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Photometry and models of selected main belt asteroids

III. 283 Emma, 665 Sabine, and 690 Wratislavia

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ABSTRACT

Photometric observations of 283 Emma (1998, 2000, 2001, 2004), 665 Sabine (1998, 1999, 2001, 2004, 2005), and 690 Wratislavia (1998, 2000, 2004, 2005–2006) carried out on 44 nights at two observatories are presented. Using all available lightcurves, the spin vectors, senses of rotation, and shape models for these three asteroids have been determined.

Key words. techniques: photometric – minor planets, asteroids

1. Introduction

Photometric observations of asteroids performed during a few oppositions allow a determination of their physical parameters, namely sidereal rotational periods, pole orientations, sense of rotation, and shape models. Pravec et al. (2002) show that there was a small excess of asteroids that rotate in the prograde sense to those rotating in the retrograde one, and the asteroid poles seemed to avoid the ecliptic plane. Contrary to this, La Spina et al. (2004) show that most near earth asteroids rotated in a retrograde sense and that their axes were spatially aligned.

The photometric database consists of the lightcurves of more than 2000 asteroids, but spin vectors have been determined for fewer than 200 of them. This paper gives the parameters for three asteroids and is the third paper in a series devoted to enlarging the number of asteroids with known physical parameters. The lightcurves of many asteroids have been only known from one or two oppostions, so it would be desirable to observe them at more apparitions. The new photometric observations, combined with the previously published ones, will be used to determine the sidereal periods, coordinates of poles, and shape models for the observed asteroids. These new models will be included in the existing database of spin parameters (http://www.astro.amu.edu.pl/Science/Asteroids/) to be used for future investigations.

2. Observations of three main belt asteroids

Photometric observations of three asteroids (283 Emma, 665 Sabine, and 690 Wratislavia) from 44 nights in the years 1998–2006 were made at two observatories. Almost all of the data came from the Borowiec Station of Poznań Astronomical Observatory (Poland). The observations from one night (22 March 2001) of the asteroid Emma were carried out at Kharkiv (Kharkiv University, Ukraine).

At Borowiec Observatory a 0.4-m, $F/4.5$ Newton reflector was used, equipped with a *KAF*400 CCD camera and a set of Bessel *BVRI* filters. An additional, clear-glass filter was also used, so that unfiltered exposures could have been mixed with the filtered ones without the need to refocus the optical system (see Michałowski et al. 2004 for a full description of the instrument and the reduction procedure). These observations have not been transformed to the standard system, mainly because of non-photometric weather and/or the clear filter used.

The CCD observations at Borowiec have been performed since 1997. Results for some selected main belt asteroids were published in Michałowski et al. (2000, 2001), Kryszczyńska et al. (2003), Torppa et al. (2003), and in two previous papers of the present series – Michałowski et al. (2004, 2005).

A 0.70-m telescope with CCD camera and V filter were used at Kharkiv Observatory. The frames were reduced with the synthetic aperture photometry package ASTPHOT (Mottola et al. 1995; Erikson et al. 2000) These photometry data were then transformed to the standard system.

Table 1 contains the aspect data for the asteroids observed. The first column is the date of the observation referring to the mid-time of the lightcurve observed. The next columns are the distances (in astronomical units) from the asteroid to the Sun and the Earth, the solar phase angle, the $J2000.0$ ecliptic longitude (λ), and latitude (β), respectively, referred to the time in the first column. The names of the observatories are listed in the last column of the table.

The basic parameters of the asteroids are summarised in Table 2. Their *IRAS* diameters (D), albedos, and taxonomic types are taken from *The Small Bodies Node of the NASA Planetary Data System* (http://pdssbn.astro.umd.edu/).

The results of our observations are presented in Figs. 1–13 as composite lightcurves. They were obtained by applying a procedure described by Magnusson & Lagerkvist (1990). The lightcurves were composited with the synodical periods shown in the graphs. Points from different nights are marked with

Table 1. Aspect data.

