Earth Moon Planet (2007) 101:189–194
DOI 10.1007/s11038-008-9229-z

Shapes and Pole Orientations of Asteroids (360) Carlova and (209) Dido

Xi-Liang Zhang · Li-Yun Zhang · Jun Xu

Received: 25 April 2007 / Accepted: 16 January 2008 / Published online: 2 February 2008

Abstract Several light-curves of asteroid (360) Carlova and (209) Dido in different epochs were analyzed to determine shapes and pole orientations by means of AM-method and least squares method. New values of a/b, b/c, λ_p and β_p for asteroid (360) Carlova were obtained, which are 1.52°, 1.5°, 120 ± 6° and 66 ± 7°, respectively. We report a first determination of the parameters of (209) Dido which are 1.3°, 1.1°, 221 ± 6° and 37 ± 3°, respectively.

Keywords Asteroid · Light-curve · Shape · Pole orientation

1 Introduction

There have been numerous attempts to discern non-random pole orientations among asteroids, which might reveal clues to origin and evolution of spins (see, for example, Kryszczynska et al. 2007). To date, only a few tentative patterns have been noted, including an excess of retrograde rotators among near-Earth asteroids, and aligned poles of some members of the Koronis family, both of which have been attributed to radiation pressure effects. More data are needed to confirm and extend these results, thus further determinations of shapes and pole orientations are needed.

The asteroid (360) Carlova, a C-type asteroid approximately 116 km in diameter (Tedesco et al. 1992), which is located in the main belt area between the Mars's and Jupiter's orbit, has been observed several times, and it's shape and pole orientation have been previously determined.

The asteroid (209) Dido, a main belt C-type asteroid, approximately 160 km in diameter (Tedesco et al. 1992), has had it's synodic period well determined, but due to the few available observations the shape and pole orientation of (209) Dido have not been previously reported.

X.-L. Zhang (✉) · L.-Y. Zhang · J. Xu
National Astronomical Observatories, Yunnan Observatory, Chinese Academy of Sciences, Kunming 650011, Yunnan, China
e-mail: zhangxiliang@ynao.ac.cn

The aim of this paper is to determine the parameters of shapes and pole orientations for the asteroid (360) Carlova and (209) Dido. In this paper, the AM-method and least squares method, which had been mentioned by Zhang et al. (2006), were used. Based on the observation data in several different epochs, the parameters of the shape and pole orientation for (209) Dido were preliminarily deduced, and meanwhile that of (360) Carlova were obtained again.

2 Data and Reduction

The asteroid (209) Dido has been observed in seven different epochs by now. Warner (2005) obtained a light-curve of (209) Dido in 2005 at Palmer Divide Observatory. We observed the asteroid (209) on February 10, 2004, using a CCD detector attached to the 1-meter telescope of Yunnan Observatory, China. Figure 1. shows the light-curve we obtained, in which the pentagram symbols are the data plotted at the actual observation times, while the triangles and the plus signs are the same data transposed in time one cycle before and after the actual times of observation, according to the rotation period of Warner (2005). The data from four other apparitions we obtained from Behrend (2007), http://obswww.unige.ch/behrend/page1cou.html.

Yet another light-curve exists, from the PhD thesis of Tedesco (1979). It was taken on March 1st 1977. But it is of less value because it is fragmentary and at almost the same aspect as the more definitive light-curves from March 2005.

The asteroid (360) Carlova had been observed in five different epochs before. Di Martino et al. (1987) at 1984 epoch and Dotto et al. (1995) at 1986 epoch observed it, respectively. Michalowski et al. (2000) obtained another two light-curves of (209) Dido during 1997 and 1998. On May 1st, 2005, Wang and Zhang (2006) observed it with a amplitude of 0.40 magnitude.

In Tables 1 and 2, the aspect data of (209) Dido and (360) Carlova in different epochs are listed, which includes the date of observations in UT, phase α, ecliptic longitude λ_{PAB} and latitude β_{PAB} in J2000.0 reference frame, the amplitude A(α) in each epoch and its amended amplitude A(0°) and reference.

