PHOTOMETRIC OBSERVATIONS OF BINARY NEAR-EARTH ASTEROID (7088) ISHTAR AND (11405) 1999 CV3.

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Introduction: Of the ~4,400 Near-Earth Asteroids (NEAs) currently known, a significant number (up to 15±4%) are binary objects [1,2]. A substantial fraction of NEAs that are smaller than 2 km and spin fast are known to be asynchronous binary asteroids. Asynchronous binary asteroids are a pair of objects that are in a mutual orbit with one (primary or secondary) of them having a rotational period different from their orbital period [3]. High-quality photometric observations can help determine the rotation period of the primary, the synodic orbital period, and the secondary-to-primary diameter ratio based on the depth of the secondary event, and the rough shape of the primary based on the amplitude of primary's lightcurve.

The Survey: In order to better understand the formation and evolution mechanisms of asynchronous binary asteroids, a photometric survey was launched in 2004 [3]. As part of this survey, a team of collaborators conducted high-quality photometric observations of favorably-placed asteroids during each lunation to discover and catalog new binary asteroids. A central repository for the data was created at Ondřejov Observatory, Czech Republic [4]. Established protocols for observation, data reduction, and dissemination of results are further discussed [4]. In 2005, the survey detected its first binary NEA 2005 AB [5,6]. Based on the photometric data, the estimated synodic orbital period was 17.93±0.01 h with the primary's rotation period of 3.339±0.002 h.

Observation and Data Reduction: Observations from Badlands were taken in R band using a 0.66-m F/4.8 Newtonian telescope and Apogee AP8 CCD camera using a 1024 x 1024 SITe back-illuminated sensor with a 26.6' x 26.6' field of view at 1.56"/pixel. Observations at Ondřejov Observatory were obtained using a 0.65-m F/3.6 Newtonian reflector with ST-8 CCD camera and Modra Observatory with a 0.60-m, F/5.5 reflector, equipped with Apogee AP8p CCD camera. Data from McDonald Observatory was obtained using 0.76-m, F/3.0 telescope with Prime Focus Corrector.

(7088) Ishtar: Amor-type NEA (7088) Ishtar has a Minor Planet Center estimated diameter of 1.4-3.1 km. Observations made from 2006 January 23-February 04 revealed a complex lightcurve (Fig. 1a) suggesting a possible binary asteroid system. Deconvolving the lightcurve, we estimate the synodic orbital period to be 20.63±0.02 h (Fig. 1b). The primary has a rotation period of 2.6786±0.0002 h (Fig. 1c) with a lightcurve amplitude of 0.11 mag, indicating a nearly spheroidal shape. 0.09 mag amplitude of the fit (Fig. 1b) suggests that the secondary is moderately elongated and rotates synchronously with the orbital motion.

Mutual eclipse and occultation events that are 0.18-0.21-mag deep indicating a secondary-to-primary mean-diameter ratio of 0.43±0.02. Assuming a slope parameter *(G)* value of 0.15±0.2, and an albedo of 0.18, the estimated absolute magnitude *(H_R)* is 16.5±0.2 which gives a primary diameter of 1.2±0.36 km.

(11405) 1999 CV3: Two sets of observations of Apollo-type NEA (11405) 1999 CV3 were obtained during two oppositions. The first data set was obtained in March 1999 from Ondřejov Observatory, Czech Republic (Fig. 3). The amplitude of the lightcurve changed from 0.50 mag on March 6.9 to 0.80 mag on March 24.9. A similar rapid lightcurve evolution was also evident from the data obtained during the 2006 apparition (Fig. 4). This change is likely due to a rapid evolution of geometry during each of the apparition. The estimated rotational period is 6.5109±0.0001 h.

Analysis: Using the derived physical parameters, one can compare (7088) Ishtar to the overall binary NEA population and also investigate possible formation mechanisms for such a system. [1] summarize the trends found in the NEA binary population based on data from an earlier photometric survey. They found that binary systems with secondary to primary mean diameter ratio $D_s/D_p \geq 0.18$ concentrate among NEAs smaller than 2 km in diameter. A majority of primaries in these binary systems were noted to have rotational periods between 2.2 to 2.8 hrs with fast rotators (bulk densities 2 g/cm^3) spinning close to the rubble pile limit. (7088) Ishtar fits this observed trend among other NEA binaries almost perfectly. Figure 2 shows the spin barrier in amplitude vs. spin rate for asteroids. The curves are limits for cohesionless elastic-plastic solid bodies with the angle of friction = 90◦ and with bulk densities 1, 2, 3, 4, 5 g/cm^3, from left to right. 7088 Ishtar (red square) has low amplitude (suggesting a near-spherical shape) and lies close to 2 g/cm^3 limit curve.

Using the total angular momentum of a binary system, it is possible to speculate its formation mechanism. [7] calculated the total angular momentum for this binary system to be $\alpha_L = 1.21$, which is very close to the critical spin limit for a single body in gravity regime. [7] argue that such systems are most likely to form from fission or mass shedding of parent bodies spinning at the critical rate dominated by the YORP effect rather than gravitational interactions during close flybys to terrestrial planets. We conclude that given the physical parameters of (7088) Ishtar binary system, the most likely formation mechanism is fission or mass shedding of its parent body due to YORP effect. Spectroscopic studies will provide a way to realistically cross-check the calculated density with composition.

