

ASTEROID LIGHTCURVE ANALYSIS AT THE PALMER DIVIDE OBSERVATORY: 2009 SEPTEMBER–DECEMBER

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Lightcurves for 26 asteroids were obtained at the Palmer Divide Observatory (PDO) from 2009 September through December: 298 Baptistina, 546 Herodias, 1355 Magoeba, 1626 Sadeya, 1750 Eckert, 2001 Einstein, 2083 Smither, 3086 Kalbaugh, 4125 Lew Allen, 4531 Asara, 4736 Johnwood, 5230 Asahina, 5841 Stone, 6141 Durdá, (6444) 1989 WW, 9739 Powell, 16669 Rionuevo, 24654 Fossett, (29242) 1992 HB₄, (29308) 1993 UF₁, (31850) 2000 EB₂₂, (37634) 1993 UZ, (38047) 1998 TC₃, (40203) 1998 SP₂₇, (218144) 2002 RL₆₆, and NEA 2009 XR₂. In addition, data for 1355 Magoeba from 2006 were re-analyzed. The periods derived from the 2006 and 2009 apparitions cannot be reconciled. The solution based on the 2009 data has been adopted as the one more likely correct. For four of the asteroids, 2001 Einstein, 3086 Kalbaugh, 4736 Johnwood, and 5841 Stone, the 2009 data were combined with those from earlier apparitions to derive spin axis and shape models.

CCD photometric observations of 26 asteroids were made at the Palmer Divide Observatory (PDO) from 2009 September through December. See the introduction in Warner (2009c) for a discussion of equipment, analysis software and methods, and overview of the plot scaling.

298 Baptistina. The period for the prototype of the family of the same name had been previously reported at 7 h (Wisniewski 1997) and 9.301 h (Ditteon 2007). Observations in 2008 by Majaess et al. (2009) found a period of 16.23 h, which was confirmed by the observations made in late 2009 at PDO.

546 Herodias. Szekely et al. (2005) found a period of 10.4 h, though it was “fairly uncertain”, mostly due to a low amplitude. The data from PDO led to a period close to theirs: 10.77 ± 0.01 h.

1355 Magoeba. The author previously reported a period of 32.9 h (Warner 2007a). The data from the 2009 apparition gave a very different result of 5.946 h. This prompted re-measuring the original images from 2006 using the 2MASS to BVRI conversions to link the several nights (see Warner 2007c). The results were different, 31.65 ± 0.05 h, but not significantly so. Given the longer runs during the 2009 apparition and the fact that they were on successive nights, it's believed that the shorter period (5.946 h) should be adopted as being more likely correct.

1626 Sadeya. Previous works by Florczak (1997), Oey (2008), and Behrend (2009) all reported a period of about 3.4 h, the same as found with the PDO data.

1750 Eckert. This asteroid shows definite signs of being in non-principal axis rotation (NPAR, tumbling). The object was followed long enough to go through a second cycle, when the lightcurve did not repeat itself. The approximate tumbling

damping time for a period of 375 h and the estimated diameter $D = 5.7$ km is well in excess of the age of the Solar System. See Pravec et al. (2005) for a discussion of damping times and tumbling.

2001 Einstein. This Hungaria member was observed by the author in 2004 and 2008 (see Warner 2005 and 2008b). The data from the three apparitions were combined with sparse data from the Catalina Sky Survey (CSS, MPC 703) to find a shape and spin axis model. See the discussion below.

2083 Smither. A period of 2.676 h was previously reported by the author (Warner 2007a). In 2009, the period was found to be 2.6717 ± 0.0005 h. There were a few minor deviations on three nights that could be “removed” by subtracting out a period of 30.09 h. However, these were too insignificant to give them credence and so their cause remains unexplained. The plot for this curve shows the data after the subtraction if for no other reason than to present a slightly “cleaner” curve.

3086 Kalbaugh. This Hungaria member was observed for the third time by the author with the intent of finding a shape and spin axis model (see Warner 2005 and 2008a). The results of the modeling are discussed below.

4125 Lew Allen. This is the second time this Hungaria member was observed by the author. The first time (Warner 2007b) the period was found to be 4.628 h with an amplitude of 0.20 mag. The period from 2009 is 4.625 h but with an amplitude of 0.46 mag, giving hope that a shape and spin axis model might be possible with data from another apparition.

4736 Johnwood. This is the third Hungaria observed for spin axis and shape modeling. It was previously observed by the author in early 2005 (Warner 2005). The modeling results, discussed below, were not as definitive as for 2001 Einstein and 3086 Kalbaugh but better than those for 5841 Stone.

5230 Asahina. The tumbling damping time for this asteroid and the period of 89.3 h is on the order of 3 Gy. In which case, it would seem likely to find some traces of the asteroid being in non-principal axis rotation (NPAR). However, no such indications were seen when portions of the lightcurve were covered a second time. Either the object is not tumbling at all or it is doing so only very slightly and so the variations in the lightcurve are hidden within the errors of the night-to-night calibrations.

5841 Stone. This Hungaria was observed in 2006 by the author (Warner 2007a). In both cases, a period of 2.89 h was found. Despite having data from only two apparitions, an attempt was made to model the asteroid by adding sparse data from the Catalina Sky Survey. The results are outlined below.

6141 Durdá. The tumbling damping time for the period of 460 h found for this asteroid exceeds the age of the Universe by many times. There were no obvious signs of NPAR, however it was not possible to cover the lightcurve completely even once, let alone a second time to see if there were any variations due to tumbling.

9739 Powell. This Hungaria was observed by the author in 2006 (Warner 2007a). At that time, a period of 18.2 h was reported, with an alternate of 36.5 h being possible. The 2009 data lead to a period of 16.7 h, assuming a monomodal curve. Given the amplitude of only 0.11 mag, this is not an unreasonable assumption, although a period of 33.5 h with bimodal curve cannot be formally excluded. The data from the 2006 apparition

could not be made to fit the shorter period. With the improvement in night-to-night data linking in recent versions of *MPO Canopus*, the new period of 16.7 h (or 33.5 h) is preferred.

