A&A 473, 633–639 (2007)
DOI: 10.1051/0004-6361:20077694

Astronomy & Astrophysics

Photometry and models of selected main belt asteroids

IV. 184 Dejopeja, 276 Adelheid, 556 Phyllis

A. Marciniak[1], T. Michałowski[1], M. Kaasalainen[2], J. Ďurech[3], M. Polińska[1], T. Kwiatkowski[1], A. Kryszczyńska[1], R. Hirsch[1], K. Kamiński[1], M. Fagas[1], F. Colas[4], S. Fauvaud[5,6], G. Santacana[5], R. Behrend[7], and R. Roy[8]

[1] Astronomical Observatory, Adam Mickiewicz University, Słoneczna 36, 60-286 Poznań, Poland
e-mail: aniab@lab.astro.amu.edu.pl
[2] Rolf Nevanlinna Institute, University of Helsinki PO Box 4, 00014 Helsinki, Finland
[3] Astronomical Institute, Charles University in Prague V Holešovičkách 2, 18000 Prague, Czech Republic
[4] Institut de Mecanique Celeste, 77 Av. Denfert Rochereau, 75014 Paris, France
[5] Association AstroQueyras, Le Bois de Bardon, 16110 Taponnat, France
[6] Groupe Européen d'Observations Stellaires (GEOS), 23 Parc de Levesville, 28300 Bailleau-l'Evêque, France
[7] Geneva Observatory, 1290 Sauverny, Switzerland
[8] Observatoire de Blauvac, 84570 St-Estève, France

Received 23 April 2007 / Accepted 15 June 2007

ABSTRACT

We report photometric lightcurve observations of 184 Dejopeja (apparition years: 2000, 2002, 2005, 2006), 276 Adelheid (2000, 2001, 2004, 2005, 2006), and 556 Phyllis (1998, 2000, 2002, 2004, 2005, 2006) carried out on 48 nights at four observatories. Using all of the available lightcurves, the spin vectors, senses of rotation, and shape models of these three asteroids have been determined.

Key words. techniques: photometric – minor planets, asteroids

1. Introduction

Modelling of the physical parameters of an asteroid on the basis of brightness measurements requires observations at a few apparitions at the largest possible span of longitudes and phase angles. So far, the parameters of almost 200 asteroids have been modelled, such as the rotational spin axes, sidereal periods, senses of rotation, and even their three-dimensional shapes. The last was possible using the *convex inversion* method.

Knowledge of the asteroid parameters is essential for understanding the formation and further evolution of the Solar System. To investigate these issues, one needs the largest possible sample of the asteroid spin vectors. Then, interesting facts are revealed, like the grouping of asteroid spin axes in the Koronis family (Slivan 2002) or a large excess of the near – Earth asteroids rotating in a retrograde sense (La Spina et al. 2004).

The lightcurves of over 2000 asteroids have been collected in the photometric database, but most of these objects were observed once or twice, which is not enough for proper modelling. But adding data from two or more new apparitions to the existing set would improve the situation a lot. It is worth stressing that only repeated observations of the same asteroids give the desired results.

This paper, fourth in the series, gives models of three new asteroids, compiling new observations with the previously published ones. These models and future ones will be included in a still growing database of spin parameters at `http://www.astro.amu.edu.pl/Science/Asteroids` and a database of the asteroid shape models at `http://astro.troja.mff.cuni.cz/projects/asteroids3D`

2. Observations of three main belt asteroids

Photometric observations of 184 Dejopeja, 276 Adelheid, and 556 Phyllis on 48 nights in the years 1998–2006 were made at four observatories. A large majority of the data came from the Borowiec Station of Poznań Astronomical Observatory (Poland). Other observatories were: Pic de Château-Renard Observatory, Pic du Midi Observatory, and Blauvac Observatory, all situated in France.

The Borowiec Observatory is equipped with a 0.4-m, F/4.5 Newton reflector, a KAF400 CCD camera, and a set of Bessel BVRI filters. A clear-glass filter was used in all of these observations, so the observations were not transformed to the standard system; see Michałowski et al. (2004) for a full description of the instrument and the reduction procedure.

Observations of other asteroids performed in Borowiec have been already published, together with the new models in, for example, Michałowski et al. (2000, 2001), Kryszczyńska et al. (2003), Ďurech et al. (2007), and in the three previous papers of the present series – Michałowski et al. (2004, 2005, 2006).

At Pic de Château-Renard, a 0.62-m, F/3 Cassegrain telescope with a KAF400 CCD camera was used. Asteroids were observed through the filters *R* and *V*. The photometry was relative, as in all presented cases. A 1.05-m telescope with a Thomson 7863 CCD camera and an *R* filter were used at the Pic du Midi Observatory, while the Blauvac Observatory is equipped with a 0.31-m telescope.

Table 1 contains the aspect data for the three observed asteroids. In the first column there is the date of observation referring to the mid-time of the observed lightcurve. The subsequent columns are the distances (in AU) from the asteroid to the Sun

Article published by EDP Sciences and available at http://www.aanda.org or http://dx.doi.org/10.1051/0004-6361:20077694

Table 1. Aspect data.

