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NEAR-EARTH ASTEROID LIGHTCURVE ANALYSIS AT CS3-PALMER DIVIDE STATION: 2018 APRIL-JUNE

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Lightcurves for 39 Near-Earth asteroids (NEAs) obtained at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2018 April-June were analyzed for rotation period and signs of satellites or tumbling. In addition, re-examination of data for 2014 UR taken in 2014 shows that the rotation period is 0.2300 h and not the 2.37 h that was originally reported.

CCD photometric observations of 39 near-Earth asteroids (NEAs) were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2018 April-June. In addition, re-examination of data obtained in 2014 of the NEA (25916) 2001 CP44 revised the original period (Warner, 2014a) from 4.208 h to 4.608 h.

Table I lists the telescope/CCD camera combinations that were used. 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 cause a 0.1-0.3 mag loss. The exposure duration varied depending on the asteroid's brightness and sky motion. Guiding on a field star sometimes resulted in a trailed image for the asteroid.

Measurements were made using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. Catalog magnitudes were taken from the APASS (Henden et al., 2009) or CMC-15 (Munos, 2017) catalogs.

The nightly zero points for the APASS and CMC-15 catalogs are generally consistent to about ± 0.05 mag or better, but occasionally reach >0.1 mag. There is a systematic offset between the two catalogs and so, whenever possible, the same catalog is used for all observations of a given asteroid. Period analysis is done with *MPO Canopus*, which implements the FALC algorithm by Harris (Harris et al., 1989).

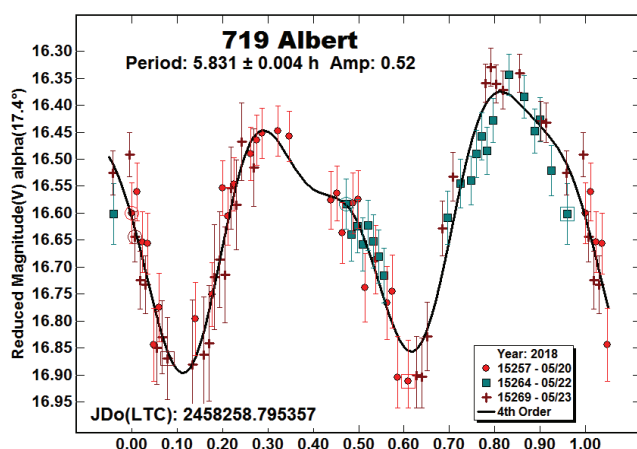
In the plots below, the "Reduced Magnitude" is Johnson V as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distances by applying $-5 \cdot \log(r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and Earth-asteroid distances in AU.

Unless otherwise stated, the magnitudes were normalized to the phase angle in parentheses using $G = 0.15$. The X-axis is the rotational phase, ranging from -0.05 to $+1.05$.

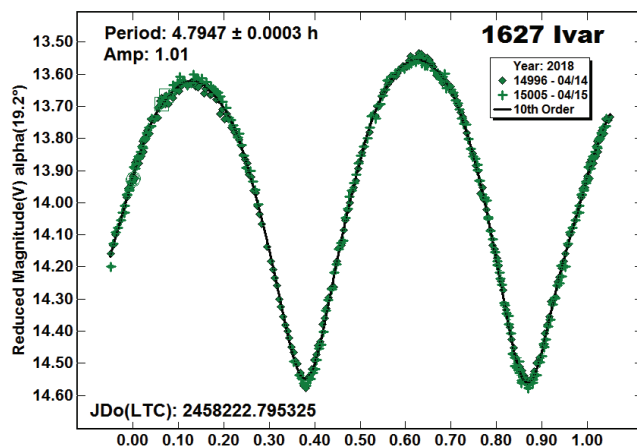
If the plot includes an amplitude, e.g., “Amp: 0.65”, this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*.

For the sake of brevity, only some of the previously reported results may be referenced in the discussions on 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 Bibcode, is also available for download. Readers are strongly encouraged, when possible, to cross-check with the original references listed in the LCDB.

719 Albert. Previous results for the “lost” asteroid that was rediscovered in 2001 include Behrend (2001; 5.8007 h) and Pravec *et al.* (2001; 5.8011 h). Even though it was occasionally accessible with larger backyard telescopes, no additional lightcurve entries in the LCDB since rediscovery. The period reported here is not quite in agreement with the earlier results; that’s likely due to the sparse data set over a short period.

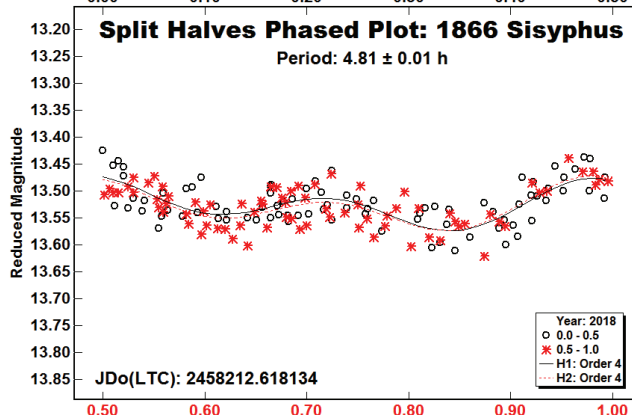
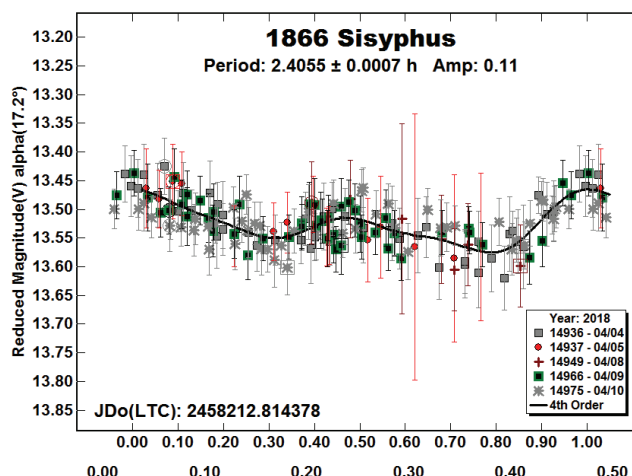
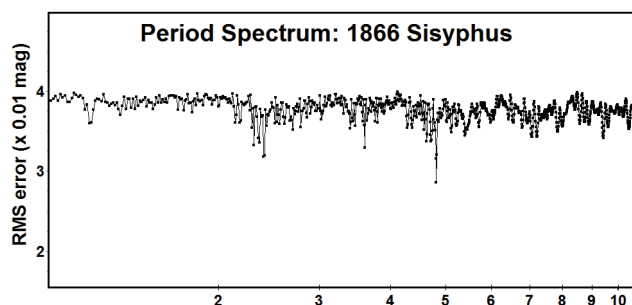


1627 Ivar. This NEA has been studied in-depth optically and by radar (see the LCDB for numerous listings). As a result, its shape and spin axis are well established. Additional observations, however, might be used to determine if the asteroid’s spin rate is changing due to the YORP effect (Rubincam, 2000).



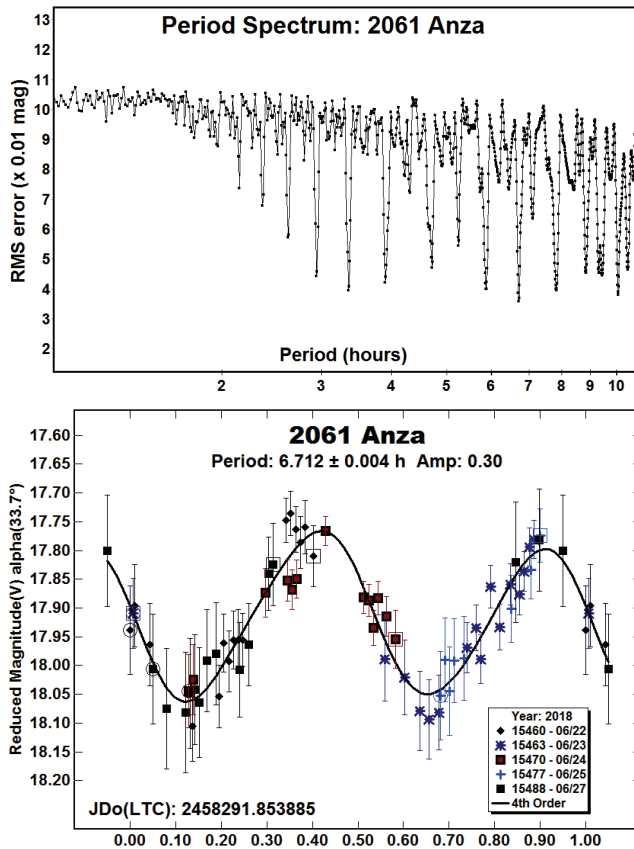
1866 Sisyphus. A rotation period of about 2.4 hours has been published before (e.g., Schober *et al.*, 1993, 2.400 h). On two occasions, Stephens *et al.* (2011) and Warner (2016c), there were reports of a possible satellite with an orbital period between 25-28 hours. There were no indications of a second period or mutual events in 2018.

The period spectrum favored a period of 4.81 h, double the accepted value. This produced a quadramodal lightcurve. Using a “split halves” plot for the longer period showed that the halves were virtually identical. Either shape is possible (Harris *et al.*, 2014); the shorter period was adopted since it was in-line with all previous results and because it was a more likely period for the primary of a binary system.

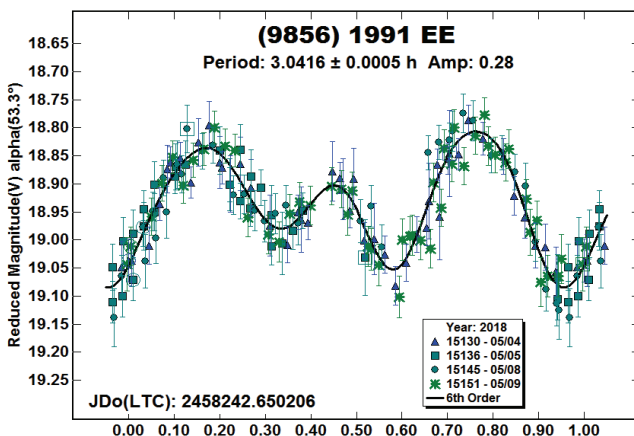


2061 Anza. Rakos (1960) reported a period of 11.50 h. Forcing the 2018 data to that period produced a quadramodal lightcurve. Given the amplitude, that shape is unlikely (Harris *et al.*, 2014). As the period spectrum shows, the solution of 6.712 h is far from definitive.

