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Rotation periods for small main-belt asteroids[⋆,⋆⋆]

R. Almeida, C. A. Angeli, R. Duffard, and D. Lazzaro

Observatório Nacional/MCT, Coordenação de Astronomia e Astrofísica – CAA, 20921-400 Rio de Janeiro, Brazil

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Abstract. The results of new CCD observations are presented as part of the campaign we are performing in Brazil to measure rotational periods for small asteroids. The observations presented here have been acquired at the Pico dos Dias Observatory between 1997 and 2002 and result in 48 single night lightcurves for 20 asteroids, most of them Main-Belt objects with $D <$ 40 km. We present the rotation periods – ranging from about 3 to 18 hr – along with the composite lightcurve obtained for each observed object.

Key words. minor planets, asteroids – solar system: general

1. Introduction

From the lightcurves of asteroids we can determine the distribution of their rotation rates and put important constraints on the evolution of the asteroid population as a whole. Special attention has been paid lately to small objects ($D < 40$ km), because in this range of diameters the fast and the slow rotators of the population are concentrated. This size demarcates a change in the spin rate distribution and is considered as a separation between the so-called "large" and "small" asteroids (Pravec & Harris 2000).

Despite the increase, in recent years, in the number of small asteroids with known rotation periods, the knowledge of this population from the point of view of their rotational evolution is still a challenge. To be able to analyse this population as a whole, to better understand their evolution, it is necessary to have in hand reliable diameters as well as rotation periods. Recent works (Pravec & Harris 2000; Fulchignoni et al. 1995) have pointed to an excess of slow and fast rotators among the small asteroids, but only studies based on a complete and secure sample will permit an unambiguous picture of this population.

In this work we present the results of lightcurve observations of 20 asteroids, mostly Main-Belt objects with diameters smaller than 40 km; it is part of a larger program that we started in 1996 in Brazil to obtain rotation periods of small asteroids (Angeli et al. 2001 and references therein). Our purpose is to increase the number of reliable rotation periods, which, through statistically meaningful studies, will permit an improvement of the picture of this population. The final aim is the analysis of all these periods, along with the ones available in the literature, in view of the diameters of those asteroids, to better understand their rotational evolution. Our rotation periods are based on 48 single-night lightcurves from data collected from April 1997 through April 2002.

2. Observations and data reduction

The photometric observations reported here were performed at the Observatório do Pico dos Dias (OPD, Brazil) on a 0.6 m telescope for most asteroids, but some asteroids (621, 1459, 3332 and 5016) were observed with a 1.6 m telescope at the same site. All the observations were made using CCD cameras in the V band. In the observations with the 0.6 m telescope a EEV-385 × 576 CCD was used, with focal-plane reducing optics, giving a $7.2' \times 5.5'$ field and yielding an image scale of $1.12''$/pix. In the observations with the 1.6 m telescope we used a 1024 × 1024 CCD with an image scale of $0.31''$/pix, giving a $5.3' \times 5.3'$ field.

All the composite lightcurves have been constructed using relative magnitudes, i.e., the difference between the instrumental magnitude of the asteroid and that of a field star. During the data reduction procedure we measure the flux of three stars in the same frame of the asteroid. These stars are chosen near the path covered by the asteroid during the night and having about the same magnitude as the asteroid. We compute the magnitude differences between the asteroid and each one of these field stars (relative magnitude) to discard variable stars. If no variable star is found, we choose as reference the star with the smallest error in the flux measure. The times reported have not been corrected for light-travel time. The images were reduced using the APPHOT task of the Image Reduction and Analysis Facility (IRAF) package, and calibrated using standard

Send offprint requests to: C. A. Angeli, e-mail: angeli@on.br
⋆ Observations carried out at the Observatório do Pico dos Dias, operated by the Laboratório Nacional de Astrofísica (Brazil).
⋆⋆ Figures 1 to 20 are only available in electronic form at http://www.edpsciences.org

methods with bias and dome flat-field images. Fourier analyses of the data were performed using the method described by Harris et al. (1989), to obtain the composite lightcurves and the rotation periods. This method consists of a Fourier analysis of the data to derive the composite lightcurves. All the data are fit by a Fourier series, which can be chosen to be of any degree. The solution provides a value for the rotation period, the magnitude offset for each individual lightcurve, and Fourier coefficients defining the shape of the composite lightcurve to any degree specified. The method also provides formal error estimates for all quantities computed.