Date (UT)	r (AU)	Δ (AU)	Phase angle (°)	λ (J2000) (°)	β (J2000) (°)	Obs.
184 Dejopeja						
2000 09 23.1	3.427	2.465	5.64	19.95	1.06	Bor
2000 09 24.0	3.426	2.461	5.36	19.80	1.06	Bor
2002 02 02.8	3.150	2.475	14.78	79.14	1.25	Bor
2002 02 03.9	3.149	2.485	14.97	79.12	1.24	Bor
2005 09 14.0	3.398	2.444	6.32	329.38	0.09	Bla
2005 09 22.9	3.401	2.507	8.96	328.10	0.12	Bla
2005 09 29.9	3.403	2.570	10.79	327.33	0.15	Bla
2005 10 10.8	3.406	2.688	13.16	326.61	0.18	Bor
2005 10 11.8	3.406	2.700	13.35	326.57	0.18	Bor
2005 10 15.8	3.407	2.748	14.04	326.48	0.20	Bor
2006 09 9.0	3.388	2.750	14.67	44.56	1.19	Bor
2006 09 15.0	3.386	2.677	13.62	44.43	1.23	Bor
2006 09 26.1	3.382	2.559	11.20	43.70	1.3	Bor
2006 10 01.0	3.380	2.514	9.91	43.17	1.34	Bor
2006 10 17.0	3.373	2.409	5.06	40.76	1.43	Bor
2006 10 25.9	3.370	2.380	2.05	39.09	1.47	Bor
276 Adelheid						
2000 08 26.0	3.248	2.366	10.23	2.75	18.95	Bor
2000 08 26.9	3.247	2.359	10.01	2.61	18.94	Bor
2000 08 27.9	3.247	2.352	9.77	2.45	18.93	Bor
2000 09 21.9	3.232	2.262	5.47	357.42	17.80	Bor
2001 10 26.1	2.965	2.234	15.06	81.22	–17.05	ChR
2001 10 28.0	2.964	2.214	14.63	81.10	–17.37	ChR
2004 05 14.0	3.244	2.305	7.86	252.41	18.25	Bor
2004 05 15.0	3.245	2.302	7.66	252.22	18.35	Bor
2004 05 28.9	3.252	2.280	6.01	249.35	19.58	Bor
2004 05 30.0	3.253	2.280	6.02	249.13	19.65	Bor
2005 09 17.9	3.313	2.532	12.53	316.07	25.99	Bor
2005 09 18.9	3.312	2.540	12.70	315.97	25.88	Bor
2005 09 22.9	3.311	2.573	13.37	315.60	25.36	Bor
2005 09 26.8	3.310	2.609	14.00	315.33	24.84	Bor
2005 10 04.9	3.307	2.689	15.14	315.05	23.74	Bor
2006 09 19.0	3.107	2.314	13.22	40.88	1.99	Bor
2006 09 27.1	3.101	2.235	11.01	40.02	1.31	Bor
2006 10 18.0	3.086	2.104	3.81	36.35	–0.67	Bor
556 Phyllis						
1998 01 30.1	2.2319	1.2489	2.14	126.56	–3.48	ChR
1998 01 30.9	2.2323	1.2498	2.48	126.36	–3.51	ChR
2000 08 27.0	2.5362	1.6098	11.46	3.07	7.52	Bor
2000 08 31.0	2.5320	1.5838	9.92	2.39	7.69	Bor
2002 01 08.1	2.2454	1.4590	18.78	154.82	–4.01	ChR
2002 01 10.2	2.2466	1.4418	18.08	154.74	–4.14	ChR
2002 01 29.2	2.2592	1.3232	10.18	152.40	–5.28	Pic
2002 02 01.2	2.2614	1.3114	8.72	151.79	–5.45	Pic
2002 03 09.0	2.2900	1.3538	10.75	143.53	–6.56	Bor
2004 09 05.1	2.4736	1.6010	14.58	20.27	7.96	Bor
2004 09 13.9	2.4638	1.5343	11.36	19.08	8.33	Bor
2004 09 16.9	2.4605	1.5153	10.17	18.56	8.44	Bor
2004 09 18.1	2.4591	1.5083	9.68	18.34	8.48	Bor
2005 12 30.2	2.2733	1.7923	24.54	172.23	–4.39	Bor
2006 01 10.1	2.2821	1.6738	22.81	173.75	–5.01	Bor
2006 01 16.2	2.2871	1.6135	21.52	174.21	–5.38	Bor

Observatory Code: Bor - Borowiec; Bla - Blauvac; ChR - Chateau-Renard; Pic - Pic du Midi.

and the Earth, the solar phase angle, the $J2000.0$ ecliptic longitude (λ), and latitude (β), given for the time from the first column. The codes of the observatories are listed in the last column of the table.

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

Table 2. Asteroid parameters.

Asteroid	D (km)	*albedo*	Type
184 Dejopeja	66	0.190	X
276 Adelheid	122	0.045	X
556 Phyllis	38	0.185	S

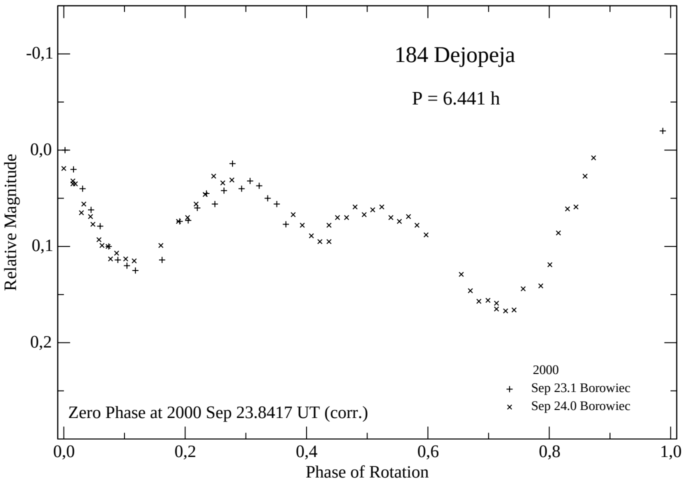

Fig. 1. Lightcurve of 184 Dejopeja in 2000.