Those observing in 2035 will see the asteroid reach $V \sim 11.6$ at a distance of 0.054 AU, or about 21 lunar distances. Until then, it is never brighter than $V \sim 18.8$.

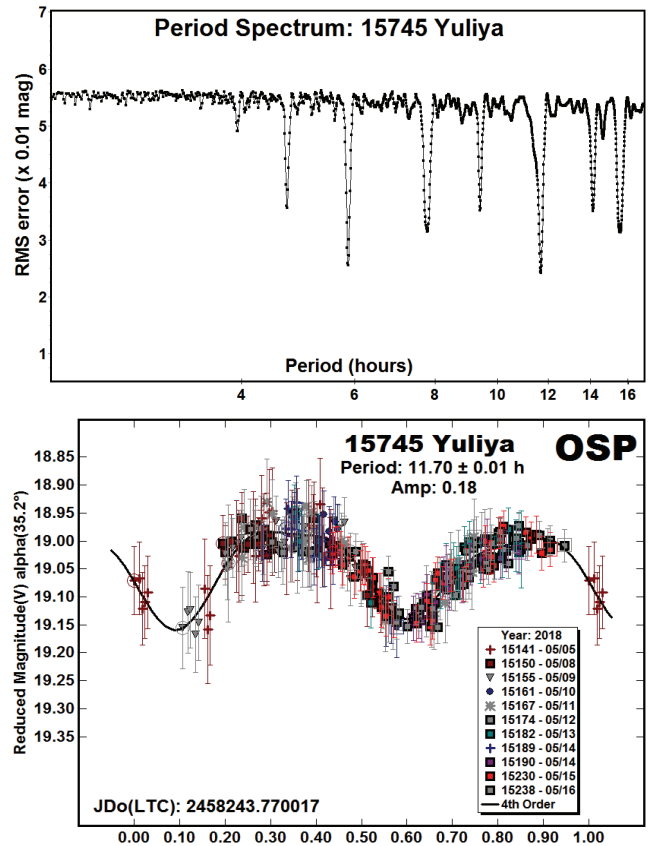


(9856) 1991 EE. Wisniewski et al. (1997) reported a period of 3.045 h for this 1-km asteroid. The results here are in good agreement. The “roller coaster” shape of the lightcurve is not unusual when observing at large phase angles, which allows shadowing effects to come into play.

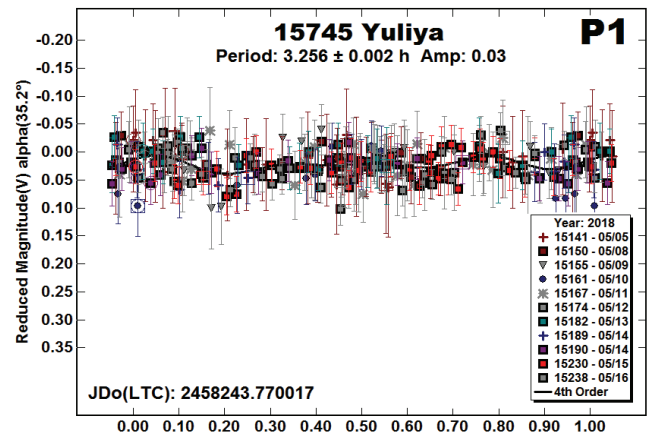


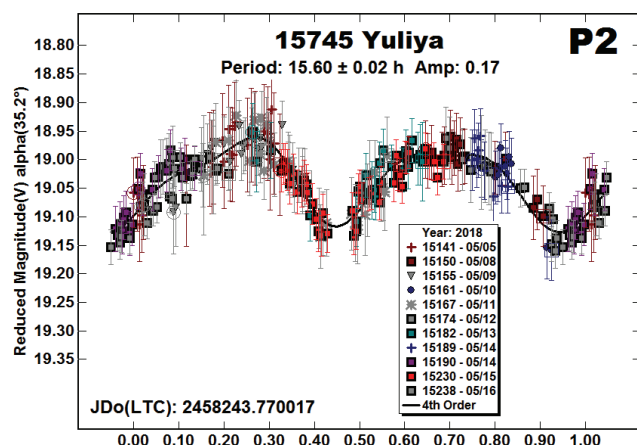
15745 Yuliya. The data from CS3-PDS in 2018 lead to several possible periods. The choice came down to 5.86 h or 11.70 h. Both were wrong. Working independently, Aznar et al. (2018) determined that the asteroid was binary with $P_1 = 3.2486$ h and $P_{ORB} = 15.63$ h. The mutual events ranged from 0.15-0.21 mag, indicating that the effective diameter of the satellite was at least 41% of the primary diameter.

The period spectrum shows the results doing a single period search using only CS3-PDS data. The “OSP” (original single period) lightcurve shows the initially adopted period. Note that the amplitude is mid-range of the mutual events from Aznar et al. (2018).



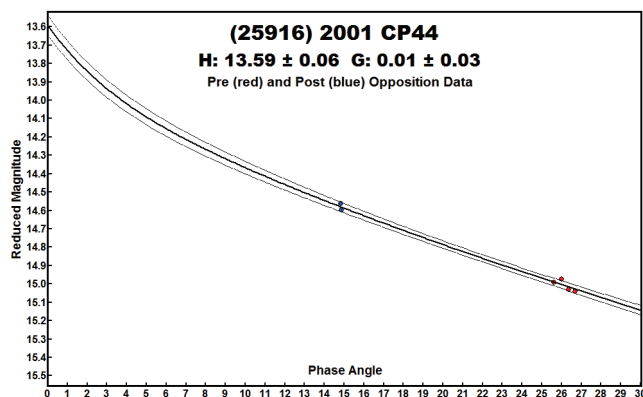
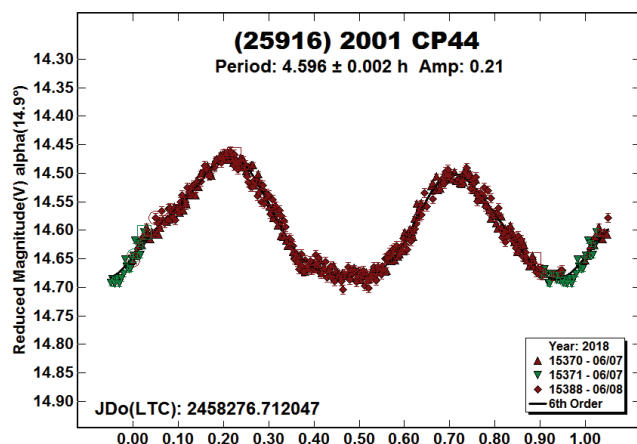
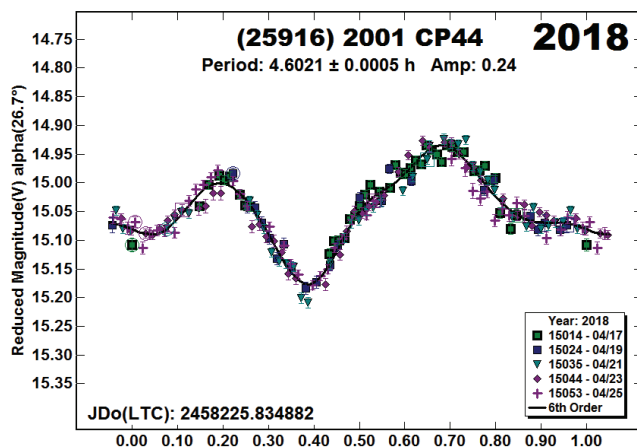
After seeing the announcement of the binary discovery, an attempt was made to force the CS3-PDS data to the results from Aznar et al. (2018). As it turns out, the analysis of the CS3-PDS data was finding the lightcurve for the satellite and its relatively deep mutual events. Furthermore, when subtracting that lightcurve from the data to find the primary’s lightcurve, the period spectrum was essentially flat with dozens of very minor “wiggles”. In other words, there was no indication of the primary in the CS3-PDS3 data. The “P1” plot is the result of forcing the search between 3.24-3.26 h. Even with that restriction, there were several possible solutions.





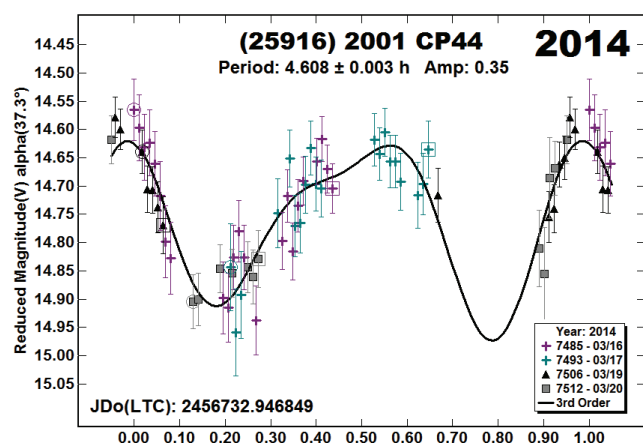
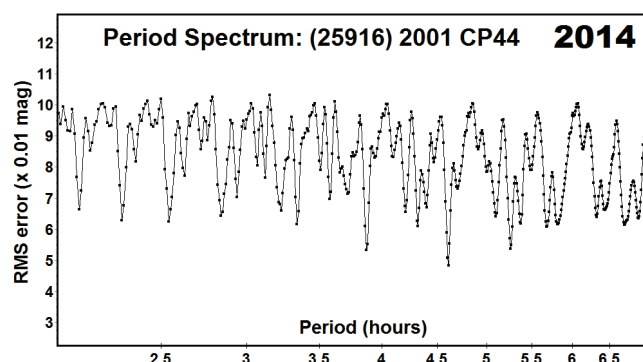
Aznar et al. (2018) reported a primary lightcurve amplitude of 0.10 mag. This should have been readily seen in the CS3-PDS data. Why it was not is unknown.

