A&A 498, 313–320 (2009)
DOI: 10.1051/0004-6361/200811078
© ESO 2009

Astronomy & Astrophysics

Photometry and models of selected main belt asteroids. VI. 160 Una, 747 Winchester, and 849 Ara*

A. Marciniak[1], T. Michałowski[1], R. Hirsch[1], M. Polińska[1], K. Kamiński[1], T. Kwiatkowski[1], A. Kryszczyńska[1], R. Behrend[2], L. Bernasconi[3], J. Michałowski[4], S. Starczewski[5], M. Fagas[1], and K. Sobkowiak[1]

[1] Astronomical Observatory, Adam Mickiewicz University, Słoneczna 36, 60-286 Poznań, Poland
e-mail: `aniab@lab.astro.amu.edu.pl`
[2] Geneva Observatory, 1290 Sauverny, Switzerland
[3] Les Engarouines Observatory, 84570 Mallemort-du-Comtat, France
[4] UNIQA Software Service, Gdańska 132, 90-520 Łódź, Poland
[5] N. Copernicus Astronomical Center, Polish Academy of Sciences, Bartycka 18, 00-716 Warsaw, Poland

Received 3 October 2008 / Accepted 29 January 2009

ABSTRACT

We present a set of new photometric observations of three main belt asteroids: 160 Una, 747 Winchester, and 849 Ara. This, combined with the available data, allowed us to construct their physical models. The lightcurve inversion method was used to obtain their spins and shapes. We have resolved problems with the rotation period of 160 Una, and found it to be 11.033176 ± 0.000011 h, almost twice the value given in the literature.

Key words. techniques: photometric – minor planets, asteroids

1. Introduction

Construction of an increasing number of spin and shape models of asteroids allows for statistical studies that reveal many unknown facts about the Solar System's history, including the forces involved. Precise determinations of the spin periods and axis orientations are important in light of recent direct YORP-effect detections (Kaasalainen et al. 2007; Lowry et al. 2007; Ďurech et al. 2008) and the apparent proofs of the consequences this effect (Slivan 2002).

Traditional dense lightcurve observations are still an abundant source of asteroids' surface properties, as well as of the overall shapes with their various asymmetries, sharp edges, and other global shape features. Various geometries obtained during a few apparitions of a given body allow a full picture of its properties to be obtained. In particular, observations that cover the wide spans of phase angles carry most of the information on its shape. They allow construction of models based on fewer apparitions than the usual near-opposition lightcurves, which means a shorter data gathering period.

This is the sixth paper in a series that gives three new asteroid models constructed with the *lightcurve inversion* method. We combined data available in the literature, taken from the Asteroid Photometric Catalogue (Lagerkvist et al. 2001), with our own observations gathered over a campaign of a few years conducted at the Borowiec Observatory, and with amateur observations.

The models presented in this work will be added to two databases. An up-to-date database of all published asteroids spin parameters is available at our website: `http://www.astro.amu.edu.pl/Science/Asteroids/` (Kryszczyńska et al. 2007), and the models from lightcurve inversion are collected at: `http://astro.troja.mff.cuni.cz/projects/asteroids3D`.

2. Photometry of three main belt asteroids

Three main belt asteroids, 160 Una, 747 Winchester, and 849 Ara, were observed photometrically over an eight-year span, for a total of 60 nights. Most of these observations were conducted at the Borowiec Station of the Poznań Astronomical Observatory in Poland. The rest of the lightcurve data come from SAAO in South Africa and from amateur observers from France. It is very beneficial to combine the data from various observatories, even during the same apparition.

The equipment and the description of the reduction procedure can be found in the first paper of the present series: Michałowski et al. (2004). The subsequent papers with different asteroid models are Michałowski et al. (2005, 2006) and Marciniak et al. (2007, 2008). Almost all of the data were collected using small telescopes, like our 40-cm Newtonian one at the Borowiec Station.

In the asteroid observations from mid-northern latitudes, there is always a problem with the lack of data from the Southern Hemisphere. Asteroids are unobservable over long parts of their orbital paths which results in poor longitude coverage. Since the time when we started observations at SAAO in South Africa three years ago, these gaps have been filled successfully (Descamps et al. 2007; Marciniak et al. 2008). Thanks to these observations, we managed to determine unique rotation period of asteroid 160 Una, which turned out to be almost two times longer than previously thought (see Sect. 2.1).

Aspect data for all of the observing runs are presented in Table 1. After the date of observation, given as the mid-time of

---

* Photometric data are only available in electronic form at the CDS via anonymous ftp to `cdsarc.u-strasbg.fr (130.79.128.5)` or via `http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/498/313`

Table 1. Aspect data.