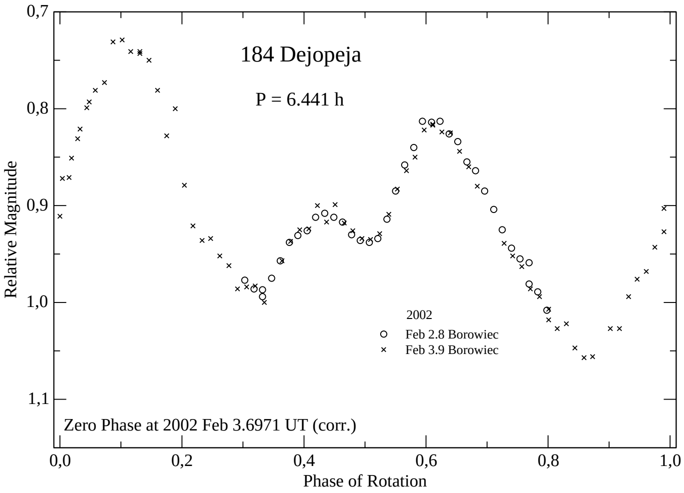

Fig. 2. Lightcurve of 184 Dejopeja in 2002.

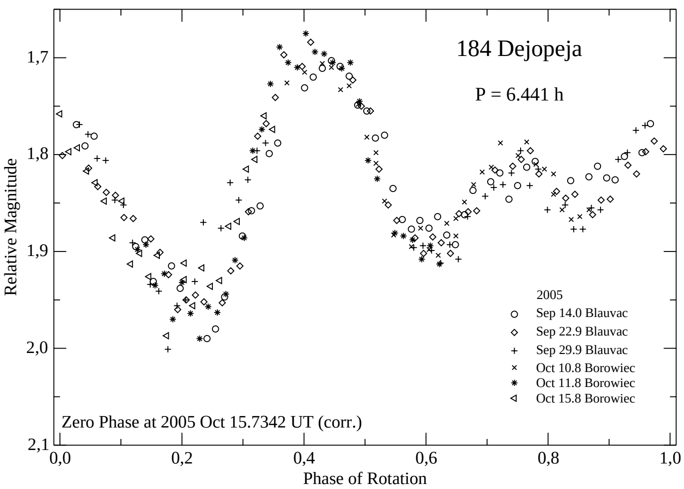

Fig. 3. Lightcurve of 184 Dejopeja in 2005.

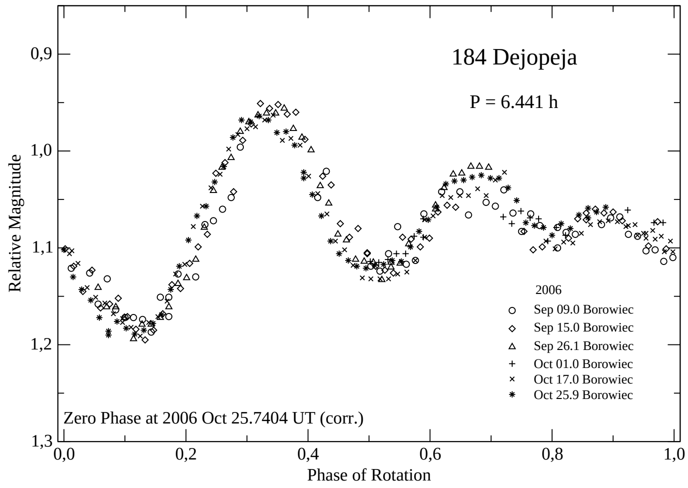

Fig. 4. Lightcurve of 184 Dejopeja in 2006.

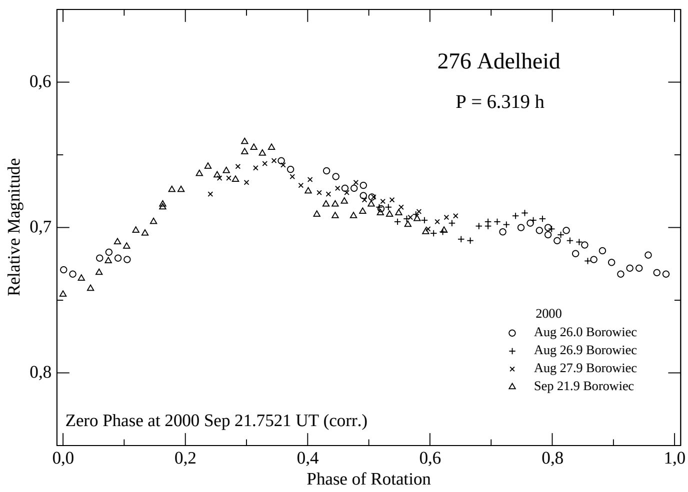

Fig. 5. Lightcurve of 276 Adelheid in 2000.

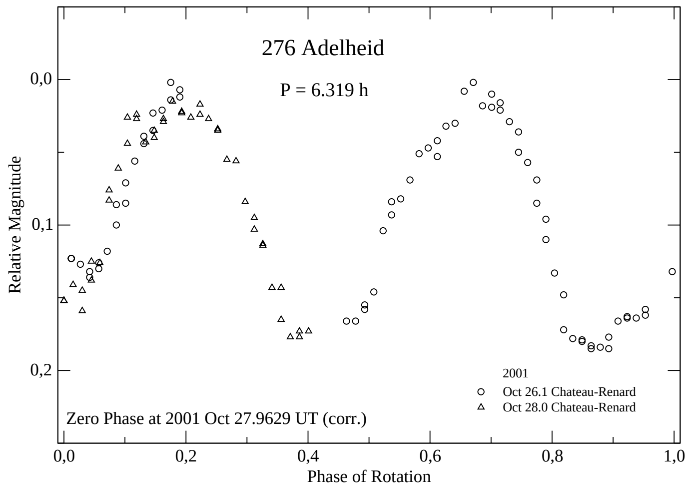

Fig. 6. Lightcurve of 276 Adelheid in 2001.

