations by the author in 2016 May (Warner, 2016c) found a more likely period of 4.987 h. The more recent PDS data, obtained in 2016 July, support the longer period, though it may need further refinement at the next favorable apparition (2022, $V \sim 18.4$).



(87684) 2000 SY2. Higgins (2005) found a period of 8.80 hours. The 2016 PDS data do not support that result, but favor one of 2.8712 h.

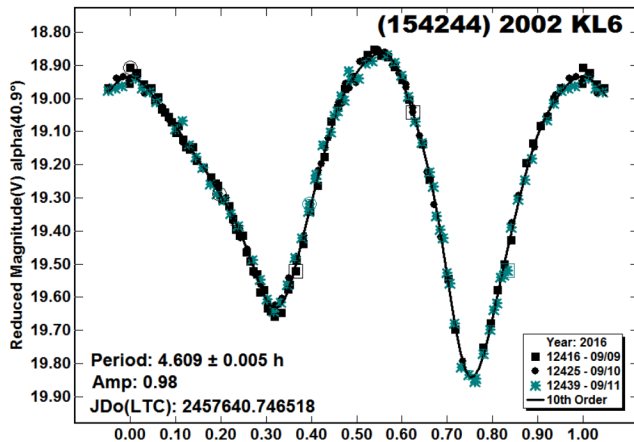


(106538) 2000 WK63. This appears to be the first reported period for 2000 WK63. The next good chance to obtain follow-up data comes in 2020 March.

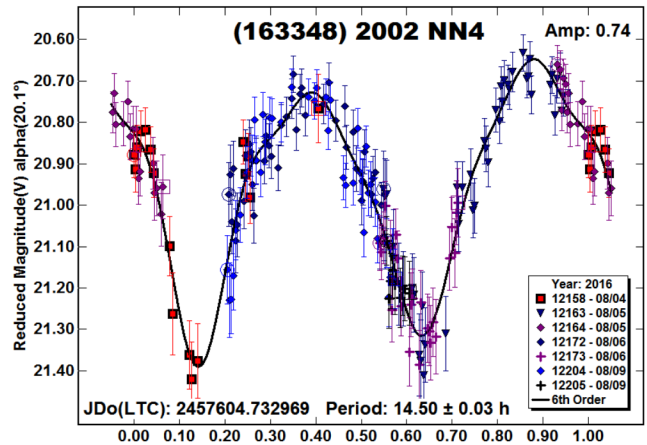
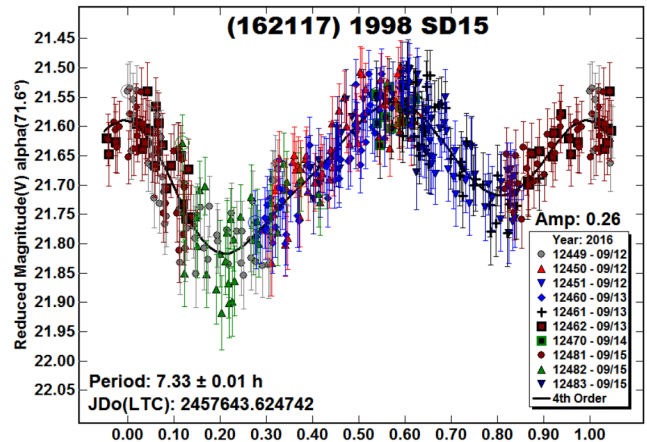


Based on times to dampen from tumbling (non-principal axis rotation) to single axis rotation (Pravec *et al.*, 2014, and references therein), there is a reasonable chance that this asteroid should be tumbling. There were no obvious signs of tumbling, *e.g.*, the slope of the data on a given night not following the slope of the Fourier curve. A better judgement of tumbling would require following the asteroid through at least another quarter rotation to see if the lightcurve repeated itself within the data noise level.

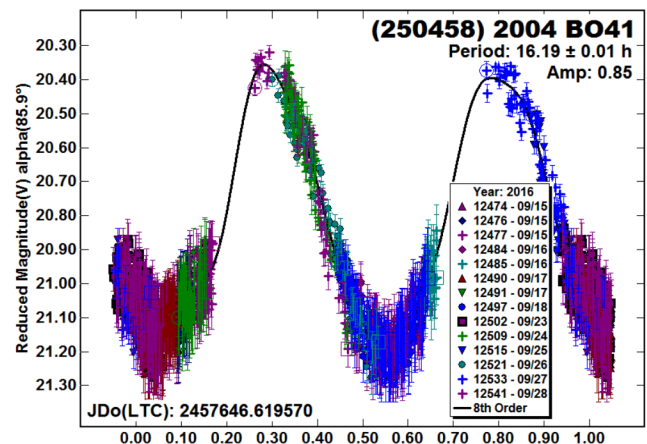
(154244) 2002 KL6. Koehn *et al.* (2014) followed this NEA for several months in 2009. The approximate average of the several synodic periods was 4.608 h, which is essentially identical to the period found with the 2016 PDS data.



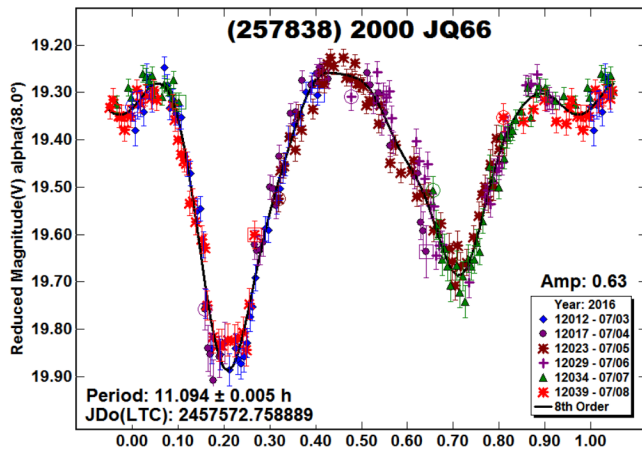
(162117) 1998 SD15, (163348) 2002 NN4. These are the first reported results in the LCDB for these two NEAs.



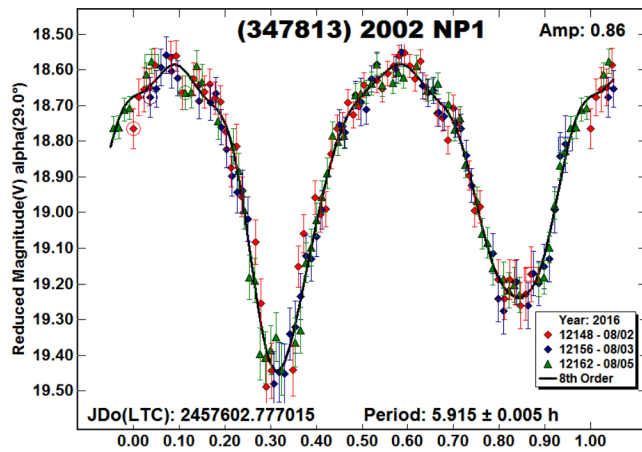
(250458) 2004 BO41. There were no previously reported periods for 2004 BO41 in the LCDB. There were several solutions, each commensurate with an Earth day. However, the best solution, based on the slopes of the lightcurve, is for a period of 16.19 h.



