Lightcurves and rotational periods of comet-sized Jovian Trojan asteroids

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Abstract

We have been conducting a survey of Trojan rotation properties since 2010 to test the Nice Model hypothesis. Our current program is a comparison of rotation properties of similar-sized Trojans and comets. We present new lightcurve information for 19 Trojans ≲ 30 km in diameter, increasing fourfold the number of objects in this size range for which some rotation information is known. The minimum densities for objects with complete lightcurves are estimated and are found to be comparable to those measured for cometary nuclei. A significant fraction (~40%) of this observed small Trojan population rotates slowly, with measured periods as long as 60 hours. Three of the rotational periods were near five hours. Computed lower limit density estimates are consistent with measured bulk density estimates for cometary nuclei.

Introduction

The Jovian Trojans are among the most enigmatic objects in the Solar System. Because of their greater distance from the Sun, they have been less studied than main belt asteroids. The spectra and the low albedos of Trojans, bear a strong resemblance to those of cometary nuclei (Abell *et al.* 2005; Fornasier *et al.* 2007; Emery *et al.* 2011). The Nice Model (Morbidelli *et al.* 2005; 2009) predicts that the Trojans may be objects that originated with today's Kuiper Belt Objects. We are surveying Trojan rotation properties as a comparison of rotation properties of similar-sized comets in order to test the Nice Model hypothesis: Are the Trojans related to comet nuclei, or could they have come from the same source?

Rotation properties of Main Belt Asteroids (MBAs) have been shown to vary dramatically with size . The rotation of MBAs larger than ~50 km in diameter seems to be determined largely by collisions, while that of smaller bodies is shaped primarily by YORP forces and torques (Pravec *et al.* 2008). Comprehensive studies have shown that MBAs smaller than ~10 km in diameter are governed by a "spin barrier" corresponding to a rotation period of ~2.2 hours. We have been obtaining lightcurves of smaller Trojans in an attempt to see whether the same forces may have shaped their rotation. The location of a spin barrier for small Trojans would be especially interesting, since it would allow an estimation of the density of the objects. Knowing the density, in turn, would give information about composition and permit comparison with the properties of comet nuclei.