(25916) 2001 CP44. This 5.7 km NEA was observed twice: first in April and then in June. As seen in the two 2018 lightcurves, the lightcurve shape evolved considerably. When trying to merge the two to get a more precise period, a considerable zero point offset was required for one data set to get the curves to merge. Sometimes this is the result of using the default value for $G = 0.15 \pm 0.2$ and not a more accurate value. Running the data through the H-G calculator in *MPO Canopus* found $H = 13.60$, $G = 0.01 \pm 0.03$. The value for H is the same as listed in the MPCORB data file (MPC, 2018), which uses the default value for G . When using the new value for G , the zero point shift was eliminated.



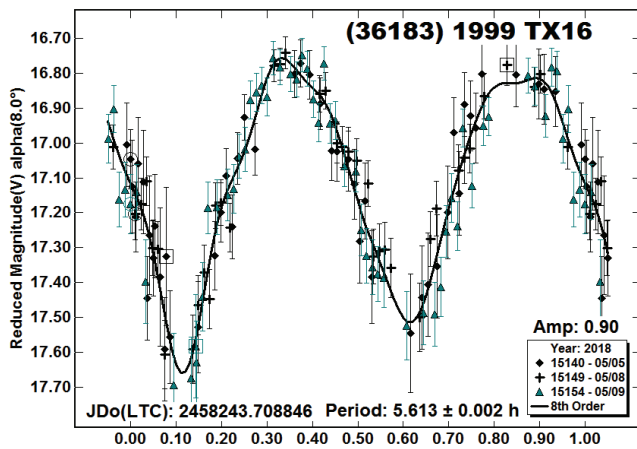
The value for H is dependent on the area of the asteroid's shape projected onto the plane of the sky. With the large changes in the lightcurve, the projected area may have changed as well, thus complicating the search for the true values of H and G . In other words, $G = 0.01$ should not be considered reliable.

When first observed in 2014 (Warner 2014a), the period was found to be 4.208 h. Following the analysis of the 2018 data, the 2014 data were given another look. This led to a revised result of 4.608 h, which is in better agreement with the latest analysis.

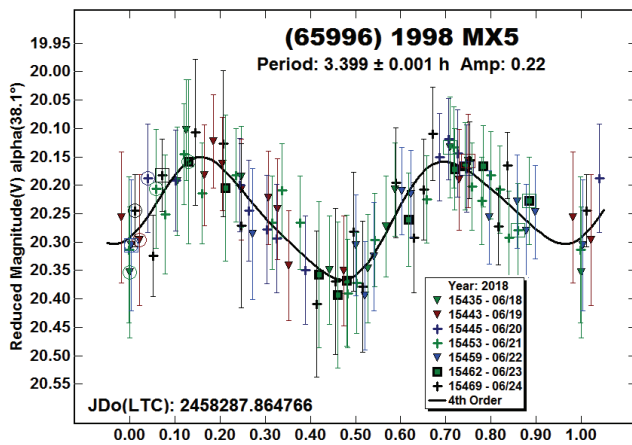


(36183) 1999 TX16. Pravec et al. (1999) observed 1999 TX16 in late 1999 when it was at phase angle $\alpha \sim 52^\circ$. They found $P = 5.6121$ h and $A = 1.3$ mag.

The observations in 2018 were at phase angle of $\alpha \sim 7^\circ$, but the phase angle bisector longitudes (Harris et al., 1984) were about 126° apart, so the reduced amplitude may not have been due only to the typical behavior of a lower amplitude at a lower phase angle (Zappala et al., 1990).

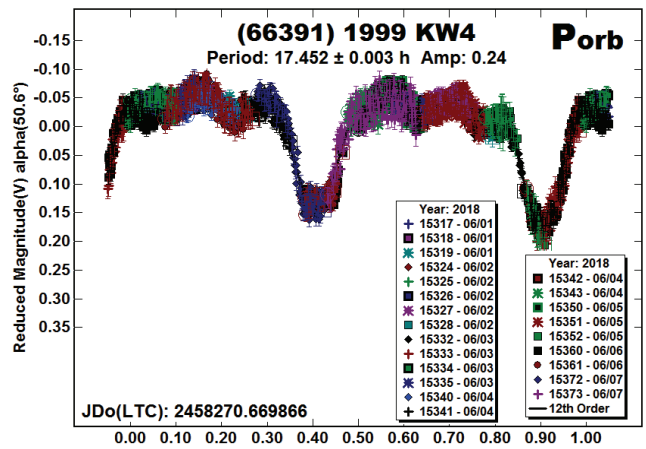
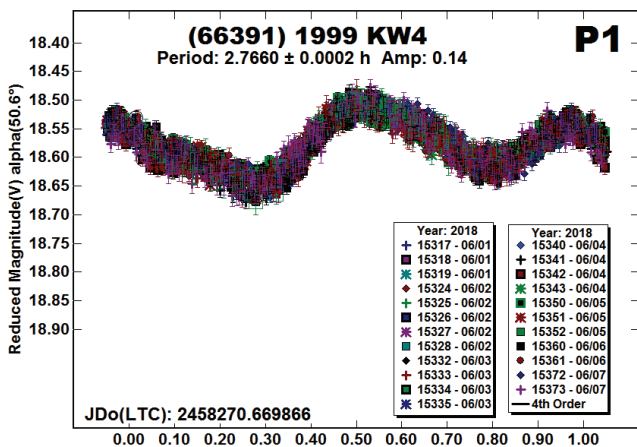


(65996) 1998 MX5. There were no previous entries of any kind the LCDB for 1998 MX5; the estimated diameter is 620 m.

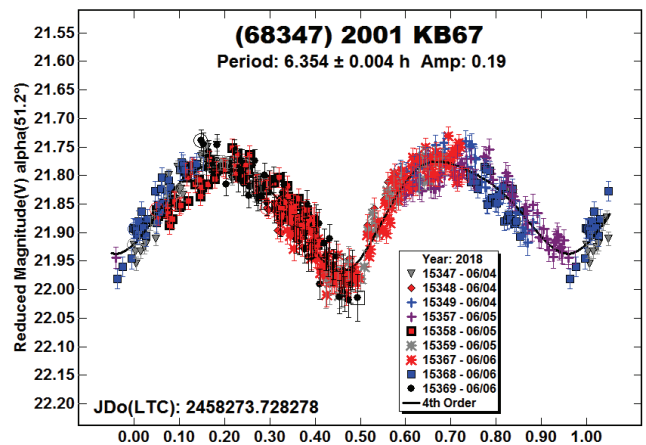


(66391) 1999 KW4. This is the famous “spinning top” asteroid thoroughly detailed with radar observations by Ostro et al. (2006). For an animation, visit http://echo.jpl.nasa.gov/asteroids/1999KW4/kw4_20060529Afour.mov. Note that the MOV file may not work when using default Windows video players.

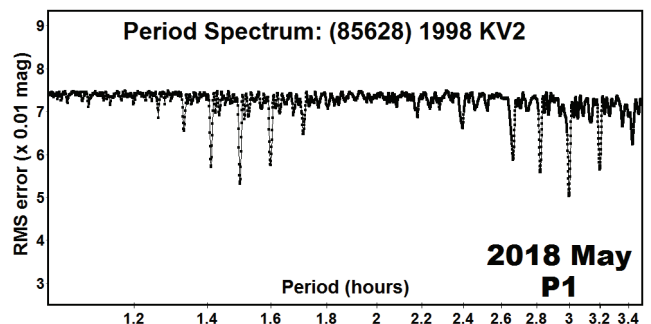
The dual period search of *MPO Canopus* was used to extract the lightcurves for the primary and the mutual events of the satellite. The eclipse at 0.4 phase in “P_{ORB}” appears total. Using the attenuation of 0.15 mag gives the ratio of satellite-to-primary diameters of 0.38 ± 0.03 . The radar data gave about 0.33.



(68347) 2001 KB67. The estimated diameter is 325 m. There were no previous entries of any kind in the LCDB.



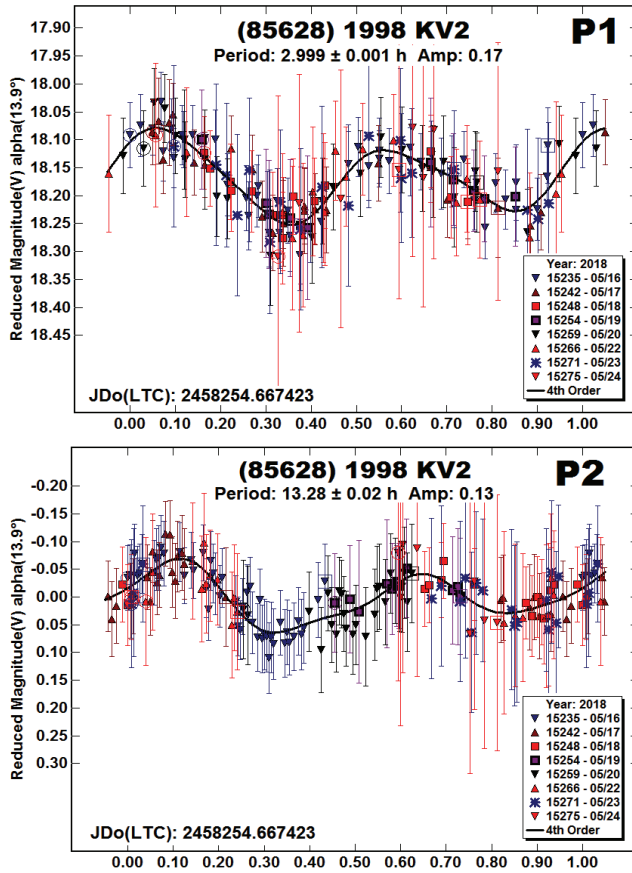
(85628) 1998 KV2. Analysis of the 2018 data found the likelihood to two periods, i.e., possible indications of a satellite. The putative primary period was ambiguous, with the more likely solution at 2.999 h, as shown in the period spectrum. The alternate, shorter period, was 2.823 h. The two differ by one-half rotation over 24 hours. Previous results by the author were all close to 2.82 h: Warner (2014b, 2.819 h; 2016a, 2.819 h; 2016c, 2.819 h).



After numerous iterations of the dual period search in *MPO Canopus*, the significantly better fit was $P_1 = 2.999$ h. Regardless of which P_1 was selected, the fit was improved significantly by subtracting out $P_2 = 13.28$ h. The P_2 value varied by no more than 0.01 h when using different values of P_1 .

