

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

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Lightcurves for 25 main-belt asteroids were obtained at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2016 July to September.

CCD photometric observations of 25 main-belt asteroids were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2016 July to 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.

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).

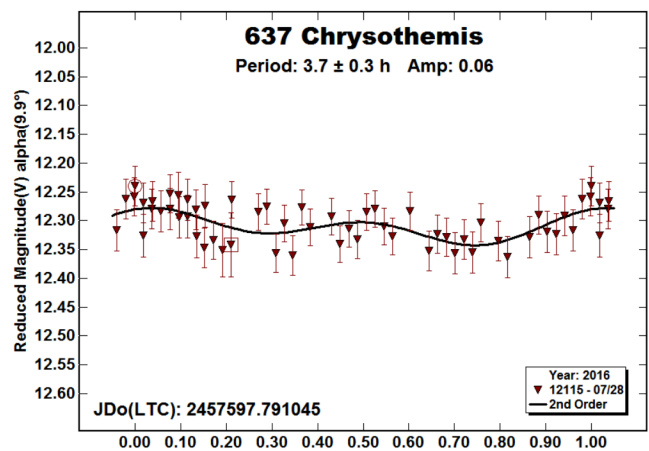
In the plots below, the “Reduced Magnitude” is Johnson V as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distance by applying $-5 \cdot \log(r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and Earth-asteroid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

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

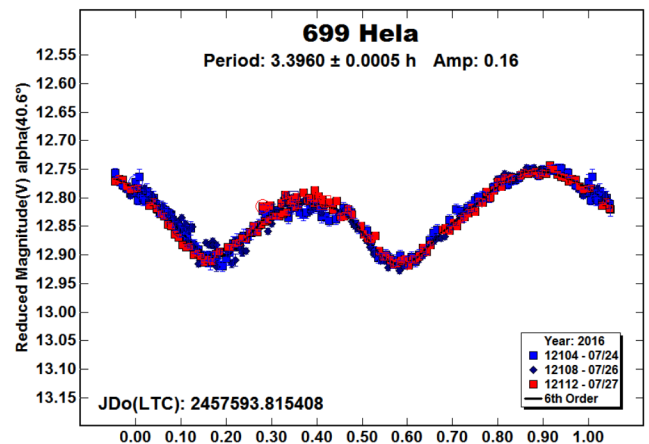
adopted amplitude for the lightcurve. The value is meant only to be a quick guide.

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.*, 2009a). The on-line version at <http://www.minorplanet.info/lightcurvedatabase.html> allows direct queries that can be filtered a number of ways and the results saved to a text file. A set of text files of the main LCDB tables, including the references with bibcodes, is also available for download. Readers are strongly encouraged to obtain, when possible, the original references listed in the LCDB for their work.

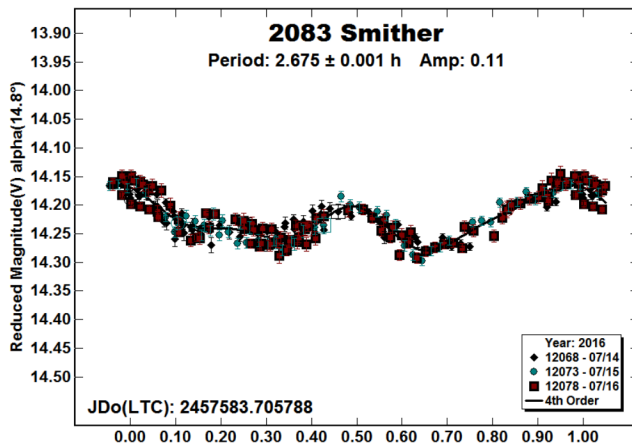
637 Chrysothemis. This Themis group member was in the field-of-view of a planned target for only one night. Without a second night, it was not possible to tell if the variations seen in the plot were systematic rather than due to rotation of the asteroid. The period shown in the plot is for informational purposes only.



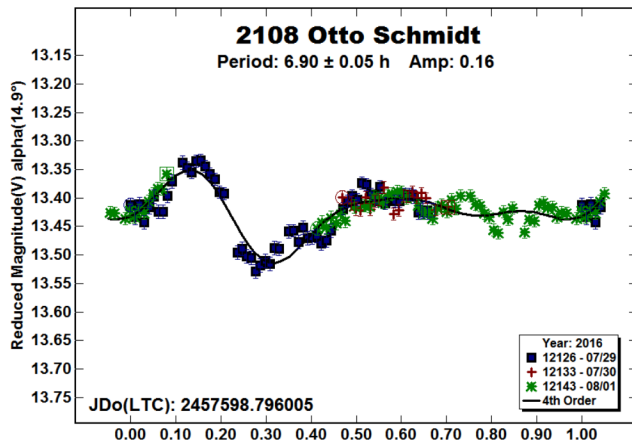
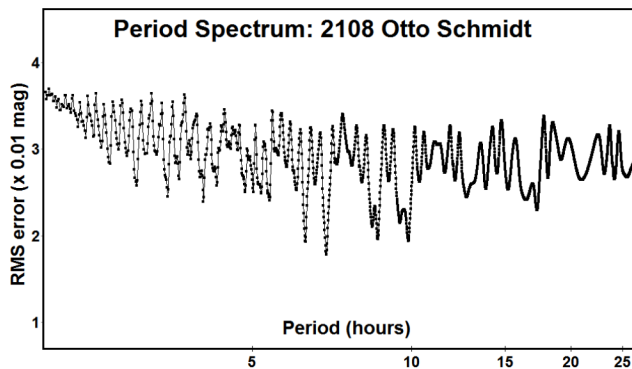
699 Hela. Previous results for this Mars-crossing asteroid have varied from 2.63 h (Monson, 2011) to 4.765 h (Behrend, 2003w). Most, however, have been approximately 3.3 hours (e.g., Pilcher *et al.*, 2000). The results from the PDS data in 2016 are in relatively good agreement with the majority of previous results.