(218144) 2002 RL66. The period of 616 h and estimated diameter $D = 3.4$ km for this Mars-crosser make it a likely candidate for being a “tumbler.” However, no signs of such were seen. Here, too, it was not possible to cover the entire lightcurve to confirm that it did or did not repeat itself from one cycle to the next.

Shape and Spin Axis Modeling

While finding a shape model provides a more graphic result, finding the orientation of the spin axis is more important in many cases. For one, determining the sense of rotation, prograde or retrograde, lends support to theories about Yarkovsky drift. This effect is the result of thermal re-radiation of sunlight by an asteroid such that the semi-major axis increases over time if the asteroid is in prograde rotation and decreases if in retrograde motion.

A sample of Yarkovsky drift is shown in Fig. 1, which shows a subset of members of the Hungaria family plotted with absolute magnitude (H) versus semi-major axis (a). If the drift were due only to the impetus received at the collision that formed the family, the spread in a would be very small, as shown by the vertical green line. Instead, one sees a “V” shape that grows wider with larger H (smaller diameter). This is as expected since the thermal push is stronger for smaller asteroids. Asteroids to the left of the vertical line are expected to be in retrograde rotation while those to the right should be in prograde rotation. See Warner et al. (2009b) and references therein for a more detailed discussion of this effect and the Hungaria population.

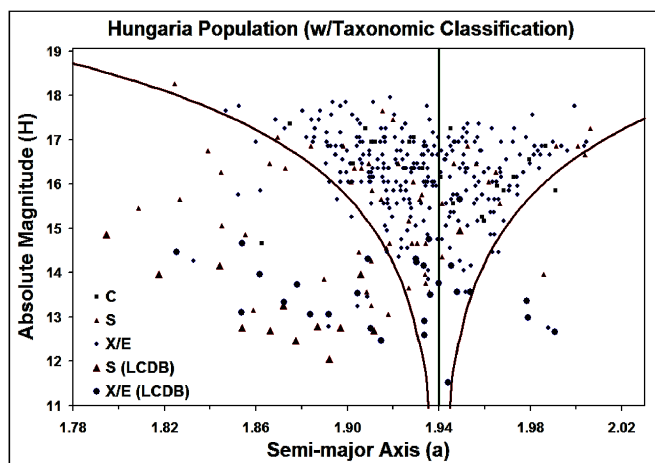


Figure 1. A plot of Hungaria population members with taxonomic classification. The “V” defines the dynamical Hungaria family with Yarkovsky spreading. The vertical green line defines the family if only collisional spreading were involved. From Warner et al. (2009b).

In the pole search plots that follow, blue represents lower values of ChiSq, i.e., the “more probable” solutions. Red represents the “worst” solutions. These plots were produced by *MPO LCInvert* (written by the author). For a discussion of shape modeling and pole searches, see Higley et al. (2008) and references therein.

2001 Einstein. The pole search plot (Fig. 2) shows a definite bias towards negative values of beta (latitude), indicating the asteroid is in retrograde rotation. A check of its H - a parameters ($H =$

12.85, $a = 1.9332$) shows that, as expected, the asteroid lies to the left of the vertical line in Fig. 1.

The “brick-like” appearance (Fig. 3) is the result of inversion method that results in large flat areas representing significant concavities. It’s possible that the true shape in this case is a bi-lobed object, i.e., something similar to a dumbbell. The large amplitude of the lightcurve at different viewing aspects supports the asteroid being highly elongated.

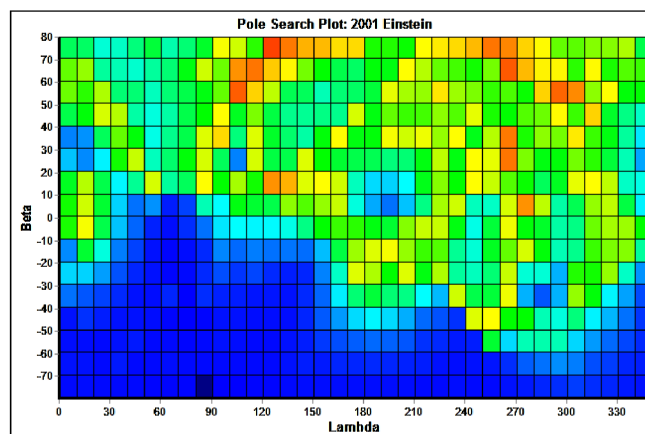


Figure 2. The pole search results for 2001 Einstein. See the text for an explanation of the color-coding.

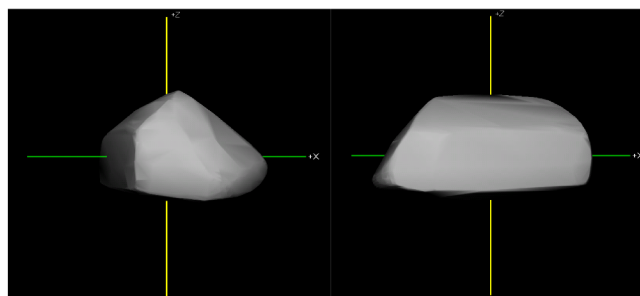


Figure 3. The asteroid equatorial view of 2001 Einstein at $Z = 0^\circ$ and $Z = 90^\circ$.

3086 Kalbaugh. This Hungaria’s pole search plot (Fig. 4) also shows that it is very likely in retrograde motion. The H - a parameters ($H = 13.6$, $a = 1.9356$) place it to the left of the center line of the “V” in Figure 1.

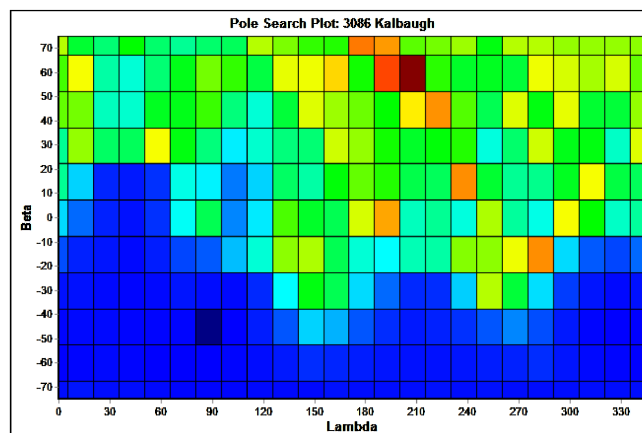


Figure 4. The pole search plot for 3086 Kalbaugh.