3. Results

In Table 1 we report a summary of the obtained results. In this table we give the asteroid number and name, the UT date (of the first observational point), the family or group to which the asteroid belongs, the estimated diameter (Tedesco et al. 2002; Tholen 1999), the total observing time during each night, the Fourier fit used in the composite lightcurve, the rotation period obtained, the composite lightcurve amplitude and the reliability code (Harris & Young 1983) attributed to the obtained period. A period with code 1 is based on inconclusive coverage and may be completely wrong; 2 corresponds to a reasonably secure result, probably not wrong by more than 10–20%, and may include also cases of ambiguity (for example, the true period may be 3/2, 2/3 or some other harmonic of the reported value); 3 indicates a secure result. The lightcurve amplitude represents the peak-to-peak (main maximum to main minimum) range of the observed points in the composite lightcurve. The lightcurves are plotted in Figs. 1 to 20, each symbol corresponding to a different night. As in Table 1, the dates in the lightcurves correspond to the day nearest the middle of the observing night. The dashed line present in all lightcurves corresponds to the Fourier series that best fits the respective data set. The data will be sent to the Asteroid Photometric Catalogue (APC) to be included in the next update and are available upon request to C. A. Angeli. In what follows we make some comments about each asteroid.

620 Drakonia

We observed this asteroid for almost 11 hours on June 5 and 6 2000. With the observations of the first night we have an almost complete lightcurve. The composite lightcurve is shown in Fig. 1. It presents relatively good coverage but one maximum and one minimum are not unambiguous, due to the high dispersion of the data in those regions. We attribute to the obtained period a reliability code 3.

621 Werdandi

This Themis family asteroid was observed on April 19–22 2002 and Fig. 2 shows the obtained composite lightcurve. Two maxima and two minima are clearly defined and the lightcurve presented here has a very low dispersion. Therefore, we attribute to the adopted value of the period a reliability code 3.

This object had been observed before, by Lagerkvist (1978), who found a period greater than 10 hr. With our data we improve that determination giving the precise value of the period, slightly smaller than 10 hr.

966 Muschi

Observations of this asteroid were obtained for about six hours during only one night, July 9 2000. The composite lightcurve of 966 Muschi, shown in Fig. 3, has a poor coverage and presents a large dispersion and doubtful extrema. Therefore, a reliability code 1 has been attributed to the computed period.

986 Amelia

We observed 986 Amelia on October 31 and November 1–2 2000. The composite lightcurve is shown in Fig. 4. Due to the dispersion of the points, the composite lightcurve does not have well defined extrema. It is relatively well covered so we attributed to the computed period a reliability code 2.

986 Amelia has a diameter larger than 40 km. It was observed by Koff (2001) who found a rotation period of 9.52 ± 0.01 hr. The value we obtained agrees with the previous determination, but unfortunately our data are not sufficient to improve it.

1028 Lydina

This member of the Cybele group was observed on November 15–16 1998. This object is the only one in this work that belongs to the outer belt, and it is also the biggest asteroid of our sample. Despite the well-covered minima of the composite lightcurve (Fig. 5), the maxima are very doubtful. We attribute a reliability code 2 to the obtained period, because additional observations are needed to define the rotation period without ambiguity.

1294 Antwerpia

This asteroid was observed on November 27 and 28 1999 for about 9 hours. Its composite lightcurve, shown in Fig. 6, presents good coverage and a relatively low dispersion so we attribute to the obtained period a reliability code 3.

1403 Idelsonia

We observed this object, a member of the Chloris family, during three nights in 1999 and on the second night we obtained a complete lightcurve, with two maxima and two minima. The composite lightcurve is shown in Fig. 7. It presents a low dispersion with well covered maxima and minima. For these reasons, a reliability code 3 has been attributed to the computed period.

1426 Riviera

This object was observed on May 8 and 10 1999. The composite lightcurve (Fig. 8) is not quite well covered, but presents a low dispersion and relatively well defined maxima and minima. We attribute a reliability code 2 to the obtained period.