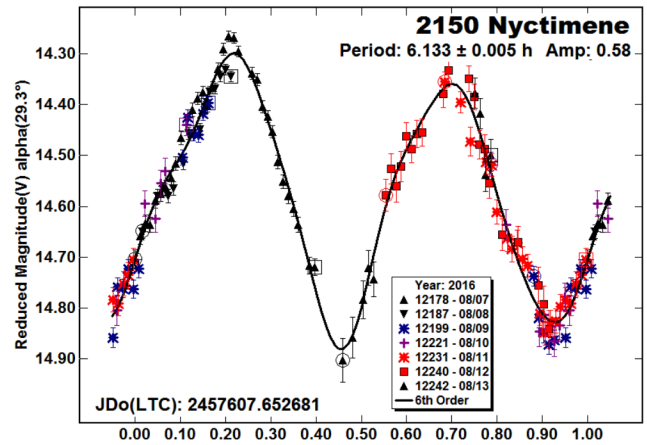
2083 Smither. This Hungaria asteroid had been observed by the author on several previous occasions (Warner, 2007a; 2010; 2012a; 2015b). Each time the period was about 2.67 hours, which is the same result found from the 2016 data.



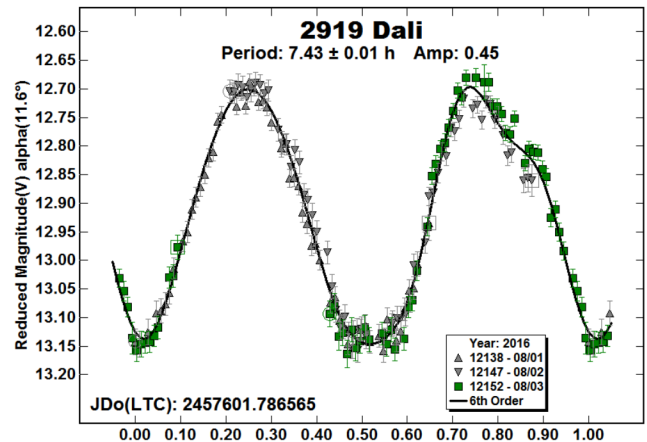
2108 Otto Schmidt. The only previous result in the LCDB for this inner main-belt asteroid is 15.24 h (Behrend, 2001w). The period spectrum based on the PDS data in 2016 does not support that result, but favors one of 6.90 h. A period of 6.31 hour cannot be formally excluded.



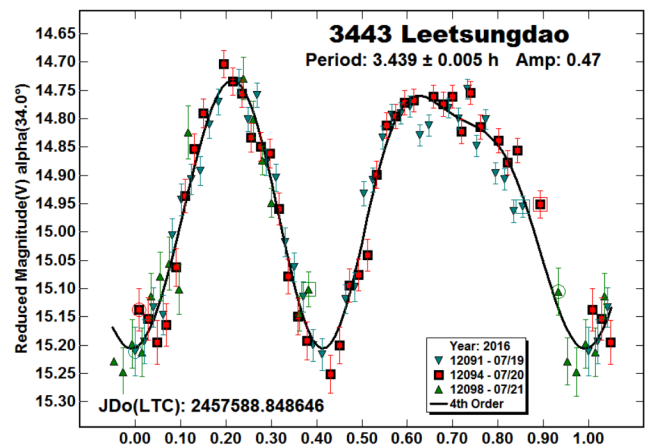
2150 Nyctimene. This is another Hungaria asteroid that was observed by the author on several previous occasions: *e.g.*, Warner (2007a, 6.125 h; 2008, 6.129 h; 2015a, 6.130 h). Over the course of all the apparitions, the amplitude has varied between 0.59 and 0.76 mag, indicating a spin axis pole that is mostly upright, but still has a significant obliquity. Lightcurve inversion using all the data obtained by the author from 2007 through 2016 found a pole of $\lambda = 285^\circ$, $\beta = -74^\circ$ and sidereal period of $P_{\text{SID}} = 6.125711$ h. The negative latitude indicates that the asteroid is in retrograde rotation. These results and those for almost 200 other Hungarias will be presented in a future paper.



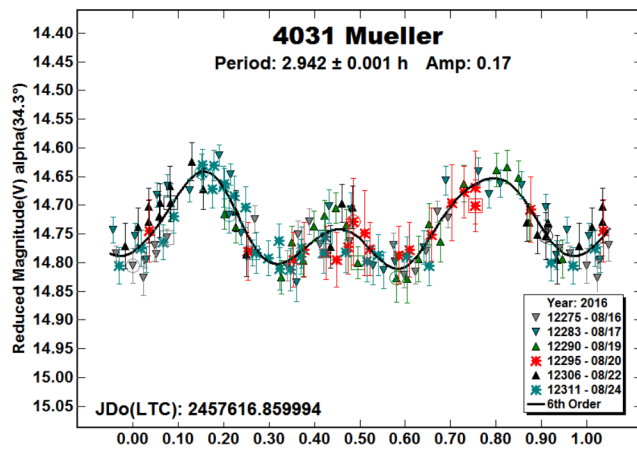
2919 Dali. This member of the Themis group has an estimated diameter of 19 km when assuming an albedo of $p_V \sim 0.08$. Both using sparse data from the Palomar Transient Survey, Waszczak (2015) and Chang (2015) found a period of about 7.4 hours. The dense lightcurve from PDS in 2016 supports those results.