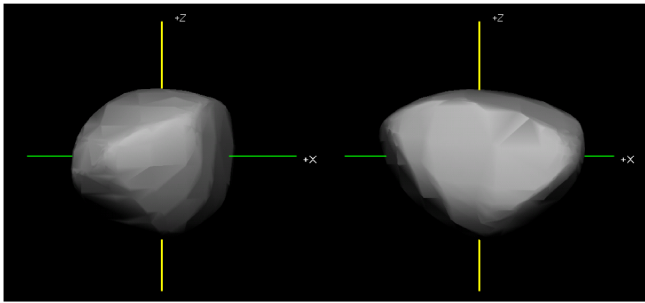


Figure 5. The asteroid equatorial view of 3086 Kalbaugh at $Z = 0^\circ$ and $Z = 90^\circ$.

4736 Johnwood. The pole search plot (Fig. 6) favors prograde motion, which is also indicated by the H - a parameters ($H = 13.5$, $a = 1.9576$). This is the most that can be determined with the available data. All the shape models showed rotation about the longest axis of the asteroid instead of the shortest, which is physically improbable.

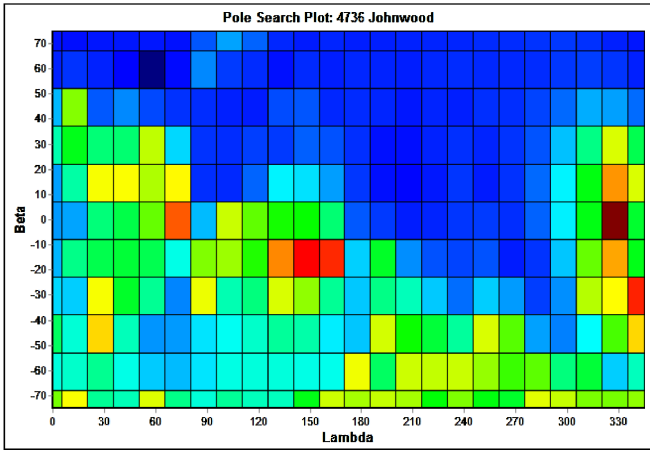


Figure 6 The pole search plot for 4736 Johnwood.

5841 Stone. This is a case of too little, too soon. The pole search plot (Fig. 7) shows only a very small region of “better” solutions, those being near $(180^\circ, 0^\circ)$. This does make some sense in light of the low amplitude of the lightcurve at viewing angles that differ by 90° and if one presumes a nearly spheroidal shape, as seen in Figure 8. A check of the H - a parameters ($H = 13.9$, $a = 1.9258$) shows that the asteroid should be in retrograde motion. The current model is inconclusive on that account. Data from future apparitions may (or may not) resolve the issue.

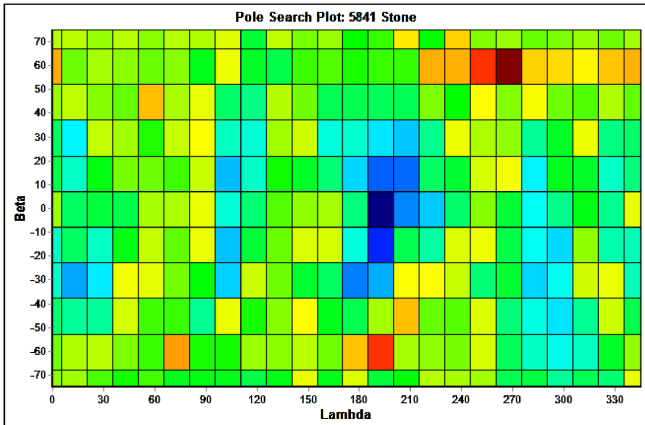


Figure 7. The pole search plot for 5841 Stone.

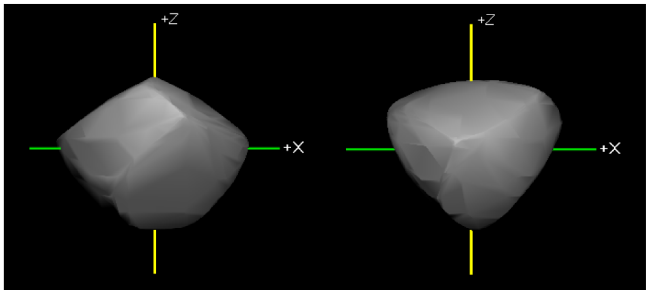


Figure 8. The asteroid equatorial view of 5841 Stone at $Z = 0^\circ$ and $Z = 90^\circ$.

Asteroid	Pole (Long,Lat)	Sidereal Per (h)
2001	(90, -70)	5.48503 ± 0.00002
3086	(90, -45)	5.17910 ± 0.00002
4736	(60, +60)	6.21576 ± 0.00003
5841	(195, +0)	2.889026 ± 0.000006

Table I. The pole is the ecliptic longitude and latitude of the “best” solution. The error is generally a circle with a 15° radius centered on the given position. The period error corresponds to a 10° rotation error over the duration of the data set.

