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PHOTOMETRY OF FOURTEEN MAIN BELT ASTEROIDS

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RESUMEN

Se presentan resultados de fotometría CCD para 14 asteroides del cinturón principal obtenida entre 1996 y 2000. Para la mayoría de los objetos observados se encontraron las curvas de luz compuestas en los filtros V o R y los períodos de rotación sinódicos. Para 11 de los objetos estudiados no existía una determinación previa de su período de rotación.

ABSTRACT

The results of CCD photometry of 14 main belt asteroids obtained between 1996 and 2000 are presented. For most of them, the V or R composite lightcurves and the values of the synodic rotational period are derived. There exists no previous determination of the period for 11 of the observed objects.

Key Words: **MINOR PLANETS, ASTEROIDS**

1. INTRODUCTION

Enlarging the observational data base of rotational properties of asteroids may allow significant conclusions to be drawn regarding the collisional evolution of the asteroid belt (Chapman et al. 1989; Binzel et al. 1989; Davis et al. 1989 and references therein) and help to gain insights into the cosmogonically important distribution of spin axis orientation (Magnusson 1986). It was suggested, on the basis of the available data on asteroids, that the outcomes of collisions are strongly dependent on size. Asteroids with diameters larger than $\approx$ 150 km have mostly "pile of rubble" structures (Davis et al. 1979) forming a group of bodies dominated by self-gravitation, but objects smaller than 100 km in diameter are mostly multigeneration fragments whose shape is controlled by solid-state forces only. As a consecuence of their different internal structure, the distribution of rotation periods for asteroids with diameter larger or smaller than $\approx$ 100 km are different and have a different mean.

On the other hand, in the available data on the rotational properties of asteroids, the prominent problems are the inaccuracy of the rotational parameters for some of the large objects, the presence of selection effects for the intermediate-size objects, and a serious lack of information for asteroids smaller than 50 km. Compared with the known population of asteroids, only about 10% of those with diameters less than 50 km have well determined rotational properties, while this percentage is 40% for objects of distances between 50 and 200 km.

With this point in mind, we have performed a regular photometry program of asteroids, the main goal of which the determination of asteroid lightcurves and rotational periods (Gil-Hutton 1988; Gil-Hutton 1998). The present paper summarizes lightcurve data for 14 asteroids obtained during different campaigns between 1996 and 2000, namely: 191 Kolga, 392 Wilhelmina, 393 Lampetia, 490 Veritas, 506 Marion, 567 Eleutheria, 570 Kythera, 713 Luscinia, 768 Struveana, 786 Bredichina, 1136 Mercedes, 1431 Luanda, 2204 Lyyli, and 4378 Voigt. Since eight of these asteroids have diameters $\approx$ 100 km and two, 1136 Mercedes and 2204 Lyyli, are very small objects of $\approx$ 27 km, the data obtained for them could help to mitigate the biases in the available data.

2. OBSERVATIONS

The observations have been obtained with the 0.76 m telescope at Estación Astronómica "Dr. Carlos Ulrrico Cesco", Félix Aguilar Observatory, San Juan, Argentina, using a 2×2-binned Texas Instrument 1024×1024 pixel CCD camera, giving an image scale of 0.4 arcsec per binned pixel and a field of view of 3.4 arcmin. Typical positional uncertainties of ± 0.5 arcmin usually allowed us to locate the