Date (UT)	r	Δ	Phase angle	λ (J2000)	β	Obs.
	(AU)	(AU)	(°)	(°)	(°)	
283 Emma						
1998 10 15.8	2.574	1.708	13.53	346.22	9.90	Bor
1998 10 16.8	2.574	1.716	13.86	346.13	9.89	Bor
1998 11 04.8	2.576	1.897	18.82	345.77	9.44	Bor
1998 12 29.7	2.594	2.596	21.84	356.65	7.69	Bor
2000 01 30.8	3.099	2.250	10.85	94.08	3.72	Bor
2000 02 11.9	3.117	2.384	13.93	93.08	3.17	Bor
2000 02 27.8	3.140	2.596	16.67	93.06	2.48	Bor
2001 03 07.0	3.493	2.507	2.11	165.73	–7.40	Bor
2001 03 22.9	3.498	2.549	5.86	162.61	–7.60	Kha
2001 04 02.9	3.501	2.621	8.97	160.84	–7.60	Bor
2004 09 17.0	2.741	2.420	21.32	76.75	8.48	Bor
2004 10 11.0	2.772	2.154	18.47	79.20	9.26	Bor
2004 11 10.8	2.815	1.913	10.09	77.08	9.93	Bor
665 Sabine						
1998 09 20.9	3.131	2.163	5.85	352.17	17.74	Bor
1998 09 21.9	3.133	2.167	5.98	351.95	17.76	Bor
1998 09 22.8	3.134	2.170	6.09	351.77	17.77	Bor
1998 10 01.8	3.148	2.215	7.82	350.03	17.80	Bor
1999 10 17.9	3.607	2.824	11.09	65.36	17.08	Bor
1999 10 19.0	3.608	2.814	10.86	65.24	17.12	Bor
2001 02 13.9	3.516	2.683	9.89	107.50	0.42	Bor
2001 04 05.9	3.460	3.287	16.80	107.58	–1.60	Bor
2004 08 19.0	3.306	2.759	16.22	30.93	17.22	Bor
2004 09 07.1	3.333	2.579	13.08	30.30	18.85	Bor
2004 09 08.0	3.335	2.572	12.91	30.23	18.92	Bor
2004 09 14.1	3.343	2.527	11.61	29.58	19.38	Bor
2004 09 16.1	3.346	2.514	11.16	29.32	19.52	Bor
2004 09 17.1	3.347	2.508	10.94	29.19	19.59	Bor
2004 09 17.9	3.349	2.503	10.77	29.08	19.64	Bor
2005 10 30.0	3.674	2.989	12.46	88.55	12.45	Bor
2005 10 31.9	3.674	2.967	12.12	88.43	12.48	Bor
690 Wratislavia						
1998 09 24.9	2.617	1.772	14.42	324.12	16.70	Bor
1998 09 25.9	2.616	1.778	14.69	324.04	16.64	Bor
1998 09 26.8	2.615	1.785	14.97	323.96	16.57	Bor
2000 02 03.9	3.008	2.311	15.20	81.45	–5.88	Bor
2004 10 03.8	2.570	1.621	8.91	29.90	14.03	Bor
2004 10 08.0	2.572	1.609	7.54	29.12	13.93	Bor
2004 10 11.8	2.574	1.602	6.42	28.36	13.79	Bor
2004 10 12.8	2.574	1.600	6.14	28.14	13.75	Bor
2004 10 13.8	2.575	1.599	5.91	27.93	13.71	Bor
2005 10 31.1	3.129	2.948	18.50	126.68	–6.87	Bor
2005 11 01.1	3.131	2.936	18.47	126.83	–6.93	Bor
2006 01 10.0	3.254	2.307	5.61	124.49	–11.66	Bor
2006 01 11.9	3.257	2.304	5.11	124.09	–11.75	Bor
2006 01 26.9	3.282	2.317	4.03	120.92	–12.23	Bor

Observatory Code: Bor – Borowiec; Kha – Kharkiv.

Table 2. Asteroid parameters.

Asteroid	D(km)	albedo	Type
283 Emma	148	0.026	X
665 Sabine	51	0.390	
690 Wratislavia	135	0.076	CPF

different symbols. The vertical position of each individual lightcurve is obtained to minimize the dispersion of data points relative to their neighbours. The abscissae are the rotational phases with the zero points corrected for light-time.

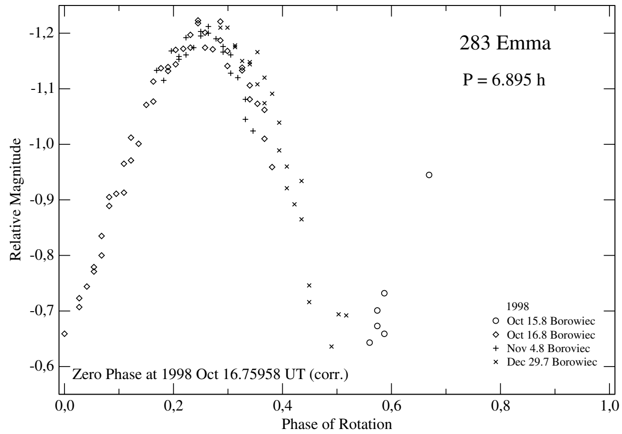

Fig. 1. Lightcurve of 283 Emma in 1998.