1459 Magnya

This asteroid was observed on April 21 and 22 2002. The composite lightcurve, shown in Fig. 9, has a low dispersion and is well covered, except around rotational phase 0.2–0.5. The most notable characteristic of 1459 Magnya is its basaltic crust (Lazzaro et al. 2000), this asteroid being the only big asteroid (D = 29.9 km) that has this composition in the outer belt. A reliability code 2 has been attributed to the computed period.

Table 1. Results.

Asteroid	Date	Family or Group!	Diameter (km)	**Total Time per night (hr)**	Fourier Fit	Period (hr)	Amplitude (mag)	Rel. Code
620 Drakonia	2000 06 05		10.1″	5,5	4	5.530 ± 0.007	0.69 ± 0.03	3
	06 06			5				
621 Werdandi	2002 04 19	Themis	27.15*	4	3	9.396 ± 0.003	0.58 ± 0.02	3
	04 20			3				
	04 21			1				
	04 22			1				
966 Muschi	2000 07 09		23.43*	6	2	6.9 ± 0.1	0.51 ± 0.04	1
986 Amelia	2000 10 31		50.94*	5	3	9.52 ± 0.01	0.46 ± 0.04	2
	11 01			4				
	11 02			4				
1028 Lydina	1998 11 15	Cybele	71.38*	5	4	15.69 ± 0.01	0.87 ± 0.02	2
	11 16			6				
1294 Antwerpia	1999 11 27		34.71*	5	3	6.618 ± 0.005	0.41 ± 0.03	3
	11 28			4				
1403 Idelsonia	1999 11 24	Chloris	32.80*	7	4	5.458 ± 0.004	1.12 ± 0.03	3
	11 26			5,5				
	11 27			4				
1426 Riviera	1999 05 08		15.44*	3	3	4.40 ± 0.01	0.30 ± 0.01	2
	05 10			4				
1459 Magnya	2002 04 21		29.90*	4	4	4.68 ± 0.01	0.57 ± 0.02	2
	04 22			4				
1619 Ueta	2000 09 22	Flora	11.3″	3	3	2.94 ± 0.01	0.44 ± 0.02	2
2228 Soyuz-Apollo	1999 07 18	Themis	29.7″	6	3	6.12 ± 0.01	0.50 ± 0.04	2
	07 19			4				
2381 Landi	2000 10 31	Eunomia	12.04*	5	3	3.91 ± 0.01	0.89 ± 0.03	2
	11 04			2				
2784 Domeyko	1999 07 17	Flora	7.9″	3	3	5.98 ± 0.01	0.22 ± 0.02	2
	07 18			7				
2880 Nihondaira	2000 06 04	Flora	18.5″	6	3	17.97 ± 0.01	0.82 ± 0.03	2
	06 05			6,5				
	06 06			5				
	06 07			2				
2988 Korhonen	1999 07 18	Eunomia	17.5″	3	4	13.51 ± 0.01	0.81 ± 0.01	2
	07 20			6				
3332 Raksha	2002 04 19	Maria	17.5″	3,5	3	4.22 ± 0.01	0.38 ± 0.02	2
	04 20			4				
3767 DiMaggio	1999 07 19	Eunomia	18.2″	4	4	6.14 ± 0.01	0.47 ± 0.04	2
	07 20			4				
3786 Yamada	2001 04 12	Maria	22.0″	2	4	4.031 ± 0.007	0.54 ± 0.03	3
	04 13			4				
	04 14			4				
4497 Taguchi	1999 11 24		19.2″	3	4	3.563 ± 0.002	0.22 ± 0.01	3
	11 25			2				
	11 26			5				
	11 27			5,5				
	11 28			2,5				
5016 Migirenko	1997 04 29		9.6″	2,5	4	4.8 ± 0.1	0.38 ± 0.03	1
	04 30			4,5				

* Diameters by the Supplemental *IRAS* Minor Planet Survey (Tedesco et al. 2002).
″ Diameters by D.J. Tholen, ephemeris program EPHEM, version 1999 (Tholen 1999).
! Family classification available at `http://pdssbn.astro.umd.edu/SBNast/holdings/EAR-A-5-DDR-FAMILY-V4.1.html`.

1619 Ueta

We observed this Flora family asteroid on a single night – September 22 2000. The composite lightcurve is shown in Fig. 10. Although it has been determined with only one night, we consider that a reliability code 2 is appropriate.