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TABLE 1

ASPECT DATA FOR THE OBSERVED ASTEROIDS

Asteroid	Filter	Date	$\lambda_{2000.0}$ (°)	$\beta_{2000.0}$ (°)	r (AU)	Δ (AU)	Phase (°)
191 Kolga	*R*	2000 May 5	247.75	16.33	3.098	2.170	8.8
		2000 May 6	247.58	16.38	3.097	2.164	8.5
		2000 Jun 1	242.27	16.92	3.084	2.107	6.1
392 Wilhelmina	*V*	1996 Jul 27	298.38	22.18	2.783	1.819	8.2
		1996 Jul 28	298.16	22.16	2.781	1.819	8.3
		1996 Aug 10	295.50	21.68	2.763	1.842	10.8
		1996 Aug 11	295.32	21.62	2.762	1.846	11.0
393 Lampetia	*V*	1998 Jan 29	117.30	−20.01	3.698	2.771	6.0
		1998 Jan 31	116.87	−19.96	3.698	2.778	6.3
		1998 Feb 1	116.66	−19.34	3.698	2.781	6.4
490 Veritas	*V*	1996 Apr 17	185.20	2.85	3.483	2.533	6.3
		1996 Apr 18	185.04	2.88	3.483	2.539	6.6
		1996 Apr 19	184.88	2.90	3.483	2.544	6.9
506 Marion	*R*	2000 Jun 2	272.21	−17.39	3.461	2.524	7.5
		2000 Jun 4	271.84	−17.37	3.462	2.515	7.1
		2000 Jul 2	266.24	−16.33	3.471	2.509	6.4
		2000 Jul 3	266.05	−16.26	3.471	2.509	6.4
		2000 Aug 3	261.98	−13.62	3.479	2.743	13.0
567 Eleutheria	*R*	2000 Aug 5	301.01	−12.30	3.206	2.222	5.3
		2000 Aug 7	300.64	−12.30	3.208	2.231	5.8
570 Kythera	*R*	2000 Jul 30	302.37	2.50	3.251	2.239	1.7
		2000 Jul 31	302.18	2.50	3.250	2.239	2.0
		2000 Aug 2	301.82	2.50	3.248	2.241	2.7
713 Luscinia	*R*	2000 Jun 3	259.53	9.35	3.312	2.312	3.5
		2000 Jul 4	253.97	10.05	3.262	2.341	9.0
		2000 Jul 17	252.47	10.01	3.240	2.424	12.4
		2000 Jul 29	251.82	9.85	3.221	3.529	15.0
768 Struveana	*R*	1996 Sep 11	324.20	−21.81	2.942	2.041	10.5
		1996 Sep 13	323.86	−21.63	2.938	2.049	11.0
		1996 Sep 14	323.70	−21.54	2.936	2.052	11.2
786 Bredichina	*R*	2000 Aug 27	327.97	−18.28	3.230	2.259	5.9
		2000 Aug 28	327.77	−18.29	3.232	2.262	6.0
		2000 Aug 29	327.57	−18.30	3.233	2.266	6.2
1136 Mercedes	*R*	1999 Dec 8	90.07	−12.35	2.355	1.401	7.9
		1999 Dec 13	88.78	−12.61	2.369	1.404	6.2
1431 Luanda	*R*	1997 Dec 6	49.98	−19.28	2.439	1.537	11.8
		1997 Dec 7	49.80	−19.16	2.441	1.544	12.1
2204 Lyyli	*R*	1997 Jan 5	99.44	−42.94	1.565	0.696	25.5
		1997 Jan 9	98.85	−41.60	1.571	0.699	25.1
		1997 Jan 10	98.85	−41.24	1.572	0.700	25.0
4378 Voigt	*V*	1997 Aug 26	327.32	−13.51	2.684	1.694	5.4
		1997 Aug 27	327.09	−13.53	2.687	1.698	5.6
		1997 Aug 29	326.63	−13.56	2.692	1.708	6.0

TABLE 2

PHYSICAL PARAMETERS OF THE OBSERVED ASTEROIDS

Asteroid	Rotational Period (hr)	Q[a]	Amplitude[b] (mag)	Diameter[c] (km)	Taxonomic Type[d]
191 Kolga	13.078 ± 0.003	3	0.447	105	XC
392 Wilhelmina	17.961 ± 0.002	3	0.779	65	···
393 Lampetia	···	···	>0.20	106	C
490 Veritas	9.962 ± 0.004	3	0.577	121	C
506 Marion	18.505 ± 0.003	3	0.683	109	C
567 Eleutheria	12.673 ± 0.003	3	0.525	99	CFB
570 Kythera	6.903 ± 0.002	3	0.206	106	ST
713 Luscinia	9.296 ± 0.002	3	0.399	109	C
768 Struveana	8.802 ± 0.004	3	0.631	···	EMP
786 Bredichina	18.61 ± 0.02	3	0.648	101	C
1136 Mercedes	6.448 ± 0.002	2	0.116	27	···
1431 Luanda	5.360 ± 0.002	3	1.050	···	···
2204 Lyyli	9.51 ± 0.01	3	0.619	28	···
4378 Voigt	10.796 ± 0.004	3	0.520	···	···

