A&A 378, L14–L16 (2001)
DOI: 10.1051/0004-6361:20011206

Astronomy & Astrophysics

CCD photometry of the binary asteroid 90 Antiope

T. Michałowski[1], F. Colas[2], T. Kwiatkowski[1], A. Kryszczyńska[1], R. Hirsch[1], and J. Michałowski[3]

[1] Astronomical Observatory, A. Mickiewicz University, Słoneczna 36, 60-286 Poznań, Poland
[2] Institut de Mécanique Céleste, 77 av. Denfert Rochereau, 75014 Paris, France
[3] Poznań University of Technology, Poznań, Poland

Received 23 July 2001 / Accepted 28 August 2001

Abstract. Lightcurves of the binary asteroid 90 Antiope were obtained at two observatories (Borowiec and Pic du Midi) on 14 nights in September through November 2000. The synodical period was found to be 16.496 ± 0.001 hours and the observed amplitude of brightness variation was 0.08 mag. This amplitude was due to the noncircular shapes of the components of the binary system rather than to mutual occultations. Some predictions of a possibility of observations of the eclipsing events during future oppositions have also been made.

Key words. techniques: photometric – minor planets: asteroids

1. Introduction

The first photometric observations of 90 Antiope, covering full rotational cycle, were performed on four nights in December 1996 (Hansen et al. 1997). The composite lightcurve with two minima and an amplitude of 0.70 mag yielded a period of 16.509 hours. This lightcurve was not quasi-sinusoidal as shown by most asteroids but similar to a typical lightcurve of an eclipsing binary star.

The binarity of this asteroid was confirmed by Merline and his collaborators in August 2000 (`http://www.boulder.swri.edu/~merline/press/`). Using the Keck Adaptive Optics system, they found that 90 Antiope was a double asteroid with similar–sized components, separated by 170 km. The orbital period was about 16.5 hours, consistent with the period derived from the 1996 photometric observations.

If we accept Antiope's diameter of 120 km as determined by IRAS satellite (`http://pdssbn.astro.umd.edu/`) and assume that it is a binary system of two spherical objects, we can found the diameter of each component to be 85 km.

2. CCD photometry in 2000

We observed 90 Antiope on 14 nights in September – November 2000 at two observatories – Borowiec (near Poznań, Poland) and Pic du Midi (France) where 0.40 m and 1.05 m telescopes, respectively, were used. Both of them were equipped with CCD cameras, and all details concerning the instruments and the reduction procedure were described by Michałowski et al. (2000).

The aspect data of the asteroid are listed in Table 1. The columns give the date of the observation referring to the mid–time of the observed lightcurve, asteroid–Sun (r) and asteroid–Earth (Δ) distances (in AU), solar phase angle, ecliptic longitude (λ) and latitude (β) for the J2000 epoch, and the name of the observatory. The last four columns provide times (corrected for light–time) of observed brightness maxima ($M1$, $M2$) and minima ($m1$, $m2$).

Our observations are presented as composite lightcurve (Fig. 1) which has been constructed according to a procedure described in Magnusson & Lagerkvist (1990). A vertical position of each lightcurve was obtained by minimizing the dispersion of data points relative to their neighbours. The abscissa is the rotational phase with zero point corrected for light–time. The observed maxima ($M1$, $M2$) and minima ($m1$, $m2$) are indicated in the graph.

The brightness of the asteroid varied with an amplitude of about 0.08 mag within the period of 16.496 ± 0.001 hours, which was consistent with the earlier reported values as mentioned above. This small amplitude was due to the non-circular shapes of the components rather than to mutual occultation.

3. Discussion and future work

In a binary system of two equal components a decrease in brightness, during central occultation, is 0.75 mag at each minimum. In December 1996 the observed amplitude of the lightcurve of Antiope was 0.70 mag, which suggests that the Earth was nearly exactly in the orbital plane

Send offprint requests to: T. Michałowski,
e-mail: `tmich@amu.edu.pl`

Table 1. Aspect data and times of observed extremes of 90 Antiope.

