

ASTEROID LIGHTCURVE ANALYSIS AT THE PALMER DIVIDE OBSERVATORY: 2009 MARCH–JUNE

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Lightcurves for 19 asteroids were obtained at the Palmer Divide Observatory (PDO) from 2009 March through June: 118 Peitho, 191 Kolga, 193 Ambrosia, 364 Isara, 521 Brixia, 1019 Strackea, 1025 Riema, 3266 Bernardus, 3873 Roddy, 3895 Earhart, 4483 Petofi, 4490 Bamberg, 4795 Kihara, (6250) 1991 VX1, 6493 Cathybennett, 6510 Tarry, 11789 Kempowski, 11976 Josephthurn, (13578) 1993 MK.

Observations of 19 asteroids were made at the Palmer Divide Observatory from 2009 March through June. One of four telescopes/camera combinations was used: 0.5m Ritchey-Chretien/SBIG STL-1001E, 0.35m SCT/FLI ProLine1001E, 0.35m SCT/ST-9E, or 0.35m SCT/STL-1001E. All images were 1x1 binning, resulting in a scale of approximately 1.2 arcseconds per pixel. All exposures were unfiltered and guided with exposures of 120–240 s. All images were processed and measured using *MPO Canopus* employing differential aperture photometry. Period analysis was also done using *MPO Canopus*, which incorporates the Fourier analysis algorithm developed by Harris (Harris et al., 1989).

The results are summarized in the table below, as are individual plots. The data and curves are presented without comment except when warranted. An “(H)” follows the name of an asteroid in the table if it is a member of the Hungaria group/family, which is a primary target of the PDO observing program. The plots are “phased”, i.e., they range from 0.0 to 1.0 of the stated period. Most of the plots are scaled such that 0.8 mag has the same linear size as the horizontal axis from 0.0 to 1.0. This is done to allow

direct comparison of amplitudes and to avoid the visual impression that the amplitude variation is greater than it actually is, which can create the impression of a physically implausible lightcurve. For low amplitude lightcurves, the scale has been expanded so that the curve is more than a nearly flat line. Even so, this was done as little as possible to avoid creating misleading interpretations. Night-to-night calibration of the data (generally $< \pm 0.05$ mag) was done using field stars converted to approximate Cousins R magnitudes based on 2MASS J-K colors (see Warner 2007 and Stephens 2008).

118 Peitho. Previous findings include Stanzel and Schober (1980, 7.78 h) and Behrend (2009, 7.8033 h). The data obtained at PDO fit a synodic period of 7.823 ± 0.002 h.

193 Kolga. This asteroid was chosen with the hope of resolving which, if any, of the previous solutions was the more likely. These include 27.8 h (Holliday, 2001), 13.7 h (Behrend, 2009), and 13.078 h (Gil-Hutton, 2003). Data at the PDO obtained on 5 nights over a week’s time fit a synodic period of 17.625 ± 0.004 h, or none of the above. Attempts to fit the data to the other periods failed decisively.

193 Ambrosia. The period of 6.580 ± 0.001 h found with PDO data agrees with that found by DeYoung and Schmidt (1996).

364 Isara. The period of 9.156 ± 0.001 h found at PDO agrees with that found by Yang (1965).

521 Brixia. The only previous period was > 24 h reported by Surdej et al. (1983). Unfortunately, the asteroid was not very cooperative for this campaign. Given the low amplitude of 0.11 ± 0.02 mag, it is not possible to say definitively if the solution should be monomodal or bimodal. Assuming the former, a period of 9.78 ± 0.02 h is found. If the bimodal solution is adopted, the period is 19.57 ± 0.02 h, with another possible solution at ~ 18.35 h. Plots of the first two periods are presented below. More data will be needed to solve this asteroid’s rotation rate.