[a]Reliability code: 1 means that the result is based on fragmentary lightcurves and may be completely wrong; 2 means that the result is based on less than full coverage and the period may be wrong by 30%, or the result is not unique; 3 denotes a reliable result with no ambiguity and full lightcurve coverage.

[b]Obtained by measuring the maximum light variation and with error always less than 0.014 mag.

[c]Tedesco et al. (1989). [d]Tholen (1989).

asteroid within an image frame centered on the predicted position. An asteroid's identity was confirmed through detection and measurement of its motion vector. Due to the brightness of the target asteroids, the telescope was tracked at sidereal rate, and exposures between 180 and 300 s were used. Differential photometry in the standard V or R bands was carried out using background stars as local comparisons due to their closeness to the asteroids. Only during the observing run of April 1996 were the nights photometric, allowing us to standardize the local comparisons used for 490 Veritas by means of the equatorial standard stars of Landolt (1992).

Flat field images were obtained for each filter using the evening and morning twilight sky. Also, more than ten bias and five dark frames were obtained during the course of each night to test the noise level and the dark current of the CCD chip, but the dark mean remained constant to within less than 1 ADU of the bias level. Magnitudes for the asteroid and at least two comparison stars were extracted from each image using the technique of aperture photometry. All image processing, including bias subtraction and flat field corrections, was performed using the Image Reduction and Analysis Facility (IRAF) software package developed by the National Optical Astronomy Observatories (NOAO).

Aspect data for all observing nights are given in Table 1, including the filter used, the date, geocentric ecliptic longitude (λ) and latitude (β) of the asteroid, heliocentric (r) and geocentric (Δ) distances, and the solar phase angle (α). The observations were corrected for light-time, and the magnitudes were reduced to $\alpha = 0°$ and corrected for distance. The exposure time was chosen in such a way that the error of any single measurement is always ≈ 0.01 mag.

3. RESULTS

To search for rotational periods and composite lightcurves, the data obtained were analyzed using the procedure described by Magnusson & Lagerkvist (1990). A Fourier series is adjusted to the data and the "true" period should be that which shows the composite lightcurve with the smallest dispersion. In Table 2 we summarize the values found for the rotational period, their reliability code Q (see footnotes to table), the amplitude of the composite lightcurve, the diameter (Tedesco et al. 1989) and taxonomic types (Tholen 1989) of all objects. Figs. 1 to 14 show the V or R composite lightcurves for all the

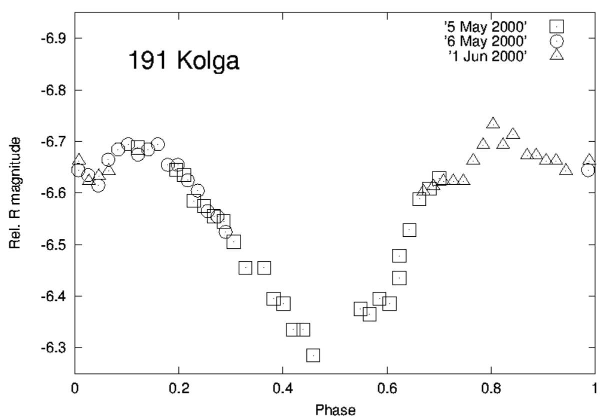

Fig. 1. Composite lightcurve of asteroid 191 Kolga; relative R magnitudes versus phase.