Date (UT)	r (AU)	Δ (AU)	Phase angle (°)	λ (J2000) (°)	β (°)	Obs.
160 Una						
2000 09 25.1	2.5936	1.6284	7.60	22.25	0.60	Bor
2000 09 27.9	2.5922	1.6160	6.34	21.68	0.68	Bor
2000 09 30.1	2.5911	1.6081	5.38	21.24	0.74	Bor
2001 12 14.2	2.6383	2.0184	19.08	143.31	4.52	Bor
2002 02 03.0	2.6722	1.6897	2.11	137.09	4.83	Bor
2002 02 04.0	2.6729	1.6896	1.90	136.84	4.82	Bor
2002 02 05.1	2.6736	1.6898	1.78	136.60	4.81	Bor
2005 10 05.1	2.5443	2.0534	21.98	84.11	3.80	Bor
2005 10 07.1	2.5444	2.0292	21.73	84.37	3.87	Bor
2005 10 09.0	2.5444	2.0066	21.47	84.59	3.93	Bor
2005 10 19.1	2.5451	1.8925	19.75	85.37	4.30	Bor
2007 03 26.1	2.8284	1.8311	0.35	185.96	0.34	Bor
2007 04 15.9	2.8397	1.8936	8.25	181.58	–0.09	Bor
2007 04 25.9	2.8449	1.9636	11.77	180.06	–0.28	Bor
2008 06 05.1	2.8786	1.9260	8.52	279.07	–5.66	SAAO
2008 06 07.0	2.8780	1.9154	7.86	278.75	–5.70	SAAO
2008 06 15.1	2.8749	1.8789	4.93	277.20	–5.82	SAAO
747 Winchester						
2002 02 22.1	3.8643	3.3340	13.36	215.98	20.21	Bor
2002 03 09.1	3.8849	3.1765	11.37	215.12	21.59	Bor
2002 03 11.1	3.8875	3.1584	11.05	214.93	21.73	Bor
2002 03 18.1	3.8965	3.1012	9.88	214.09	22.29	Bor
2002 03 19.0	3.8978	3.0942	9.71	213.95	22.36	Bor
2002 04 02.0	3.9148	3.0171	7.33	211.63	23.22	Bor
2002 04 03.0	3.9154	3.0152	7.26	211.54	23.25	Bor
2002 04 23.0	3.9380	2.9997	6.02	207.36	23.71	Bor
2003 06 29.0	3.7997	2.9268	8.96	246.65	19.85	EnO
2003 06 30.0	3.7980	2.9322	9.15	246.49	19.77	EnO
2006 01 11.1	2.5614	1.6726	11.68	142.48	0.26	Bor
2006 02 15.0	2.6886	1.7164	4.64	134.14	4.22	Bor
2006 02 22.9	2.7173	1.7754	7.90	132.44	4.94	Bor
2006 03 08.9	2.7681	1.9201	12.84	130.26	5.97	Bor
2006 03 22.9	2.8184	2.1043	16.40	129.36	6.71	Bor
2007 03 16.1	3.7969	2.9511	8.97	205.15	21.84	Bor
2007 03 23.0	3.8085	2.9184	7.71	203.93	22.30	Bor
2007 03 27.1	3.8151	2.9053	7.06	203.15	22.52	Bor
2007 03 28.1	3.8167	2.9027	6.91	202.95	22.56	Bor
2007 03 30.0	3.8197	2.8987	6.65	202.58	22.65	Bor
2007 04 13.0	3.8415	2.8997	5.90	199.62	23.01	Bor
2007 04 27.0	3.8619	2.9559	7.43	196.79	22.88	Bor
2007 04 27.9	3.8632	2.9615	7.58	196.62	22.86	Bor
2008 04 24.0	3.9630	3.1446	9.50	249.31	21.78	Bor
2008 04 27.0	3.9603	3.1175	8.99	248.88	21.92	Bor
2008 05 07.0	3.9512	3.0439	7.31	247.25	22.26	Bor
2008 05 13.0	3.9455	3.0122	6.44	246.13	22.38	Bor
2008 05 15.0	3.9435	3.0035	6.20	245.74	22.40	Bor
2008 05 20.0	3.9385	2.9873	5.77	244.74	22.42	Bor
2008 05 30.0	3.9279	2.9752	5.81	242.68	22.28	Bor
849 Ara						
2004 07 11.0	2.5940	1.8935	19.14	341.07	27.14	EnO
2004 07 13.0	2.5958	1.8790	18.79	341.06	27.37	EnO
2004 07 15.0	2.5978	1.8643	18.41	341.03	27.61	EnO
2006 01 17.8	3.5196	3.0051	14.81	51.57	–7.26	Bor
2006 01 22.7	3.5263	3.0810	15.30	51.72	–7.34	Bor
2006 01 27.8	3.5331	3.1607	15.68	51.99	–7.41	Bor
2006 02 10.9	3.5516	3.3890	16.13	53.35	–7.58	EnO
2006 02 11.8	3.5528	3.4044	16.13	53.47	–7.59	EnO
2007 02 03.9	3.7698	2.9236	8.73	107.14	–23.33	Bor
2007 03 07.8	3.7645	3.2315	13.78	104.18	–21.54	Bor
2007 03 10.8	3.7637	3.2689	14.10	104.16	–21.33	Bor
2008 03 29.9	3.3858	2.5052	9.27	164.57	–22.51	Bor
2008 04 08.9	3.3693	2.5538	11.37	162.98	–21.56	Bor
2008 04 23.8	3.3441	2.6652	14.28	161.55	–19.88	Bor

Observatory Code: Bor – Borowiec; EnO – Les Engarouines Observatory; SAAO – South African Astronomical Observatory.

Table 2. Asteroid parameters.

Asteroid	D(km)	*albedo*	Type
160 Una	81	0.062	CX
747 Winchester	172	0.050	PC
849 Ara	62	0.266	M

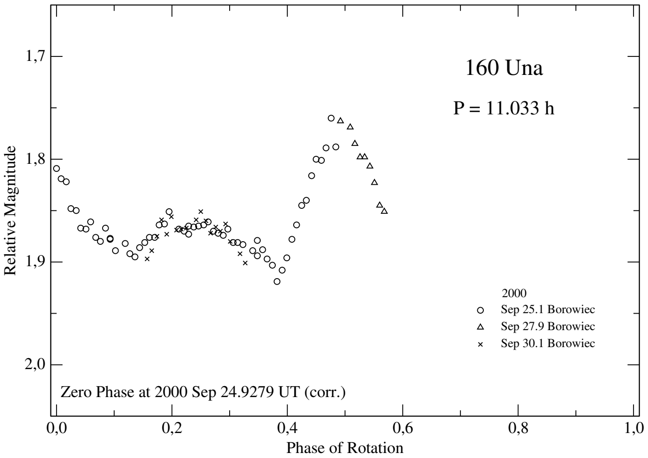

Fig. 1. Composite lightcurve of 160 Una in 2000.

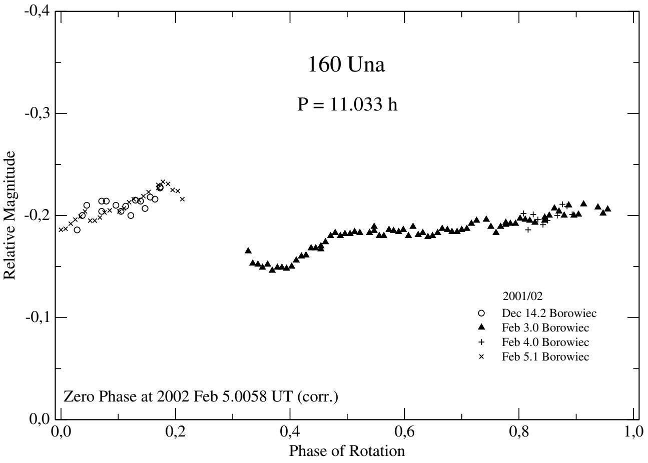

Fig. 2. Composite lightcurve of 160 Una in 2001/2002.

the lightcurve, there follow the distances from the object to the Sun and to the Earth in AU. In the fourth column there is the Sun-asteroid-Earth phase angle, and the other two columns show the *J*2000 ecliptic coordinates of a given object at any given moment. The last column contains the observatory code.