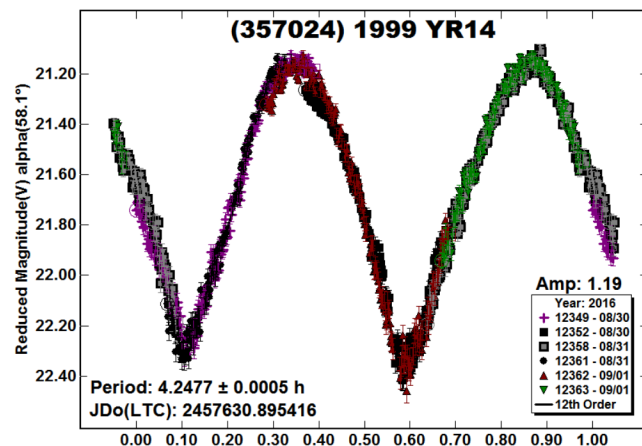
(257838) 2000 JQ66. Using observations from 2000, Pravec *et al.* (2000w) found a period of 11.1 hours. The PDS data from 2016 led to a consistent and slightly more refined result of 11.094 h.



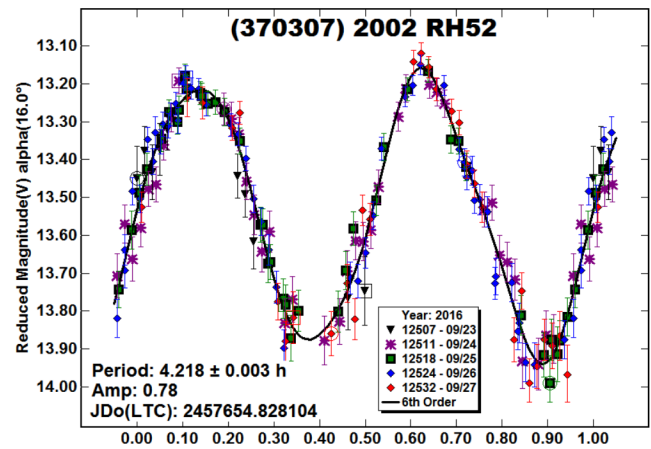
(347813) 2002 NP1, (357024) 1999 YR14. There were no previous entries in the LCDB for 2002 NP1 and 1999 YR14.



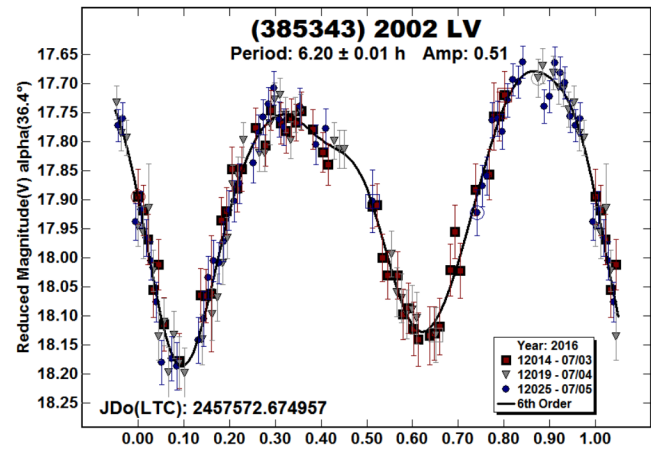
Spectroscopic observations by Thomas *et al.* (2014) determined that 2002 NP1 is a type Q asteroid on the Bus-DeMeo taxonomic system (DeMeo *et al.*, 2009, and references therein). The Q asteroids, 1862 Apollo being one of the well-known members, are uncommon among the inner main-belt. They are an “outlier” class in the Bus-DeMeo system, being an intermediate type between the Vestoids (V) and much more common S-complex.



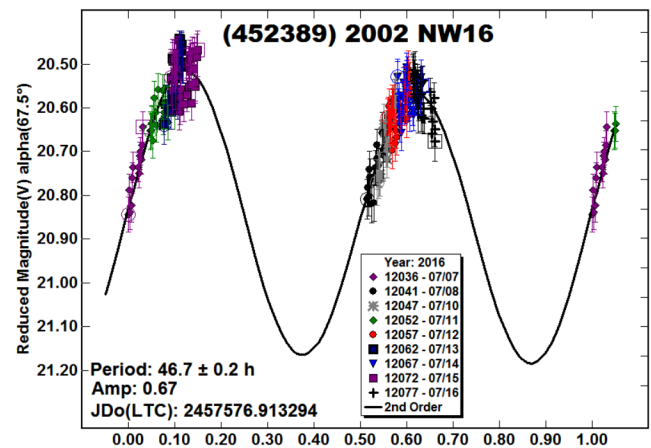
(370307) 2002 RH52. The period found from the 2016 PDS data agrees well with the one of 4.222 h found by Pravec *et al.* (2003w).



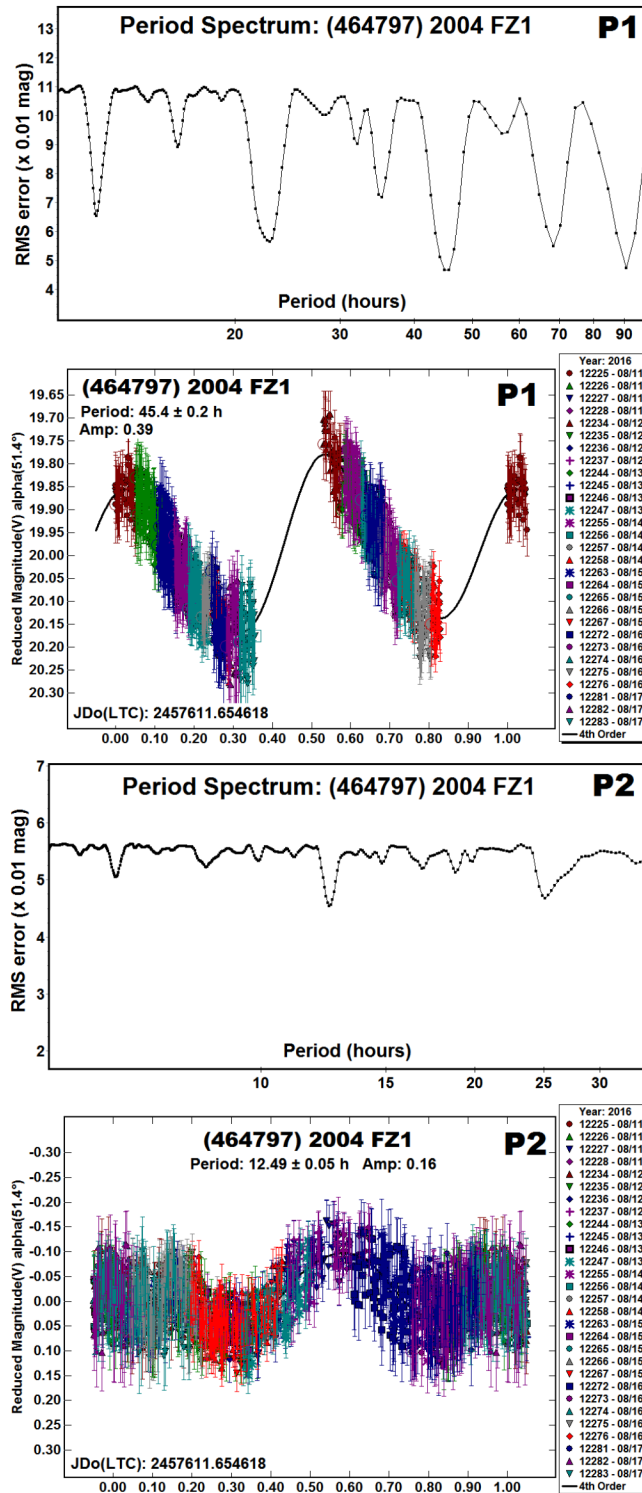
(385343) 2002 LV. Pravec *et al.* (2002w) and Hicks *et al.* (2009w) both reported a period of about 6.20 h. The results from the PDS observation agree with that period.