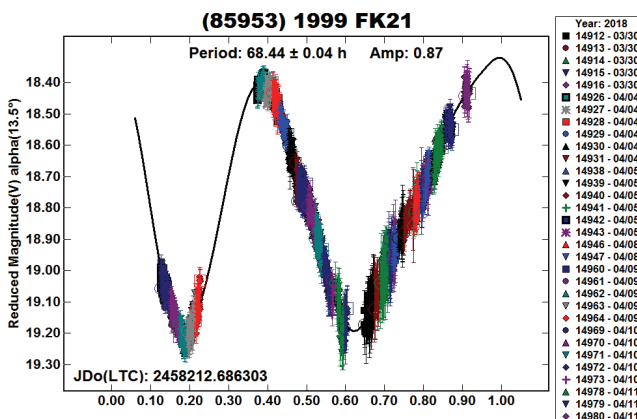
The data from earlier apparitions were analyzed anew, but in three of the four cases, the shorter period had a lower RMS fit to 2.82 h no matter how the nightly zero points were adjusted.

Since the two periods are nearly Earth-day commensurate and the curves are nearly symmetrical, it's very easy for one to be a *rotational alias* of the other. In other words, it's not certain how many rotations occurred over the range of observations. The 2018 observations spanned 8 days, at least 3 days longer than the earlier data sets. It's possible that the longer span almost allowed the ambiguity to resolve itself.

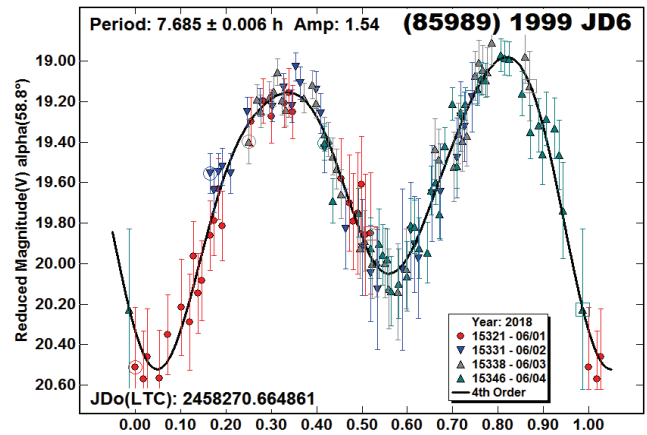


(85953) 1999 FK21. Skiff (2011) found a period of 28.1 h. Warner (2016a) found a period of 17.62 h. The 2018 data led to yet another result, $P = 68.44$ h. In this case, however, the data set was denser and three of the four extrema were reasonably defined.

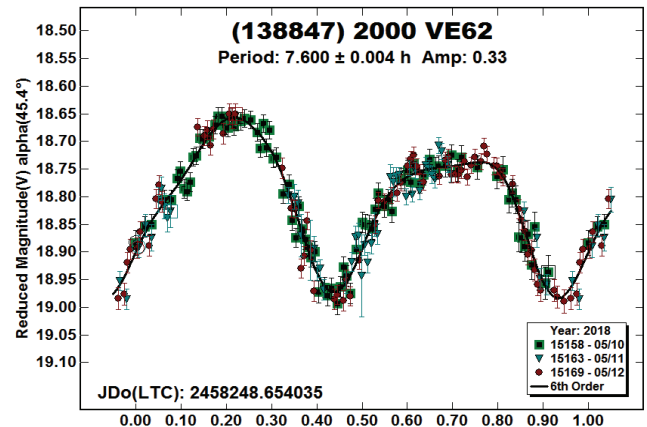
There are no obvious signs of tumbling (Pravec et al., 2005; 2014) even though the combination of diameter and period would make it likely.



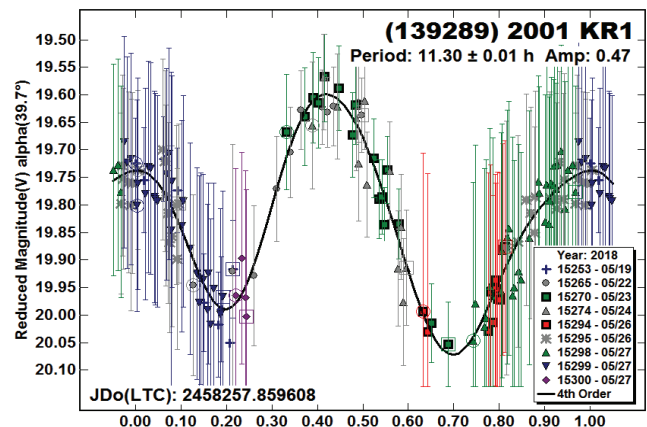
(85989) 1999 JD6. Pravec et al. (1999) reported a period of 7.666 h. This was followed with 7.6638 h by Polishook and Brosch (2008a) and 7.6611 h by Vaduvescu et al. (2017). The period reported here is in good agreement with the earlier results and those by Warner (2014b, 7.667h; 2015, 7.673 h).



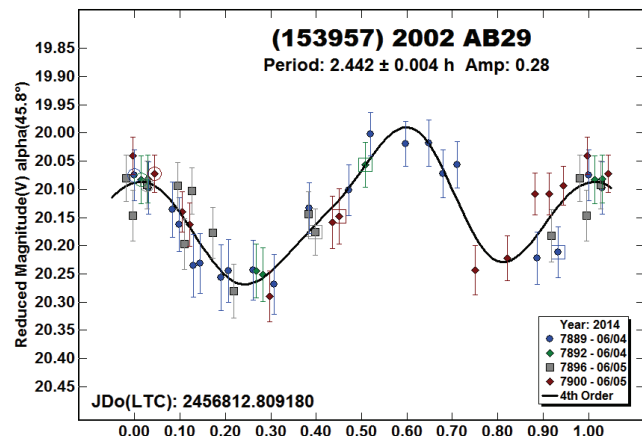
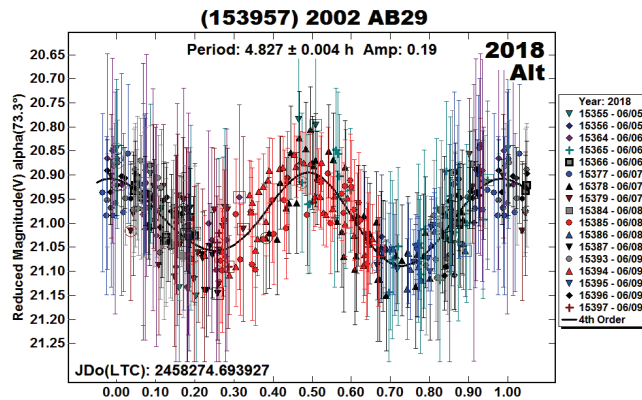
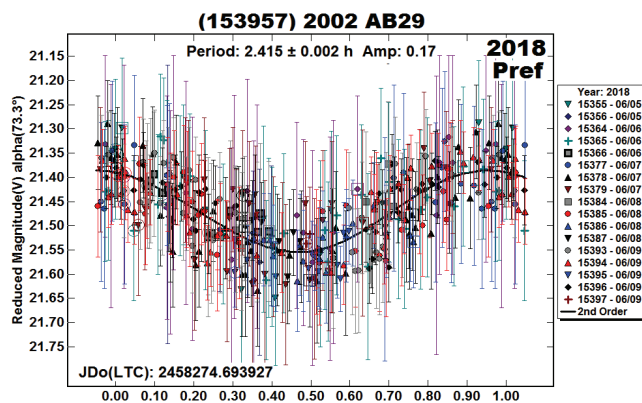
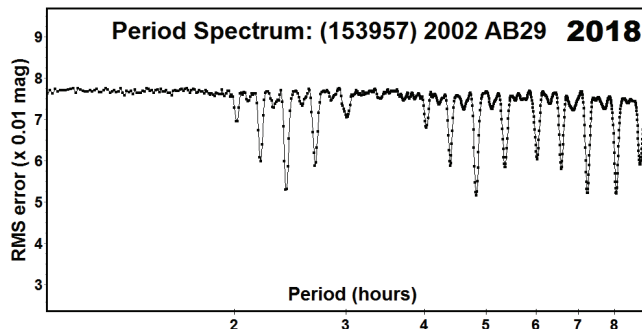
(138847) 2000 VE62. Monteiro et al. (2017) reported a period of 6.469 h. This disagrees with the results here and from Percy (2018) of 7.600 h. The two periods differ by almost one-half rotation over 24 hours, possibly indicating a *rotational alias*, i.e., a miscount of the number of rotations over the range of the observations.



(139289) 2001 KR1. There was no previous lightcurve entry in the LCDB for this 900-m asteroid.

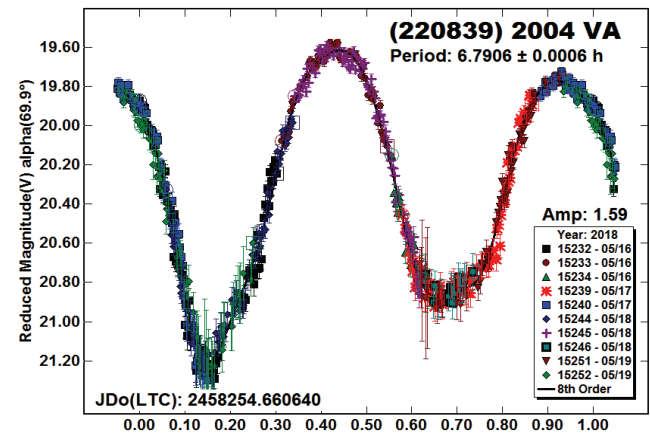
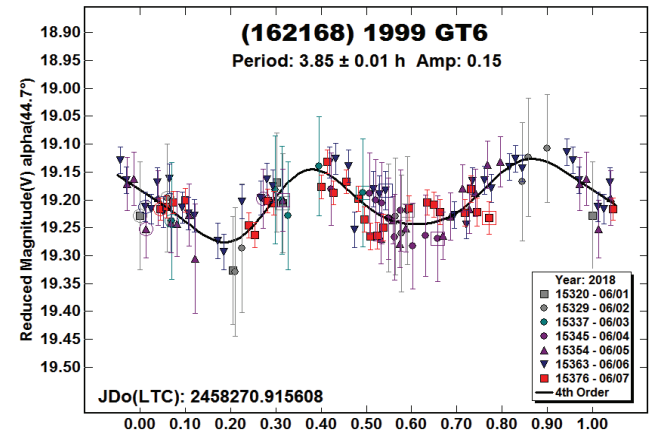


(153957) 2002 AB29. A period of 2.545 h (Warner, 2014b) was the only previous result in the LCDB. The 2018 data set was much denser but also extremely noisy. The period spectrum shows a number of possible solutions. Given the earlier result, the search was narrowed to 2-3 h. This produced a period of 2.415 ± 0.002 h, with a bimodal solution at 4.827 h.