Table 2 shows the physical properties of three asteroids. After the object's name there is its *IRAS* diameter, albedo, and the taxonomic type. The data for this table come from *The Small Bodies Node of the NASA Planetary Data System* (`http://pdssbn.astro.umd.edu/`), where the diameters and albedos we cite come from the IRAS Minor Planet Survey (Tedesco et al. 2004), and the taxonomic classifications are given after Tholen (1989).

Our observations are presented in the form of composite lightcurves, one for each apparition (Figs. 1–14). The composites were created by means of vertical shift, to obtain the smallest possible scatter, with a fixed synodic period, that is shown in the graphs. Different symbols denote different observing runs. The vertical scale, which is the same for all the lightcurves of one object, is the relative magnitude, while the horizontal scale is the phase of rotation. Such compositing allows one to find the first approximation of the rotation period for the inversion procedure.

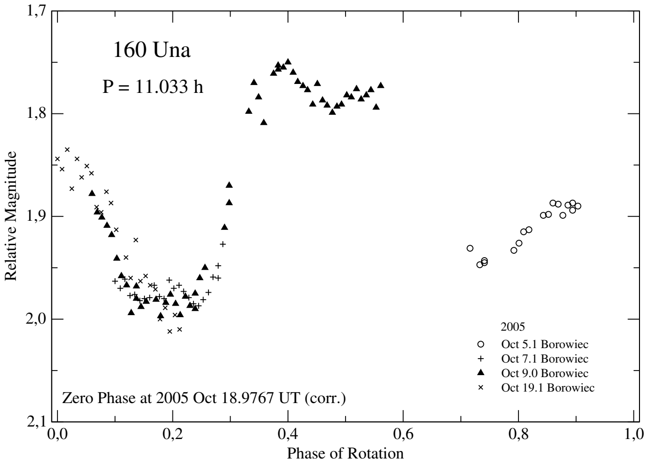

Fig. 3. Composite lightcurve of 160 Una in 2005.

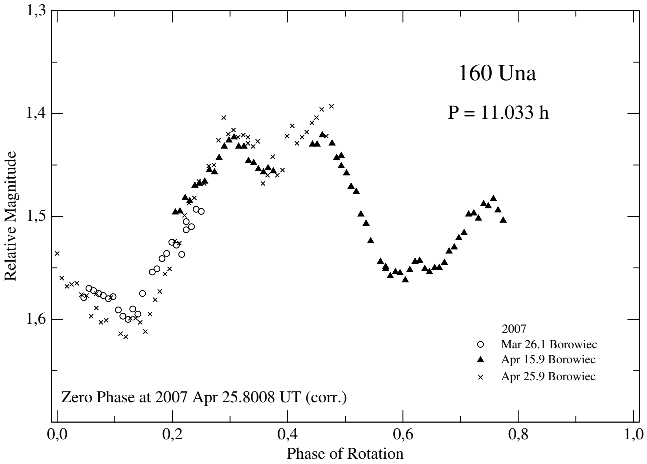

Fig. 4. Composite lightcurve of 160 Una in 2007.

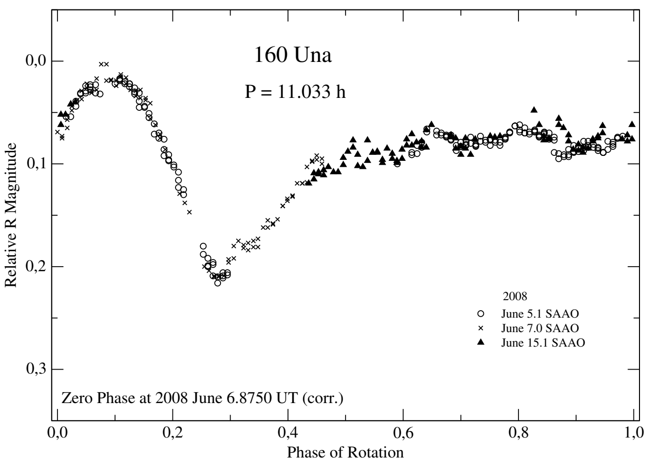

Fig. 5. Composite lightcurve of 160 Una in 2008.

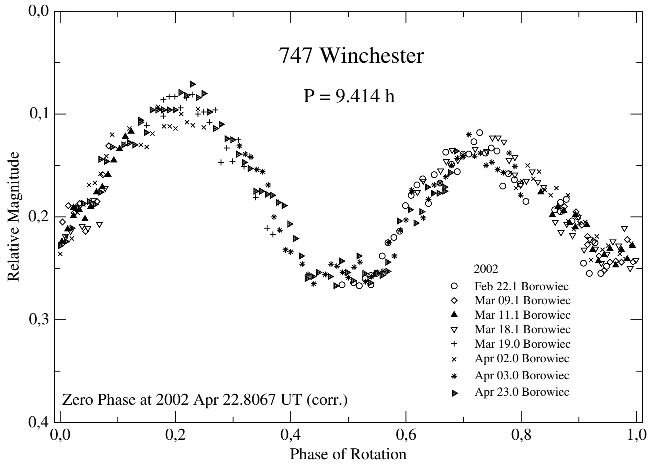

Fig. 6. Composite lightcurve of 747 Winchester in 2002.