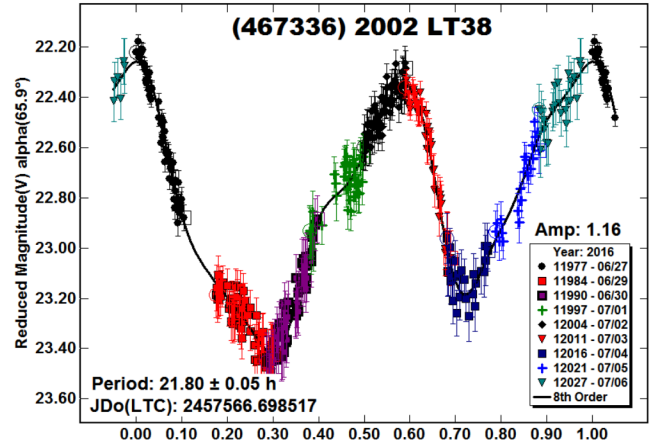
(452389) 2002 NW16. There were no previous results in the LCDB to help guide finding the period for 2002 NW16. The period appears commensurate with an Earth day. Based on a half-period solution and the reasonable slopes of the Fourier curve, a period of 46.7 h is adopted for this paper. The amplitude of 0.67 mag could be off significantly from the true value.



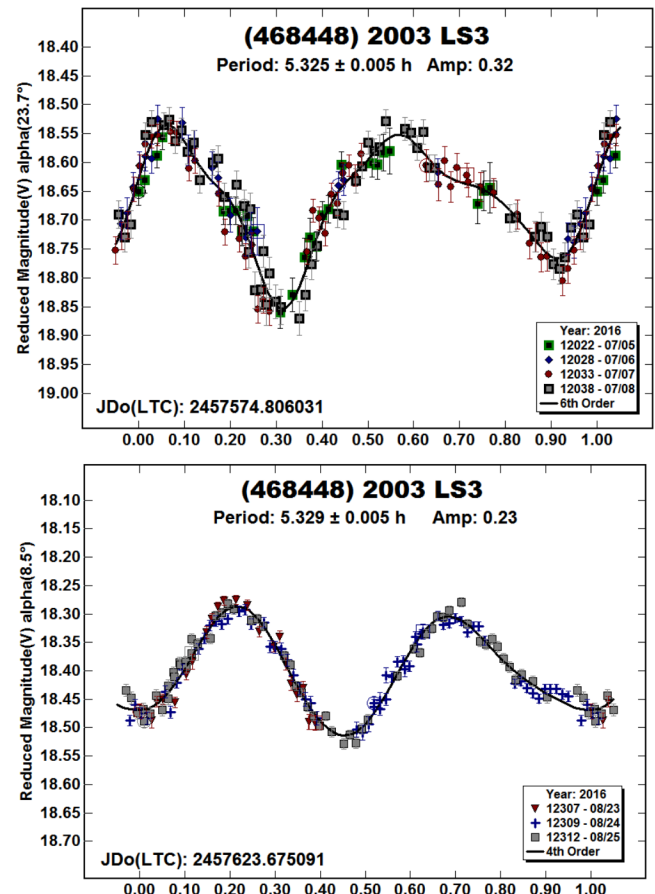
(464797) 2004 FZ1. This appears to be another example of a very wide binary asteroid. The lightcurve for these objects consists of a long-period component with an amplitude $A > 0.3$ mag and a short-period component with a smaller amplitude, usually $A < 0.15$ mag. The primary body is presumed to be the one with the long period. See Warner (2016b) for more about these asteroids.



(467336) 2002 LT38. This appears to be the first published period for 2002 LT38. Even when assuming a longer damping time from tumbling to single axis rotation (Pravec *et al.*, 2014, and references therein), the 21.8 hour period found here makes this a likely tumbler candidate. There may be some indications of tumbling in the lightcurve, for example, the “break” in the Fourier curve around 0.45 rotation phase.

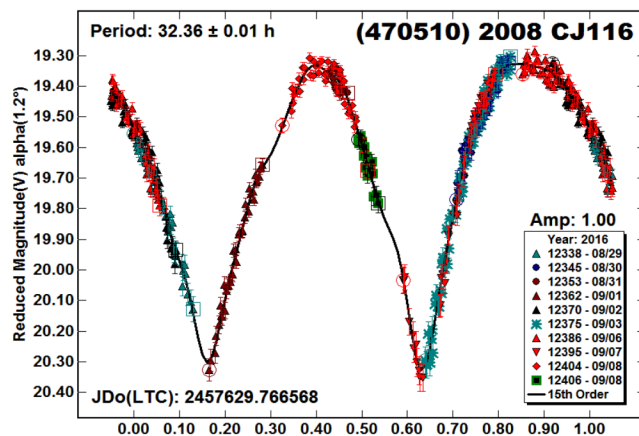
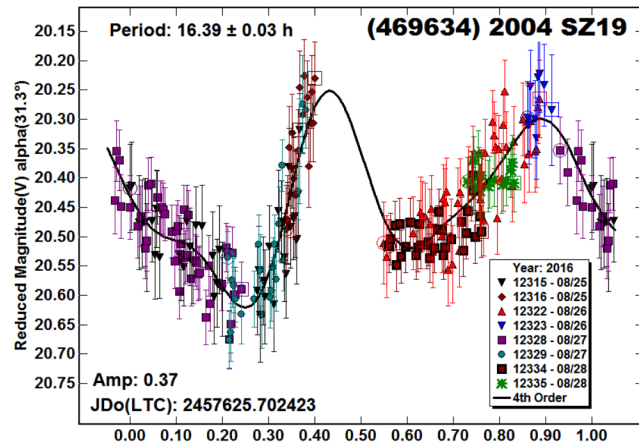
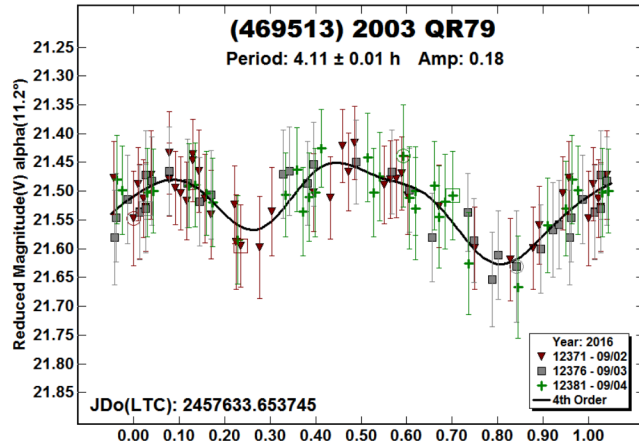


(468448) 2003 LS3. This NEA was observed twice at PDS in 2016. The first time was in July, when a period of 5.325 h and amplitude of 0.32 mag were found. The phase angle was about 23° . About six weeks later, the synodic period was statistically the same, but the amplitude had dropped to 0.23 mag, which was expected due to the lower phase angle of about 8° .