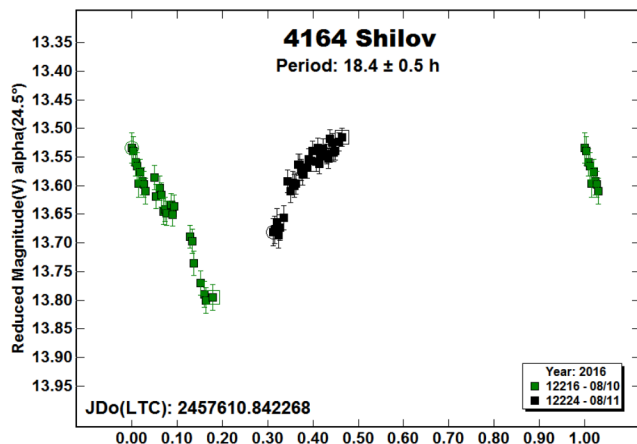
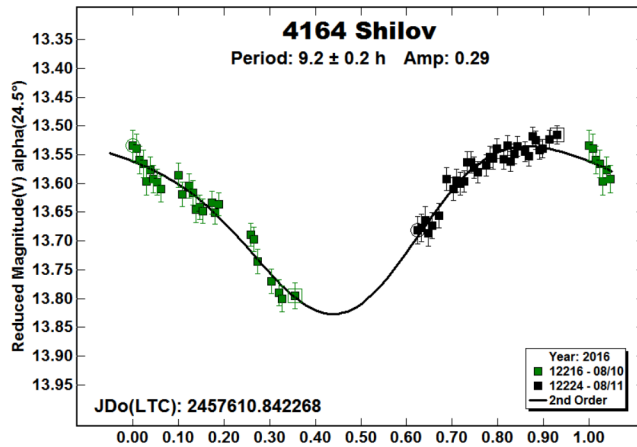
3443 Leetsungdao. Ivanova *et al.* (2002) found a period of 3.313 h for this Mars-crosser. Subsequent studies by Stephens (2002), Behrend (2001w), and Ferrero (2013) found a longer period of about 3.44 hours, as did the analysis using the 2016 PDS data.



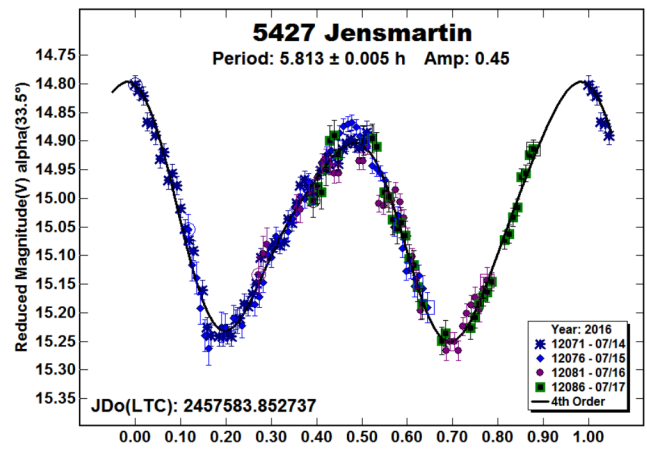
4031 Mueller. This was the fourth apparition at which the author observed this Hungaria asteroid. All previous results and those from 2016 have a period near 2.94 h and amplitude that remained at $A < 0.20$ mag.



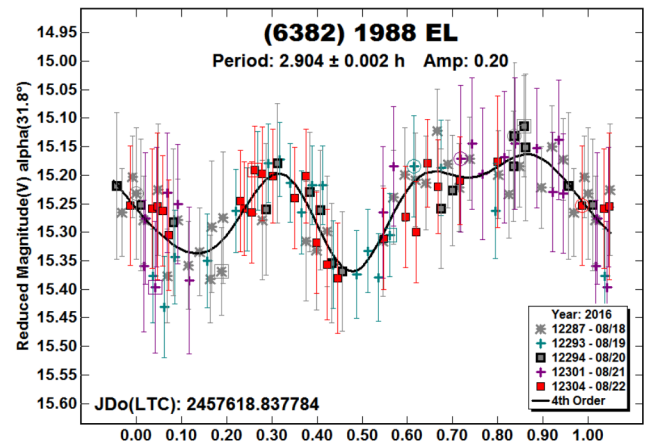
4164 Shilov. Shilov is a member of the Eunomia orbital group. It was a target of opportunity for two nights, *i.e.*, it was in the same field as a targeted asteroid. Angeli and Barucci (1996) found a period of 18.35 h, but it is rated $U = 1$ (“probably wrong”) in the LCDB. The period of 18.4 hours reported here is based on a half-period solution of about 9.2 hours. This solution is rated only slightly higher, $U = 2$ -. Future observations are encouraged.