2228 Soyuz-Apollo

Observations of this Themis family asteroid were made on July 18 and 19 1999. On the first night we obtained a complete lightcurve and on the second one we obtained an almost complete lightcurve (with one and a half maxima). The composite lightcurve obtained is shown in Fig. 11. Both maxima are well covered, but minima are doubtful due to the dispersion near these regions. A reliability code 2 has been attributed.

2381 Landi

We observed this Eunomia family member on October 31 and November 4 2000. Figure 12 shows the obtained composite lightcurve. Two maxima and two minima are clearly seen and this lightcurve shows a high amplitude and a low dispersion (the dispersion is mainly concentrated near the minima). We attributed a reliability code 2 to the computed period.

2784 Domeyko

Observations of this Flora family asteroid were made for more than 10 hours on July 17 and 18 1999. In Fig. 13 we present the obtained composite lightcurve, which presents a relatively high dispersion and a small amplitude. Although this curve has some regions poorly covered, we attribute a reliability code 2 to the obtained period.

2880 Nihondaira

Another Flora family member, this asteroid was observed on June 4–7 2000. The composite lightcurve obtained from the data has a high amplitude and is very irregular. This curve presents a high dispersion, as can be seen in Fig. 14. The computed period is the longest we have obtained and we attribute to it a reliability code 2 due to the poor coverage in some regions of the composite lightcurve.

2988 Korhonen

This asteroid, an Eunomia family member,was observed on July 18 and 20 1999. The composite lightcurve (Fig. 15) presents a high amplitude and a low dispersion. It has some poorly covered regions, at both maxima and one minimum. A reliability code 2 has been attributed to the obtained period.

3332 Raksha

We observed this asteroid, a Maria family member, during two nights on April 19 and 20 2002. The composite lightcurve (Fig. 16) is quite irregular, showing two different maxima and minima. It has a small amplitude and presents some poorly covered regions. Therefore, we attribute a reliability code 2 to the obtained period.

3767 DiMaggio

Another small Eunomia family member, 3767 Di Maggio was observed on July 19 and 20 1999. The composite lightcurve is shown in Fig. 17. We obtained a period of 6.14 hr with a fourth-order Fourier fit. This lightcurve is not completely covered but two maxima and two minima are clearly seen. A reliability code 2 was attributed to the computed period.

3786 Yamada

This Maria family member was observed during three nights in April 2001. The composite lightcurve is shown in Fig. 18. It has a high dispersion, but was made over three nights and is well covered. Two maxima and two minima are clearly seen and a reliability code 3 has been attributed to the computed period.

4497 Taguchi

This asteroid was observed on five nights in November 1999. The composite lightcurve that best fits our data is shown in Fig. 19. It shows a high dispersion and a small amplitude but has good coverage. A reliabity code 3 is attributed to the obtained period.

5016 Migirenko

We observed this asteroid for about 7 hours in April 1997. The composite lightcurve is shown in Fig. 20. Because it is very asymmetric, has a low dispersion and is not well covered, we attribute a reliability code 1 to the computed period. Additional observations are needed to confirm or refute this value.

4. Summary of results

We have obtained the synodic rotation periods for 20 asteroids, most of them small Main-Belt objects (only two objects are larger than 40 km), with observations carried out between April 1997 and April 2002. The computed periods lie in the range between 2.94 hr and 17.97 hr, with lightcurve amplitudes ranging from about 0.2 to 1.1 mag. Fifty percent of the periods found in our sample are smaller than 6 hr and seventy-five percent are smaller than 9 hr. Only one object in our sample (the Flora member 1619 Ueta), with a rotation period $P = 2.94$ hr, has a spin rate that places it in the population of the "fast-rotators" (fast-rotating asteroid or FRA), as introduced by Pravec & Harris (2000). Some asteroids of our sample (1028 Lydina, 1403 Idelsonia, 2381 Landi, 2880 Nihondaira and 2988 Korhonen) have high lightcurve amplitudes, suggesting elongated objects, but additional observations on different aspects and solar phase angles are needed to better constrain their shapes.