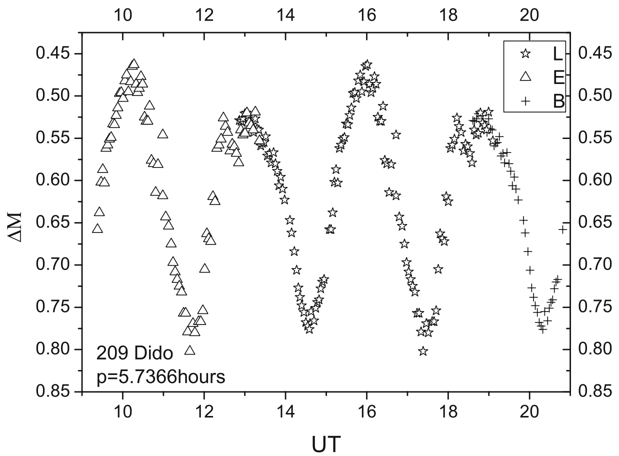

Fig. 1 The light-curve of asteroid (209) Dido we obtained on February 10, 2004

Table 1 Aspect data of (209) Dido for each observation

Asteroid	Date (UT)	λ_{PAB} (°)	β_{PAB} (°)	*P.A.* (°)	A(α) (Mag)	A(0°) (Mag)	Reference
(209)	2005/05/01	182.2	−1.2	13.61	0.19	0.16	Warner (2005)
	2005/03/04	181.6	+0.4	6.81	0.19	0.17	Behrend (2007)
	2004/02/10	106.4	+7.8	11.21	0.32	0.27	Present work
	2004/02/03.5	106.3	+ 8.0	9.47	0.29	0.25	Behrend (2007)
	2002/09/17	38.1	+ 4.2	13.78	0.11	0.09	Behrend (2007)
	2001/08/17.5	323.1	−5.5	2.23	0.27	0.26	Behrend (2007)
	1977/03/24	171.1	+ 1.2	4.68	0.18	0.17	Tedesco (1979)

Table 2 Aspect data of (360) Carlova for each epoch observation

Asteroid	Date (UT)	λ_{PAB} (°)	β_{PAB} (°)	*P.A.* (°)	A(α) (Mag)	A(0°) (Mag)	Reference
(360)	2000/11/15	27.7	−14.8	13.35	0.40	0.333	Wang and Zhang (2006)
	1998/04/30	233.1	13.8	6.26	0.49	0.448	Michalowski et al. (2000)
	1997/03/03	166.7	8.0	3.50	0.30	0.285	Michalowski et al. (2000)
	1986/01/10	107.7	−6.5	3.15	0.33	0.315	Dotto et al. (1995)
	1984/09/21	341.1	−7.9	8.06	0.30	0.268	Di Martino et al. (1987)

Before being used to determine the shapes and pole orientations, a light-curve should be reduced to an equivalent zero phase angle observation, which include not only the adjustment of amplitude as is done with Eq. 1 (Zappalá et al. 1990),

$$A(0^{\circ}) = A(\alpha)/(1 + m\alpha) \tag{1}$$

(for C-type asteroid, m = 0.015), but also an adjustment to the equivalent aspect direction as if the observation were taken at zero phase angle. This adjustment is approximately done by using the position of the phase angle bisector (PAB), as described in Harris et al. (1984). The PAB is the line which bisects the heliocentric and geocentric positions of the asteroid, that is, the direction along which one would be viewing if the Sun and Earth directions were collapsed equally to a single line of sight, at zero phase angle. An interesting property of the PAB is that it hardly changes during the retrograde loop of an asteroid in the sky, since the heliocentric direction is moving prograde and the geocentric position is moving retrograde at about the same rate.

3 Analyses and Calculation

3.1 Determination of the Shape

The brightness of an asteroid is determined by reflected light from a constant source, the sun. The variation of the asteroid magnitude is caused by the difference of the projected area and the surface properties. Here we will adopt the triaxial ellipsoid model which was set up by Zappalá (1981). If the asteroid is considered as a triaxial ellipsoid (a > b > c), there is such a relation as formula 2 between the amplitude of the light-curve of asteroid and its shape parameters(c/b and c/a), in which the ξ_i is the angle between the direction of view and the polar axis as seen from the center of the asteroid (see Fig. 2.), A(ξ_i) represents the amplitude of the asteroid in the apparition of ξ_i.

$$A(\xi_i) = 1.25\,\mathrm{lg}\frac{(c/b)^2\sin^2\xi_i + \cos^2\xi_i}{(c/a)^2\sin^2\xi_i + \cos^2\xi_i}. \tag{2}$$

When the ξ_i is 90°, then

$$A(90^\circ) = 2.5\,\mathrm{lg}\left(\frac{a}{b}\right). \tag{3}$$

3.2 Determination of the Pole Orientations

As we know, the aspect ξ_i is connected to the ecliptic coordinates of the pole orientations(λ_p,β_p) and to the ecliptic coordinates of the asteroid(λ_i,β_i) by following formula 4 (Zappalá 1981.).

$$cos(\xi_i) = -sin(\beta_i)sin(\beta_p) - cos(\beta_i)cos(\beta_p)cos(\lambda_i - \lambda_p) \tag{4}$$

Combining the formula 2 with formula 4, we will get a set of nonlinear equations which include the parameters c/b, c/a, λ_p and β_p. Therefore, if the photometric observations of the asteroid are achieved in at least four different epochs, the values of these parameters can in principle be determined.