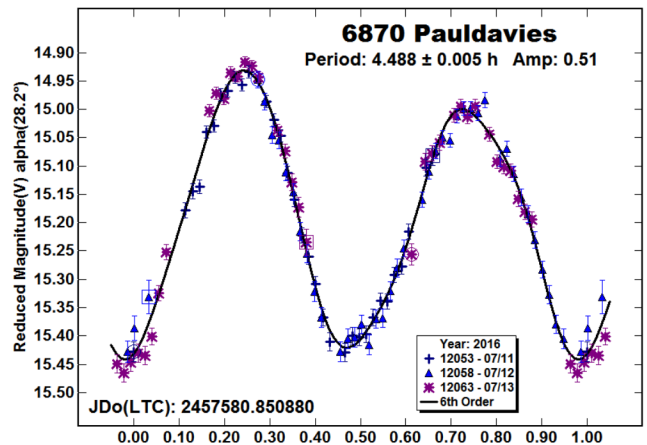
5427 Jensmartin. The results from the 2016 PDS data give a period of 5.813 h. This is the fourth apparition at which the author observed this Hungaria and the fifth time it was worked by any CS3 observer. All previous results are in close agreement with the latest period (*e.g.*, Warner, 2009c, 5.810 h; Stephens *et al.*, 2014a, 5.812 h)



(6382) 1988 EL. Previous results by the author for this Hungaria include Warner (2005, 2.895 h; 2012b, 2.894 h; 2015c, 2.893 h). The 2016 results are in good agreement with those and other previous results.

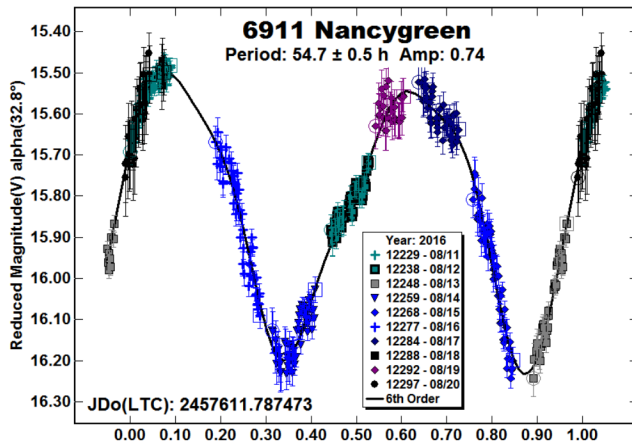


6870 Pauldavies. Warner (2007b) and Stephens (2015) both found a period of 4.487 h. The period found from the 2016 data is essentially the same.

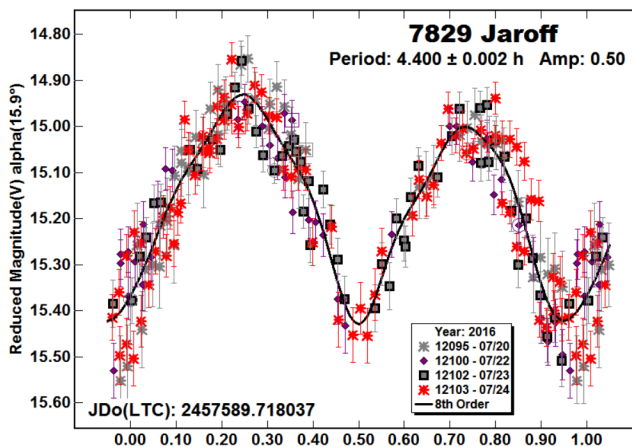


6911 Nancygreen. This is another Hungaria observed by the author as part of a final push before doing lightcurve inversion on more than 200 Hungaria asteroids. Previous results include Warner (2006, 5.3 h; 2009b, 4.33 h; 2014, 59.1 h). The mostly complete lightcurve with high amplitude in 2016 virtually assures a bimodal solution with a period of about 55 h (see Harris *et al.*,

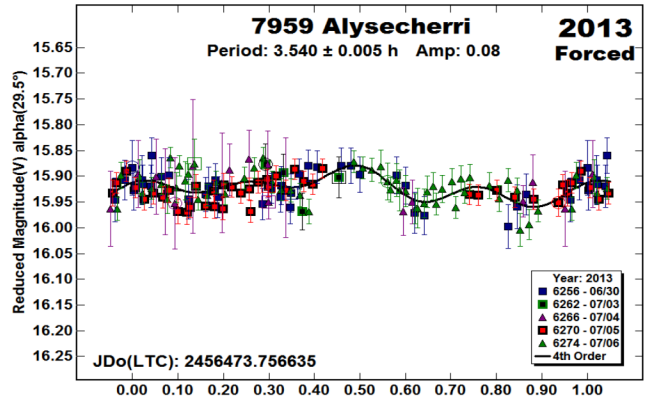
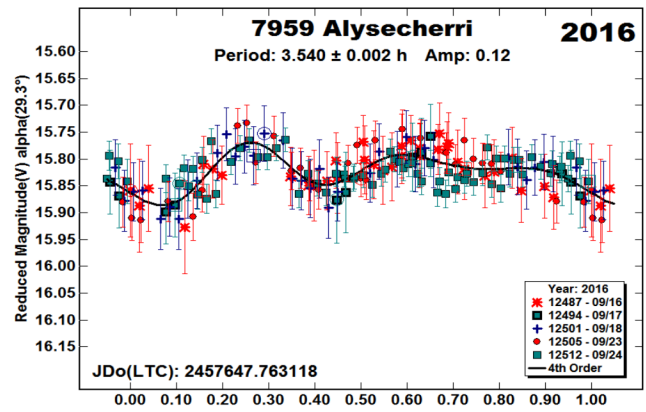
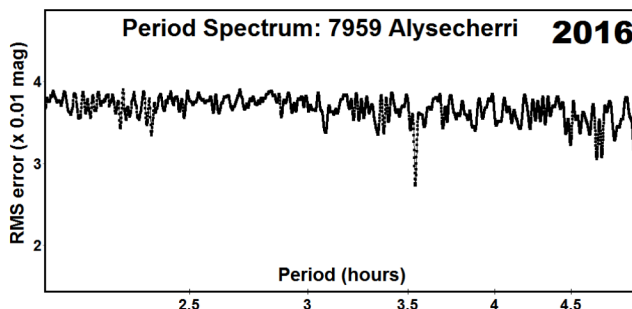
2014). The damping time from a tumbling state to principal axis rotation for the given period and estimated diameter is about 2-4 Gyr (see Pravec *et al.*, 2005, 2010). If there were any indications of tumbling, they were hidden within the noise and incomplete coverage of the lightcurve.