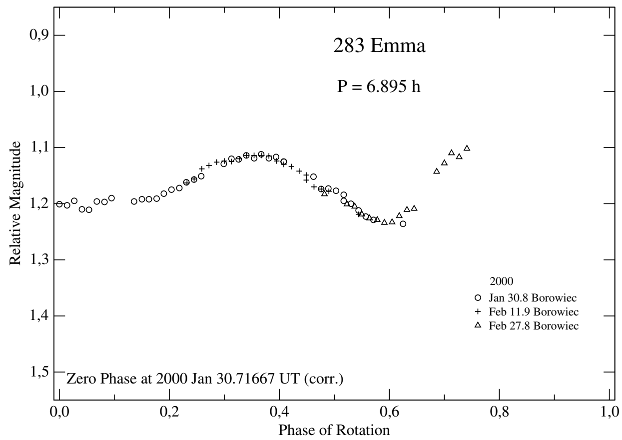

Fig. 2. Lightcurve of 283 Emma in 2000.

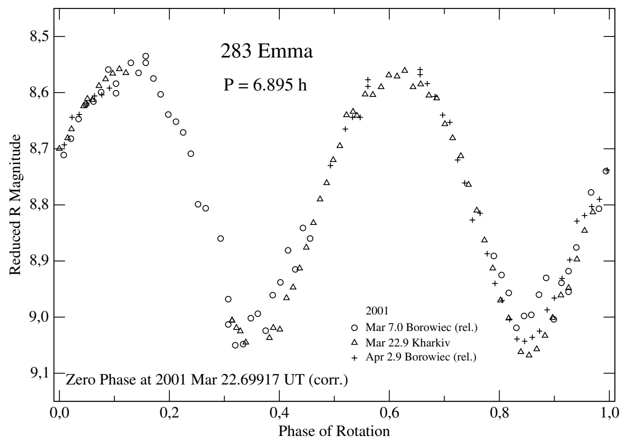

Fig. 3. Lightcurve of 283 Emma in 2001.

2.1. 283 Emma

The first photometric observations of this asteroid, a member of the Eos family, were performed by Stanzel (1978) on five nights in October 1977. The lightcurve had a sinusoidal shape with an amplitude of 0.31 mag, and a synodical period of 6.89 h was obtained.

On 14 July 2003 the asteroid 283 Emma was discovered to be a binary system (Merline et al. 2003) with a satellite orbital period of 3.364 days and separation 0.26″ (370 km). Emma's satellite was observed with the 10-m Keck II telescope and an adaptive optics system. Its diameter was determined to be about

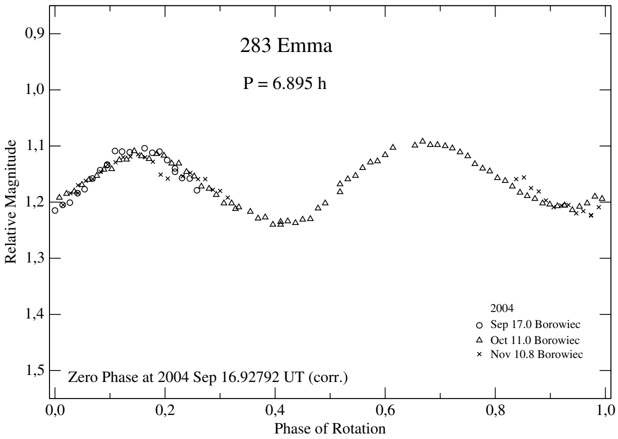

Fig. 4. Lightcurve of 283 Emma in 2004.

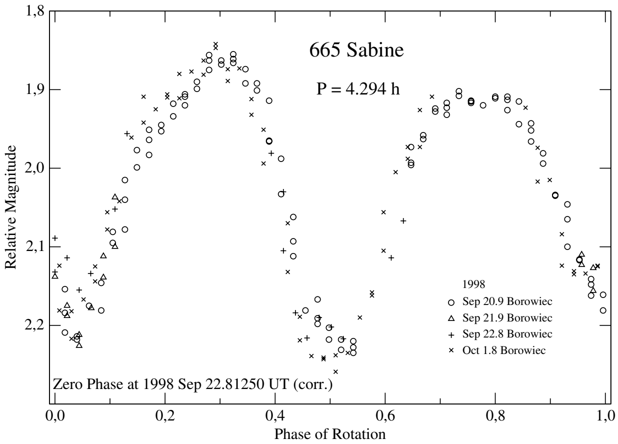

Fig. 5. Lightcurve of 665 Sabine in 1998.