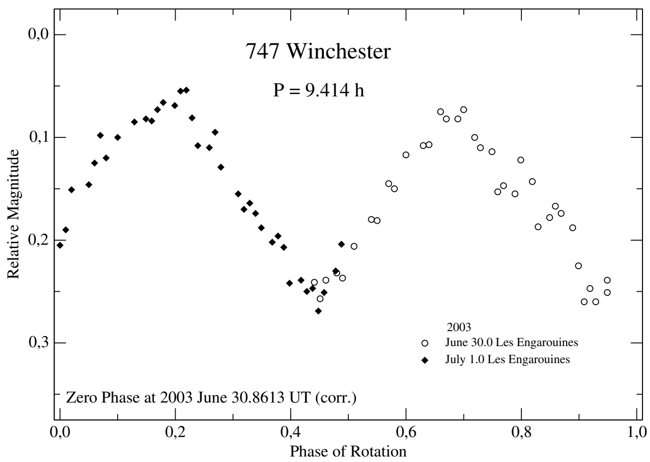

Fig. 7. Composite lightcurve of 747 Winchester in 2003.

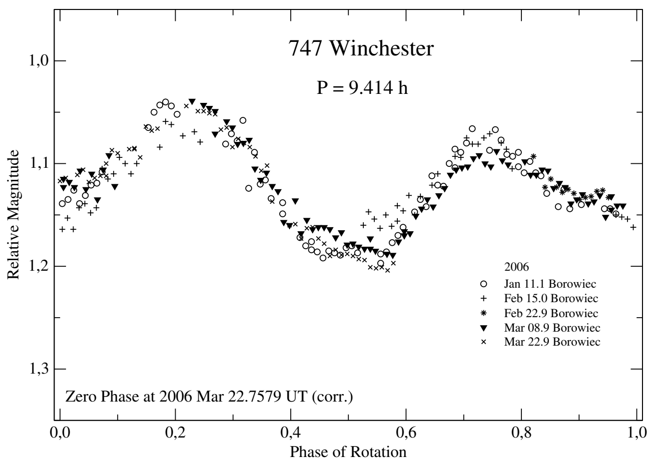

Fig. 8. Composite lightcurve of 747 Winchester in 2006.

2.1. 160 Una

Una was first observed photometrically by Harris et al. (1999). On three consecutive nights in October 1982, the authors obtained three sparse lightcurves, later composited with the 5.55 ± 0.02 h period, which they considered the most probable, although they did not rule out periods that were two or three times longer. The 0.10 mag amplitude lightcurve was asymmetric, with two "maxima" very close to each other and with shallow minimum between them. The authors also gave its $H-G$ values as $H = 9.050 \pm 0.004$ and $G = 0.05 \pm 0.04$. Next observations of this object were made by DiMartino et al. (1994) on two consecutive nights in October 1991, almost at the same place on this asteroid's orbit, due to its 9-year commensurability with the Earth's year. Their clumpy lightcurves were composited with a similar 5.61 ± 0.01 h period, had an amplitude of 0.14 ± 0.01 mag, and looked more symmetric than the previous

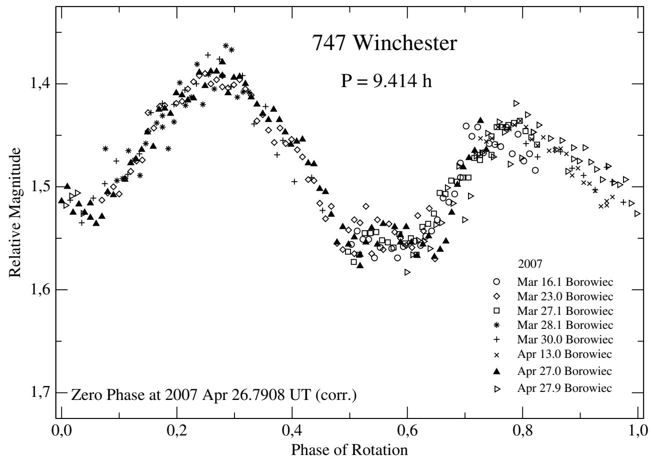

Fig. 9. Composite lightcurve of 747 Winchester in 2007.

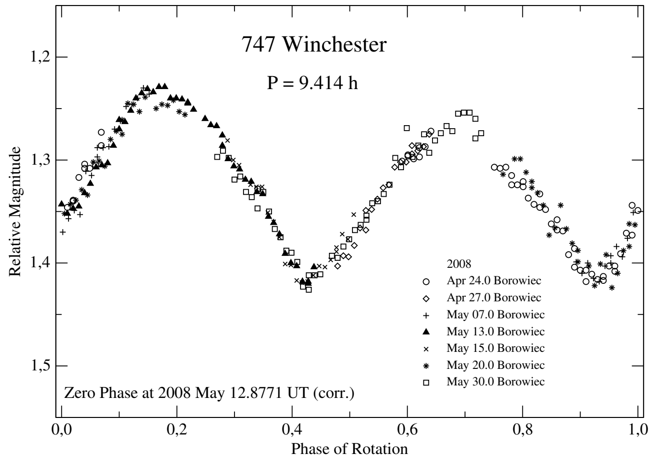

Fig. 10. Composite lightcurve of 747 Winchester in 2008.

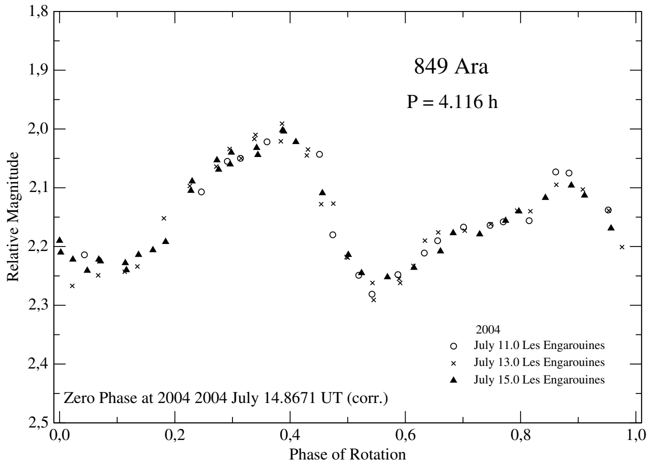

Fig. 11. Composite lightcurve of 849 Ara in 2004.

one. Finally, Warner (2007b) estimated Una's $H-G$ parameters as $H = 8.95 \pm 0.02$ and $G = 0.05 \pm 0.05$.

