LIGHTCURVE ANALYSIS OF A MAGNITUDE LIMITED ASTEROID SAMPLE

Lawrence A. Molnar, Melissa J. Haegert, Christopher N. Beaumont, Marjorie J. Block, Timothy H. Brom, Andrew R. Butler, Peter L. Cook, Allyson G. Green, Joshua P. Holtrop, Kathleen M. Hoogeboom, Jason J. Kulisek, Jonathan S. Lovelace, Jeffery S. Olivero, Achyut Shrestha, Jessie F. Taylor, Kenneth D. Todd, John D. Vander Heide, and Samuel O. Van Scoter
Calvin College
1734 Knollcrest Circle SE
Grand Rapids, MI 49546-4403
lmolnar@calvin.edu

(Received: 20 August Revised: 16 October)

Synodic rotation periods and amplitudes for twelve main-belt asteroids observed at the Calvin-Rehoboth Observatory are reported: 285 Regina, 939 Isberga, 1104 Syringa, 1206 Numerowia, 1613 Smiley, 1623 Vivian, 1835 Gajdariya, 3013 Dobrovoleva, 3170 Dzhanibekov, 4411 Kochibunkyo, (5854) 1992UP, and (119245) 2001 QD293. The asteroid 939 Isberga is a binary with orbital period 26.8 ± 0.1 h. Together with five asteroids previously measured these constitute a complete magnitude limited sample which can be used to test for bias in the larger catalog of rotation periods.

The goal of this project was to study a complete, magnitude limited sample of main-belt asteroids. The sample was defined as all asteroids with V brighter than 15.8 (as computed by the Minor Planet Center) and located within 250 arcminutes of (RA = 9^h, Dec = +20°) at 7 UT on 2 February 2006. Seventeen asteroids met these criteria, of which five had periods listed in the catalog of Harris (2006) with quality code of "2" or better (135 Hertha, 534 Nassovia, 760 Massinga, 2415 Ganesa, and 7895 Kaseda). This paper presents new data on the remaining twelve asteroids, establishing secure periods for eleven of them (and a tentative period for 285 Regina). A brief comparison is also made between the sample and the larger catalog of main belt rotation periods.

Calvin College operates a robotic observatory located in Rehoboth, NM, at an elevation of 2024 m. Data were taken using a 0.4 m OGS Ritchey-Chretien telescope and an SBIG ST-10XE camera. All images were taken with an R filter at a pixel scale of 1.97 arcseconds per pixel. Exposure times ranged from 120 to 240 s. Standard image calibration was done with MaxIm DL. Differential aperture photometry was done both with Canopus 9.3.1.0 (BDW Publishing 2007) and MaxIm DL. Period analysis was done with Canopus 9.3.1.0 and Peranso 2.20 (Vanmunster 2006), using the Fourier algorithm (FALC) developed by Harris et al. (1989). All times were corrected for light travel. Magnitude scales on adjoining nights are tied together via common reference stars for all asteroids except (119245) 2001 QD293, for which there was insufficient overlap.

Of the twelve objects, previously published lightcurves exist only for 939 Isberga and 1613 Smiley (cf. the catalog of Harris et al. 2007). Our results are summarized in the figures and table below, along with additional comments on individual objects as needed.

285 Regina This asteroid had the smallest amount of variation in our sample. The period used in the figure (and given in the table) represents the most likely fit to our data. However, despite complete phase coverage from eight nights of data, the amplitude of the fit is not sufficiently greater than the data uncertainties for this to be considered a certain result. The amplitude of the fit may be considered a secure upper limit for any reasonable period.

939 Isberga A short period (2.9 h), moderate amplitude (0.25 mag) cycle was easily observed on each of the six nights we observed 939 Isberga. This period is inconsistent with Tedesco (1979), which reports a lower limit of 20 h for the period and a lower limit of 0.2 magnitudes for the amplitude. However, Harris et al. (2007) assign a quality code of "1" to this estimate.

During portions of four of the nights, 939 Isberga was fainter than expected. We determined the lightcurve shape and period omitting these data and then used the results to obtain residuals of all of the data with respect to that fit. We then analyzed the residuals and found in them a period of 26.8 ± 0.1 h, which we interpret to be the orbital period of a companion. Plotting the residuals folded on this period shows the observations of February 26 and 27 include primary eclipses approximately 0.15 mag in depth, while the observations of March 3 and 4 include portions of secondary eclipses. To establish the statistical significance of these dips, we note that three other asteroids were observed during three of the nights 939 Isberga was observed. Plots of their residuals folded on the same period show no systematic trends greater than 0.05 mag. We conclude the evidence for the companion is strong.