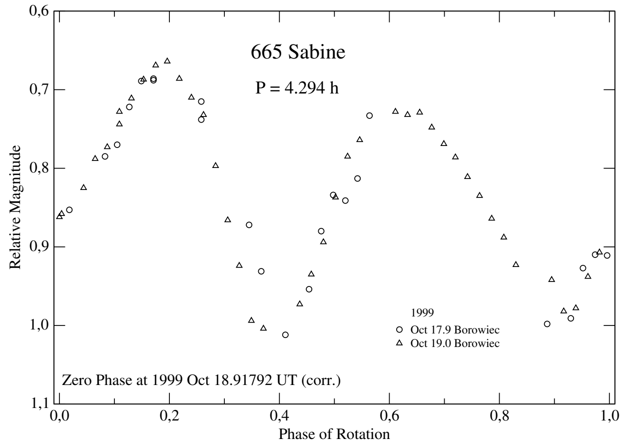

Fig. 6. Lightcurve of 665 Sabine in 1999.

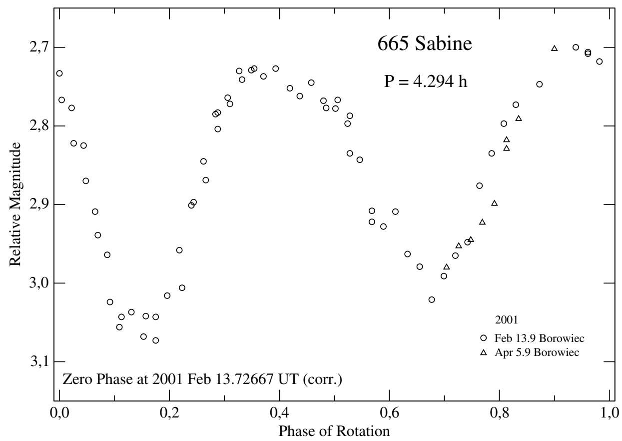

Fig. 7. Lightcurve of 665 Sabine in 2001.

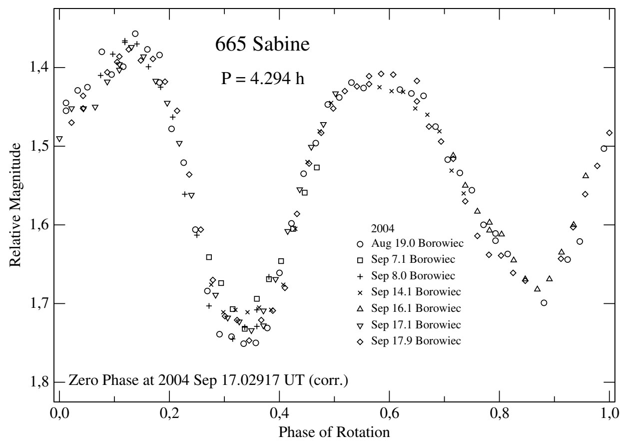

Fig. 8. Lightcurve of 665 Sabine in 2004.

12 km, It is a small satellite relative to the diameter of the primary body (see Table 2)

We observed 283 Emma on 13 nights during four apparitions: 1998, 2000, 2001, and 2004. The composite lightcurves were constructed with the synodical period of 6.895 ± 0.003 h, which is consistent with the value given by Stanzel (1978).

The lightcurve obtained in October–December 1998 (Fig. 1) covered about 60% of the rotational cycle, and only one maximum and one minimum were clearly visible. An amplitude was 0.57 ± 0.02. The observations carried out in January–February 2000 (Fig. 2) covered 70% of the cycle and revealed a smaller amplitude of 0.13 ± 0.01 mag. The lightcurve from 3 nights in March–April 2001 (Fig. 3) showed a larger amplitude of 0.50 ± 0.02 mag. The light variation recorded on 3 nights in September–November 2004 (Fig. 4) revealed an amplitude of 0.14 ± 0.01 mag.

2.2. 665 Sabine

This asteroid was observed by Hainaut-Rouelle et al. (1995) on 20 April 1991. This one-night run covered almost two rotational cycles of the asteroid. The amplitude was 0.34 mag and the period of 4.292 h was determined. Next observations were carried out on 25 and 29 August 1992 by Riccioli et al. (1995). The amplitude was 0.35 mag, similar to the one from the previous opposition. These two runs did not cover the whole rotational cycle and the authors made an incorrect composite lightcurve with a period of 3.932 h. With a different identification of the visible extrema, they could obtain the same period as in Hainaut-Rouelle et al. (1995). Our observations (see below) have confirmed this longer period.