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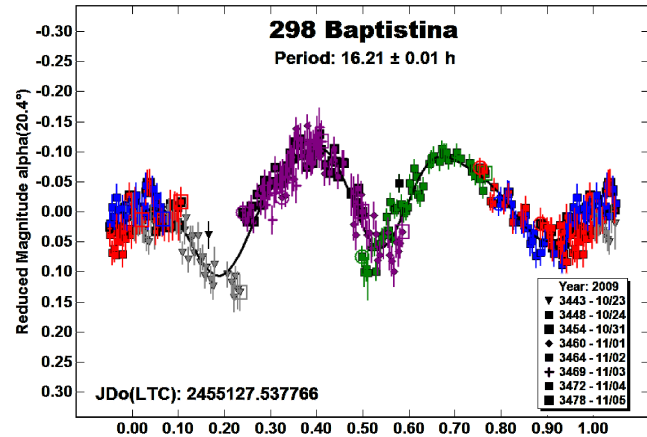
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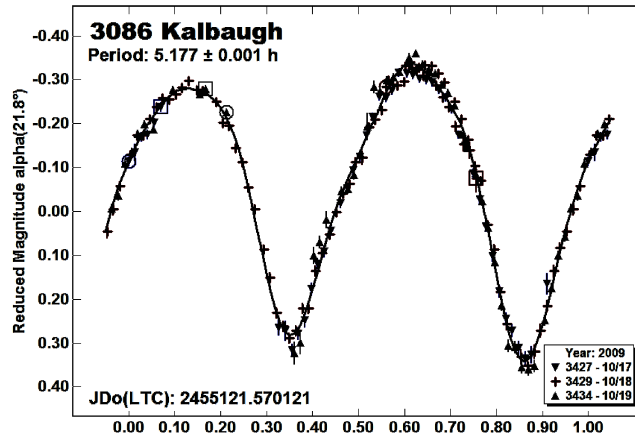
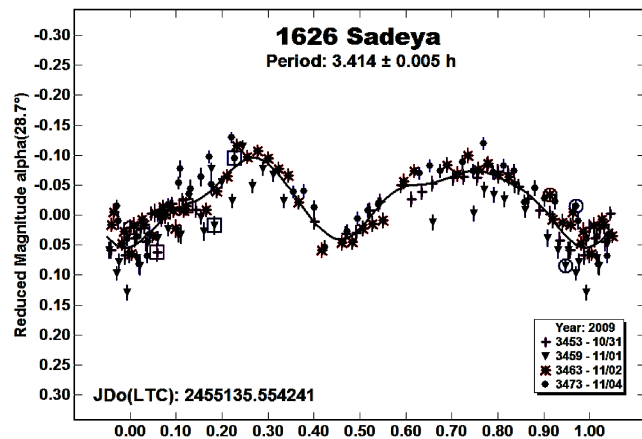
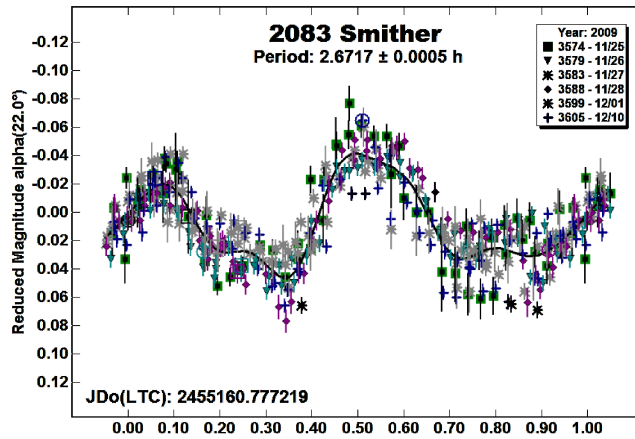
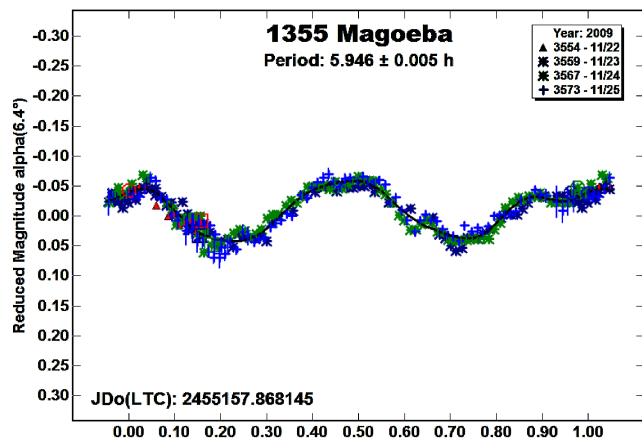
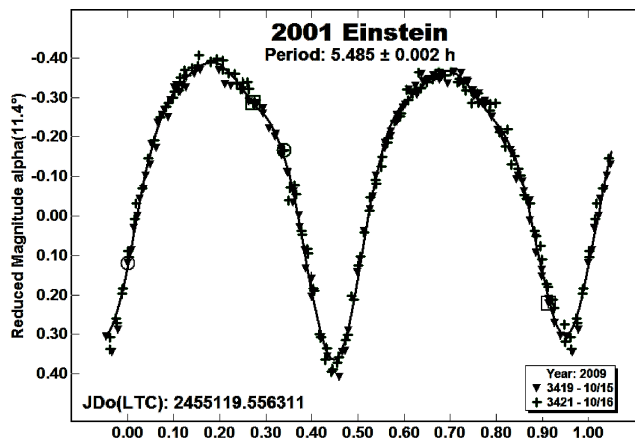
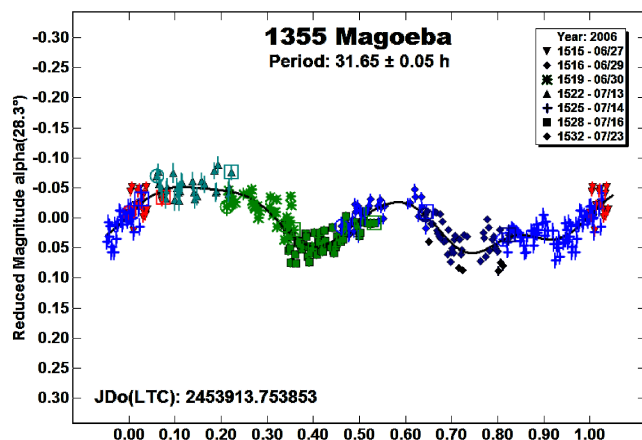
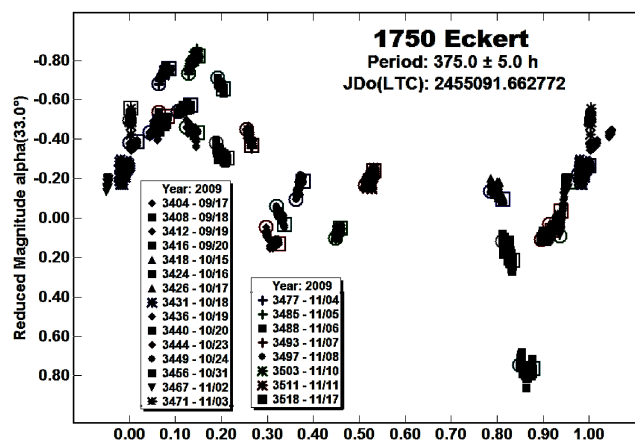