We observed Una at five more apparitions: 2000, 2001/2002, 2005, 2007, and 2008. We usually restricted our observing runs according to its period from the literature: 5.61 h. But after the 2002 apparition, it was clear that the period must be longer than 6 h. Finally, we found that only a much longer period of 11.033 ± 0.001 h fits all the apparitions, so that is the period for all the composite lightcurves shown in Figs. 1 to 5. In most of the composites, the individual parts of the lightcurve were too short or not overlapping, so they were arbitrarily shifted in the vertical axis. Asteroid Una showed unusual, flat lightcurves with one pair of extrema in some apparitions, and bimodal curves with wide extrema in the other. The amplitudes ranged from 0.08 to 0.25 mag.

2.2. 747 Winchester

The first observations of Winchester come from the years 1970 and 1973. Vesely & Taylor (1985) gave those two lightcurves, the first obtained on one night in March 1970 and the other in August 1973. Both of them are rather noisy and partial, with an amplitude not exceeding 0.13 mag. On two close nights in July and August 1978 Harris & Young (1980) obtained two, rather sparse lightcurves of this asteroid, with an amplitude of 0.13 mag. The lightcurves did not cover the whole rotational cycle, so the period of rotation was suggested to be of over 8 h. Next, Winchester was observed by Zappala et al. (1983). On six nights in February 1980 this object produced an asymmetric, 0.13 mag amplitude lightcurve. The extrema were at slightly different heights. Unfortunately, the data came as a composite lightcurve with a period of 9.40 ± 0.01 h, which was later corrected, so only one lightcurve of this set fits our model closely. On five nights in March-April 2007, Warner (2007a) observed Winchester obtaining a smooth, asymmetric composite lighcurve with 0.16 ± 0.02 mag amplitude and 9.4146 ± 0.0002 h period. All these data were included in our modelling.

We added five apparitions to the existing set, from the years: 2002, 2003, 2006, 2007, and 2008. All the lightcurves from the separate apparitions (Figs. 6–10) were composited with a synodic period of 9.414 ± 0.001 h. Winchester always showed regular bi-modal lightcurves with similar amplitudes, ranging from 0.16 to 0.21 mag.

2.3. 849 Ara

The only available lightcurves of this object can be found in Harris et al. (1992). There is one dense and four sparse lightcurves, coming from May-June 1981. The period determined by the authors was 4.11643±0.00005 h, this precision followed from its shortness and a month-long observing span. The lightcurve itself had 0.34 mag amplitude and one of the maxima was asymmetrically shaped. The authors provided also the $H-G$ values as 8.33 ± 0.01 and 0.21 ± 0.01, respectively.

Our observations of this asteroid spanned four apparitions: 2004, 2006, 2007, and 2008. The period 4.116 ± 0.001 h has been confirmed and it fits all the composite lightcurves shown in Figs. 11–14. The look of the lightcurves changed profoundly from one apparition to the next, from a slightly irregular bimodal lightcurve to the ones where one of the minima is almost flat. The amplitudes were in the range of 0.20 to 0.57 mag.

3. Pole and shape results

To construct the spin and shape models, we used the *lightcurve inversion* method, whose details can be found in Kaasalainen & Torppa (2001) and Kaasalainen et al. (2001, 2002a). The procedure uses all the available brightness measurements directly. In the iteration process, the shape model and its spin axis are changed so as to reproduce the observed lightcurves as closely as possible. The resulting fits are usually very good, as the model can even reproduce the small features of the lightcurves. The

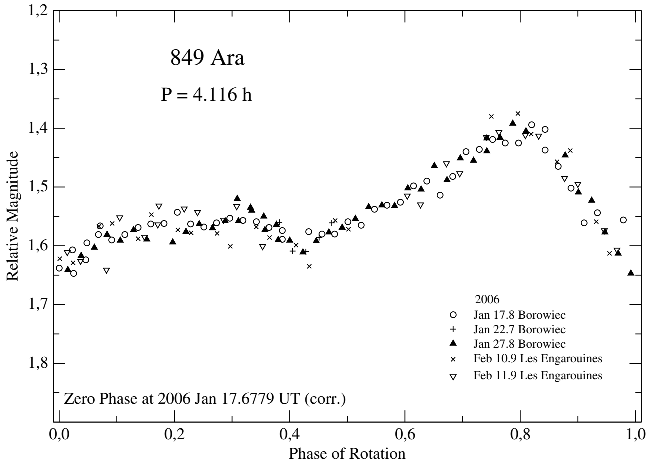

Fig. 12. Composite lightcurve of 849 Ara in 2006.

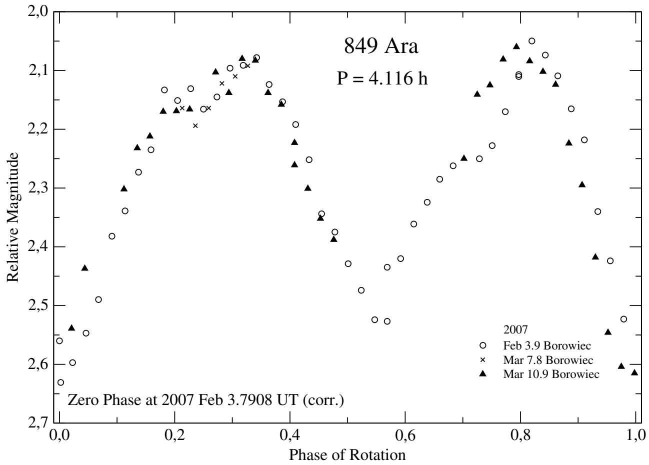

Fig. 13. Composite lightcurve of 849 Ara in 2007.

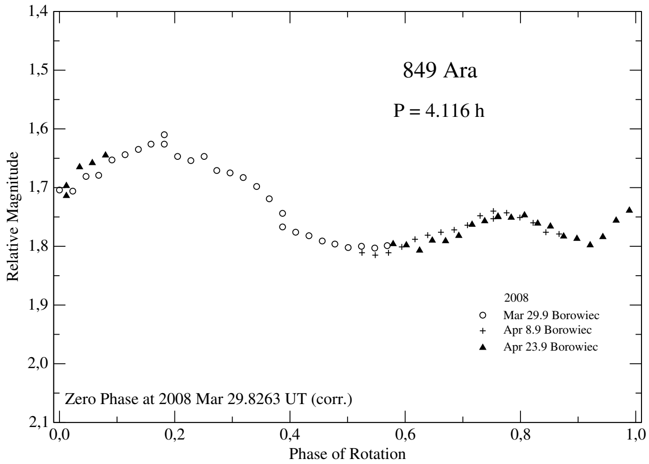

Fig. 14. Composite lightcurve of 849 Ara in 2008.

key requirement for the data is the possibly widest span of the observing geometries. This may not always be the case, as the example of 747 Winchester shows (see below).