We obtained observational data on 17 nights during 5 apparitions: 1998, 1999, 2001, 2004, and 2005. The synodical period was determined to be 4.294 ± 0.001 h, consistent with the value given by Hainaut-Rouelle et al. (1995). We would like to stress that we are not able to obtain any composite lightcurves based on our observations with the shorter period published by Riccioli et al. (1995).

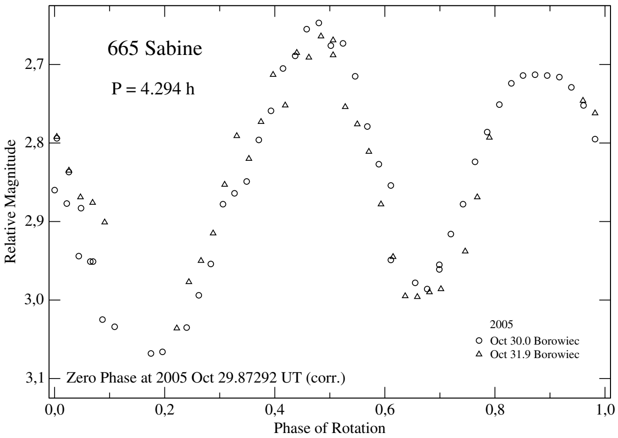

Fig. 9. Lightcurve of 665 Sabine in 2005.

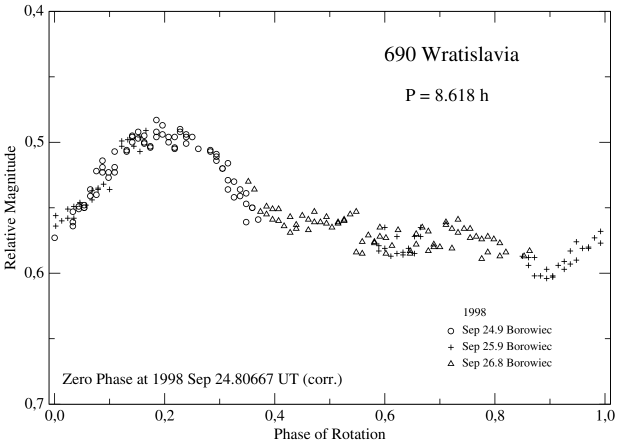

Fig. 10. Lightcurve of 690 Wratislavia in 1998.

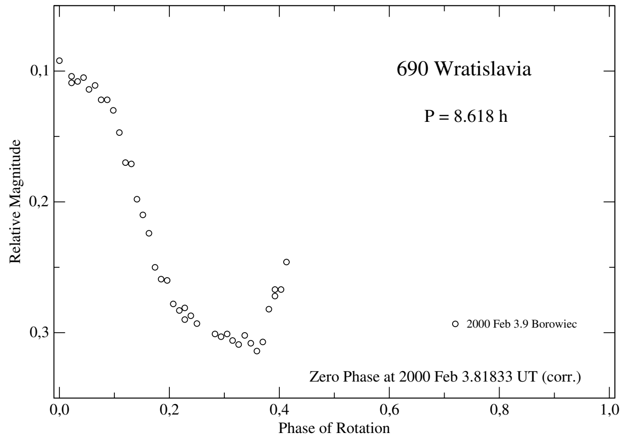

Fig. 11. Lightcurve of 690 Wratislavia in 2000.

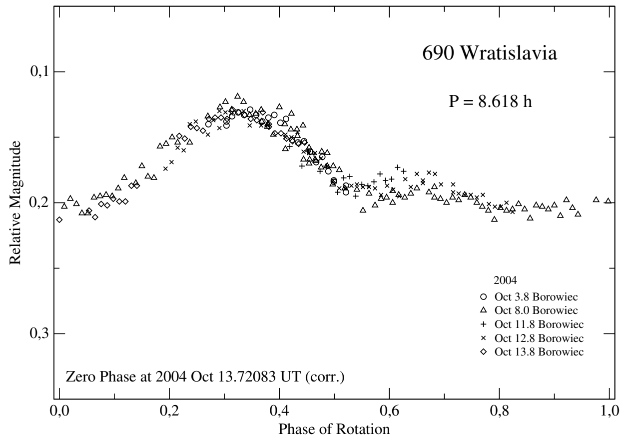

Fig. 12. Lightcurve of 690 Wratislavia in 2004.