Date (UT)	r (AU)	Δ (AU)	Phase angle (°)	λ (J2000) (°)	β (°)	Obs.	$M1$	$M2$	$m1$	$m2$
							Julian Days +2 451 800			
2000										
Sep. 29.9	2.815	1.820	3.0	359.3	−3.2	Bor			17.384	
Sep. 30.9	2.816	1.823	3.4	359.1	−3.2	Bor		18.321		
Oct. 21.9	2.842	1.956	11.0	355.8	−2.9	Bor			39.379	
Oct. 22.9	2.843	1.965	11.4	355.7	−2.9	Bor		40.320		40.471
Oct. 23.8	2.845	1.974	11.7	355.6	−2.9	Bor	41.297		41.441	
Nov. 01.9	2.856	2.066	14.2	354.9	−2.7	Bor			50.378	
Nov. 02.8	2.858	2.077	14.4	354.9	−2.7	Bor		51.321		
Nov. 03.8	2.859	2.088	14.7	354.9	−2.7	Bor	52.295			
Nov. 10.9	2.868	2.173	16.2	354.8	−2.6	Pic			59.312	
Nov. 11.9	2.870	2.185	16.4	354.8	−2.5	Pic		60.253		60.400
Nov. 14.9	2.874	2.224	17.0	354.8	−2.5	Pic	63.294		63.436	
Nov. 15.9	2.875	2.238	17.1	354.9	−2.5	Pic		64.354		64.533
Nov. 16.8	2.876	2.250	17.3	355.0	−2.4	Bor	65.354			
Nov. 19.8	2.880	2.289	17.7	355.1	−2.4	Bor			68.246	

Observatory code: Bor – Borowiec; Pic – Pic du Midi.

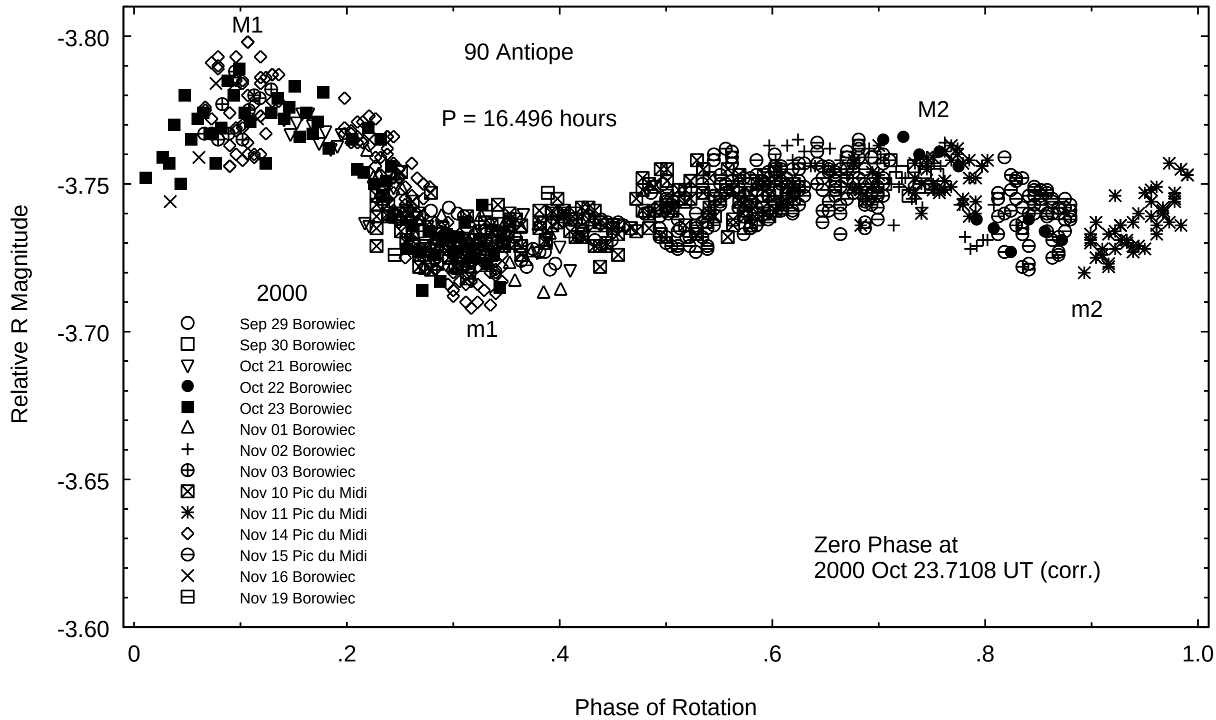

Fig. 1. Composite lightcurve of 90 Antiope in September–November 2000.

of the Antiope system (the inclination i of the orbit was almost 90°). If we assume the diameter of each component to be 85 km, and their seperation equal to 170 km, then for speherically shaped bodies a partial occultation occurs for $i > 60°$.