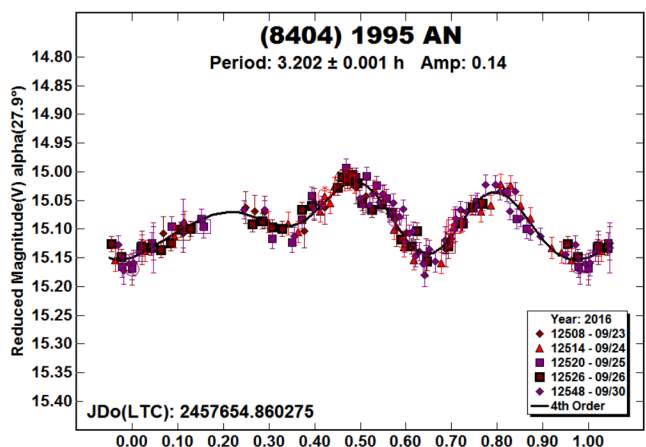
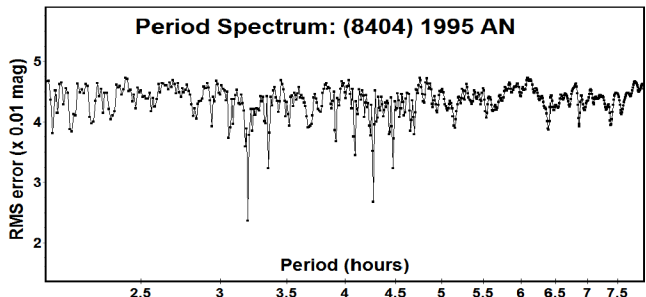
7829 Jaroff. All previous results for this Hungaria are within 0.01 h of the period found from the 2016 data (*e.g.*, Warner and Stephens, 2009b; Stephens 2015).



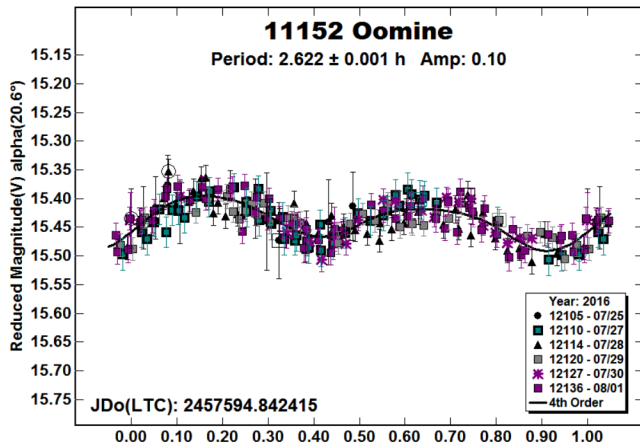
7959 Alysecherri. In 2013, Warner (2014) reported a period of 3.161 h for this Hungaria member. The 2016 data did not support this result, with the period spectrum showing only a minor drop below the noise in the RMS values for a period near 3.16 h. The data from 2013 were forced to fit the period found using the 2016 data. While the fit is not quite as good as to 3.161 h, it is still plausible given the noise and low amplitude. A period of 3.540 hours is adopted for this paper.



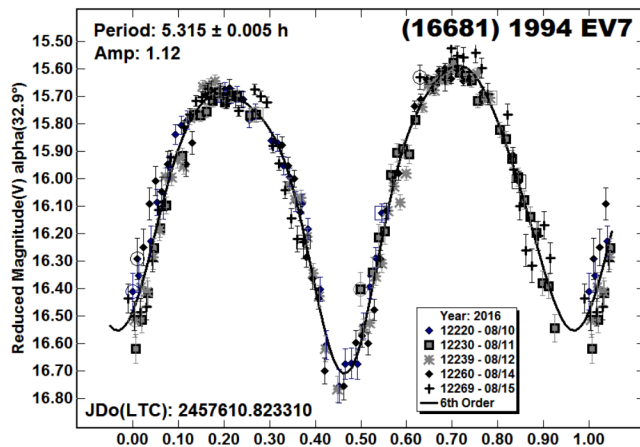
(8404) 1995 AN. Previous results for this Hungaria were ambiguous. Warner (2009d) found a period of 4.612 h but one of 3.204 h could not be formally excluded. Follow-up observations in 2012 (Warner, 2012c) led to a period of 3.200 hours, as did the results from the 2016 data analysis. A period of 3.202 h is adopted for this paper.