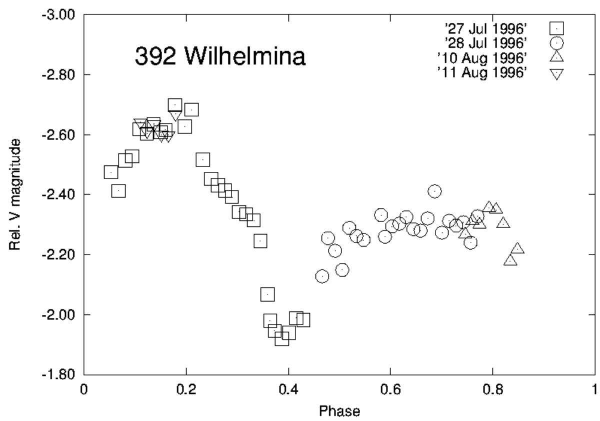

Fig. 2. Composite lightcurve of asteroid 392 Wilhelmina; relative V magnitudes versus phase.

asteroids observed, except 393 Lampetia, for which three single lightcurves are presented. The different symbols denote different observing nights. The 0 rotational phase corresponds to the 0 hours. UT of the first observing day shown in the figures. The phases were computed according to the rotational period reported in Table 2.

3.1. *191 Kolga*

This relatively large object was observed during three nights in May and June 2000. The composite lightcurve (Figure 1), obtained using a rotational period of 13.078 ± 0.003 hrs, appears asymmetric and shows four extrema but unequal minima. The amplitude of the light variation is 0.447 mag.

3.2. *392 Wilhelmina*

We observed this asteroid during four nights in July and August 1996. The rotational period that gives the best fit of the composite lightcurve is 17.961 ± 0.004 hrs (Figure 2). The symmetric lightcurve shows a well defined primary maximum, while the secondary one appears to be shallow and flat. The amplitude of the light variation is 0.779 mag.

3.3. *393 Lampetia*

The only published lightcurves of this asteroid are those obtained during October 1977 by Scaltritti, Zappalà, & Schober (1979). From the analysis of the individual lightcurves a rotational period of 38.7 hrs and an amplitude larger than 0.09 mag were proposed. The data presented in this paper were obtained during three nights in January and February 1998 (Figure 3), but we were not able to determine a rotational period because the lightcurves cover only part of the rotational phase. The amplitude is larger than 0.20 mag.

3.4. *490 Veritas*

This large C-type asteroid was observed during three nights in April 1996. The rotational period which gives the best fit of the composite lightcurve (Figure 4) is 9.962 ± 0.004 hrs. The symmetric lightcurve shows four extrema with a shallow and flat secondary maximum. The amplitude of the light variation is 0.577 mag.

3.5. *506 Marion*

The observations of this object were performed during five nights in June, July, and August 2000. The best value of the rotational period which we determined is 18.505 ± 0.003 hrs. The very asymmetric composite lightcurve (Figure 5) shows a well-defined maximum at phase 0.9 and a tiny secondary maximum at phase 0.35. On the other hand, a bump on the lightcurve appears at phase 1.0, which could be the effect of an irregular shape or an albedo spot. The amplitude of the light variation is 0.683 mag.

3.6. *567 Eleutheria*

The observations of 567 Eleutheria were carried out during two nights in August 2000. The rotational period found is 12.673 ± 0.003 hrs, and the composite lightcurve (Figure 6) is asymmetric with four well-defined extrema. The amplitude of the light variation is 0.525 mag.