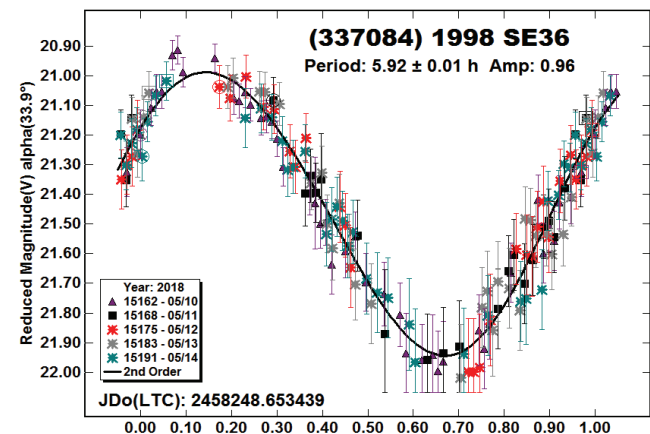


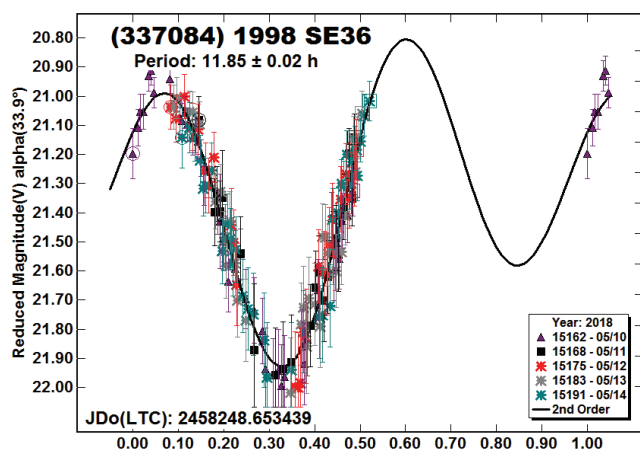
The shorter period was adopted since the 2014 data produced an unlikely quadramodal lightcurve using the longer period. In the review of the 2014 data, the period was refined to 2.442 h.

(162168) 1999 GT6, (220839) 2004 VA. These appear to be the first reported lightcurve results for these two NEAs. The estimated diameters are, respectively, 1.2 km and 1.0 km.

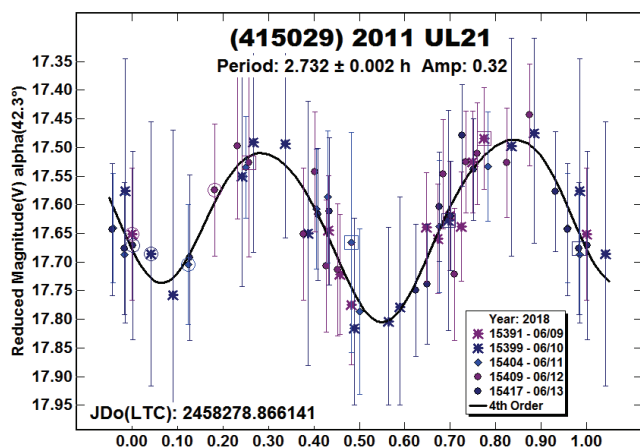


(337084) 1998 SE36. It wasn't possible to get a full lightcurve for 1998 SE36 from a single station because its period is nearly commensurate with an Earth day. The amplitude virtually requires a bimodal lightcurve (Harris et al., 2014), and so a search was made for a good fit to a monomodal lightcurve. Once found, the period was doubled to get the final result. There were no previous results in the LCDB.

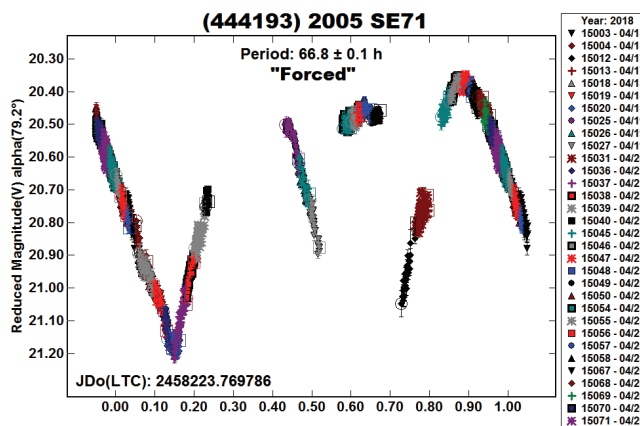
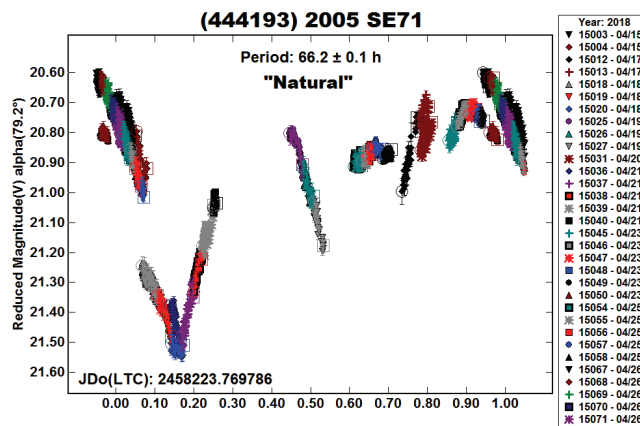
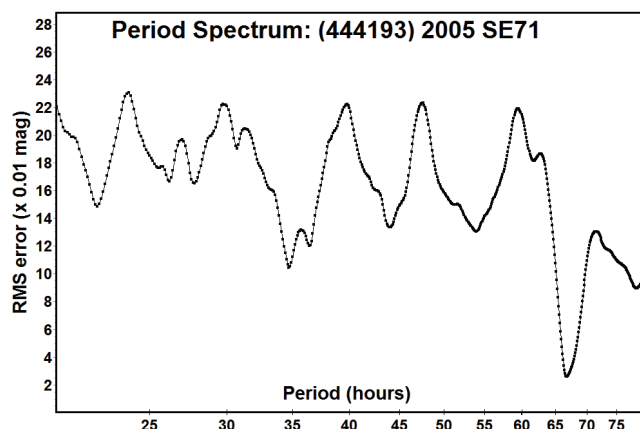




(415029) 2011 UL21. The period for this 2-km asteroid was first reported to be 1.562 h (Warner, 2018d), but that was rated “probably wrong” in the LCDB. The additional data from six months later seems to make a case for a more typical short period of 2.732 h. The large error bars reduce the reliability of the solution, however.



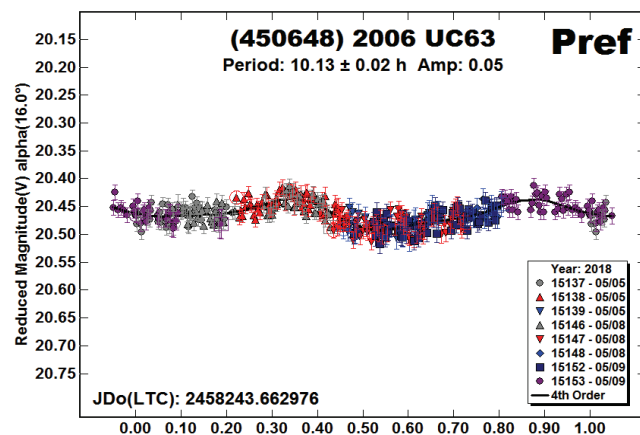
(444193) 2005 SE71. Because of its diameter of 700 meters and period of about 66 h, this asteroid is a very likely candidate for tumbling (Pravec et al., 2005). This appears to be the case. The “Natural” plot uses zero shifts $\Delta_0 < 0.05$ mag. This produces a lightcurve that clearly does not repeat with additional cycles: a good sign of tumbling. Even when introducing much larger than usual zero shifts to fit most data, there is still a “rouge night.”

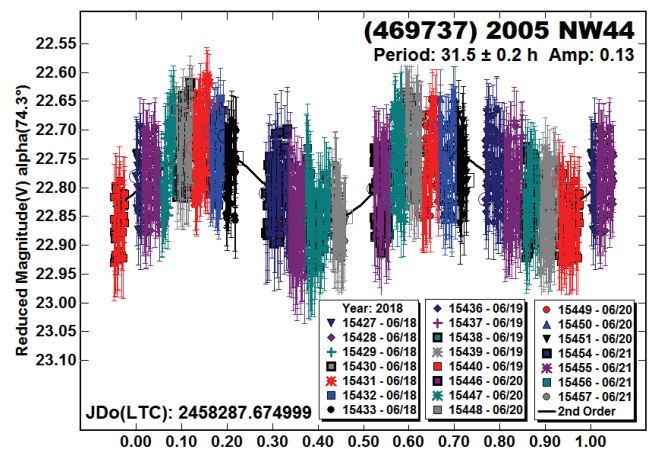
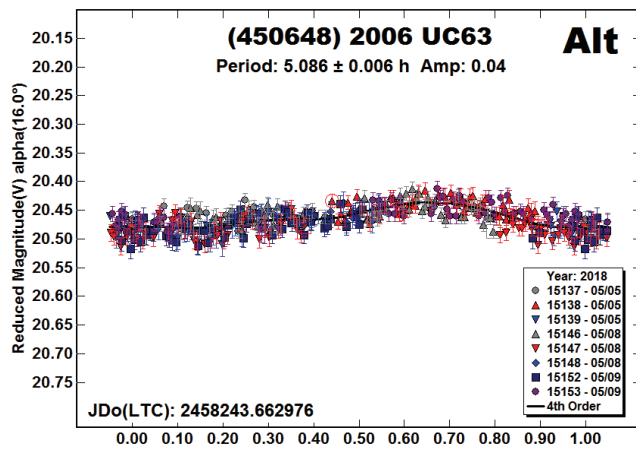


From this, it's possible that the asteroid is a low-level tumbler, meaning that there only a slight “wobble” in the primary spin axis rotation and that the two periods, rotation and precession, are close to one another.

