NEW ASTEROID PAIR CANDIDATES IN THE MAIN BELT

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Introduction: An asteroid pair can be formed as either a result of a catastrophic asteroid collision or rotational disruption of an asteroid accelerated by the YORP effect to a high rotation rate (Figure 1). Thus two asteroids form at initially close orbits, but later their orbits diverge due to planetary perturbations and the Yarkovsky effect. Asteroid pairs are crucial for reconstructing the evolutionary history of the asteroid belt, although discovering pairs from the present orbital elements is a challenging task, which requires a smart pre-selection of pair candidates and their subsequent backtrack orbital integration.

Methods: Our pipeline consists of a hierarchical clustering method [1] and backtrack integration. For the preliminary selection of asteroids into pair candidates, we implement hierarchical clustering in the 5-dimensional phase space of the osculating orbital elements [2]. Thus we find asteroids, whose orbits are the most similar to each other, just as it is expected for young pairs.

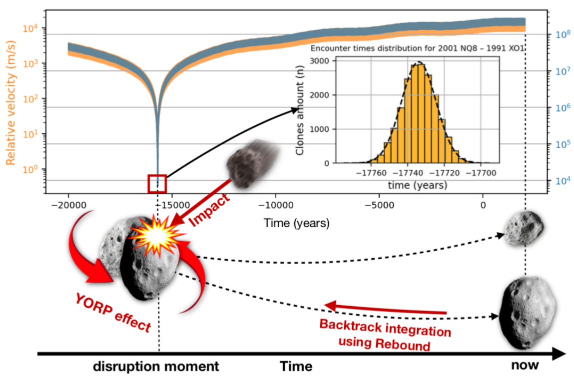

Figure 1. The physical distance (blue) and the relative velocity (orange) between the simulated clones of asteroids 2001 NQ8 and 1991 XO1 are shown in the same plot as a function of time. The scheme at the bottom of the plot sketches the pair formation and subsequent divergence of pair member asteroids. The histogram in the inset shows the distribution of the moments of the closest encounter for the ensemble of simulated clones.

The candidates selected by hierarchical clustering are further studied using backtrack orbital integration. We simulate asteroid dynamics using the REBOUND package taking [3] into account the gravitational perturbations from planets and the most massive asteroids [7]. Each simulated asteroid is represented by a number of clones, with the initial orbit randomly selected within the error ellipsoid of the asteroid orbital elements [5]. The value of the Yarkovsky effect of both of the asteroids is prescribed a random sign and a random value, with the order of magnitude being determined by the size of the asteroid, which in turn is estimated from the asteroid absolute magnitude [8].

The distance and the relative velocity between the candidate pair members are calculated at each timestep. Instants when simultaneously the distance is of the order of the Hill radius and the relative velocity is of the order of the escape velocity from the larger body, are marked as close encounters (Figure 1). The pair candidates, for which some clones demonstrate such close encounters, are studied further [4]. The distribution of the instants of the closest encounter over all the clones gives us the estimated time of the pair formation and its error margin. [6]

Results: After applying the pipeline to the inner part of the main asteroid belt, we reproduced a number of already known asteroid pairs. We observed a good agreement between our results and the results obtained by other studies, which validated the reliability of our pipeline.

Twelve more candidates produced by our pipeline, which we were not able to find in the existing literature on the asteroid pairs, are considered to be the new ones. Table 1 lists the members of these pair candidates and the estimated pair formation ages. All the ages are under 300 Myr, with the typical relative error of about 10-20%. To recover older pairs, one should start with a wider limiting distance for hierarchical clustering, so that the predominant majority of the preliminary candidates are false positives, and just a small percentage of them are true pairs. Further, one must implement the most precise methods of orbital integration and the Yarkovsky effect estimate and use only the asteroids with small orbital errors.

For some of the asteroids, we could find SDSS colors [9], and in the only case when the sufficiently precise colors were available for both presumed pair members (2004 RF90 - 2003 UT336) they turned out to coincide within the error bars ($a^*=0.15\pm0.07$ vs 0.18 ± 0.13) thus further confirming the common origin of the two asteroids.

Conclusions: We performed a survey of the inner part of the main asteroid belt and found 12 candidates for the asteroid pairs. Their estimated formation ages lie between 13 and 300 kyr. In addition, our pipeline recovered 17 known pairs, and our age estimates agreed with the ones indicated in literature in most of the cases.

The dependence of the orbital evolution on the unknown Yarkovsky effect is not only an obstacle for finding asteroid pairs, but also a potential tool for measuring the Yarkovsky effect of the pair members. One can assume that two asteroids with similar orbital and physical parameters constitute a pair, and then fit their Yarkovsky effects to provide convergence of their trajectories in the past. This would allow us to evaluate the Yarkovsky acceleration of the asteroids, and by comparing it to the theoretical predictions estimate the asteroid densities, providing a method to distinguish between rocky or metal mineralogies of asteroid interiors.

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Table 1. The members of newly found pair candidates, and their estimated formation ages.

№	primary component	secondary component	estimated age [kyr]
1.	2010 QR3	2011 UU70	13^{+65}_{-5}
2.	2004 RF90	2003 UT336	$27.1^{+2.6}_{-0.6}$
3.	2000 HS9	2015 DF67	$28.7^{+3.1}_{-0.3}$
4.	2003 RV20	2010 TH35	$48.3^{+4.1}_{-7.2}$
5.	1999 WM4	2017 QD23	$60.2^{+9.1}_{-8.9}$
6.	2015 XO12	2001 WY4	$69^{+0.5}_{-1.4}$
7.	2006 BJ193	2017 FE106	80^{+80}_{-70}
8.	2002 CR55	2015 VP32	147^{+77}_{-83}
9.	1981 VL	2013 CX44	$209^{+37.7}_{-70.8}$
10.	2007 WU1	2002 QR152	$237.7^{+15.2}_{-26.2}$
11.	2000 XH16	2002 TM148	$291.1^{+12}_{-0.3}$
12.	1999 XF200	2008 EL40	$299.2^{+81.7}_{-31}$