Physical models of ten asteroids from an observers' collaboration network

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ABSTRACT

Aims. We present physical models of ten asteroids obtained by means of lightcurve inversion. A substantial part of the photometric data was observed by amateur astronomers. We emphasize the importance of a coordinated network of observers that will be of extreme importance for future all-sky asteroid photometric surveys.

Methods. The lightcurve inversion method was used to derive spin states and shape models of the asteroids.

Results. We derived spin states and shape model for ten new asteroids: (110) Lydia, (125) Liberatrix, (130) Elektra, (165) Loreley, (196) Philomela, (218) Bianca, (306) Unitas, (423) Diotima, (776) Berbericia, and (944) Hidalgo. This increases the number of asteroid models up to nearly one hundred.

Key words. minor planets, asteroids

1. Introduction

The lightcurve inversion method has become a standard tool for asteroid shape and spin state determination (Kaasalainen & Torppa 2001; Kaasalainen et al. 2001, 2002a). Convex models are a good representation of real shapes of asteroids, as has been proven by ground truths from, e.g., Kaasalainen et al. (2001, 2005), and Marchis et al. (2006). Slightly fewer than one hundred asteroid models have been derived so far (Kaasalainen et al. 2002c, 2004; Torppa et al. 2003). However, the number of asteroid models increases slowly, mainly due to the fact that at least three well-covered apparitions are necessary for a main-belt asteroid to be modeled. The Uppsala Asteroid Photometric Catalogue (UAPC, Lagerkvist et al. 2001) – the main source of asteroid photometric data – has been already exploited and the global morphology of all well-observed asteroids has been determined. The UAPC still contains valuable photometric data of many asteroids, but the amount of the data is not sufficient for a unique physical model. For many such targets, observations from only one more apparition are sufficient for a model, and many of those targets are within the reach of amateur astronomers. We present new observations and physical models of asteroids (110) Lydia, (125) Liberatrix, (130) Elektra, (165) Loreley, (196) Philomela, (218) Bianca, (306) Unitas, (423) Diotima, (776) Berbericia, and (944) Hidalgo. In the last section, we discuss the possibility of combining the ordinary lightcurves with the sparse photometric data that will be available from all-sky photometric surveys in the near future.

⋆ Tables 1–3 are only available in electronic form at `http://www.aanda.org`

2. Observations

To derive unique spin state solutions and shape models, we combined photometric data published in the UAPC with the new observations that were carried out by a large number of both amateur and professional observers. Some lightcurves from the UAPC that were too noisy, consisted of only a few points, or were clearly wrong were not included in the analysis. Information about observers and telescopes is listed in Table 1. All the new observations are listed in Table 2. For each lightcurve, there is the date of observation, the aspect data, the asteroid's ecliptic coordinates, and the code number of the observatory referring to Table 1. All photometric observations were treated as relative and we used a combination of the Lommel-Seeliger and Lambert light-scattering laws (Kaasalainen et al. 2002a) as our scattering model.

We do not present all the lightcurves in a graphical form, but only a selection of three representative lightcurves for each asteroid. Most of the lightcurves from Table 2 can be found at the Collaborative Asteroid Lightcurve Link (`http://www.MinorPlanetObserver.com/astlc/default.htm`) or at `http://obswww.unige.ch/~behrend/page_cou.html`. The complete lightcurve datasets that were used for deriving shape models in the following section can be downloaded from `http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/465/331`.

3. Models

The spin solutions and shape models were derived using the lightcurve inversion method developed by Kaasalainen & Torppa (2001), and Kaasalainen et al. (2001). The spin axis

Fig. 1. The shape model of (110) Lydia. There are two equatorial views 90° apart (the first two figures) and a pole-on view (the third plot).

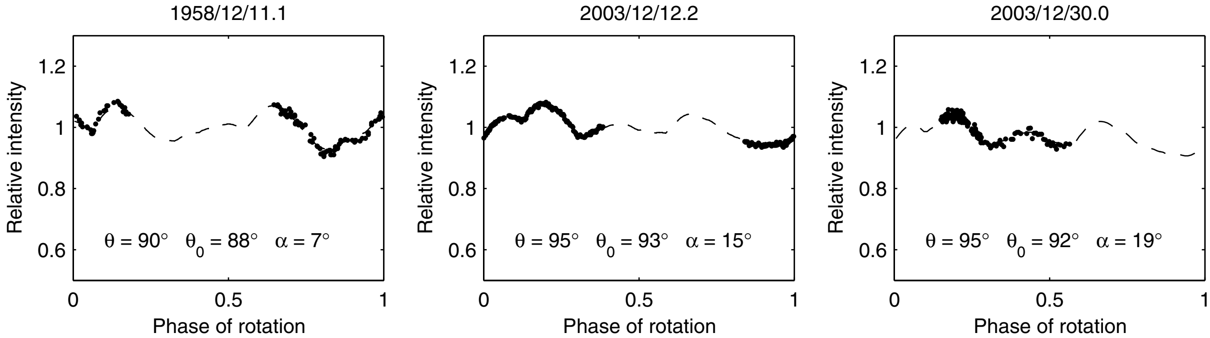

Fig. 2. Observed data (points) and the modeled brightness (dashed curve) for three representative lightcurves of (110) Lydia. The plots cover one rotation cycle, the brightness is given in relative intensity units. The viewing/illumination geometry is given by the aspect angle of the Earth θ and of the Sun θ_0 and by the solar phase angle α.