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Online Material

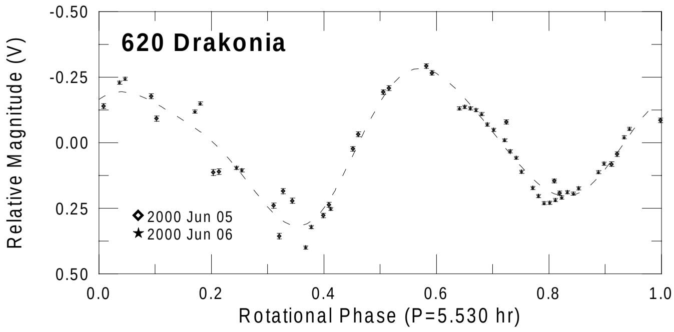

Fig. 1. Composite lightcurve of 620 Drakonia. Zero phase corresponds to UT 2000 June 6.08.

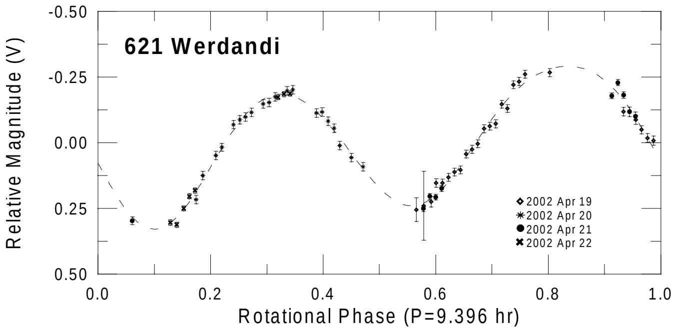

Fig. 2. Composite lightcurve of 621 Werdandi. Zero phase corresponds to UT 2002 April 19.62.

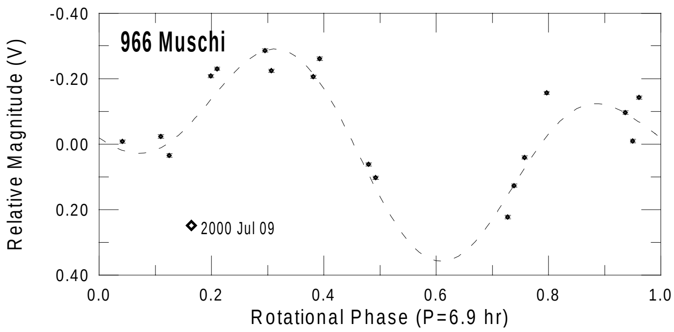

Fig. 3. Composite lightcurve of 966 Muschi. Zero phase corresponds to UT 2000 July 9.52.

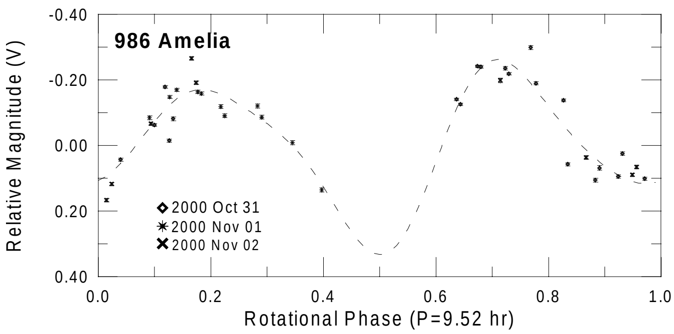

Fig. 4. Composite lightcurve of 986 Amelia. Zero phase corresponds to UT 2000 November 1.36.

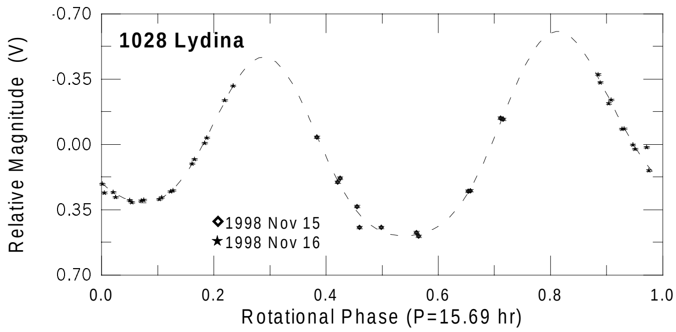

Fig. 5. Composite lightcurve of 1028 Lydina. Zero phase corresponds to UT 1998 November 16.23.