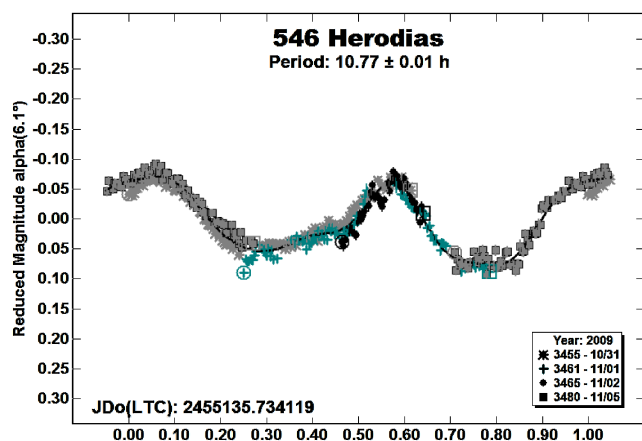
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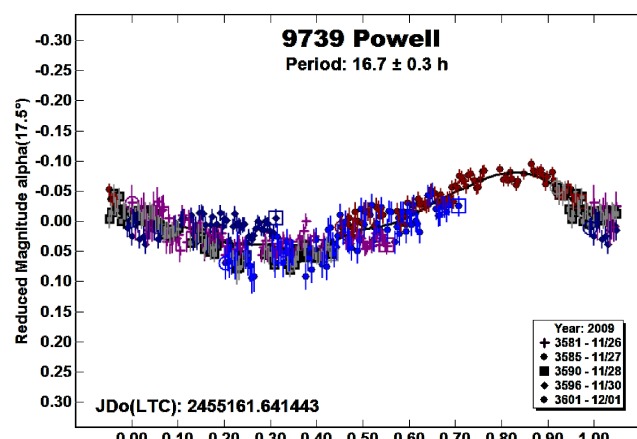
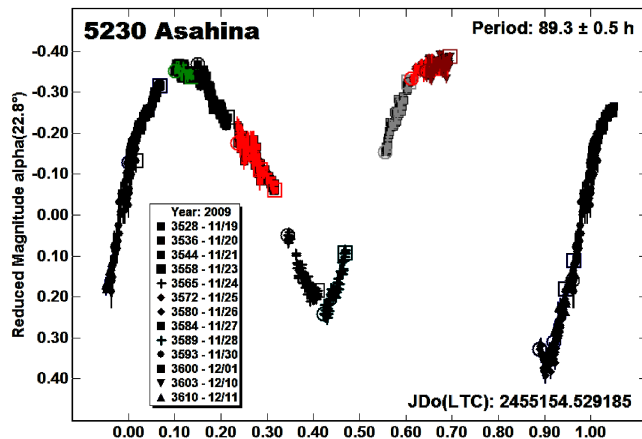
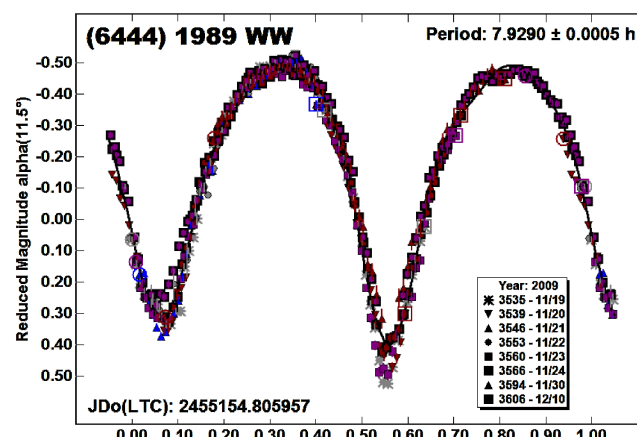
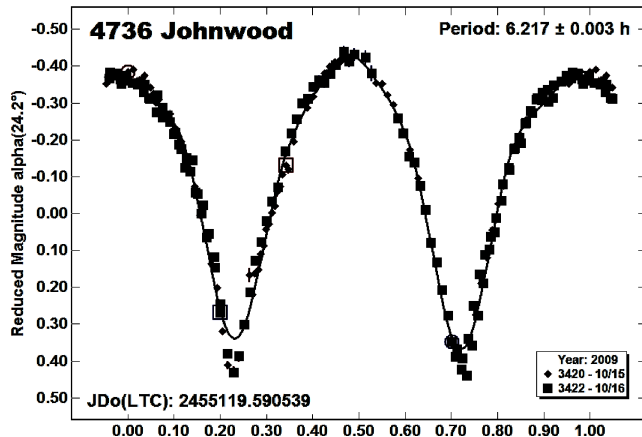
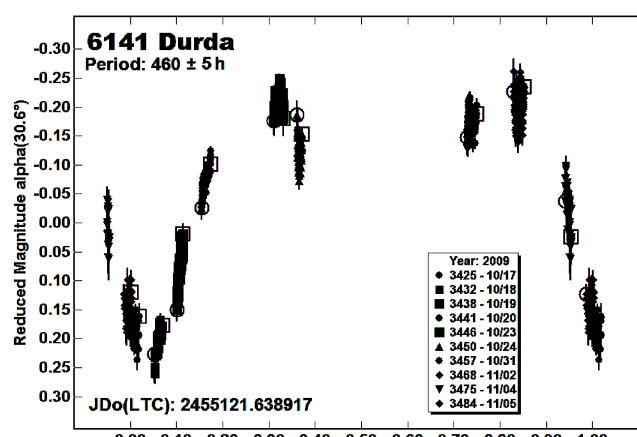
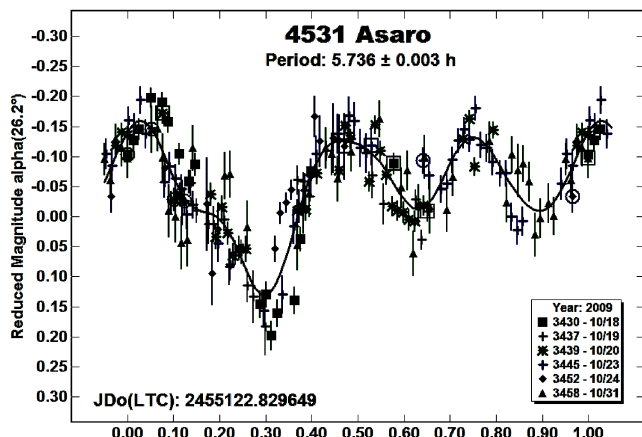
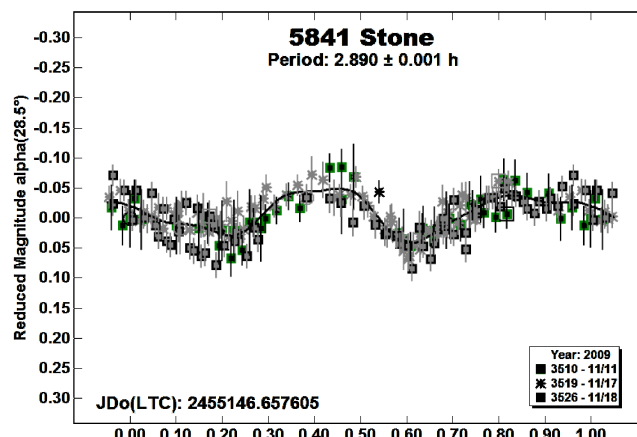
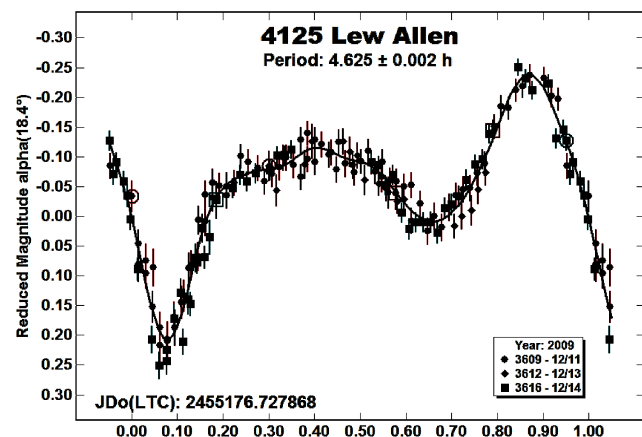