1019 Strackea. Ivanova et al. (2002) found a period of 3.832 h with an amplitude of 0.31 mag. Behrend (2009) reports $P = 3.98$, $A = 0.17$. The former would seem to be conclusive given the amplitude and the 7 nights of data with several of them being

#	Name	mm/dd 2009	Data Pts	α	L_{PAB}	B_{PAB}	Per (h)	PE	Amp (mag)	AE
118	Peitho	05/07–05/14	400	20.8, 21.9	177	6	7.823	0.002	0.15	0.02
191	Kolga	05/07–05/14	319	15.2, 16.4	180	6	17.625	0.004	0.30	0.03
193	Ambrosia	04/10–04/21	450	17.5, 19.9	161	0	6.580	0.001	0.11	0.02
364	Isara	05/07–05/14	416	13.8, 16.1	198	7	9.156	0.001	0.37	0.02
521	Brixia	05/07–05/14	200	19.2	161	11	9.78/19.57	0.02	0.11	0.02
1019	Strackea (H)	04/20–04/22	155	30.1	244	38	4.044	0.002	0.15	0.01
1025	Riema (H)	05/28–05/30	93	26.0	283	34	3.566	0.003	0.11	0.02
3266	Bernardus (H)	03/22–04/07	232	21.5, 20.2	203	36	10.757	0.001	0.63	0.02
3873	Roddy (H)	06/16–06/23	203	9.9, 14.2	252	5	2.480	0.001	0.06	0.01
3895	Earhart	04/20–04/21	146	19.4	224	32	3.564	0.001	0.28	0.02
4483	Petofi (H)	03/28–04/01	124	22.9, 24.0	148	-15	4.334	0.001	0.86	0.02
4490	Bamberg (H)	03/28–04/07	170	23.5, 22.1	221	34	5.823	0.001	1.16	0.02
4795	Kihara	04/23–05/14	249	6.0, 16.3	208	7	16.03	0.01	0.25	0.02
6250	1991 VX1 (H)	05/28–06/24	207	8.4, 22.0	239	10	82.6	0.5	0.78	0.05
6493	Cathybennett (H)	05/28–05/30	114	20.5	261	32	3.490	0.005	0.19	0.02
6510	Tarry	04/21–04/22	187	17.8	205	26	6.370	0.003	0.50	0.02
11789	Kempowski (H)	04/21–04/30	260	16.6, 19.9	193	14	48.6	0.5	>0.4	
11976	Josephthurn (H)	04/22–04/30	105	2.6	216	0	3.50	0.01	0.08	0.02
13578	1993 MK (H)	05/28–05/30	152	17.2	246	27	7.95	0.03	0.15	0.03

Table I. Observing circumstances. The phase angle is given at the start and end of each date range, unless it reached a minimum, which is then the second of three values. If a single value is given, the phase angle did not change significantly and the average value is given. L_{PAB} and B_{PAB} are each the average phase angle bisector longitude and latitude, unless two values are given (first/last date in range).

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consecutive. However, the PDO data, also on contiguous dates, cannot be fit to that period, but instead give a best fit with a period of 4.044 ± 0.002 h. The period spectrum for the PDO data (see below) shows a very weak solution at 3.84 h, close to that of Ivanova et al. More data will be needed for this asteroid as well to solve the conundrum.

1025 Riema. Schevchenko et al. (2003) reported a period of 6.557 h for this Hungaria asteroid. Stephens (2003) found 3.580 h. The PDO data support the shorter period.

3873 Roddy. The author worked this asteroid in late 2005 (Warner, 2006) and found a period of 2.4782 h. There were hints of mutual events (occultations or eclipses in a binary system). There were no such indications in 2009. The phase angle bisector longitudes differed by $\sim 138^\circ$ for the two apparitions. It's possible, but not considered likely, that the different aspect in 2009 prevented seeing such events. However, further follow-up is recommended, just in case.

4483 Petofi. The period for this asteroid is well-established (see Warner et al., 2009, for several references). The PDO data affirmed the period by finding $P = 4.334 \pm 0.001$ h.

4490 Bamberg. The author worked this asteroid in 2006 (Warner, 2006). The 2009 apparition was used to build the data set for shape and spin axis modeling. The period found with the 2009 data, $P = 5.823 \pm 0.001$ h, is in excellent agreement with the previously found period of $P = 5.815$ h.

(6250) 1991 VX1. The approximate period for a tumbling damping time equal to the age of the Solar System for this asteroid is 78 h; therefore, the derived period of 82.6 ± 0.5 h would make this a good candidate to be tumbling (see Pravec et al., 2005, for more on damping time and tumbling, or non-principal axis rotation). However, the symmetry of the curve's overall shape and maxima and minima show no outward indication of tumbling. Unfortunately a combination of prolonged bad weather, a waxing moon, and rapidly fading asteroid prevented obtaining additional data.