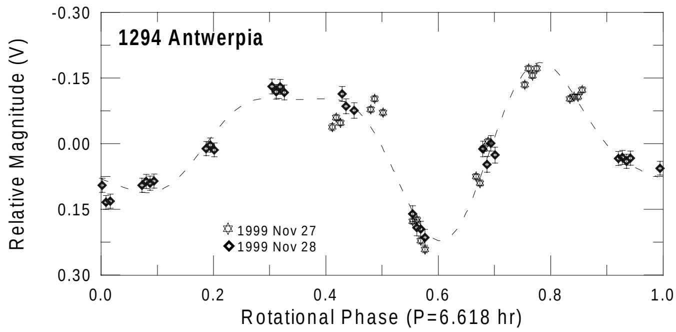

Fig. 6. Composite lightcurve of 1294 Antwerpia. Zero phase corresponds to UT 1999 November 27.96.

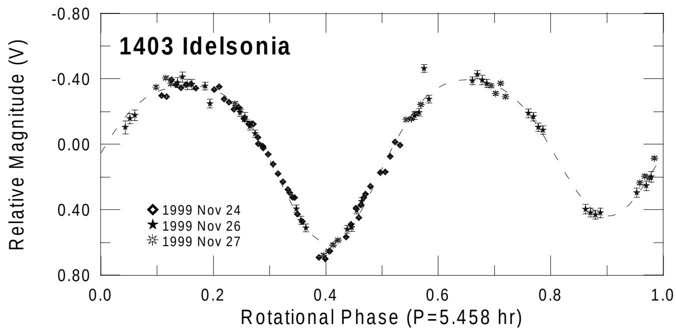

Fig. 7. Composite lightcurve of 1043 Idelsonia. Zero phase corresponds to UT 1999 November 25.95.

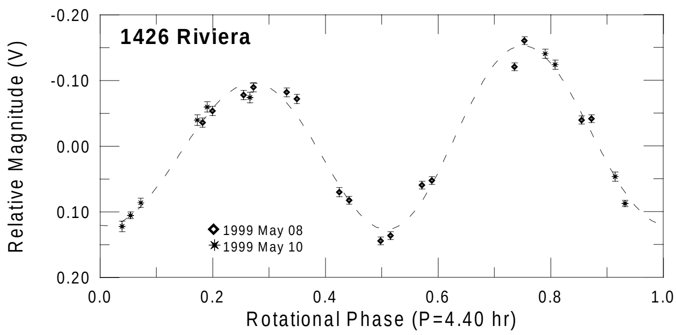

Fig. 8. Composite lightcurve of 1426 Riviera. Zero phase corresponds to UT 1999 May 9.27.

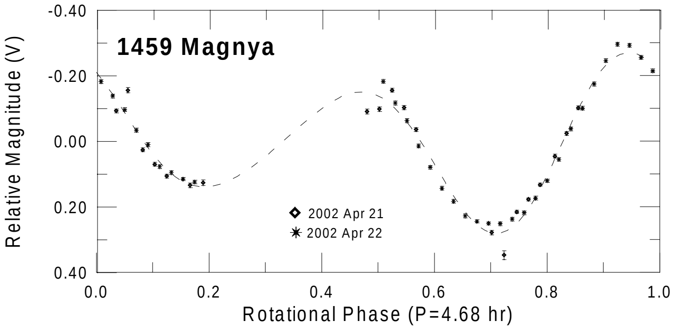

Fig. 9. Composite lightcurve of 1459 Magnya. Zero phase corresponds to UT 2002 April 21.26.

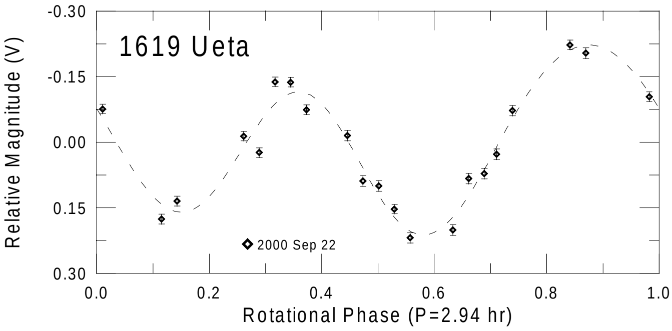

Fig. 10. Composite lightcurve of 1619 Ueta. Zero phase corresponds to UT 2000 September 21.65.