Because of the existence of error, we can not obtain exact solutions for the nonlinear equations formulas 2 and 4, so the Newtonian iteration method was used to achieve a convergent least-squares solution.

The whole progress of derivation and calculation was performed with a fortran program.

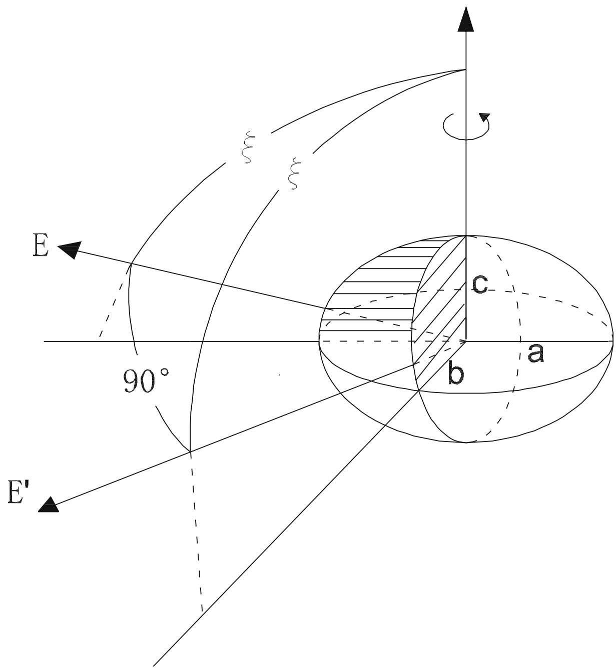

Fig. 2 The triaxial ellipsoid which is taken as model in AM-method

4 Result

4.1 Shape and Pole Orientations of (360) Carlova

In order to examine the reliability of the method and our program, we take the asteroid (360) Carlova, whose physical parameters (shape and pole orientations) had been determined several times before, as an example.

The data in Table 2 was substituted into the equations formulas 2 and 4, follow that the least squares method and Newtonian iteration method were used, and then the values of a/b, b/c, λ_p and β_p for asteroid (360) Carlova were obtained again, which were 1.52°, 1.5°, 120 ± 6° and 66 ± 7°, respectively.

The shape and pole orientation of asteroid (360) Carlova had been determined three times before. In Table 3, we listed the results of each determination, which includes the value of a/b, b/c, λ_p, and β_p for the asteroid (360) Carlova as well as the authors of the references.

By comparison, we conclude that our results are consistent with those of others despite of the little discrepancy. The difference between our result and that of Wang and Zhang (2006) based on the same data is likely due to the different methods.

4.2 Shape and Pole Orientations of (209) Dido

The reliability of our method and program is proved by the determination of the shape and pole orientation for asteroid (360) Carlova. Follow that the determination of the shape and pole orientations for asteroid (209) would be carried out in the same way as that for (360).

Substitute the data in Table 1 into the equations formulas 2 and 4, then the least squares method and Newtonian iteration method were used as before, finally the values of a/b, b/c, λ_p and β_p for asteroid (209) Dido were obtained, which are 1.3, 1.1, 221 ± 6° and 37 ± 3°, respectively.

5 Discussion

In this paper, the values of the parameters of shape and pole orientation for asteroid (360) Carlova were determined again through combining the AM-method with least squares method, carrying out with Newtonian iteration method, which are proved to be consistent with that of before determinations. In the same way, the values of a/b, b/c/,λ_p and β_p for asteroid (209) Dido were preliminarily determined, which are 1.3°, 1.1°, 221 ± 6° and 37 ± 3°, respectively. At the same time, our light-curve of (209) Dido is consistent with the period of 5.7366 h as reported by Warner (2005).

Table 3 The shape and pole orientations of (360) Carlova for each determination

Asteroid	a/b	b/c	λ_p (°)	β_p (°)	Reference
(360)	1.52	1.50	120 ± 6	66 ± 7	Present work
	1.51	1.37	127	47	Wang and Zhang (2006)
	1.42	1.52	105	47	Michalowski et al. (2000)
	1.57	1.00	108	51	Dotto et al. (1995)

Acknowledgements We would like to thank Dr. Xiao-Bin Wang, along with the staff of Optic & Electronic Laboratory of Southern Observatories, Chinese Academy of Sciences, and the observational assistants of 1-m telescope team of Yunnan Observatory for their help and support during our work. Especially, we would also like to thank Dr. Alan Harris (USA) for his valuable suggestions and comments, which led to large important improvement in the manuscript. This work was supported by 973 Project of China(No.2006CB806300).

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