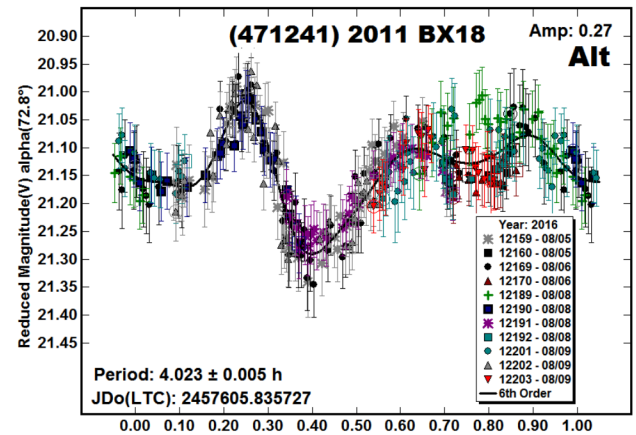
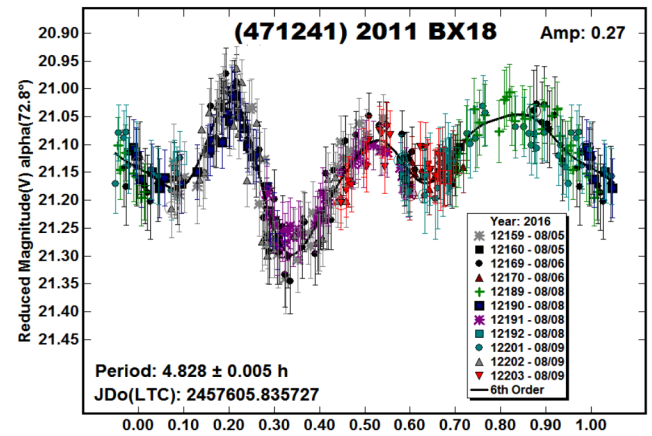
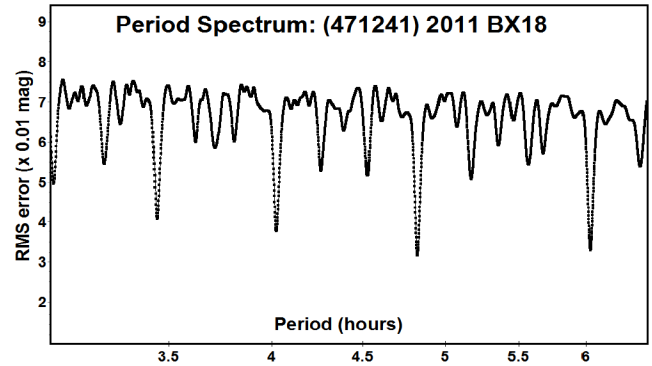


(469513) 2003 QR79, (469634) 2004 SZ19, (470510) 2008 CJ116. These look to be the first reported periods for the three NEAs. The low amplitude and significant noise in the lightcurve for 2003 QR79 make the solution less than secure, but it is still a reasonable estimate. The gap in the lightcurve for 2004 SZ19 is partly due to the adopted period being commensurate with an Earth day. Every 48 hours, approximately the same part of the lightcurve was covered. The gap was outside the observing window between the asteroid rising and setting or start of twilight.

The period for 2008 CJ116 makes it a good candidate for being a tumbler. However, there were no obvious signs in the data set. See Pravec *et al.* (2005) for a detailed discussion of tumbling asteroids.

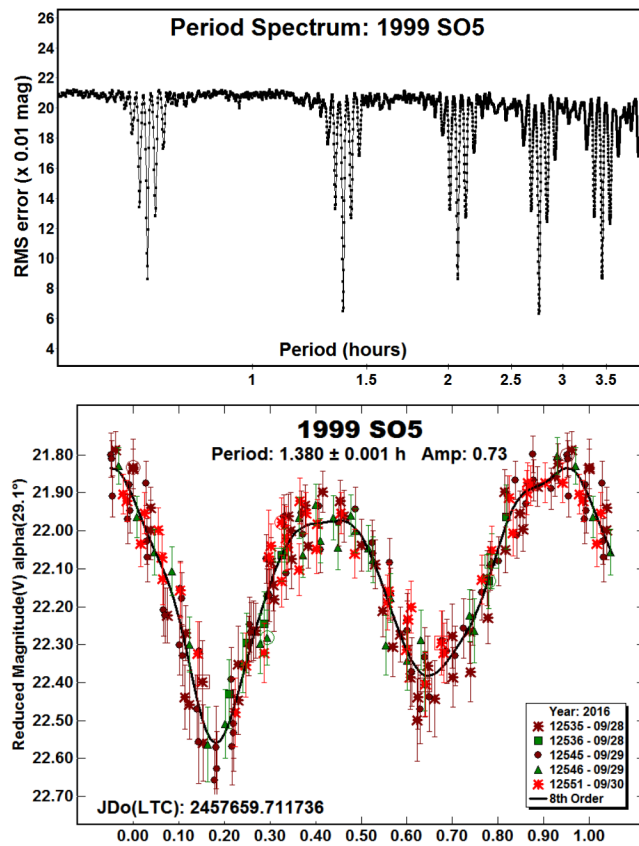


(471241) 2011 BX18.

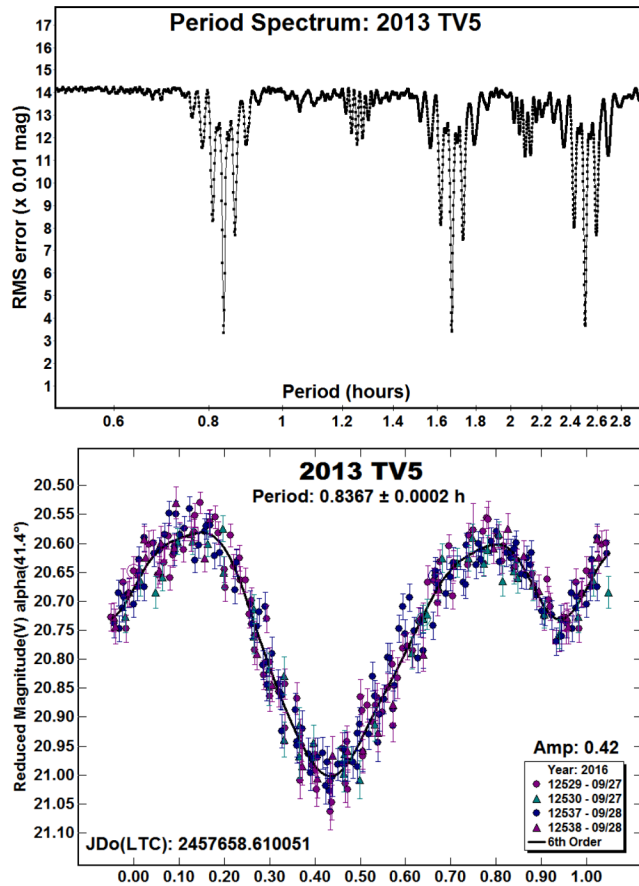


The high phase angle at which the observations of 2011 BX18 were made introduced the likelihood of strong shadowing effects that would produce an atypical lightcurve. Combined with possible solutions commensurate with an Earth day, a definitive solution could not be found. The period spectrum favored 4.828 hours. However, as seen in the alternate lightcurve, the data fit almost as well to a period of 4.023 h. The two periods represent a difference of almost exactly one rotation over 24 hours.