We note that there is one other period, 17.2 h, which can adequately describe the residual data. This is not a physically plausible value, however, as requiring a binary separation greater than the Roche limit would imply a lower limit to the mean density of 4.2 gm/cm^3 (assuming two equal density objects). For

#	Name	Date range (2006) (mm/dd)	Data pts	Period (h)	P. error (h)	Est. amp. (mag)	V_{min} (mag)
285	Regina	02/01-02/26	190	31.64	0.05	0.15	13.21
939	Isberga	02/24-03/04	188	2.9173	0.0003	0.25	13.10
1104	Syringa	02/01-02/06	108	5.1547	0.0012	0.27	12.92
1206	Numerowia	02/07-02/09	92	4.7743	0.0013	0.68	15.08
1613	Smiley	01/14-02/28	576	80.61	0.05	0.28	12.99
1623	Vivian	02/01-04/19	335	20.5209	0.0007	0.88	14.18
1835	Gajdariya	02/07-02/09	89	6.3276	0.0035	0.50	14.54
3013	Dobrovoleva	02/01-02/03	117	8.3025	0.0021	0.41	14.90
3170	Dzhanibekov	02/01-02/03	91	6.0724	0.0031	0.64	15.30
4411	Kochibunkyo	02/01-02/03	93	2.6958	0.0018	0.20	15.32
5854	1992 UP	02/01-02/20	301	7.1296	0.0008	0.33	14.66
119245	2001 QD293	02/01-02/04	108	4.8249	0.0021	0.27	14.87

V_{min} is the approximate opposition magnitude of the asteroid at perihelion distance, q, and is given by $V_{min} = H + 5 \log[q(q-1)]$.

the longer period, the lower limit is 1.7 gm/cm^3. Well-measured values range from 0.89 gm/cm^3 (for 854 Frostia, Behrend et al. 2006) to 3.4 gm/cm^3 (for 4 Vesta, Britt et al. 2002).

1613 Smiley The slow rotation of this object makes the three full nights we observed in late February of 2006 inadequate by themselves to determine the period. Warner (2006) reported a period of 81.0 ± 0.1 h based on data from late January 2006, although those data also had significant gaps. We combined the data sets, filling all but one gap and improving the period determination: 80.61 ± 0.05 h. The uncertainty is still dominated by the systematic error introduced by the remaining gap; we estimated it by evaluation of how the best fit period depends on the order of the solution used.

1623 Vivian Data were taken on this object for eight nights in February of 2006. Although a bimodal fit was preferred, the lightcurve was nearly symmetric, so observations were made on four additional nights in April in order to resolve any ambiguities. These later data show a slightly different lightcurve shape (a greater amplitude), as might be expected due to the changing aspect. Our final period determination was based on a fit to all of the data.

(119245) 2001 QD293 Within our uncertainties, these data could be fit either by one or two peaks per cycle. Since the amplitude is 0.25 mag (larger than expected from a pole-on perspective), we consider the bimodal fit more likely.

It is interesting to compare our magnitude limited sample with the catalog of known rotation periods (Harris et al. 2007), which contains 1815 well observed main belt asteroids (objects with orbits between Mars and Jupiter, excluding Mars crossing objects, with quality code "2" or better). This is only 10% of the known main belt objects (Minor Planet Center 2007) with a minimum opposition magnitude, V_{min}, less than our survey limit, leaving the possibility for significant observational bias against longer (difficult to determine) periods. In particular, we restrict our comparison to asteroids between 5 and 20 km in diameter (636 catalog objects). This is the upper end of the range of small asteroids, for which Pravec et al. (2002) find weak dependence of spin on asteroid size, and it includes the bulk of our sample: 11 of 17 objects (assuming a typical albedo of 0.16). Our sample has a median spin period of 6.07 hours, statistically indistinguishable from the 5.99 hour median of the catalog. We conclude there is no evidence for observational bias in the known spin periods of small asteroids.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 0126841. We thank the Rehoboth Christian School for the use of their campus as a location for the Calvin-Rehoboth Robotic Observatory. We thank Brian Warner for providing us his data on 1613 Smiley.

