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Slopes on asteroid pairs as indicators of internal properties

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Abstract

Rotationally-disrupted asteroid pairs [1] offer unique insights into the internal strength of asteroids [2]. By constructing shape models of asteroid pairs using a lightcurve inversion technique, we define a failure criterion to determine the maximum rotation rate at which an area larger than half the surface area of the secondary member has a slope value greater than the angle of repose. We find that the shape models only reach the known spin barrier of 2.2 hours when their bulk density is larger than Itokawa's density of a rubble pile structure (~2 g cm^{-3}), and better matches Eros' value (~2.7 g cm^{-3}), suggesting that km-sized asteroid pairs are dense compared to sub-km bodies. Ejection of secondary components that are larger than those observed, can also increase the spin barrier of the asteroids, thus supporting previously suggested scenario of continuous disruption of the secondary [3]. In addition, cohesion levels of hundreds of Pascals are also required to prevent these models from disrupting at spin rates slower than the usual spin barrier.

1. Introduction

A significant number of km and sub-km sized asteroids consist of collection of boulders, rocks and gravel, are referred to as rubble piles. These fragile asteroids, such as Bennu, Itokawa and Ryugu, have a low bulk density, high porosity, and a weak internal strength. Therefore, a fast spin rate, usually induced by the thermal YORP effect, can modify their shapes and even make them split to form asteroid pairs, bodies that share similar orbits but not positions (i.e. not binary asteroids). Due to their young disruption age, measuring the size, shape and spin state of the pairs allow us to correlate between these parameters and the rotational disruption mechanism and to constrain their density and cohesion.

2. Method

We collected photometry of 11 primary members of asteroid pairs at multiple apparitions for over a decade from the Wise Observatory in the Israeli desert. We constructed the pairs' shape models using a lightcurve inversion technique [4] and found their spin axes. We mapped the gravitational and rotational accelerations on the surfaces of these shape models and calculate their local slopes. We determined the rotation rate at which frictional failure occurs for each asteroid. Our simplifying criterion is reached when a region on the shape model of an area half the surface area of the secondary member has a slope larger than the angle of repose. The angle of repose is set to 40^{o}, similar to values measured on Lunar and Martian regolith. We also evaluate the contribution of the shape's elongation and flattening to the critical period.

3. Results and Conclusions

The concentration of the spin axes on the ecliptic poles is consistent with the YORP effect as the physical mechanism responsible for the spin-up and the spin axis alignment; thus it supports the notion asteroid pairs were disintegrated by the YORP effect (Fig. 1).

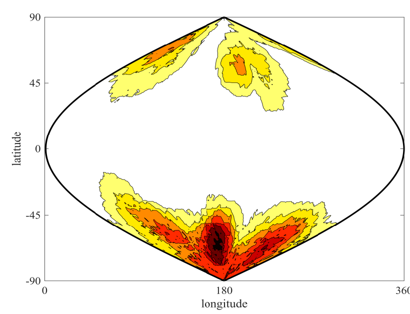

Figure 1: A density map of the possible spin axis solutions averaged for all asteroids in our sample.

The elongation (A/B) and flattening (B/C) of the asteroid's shape can significantly increase the critical rotation period, even by almost an hour relative to a spherical object. The flattening is effective and can account for about half the effect (Fig. 2).

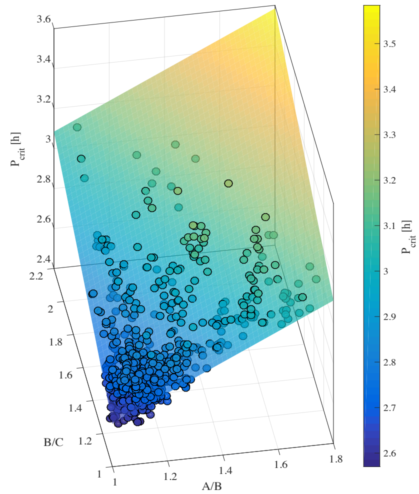

Figure 2: The physical axes ratios (A/B $vs.$ B/C), with the markers' colors representing the critical rotation period of each shape model of the asteroids in our sample (multiple shapes per asteroid). The partially transparent color scheme is a linear fit to both ratios.

Density plays a significant role in determining the critical spin. A density of 2.7 g cm^{-3} (Eros' value and average density of S-type asteroids), decreases the critical rotation period by ~0.4 h on average, compared to an Itokawa-like density of 2 g cm^{-3}. If the pairs analyzed here broke up at a spin period similar to the breakup speed usually observed (~2.2 h), then we predict the density of such km-sized objects is high, more similar to Eros's than Itokawa's (Fig. 3).

The critical spin rate can be partially, but not completely, explained if the ejected body had a larger size when disruption occurred, and subsequently continued to break up to the present size (Fig. 3). This supports the secondary fission model by [3].

Cohesion of hundreds of Pa allows the shape models to reach a critical rotation of 2.2 h for all objects. Even for the most stable case, of spherical-shape asteroids, with density of 2.7 g cm^{-3} and a large secondary, some cohesion is required. A cohesionless structure for km-sized rubble pile asteroids is possible only if they disintegrate at a slower rotation period of 2.4-2.6 h and their density is near the higher range considered here.

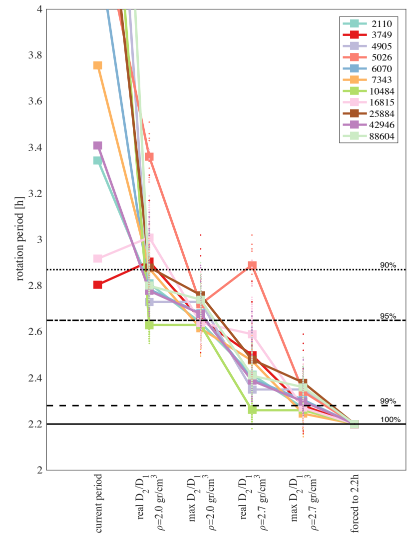

Figure 3: Rotation periods of the 11 pairs in our sample determined in a suite of six scenarios from left to right: current rotation period, critical rotation with density of 2.0 g cm^{-3} and current diameter ratio D_2/D_1, with density of 2.0 g cm^{-3} and maximal $D_2/D_1 = 0.6$, with density of 2.7 g cm^{-3} and current D_2/D_1, with density of 2.7 g cm^{-3} and maximal $D_2/D_1 = 0.6$, and rotation period forced to the spin barrier at 2.2 h. The dots represent each shape model and the squares represent the median of all models per asteroid. The horizontal lines indicate the rotation for which 90%, 95%, 99%, or 100% of similar-sized objects rotate slower than this value.

References

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