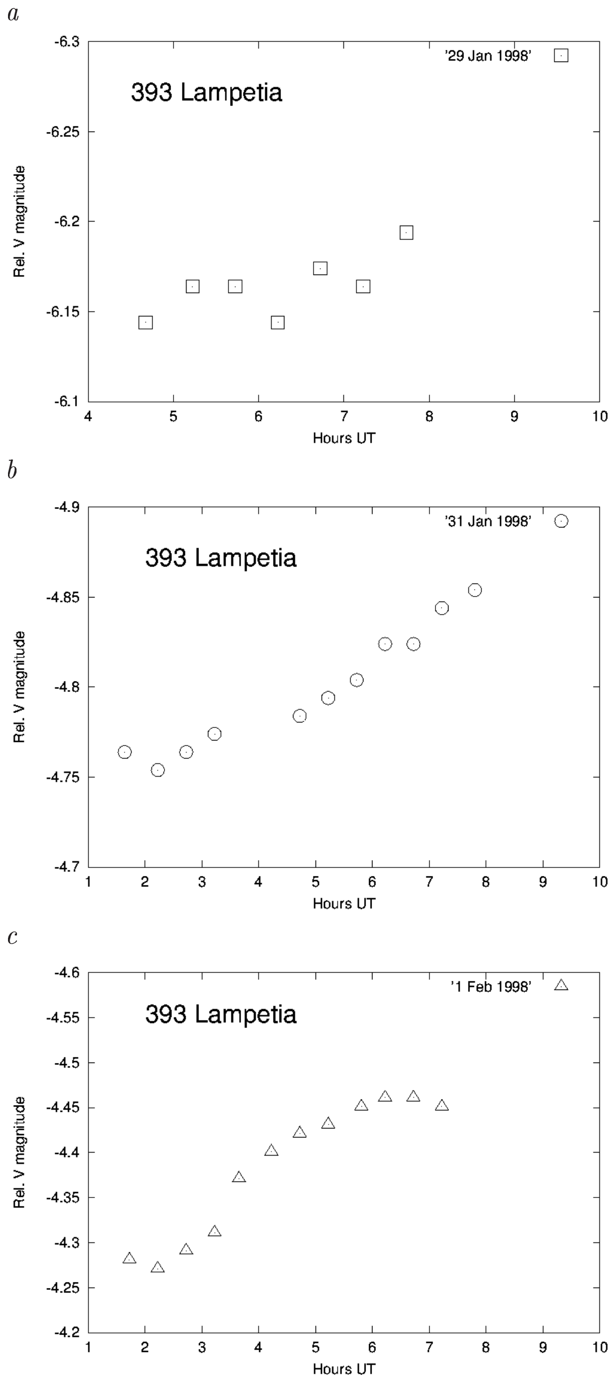

Fig. 3. Individual lightcurves of asteroid 393 Lampetia; relative V magnitudes versus phase for the nights of: (*a*) 01/29/98; (*b*) 01/31/98; and (*c*) 02/01/98.

3.7. *570 Kythera*

This asteroid was observed during two nights in September 1994 by Blanco, Di Martino, & Riccioli (2000) who found a rotational period of 6.919 ± 0.006 hrs and an amplitude of 0.15 mag. From three nights of photometry during July and August 2000, we determined a rotational period of 6.903 ± 0.002 hrs which is in good agreement with the previous value.

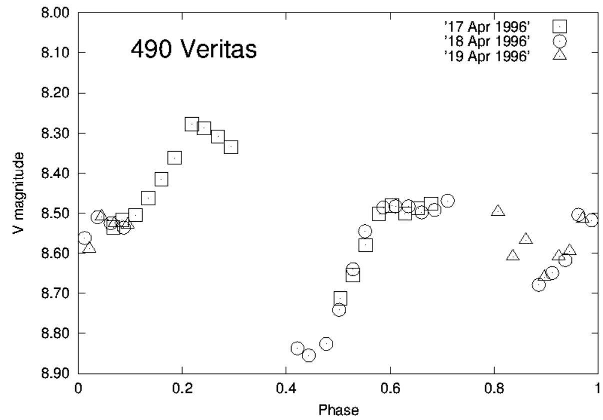

Fig. 4. Composite lightcurve of asteroid 490 Veritas; standard V magnitudes versus phase.