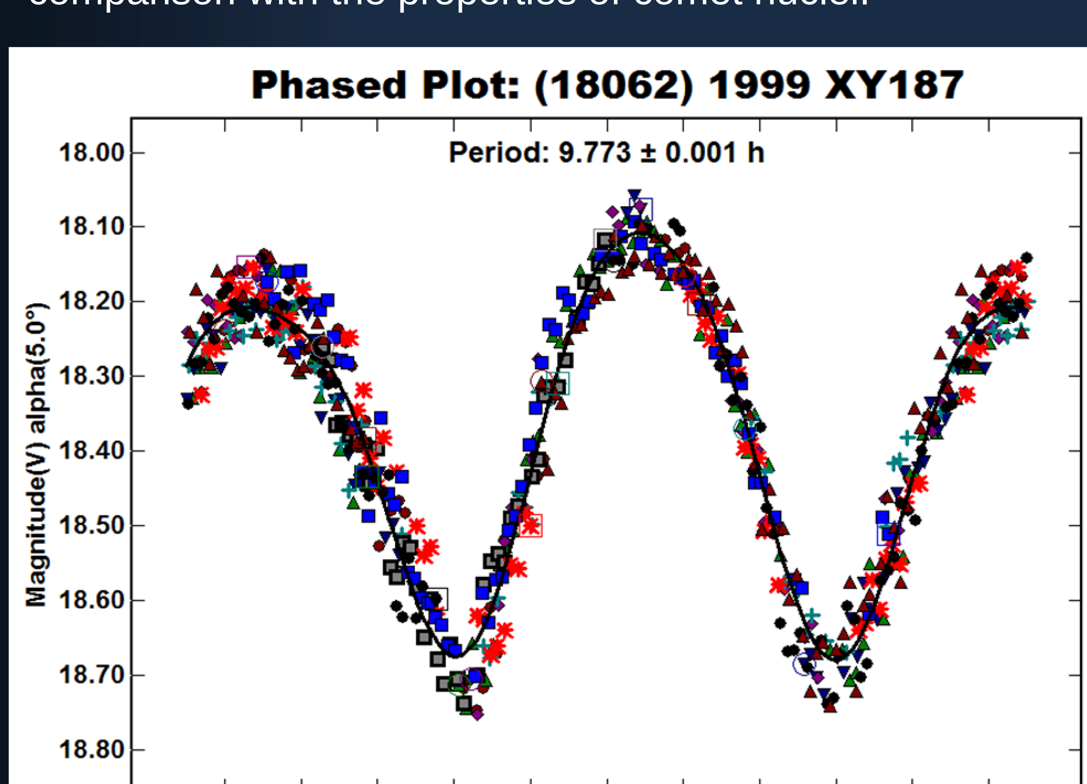

Figure 1. lightcurve of L4 Trojan (18062) 1999 XY_{187}.

Observations

Observations were obtained at two observatories using five telescopes.

The five L5 objects were observed on two nights with the Cerro Tololo Blanco 4-meter telescope in August 2011 using the MOSAIC II CCD imager. The imager comprised eight 2048 x 4096 SiTe CCDs, creating an overall image of 8192 x 8192 pixels.

Five of the L4 Trojans were observed over 10 nights with the Cerro Tololo 0.9-meter SMARTS telescope between 25 April and 4 May 2014. The imager is a 2048x2046 Tek2K CCD camera creating an overall image 13.6 X 13.6 arcseconds in size.

The other nine L4 Trojans were observed between February and May 2014 at the Center for Solar System Studies (CS3, MPC U81). They were observed with a 0.35-m SCT using an SBIG STL-1001E CCD camera, a 0.35-m SCT using an SBIG ST9e CCD camera, and a 0.4-m SCT and a FLI Microline 1001E CCD camera.

Results

The derived Trojan lightcurve periods and amplitudes with Quality Indicator U > 2- in the Asteroid Lightcurve Database as of 1 May 2014 are shown in Table 1. A Quality indicator of U = 2- is generally considered the lowest lightcurve rating useful for analysis. Table 2 contains 22 entries, three from previously published work and 19 from our new observations.

Asteroid	H	Dia. (km) p_V=0.057	Dia. (km) WISE	Period (hr)	Period Uncert. (hr)	Amp. (mag)	Amp. Uncert. (mag)
13184 Augeias	10.9	36.8	34.0	50.54	0.05	0.15	0.03
13230 1997 VG_1	11.2	32.0	23.9	42.4	.1	0.20	0.05
13353 1998 TU_{12}	11.4	29.2	23.6	53.52	0.04	0.24	0.03
13362 1998 UQ_{16}	10.9	36.8	28.3	15.13	0.02	0.35	0.03
14268 2000 AK_{156}	10.4	46.3	33.8	7.51	0.01	0.27	0.03
15536 2000 AG_{191}	11.1	33.5	29.0	11.71	0.02	0.54	0.03
17874 1998 YM_3	11.6	26.6	17.4	9.81	0.02	0.18	0.03
18062 1999 XY_{187}	10.8	38.5	30.6	9.773	0.001	0.59	0.02
18263 Anchialos	11.2	32.0	21.3	10.39	0.02	0.35	0.04
19725 1999 WT_4	10.7	42.2	31.7	56.70	0.05	0.22	0.05
19913 Aigyptios	11.1	33.5	25.0	40.43	0.05	0.15	0.03
24275 1999 XW_{167}	11.1	33.5	28.4	57.98	0.07	0.32	0.05
32370 2000 QY_{151}	12.3	19.3	18.49	long	--	--	--
54652 2000 SZ_{344}	11.8	24.3	16.37	5.26	0.05	0.10	0.03
90337 2003 FQ_{97}	11.4	29.2	29.39	60.0	1.0	0.53	0.10
127532 2002 WH_9	12.9	16.1	--	long	--	--	--
129602 1997 WA_{12}	12.0	22.2	--	54.0	0.5	0.28	0.05
187463 2005 XX_{106}	12.8	14.6	--	4.84	0.13	0.06	0.02
286227 2001 UV_{140}	13.5	10.6	--	5.82	0.03	0.30	0.02