Fig. 3. The shape model of (125) Liberatrix. The viewing geometry is the same as in Fig. 1.

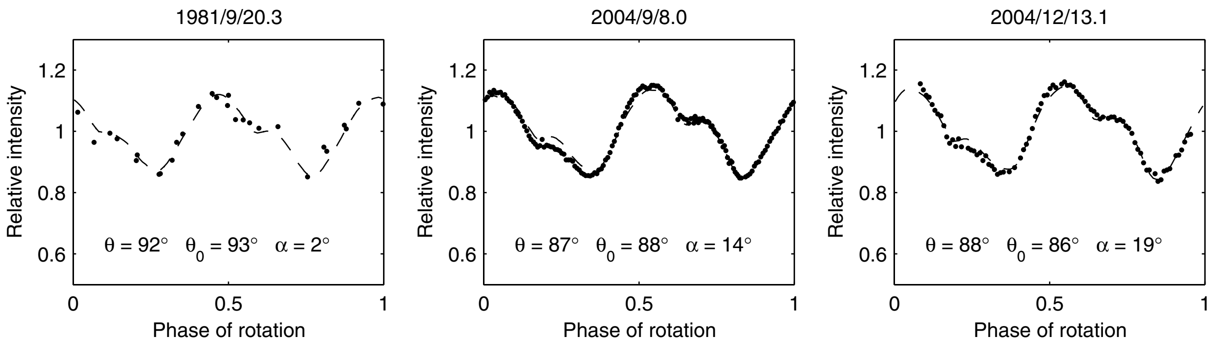

Fig. 4. Lightcurves and the corresponding fits for (125) Liberatrix.

direction in J2000 ecliptic coordinates λ_p,β_p and the rotation period P for each asteroid are listed in Table 3. In the case of the lightcurve inversion, the systematic errors in lightcurves and model errors dominate over the observational noise. Thus formal errors for pole positions derived from confidence limits based on χ^2 distribution would be underestimated. A good estimation of a typical error in the pole direction obtained by comparison of lightcurve inversion results with ground truths from space probes and laboratory experiments (Kaasalainen et al. 2005) is about 5° of arc. The accuracy of the period determination is of the order of the last unit digit of the period value given in Table 3. For more detailed discussion of error estimation see Torppa et al. (2003), and Kaasalainen & Ďurech (2007).

In Figs. 1 to 20, we plot the the shape model of each asteroid viewed from the plane of its equator (two views 90° apart) and pole-on, and the corresponding lightcurve fit. In some cases, there are two possible pole solutions with the ecliptic longitudes λ about 180° apart and with similar values

Fig. 5. The shape model of (130) Elektra. The viewing geometry is the same as in Fig. 1.

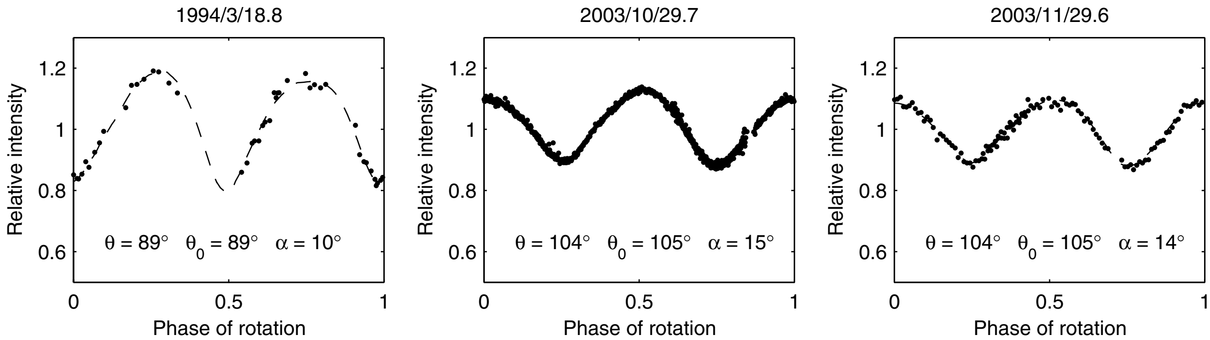

Fig. 6. Lightcurves and the corresponding fits for (130) Elektra.

Fig. 7. The shape model of (165) Loreley. The viewing geometry is the same as in Fig. 1.

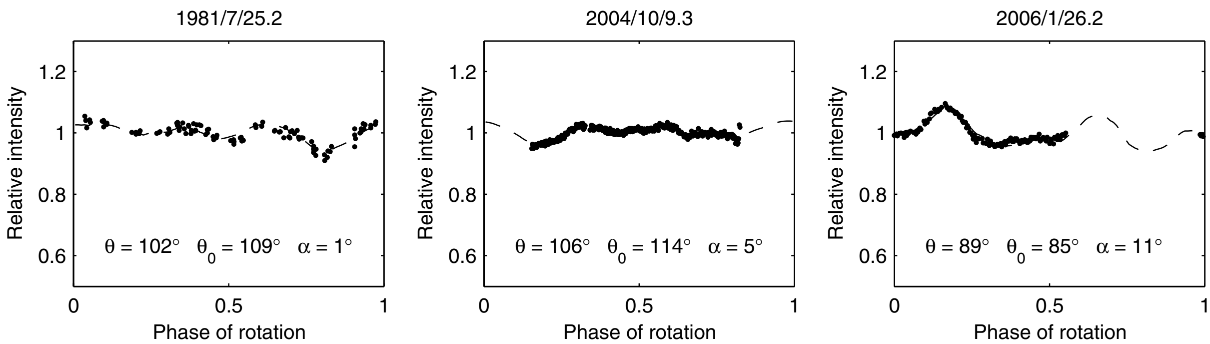

Fig. 8. Lightcurves and the corresponding fits for (165) Loreley.