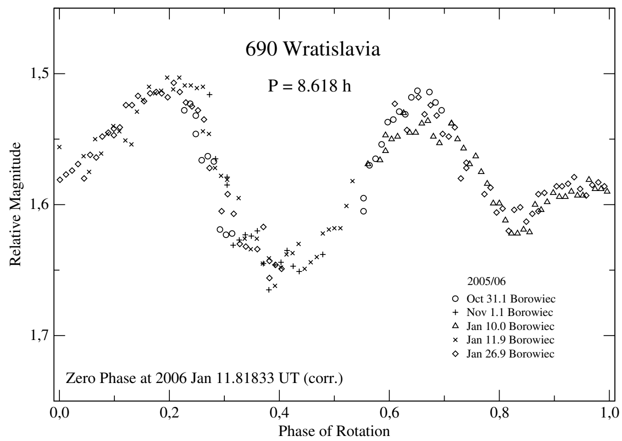

Fig. 13. Lightcurve of 690 Wratislavia in 2005–06.

The lightcurve from four nights in September–October 1998 (Fig. 5) was quite regular and had an amplitude of 0.39 ± 0.02 mag. The data from two nights in October 1999 (Fig. 6) indicated a very similar lightcurve with a slightly smaller amplitude of 0.34 ± 0.01 mag. The runs from two nights in February and April 2001 (Fig. 7) showed the lightcurve with an amplitude of 0.36 ± 0.02 mag. The observations from seven nights in August–September 2004 (Fig. 8) also revealed a regular lightcurve and the amplitude was 0.37 ± 0.02 mag. A composite lightcurve from two nights in October 2005 (Fig. 9) was with the largest amplitude (0.41 ± 0.02 mag) obtained for this asteroid. However, the amplitudes from all the apparitions were very similar, indicating that the asteroid's axis was far from the ecliptic plane.

2.3. 690 Wratislavia

There is an interesting history of observations and period determinations for 690 Wratislavia. Gil-Hutton (1988) observed this asteroid on three nights in September 1987. He obtained a synodical period of 6.31 h from the one-pair extrema lightcurve with an amplitude of 0.13 mag. Wratislavia was observed by the same author on one night in July 1992 (Gil-Hutton 1995). Due to instrumental problems, the lightcurve had significant gaps. These data did not allow a determination of the period but showed that the previous reported period was not correct. He reanalysed the 1987 observations and suggested that the new values for the period are 9.906 or 12.621 h.

Denchev (2000) observed Wratislavia on two nights in July and on one night in September 1998. He obtained a two-pair extrema lightcurve with a period of 9.909 h. The composite lightcurve contained two separate parts and the amplitude seemed to be smaller than 0.16 mag.

The observations performed by Sada (2000) on five nights in December 1999 revealed completely different results. The period of 8.60 ± 0.02 h was obtained on the basis of the composite lightcurve showing two maxima and two minima. The amplitude was 0.20 mag, the largest observed for this asteroid. It was

Table 3. Spin and shape models.

Sidereal period (days)	Sense of rotation	Pole 1 λ_p	Pole 1 β_p	Pole 2 λ_p	Pole 2 β_p	a/b	b/c	Method	Reference
283 Emma									
0.2873008	P	80°	+37°	261°	+28°	1.4	1.0	L	Present work
±0.0000004		±5°	±5°	±5°	±5°				
665 Sabine									
0.1789179	R	310°	−77			1.3	1.2	L	Present work
±0.0000004		±5°	±5°						
690 Wratislavia									
0.3590825	P	177°	+17°	359°	+45°	1.1	1.3	L	Present work
±0.0000004		±5°	±5°	±5°	±5°				

pointed out that the new period was about 2/3 of the 12.621 h suggested by Gil-Hutton (1995).

Stephens & Durkee (2005) reported their results obtained from the five nights of observations performed between 24 and 29 September 2004. They could not obtain any composite lightcurves with the period reported by Gil-Hutton (1995) and Denchev (2000). Finally, they estimated the period to be 8.64 ± 0.01 h. Moreover, the 2004 observations revealed the lightcurve with an amplitude of 0.12 mag and one maximum and one minimum within this period, contrary to the two-pair extrema lightcurve in December 1999. They also replotted the data from 1987 and 1998 (Gil-Hutton 1995 and Denchev 2000, respectively) and obtained the composite lightcurves with one pair of extrema. They concluded that Wratislavia showed one-pair extrema lightcurves in 1987, 1998, and 2004 oppositions, and two-pair extrema in 1992 and 1999 within the same rotational period. Our data confirm this conclusion (see below).