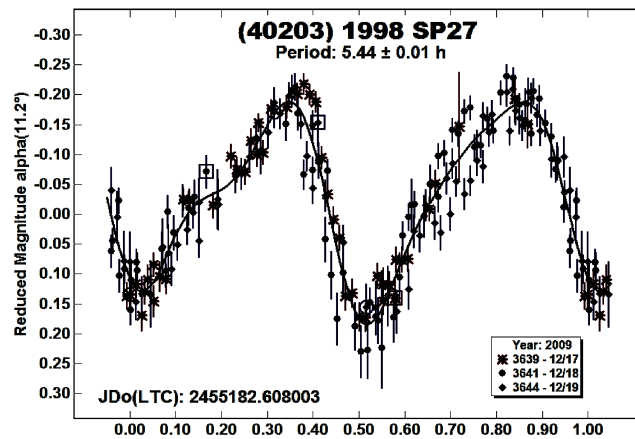
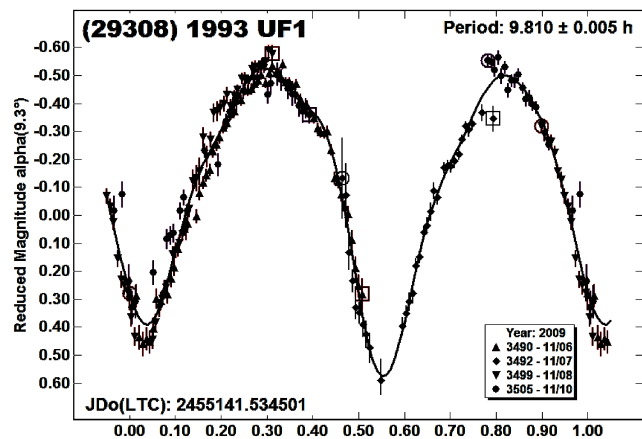
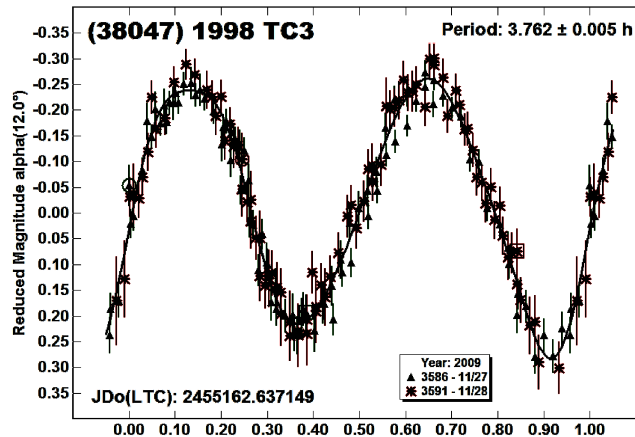
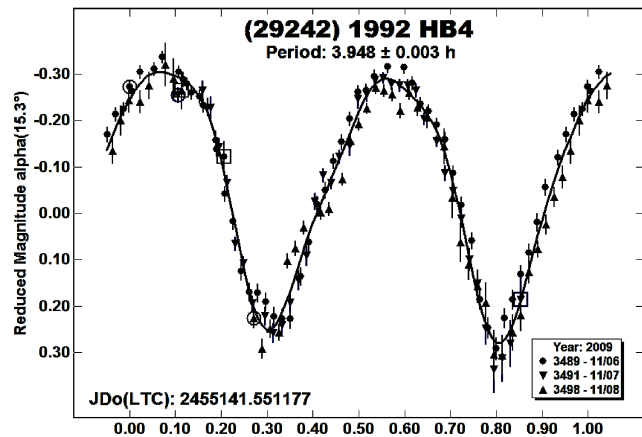
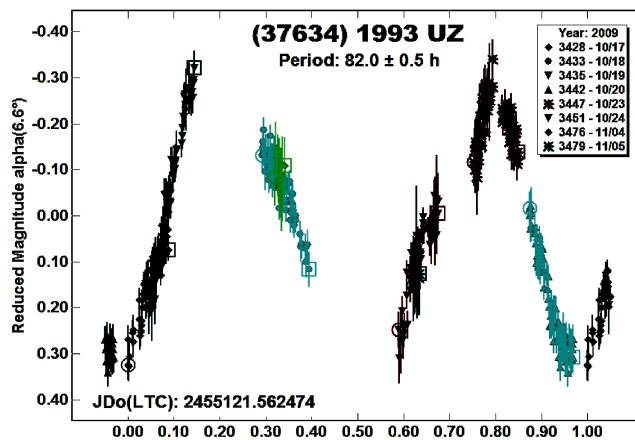
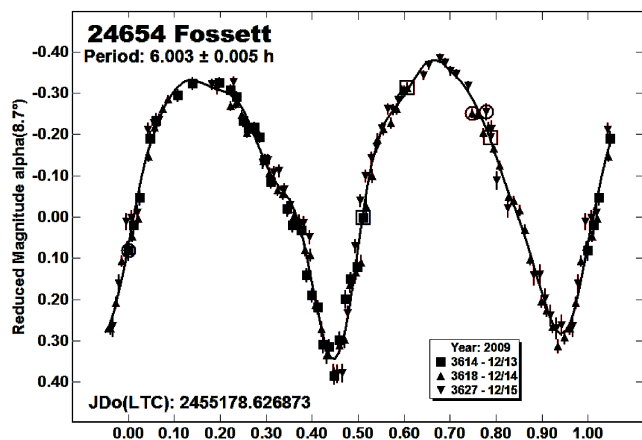
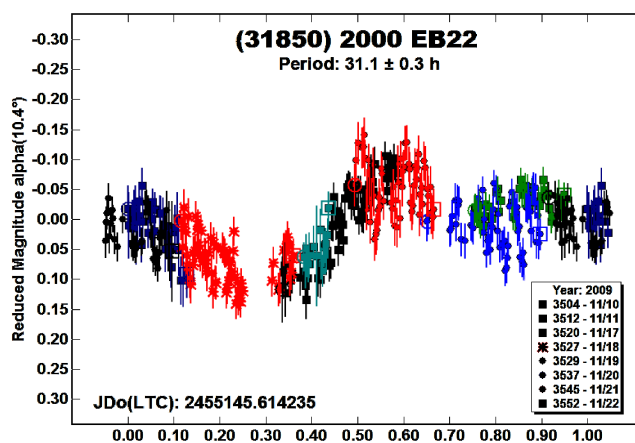
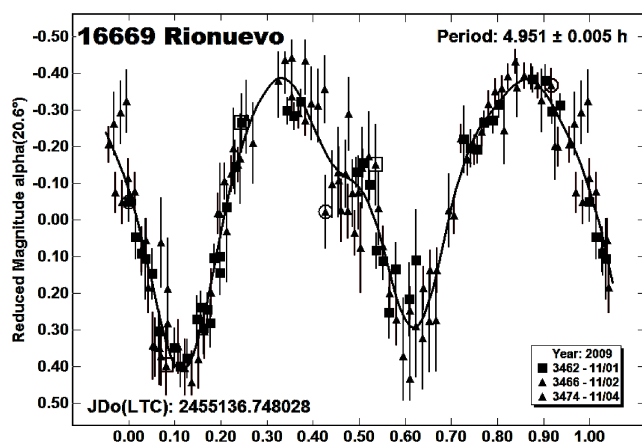
#	Name	mm/dd 2009	Data Pts	α	L _{PAB}	B _{PAB}	Per (h)	PE	Amp (mag)	AE
298	Baptistina	10/23-11/05	306	20.1, 22.4	343	-2	16.21	0.01	0.25	0.02
546	Herodias	10/31-11/05	387	6.5, 5.0	48	8	10.77	0.01	0.18	0.02
1355	Magoeba (H)	11/22-11/25	259	5.7, 7.2	56	-8	5.946	0.005	0.12	0.01
1355	Magoeba (H)	06/27-07/23*	300	28.4, 24.1	315	32	31.65	0.05	0.10	0.01
1626	Sadeya	10/31-11/04	172	28.7	338	29	3.414	0.005	0.19	0.02
1750	Eckert (H)	09/17-11/17	1764	33.2, 21.9	35	26	375	5	0.87	0.05
2001	Einstein	10/15-10/16	237	11.5	31	17	5.485	0.002	0.74	0.02
2083	Smither (H)	11/25-12/10	396	22.6, 15.0	97	-4	2.6717/30.09	0.0005	0.09	0.01
3086	Kalbaugh (H)	10/17-10/19	176	21.6	356	24	5.177	0.001	0.66	0.02
4125	Lew Allen (H)	12/11-12/13	102	18.5	114	-4	4.625	0.002	0.44	0.02
4531	Asaro (H)	10/18-10/31	177	26.4, 22.8	65	22	5.736	0.003	0.29	0.03
4736	Johnwood (H)	10/15-10/16	187	24.1	20	33	6.217	0.003	0.84	0.02
5230	Asahina	11/19-12/11	782	22.0, 31.8	31	-15	89.3	0.5	0.67	0.05
5841	Stone (H)	11/11-11/18	192	28.8, 27.1	86	29	2.890	0.001	0.10	0.01
6141	Durda (H)	10/17-11/05	684	30.9, 24.2	59	23	460	5	0.50	0.03
6444	1989 WW	11/19-12/10	507	12.3, 3.0, 4.1	73	-4	7.9290	0.0005	0.98	0.03
9739	Powell (H)	11/26-12/01	420	18.1, 15.6	89	13	16.7/33.5	0.3	0.11	0.01
16669	Rionuevo (H)	11/01-11/04	137	21.3, 19.6	68	-7	4.951	0.005	0.73	0.03
24654	Fossett (H)	12/13-12/15	139	9.0, 8.5	89	10	6.003	0.005	0.74	0.02
29242	1992 HB4 (H)	11/06-11/08	139	14.4, 15.7	24	0	3.948	0.003	0.58	0.02
29308	1993 UF1 (H)	11/06-11/10	198	8.3, 11.1	32	1	9.810	0.005	0.94	0.02
31850	2000 EB22 (H)	11/10-11/22	392	9.5, 16.8	37	9	31.1	0.3	0.20	0.05
37634	1993 UZ (H)	10/17-11/05	426	6.6, 15.4	20	6	82.0	0.5	0.70	0.05
38047	1998 TC3 (H)	11/27-11/28	182	12.6, 12.1	82	9	3.762	0.005	0.54	0.02
40203	1998 SP27 (H)	12/17-12/19	188	10.9, 11.3	85	14	5.44	0.01	0.37	0.02
218144	2002 RL66	11/18-12/11	1162	27.3, 28.4	79	30	616	10	0.34	0.03
	2009 XR2	12/15-12/17	184	25.0, 18.9	90	12	5.828	0.005	0.88	0.05