11789 Kempowski. Review of the individual sessions in combination with the Fourier analysis in *MPO Canopus*, favors a period of 48.6 ± 0.5 h for this Hungaria asteroid. A solution of ~ 24.2 h cannot be formally excluded, however.

11976 Josephthurn. The low amplitude led to several solutions. A period of 3.50 ± 0.01 h produced the most symmetrical bimodal solution, although one at ~ 4.89 h had a lower RMS error. A search of possible half-periods, which would be a monomodal curve, favored a period of 1.75 h (and definitely shied away from a half-period of 2.45 h), lending support to the 3.5 h solution. The 1.75 h period is well below the so-called "spin barrier", which – if true – would mean that the asteroid could not be a rubble pile and, given its size ($D \sim 4.5$ km), that it would likely break apart even if a monolith. So, the 3.5 h period is the more likely of the two. That still does not preclude a longer period with a more complex curve.

(13578) 1993 MK. The author previously reported the period to be 7.924 h (Warner, 2008). The 2009 apparition data are in fair agreement, yielding a period of 7.95 ± 0.03 h. The 2008 data set was more extensive and covered a longer span of time, thus allowing a greater precision and higher accuracy.

Acknowledgements

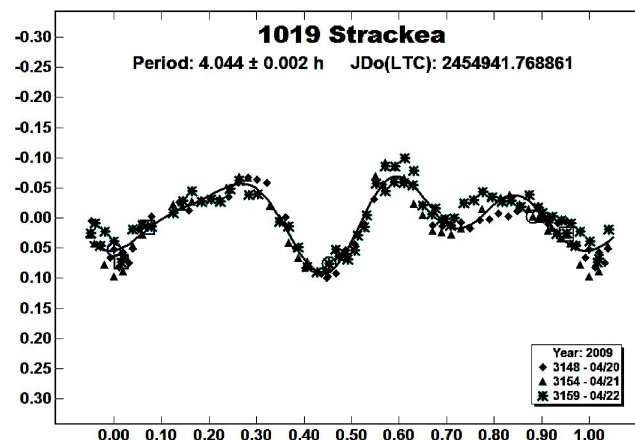
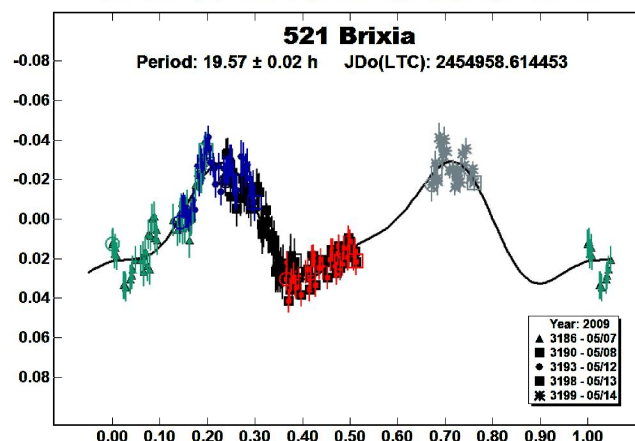
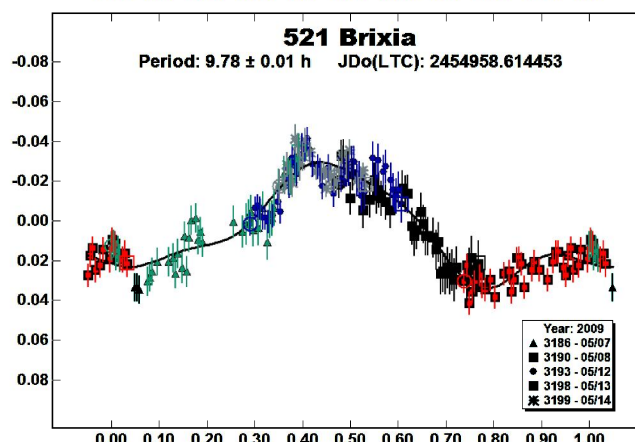
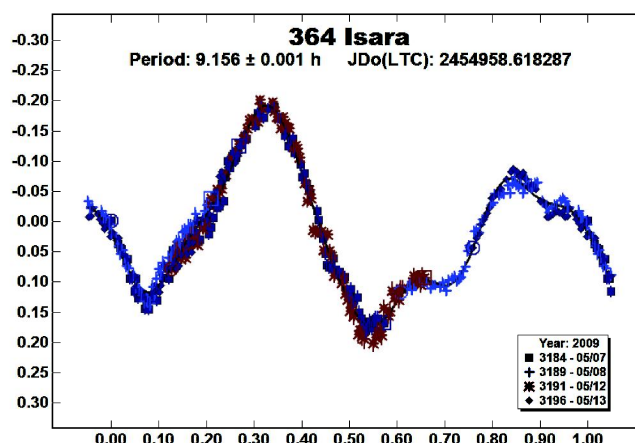
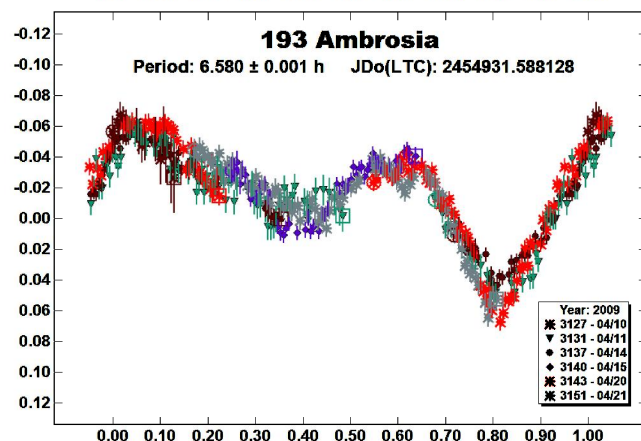