Fig. 9. The shape model of (196) Philomela. The viewing geometry is the same as in Fig. 1.

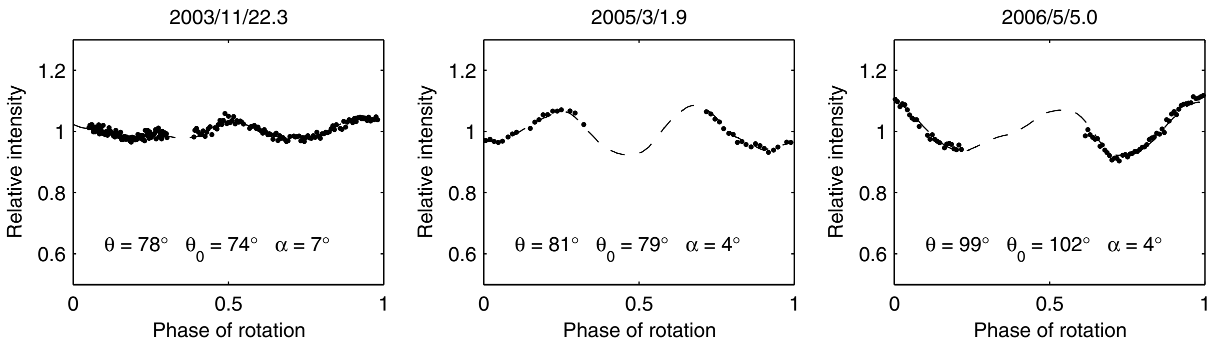

Fig. 10. Lightcurves and the corresponding fits for (196) Philomela.

Fig. 11. The shape model of (218) Bianca. The viewing geometry is the same as in Fig. 1.

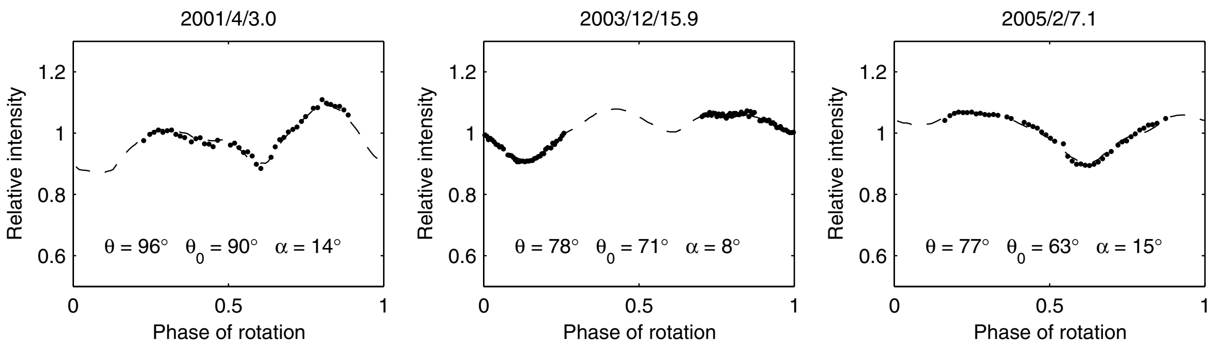

Fig. 12. Lightcurves and the corresponding fits for (218) Bianca.

Fig. 13. The shape model of (306) Unitas. The viewing geometry is the same as in Fig. 1.

of the pole ecliptic latitude β. This ambiguity is inevitable for disk-integrated measurements of objects orbiting near the plane of ecliptic (see Kaasalainen & Lamberg 2006). Due to the fact that we used only relative photometry, the dimensions along the rotation axis are not well constrained. The pole-on silhouettes are very good approximations of asteroids' real shapes, whereas the silhouettes viewed from the equatorial plane can be significantly stretched or squeezed along the rotation axis. The principal axis of the inertia tensor (assuming uniform density) corresponding to the maximum moment of inertia is very close to the rotation axis for every model. The models together with the spin vector solutions are available at `http://astro.troja.mff.cuni.cz/projects/asteroids3D`.

(110) Lydia. Lightcurve amplitudes do not exceed 0.2 mag. The shape is flat with a regular pole-on silhouette. There are two pole solutions.