References

Behrend, R., et al. (2006). "Four new binary minor planets: (854) Frostia, (1089) Tama, (1313) Berna, (4492) Debussy." *Astronomy & Astrophysics*, **446**, 1177-1184.

Britt, D.T., Yeomans, D., Housen, K., and Consolmagno, G. (2002). "Asteroid Density, Porosity, and Structure." *Asteroids III*, W.F. Bottke Jr., A. Cellino, P. Paolicchi, R.P. Binzel (eds.), University of Arizona Press, Tucson, p. 485-500.

Harris, A. W. (2006). "Asteroid Lightcurve Data File", 2 January 2006 update. From the CALL homepage. http://minorplanetobserver.com/astlc/

Harris, A. W., Warner, B. D. and Pravec, P. (2007). "Asteroid Lightcurve Data Files." From the CALL homepage, last updated May 12, 2007. http://minorplanetobserver.com/astlc/

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

Minor Planet Center (2007). "MPC Orbit Database." From the MPC website, updated 6 August, 2007. http://www.cfa.harvard.edu/iau/MPCORB.html

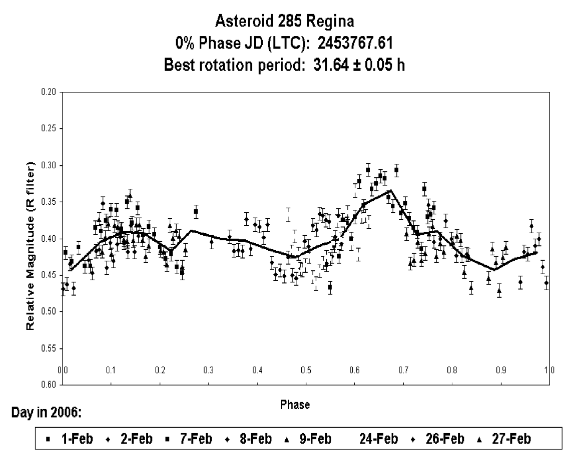
Pravec, P., Harris, A. W., and Michalowski, T. (2002). "Asteroid Rotations." *Asteroids III*, W.F. Bottke Jr., A. Cellino, P. Paolicchi, R.P. Binzel (eds.), University of Arizona Press, Tucson, p. 113-122.

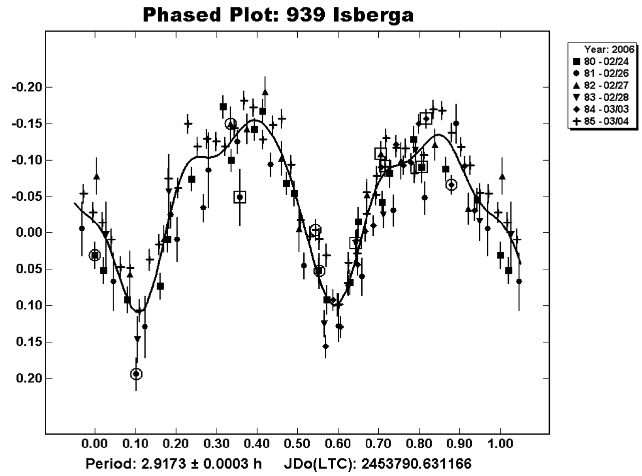
Tedesco, E. F. (1979). Ph.D. Dissertation, New Mexico State Univ. 280 pp.

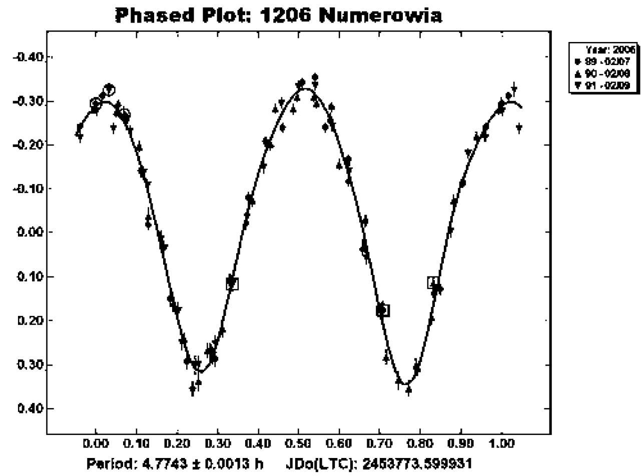
Vanmunster, T. (2006). Peranso Period Analysis Software, Peranso version 2.20, CBA Belgium Observatory.