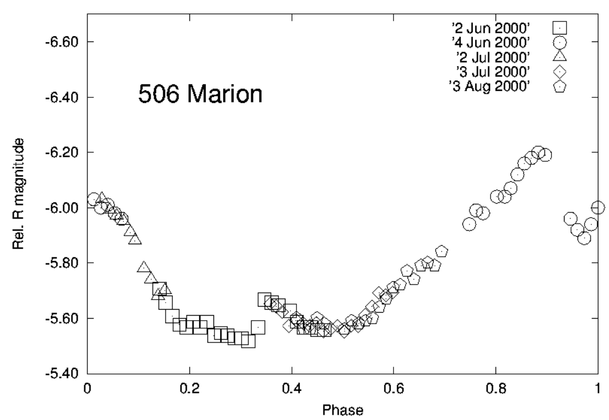

Fig. 5. Composite lightcurve of asteroid 506 Marion; relative R magnitudes versus phase.

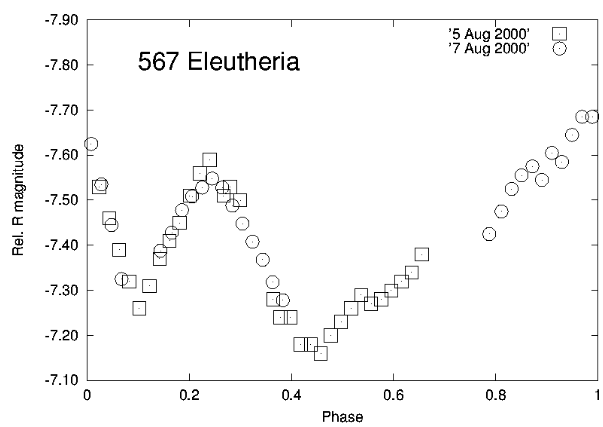

Fig. 6. Composite lightcurve of asteroid 567 Eleutheria; relative R magnitudes versus phase.

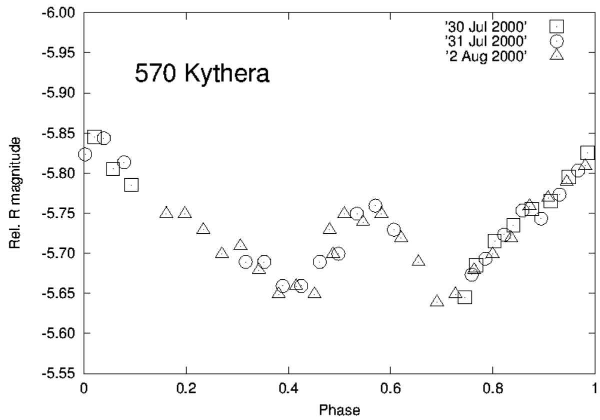

Fig. 7. Composite lightcurve of asteroid 570 Kythera; relative R magnitudes versus phase.

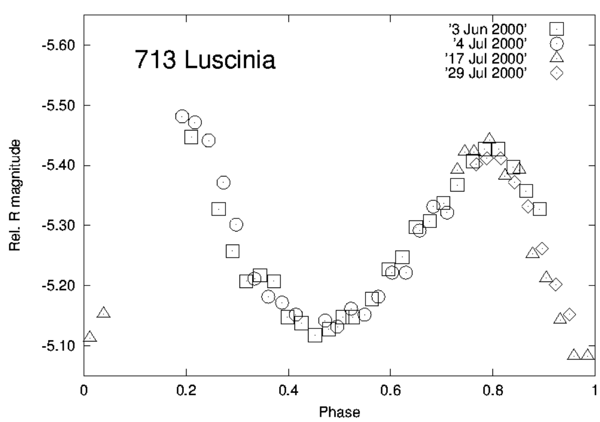

Fig. 8. Composite lightcurve of asteroid 713 Luscinia; relative R magnitudes versus phase.

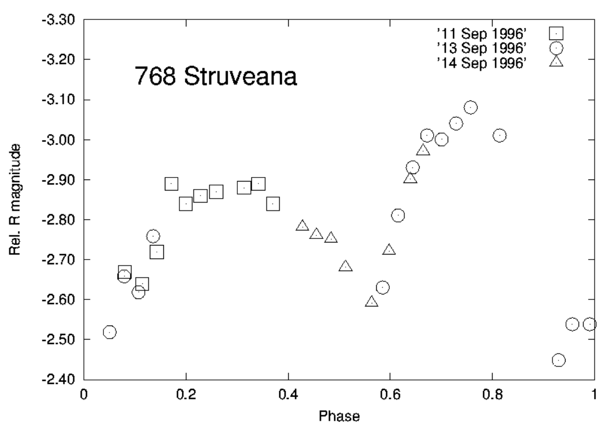

Fig. 9. Composite lightcurve of asteroid 768 Struveana; relative R magnitudes versus phase.