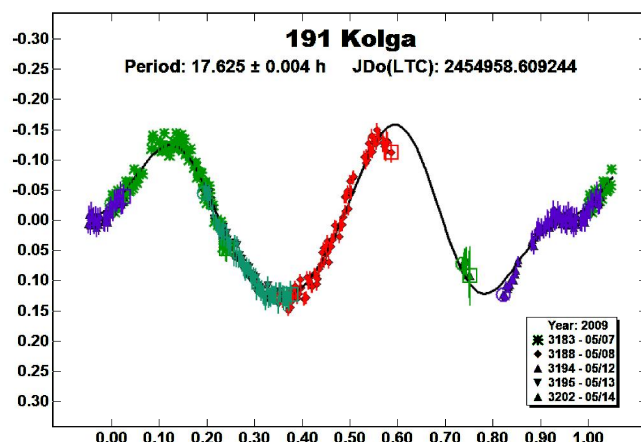
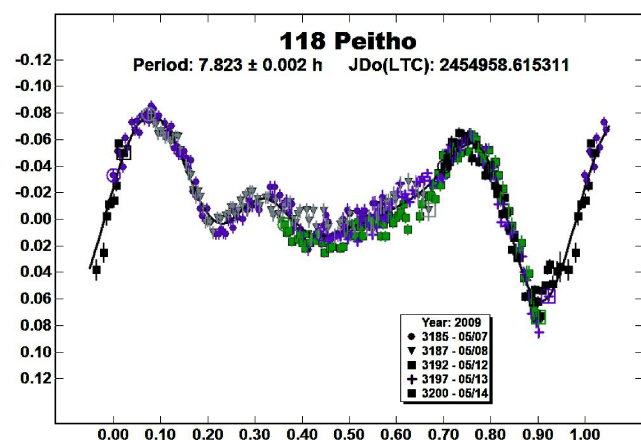
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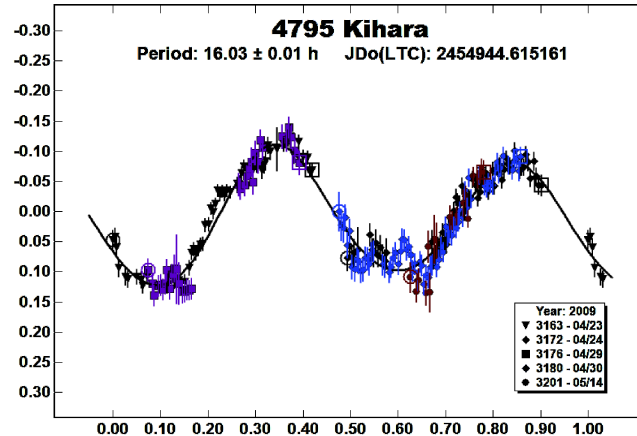
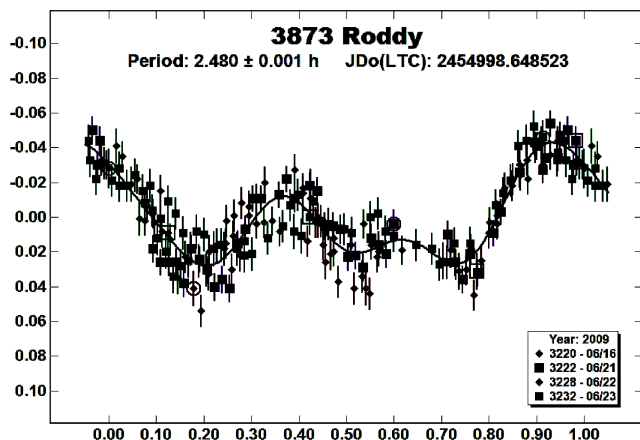
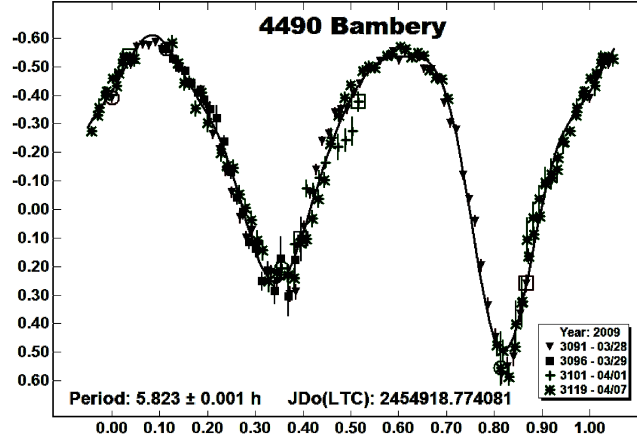
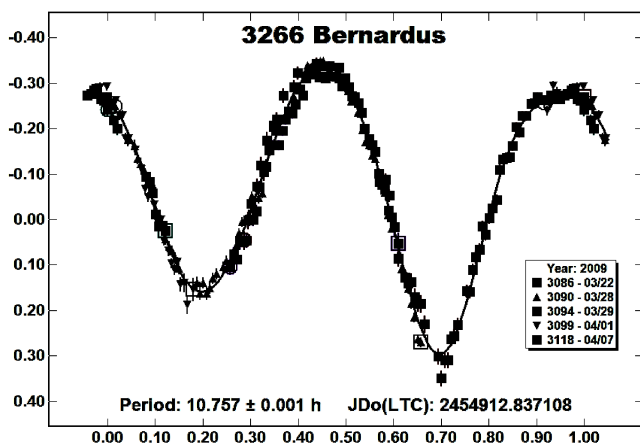
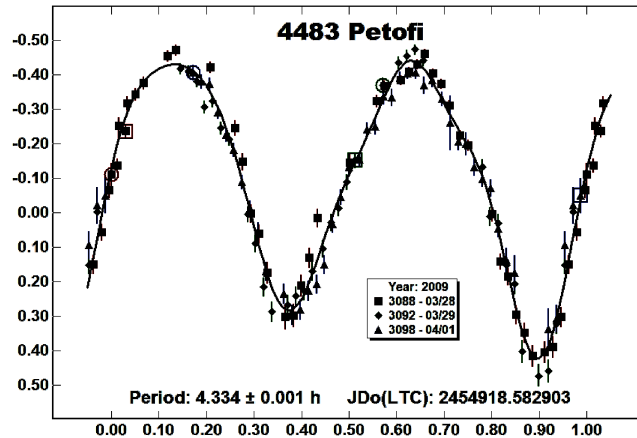
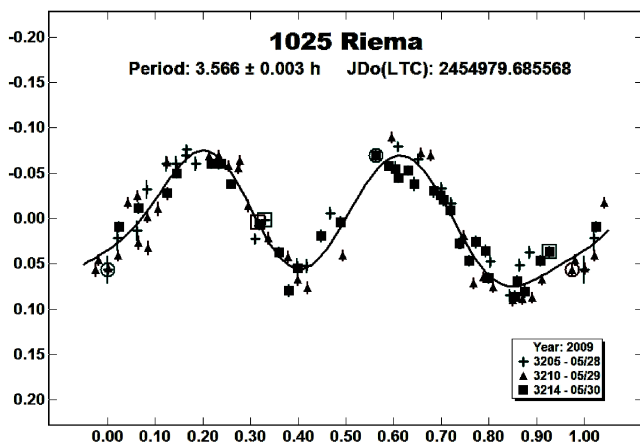
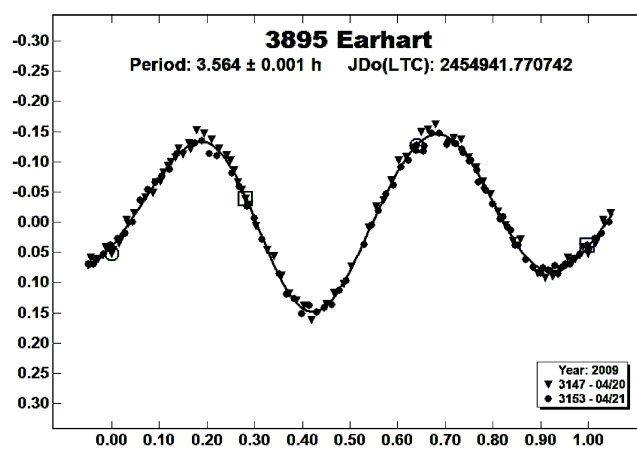
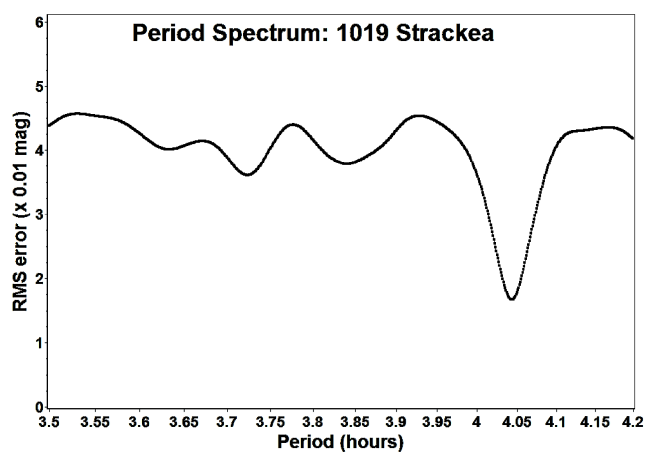
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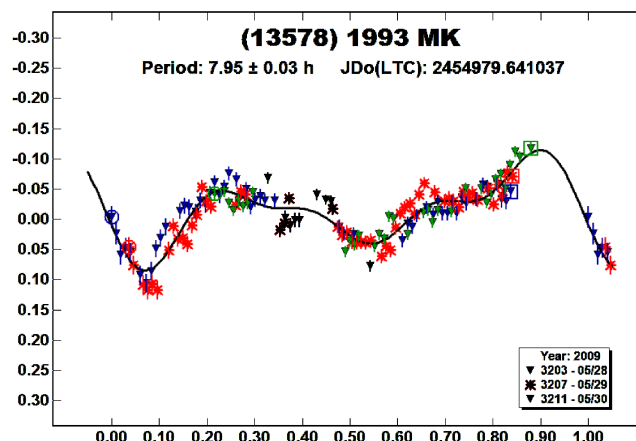
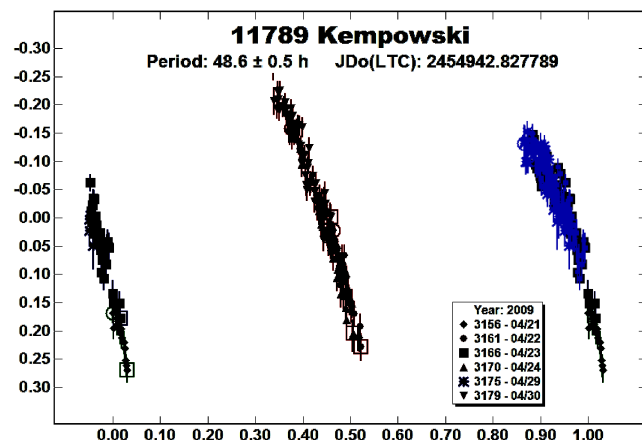
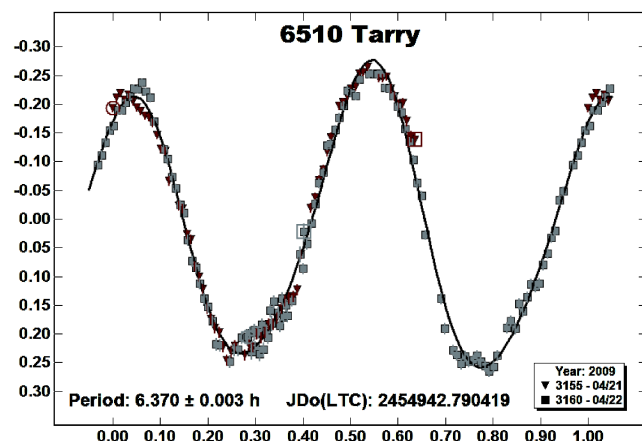
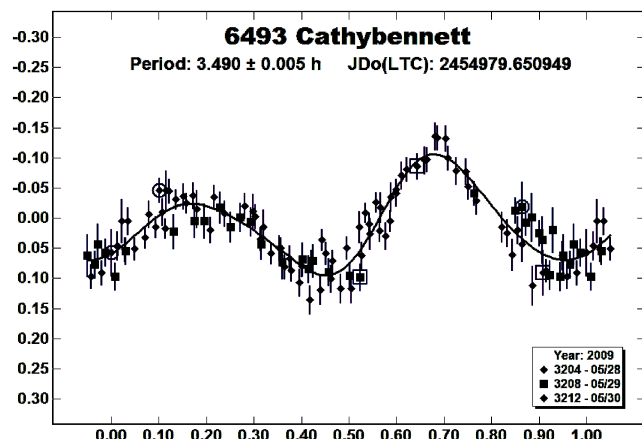
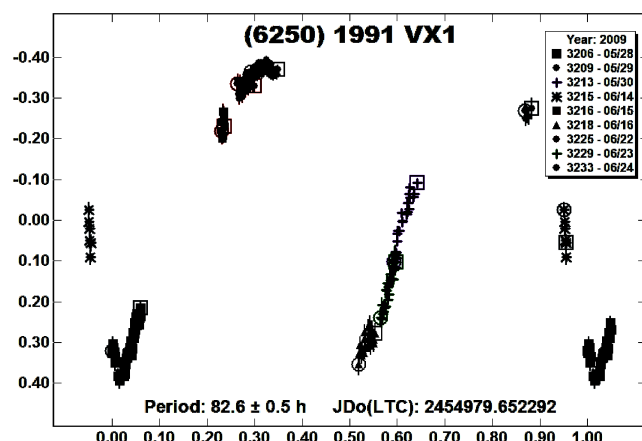