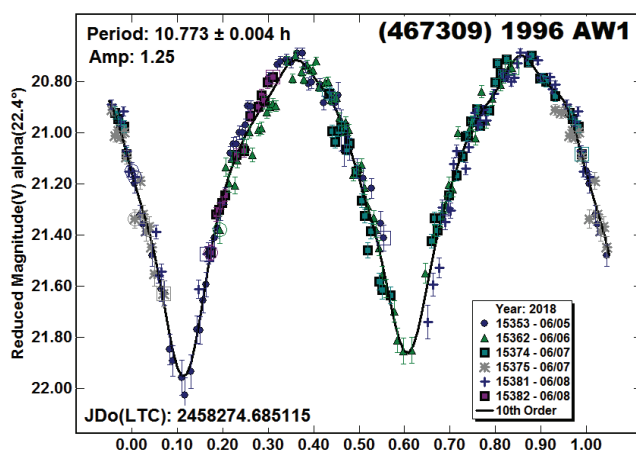
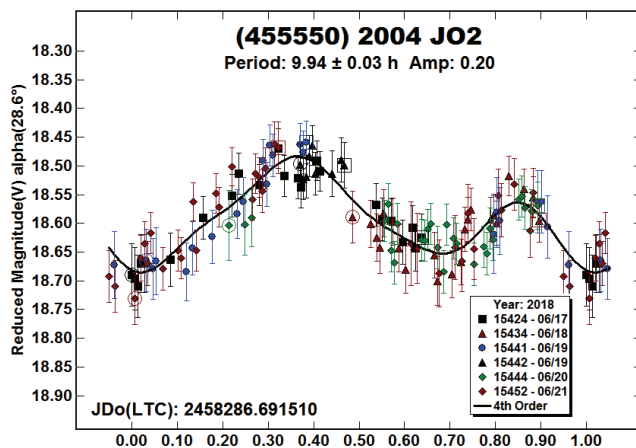
(450648) 2006 UC63 has an estimated diameter of 350 km. There were no previous lightcurve results in the LCDB.

As noted in Harris et al. (2014), at relatively low phase angles a low-amplitude lightcurve cannot be assumed to be bimodal and could have 1, 2, or 3 or more extrema pairs per rotation. While two possible periods, including the preferred one of 10.13 h, are shown here, other periods, such as one about 15.3 h (trimodal) are possible. Unfortunately, the ambiguity will not be resolved any time soon. The asteroid stays at $V \geq 20$ until 2041 May, when it “blazes forth” at $V = 18.1$.



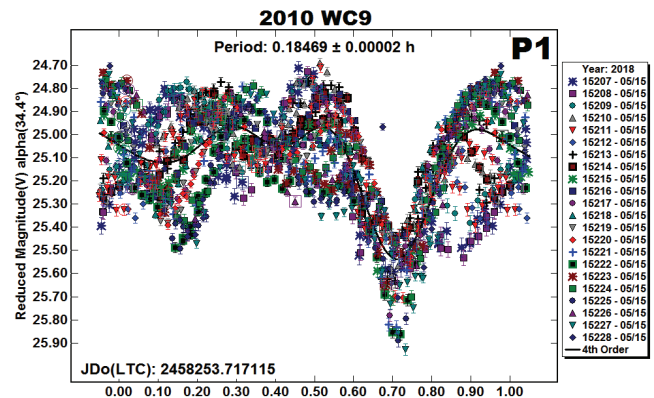
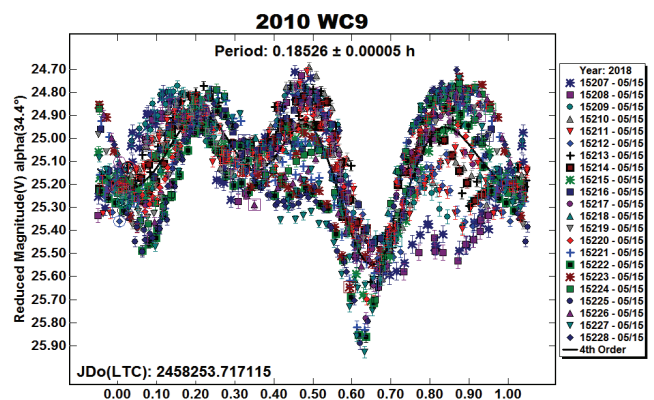
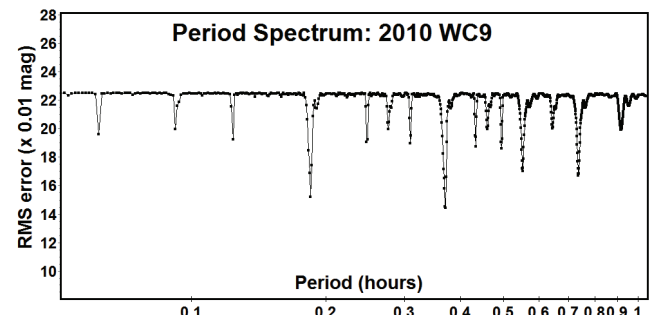


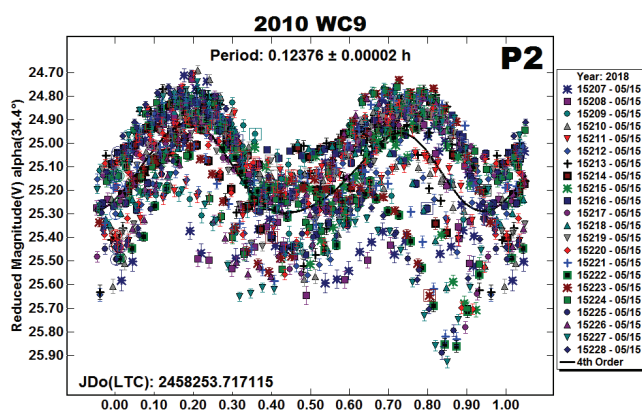
(455550) 2004 JO2, (467309) 1996 AW1. There were no previous lightcurve entries in the LCDB for the 1-km 2004 JO2. The same applies to 1996 AW1, which has an estimated diameter of 300 meters. Both solutions are considered secure, especially for 1996 AW1 because of its large amplitude lightcurve.



(469737) 2005 NW44. There were no previous lightcurve results in the LCDB for 2005 NW44. The estimated diameter is 250 meters. The low SNR (large error bars) is due to the asteroid's rapid sky motion. Exposures had to be limited to 30 sec to keep trailing to a minimum. The raw plots of individual nights showing a steady increase or decrease in brightness added some confidence to the solution, though it still far from certain.

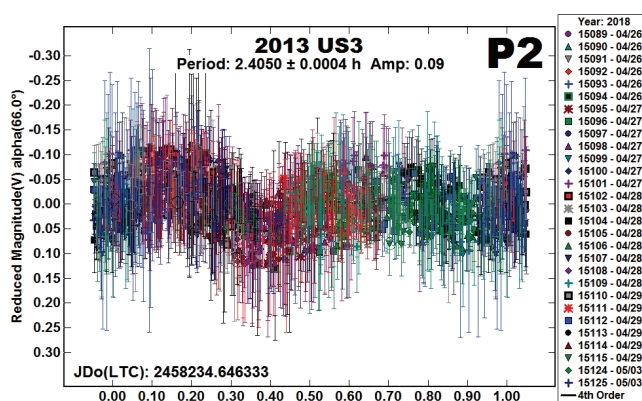
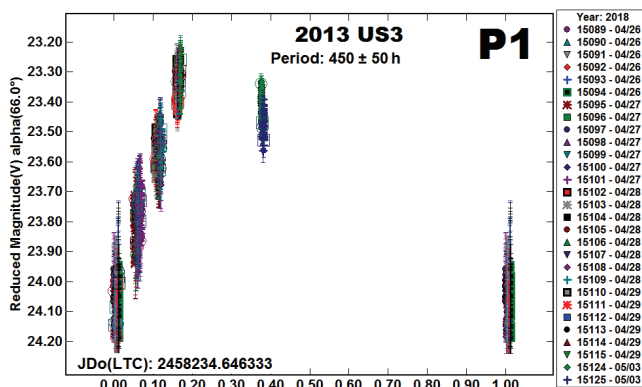
2010 WC9. This is a tumbling asteroid with nearly commensurate periods of 0.18469 h and 0.12376 h (Petr Pravec, private communications). *MPO Canopus*, which cannot analyze tumbling asteroids, was used to generate the plots at the two frequencies along with a single period lightcurve that is *almost* a good fit. The total amplitude of the lightcurve is about 1.2 mag.



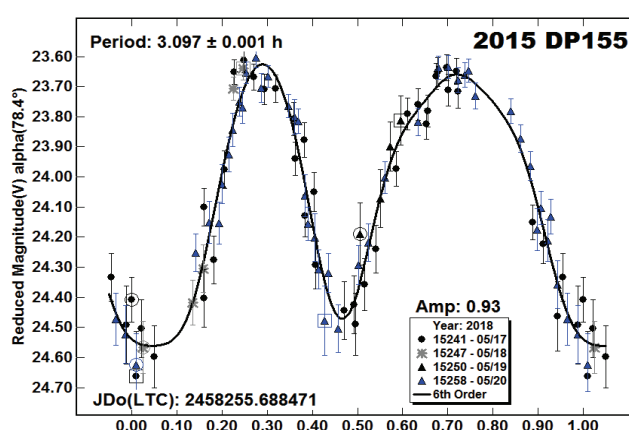


2013 US3. There may be in a subclass of asteroids called “very wide binaries” (see Warner, 2016b) where the primary has a long to very long period and the satellite has a short period, usually $P \leq 7$ h. It was not possible to follow this NEA long enough to get a complete lightcurve of the long period, but using half-period solutions gave $P_1 = 450 \pm 50$ h as a reasonable estimate. When this was subtracted from the data, despite the large error bars, a second period appeared, $P_2 = 2.4050 \pm 0.0004$ h, which is a typical period for the satellites in these systems.