We present the lightcurves from 14 nights obtained during four apparitions: 1998, 2000, 2004, and 2005/06. The lightcurves from 3 nights in September 1998 (Fig. 10) were additional data to those obtained by Denchev (2000) during the same opposition. Our observations agree well with the previously published lightcurve and confirmed the conclusion by Stephens & Durkee (2005) about one maximum and one minimum in that apparition. The amplitude was small, 0.11 ± 0.01 mag. Figure 11 presents the data obtained on 3 February 2000 covering only 40% of the cycle. This lightcurve provides the data additional to those recorded in December 1999 (Sada 2000). The amplitude seemed to be 0.31 mag, larger than that obtained by Sada, which was due to a much larger phase angle in February 2000 than in December 1999. Our observations from 5 nights in October 2004 (Fig. 12) were obtained in the same opposition as that in September by Stephens & Durkee (2005). The October data showed a one-pair extrema lightcurve with an amplitude of only 0.08 ± 0.01 mag. The difference between the amplitudes reported here and in Stephens & Durkee (2005) was probably due to much higher noise in the observations from September 2004. The lightcurves obtained on five nights between 31 October 2005 and 26 January 2006 (Fig. 13) showed two maxima and two minima per rotational cycle. The amplitude of light variation was 0.15 ± 0.02 mag.

It should be mentioned that the earlier spurious attempts on Wratislavia's period by Gil-Hutton (1988, 1995) and by Denchev (2000), who used limited data (1–3 nights), were resolved when more abundant data were obtained by Sada (2000) and by Stephens & Durkee (2005). We have refined the synodic period estimate to 8.618 ± 0.003 with more data available. The estimates by Sada (2000) and by Stephens & Durkee (2005) were in agreement with the new value to 1–2 times their formal errors. We have checked all the other data and can conclude that the value of 8.618 revealed good composite lightcurves for the observations obtained in all available oppositions. This value appears on all graphs displaying our observations in the present paper.

3. Pole and shape of the observed asteroids

The spin vectors, sidreal periods, and shape models of the observed asteroids were determined by the so-called *lightcurve inversion* method described by Kaasalainen & Torppa (2001) and Kaasalainen et al. (2001, 2003). This method uses all data points (both relative and absolute photometry) and finds a physical model with a large number of parameters that accurately reproduce the photometric data down to the noise level. As in other methods, the $\lambda_p \pm 180°$ ambiguity for the pole solution is always physically inevitable for asteroids moving close to the ecliptic plane. This method was also used in two previous papers of the present series (Michałowski et al. 2004, 2005).

Table 3 contains the spin and shape models of the asteroids studied in the present paper. This table shows the sidereal periods, the rotation directions (*P* – prograde, *R* – retrograde), the ecliptic coordinates (equinox 2000) of the north poles, and the ratios a/b, b/c of triaxial ellipsoid models. There are only coarse estimations of the ellipsoid models for the shapes obtained with the *lightcurve inversion* method. This method is indicated by *L* in the next column. There are no earlier published pole results for the asteroids studied in the present paper.

At present there are the lightcurves from five apparitions (1977, 1998, 2000, 2001, and 2004) available for the asteroid 283 Emma. We obtained the prograde sense of rotation for this asteroid and two solutions for the pole orientation (see Table 3). The shape model of Emma is shown in Fig. 14.

We can use the lightcurves from seven apparitions (1991, 1992, 1998, 1999, 2001, 2004, and 2005) for 665 Sabine. This asteroid is a retrograde rotator with its pole far from the ecliptic plane (Table 3). Due to a high inclination orbit of this asteroid, there is no "$\lambda + 180°$" mirror pole. The model of this asteroid is shown in Fig. 15.

There are data from six oppositions (1987, 1992, 1998, 1999–2000, 2004, and 2005–2006) available for 690 Wratislavia. We obtained the prograde sense of rotation and quite a small a/b consistent with rather small amplitudes observed (Table 3). The first solution for the pole is preferred, but