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A RE-EXAMINATION OF THE LIGHTCURVES FOR SEVEN HUNGARIA ASTEROIDS

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During the course of a study of long period asteroids ($f < 1 \text{ d}^{-1}$) within the Hungaria asteroid population, the lightcurves for seven asteroids were re-examined using updated software and techniques. Several were found to have significantly different periods from those previously reported by two of the authors (Warner and Stephens). The most significant change was 2074 Shoemaker, which was initially reported to have a period of 57 h but now appears to be a binary asteroid with a primary period of $2.5328 \pm 0.0004 \text{ h}$ and a possible orbital period of $55.52 \pm 0.01 \text{ h}$. The other asteroids that were re-examined were 1919 Clemence, 3043 San Diego, 3353 Jarvis, 4142 Dersu-Uzala, (20232) 1997 YK, and (101549) 1998 YY2. The re-examination showed once again the importance of placing data on at least an internal system to achieve accurate night-to-night calibrations.

Authors Warner and Harris have conducted a concentrated study on the Hungaria population of asteroids since 2004 with one result being the determination of lightcurve parameters for approximately 130 Hungaria members and the discovery of no less than 7 binary asteroids. Analysis of the rotation rates shows strong excess of “slow rotators”, i.e., those with a period $> 24 \text{ h}$ (or