1999 SO5. While the period spectrum allows for several possible solutions, the dominant one is the most physically plausible (see Harris *et al.*, 2014). The alternate solutions represent either the half-period or integral multiples of the half-period greater than the adopted period of 1.380 hours.

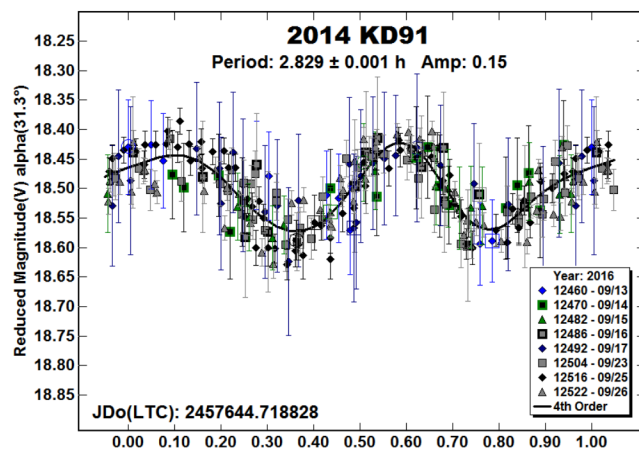


2013 TV5. The maximums of the lightcurve for 2013 TV are not 0.5 rotation phase apart, but the minimums nearly are. Such asymmetry is not impossible, especially at higher phase angles. However, it does make the solution at least somewhat suspect.

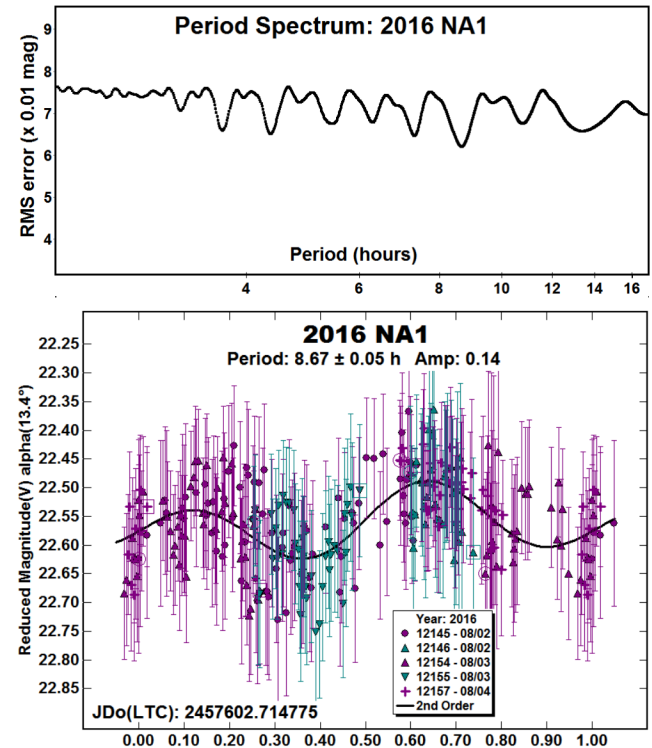


On the other hand, the period spectrum shows only a few obvious possibilities and the longer periods produce physically improbable lightcurves with multiple maximum/minimum pairs.

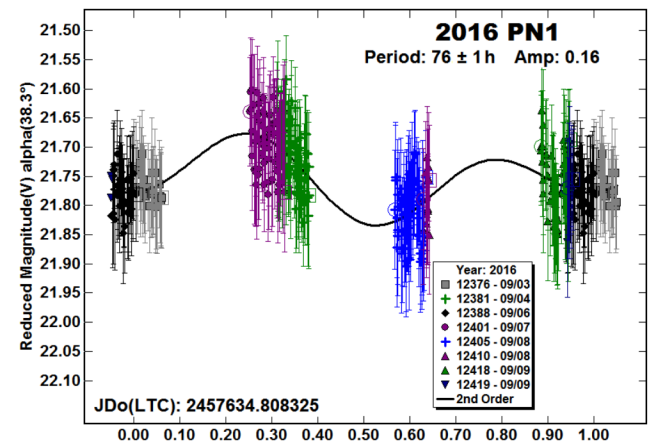
2014 KD91. There were no previously reported periods in the LCDB for 2014 KD91. Given the extensive coverage of the lightcurve and time span of the observations, the period is considered secure despite the low amplitude and somewhat noisy data set.



2016 NA1. The period of 8.67 hours adopted here is considered a "best guess" given the low amplitude and noisy data set. The period spectrum offered little help, showing a number of nearly likely solutions.

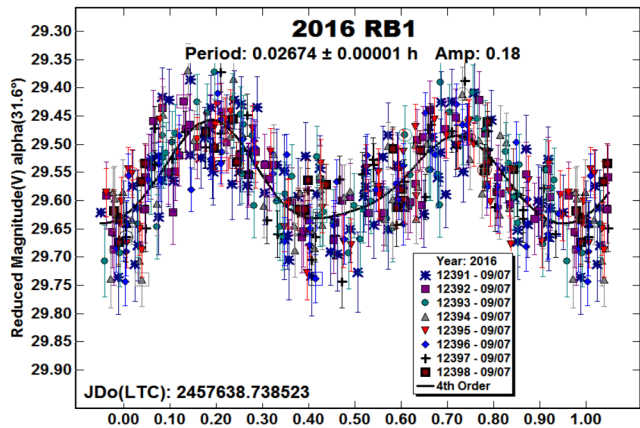
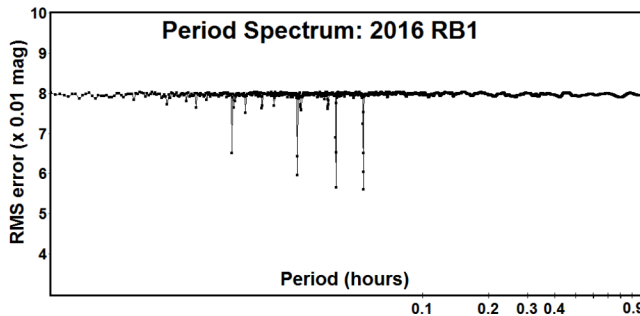
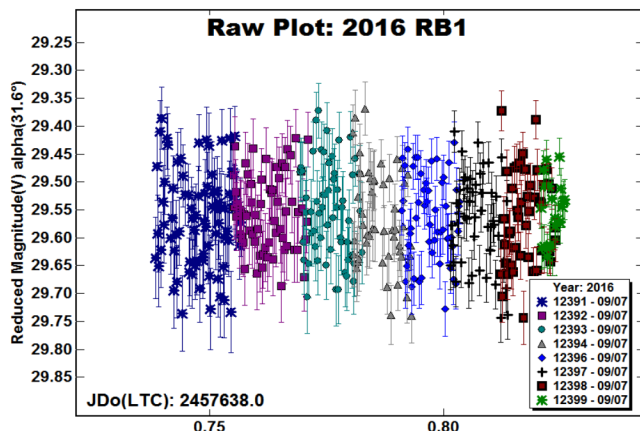


2016 PN1. This asteroid faded from view too soon, and so it was not possible to get a more complete data set. The period of 76 hours is a best fit to the data, but it is likely wrong.