(125) Liberatrix. The rotation axis is almost perpendicular to the ecliptic plane and the orbit is close to the ecliptic (for most

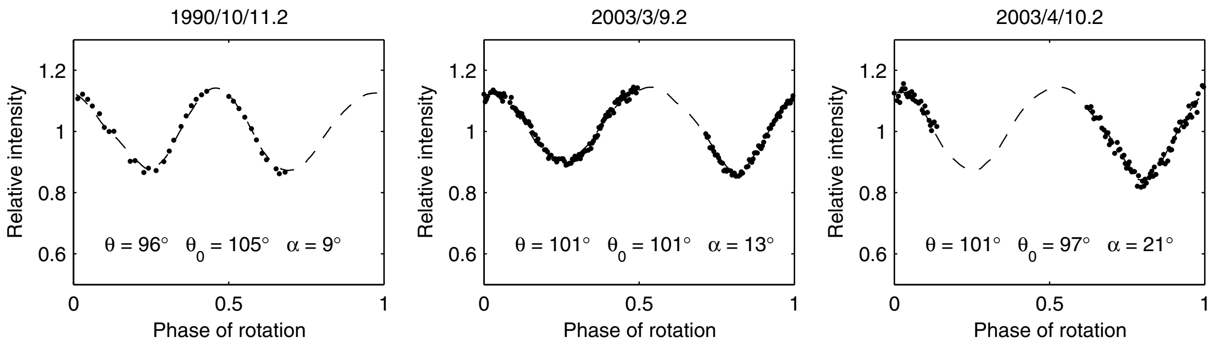

Fig. 14. Lightcurves and the corresponding fits for (306) Unitas.

Fig. 15. The shape model of (423) Diotima. The viewing geometry is the same as in Fig. 1.

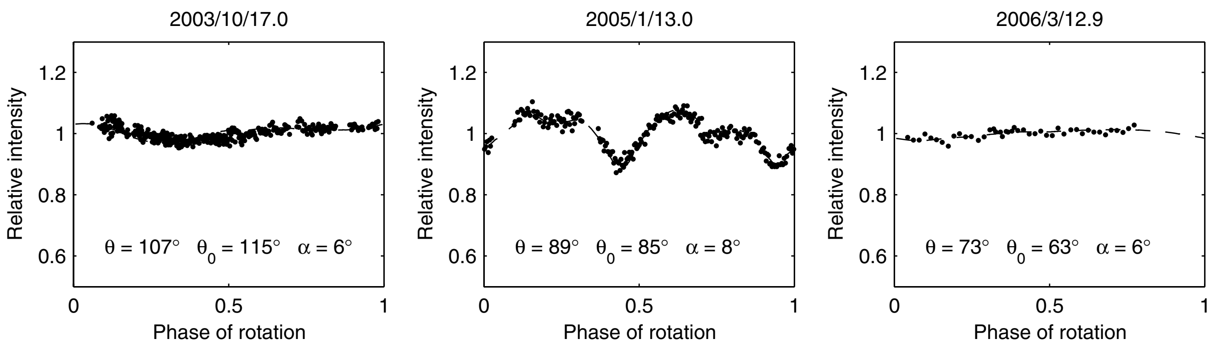

Fig. 16. Lightcurves and the corresponding fits for (423) Diotima.

Fig. 17. The shape model of (776) Berbericia. The viewing geometry is the same as in Fig. 1.

lightcurves $|\beta| \leq 5°$). Liberatrix has been seen equator-on all the time and the lightcurves hardly change from one opposition to another, having the same amplitude 0.4 mag. Relative lightcurves and the restricted geometry do not allow us to constrain the dimension along the rotation axis accurately – the shape model can be more or less stretched along this axis and the lightcurve fits remain almost the same.

(130) Elektra. Lightcurves of Elektra are typical double sinusoidal, the shape model is regular and elongated. Although the rotation axis is perpendicular to the plain of ecliptic, the viewing/illumination geometry is not restricted to the equatorial view/illumination (contrary to the previous case of Liberatrix), due to the high ecliptic latitude Elektra reached ($-35° < \beta < 25°$).

(165) Loreley. The shape model has many flat areas, the lightcurves have small amplitudes of 0.2 mag at most and a complicated structure. The pole direction solution $(346°, +29°)$ is

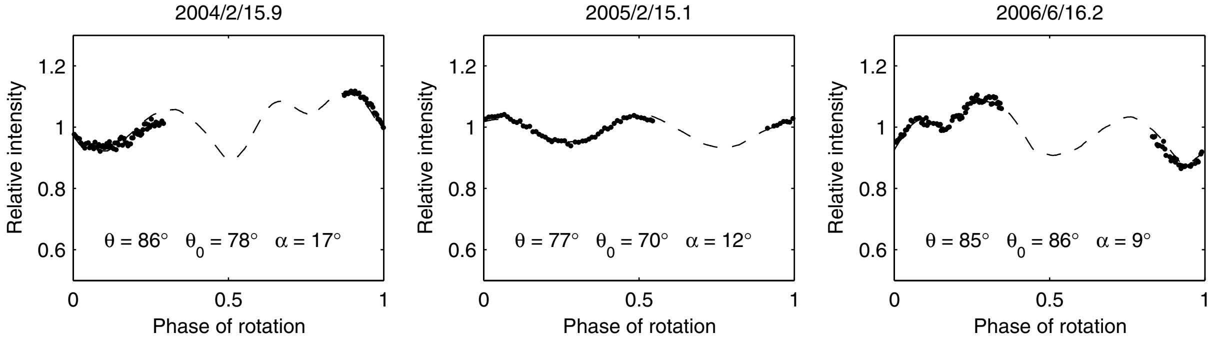

Fig. 18. Lightcurves and the corresponding fits for (776) Berbericia.

