**BINARY SYSTEMS AMONG ASTEROID PAIRS.** Petr Pravec[1], Petr Scheirich[1], Petr Fatka[1], and the Asteroid Pairs & Clusters Photometry Team. [1]Astronomical Institute AS CR, Ondřejov, Czech Republic

**Introduction:** In [1], we published our study of 93 asteroid pairs. 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 86 of the 93 studied pairs follow the trend of primary rotation period vs mass ratio predicted by the theory of their formation by rotational fission [2], [3]. A few outlying pairs need an additional explanation or another formation mechanism. A very interesting result is that we found that 13 asteroid pairs contain also bound (unescaped) secondaries; their primaries are binary or triple asteroid systems. We will focus on them in our contribution to this workshop.

**Observations:** In Fig. 1, we plot the primary period $P_1$ vs mass ratio $q$ data for the 93 asteroid pairs. The observed 13 pairs with binary or triple primaries are highlighted with green plusses. (A few more binary suspects that we found among asteroid pair primaries need to be confirmed with more observations.) Of the 34 asteroid pairs with $P_1 < 3.4$ h in our sample, the 13 ones with binary primaries represent a fraction of 38%. Considering that the binary asteroid detection probability of the photometric method is substantially less than 100% [4], it is likely that a true fraction of binary systems among the fastest rotating primaries of asteroid pairs is actually at least 50%. It may be comparable to the binary fraction among the fastest rotating near-Earth asteroids larger than 0.3 km that is $(66^{+10}_{-12})$% [5].

Other than the fast primary rotations, the binary systems among asteroid pair primaries share also other common features with many known near-Earth and small main belt binary asteroids. (See the binary asteroid parameters data published in [6].) Specifically, the bound secondaries are relatively small with $D_{1,s}/D_{1,p} < 0.5$, their normalized total angular momentum content is close to critical with $\alpha_L$ = 0.9 to 1.3, the primaries are nearly spheroidal with $a_{1,p}/b_{1,p} \leq 1.2$, the secondaries have low to moderate equatorial elongations with $a_{1,s}/b_{1,s} \leq 1.5$, and the orbital periods of the bound secondaries are in the realm of tens of hours. It is also notable that, with an exception of (3749) Balam and (21436) Chayoichi, the orbits and rotations of the bound secondaries appear relaxed with eccentricities close to 0 and synchronous spin states. With the estimated ages of these pairs from 140 to about 1000 kyr, it may place constraints on relaxation timescales in such small a few-km diameter asteroid binaries.

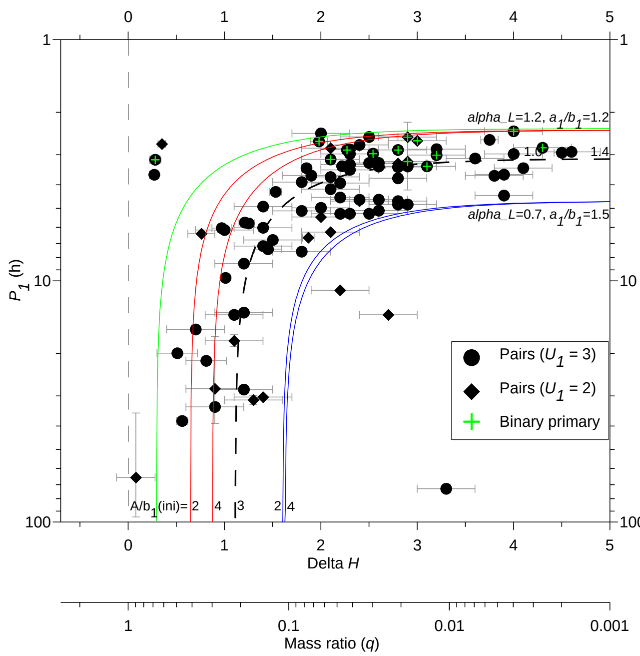


Figure 1. Primary rotation periods vs mass ratios of asteroid pairs. (For description of the plotted curves, see [1] and references therein.)

**Formation theories:** Asteroid pairs having both bound, orbiting and unbound, escaped secondaries might be outcomes of the secondary fission process proposed in [7]. In [8], the secondary fission process was proposed to be involved in formation of young asteroid clusters. We suspect that the asteroid pairs with binary primaries could be “failed clusters” where only one of the two formed secondaries was ejected. We will look into this in our talk.

One particularly significant feature that needs to be explained is that the bound secondaries occur only around the fastest rotating asteroid pair primaries with

$P_1$ < 3.4 h, but not around slightly slower rotating ones, see the concentration of pairs with binary primaries in the narrow horizontal band in Fig. 1. This suggests that, if the asteroid pairs with binary primaries are indeed "failed clusters", there must be involved a mechanism that stabilizes some secondary orbits around the fastest rotating primaries with $P_1$ < 3.4 h, but not around somewhat slower rotating ones. Such mechanism has yet to be found.

Another hypothesis for the asteroid pairs with binary primaries is that they could be formed by a cascade fission of the primary. The scenario is following. There was formed a satellite (orbiting secondary) of the primary in a spin fission event at an earlier time in the past, with the primary rotating sub-critically after the satellite formation. Then the primary was spun up by YORP to the critical spin rate again and underwent another fission event. The new secondary started chaotically orbiting the primary and it gravitationally interacted with both the primary and the older secondary. One of the two secondaries was then ejected from the system, becoming the unbound secondary (the smaller member of asteroid pair), and the other secondary's orbit around the primary was stabilized, so the system became an asteroid pair with binary primary. We will explore this hypothesis in the future. We note that a cascade disruption process was also suggested for the asteroid cluster of (14627) Emilkowalski in [8] where they found that two of the six secondaries of the cluster separated from the primary relatively recently, about 320 kyr ago, while the other four secondaries separated at an earlier time, 1-4 Myr ago. (See also the talk on asteroid clusters with multiple secondary separation events by Petr Fatka.)

**Concluding remarks:** Asteroid pairs having both bound and unbound secondaries require further thorough studies, both observational and theoretical, so that we obtain or refine their properties and reveal their formation and evolution mechanisms. As they represent a significant fraction of the asteroid pairs population, and they also have connections to asteroid clusters, their studies will likely bring key information for our understanding of how small rubble pile asteroids fission and evolve.

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