Table 3 presents the resulting model parameters. In the first column there is the asteroid's sidereal period of rotation, with an uncertainty restricted to the last digit. Then both pole solutions follow with their J2000 ecliptic longitude $\lambda_{\rm p}$ and latitude $\beta_{\rm p}$. The negative value of $\beta_{\rm p}$ indicates a retrograde rotation, which was confirmed by calculating obliquities $\beta_{\rm p}$ with respect to the orbits of individual objects. The next three columns of Table 3 give the observing span in years, the number of apparitions, and the number of lightcurves that were used to construct the model. The last two columns show the method used to construct the model and the reference ("L (com)" denotes the lightcurve inversion applied to a combined dataset, with sparse datapoints and a few dense lightcurves). For 747 Winchester and 849 Ara, the pole results have been previously reported and are listed in Table 3 before the present solution.

We give the error values next to the pole coordinates, as they turned out to be unusual. Usually, the uncertainty of the pole solution in the lightcurve inversion is around ±5° on the celestial sphere. In this method, the solution errors can only be estimated by starting the procedure with various parameters and determining the scatter of the proper solutions. (In Torppa et al. 2003 and Kaasalainen & Ďurech 2007 one can find more details on errors in the lightcurve inversion.) All three cases are described below with their errors.

To demonstrate how the model lightcurves fit the observed ones, we present lightcurves coming from three apparitions superimposed on the model lightcurves covering the whole rotational phase (Figs. 15, 17 and 19). The angles ϕ, ϕ_0, and α denote the aspect angles of the Earth (as the angle between asteroid's north pole and the direction to the Earth), the Sun, and the phase angle at the epoch of observation, respectively.

3.1. 160 Una

The model of 160 Una was successfully constructed with the newly found period of 11.033165 h. Twenty-four lightcurves taken over 7 apparitions were used (from 1982, 1991, 2000, 2001/2002, 2005, 2007, and 2008). Three of the apparitions happened at almost the same place on its orbit, so the actual number of different apparitions was five. This asteroid shows interesting changes in lightcurves, switching from a bimodal look with ditches in maxima to flat lightcurves with a wavy pair of extrema in them. The shape model that reproduces such data has a triangular polar cross-section (Fig. 16) and rather low pole inclination (Table 3), which allows large variations in the visible parts of the surface with the changing aspect. The interesting feature of this asteroid is that its amplitudes sometimes get smaller in aspects close to equatorial, while growing bigger in aspect closer to polar ones (Fig. 15). We usually expect the opposite. For most asteroids the amplitudes of the lightcurves increase at equatorial aspects. But this object's shape is so far from ellipsoidal that we observe smaller amplitudes and the disappearance of one pair of extrema in the equatorial aspects, not close to polar ones. Una proved to be a retrograde rotator. This is the first complete model of this asteroid.

3.2. 747 Winchester

The 4-cycle semi-commensurability with the Earth's year makes 747 Winchester a difficult case. It was not until we had 44 lightcurves coming from 9 apparitions of this object (1970, 1973, 1978, 1980, 2002, 2003, 2006, 2007, and 2008) that we managed to obtain its unique model. Although the rotation period is precisely determined, the pole solution (Table 3) and the shape model's vertical dimension (Fig. 18) are not fully constrained. The error in the longitude of the pole solutions reaches 15°, while it is 10° in latitude, probably due to the restricted viewing geometry of this asteroid. New observations are not

Table 3. Spin models.

Sidereal period (hours)	Pole 1 λ_p	β_p	Pole 2 λ_p	β_p	Observing span (years)	N_{app}	N_{lc}	Method	Reference
160 Una									
11.033176	125°	−33°	308°	−41°	1982–2008	7	24	L	Present work
±0.000011	±5°	±2°	±5°	±2°					
747 Winchester									
9.402	27°	+50°			1970–1980	4	5	EAM	Michałowski (1993)
			353°	39°	1970–1980	4	5	EA	De Angelis (1995)
9.414807	166°	−44°	296°	−61°	1970–2008	9	44	L	Present work
±0.000005	±15°	±10°	±15°	±10°					
849 Ara									
4.116391	17°	−10°	213°	−33°	1981–2003	1*	5	L (com)	Ďurech et al. (2009)
4.116391	10°	−25°	223°	−40°	1981–2008	5	20	L	Present work
±0.000001	±1°	±1°	±3°	±3°					

* 1 appartition with 5 dense lightcurves +133 sparse data points.

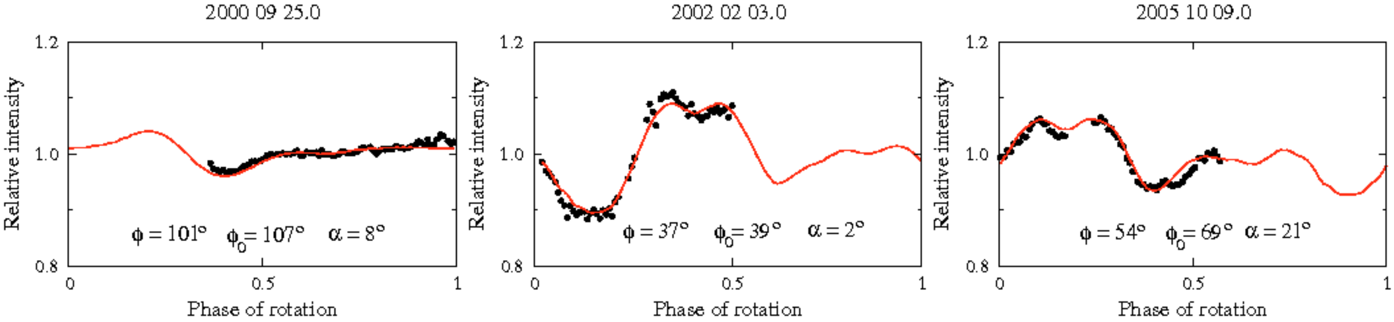

Fig. 15. Observed lightcurves (points) superimposed on the lightcurves created by a model (curves) at the same epochs for 160 Una.