Fig. 19. The shape model of (944) Hidalgo. The viewing geometry is the same as in Fig. 1.

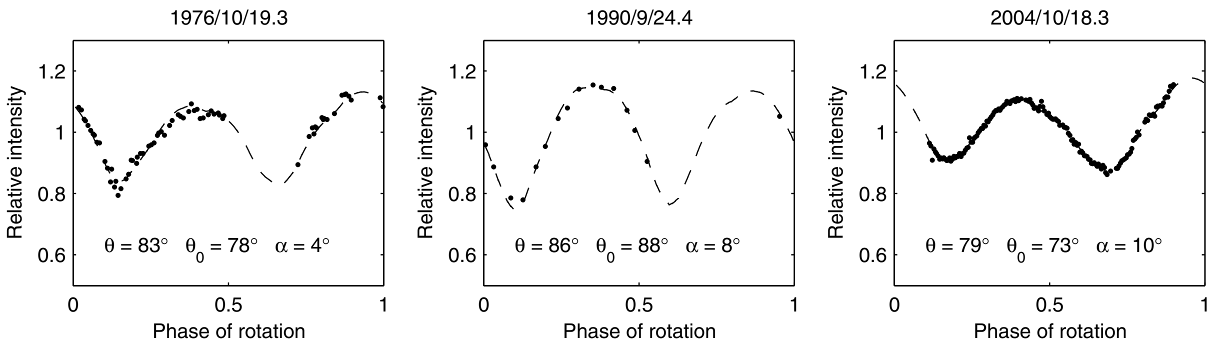

Fig. 20. Lightcurves and the corresponding fits for (944) Hidalgo.

clearly the best one, but there is the second solution (165°, +15°) giving only a slightly worse fit.

(196) Philomela. The shape model is asymmetric and smooth, the geometry varies a lot, lightcurves vary from almost flat to those with amplitudes up to 0.4 mag.

(218) Bianca. There are two pole solutions corresponding to almost the same spin axis with both a prograde and a retrograde sense of rotation. The shape is asymmetric.

(306) Unitas. The shape is regular, lightcurves typically exhibit two extrema per rotation.

(423) Diotima. The lightcurves vary a lot – some are almost flat and others exhibit 0.2 mag deep minima. From the photometric data we obtained two solutions for the pole direction: (351°, +4°) and (176°, +33°), but only the first one is consistent with the adaptive optics image obtained by Marchis et al. (2006).

(776) Berbericia. Lightcurves are very different for different apparitions – sometimes there is only one maximum per period. The corresponding shape model is asymmetric with sharp edges.

(944) Hidalgo. Although our model is based on only 14 lightcurves from four oppositions, the pole and period solution is unique. The shape model has very large flat areas and a "rectangular" pole-on silhouette, which are strong indications of a highly nonconvex shape (Kaasalainen et al. 2002b; Ďurech & Kaasalainen 2003). Also, the sharp minima of some lightcurves support the idea of a two-lobed shape.

4. Future work

The number of asteroid models available so far is very small when compared with the whole asteroid population. The classical approach of observing a selected target (or a few targets) during the night to densely cover the lightcurve in the rotation phase is time consuming. The number of asteroids with enough observations to derive a model increases only slowly. The situation is going to change in the near future with the asteroid photometric surveys (for example Pan-STARRS). It has been shown (see Kaasalainen 2004; Ďurech et al. 2005) that asteroid models can be derived from calibrated photometric measurements that are sparse in time. This kind of data will be provided by future photometric surveys – instead of tens of lightcurves covering several apparitions we will have typically a hundred or more individual brightness measurements spread over several years. A difficulty that appears when analyzing sparse data is that the rotation period of an asteroid is not "visible" from the data as it is in the case of an ordinary well-covered lightcurve. Thus a very wide interval of all possible periods must be densely scanned for the correct value. The time-consuming process of period search can be sped up dramatically by adding just one ordinary lightcurve that constrains the search to a narrow interval of periods. A network of observers who will carry out photometric follow-up observations of selected asteroids will be very important for the next generation of all-sky surveys.

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Online Material

Table 1. The list of observatories and telescopes, D is the telescope aperture diameter.