The composite lightcurve (Figure 7) is asymmetric and the amplitude of the light variation is 0.206 mag.

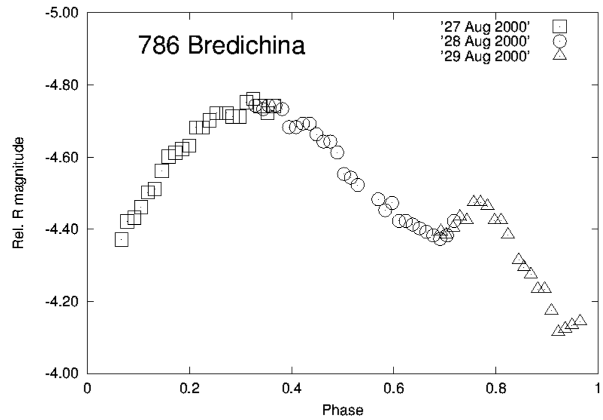

Fig. 10. Composite lightcurve of asteroid 786 Bredichina; relative R magnitudes versus phase.

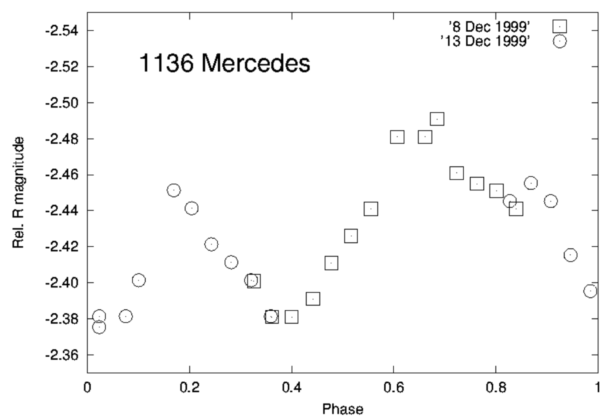

Fig. 11. Composite lightcurve of asteroid 1136 Mercedes; relative R magnitudes versus phase.

3.8. *713 Luscinia*

This quite large object was observed during one night in October 1995 by Blanco et al. (2000) who obtained a rotational period of 9.274 ± 0.002 hrs. We observed this asteroid during four nights in June and July 2000, and the rotational period that gives the best fit of the composite lightcurve (Figure 8) is 9.296 ± 0.002. The lightcurve shows two maxima and two minima, all well-defined, and an amplitude of 0.399 mag.

3.9. *768 Struveana*

The data for this asteroid were obtained during three nights in September 1996. We derived a rotational period of 8.802 ± 0.004 hrs. The composite lightcurve (Figure 9) is symmetric with a broad secondary maximum. The amplitude of the light variation is 0.631 mag.

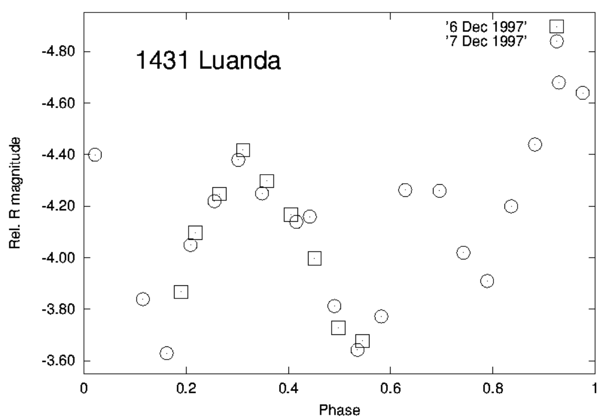

Fig. 12. Composite lightcurve of asteroid 1431 Luanda; relative R magnitudes versus phase.