Fig. 16. Shape model of 160 Una, shown at equatorial viewing and illumination geometry, with rotational phases 90° apart (two pictures *on the left*) and the pole-on view *on the right*.

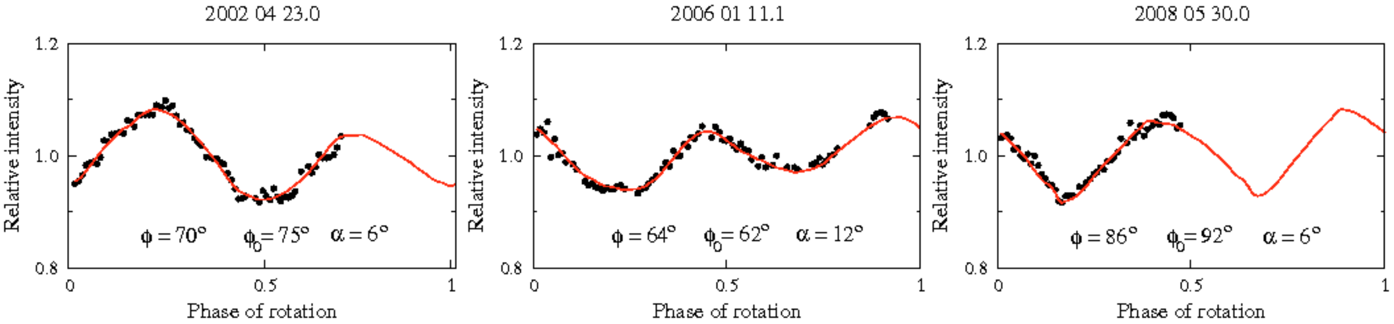

Fig. 17. Observed versus modelled lightcurves for 747 Winchester.

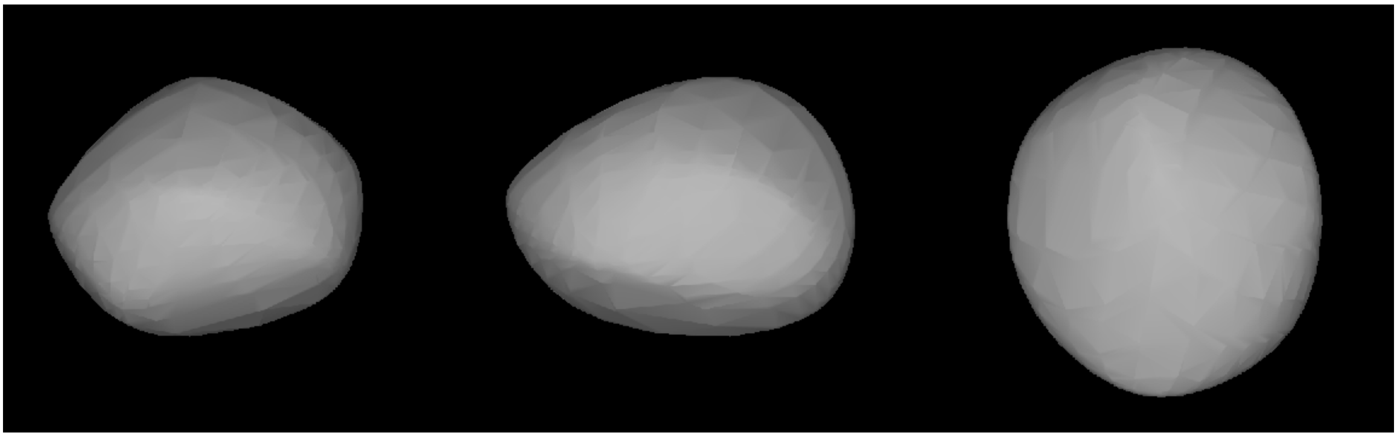

Fig. 18. Shape model of 747 Winchester.

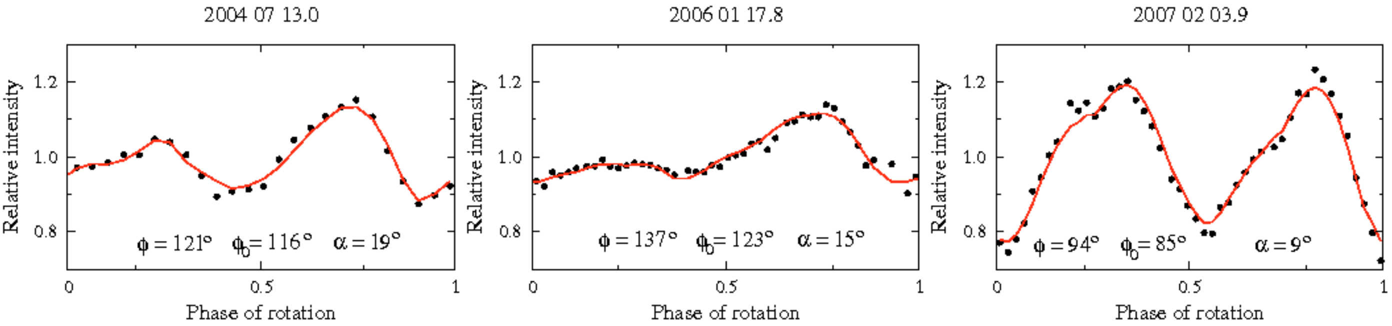

Fig. 19. Observed versus modelled lightcurves for 849 Ara.