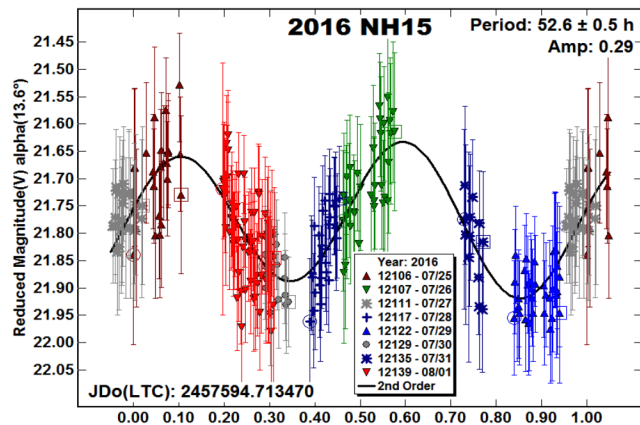


2016 RB1. The estimated diameter of only 7 meters made 2016 RB1 an excellent candidate for being a super-fast rotator ($P < 1$ hour). For this reason, exposures were kept to 10 seconds in order to avoid *rotational smearing* (see Pravec *et al.*, 2000). This would work only if the rotation period was greater than about 50 seconds.

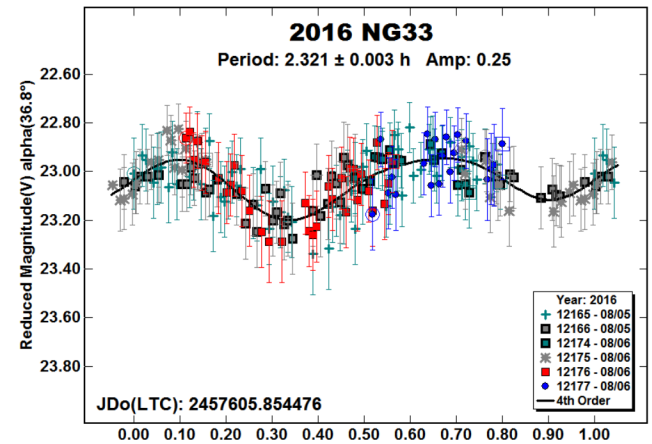
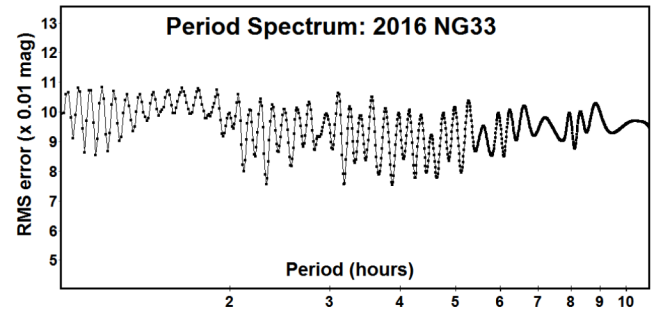
The raw lightcurve showed what appeared to be just noise but, given the possibility for a very short period, a search was made from 0.001 to 2.5 hours in 0.001 h steps. This led to the approximate period of 0.027 h, which was further refined to 0.02674 h.



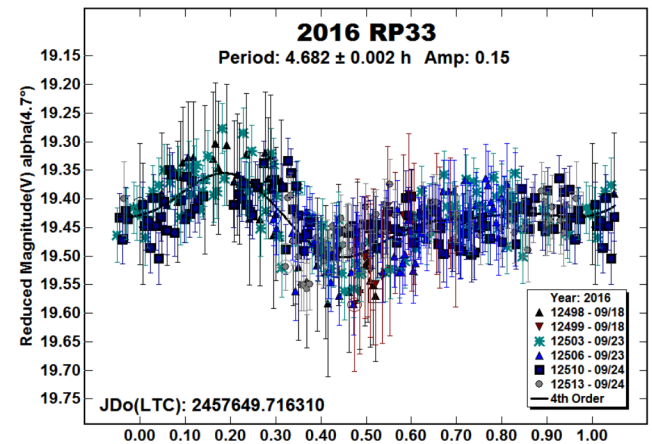
2016 NH15. The adopted period of 52.6 h makes this a good tumbling candidate. The data set was too limited and noisy to see any obvious signs of tumbling.



2016 NG33. A period of 2.321 hours is adopted for this paper. However, as the period spectrum shows, a number of other solutions are possible. The amplitude of 0.25 mag lends support to the adopted period (see Harris *et al.*, 2014).

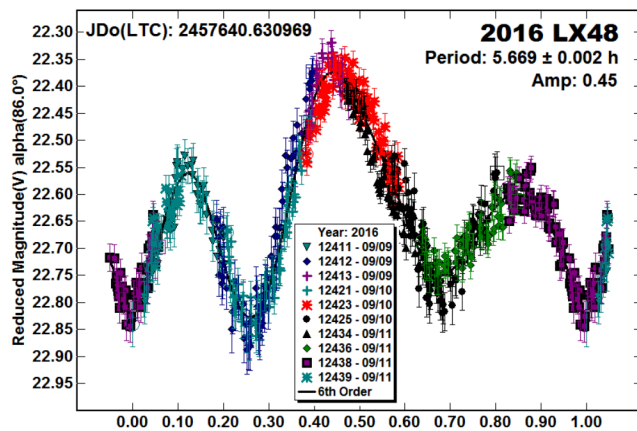


2016 RP33. There were no previous entries in the LCDB for this NEA.

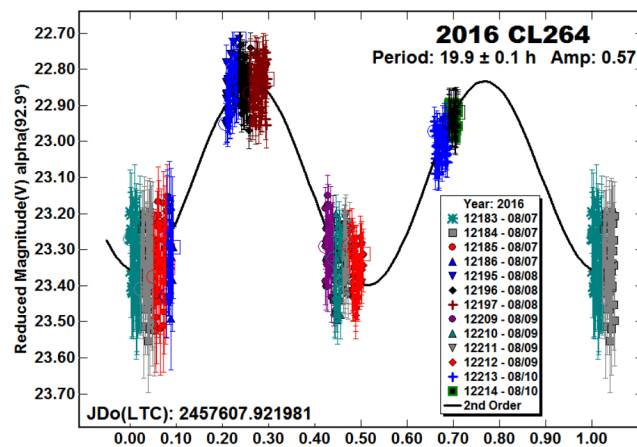


2016 LX48. Initial analysis of the data set led to a solution of about 3.8 hours, which produced a bimodal lightcurve. At large phase angles, this is not always a good assumption. Soon after the PDS observations, Amadeo Aznar in Spain also made observations of the asteroid. His analysis showed that a period of about 5.5 hours was more likely (Aznar, private communications).

Another search was made with the PDS data set, which led to the adopted period of 5.669 h for this paper, despite the unusual shape of the lightcurve and the fact that the PDS data fit *almost* as well to the 3.8 hour period.



2016 CL264. There were no previous entries in the LCDB for this NEA. The sparse coverage of the lightcurve makes the period less than certain. However, as with some earlier cases, a search on half-periods and the slopes of the Fourier curve make the adopted period a good “best estimate.”