Code	Observing site	D [cm]	Observers
1	Blauvac Observatory, France	31	R. Roy
2	Borowiec Station, Poznań Observatory, Poland	40	A. Marciniak, R. Hirsch, K. Kamiński, M. Fagas, T. Michałowski, T. Kwiatkowski
3	Carbuncle Hill Observatory, Rhode Island, USA	35	D. Pray
4	Egan Observatory, Florida, USA	40	M. Fauerbach, T. Bennett
5	Observatori Astronomic de Consell, Mallorca, Spain	40	A. Lopez, R. Pacheco
7	Ondřejov Observatory, Czech Republic	65	M. Wolf, J. Ďurech
8	Ostrowik, Poland	60	W. Pych
9	Pic du Midi, France	105	T. Michałowski, J. Berthier
11	Santana Observatory, CA, USA	35	R. Stephens
12	Shed of Science Observatory, Minneapolis, USA	25	R. Durkee
13	Pic de Chateau-Renard Observatory, France	62	S. Fauvaud, G. Santacana
14	Waterlooville, Hampshire, England	25	R. Dymock
15	Whitin Observatory, Massachusetts, USA	61	S. Slivan, M. Frey
16	Mt Tarana Observatory, Bathurst, Australia	40	C. Bembrick
17	Craigie, Australia	25	G. Bolt
18	Pleasant Plains, Illinois, USA	35	F. Pilcher, D. Jardine
19	Le Crès, France	25	R. Poncy
20	Linhaceira Observatory, Portugal	25	R. Gonçalves
21	Stazione Astronomica di Sozzago, Italy	40	R. Crippa, F. Manzini
22	Vintage Lane Observatory, Blenheim, New Zealand	30	W. H. Allen
23	The WW Crow Observatory, England	20	M. Crow
24	Antelope Hills Observatory, Colorado, USA	25	R. Koff
25	Les Engarouines Observatory, France	21	L. Bernasconi
26	Goat Mountain Astronomical Research Station, USA	35	R. Stephens
27	Gnosca Observatory, Switzerland	40	S. Sposetti
28	Wallace Astrophysical Observatory, Massachusetts, USA	61	S. Slivan
29	Wallace Astrophysical Observatory, Massachusetts, USA	35	M. Pan, L. Crespo da Silva, S. Boroumand

Table 2. Aspect data for new observation of the modeled asteroids. The table lists asteroid distance from the Sun r, from the Earth Δ, the solar phase angle α, and the ecliptical coordinates of the asteroid (λ, β).

Date	r [AU]	Δ [AU]	α [deg]	λ [deg]	β [deg]	Obs. code
			(110) Lydia			
2003 12 02.2	2.642	1.757	11.6	37.0	−1.3	3
2003 12 13.1	2.651	1.857	15.1	35.9	−0.9	3
2003 12 21.2	2.657	1.947	17.2	35.7	−0.6	3
2003 12 22.0	2.658	1.957	17.4	35.7	−0.6	3
2003 12 23.1	2.659	1.969	17.6	35.7	−0.5	3
2003 12 26.1	2.661	2.007	18.3	35.8	−0.4	3
2003 12 27.1	2.662	2.018	18.5	35.8	−0.4	3
2003 12 28.0	2.663	2.029	18.6	35.8	−0.4	3
2003 12 29.1	2.663	2.042	18.8	35.9	−0.3	3
2003 12 30.0	2.664	2.055	19.0	35.9	−0.3	3
2003 12 12.2	2.650	1.848	14.9	36.0	−0.9	11
2003 12 17.2	2.654	1.901	16.3	35.8	−0.7	11
2003 12 19.2	2.656	1.923	16.8	35.7	−0.7	11
2003 12 22.2	2.658	1.958	17.5	35.7	−0.6	11
			(125) Liberatrix			
2004 12 13.0	2.818	2.278	18.7	14.7	−4.0	4
2004 12 13.1	2.818	2.279	18.7	14.7	−4.0	4
2004 12 15.0	2.820	2.305	18.9	14.9	−4.0	4
2004 12 28.0	2.830	2.489	20.0	16.4	−3.9	4
2004 12 28.1	2.830	2.490	20.0	16.4	−3.9	4
2004 09 08.0	2.740	1.907	14.2	27.5	−2.7	7
2004 10 08.0	2.765	1.773	3.0	22.3	−3.7	7
2004 12 30.7	2.832	2.529	20.1	16.9	−3.9	7
2005 01 13.8	2.842	2.734	20.2	19.6	−3.7	7
2004 11 10.1	2.792	1.905	11.0	15.7	−4.2	15
			(130) Elektra			
2001 04 22.9	3.705	2.817	8.4	226.1	29.9	27
2001 04 23.0	3.705	2.817	8.4	226.1	29.9	27
2003 10 21.8	2.503	1.701	16.4	59.4	−34.4	17
2003 10 23.7	2.505	1.694	16.1	59.1	−34.7	17
2003 10 24.7	2.506	1.690	15.9	58.9	−34.8	17
2003 10 29.7	2.511	1.676	15.0	58.0	−35.4	17
2003 11 14.5	2.528	1.662	13.4	54.5	−36.2	16
2003 11 15.6	2.530	1.663	13.4	54.2	−36.2	16
2003 11 19.5	2.534	1.669	13.4	53.3	−36.2	16
2003 11 27.6	2.544	1.692	13.8	51.5	−35.8	16
2003 11 29.6	2.547	1.700	14.0	51.0	−35.6	16
			(165) Loreley			
2004 09 28.3	3.064	2.102	6.3	17.7	15.6	12
2004 10 09.2	3.073	2.100	5.1	15.4	15.8	12
2004 10 09.3	3.073	2.100	5.1	15.4	15.8	12
2004 10 23.9	2.778	1.799	4.5	18.8	−4.0	1
2004 11 05.9	2.789	1.872	9.5	16.4	−4.1	1
2004 11 06.9	2.790	1.880	9.9	16.2	−4.1	1
2004 11 10.0	2.792	1.904	10.9	15.8	−4.2	1
2004 11 10.9	2.793	1.912	11.3	15.6	−4.2	1
2006 01 15.2	3.365	2.482	8.6	84.8	7.6	18
2006 01 26.3	3.368	2.581	11.5	83.5	6.9	18
2006 01 26.2	3.368	2.579	11.5	83.5	6.9	18
			(196) Philomela			
2003 11 16.3	3.182	2.279	8.6	82.1	0.2	3
2003 11 22.3	3.183	2.244	6.6	81.1	0.3	3
2003 11 23.4	3.183	2.238	6.2	80.9	0.4	3
2005 03 01.9	3.152	2.182	4.5	151.5	10.4	19
2005 03 02.8	3.152	2.184	4.7	151.3	10.4	19
2005 03 04.9	3.151	2.189	5.3	150.9	10.4	19
2005 03 06.9	3.151	2.195	5.9	150.5	10.4	19
2006 05 05.0	3.061	2.068	4.1	236.2	3.7	20
2006 05 07.0	3.060	2.062	3.4	235.8	3.7	20
2006 05 05.1	3.061	2.068	4.0	236.1	3.7	20
2006 05 19.0	3.059	2.050	1.8	233.4	3.3	20
2006 05 19.0	3.059	2.050	1.8	233.4	3.3	20
2006 05 12.0	3.060	2.052	1.7	234.8	3.5	21