Results of our new observations are presented in Figs. 1–14 in the form of composite lightcurves. They were created using the procedure described by Magnusson & Lagerkvist (1990). The lightcurves from individual oppositions were composited with the synodical periods written in the graphs. The points from different nights are marked with 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.

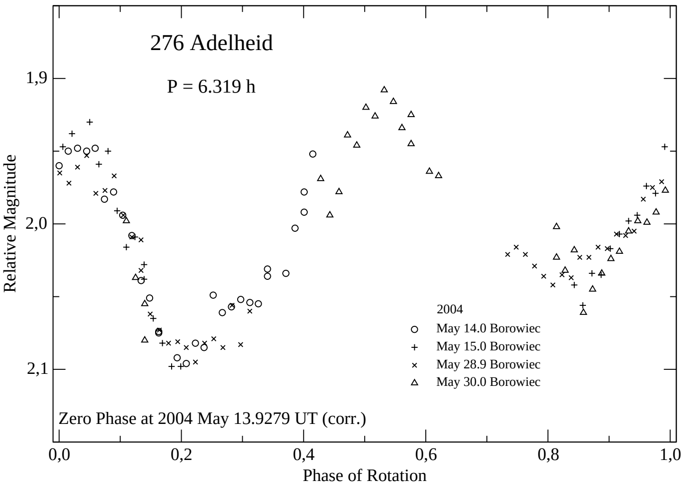

Fig. 7. Lightcurve of 276 Adelheid in 2004.

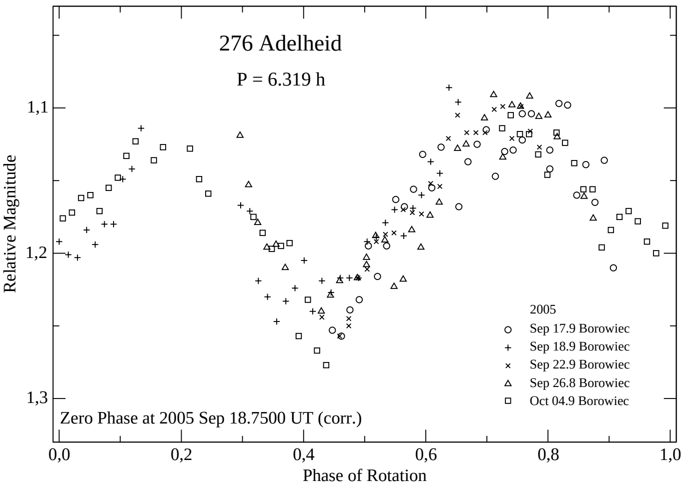

Fig. 8. Lightcurve of 276 Adelheid in 2005.

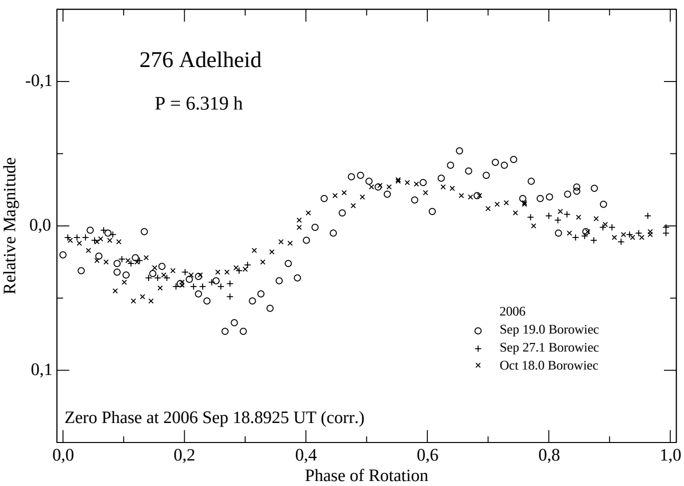

Fig. 9. Lightcurve of 276 Adelheid in 2006.

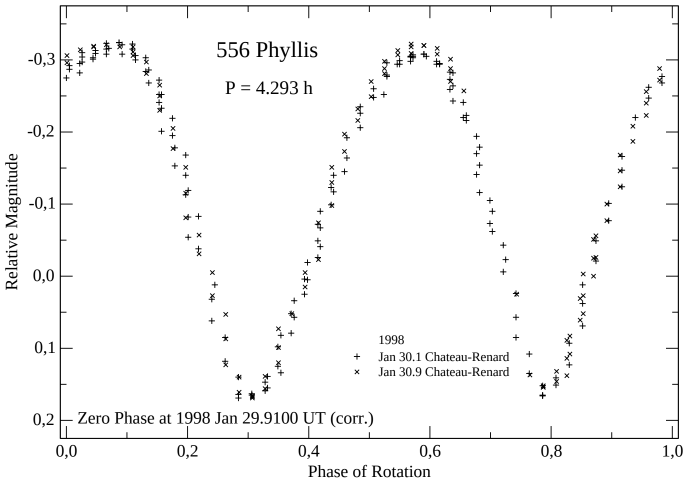

Fig. 10. Lightcurve of 556 Phyllis in 1998.