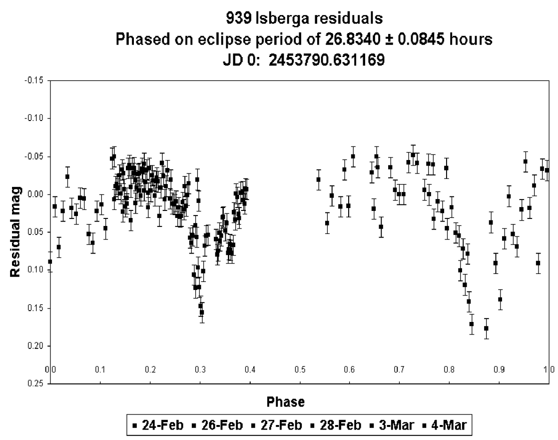
Warner, B. D. (2006). "Asteroid lightcurve analysis at the Palmer Divide Observatory – late 2005 and early 2006." *Minor Planet Bulletin*. **33**, 58-62.

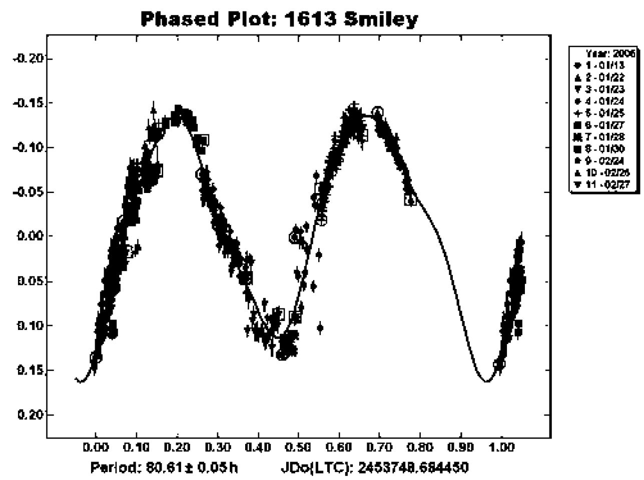
Warner, B. D. (2007). MPO Software, Canopus version 9.3.1.0. Bdw Publishing, Colorado Springs, CO.