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References

Benner, L.A.M., Nolan, M.C., Ostro, S.J., Giorgini, J.D., Pray, D.P., Harris, A.W., Magri, C., Margot, J.-L. (2006). “Near-Earth

Asteroid 2005 CR37: Radar images and photometry of a candidate contact binary." *Icarus* **182**, 474-481.

Binzel, R.P. (1987). "A photoelectric survey of 130 asteroids." *Icarus* **72**, 135-208.

DeMeo, F.E., Binzel, R.P., Slivan, S.M., Bus, S.J. (2009). “An Extension of the Bus Asteroid Taxonomy into the Near-Infrared.” *Icarus* **202**, 160-180.

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

Harris, A.W., Harris, A.W. (1997). "On the Revision of Radiometric Albedos and Diameters of Asteroids." *Icarus* **126**, 450-454.

Harris, A.W., Young, J.W., Bowell, E., Tholen, D.J. (1999). "Asteroid Lightcurve Observations from 1981 to 1983." *Icarus* **142**, 173-201.

Harris, A.W., Pravec, P., Galad, A., Skiff, B.A., Warner, B.D., Vilagi, J., Gajdos, S., Carbognani, A., Hornoch, K., Kusnirak, P., Cooney, W.R., Gross, J., Terrell, D., Higgins, D., Howell, E., Koehn, B.W. (2014). "On the maximum amplitude of harmonics on an asteroid lightcurve." *Icarus* **235**, 55-59.

Henden, A.A., Terrell, D., Levine, S.E., Templeton, M., Smith, T.C., Welch, D.L. (2009). <http://www.aavso.org/apass>

Hicks, M, Rhoades, H., Somers, J., Grote, M. (2009w).
Astronomer's Telegram **2134**.
<http://www.astronomerstelegam.org>

Higgins, D.J. (2005). "Lightcurve and period determination for 479 Caprera, 2351 O'Higgins (36378) 2000 OL19, (52750) 1998 KK17, (87684) 2000 SY2." *Minor Planet Bul.* **32**, 36-38.

Koehn, B.W., Bowell, E.L.G., Skiff, B.A., Sanborn, J.J., McLelland, K.P., Pravec, P., Warner, B.D. (2014). "Lowell Observatory Near-Earth Asteroid Photometric Survey (NEAPS) - 2009 January through 2009 June." *Minor Planet Bul.* **41**, 286-300.

Koff, R.A., Pravec, P., Sarounova, L., Kusnirak, P., Brincat, S., Goretta, V., Sposetti, S., Stephens, R., Warner, B. (2002). Collaborative Lightcurve Photometry of Asteroid (5587) 1990 SB." *Minor Planet Bul.* **29**, 51-53.

Mottola, S., De Angelis, G., Di Martino, M., Erikson, A., Hahn, G., Meukum, G. (1995). "The near-earth objects follow-up program: First results." *Icarus* **117**, 62-70

Ostro, S.J., Harris, A.W., Campbell, D.B., Shapiro, I.I., Young, J. (1984). "Radar and photoelectric observations of asteroid 2100 Ra-Shalom." *Icarus* **60**, 391-403.

Pravec, P., Sarounova, L., Wolf, M. (1996). "Lightcurves of 7 Near-Earth Asteroids." *Icarus* **124**, 471-482.

Pravec, P., Wolf, M., Sarounova, L. (1998). "Lightcurves of 26 Near-Earth Asteroids." *Icarus* **136**, 124-153.

Pravec, P., Wolf, M., Sarounova, L. (1997w, 1999w, 2000w, 2002w, 2003w). <http://www.asu.cas.cz/~ppravec/neo.htm>

Number	Name	2016 mm/dd	Pts	Phase	L _{PAB}	B _{PAB}	Period	P.E.	Amp	A.E.	Grp
433	Eros	07/04-07/06	223	28.8, 28.2	326	2	5.271	0.001	0.47	0.01	NEA
433	Eros	08/29-08/31	1272	9.2, 10.4	329	9	5.270	0.001	0.33	0.01	NEA
1863	Antinous	08/06-08/10	159	42.6, 40.2	7	0	7.471	0.005	0.33	0.02	NEA
2100	Ra-Shalom	08/10-08/20	287	57.2, 54.5	12	4	19.89	0.05	0.55	0.03	NEA
3352	McAuliffe	09/25-09/27	156	23.2, 22.5	34	-7	2.212	0.002	0.12	0.02	NEA
5143	Heraclides	09/12-09/17	133	31.4, 31.8	52	11	2.704	0.002	0.15	0.03	NEA
5587	1990 SB	08/05-08/10	129	38.4, 37.2	23	2	5.0520	0.0005	0.70	0.02	NEA
5836	1993 MF	09/09-09/11	212	45.9, 44.7	31	11	4.953	0.005	0.88	0.02	NEA
7341	1991 VK	09/05-09/08	142	20.8, 19.5	8	8	4.211	0.003	0.21	0.03	NEA
7888	1993 UC	09/09-09/15	109	42.4, 44.4	52	-25	2.337	0.002	0.16	0.02	NEA
10636	1998 QK56	09/12-09/15	163	2.7, 0.2	353	0	9.84	0.01	0.32	0.03	NEA
16834	1997 WU22	08/06-08/10	365	79.9, 74.2	275	38	9.343	0.005	0.60	0.02	NEA
40263	1999 FQ5	08/29-09/11	211	48.6, 46.3	25	-8	28.00	0.05	0.27	0.03	NEA
52750	1998 KK17	08/26-09/08	259	47.6, 54.0	29	-14	26.43	0.05	0.24	0.01	NEA
68346	2001 KZ66	07/17-07/19	123	67.3, 69.3	269	46	4.996	0.003	0.35	0.02	NEA
87684	2000 SY2	08/22-09/04	216	59.5, 51.8	32	-13	2.8712	0.0004	0.09	0.01	NEA
106538	2000 WK63	08/21-09/01	224	64.8, 52.4	278	11	51.2	0.2	0.60	0.04	NEA
154244	2002 KL6	09/09-09/11	210	40.9, 38.7	14	7	4.609	0.005	0.92	0.02	NEA
162117	1998 SD15	09/12-09/15	402	71.2, 62.5	345	40	7.33	0.01	0.26	0.03	NEA
163348	2002 NN4	08/04-08/09	196	20.2, 19.9, 20.6	316	14	14.50	0.03	0.74	0.05	NEA
250458	2004 BO41	09/15-09/28	1398	85.2, 61.6	330	39	16.19	0.01	0.85	0.05	NEA
257838	2000 JQ66	07/03-07/08	254	38.0, 12.4, 36.8	281	15	11.094	0.005	0.63	0.03	NEA
347813	2002 NP1	08/02-08/05	177	29.1, 27.4	337	6	5.915	0.005	0.86	0.03	NEA
357024	1999 YR14	08/30-09/01	1085	57.7, 63.9	7	-16	4.2477	0.0005	1.19	0.03	NEA
370307	2002 RH52	09/23-09/27	171	36.0, 36.3	37	9	4.218	0.003	0.78	0.03	NEA
385343	2002 LV	07/03-07/05	138	36.4, 37.3	254	36	6.20	0.01	0.51	0.03	NEA
452389	2002 NW16	07/07-07/16	196	67.5, 65.8	334	0	46.7	0.2	0.65	0.05	NEA
464797	2004 FZ1	08/11-08/17	1754	51.1, 31.6	338	26	45.4	0.2	0.39	0.03	NEA
467336	2002 LT38	06/27-07/06	391	66.2, 87.2	238	14	21.80	0.05	1.16	0.05	NEA
468448	2003 LS3	07/05-07/08	146	23.7, 23.2	299	16	5.325	0.005	0.32	0.02	NEA
468448	2003 LS3	08/23-08/25	148	8.5, 8.3	327	4	5.329	0.005	0.02	0.02	NEA
469513	2003 QR79	09/02-09/04	95	11.4, 15.3	335	7	4.11	0.01	0.18	0.03	NEA
469634	2004 SZ19	08/25-08/28	234	31.3, 28.0	353	13	16.39	0.03	0.34	0.04	NEA
470510	2008 CJ116	12/31-12/31	445	31.3, 0.0, 28.0	0	0	32.26	0.01	1.00	0.03	NEA
471241	2011 BX18	08/05-08/09	337	73.0, 61.3	356	14	4.828	0.005	0.27	0.02	NEA
	1999 SO5	09/28-09/30	194	29.1, 26.4	24	5	1.380	0.001	0.73	0.03	NEA
	2005 TF	09/28-10/02	163	15.8, 13.9	18	-3	2.57	0.005	0.29	0.03	NEA
	2009 ES	09/10-09/14	960	37.2, 44.3	332	16	28.0	0.5	0.33	0.04	NEA
	2013 TV5	09/27-09/28	287	41.6, 43.4	340	12	0.8367	0.0002	0.42	0.03	NEA
	2014 KD91	09/13-09/26	250	31.3, 25.8	19	19	2.829	0.001	0.15	0.02	NEA
	2016 NA1	08/02-08/04	268	13.5, 15.6	317	7	8.67	0.05	0.14	0.04	NEA
	2016 PN1	09/03-09/09	342	38.4, 35.1	10	6	76	1	0.16	0.03	NEA
	2016 RB1	09/07-09/07	422	0.0, 0.0	0	0	0.02674	0.00001	0.18	0.03	NEA
	2016 NH15	07/25-07/31	230	13.6, 14.3	309	9	52.6	0.5	0.29	0.04	NEA
	2016 NG33	08/05-08/06	205	36.9, 35.3	335	-3	2.321	0.003	0.25	0.04	NEA
	2016 RP33	09/18-09/24	411	4.6, 6.6	357	1	4.682	0.002	0.15	0.03	NEA
	2016 LX48	09/09-09/11	614	85.5, 79.1	312	27	5.669	0.002	0.45	0.03	NEA
	2016 CL264	08/07-08/10	601	102.5, 75.9	93	-9	19.9	0.1	0.57	0.05	NEA