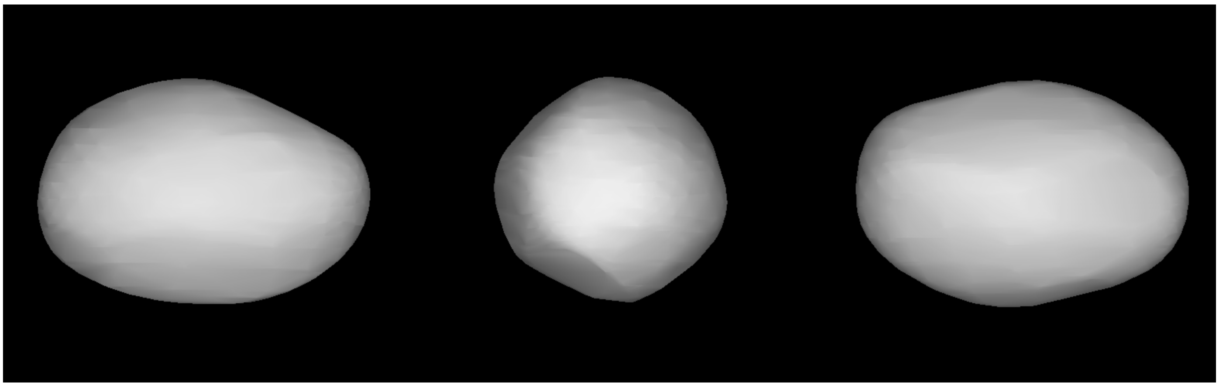

Fig. 14. Shape model of 283 Emma, shown at an equatorial viewing geometry, with rotational phases 90° apart (two pictures on the left) and the pole-on view on the right.

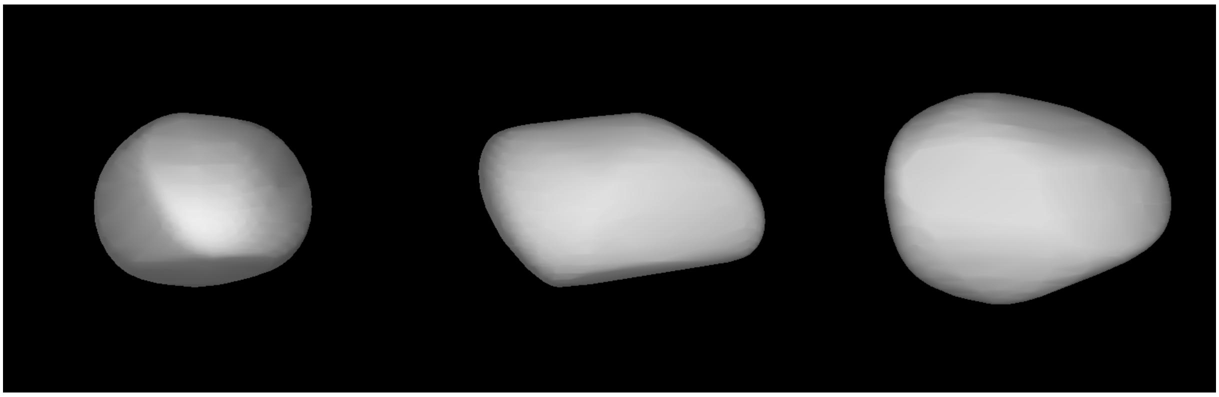

Fig. 15. Shape model of 665 Sabine.

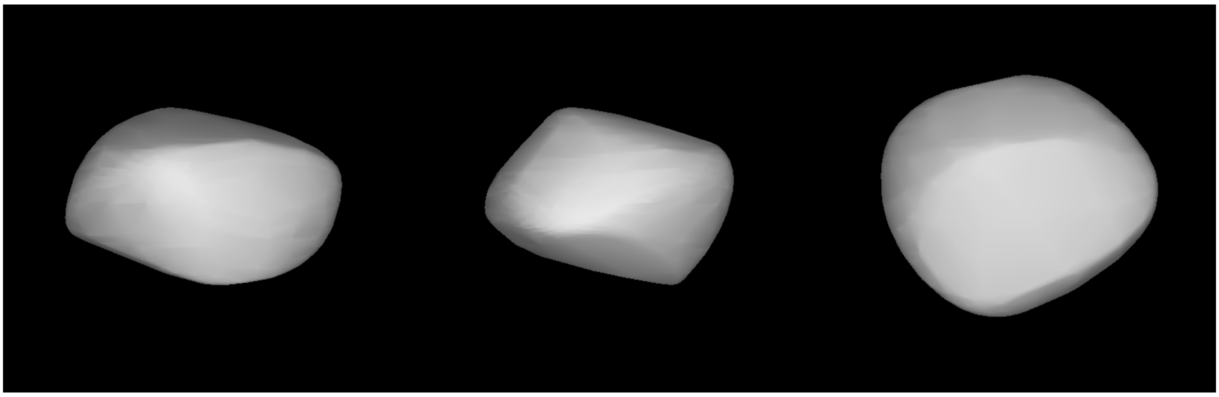

Fig. 16. Shape model of 690 Wratislavia.

the mirror pole cannot be ruled out. Figure 16 presents the shape model of the asteroid 690 Wratislavia.

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