Table1:. Rotation data for all Jovian Trojans ≲ 30 km in diameter in the Asteroid Lightcurve Database as of 1 May 2014, Diameters in Column 3 are computed from an assumed value of the geometric albedo. Diameters in column 4 are those measured by WISE.

Object	Observed Lightcurve Amplitude	Implied Minimum Density (gm/cm^3)
(23480) 1991 EL	0.03	0.68
(54652) 2000 SZ_{344}	0.10	0.43
(187463) 2005 XX_{106}	0.06	0.49
(286227) 2001 UV_{140}	0.30	0.42

Table2: Implied minimum densities for four short-period Trojans if they are rotating near the critical period. .

Results (continued)

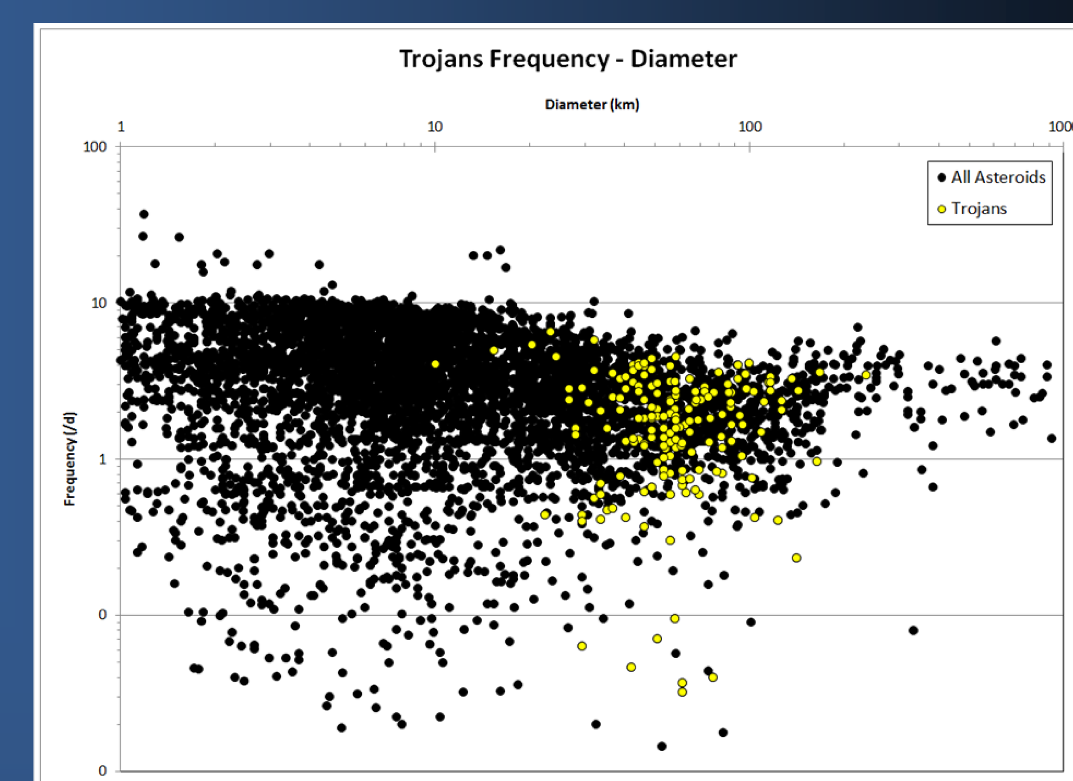

Figure 2. The observed spin rate for Trojans of all sizes versus NEA and Main Belt Asteroids. A significant fraction rotates slower than once per day, and no Trojan has yet been found rotating as fast as ~2.2 hours--the "spin barrier" for MBAs.