Table 2. continued.

Date	r [AU]	Δ [AU]	α [deg]	λ [deg]	β [deg]	Obs. code
			(218) Bianca			
1996 01 19.1	2.676	1.776	10.4	144.5	−13.7	9
1996 03 18.9	2.605	1.818	16.2	132.4	−8.5	8
1997 05 14.0	2.396	1.632	19.2	280.7	22.7	2
1997 05 17.0	2.398	1.609	18.5	280.6	23.0	2
1997 05 19.0	2.399	1.595	18.1	280.5	23.2	2
1997 06 06.0	2.411	1.498	13.4	278.4	24.8	2
1997 06 07.0	2.412	1.494	13.1	278.2	24.8	2
1997 06 07.9	2.412	1.491	12.9	278.0	24.9	2
2000 03 22.8	2.756	2.467	21.1	98.6	−13.3	2
2000 03 23.8	2.755	2.479	21.1	98.8	−13.2	2
2001 03 02.1	2.384	1.779	22.0	225.2	11.1	2
2001 03 06.1	2.382	1.734	21.3	225.6	11.7	2
2001 03 07.1	2.381	1.723	21.1	225.6	11.9	2
2001 04 01.1	2.369	1.494	14.7	225.3	16.0	2
2001 04 03.0	2.368	1.481	14.1	225.1	16.4	2
2003 12 13.9	2.949	2.026	8.0	70.5	−22.3	5
2003 12 15.9	2.949	2.031	8.4	70.1	−22.3	5
2003 12 16.9	2.948	2.034	8.5	69.8	−22.3	5
2003 12 17.8	2.948	2.037	8.7	69.6	−22.2	5
2003 12 20.8	2.946	2.048	9.4	68.9	−22.1	5
2004 01 10.8	2.935	2.183	14.4	65.6	−20.7	5
2004 01 14.8	2.932	2.219	15.3	65.2	−20.3	5
2004 01 17.8	2.931	2.248	15.9	65.1	−20.0	5
2005 01 17.1	2.546	1.925	19.8	178.4	−4.4	2
2005 02 02.0	2.527	1.736	16.1	178.5	−3.4	2
2005 02 07.1	2.521	1.684	14.5	178.1	−3.0	2
2005 02 09.1	2.519	1.665	13.8	177.9	−2.8	2
2005 03 11.6	2.485	1.491	0.4	172.0	0.3	16
2005 03 12.6	2.484	1.490	0.2	171.8	0.4	16
2005 03 13.6	2.483	1.489	0.6	171.5	0.5	22
2005 03 13.6	2.482	1.489	0.7	171.5	0.5	16
2005 03 26.5	2.469	1.499	7.0	168.4	2.0	16
2005 03 31.5	2.464	1.515	9.4	167.3	2.5	16
2005 04 03.4	2.461	1.527	10.7	166.8	2.8	22
2005 04 16.9	2.447	1.609	16.0	164.9	4.1	23
2005 04 18.9	2.445	1.624	16.7	164.7	4.2	23
2005 04 19.9	2.444	1.632	17.0	164.6	4.3	23
2005 04 06.9	2.457	1.545	12.1	166.1	3.2	23
2005 04 10.9	2.453	1.568	13.8	165.5	3.5	23
2005 02 08.4	2.520	1.671	14.1	178.0	−2.9	4
2005 02 11.4	2.516	1.643	13.0	177.6	−2.6	4
2005 02 12.2	2.515	1.636	12.7	177.5	−2.5	4
2005 03 30.1	2.465	1.510	8.7	167.6	2.4	4
2005 04 05.1	2.459	1.535	11.4	166.5	3.0	4
2005 04 06.1	2.458	1.540	11.8	166.3	3.1	4
			(306) Unitas			
2003 03 09.2	2.700	1.849	13.2	129.8	0.2	24
2003 03 10.2	2.699	1.857	13.5	129.6	0.2	24
2003 04 01.1	2.689	2.077	19.3	128.4	0.9	24
2003 04 10.2	2.684	2.184	20.7	128.8	1.2	24
			(423) Diotima			
1998 09 24.3	3.114	2.365	14.1	49.6	−8.4	28
1998 09 25.3	3.115	2.354	13.9	49.5	−8.4	28
1998 09 26.3	3.115	2.344	13.6	49.5	−8.4	28
1998 09 28.3	3.116	2.326	13.1	49.3	−8.4	28
1998 09 29.2	3.116	2.317	12.9	49.2	−8.4	28
1998 10 16.2	3.122	2.194	7.9	47.0	−8.1	29
1998 10 28.2	3.126	2.150	4.0	44.7	−7.8	29
1998 10 28.2	3.126	2.150	4.0	44.7	−7.8	28
1998 10 30.1	3.127	2.146	3.5	44.3	−7.7	29
1998 10 30.2	3.127	2.146	3.5	44.3	−7.7	28
1998 11 10.2	3.131	2.149	2.9	42.0	−7.2	28
1998 11 12.2	3.131	2.153	3.4	41.6	−7.1	28
2003 10 16.1	3.078	2.111	5.5	11.6	−13.5	13
2003 10 17.0	3.078	2.113	5.7	11.5	−13.4	13

