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Asteroid pairs, paired binaries, and spin-fission clusters

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Abstract

We studied 93 asteroid pairs and 13 asteroid clusters. We estimated their ages between $7*10^3$ and a few 10^6 yr. From photometric observations, we derived their mass ratios q and primary body rotation periods P_1. We found that most of the studied pairs and clusters, specifically, 87 pairs and 11 clusters, follow the trend of primary rotation period vs mass ratio predicted by the theory of their formation by rotational fission [1], [2]. A few outlying pairs and clusters need an additional explanation or another formation mechanism. Another importatnt result is that we found that 13 asteroid pairs contain also bound (unescaped) secondaries; their primaries are binary or triple asteroid systems. We present two hypotheses for their formation: The asteroid pairs with both bound and unbound secondaries could be "failed asteroid clusters", or they could be formed by a cascade primary spin fission process.

1. Introduction

In the main belt of asteroids, there exist pairs and clusters of asteroids that are on highly similar heliocentric orbits [3], [4 and references therein]. They are genetically related, i.e., they are not random orbital coincidences of unrelated asteroids. Backward integrations of their heliocentric orbits, taking into account their orbit uncertainties and Yarkovsky effect drift, indicate their typical ages between 10^4 and 10^6 yr. Their spectral and color observations indicate the same or similar surface composition of asteroid pair members, sometimes showing a small spectral difference that is interpreted as a different degree of space weathering of the primary and secondary surfaces [5]. The initial study of physical properties of 32 asteroid pairs indicated that they formed by rotational fission of critically spinning weakly bound rubble-pile parent asteroids [2]. Recently we run an extensive survey of 93 asteroid pairs and 13 asteroid clusters [4], [6]. Our results generally confirm and extend the findings in [2] for most asteroid pairs and clusters, but extend them to smaller asteroid sizes and reveal new features of the asteroid pair population, among them the most interesting is that there exist asteroid pairs with binary primaries (also called "paired binaries"). We will outline the new results in this contribution.

2. Observations

We collected or obtained photometric observations for all the primaries (largest members) and a sample of secondaries (smaller members) of 93 asteroid pairs and 13 asteroid clusters. From their absolute magnitudes, we derived the pair or cluster mass ratios q. We measured the primary rotation periods P_1. As a by-product, we also measured color indices and refined WISE albedos for a part of the paired and clustered asteroids. For a sample of the bodies, we also obtained their spin vectors and shape models. We run the photometric observations with a strategy designed properly to allow detecting deviations in the rotational lightcurves from single periodicity caused by a non-principal axis rotation (tumbling) or a satellite. While no tumbler was detected –all the primaries and observed secondaries appear to be in or very close to principal-axis rotation states–, we found that the primaries of 13 asteroid pairs have satellites (i.e., bound secondaries).

3. Main results

3.1 Rotational fission of asteroids – a predominant pair and cluster formation mechanism

In Fig. 1, we plot the primary rotation period P_1 vs mass ratio q data for the 93 studied asteroid pairs and 13 asteroid clusters. 87 and 11 of them, respectively, follow the P_1-q relation derived from a model of asteroid rotational fission in [2], based on the theory of [1]. This indicates that rotational fission of weakly bound rubble-pile parent asteroids is a predominant formation mechanism of asteroid pairs and clusters. The 2 outlying clusters, with the primary bodies 18777 Hobson and 22280

Mandragora (the two leftmost blue crosses in Fig. 1) have a too high mass ratio and a different formation mechanism is required for them. Of the 7 outlying asteroid pairs, 3 lie below the limit blue curves in Fig. 1, but they appear insignificant (may be due to our uncertain or incomplete knowledge of the 3 pairs as discussed in [6]). The other 4 outlying pairs (the 4 black points to the left of the green curve in Fig. 1) have a too high mass ratio to be formed by rotational fission. Further studies are needed to reveal how they formed.

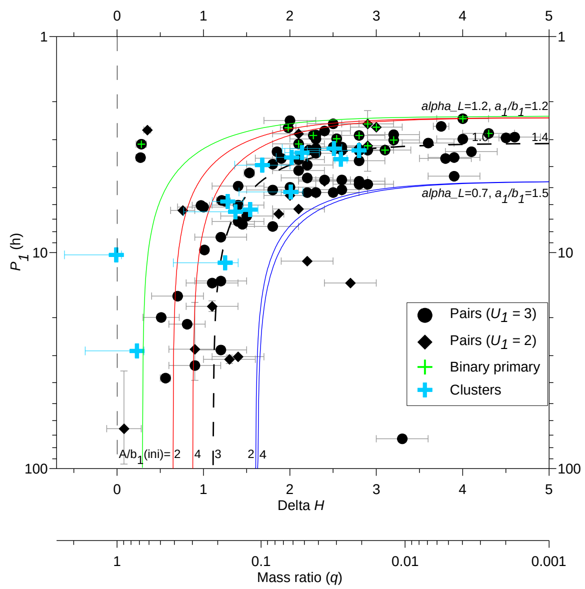

Figure 1: The correlation between Primary period and Mass ratio of asteroid pairs and clusters. See [4] for description of the plotted curves.

3.2 Pairs with binary primaries

We found that the primaries of 13 of the 93 studied asteroid pairs have satellites (i.e., bound secondaries). They are marked with green pluses in Fig. 1. As apparent, the “paired binaries” concentrate in a narrow strip there, their primary rotation periods are $P_{1,p} < 3.4$ h. Among pairs with such fastest rotating primaries, the fraction of binaries is probably > 50%, comparable to the fraction of binaries among fast rotating near-Earth asteroids [7]. The high rate of occurrence of satellites at the fastest rotating asteroids and the lack of them at slower rotating ones indicate that there is involved a mechanism that stabilizes some secondary orbits around the fastest rotating primaries with $P_{1,p} < 3.4$ h, but not around somewhat slower rotating ones. We propose two hypotheses for their formation: The asteroid pairs having both bound and unbound secondaries could be “failed asteroid clusters”, or they could be formed by a cascade primary spin fission process. An important related finding is that the unbound secondaries of some asteroid clusters, most notably the Emilkowalski cluster, separated at (at least) two distinct times, suggesting a cascade disruption process [4].

4. Concluding remark

A knowledge of the properties and formation and evolution processes of asteroid systems formed by rotational fission is going to be important for advancing our understanding of the population of small asteroids, both near-Earth and main-belt ones. Data from surveys for these small bodies will be particularly fruitful for advancing our knowledge of these interesting complex asteroid systems.

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