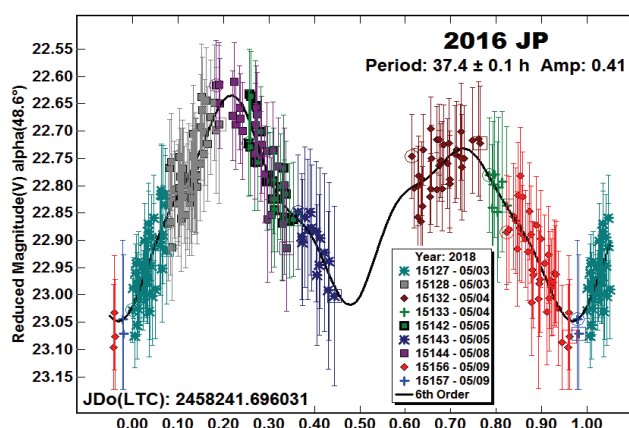
To date, mutual events (occultations and/or eclipses) have not been seen, nor are they likely to be since the orbital period is very long. Therefore, 2013 US3 joins a small, but growing list of suspected candidates for the very wide binary group.



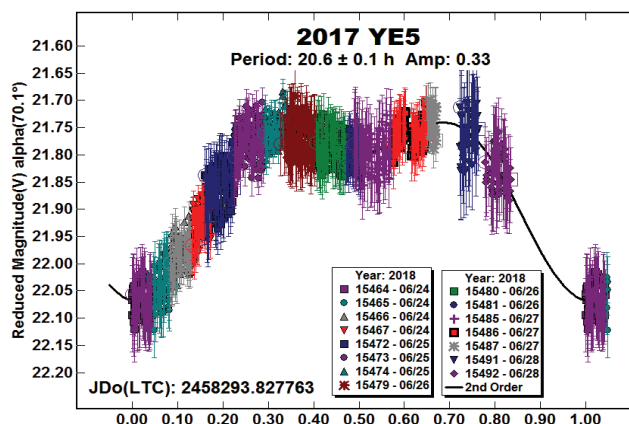
2015 DP155. Reshetnyk et al. (2018) reported $P = 3.105$ h and $A = 1.0 \pm 0.1$ mag. The CS3-PDS data were obtained about two weeks later, when the amplitude had decreased to 0.93 ± 0.05 mag. This was the brightest apparition through 2050. The best it will be is $V \sim 18.9$ in 2021 July at -25° declination.



2016 JP. There's a chance to confirm this first-time result in 2019 April. That will be the last time through 2050 that it is brighter than $V \sim 18.3$.

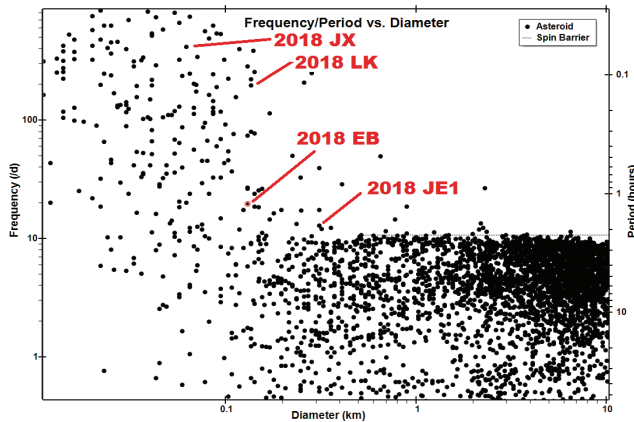


2017 YE5. Radar observations in 2018 mid-June showed this to be an “equal-mass, Hermes-like binary” (Patrick Taylor, private communications). With the large phase angle and unknown viewing geometry, just about any lightcurve could be generated. The one obtained at CS3-PDS has a large amplitude, which might be expected, but the very small secondary minimum was a challenge to explain.



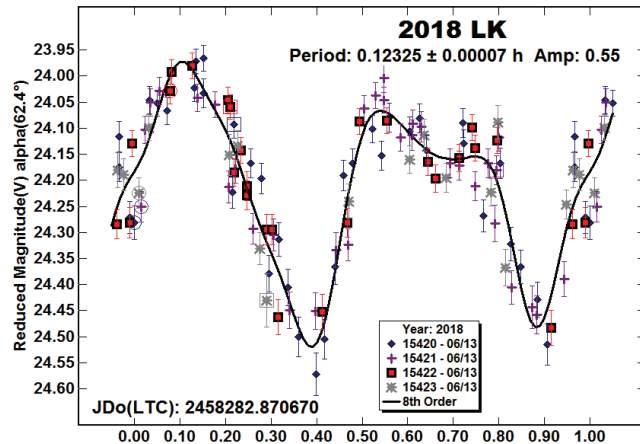
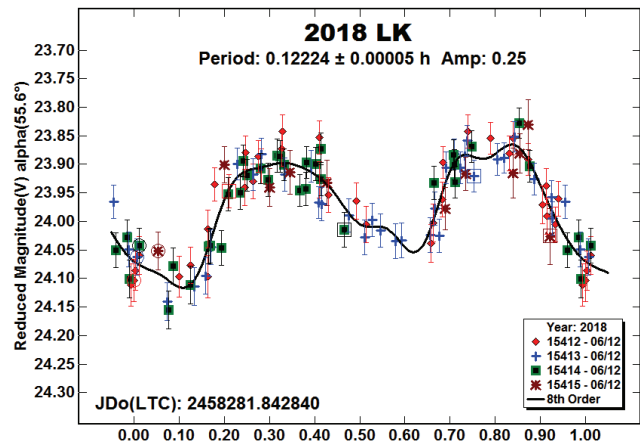
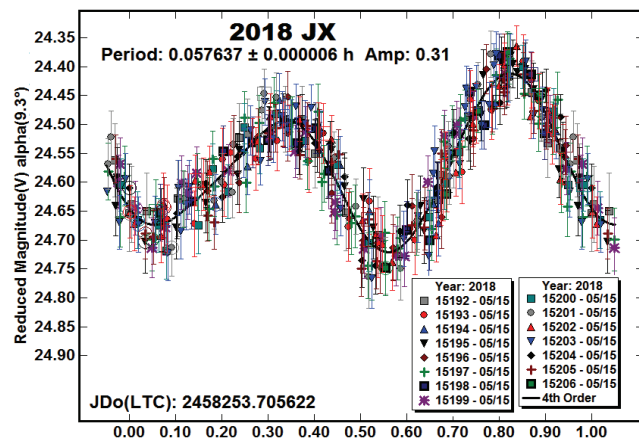
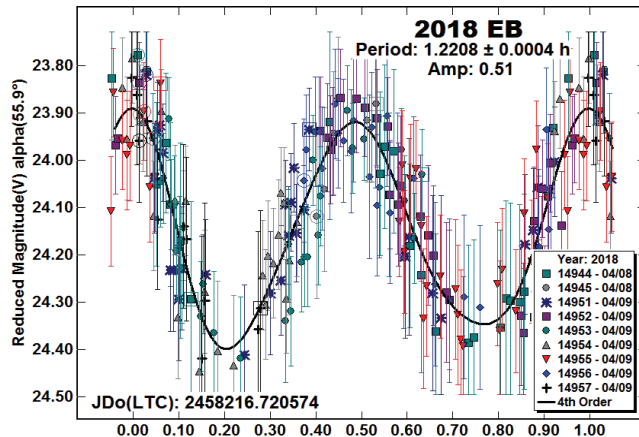
Additional radar observations in late June (JPL, 2018) at Arecibo, Goldstone, and Green Bank (West Virginia) confirmed that the asteroid is binary. The two bodies are each 900 meters in diameter and are widely separated. The orbital period was estimated to be 20-24 h, which fits with the period found using the CS3-PDS data.

2018 EB, 2018 JX, 2018 LK. These are first-time entries into the LCDB for these three NEAs, each one having a super-fast rotation period. Their positions in the frequency-diameter plot from the LCDB show that they are in the “ascending branch” that features small, super-fast rotators.



For 2018 EB, the large phase angle puts forcing a bimodal solution into question, but that is countered by the relatively large amplitude. The estimated diameter is only 130 meters, so it's not surprising for the asteroid to have a period well above the “spin barrier.”

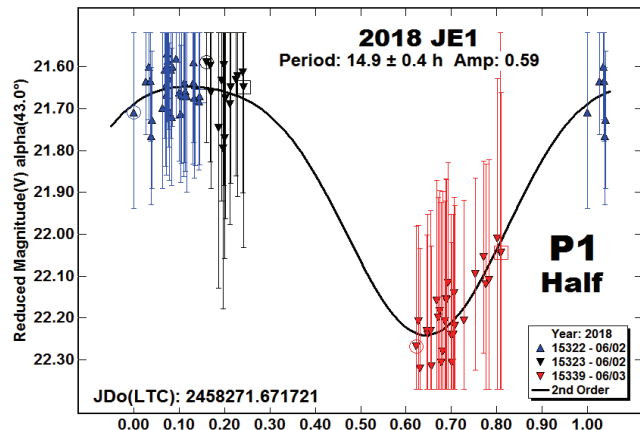
The fastest rotator of the group is 2018 JX. To avoid excessive trailing, exposures were only 6 seconds. Fortunately, the asteroid was $V \sim 14.5$ at the time and so the SNR was reasonable and the result was an unusually “tight” lightcurve.

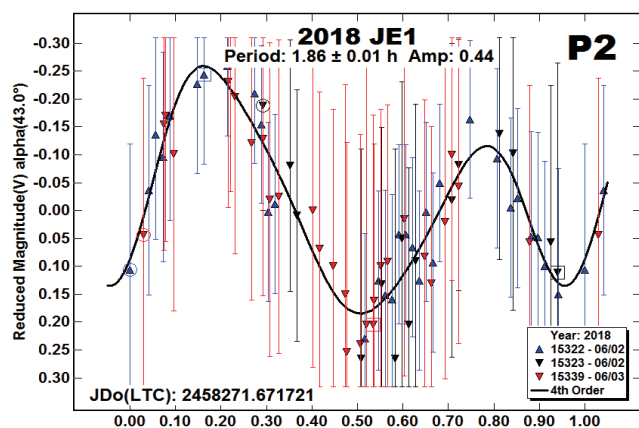


The shape of the lightcurve for 2018 LK changed so dramatically from 2018 June 12 to 13 that there was little point in merging the two nights to get a single period. The mismatch between the curves might have actually hurt the accuracy of the result.

2018 JE1. At $V \sim 18.5$, exposures of 240 s or more would have been preferred. However, sky motion kept them to 90 sec. The large error bars rival the amplitude of the half-period lightcurve, which was the only reasonable means to get an estimate the period.