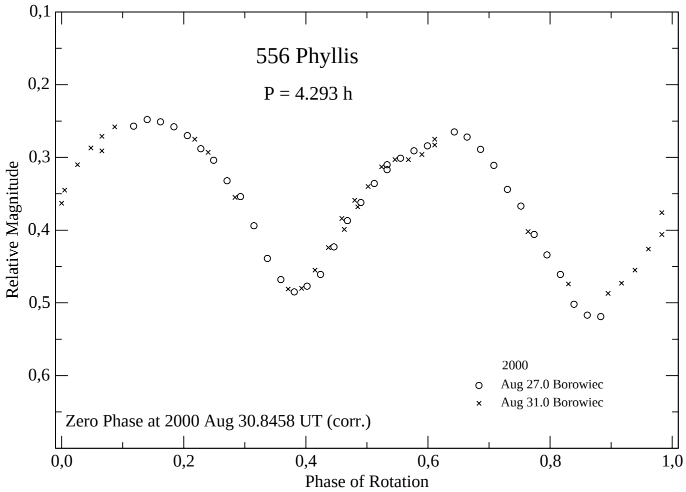

Fig. 11. Lightcurve of 556 Phyllis in 2000.

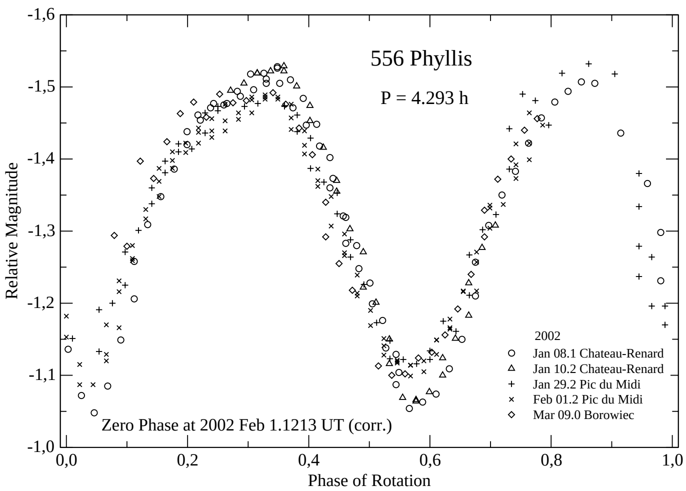

Fig. 12. Lightcurve of 556 Phyllis in 2002.

2.1. 184 Dejopeja

Dejopeja was first observed by Tedesco (1979). The tri-modality of its lightcurve was already visible at that time. It was only a one-night run on 9 September 1977, with the estimated period of 6.7 h, and the amplitude about 0.21 mag. The next photometric observations of this asteroid were made by Gil-Hutton (1995). Observed during three nights in April 1992, Dejopeja showed unequal extrema with an amplitude over 0.28 mag. The period was determined as 6.455 ± 0.008 h, but the composite lightcurve had gaps.

We observed 184 Dejopeja on 13 nights during four apparitions in the years 2000, 2002, 2005, and 2006. The composite

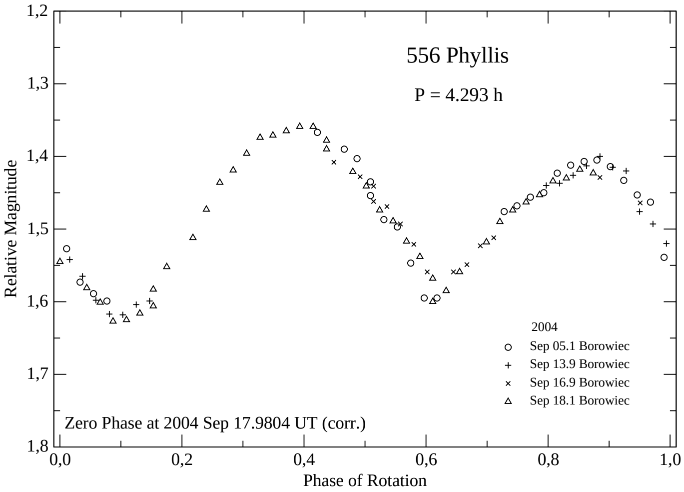

Fig. 13. Lightcurve of 556 Phyllis in 2004.

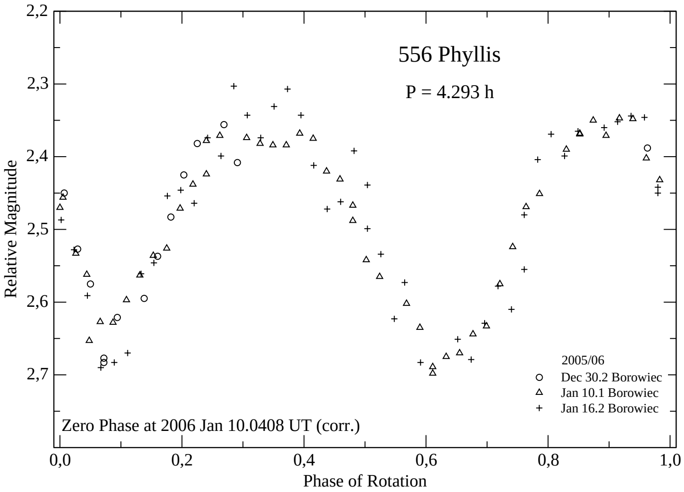

Fig. 14. Lightcurve of 556 Phyllis in 2006.

lightcurves are constructed with the synodical period of 6.441 ± 0.001 h, which is a little shorter than the value given by Gil-Hutton (1995).

The lightcurve from two nights in September 2000 (Fig. 1) was apparently tri-modal, but the third maximum was lacking due to the gap in observations. The coverage was almost 90% of the rotational cycle. The peak-to-peak amplitude was 0.19 ± 0.01 mag, but it must have been larger at that time. On the fully covered lightcurve, from two nights in February 2002 (Fig. 2), there were three distinct maxima, each a different height. The amplitude was larger at 0.32 ± 0.01 mag, and the estimated period was confirmed. On six nights in September-October 2005, we obtained a similar lightcurve (Fig. 3), but with more noise and with an amplitude of 0.25 ± 0.03 mag. The "noise" of the composite lightcurve might be due to the changing phase angle over a month-long time span. In the 2006 apparition (Fig. 4), Dejopeja showed a lower amplitude of 0.22 ± 0.01 mag and a smaller difference between the two of the minima. The fully-covered lightcurve came from the observations on six nights in September–October 2006.