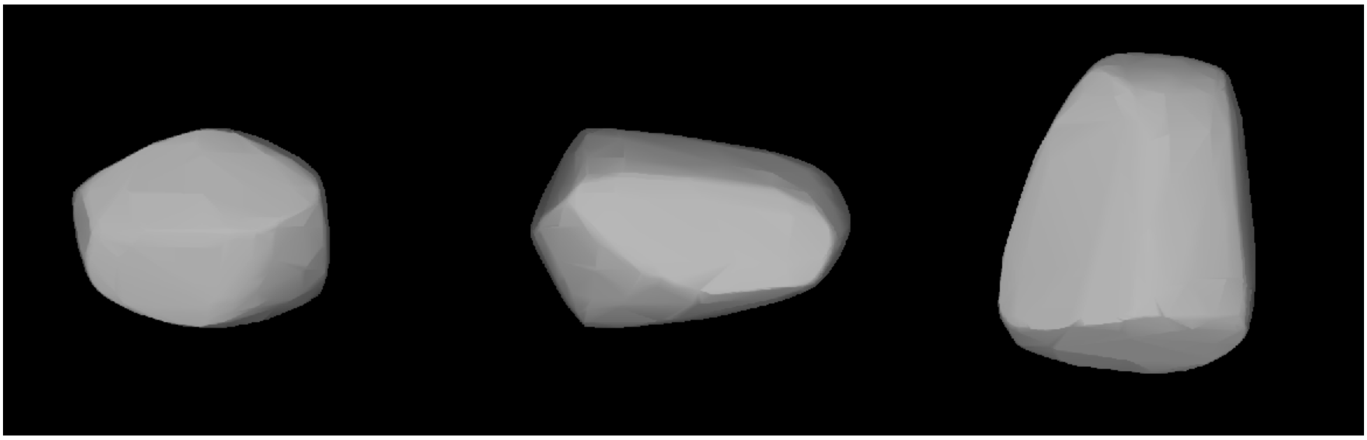

Fig. 20. Shape model of 849 Ara.

expected to improve the model until about ten years from now, when the repeating pattern shifts considerably along the orbit.

Our pole solution differs a lot from the previous pole determinations made by Michałowski (1993) or by De Angelis (1995). However, the latter author wrote that the sense of rotation has not been determined, but he did not give an alternative pole solution (around $\lambda_{\rm p} = 173°, \beta_{\rm p} = -39°$), which would then be close to our solution, because Winchester seems to be a retrograde rotator.

3.3. 849 Ara

For a change 894 Ara was a graceful object to model and to observe. With its lightcurves of unusual shape and evenly distributed apparitions, a unique model already appeared after 5 of them (from 1981, 2004, 2006, 2007, and 2008). Here, the scatter of the pole solutions was unprecedently small, as low as 1° for the first pole and 3° for the other (see Table 3). This probably originates in the high orbital inclination of this asteroid, resulting in large changes in the ecliptic latitudes of the object in the sky (Table 1). Still, it did not allow rejection of any one of the solutions. The rotation proved to be retrograde, as for the two previous asteroids. Our poles are close to the poles found by Ďurech et al. (2009), who used the lightcurve inversion with sparse photometric measurements combined with a few traditional lightcurves, and the sidereal periods are identical. Our shape model of Ara (Fig. 20) contains large planar sections and has a cone-like appearance, possible indicators of a double-lobed or even a binary shape (Kaasalainen et al. 2002b).

Acknowledgements. Borowiec observations were reduced with the *CCLRS STARLINK* package. This work was partially supported by grants N N203 3959 33 and N N203 302535 from the Polish Ministry of Science and Higher Education. This paper uses observations made at the South African Astronomical Observatory (SAAO). The *lightcurve inversion* code was created

by Mikko Kaasalainen and modified by Josef Ďurech, and is available at `http://astro.troja.mff.cuni.cz/projects/asteroids3D`.

References

De Angelis, G. 1995, Planet. Space Sci. 43, 649

Descamps, P., Marchis, F., Michałowski, T., et al. 2007, Icarus, 187, 482

Di Martino, M., Blanco, C., Riccioli, D., & De Sanctis, G. 1994, Icarus, 107, 269

Ďurech, J., Vokrouhlicky, D., Kaasalainen, M., et al. 2008, A&A, 489, L25

Ďurech, J., Kaasalainen, M., Warner, B., et al. 2009, A&A, 493, 291

Harris, A. W., & Young, J. W. 1980, Icarus, 43, 20

Harris, A. W., Young, J. W., Dockweiler, T., et al. 1992, Icarus, 95, 115

Harris, A. W., Young, J. W., Bowell, E., & Tholen, D. J. 1999, Icarus, 142, 173

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), 151

Kaasalainen, M., Torrpa, J., & Muinonen, K. 2001, Icarus, 153, 37

Kaasalainen, M., Mottola, S., & Fulchignoni, M. 2002a, In Asteroids III, ed. W. F. Bottke, A. Cellino, P. Paolicchi, & R. P. Binzel (Univ. Arizona Press), 139

Kaasalainen, M., Torrpa, J., & Piironen, J. 2002b, A&A, 383, L19

Kaasalainen, M., Ďurech, J., Warner, B. D., et al. 2007, Nature, 446, 420

Kryszczyńska, A., La Spina, A., Paolicchi, P., et al. 2007, Icarus, 192, 223

Lowry, S. C., Fitzsimmons, A., Pravec, P., et al. 2007, Science, 316, 272

Lagerkvist, C.-I., Magnusson, P., & Erikson, E. 2001, Asteroid Photometric Catalogue, fifth update, Uppsala Astronomical Observatory

Marciniak, A., Michałowski, T., Kaasalainen, M., et al. 2007, A&A, 473, 633

Marciniak, A., Michałowski, T., Kaasalainen, M., et al. 2008, A&A, 478, 559

Michałowski, T. 1993, Icarus, 106, 563

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

Slivan, S. M. 2002, Nature, 419, 49

Tedesco, E. F., Noah, P. V., Noah, M., & Price, S. D. 2004, IRAS Minor Planet Survey. IRAS-A-FPA-3-RDR-IMPS-V6.0. NASA Planetary Data System

Tholen, D. J. 1989, In Asteroids II, ed. R. P. Binzel, T. Gehrels, & M. S. Matthews (Univ. Arizona Press), 1139

Torppa, J., Kaasalainen, M., Michalowski, T., et al. 2003, Icarus, 164, 346

Vesely, C. D., & Taylor, R. C. 1985, Icarus, 64, 37

Warner, B. D. 2007a, Minor Planet Bull., 34, 104

Warner, B. D. 2007b, Minor Planet Bull., 34, 113

Zappala, V., Scaltriti, F., Di Martino, M. 1983, Icarus, 56, 325