The data from June 3 required a zero point shift of 0.81 mag to match June 2. That is far beyond what was expected and so it was assumed that there was a very long period component in the data. A short period seemed likely looking only at the June 2 data.

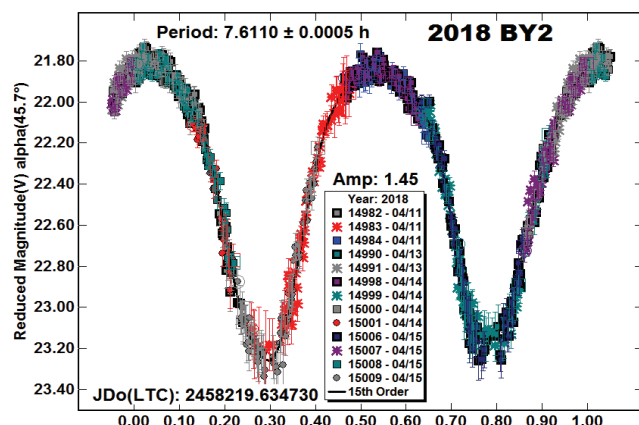




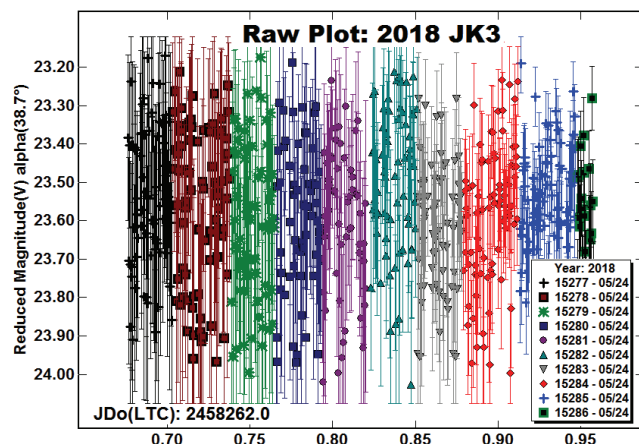
The dual period search feature in *MPO Canopus* was used to remove what appeared to be a long period, which is very probably not valid: it was a just a means to remove the large zero-point shift that could not be reasonably accounted for by other means.

Removing the supposed long period produced a secondary period, $P_2 = 1.86 \pm 0.01$ and $A_2 = 0.44$ mag, or about the same as the error bars. Its location is also seen in the frequency-diameter plot above. The diameter vs. period is reasonable, the period solution is not so much so. Next chance: 2035 May, $V \sim 17.9$ at $+5^\circ$ declination.

2018 BY2. Pravec et al. (2018) found a period of 7.6170 h. The result presented here is similar.

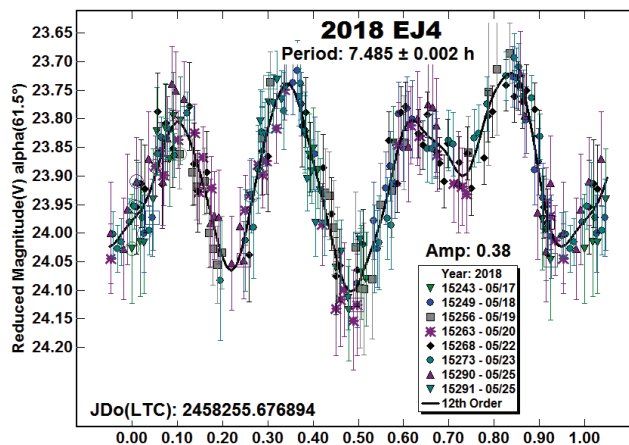


2018 JK3. A search for a very short period was fruitless. This was just an extremely noisy, “flat” data set.

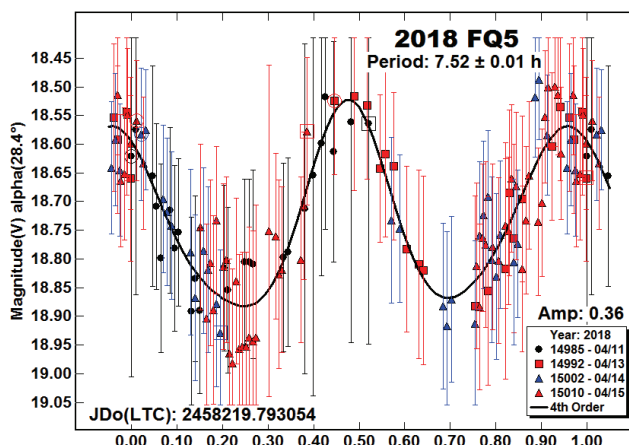


2018 EJ4. The shape of the lightcurve calls to mind a tumbling asteroid with two, nearly commensurate periods (e.g., 2010 WC9 in this paper). Radar observations (Sean Marshall, private communications) indicated the half-period of 3.742 h was more likely. When using that as a starting period for a dual period search (even though *MPO Canopus* cannot handle tumbling asteroids properly), the result was just the 7.48 h solution with a lower amplitude and considerably different shape.

The raw photometry data have been uploaded to the ALCDEF web site (alcdef.org) for others to try their hand at a solution.



2018 FQ5. There were no previous entries in the LCDB for this 500-m NEA.



Acknowledgements

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Number	Name	2018 mm/dd	Pts	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.
719	Albert	05/20-05/23	78	17.4,16.7	257	17	5.831	0.004	0.52	0.03
1627	Ivar	04/14-04/15	412	19.2,19.0	219	15	4.7947	0.0003	1.01	0.02
1866	Sisyphus	04/04-04/10	164	17.2,17.6	171	46	2.4055	0.0007	0.11	0.02
2061	Anza	06/22-06/25	68	33.7,33.8	306	7	6.712	0.004	0.30	0.02
9856	1991 EE	05/04-05/09	162	53.4,60.2	183	17	3.0416	0.0005	0.28	0.02
15745	Yuliya	05/05-05/16	258	35.2,35.4	241	31	5.86	0.01	0.15	0.02
25916	2001 CP44	04/17-04/25	193	26.7,25.2	238	19	4.6021	0.0005	0.24	0.02
25916	2001 CP44	06/07-06/08	447	14.9,14.8	252	12	4.596	0.002	0.21	0.01
25916	2001 CP44	²⁰¹⁴ 03/16-03/20	67	37.3,37.9	246	14	4.608	0.003	0.35	0.04
36183	1999 TX16	05/05-05/09	147	8.0,7.3	226	10	5.613	0.002	0.90	0.04
65996	1998 MX5	06/18-06/24	90	38.1,40.0	301	7	3.399	0.001	0.22	0.02
66391	1999 KW4	06/01-06/07	1786	50.8,59.6	240	30	2.7660	0.0002	0.14	0.01
68347	2001 KB67	06/04-06/06	499	51.1,47.7	254	27	6.354	0.004	0.19	0.02
85628	1998 KV2	05/16-05/24	167	14.0,18.1	222	7	2.8234	0.0005	0.18	0.02
85953	1999 FK21	03/30-04/13	2023	13.6,68.2	175	15	68.44	0.04	0.87	0.03
85989	1999 JD6	06/01-06/04	130	58.7,57.0	204	32	7.685	0.006	1.54	0.05
138847	2000 VE62	05/10-05/12	215	45.4,47.1	206	23	7.600	0.004	0.33	0.02
139289	2001 KR1	05/19-05/27	150	39.7,45.8	260	32	11.30	0.01	0.47	0.05
153957	2002 AB29	06/05-06/09	363	73.0,59.2	266	44	2.415	0.002	0.17	0.03
162168	1999 GT6	06/01-06/07	108	44.7,47.2	286	10	3.85	0.01	0.15	0.03
220839	2004 VA	05/16-05/19	581	69.6,61.3	198	14	6.7906	0.0006	1.59	0.04
337084	1998 SE36	05/10-05/14	158	33.9,36.9	210	15	11.85	0.02	0.96	0.04
415029	2011 UL21	06/09-06/12	59	42.3,41.3	325	23	2.732	0.002	0.32	0.03
444193	2005 SE71	04/15-04/26	1826	79.2,2.3,37.8	189	30	66.8	0.1	0.8	0.1
450648	2006 UC63	05/05-05/09	369	16.2,23.5	219	10	10.13	0.02	0.05	0.01
455550	2004 JO2	06/17-06/21	137	28.6,31.1	270	29	9.94	0.03	0.20	0.02
467309	1996 AW1	06/05-06/08	240	22.5,26.3	253	15	10.773	0.004	1.25	0.04
469737	2005 NW44	06/18-06/21	1360	73.6,61.2	251	32	31.5	0.2	0.13	0.02
	2010 WC9	05/15-05/15	1325	32.7,32.7	242	15	0.18469	0.00002	0.95	0.10
	2013 US3	04/26-05/03	1244	65.2,37.0	195	12	450	50	1.2	0.1
	2015 DP155	05/17-05/19	58	78.4,78.9	212	36	3.089	0.003	1.09	0.05
	2016 JP	05/03-05/09	230	48.6,44.3	209	23	37.4	0.1	0.41	0.03
	2017 YE5	06/24-06/28	1069	70.3,42.2	303	9	20.6	0.1	0.33	0.02
	2018 EB	04/08-04/09	218	56.6,62.1	197	32	1.2208	0.0004	0.51	0.05
	2018 JX	05/15-05/15	375	6.4,6.4	233	3	0.057637	0.000006	0.31	0.03
	2018 LK	06/12-06/12	227	55.6	287	13	0.12296	0.000005	0.25	0.02
	2018 LK	06/13-06/13	113	62.4	292	11	0.12325	0.000007	0.55	0.03
	2018 JE1	06/02-06/03	75	43.1,44.5	223	10	29.8	0.5	0.59	0.05
	2018 BY2	04/11-04/15	749	45.3,35.8	181	-2	7.6110	0.0005	1.45	0.03
	2018 JK3	05/24-05/24	667	38.3,38.3	237	21	-	-	flat	-
	2018 EJ4	05/17-05/25	245	61.5,62.1	227	33	7.484	0.002	0.37	0.03
	2018 FQ5	04/11-04/15	127	28.4,25.7	219	18	7.52	0.01	0.36	0.04

Table II. Observing circumstances. [^](Period): preferred period of an ambiguous solution. ^{yy}(Dates): data are from the year 20YY. 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. L_{PAB} and B_{PAB} are, respectively the average phase angle bisector longitude and latitude.