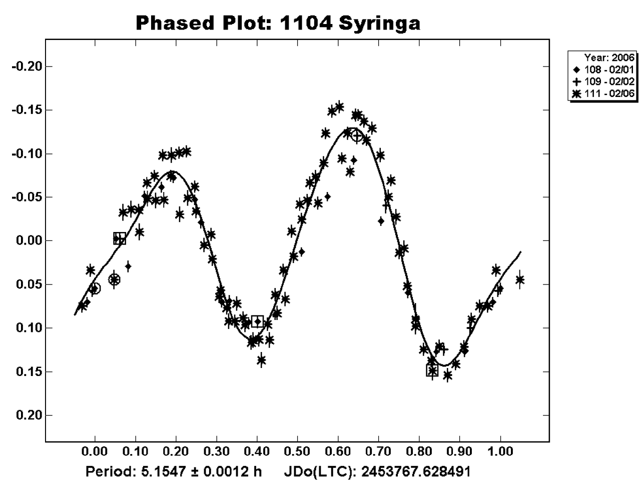


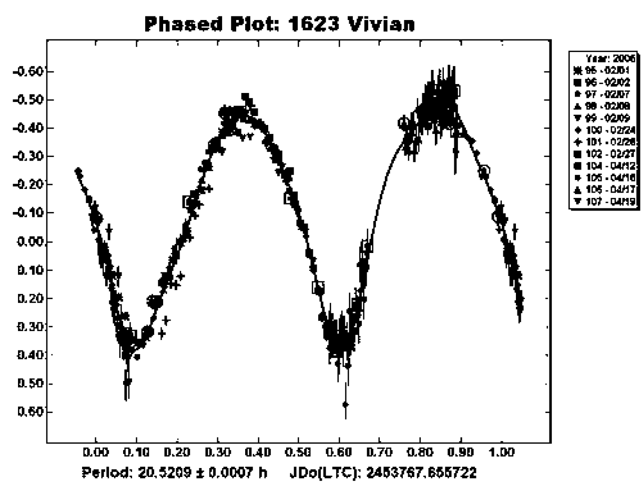

Phased Plot: 939 Isberga
Period: 2.9173 ± 0.0003 h JDo(LTC): 2453790.631166

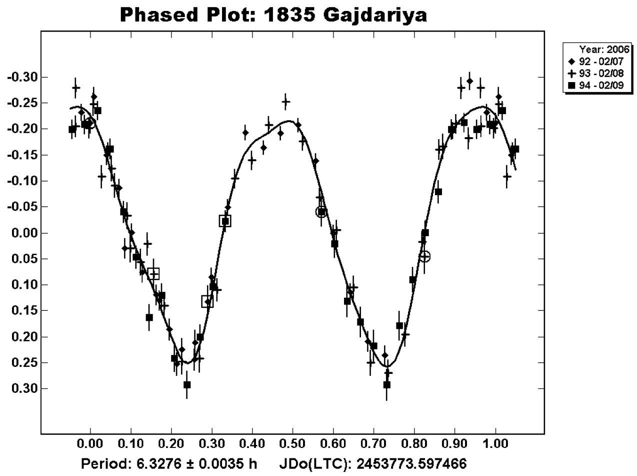

Phased Plot: 1206 Numerowia
Period: 4.7743 ± 0.0013 h JDo(LTC): 2453773.599931

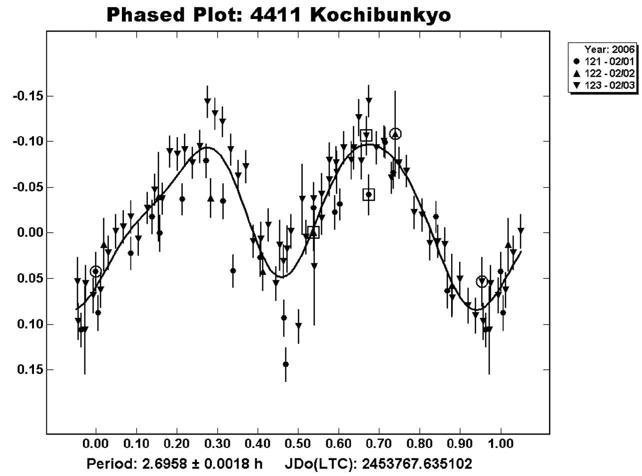

939 Isberga residuals
Phased on eclipse period of 26.8340 ± 0.0845 hours
JD 0: 2453790.631169
Residual mag
Phase
24-Feb 26-Feb 27-Feb 28-Feb 3-Mar 4-Mar