11152 Oomine. The period of 2.622 h reported here appears to be the first one for this Mars-crosser that was observed as a “full moon project.”

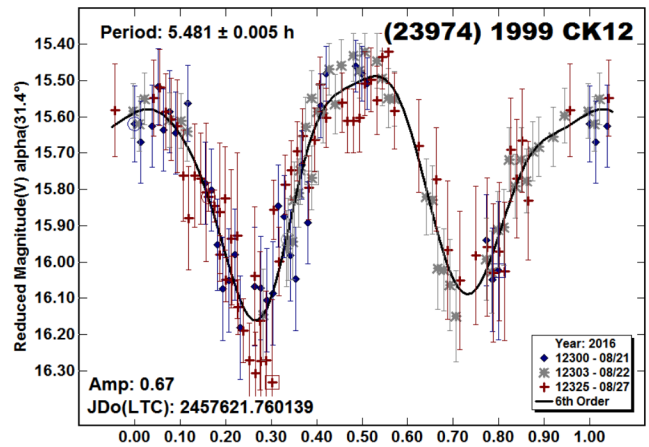


(16681) 1994 EV7. The 2016 apparition was the third one at which the author observed this Hungaria. The previous results (Warner, 2007b; 2012b) are in good agreement with the period found from the 2016 data.

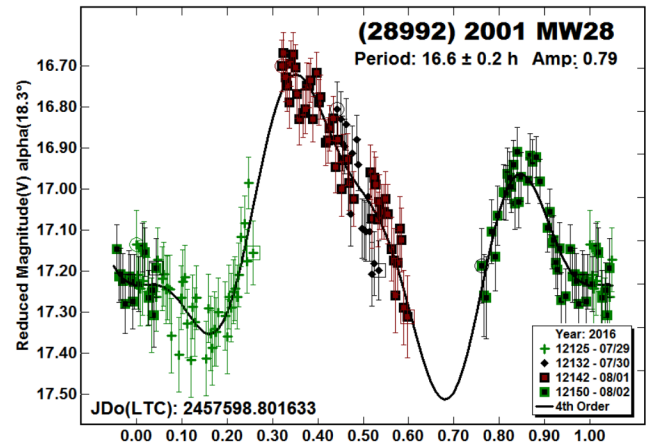


(23974) 1999 CK12. The only previously reported lightcurve period is 5.485 h (Warner, 2012c). Masiero *et al.* (2012) observed this Hungaria with the WISE spacecraft and reported an albedo of $p_V = 0.697$ using $H = 14.5$. This is unusually high, but not completely unreasonable if taking into account that the WISE survey may have at times been using faulty values for H (absolute magnitude) for many of the Hungaria members, mostly because the H values were probably determined at larger phase angles and may not have accounted for rotational variation.

If using $H = 14.7$ (the current value in MPCORB) and the correction algorithm from Harris and Harris (1997), p_V becomes 0.61 ± 0.13 . This is within 1-sigma of the average value for E-type asteroids (that of Hungaria collisional family member) as found by Warner *et al.* (2009). If using $H = 14.8 \pm 0.3$ and $G = 0.162$ (Veres *et al.*, 2015), $p_V = 0.57 \pm 0.19$, which is even closer to the average albedo for E-type asteroids in the LCDB.

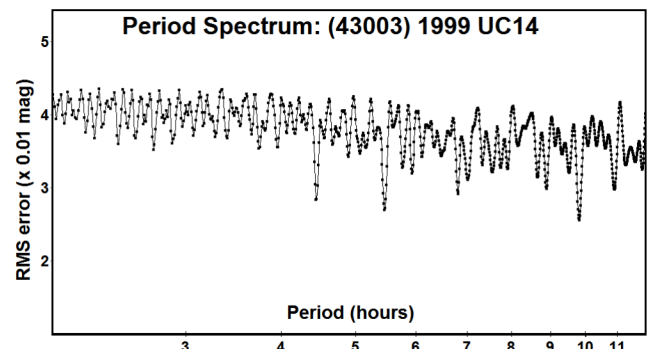


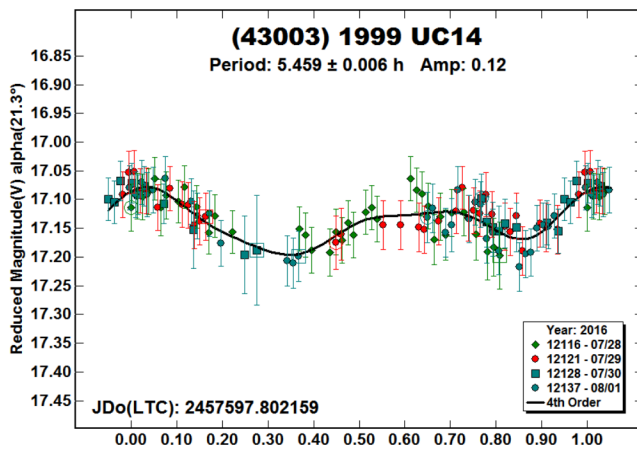
(28992) 2001 MW28. This inner main-belt asteroid was a target of opportunity that stayed in the same field as the planned target for several nights. There were no previous entries in the LCDB for the asteroid.