Table III. Observing circumstances. 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). Grp is the orbital group of the asteroid. See Warner *et al.* (LCDB; 2009; *Icarus* **202**, 134-146.).

Pravec, P., Harris, A.W., Scheirich, P., Kušnirák, P., Šarounová, L., Hergenrother, C.W., Mottola, S., Hicks, M.D., Masi, G., Krugly, Yu.N., Shevchenko, V.G., Nolan, M.C., Howell, E.S., Kaasalainen, M., Galád, A., Brown, P., Degraff, D.R., Lambert, J. V., Cooney, W.R., Foglia, S. (2005). "Tumbling asteroids." *Icarus* **173**, 108-131.

Pravec, P., Harris, A.W., Kusnirak, P., Galad, A., Hornoch, K. (2012). "Absolute magnitudes of asteroids and a revision of asteroid albedo estimates from WISE thermal observations." *Icarus* **221**, 365-387.

Pravec, P., Scheirich, P., Durech, J., Pollock, J., Kusnirak, P., Hornoch, K., Galad, A., Vokrouhlicky, D., Harris, A.W., Jehin, E., Manfroid, J., Opitom, C., Gillon, M., Colas, F., Oey, J., Vrástil, J.,

Reichart, D., Ivarsen, K., Haislip, J., LaCluyze, A. (2014). "The tumbling state of (99942) Apophis." *Icarus* **233**, 48-60.

Stephens, R.D. (2013w). http://www.planetarysciences.org/PHP/CS3_Lightcurves.php

Taylor, P., Nolan, M.C., Howell, E.S. (2012) *CBET* **3176**.

Thomas, C.A., Emery, J.P., Trilling, D.E., Delbo, M., Hora, J.L., Mueller, M. (2014). Physical characterization of Warm Spitzer-observed near-Earth objects." *Icarus* **228**, 217-246.

Usui, F., Kuroda, D., Müller, T.G., Hasegawa, S., Ishiguro, M., Ootsubo, T., Ishihara, D., Katata, H., Takita, S., Oyabu, S., Ueno, M., Matsuhara, H., Onaka, T. (2011). "Asteroid Catalog Using

Akari: AKARI/IRC Mid-Infrared Asteroid Survey.” *Pub. Ast. Soc. of Japan* **63**, 1117-1138.

Warner, B.D. (2007). “Initial Results of a Dedicated H-G Program.” *Minor Planet Bull.* **34**, 113-119.

Warner, B.D., Harris, A.W., Pravec, P. (2009). “The Asteroid Lightcurve Database.” *Icarus* **202**, 134-146. Last update: 2016 Feb. <http://www.minorplanet.info/lightcurvedatabase.html>

Warner, B.D. (2012). “Asteroid Lightcurve Analysis at the Palmer Divide Observatory: 2011 December - 2012 March.” *Minor Planet Bul.* **39**, 158-167.

Warner, B.D. (2015). Near-Earth Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2015 March-June.” *Minor Planet Bul.* **42**, 256-266.

Warner, B.D. (2016a). “Near-Earth Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2016 January-April.” *Minor Planet Bul.* **43**, 240-250.

Warner, B.D. (2016b). Three Additional Candidates for the Group of Very Wide Binary Asteroids.” *Minor Planet Bul.* **43**, 306-309.

Warner, B.D. (2016c). “Near-Earth Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2016 April-July.” *Minor Planet Bul.* **43**, 311-319.

Zappala, V., Cellini, A., Barucci, A.M., Fulchignoni, M., Lupishko, D.E. (1990). “An analysis of the amplitude-phase relationship among asteroids.” *Astron. Astrophys.* **231**, 548-560.

LIGHTCURVE ANALYSIS OF HILDA ASTEROIDS AT THE CENTER FOR SOLAR SYSTEM STUDIES: 2016 JUNE-SEPTEMBER

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Lightcurves for 16 Hilda asteroids were obtained at the Center for Solar System Studies (CS3) from 2016 June to September.

CCD photometric observations of 16 Hilda asteroids were made at the Center for Solar System Studies (CS3) from 2016 June to September. This is the first of a planned series on this group of asteroids located between the outer main-belt and Jupiter Trojans. The overall goal is to determine the spin rate statistics of this group that has a 3:2 orbital resonance with Jupiter. More specifically we look to examine the degree of influence that the YORP effect (Rubincam, 2000) has on more distant objects and to compare the spin rate distribution to the Jupiter Trojans, which can provide evidence that the Hildas are more “comet-like” than main-belt asteroids.

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

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

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

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

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

If the plot includes an amplitude, e.g., “Amp: 0.65”, this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*. The value is meant only to be a quick guide.

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