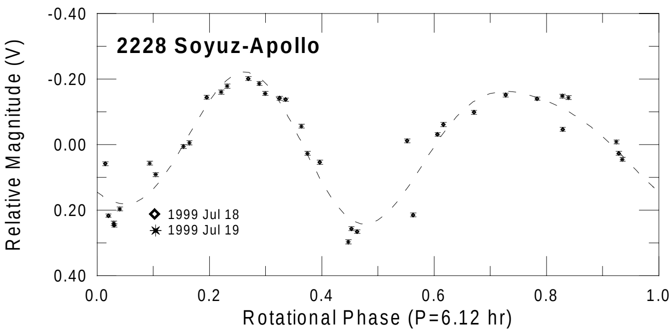

Fig. 11. Composite lightcurve of 2228 Soyuz-Apollo. Zero phase corresponds to UT 1999 July 19.05.

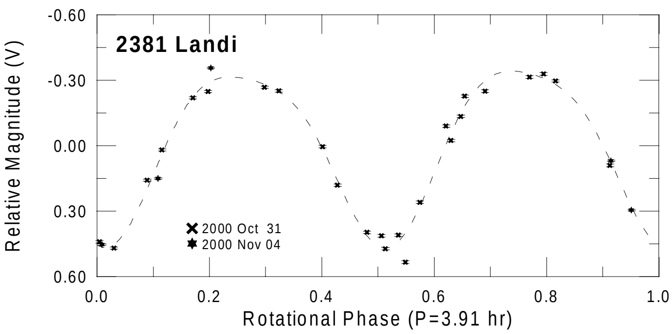

Fig. 12. Composite lightcurve of 2381 Landi. Zero phase corresponds to UT 2000 October 31.37.

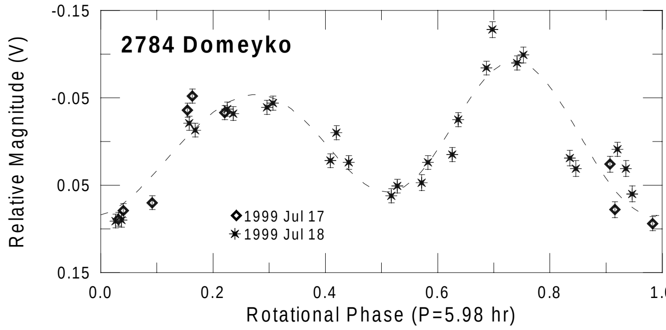

Fig. 13. Composite lightcurve of 2784 Domeyko. Zero phase corresponds to UT 1999 July 18.15.

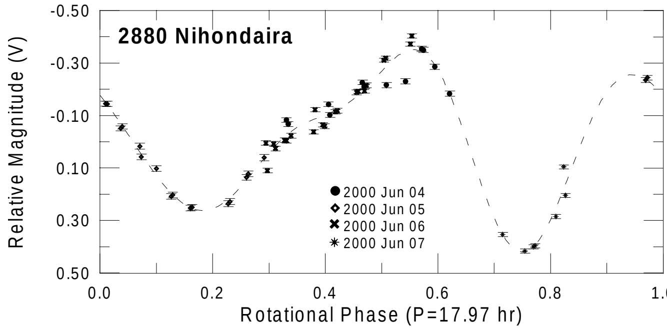

Fig. 14. Composite lightcurve of 2880 Nihondaira. Zero phase corresponds to UT 2000 June 5.77.

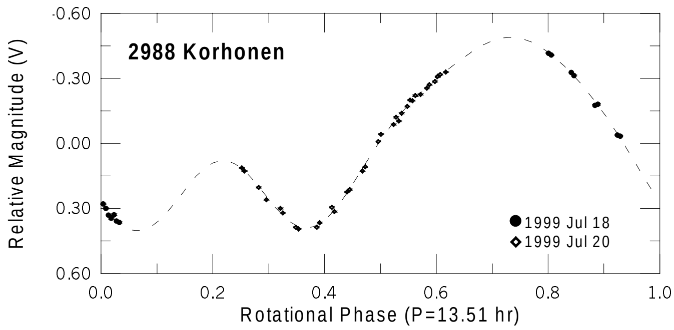

Fig. 15. Composite lightcurve of 2988 Korhonen. Zero phase corresponds to UT 1999 July 19.14.