Discussion

The median of the Trojan periods is 13.37 hours, as compared to a median of 14.00 hours for 10 comets in the size range 10 km < D < 30 km (Lamy *et al.* 2004). The median period for 689 Main Belt Asteroids in the same size range (Asteroid Lightcurve Database) is 7.50 hours. These median values for comets and MBAs are likely to be underestimates due to observational biases against long period objects.

Figure 2 shows the rotation properties of 5,631 NEAs and MBAs and 175 Trojans, including our new data points. A two-tailed K-S test indicated an 82% probability that the small Trojan rotation rates and those of comet nuclei in the same size range were drawn from the same distribution. The K-S test indicates zero probability that the small Trojan rotation rates and those of the 689 MBAs were drawn from the same population. These preliminary results suggest that the rotation rates of Trojans may have been shaped by processes similar to those affecting the rotation of comet nuclei.

The population of Trojans with periods greater than 24 hours is clearly seen in Figure 2. We attempted to determine rotational periods for all Trojans observed to diminish observing bias and have found that about 40% of all small Trojans were slow rotators.

For main belt asteroids, this critical rotation period, before it will fly apart due to centrifugal force, known as the spin barrier, is ~2.2 hours. Three of the rotation periods we determined for the smallest Trojans studied were near 5 hours. If 5 hours is a spin barrier for Trojans it implies a minimum bulk density of these objects of ~0.5 gm/cm^3. Such low densities imply an icy composition and a significant amount of internal space similar to comet nuclei.

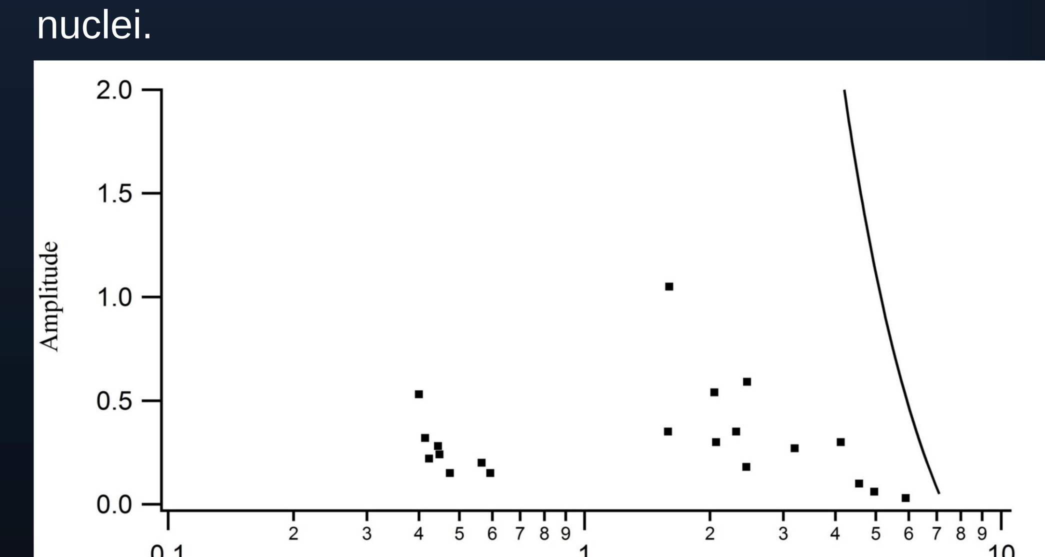

Figure 3. The observed spin rate (in rev/day) versus lightcurve amplitude (in magnitudes) for small Jovian Trojans. The line represents the critical spin rate for a bulk density of 1.0 gm/cm^3 .

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