Table 2. continued.

Date	r [AU]	Δ [AU]	α [deg]	λ [deg]	β [deg]	Obs. code
2004 12 07.1	3.189	2.237	5.4	92.4	4.9	4
2004 12 07.3	3.189	2.236	5.3	92.3	4.9	4
2004 12 13.2	3.190	2.218	3.4	91.1	5.2	4
2004 12 13.4	3.190	2.218	3.3	91.1	5.2	4
2005 01 12.8	3.191	2.291	8.4	85.0	6.4	14
2005 01 13.0	3.191	2.291	8.5	85.0	6.4	14
2005 01 31.8	3.191	2.461	13.6	82.9	6.7	2
2005 02 21.9	3.191	2.720	17.0	82.9	6.7	2
2005 03 20.8	3.190	3.099	18.1	86.2	6.7	2
2006 01 17.1	3.124	2.477	15.3	172.4	14.2	2
2006 02 28.1	3.109	2.152	5.7	167.2	16.3	2
2006 03 09.1	3.106	2.141	5.2	165.3	16.3	2
2006 03 13.0	3.105	2.144	5.7	164.5	16.3	2
		(776) Berbericia				
2003 11 24.3	2.673	1.863	14.5	104.0	4.4	3
2003 11 26.2	2.676	1.848	13.9	103.8	4.7	3
2004 02 10.8	2.796	2.078	16.1	90.2	11.2	5
2004 02 12.8	2.799	2.102	16.6	90.2	11.2	5
2004 02 13.8	2.801	2.115	16.8	90.2	11.2	5
2004 02 15.9	2.804	2.141	17.2	90.2	11.3	5
2004 02 19.9	2.811	2.194	17.9	90.2	11.3	5
2004 02 23.9	2.817	2.249	18.5	90.4	11.4	5
2004 02 28.9	2.826	2.319	19.1	90.7	11.4	5
2005 02 15.1	3.309	2.529	12.0	184.5	24.1	21
2005 02 19.1	3.313	2.500	11.2	184.0	24.4	21
2005 03 12.0	3.330	2.412	7.7	180.0	25.3	25
2005 03 13.0	3.331	2.411	7.6	179.8	25.4	25
2005 05 09.9	3.370	2.759	15.2	171.0	21.6	2
2006 06 14.2	3.276	2.335	8.0	237.3	6.8	11
2006 06 15.2	3.275	2.340	8.3	237.1	6.7	11
2006 06 16.2	3.274	2.345	8.6	237.0	6.6	11
2006 06 18.2	3.272	2.357	9.1	236.6	6.4	26
2006 06 19.2	3.271	2.363	9.4	236.5	6.4	11
2006 06 20.2	3.270	2.369	9.7	236.3	6.3	11
		(944) Hidalgo				
2004 10 14.3	2.184	1.240	11.2	40.6	16.3	24
2004 10 17.3	2.171	1.221	10.6	39.8	17.8	24
2004 10 18.3	2.166	1.215	10.4	39.5	18.4	24
2004 10 21.4	2.153	1.200	10.2	38.7	20.0	24

Table 3. The table lists the ecliptic coordinates of the asteroid's spin axis direction (λ_p, β_p), its sidereal rotation period P, the span of observations in years, the number of oppositions N_{opp}, the number of lightcurves N_{lc}, and the rms residual of the fit.

Asteroid	λ_p [deg]	β_p [deg]	P [hr]	Years of obs.	N_{opp}	N_{lc}	rms [mag]
(110) Lydia	331	−61	10.92580	1958–2003	4	26	0.011
	149	−55					
(125) Liberatrix	280	+74	3.968199	1981–2005	7	34	0.024
	95	+68					
(130) Elektra	65	−88	5.224664	1980–2003	11	54	0.013
(165) Loreley	346	+29	7.22667	1981–2006	6	29	0.015
(196) Philomela	276	−49	8.332827	1964–2006	8	27	0.013
	111	−41					
(218) Bianca	305	+17	6.33717	1979–2005	10	50	0.015
	121	−10					
(306) Unitas	79	−35	8.73875	1979–2003	5	15	0.015
	254	−18					
(423) Diotima	351	+4	4.775377	1981–2006	10	48	0.017
(776) Berbericia	347	+12	7.66701	1977–2006	8	36	0.012
(944) Hidalgo	281	+5	10.058634	1976–2004	4	14	0.013