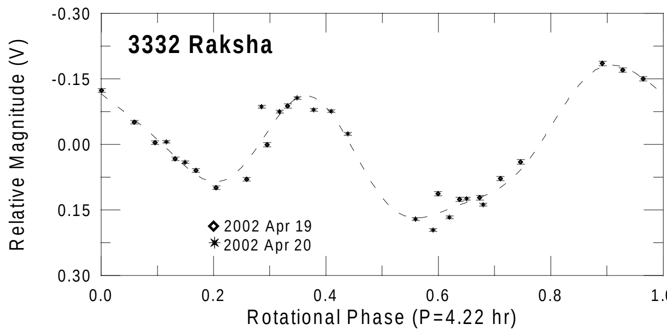

Fig. 16. Composite lightcurve of 3332 Raksha. Zero phase corresponds to UT 2002 April 19.22.

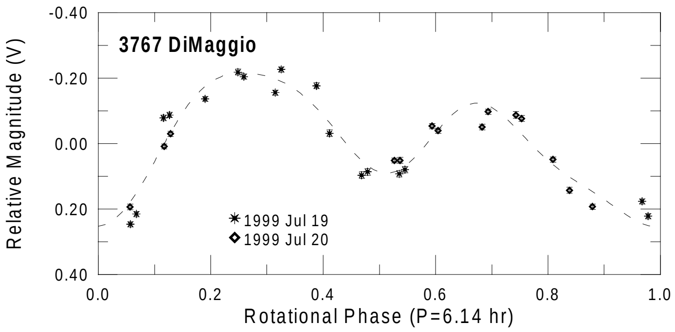

Fig. 17. Composite lightcurve of 3767 DiMaggio. Zero phase corresponds to UT 1999 July 19.64.

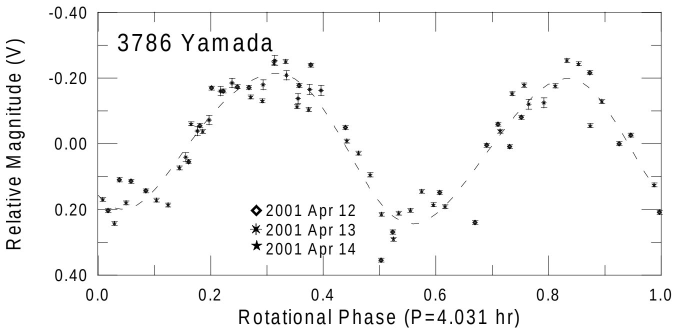

Fig. 18. Composite lightcurve of 3786 Yamada. Zero phase corresponds to UT 2001 April 13.64.

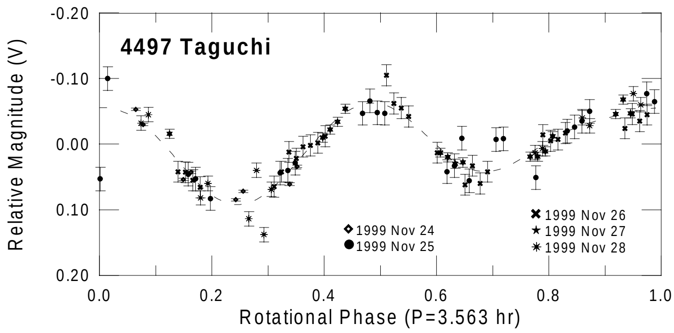

Fig. 19. Composite lightcurve of 4497 Taguchi. Zero phase corresponds to UT 1999 November 26.84.

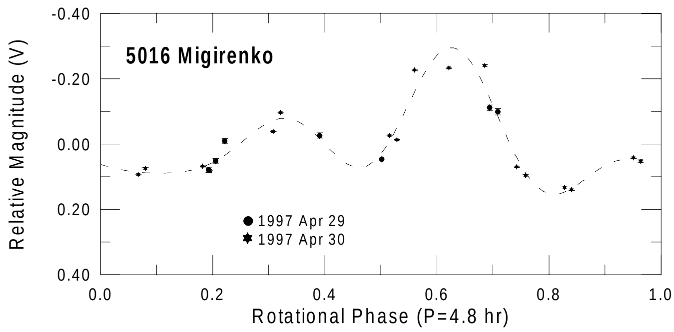

Fig. 20. Composite lightcurve of 5016 Migirenko. Zero phase corresponds to UT 1995 April 30.45.