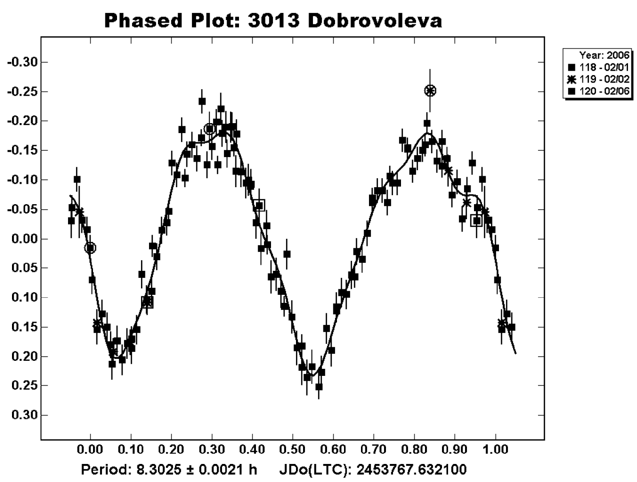

Phased Plot: 1613 Smiley
Period: 80.61 ± 0.05 h JDo(LTC): 2453748.684450

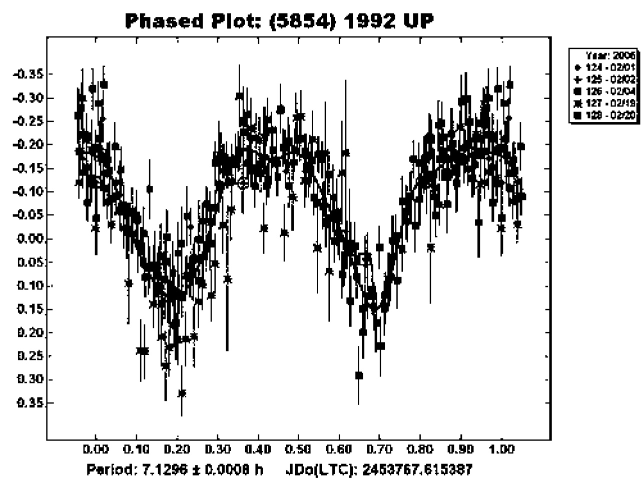

Phased Plot: 1104 Syringa
Period: 5.1547 ± 0.0012 h JDo(LTC): 2453767.628491

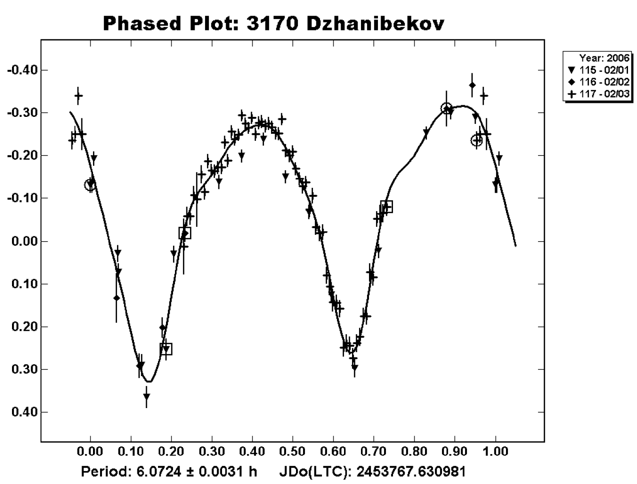

Phased Plot: 1623 Vivian
Period: 20.5209 ± 0.0007 h JDo(LTC): 2453767.655722

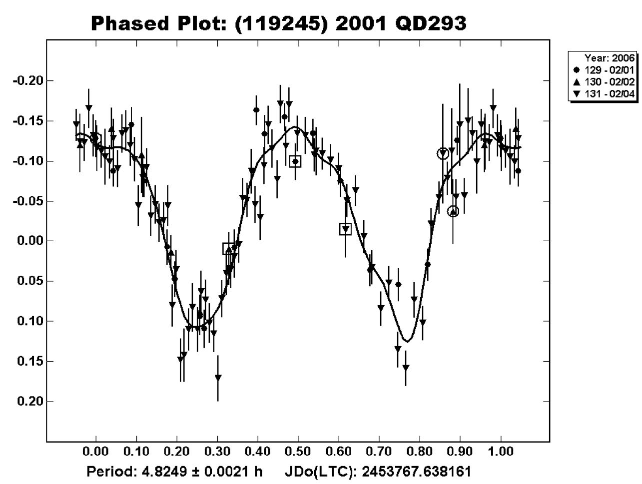

Phased Plot: 1835 Gajdariya
Year: 2006
92 - 02/07
93 - 02/08
94 - 02/09
Period: 6.3276 ± 0.0035 h JDo(LTC): 2453773.597466


Phased Plot: 4411 Kochibunkyo
Year: 2006
121 - 02/01
122 - 02/02
123 - 02/03
Period: 2.6958 ± 0.0018 h JDo(LTC): 2453767.635102


Phased Plot: 3013 Dobrovoleva
Year: 2006
118 - 02/01
119 - 02/02
120 - 02/06
Period: 8.3025 ± 0.0021 h JDo(LTC): 2453767.632100


Phased Plot: (5854) 1992 UP
Year: 2006
124 - 02/01
125 - 02/02
126 - 02/04
127 - 02/19
128 - 02/20
Period: 7.1296 ± 0.0008 h JDo(LTC): 2453767.615387


Phased Plot: 3170 Dzhanibekov
Year: 2006
115 - 02/01
116 - 02/02
117 - 02/03
Period: 6.0724 ± 0.0031 h JDo(LTC): 2453767.630981


Phased Plot: (119245) 2001 QD293
Year: 2006
129 - 02/01
130 - 02/02
131 - 02/04
Period: 4.8249 ± 0.0021 h JDo(LTC): 2453767.638161