2.2. 276 Adelheid

The first photometric observations of Adelheid were made by Carlsson & Lagerkvist (1983). No lightcurve was given, but the colour indices were determined as $B - V = 0.73$ and $U - B = 0.22$. Chronologically, the first lightcurve observations of this asteroid were conducted by Piironen et al. (1994), who observed it during eight nights between October and November 1984. The amplitude was very small, around 0.1 mag, but in the composite lightcurve there were two clearly visible pairs of extrema. The period determined was 6.32 ± 0.02 h.

The period determination was made by Dotto et al. (1994): 6.328 ± 0.012 h. DiMartino et al. (1995) published the observations from three nights between February and March 1992 made at ESO. The composite, bimodal lightcurve still had a small amplitude of 0.1 mag and was constructed with the period given by Dotto et al. (1994).

In November 2000, Wang & Shi (2002) got two lightcurves of this object, unfortunately quite noisy; still, the change in the lightcurve was clearly visible. This time there was only one maximum and one minimum. The amplitude reached 0.18 mag and the period was 6.29 ± 0.01 h, close to the previous determinations. Pray (2005) observed Adelheid on four nights in June 2004. The second pair of extrema were again visible in that asymmetric lightcurve. The light variation was within 0.17 mag, with the period of 6.315±0.002 h. Lastly, Adelheid was observed by Sada (2006). Five nights run in August 2005 confirmed the period and amplitude: $P = 6.315 \pm 0.005$ h, $A = 0.17$ mag. All of the reported periods closely resemble each other.

We gathered the observational data of Adelheid on 19 nights in the years 2000, 2001, 2004, 2005, and 2006. The obtained synodical period is 6.319 ± 0.001 h, very close to the values from Pray and Sada.

On four nights in August and September 2000 (Fig. 5), the lightcurve of Adelheid showed one pair of extrema, with an indication of a second pair. The amplitude was small at 0.08 ± 0.01 mag. The lightcurve from the next apparition (Fig. 6) was completely different: on two nights, in October 2001 Adelheid showed two extrema at the same levels, but with larger amplitude 0.17 ± 0.01 mag and irregurally shaped minima. In 2004 the situation changed again (Fig. 7). There were two extrema visible on four nights in May, but the lightcurve became more irregular, and the maximum amplitude was 0.17 ± 0.02 mag. On five nights in September–October 2005 (Fig. 8) the amplitude of Adelheid lightcurves appeared to decrease to 0.13 ± 0.03 mag but the assymetry remained. Finally in the 2006 apparition (Fig. 9), the lightcurve switched to a single mode again. During the three nights observations in September–October 2006, the amplitude fell to 0.09 ± 0.03 mag.

2.3. 556 Phyllis

On 16 November 1981 Zappala et al. (1983) observed this object, and constructed a clumpy lightcurve with a period of 4.28 ± 0.002 h, and 0.24 mag amplitude. In November-December 1981 Harris et al. (1992) made three sparse lightcurve observations, from which they were unable to determine an unambiguous synodic rotational period. But adding the lightcurve by Zappala et al., they obtained a period of 4.2932 ± 0.0004 h. Such good precision was possible because the short rotation period of this asteroid resulted in many revolutions over the two-week observation span.

We observed the asteroid Phyllis during its five apparitions in 1998, 2000, 2002, 2004, and 2005–2006. The regular, bimodal lightcurves were composited with the synodical period of 4.293 ± 0.001 h, which was consistent with previous determinations.

Table 3. Spin and shape models.

Sidereal period (hours)	Sense of rotation	Pole 1 λ_p	Pole 1 β_p	Pole 2 λ_p	Pole 2 β_p	Observing span (years)	$N_{\rm opp}$	$N_{\rm lc}$	Method	Reference
184 Dejopeja										
6.441111	P	18°	+54°	201°	+52°	1977-2006	6	17	L	Present work
276 Adelheid										
6.319204	R	9°	−4°	198°	−20°	1984-2006	7	31	L	Present work
556 Phyllis										
4.292623	P	35°	+55°	209°	+41°	1981-2006	6	19	L	Present work

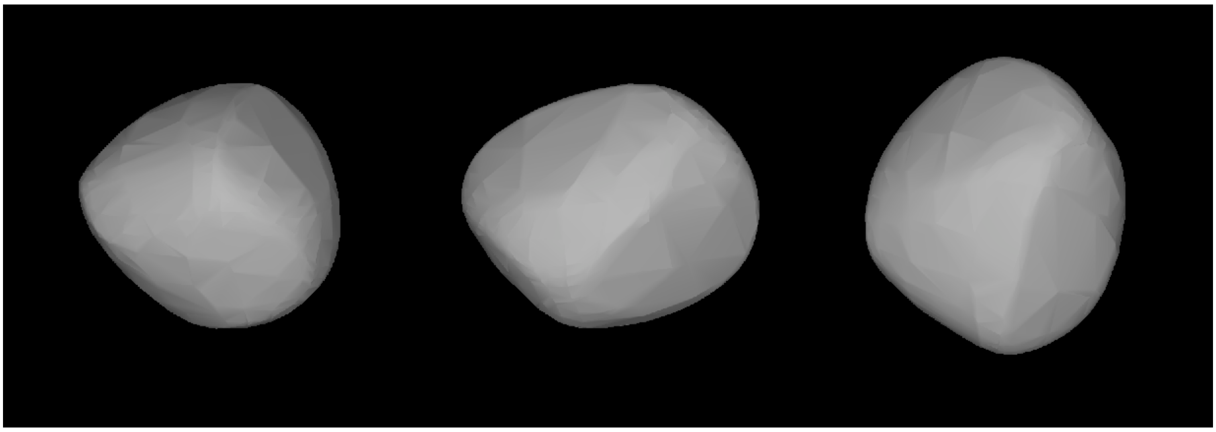

Fig. 15. Shape model of 184 Dejopeja, shown at equatorial viewing and illumination geometry, with rotational phases 90° apart (two pictures in the left) and the pole-on view to the right.