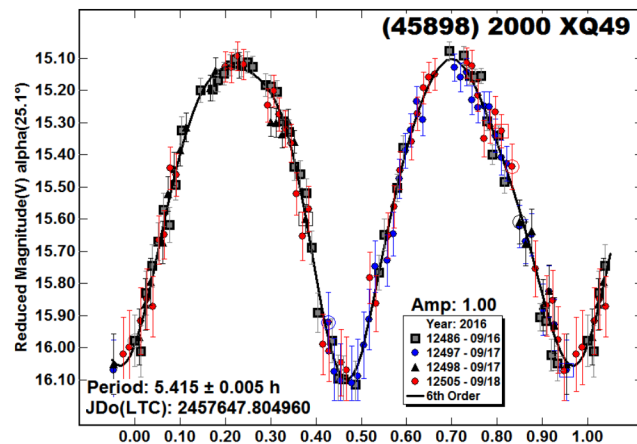
(43003) 1999 UC14. 1994 UC14 was another target of opportunity. The inner main-belt asteroid's lightcurve had a small amplitude, which made finding a definitive period more difficult. The period spectrum shows several possible solutions with the one at about 5.5 hours favored even though it did not have the lowest RMS fit, which was near 10 hours. The shape of the lightcurve for the longer period was multimodal and asymmetric, implying a physically improbable shape.

It won't be until 2023 October that 1999 UC14 will be brighter than $V \sim 17.5$. Between then, most apparitions are well into the 18th and 19th magnitude range.

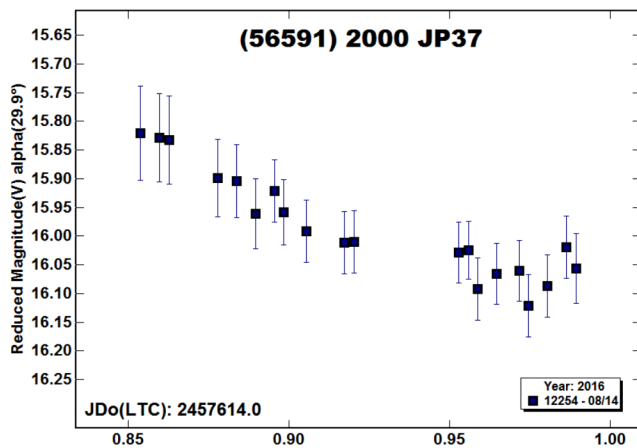




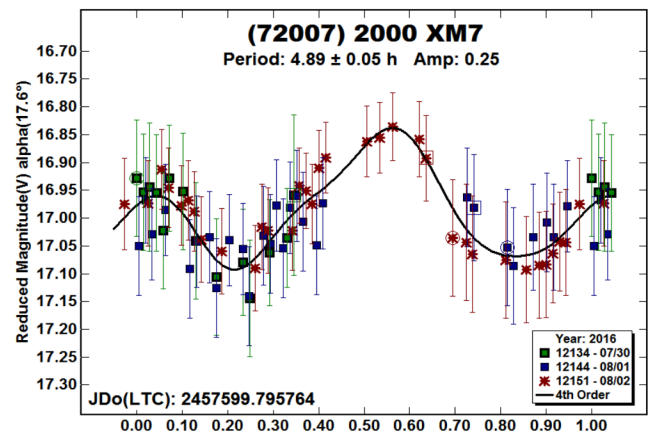
(45898) 2000 XQ49. The 2016 apparition was the fourth one that the author observed this Hungaria asteroid. All previous results had a period near 5.42 hours (*e.g.*, Warner 2014), making the results from 2016 in good agreement with those earlier findings.



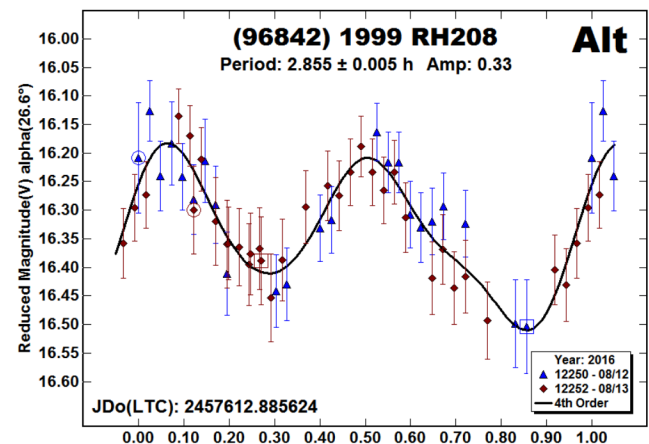
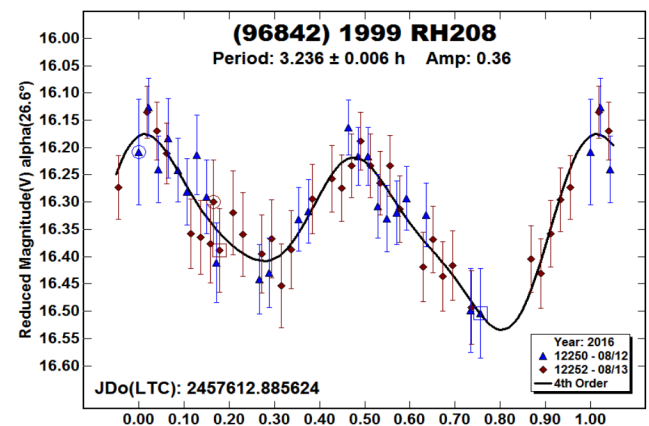
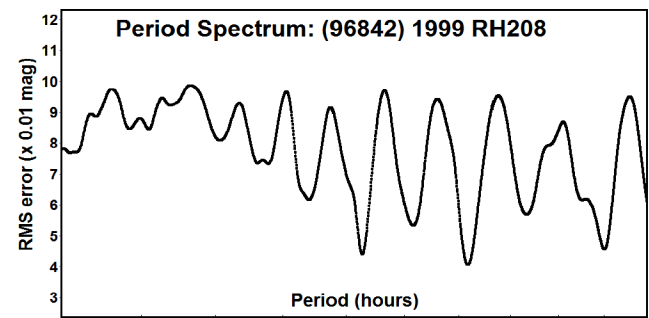
(56591) 2000 JP37. This inner main-belt asteroid was in the field of a planned target for only one night. No period could be determined from the limited data set, though it seems probable that the period exceeds 10 hours and the amplitude was at least 0.2 mag.