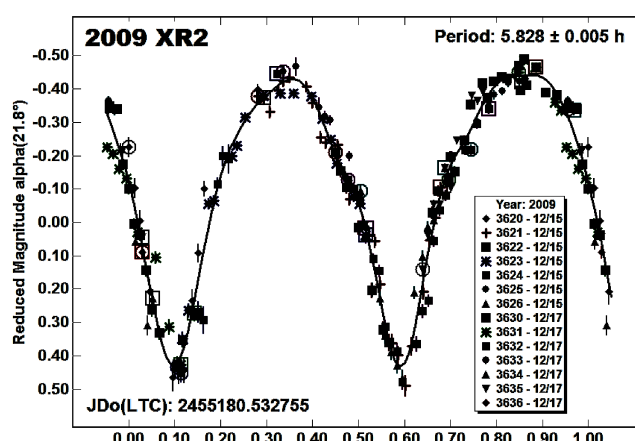
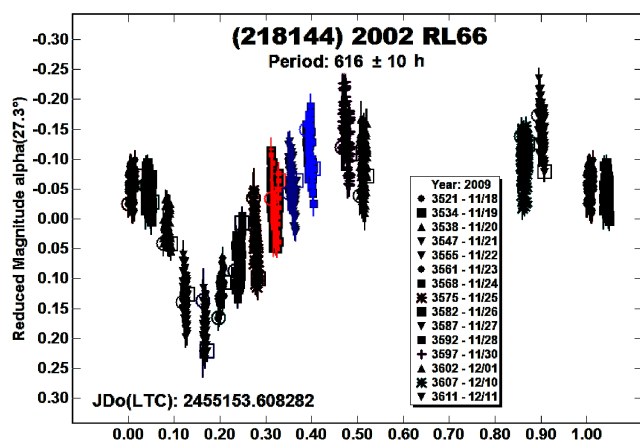
* 2006 observations