On two nights in January 1998, Phyllis showed a regular lightcurve with a large amplitude of 0.48 ± 0.01 mag (Fig. 10). There was a slight asymmetry in the shape of the extrema. In the apparition in August 2000, the two-night lightcurve showed a much smaller amplitude of 0.27 ± 0.01 mag, and some irregularity was still visible, especially in the second maximum (Fig. 11). We obtained the next lightcurve in January – March 2002 (Fig. 12). The changing amplitude resulted from the changing phase angle over the two-month observing span. The characteristic shape of the extrema was still visible, and the ampitude grew to 0.45 ± 0.01 mag. On four nights in September 2004, the amplitude was 0.26 ± 0.01 mag and one minimum became quite sharp (Fig. 13). In the last apparition (Fig. 14) at the turn of the year 2005 and 2006, our three-night noisy lightcurve had 0.33 ± 0.03 mag amplitude.

3. Pole and shape results of the asteroids observed

The pole and period solution, together with a three-dimensional convex shape model, were obtained using the *lightcurve inversion* method by Mikko Kaasalainen (Kaasalainen & Torppa 2001; and Kaasalainen et al. 2001, 2003). The method uses all the available data points and models the shape, along with spin and scattering properties, using a large number of parameters. The photometric data can be absolute and/or relative. The model lightcurves closely fit the observed ones, within the noise level. As in the other methods, one often obtains two solutions, with a $\lambda_p \pm 180°$ ambiguity for the asteroids moving close to the ecliptic plane.

Table 3 presents the results. The first column contains the sidereal period in hours, where the uncertainty is limited to the last digit, as the method determines the rotation period very well. Next, there is the sense of rotation (P – prograde and R – retrograde) and two pole solutions. They are given as the ecliptic coordinates of the north asteroids' poles for a J2000 epoch. Here, the error is usually at the level of ±5° on the celestial sphere and is influenced by the systematic errors present in lightcurves and model errors rather than the formal error derived from the observational noise level. The errors given here were estimated based on comparing of various models obtained from lightcurve inversion with different starting parameters. The resulting pole positions always fell within ±5° of each other and the period remained the same, varying only on the last digit. More details on error estimation in the lightcurve inversion method are given in Torppa et al. (2003), and Kaasalainen & Ďurech (2007)

Table 3 also shows the observing span in years, the number of oppositions, and the number of all lightcurves used for modelling. This table finally gives the method used (L stands for *lightcurve inversion*) and the reference. There are no previously published pole results for these three asteroids.

We constructed the model of 184 Dejopeja using 17 lightcurves from 6 apparitions (1977, 1992, 2000, 2002, 2005, and 2006). But even before we got all the data, we were able to obtain a uniqe model, with only 11 lightcurves from 5 apparitions. That was probably due to the atypical tri-modal lightcurve of this asteroid caused by its angular shape. Usually, many more lightcurves are needed. The obtained prograde sense of rotation and two pole solutions are indicated in Table 3. The shape model of Dejopeja is shown in Fig. 15.

The data from seven apparitions are available for the asteroid 276 Adelheid (1984, 1992, 2000, 2001, 2004, 2005, and 2006). We used 31 lightcurves to obtain a model, after excluding especially noisy ones. Adelheid was found to be a retrograde rotator with an angular shape (Fig. 16) that made the second pair of the

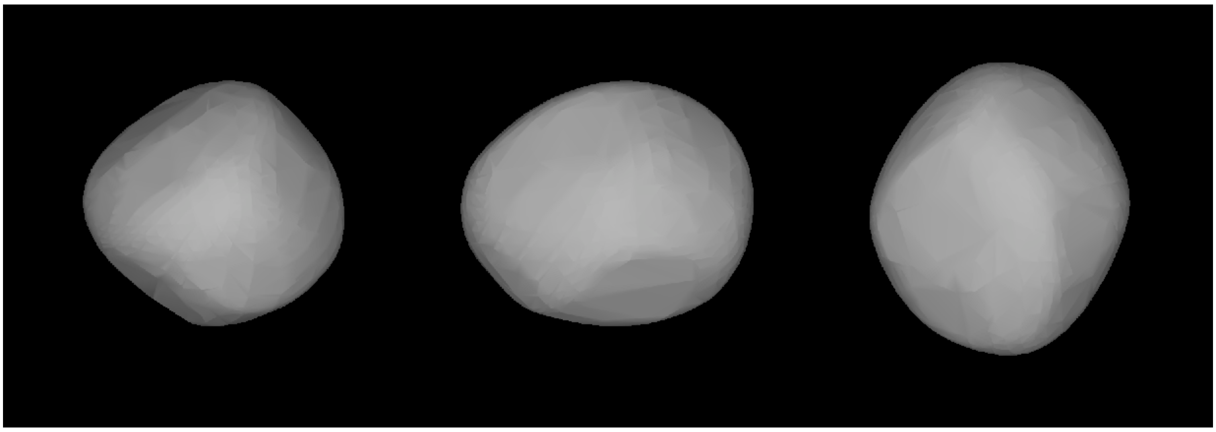

Fig. 16. Shape model of 276 Adelheid.