The photometric observations obtained so far do not allow us to determine the orientation of the orbital plane of the Antiope's system. However, we can put some limits on the expected inclination i during the future oppositions.

Let $\boldsymbol{r}_{\rm n}$ is a unit vector normal to the orbital plane of the binary system and $\boldsymbol{r}_{\rm e}$ is a unit vector pointing from the centre of mass towards the Earth. These vectors have the following components:

$$\boldsymbol{r}_{\rm n} = \Big[\cos(\lambda_{\rm n})\cos(\beta_{\rm n}), \sin(\lambda_{\rm n})\cos(\beta_{\rm n}), \sin(\beta_{\rm n})\Big],$$

$$\boldsymbol{r}_{\rm e} = \Big[-\cos(\lambda)\cos(\beta), -\sin(\lambda)\cos(\beta), -\sin(\beta)\Big],$$

where $(\lambda_{\rm n},\ \beta_{\rm n})$ are the ecliptic coordinates of the pole of the orbital system, and (λ, β) – geocentric ecliptic coordinates of the asteroid. Thus, the inclination i (an angle between the normal to the orbital system and direction to the Earth) can be calculated from:

$$\cos(i) = -\sin(\beta)\sin(\beta_{\rm n}) - \cos(\beta)\cos(\beta_{\rm n})\cos(\lambda - \lambda_{\rm n}),$$

or, after putting $\beta \approx 0°$ (which is evident from Table 2):

$$\cos(i) = -\cos(\beta_{\rm n})\cos(\lambda - \lambda_{\rm n}). \quad (1)$$

This equation can be used to bracket $\lambda_{\rm n}$ and $\beta_{\rm n}$. For the 1996 opposition we have $\lambda = 120°$ and $i \approx 90°$, which gives us $\lambda_{\rm n} = 30°$ (or 210°) for any value of $\beta_{\rm n}$.

Additional constraints can be inferred from the 2000 observations. As they showed no visible eclipsing event, from our simplified assumptions (see above) we can get $0° < i < 60°$. Using Eq. (1), the ecliptic longitude $\lambda = 355°$ and the previously estimated value for $\lambda_{\rm n}$ we can bracket $\beta_{\rm n}$ in the interval $0° < \beta_{\rm n} < 52°$. This allows us to determine the expected inclinations i during the future oppositions.

Table 2 gives the dates of the oppositions, the asteroid ecliptic coordinates $(\lambda,\ \beta)$ as well as the expected inclinations i of the orbital plane and brightness drops due to eclipsing events.

We predict it should be possible to observe partial occultations in the Antiope system in the years 2003, 2005, and 2008. The oppositions in 2001, 2004, and 2006 will probably not reveal any eclipsing events. However, due to changes in the observing geometry, photometric observations even in the absence of occultations will be very useful for studying brightness variations of the components caused by their rotation and orbital movement.

It should be mentioned that the predictions presented in Table 2 depend on all approximations assumed for Antiope's system. It is interesting to notice that no future opposition up to 2008 will show a full occultation event as it was in 1996.

Table 2. Oppositions of 90 Antiope.

Opposition	λ [°]	β [°]	Expected inclination [°]	Expected amplitude [mag]
1996 Dec.	120	2	90	0.75
2000 Nov.	355	−3	35–60	0
2001 Dec.	80	1	50–66	0–0.05
2003 Feb.	137	3	73–80	0.18–0.36
2004 Apr.	197	3	13–54	0
2005 Jul.	287	−2	77–82	0.27–0.43
2006 Oct.	35	−2	5–53	0
2008 Jan.	103	2	73–80	0.18–0.36

Acknowledgements. This work was partially supported by the Polish KBN Grant 2 P03D 007 18. The Borowiec observations were reduced with the *CCLRS STARLINK* package.

References

Hansen, A. T., Arentoft T., & Lang, K. 1997, Minor Planet Bull., 24, 17

Magnusson P., & Lagerkvist C.-I. 1990, A&AS, 86, 45

Michałowski T., Pych W., Berthier J., et al. 2000, A&AS, 146, 471