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References: [1] Pravec et al. (2006) *Icarus* 181, 63-93. [2] Margot et al., 2002 *Science* 296, 1445-1448. [3] Pravec (2005) SAS Symposium [4] Photometric Survey for Asynchronous Binary Asteroids (http://www.asu.cas.cz/~asteroid/binastphotsurvey.htm) [5] Reddy et al. (2005) 2005 AB, *IAU Circ.,* 8483, 3. [6] Kumar et al. (2006) *LPSC XXXVII,* Abs. # 1113. [7] Pravec and Harris (2007) *Icarus* (submitted).

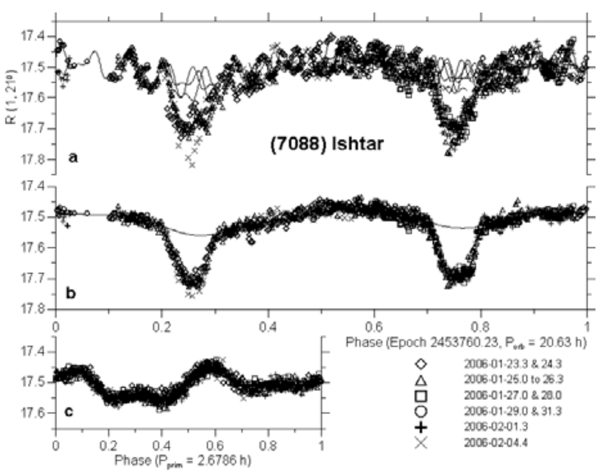

Figure 1: Lightcurves of (7088) Ishtar from 2006-01-23.3 to 2006-02-04.4 (a) complete data set showing both lightcurve components. The additive Fourier series with the periods of 2.6786 and 20.63 h was fitted to the primary and the secondary rotation data. (b) The long-period component showing the mutual events and the secondary rotation lightcurve. The primary lightcurve component was subtracted. (c) The primary lightcurve component.

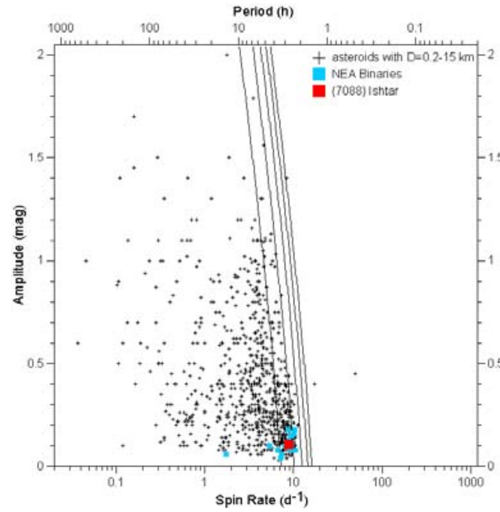

Figure 2: The spin barrier in amplitude vs. spin rate. The curves are limits for cohesionless elastic-plastic solid bodies with the angle of friction = 90◦ and with bulk densities 1, 2, 3, 4, 5 g/cm^3, from left to right. (7088) Ishtar has low amplitude (suggesting a near-spherical shape) and it is close to the 2 g/cm^3 limit.

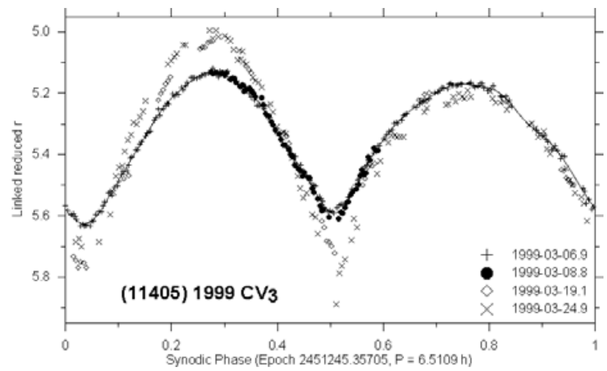

Figure 3: Composite lightcurve of NEA (11405) 1999 CV3 from 1999 apparition.

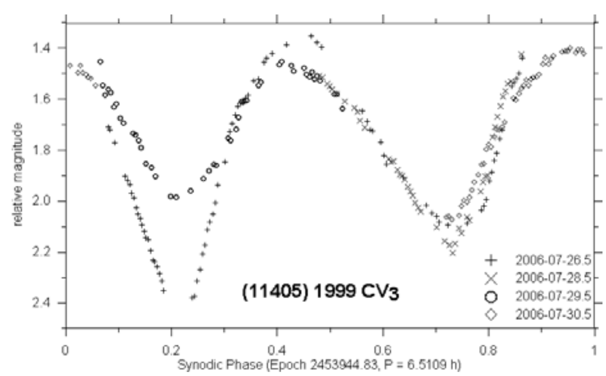

Figure 4: Figure 3: Composite lightcurve of NEA (11405) 1999 CV3 from 2006 apparition.