Table II. Observing circumstances and results summary. 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).









PERIOD DETERMINATIONS FOR 1131 PORZIA AND 1819 LAPUTA

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Lightcurve analyses for 1131 Porzia and 1819 Laputa are reported. The synodic rotation period and lightcurve amplitude values are, respectively: 4.6584 ± 0.0005 h, 0.15 ± 0.02 mag; 9.8004 ± 0.0002 h, 0.51 ± 0.03 mag.

Unfiltered CCD photometric observations of two minor planets, 1131 Porzia and 1819 Laputa, were made at the Belgrade Astronomical Observatory during 2009 in order to determine their synodic rotation periods. A 0.4-m Meade LX-200 GPS Schmidt-Cassegrain telescope operating at f/10 was coupled with an unguided SBIG ST-10 XME CCD in the case of 1131 Porzia. An Apogee AP47p CCD was used on 1819 Laputa. *MPO Canopus* software (BDW Publishing) was used for the photometric reductions and period analysis. Both asteroids were selected from the lists of the potential lightcurve targets on the Collaborative Asteroid Lightcurve Link (CALL) web-site (Warner and Harris, 2009a; 2009b).

1131 Porzia. Prior to this work only one reference on rotation period determination for this Mars-crossing asteroid had been published. Wisniewski et al. (1995) reported a value for the period of 4.0 hours. Since it was marked with an uncertainty of $U = 2$ on the CALL web-site (see Warner et al. 2009c, for an explanation of the U code system), the reported period was likely still uncertain. This degree of uncertainty and the fact that the period was given to only one significant figure were the reasons for observing the asteroid. Observations were started on 2009 November 18, six days before the opposition, and the last images were taken on 2009 November 27, resulting in 6 data sets. Unfortunately, unfavorable weather conditions prevented further observations and so expanding the data set over a longer interval. Based on the available data, two equally-possible lightcurve solutions were found: a bimodal lightcurve with $P = 4.6584$ h (Figure 1) and a

physically justified quadramodal lightcurve with $P = 9.3171$ h (Figure 2). The RMS errors of both solutions were comparable and so could not be used to distinguish the “true” period.

On the other hand, a simple visual inspection of the 9.3171 h period lightcurve shows that the two halves of the curve appear nearly the same. In addition, analysis of the higher orders of the Fourier series coefficients (Frederick Pilcher, private communications) shows that even and odd terms are comparable for the short period while the odd terms have much smaller coefficients than the even terms for the long period. These facts strongly favor the 4.6584 ± 0.0005 h period. The amplitude of the curve is 0.15 ± 0.02 mag.

1819 Laputa. No results for the rotation period of this main-belt asteroid have been published previously. Given that the object reached $V \sim 13.9$ in opposition on 2009 June 7, it was favorably-suited for photometric observations. Data were collected over 10 nights from 2009 May 23 through June 18. Even the first data sets indicated a simple bimodal lightcurve with an amplitude of about 0.5 mag. Analysis of the expanded data set confirmed the initial result: a bimodal lightcurve with a period of $P = 9.8004 \pm 0.0002$ h and amplitude $A = 0.51 \pm 0.03$ mag (Figure 3).

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