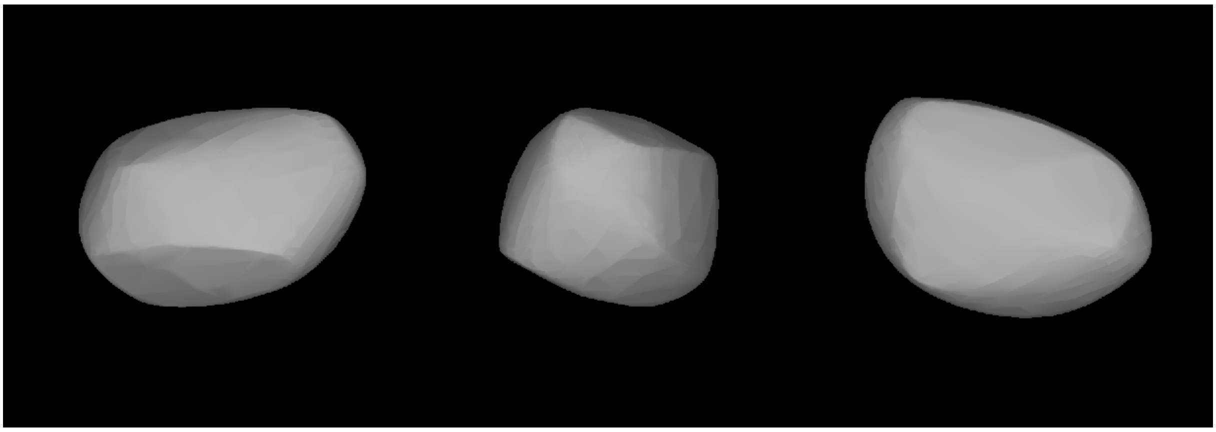

Fig. 17. Shape model of 556 Phyllis.

extrema switch on and off. There are two possible pole solutions (Table 3), one quite close to the ecliptic plane, which is rather rare.

Phyllis is the elongated asteroid producing regular lightcurves. Using all the 6 oppositions available (1981, 1998, 2000, 2002, 2004, and 2006) and 19 lightcurves, we obtained a model with the prograde sense of rotation and a pole at medium latitude (Table 3). Figure 17 shows the shape model of Phyllis.

Acknowledgements. Borowiec observations were reduced with the *CCLRS STARLINK* package.
This work was supported by the Polish Grant 1 P03D 020 27.
The work of J.Ď. was supported by the Czech Grant Agency through grant GAČR 205/07/P070. M.K. is supported by the Academy of Finland. S.F. is grateful to F. Bererd, M. Fauvaud, N. Heck, D. Jolivet, A. Paschke, J.-P. Sareyan, and H. Wucher for their help and technical assistance during observing runs.

References

Carlsson, M., & Lagerkvist, C.-I. 1983, A&AS, 53, 157
Di Martino, M., Dotto, E., Celino, A., Barucci, M. A., & Fulchignoni, M. 1995, A&AS, 112, 1
Dotto, E., Rotundi, A., & De Sanctis, M. C. 1992, in Physical properties of small solar system bodies. ed. A. Brahic, J.-C. Gerard, & J. Surdej, Université de Liège, Institut d'Astrophysique, Liège, 211
Ďurech, J., Kaasalainen, M., & Marciniak, A. and 39 coauthors 2007, A&A, 465, 331
Gil–Hutton, R. 1995, Rev. Mex. Astron. Astrofis., 31, 19
Harris, A. W., Young, J. W., Dockweiler, T., et al. 1992, Icarus, 95, 115
Kaasalainen, M., & Torppa, J. 2001, Icarus, 153, 24
Kaasalainen, M., & Ďurech, J. 2007, in Near Earth Objects, our Celestial Neighbors: Opportunity and Risk, ed. A. Milani, G. B. Valsecchi, & D. Vokrouhlicky (Cambridge: Cambridge University Press), in press
Kaasalainen, M., Torrpa, J., & Muinonen, K. 2001, Icarus, 153, 37
Kaasalainen, M., Mottola, S., & Fulchignoni, M. 2003, in Asteroids III, ed. W. F. Bottke, A. Cellino, P. Paolicchi, & R. P. Binzel (Univ. Arizona Press), 139
Kryszczyńska, A., Kwiatkowski, T., & Michałowski, T. 2003, A&A, 404, 729
La Spina, A., Paolicchi, P., Kryszczyńska, A., & Pravec, P. 2004, Nature, 428, 400
Magnusson, P., & Lagerkvist, C.-I. 1990, A&AS, 86, 45
Michałowski, T., Pych, W., Berthier, J., et al. 2000, A&AS, 146, 471
Michałowski, T., Pych, W., Kwiatkowski, T., et al. 2001, A&A, 371, 748
Michałowski, T., Kwiatkowski, T., Kaasalainen, M., et al. 2004, A&A, 416, 353
Michałowski, T., Kaasalainen, M., Marciniak, A., et al. 2005, A&A, 443, 329
Michałowski, T., Kaasalainen, M., Polińska, M., et al. 2006, A&A, 459, 663
Piironen, J., Bowell, E., Erikson, A., & Magnusson, P. 1994, A&AS, 106, 587
Pray, D. 2005, Minor Planet Bul., 32, 8
Sada, P. V. 2006, Minor Planet Bul., 33, 78
Slivan, S. M. 2002, Nature, 419, 49
Tedesco, E. F. 1979, Ph.D. Dissertation, New. Mex. State Univ., 280
Torppa, J., Kaasalainen, M., Michalowski, T., et al. 2003, Icarus, 164, 346
Wang, X.-B., & Shi, Y. 2002, Earth, Moon and Planets, 91, 181
Zappala, V., Scaltriti, F., & Di Martino, M. 1983, Icarus, 56, 325