(72007) 2000 XM7. There were no previously reported periods in the LCDB for this member of the Flora group, which was another target of opportunity. Fortunately, it was in the planned field for several nights, which allowed finding a reliable period estimate.



(96842) 1999 RH208. A middle main-belt asteroid, 1999 RH208 was in the same field as a planned target for two nights.



Number	Name	2016 mm/dd	Pts	Phase	L _{PAB}	B _{PAB}	Period	P.E.	Amp	A.E.	Group
637	Chrysothemis	07/28-07/28	53	9.9, 9.9	338	0	3.7	0.3	0.06	0.01	THM
699	Hela	07/24-07/27	375	40.7, 40.4	2	20	3.396	0.0005	0.16	0.01	MC
2083	Smither	07/14-07/16	213	14.9, 14.4	305	19	2.675	0.001	0.11	0.01	H
2108	Otto Schmidt	07/29-08/01	135	15.0, 13.8	337	0	6.9	0.05	0.16	0.01	MB-I
2150	Nyctimene	08/07-08/13	126	29.3, 29.7	259	29	6.133	0.005	0.58	0.03	H
2919	Dali	08/01-08/03	179	11.6, 10.9	337	0	7.43	0.01	0.45	0.02	THM
3443	Leetsungdao	07/19-07/21	93	34.1, 33.7	356	7	3.439	0.005	0.47	0.03	MC
4031	Mueller	08/16-08/24	132	34.3, 34.1	34	8	2.942	0.001	0.17	0.02	H
4164	Shilov	08/10-08/11	58	24.5, 24.4	27	6	18.5	0.5	0.29	0.02	V
5427	Jensmartin	07/14-07/16	175	33.5, 33.4	355	22	5.813	0.005	0.45	0.02	H
6382	1988 EL	08/18-08/21	109	31.8, 31.7	33	10	2.904	0.002	0.2	0.03	H
6870	Pauldavies	07/11-07/13	112	28.2, 27.7	335	4	4.488	0.005	0.51	0.02	H
6911	Nancygreen	08/11-08/20	421	32.9, 31.2	13	16	54.7	0.5	0.75	0.05	H
7829	Jaroff	07/20-07/24	222	15.9, 14.8	317	18	4.4	0.002	0.55	0.05	H
7959	Alysecherri	09/16-09/24	178	29.4, 26.9	41	13	3.54	0.002	0.12	0.02	H
8404	1995 AN	09/23-09/30	149	27.9, 26.6	48	19	3.202	0.001	0.14	0.01	H
11152	Oomine	07/25-08/01	210	20.7, 17.7	333	0	2.622	0.001	0.1	0.01	MC
16681	1994 EV7	08/10-08/15	204	32.9, 32.3	17	10	5.315	0.005	1.12	0.03	H
23974	1999 CK12	08/21-08/27	141	31.4, 30.3	14	20	5.481	0.005	0.67	0.05	H
28992	2001 MW28	07/29-08/02	156	18.4, 16.5	336	0	16.6	0.2	0.79	0.05	MB-I
43003	1999 UC14	07/28-08/01	119	21.3, 19.3	332	0	5.459	0.006	0.12	0.01	MB-I
45898	2000 XQ49	09/16-09/18	153	25.1, 24.6	35	17	5.415	0.005	1	0.03	H
56591	2000 JP37	08/14-08/14	20	30.0, 30.0	25	5			0.25		MB-I
72007	2000 XM7	07/30-08/02	75	17.6, 16.3	336	0	4.89	0.05	0.25	0.03	FLOR
96842	1999 RH208	08/12-08/13	56	26.6, 26.5	23	11	3.236	0.006	0.36	0.03	MB-M

Table II. Observing circumstances. 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 (see Harris *et al.*, 1984), unless two values are given (first/last date in range). The Group column gives the orbital group to which the asteroid belongs. The definitions and values are those used in the LCDB (Warner *et al.*, 2009). THM = Themis; H = Hungaria; MC = Mars-crosser; V = Vestoid; MB-I = Inner main-belt; MB-M = middle main-belt; FLOR = Flora.

The period spectrum favored a period of 3.236 h, but a solution of 2.855 h cannot be formally excluded. The difference between the two is almost exactly one rotation over 24 hours. This uncertainty of the number of rotations over the span of the observations is sometimes called a *rotational alias*.

Acknowledgements

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