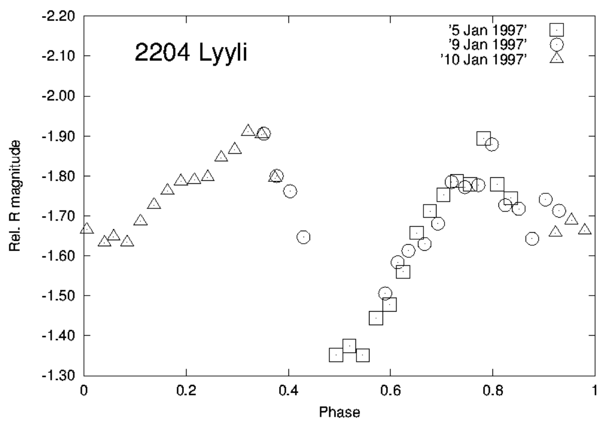

Fig. 13. Composite lightcurve of asteroid 2204 Lyyli; relative R magnitudes versus phase.

3.10. *786 Bredichina*

This C-type asteroid was observed during three nights in August 2000. The best rotational period found is 18.61 ± 0.02 hrs, and the composite lightcurve (Figure 10) is very asymmetric with unequal maxima and minima. The amplitude of the light variation is 0.648 mag.

3.11. *1136 Mercedes*

The observations of this small object were carried out during two nights in December 1999. The rotational period that gives the best fit of the composite lightcurve (Figure 11) is 6.448 ± 0.002 hrs. Due to the short individual lightcurves used to make the composite, alternative values cannot be ruled out. The amplitude of the light variation is 0.116 mag.

3.12. *1431 Luanda*

We observed this asteroid during two nights in December 1997. The best rotational period found is

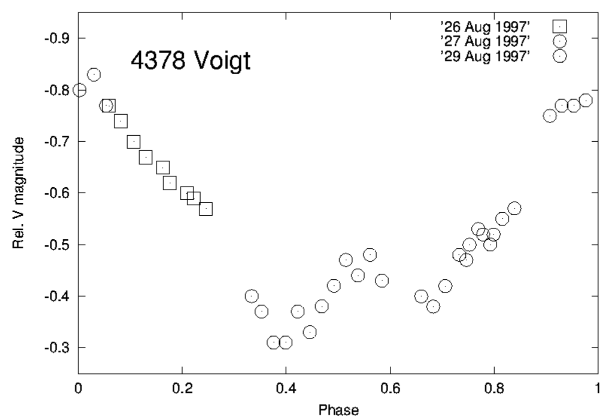

Fig. 14. Composite lightcurve of asteroid 4378 Voigt; relative V magnitudes versus phase.

5.360 ± 0.002 hrs. The composite lightcurve (Figure 12) has a large amplitude of 1.050 mag, and shows two sharp maxima, but also a bump that appears around the rotational phase 0.6–0.7, which could be the effect of an irregular shape or an albedo spot.

3.13. *2204 Lyyli*

This object was observed during three nights in January 1997. We derive a rotational period of 9.51 ± 0.01 hrs. The composite lightcurve (Figure 13) appears symmetric and shows a shallow secondary minimum. The amplitude is 0.619 mag.

3.14. *4378 Voigt*

The observations of 4378 Voigt were performed during three nights in August 1997. The rotational period that gives the best fit of the composite lightcurve (Figure 14) is 10.796 ± 0.004 hrs. The lightcurve is very asymmetric with four well-defined extrema. The amplitude of the light variation is 0.520 mag.

4. CONCLUSIONS

We have presented lightcurves for 14 main belt asteroids obtained between 1996 and 2000. The rotational periods of 191 Kolga, 393 Wilhelmina, 490 Veritas, 506 Marion, 567 Eleutheria, 768 Struveana, 786 Bredichina, 1136 Mercedes, 1431 Luanda, 2204 Lyyli, and 4378 Voigt were determined for the first time. All the composite lightcurves are potentially useful in future pole determinations of the observed asteroids.

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