ESTIMATION OF THE AGE OF TWO YOUNG PAIRS OF ASTEROIDS

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Introduction:

Among the asteroids of the Main Belt, there are pairs of objects in close orbits whose members, as a rule, have a common origin, and the dynamic evolution of their orbits has common laws [1]. In [2], we identified candidates for young pairs by calculating the Kholshevnikov metrics [3] and studying their dynamic evolution using nominal orbits.
We will estimate the age of two young pairs of asteroids (87887) 2000 SS286 – (415992) 2002 AT49 and (320025) 2007 DT76 – (489464) 2007 DP16 by studying their probabilistic evolution.

Method:

To study probabilistic evolution for each asteroid, we generated 1000 trajectories with initial data from the confidence region, which corresponds to 1 million variants of the dynamic evolution of pair. The simulation was carried out in the Orbit9 program (http://adams.dm.unipi.it/orbfit/), which is part of the OrbFit software package. The equations of motion of eight major planets, the dwarf planet Pluto and the asteroid, were integrated consistently, considering the influence of the Yarkovsky effect, the oblateness of the Sun, and relativistic effects. We have studied the orbital evolution of asteroids over 100 kyr.

To estimate the drift rate of the semimajor axis, we used the approach proposed in [4]. Estimates of the maximum modulus of the drift rate of the semimajor axis $|da/dt|_{max}$ were obtained based on the relations between the parameters of the studied asteroid and asteroid (101955) Bennu. In contrast to the traditional approach, considering the Yarkovsky effect, we obtained age estimates for several fixed values of the semimajor axis drift velocities corresponding to different positions of the asteroid's rotation axis to the orbital plane. For each asteroid five variants of evolution were considered at the values of the drift rate corresponding to different orientations of the asteroid's axis of rotation relative to the plane of its orbit: $da/dt = 0$ at $\varphi = 90°$ or $270°$; $da/dt = \pm 1/2|da/dt|_{max}$ at $\cos\varphi = \pm 1/2$, respectively; $da/dt = \pm|da/dt|_{max}$ at $\varphi = 0°$ and $180°$, respectively.

We used two techniques to estimate the age of a pair of asteroids.
The first is based on an analysis of low relative-velocity close encounters:

$$\Delta r < 10R_H \text{ and } \Delta v < 4V_{esc}$$

where R_H is the radius of the Hill sphere of the more massive asteroid in the pair, V_{esc} is the escape velocity relative to the more massive asteroid, Δr is the distance between asteroids, and Δv is the relative velocity of the asteroids.

The second is based on the search for the minimum distance between the orbits using the Kholshevnikov metrics [3].

Results:

Table 1. Estimates of the age of the (87887) 2000 SS286 - (415992) 2002 AT49 in years

$\left(\frac{da}{dt}\right)_{87887}$ [au/Myr]	$\left(\frac{da}{dt}\right)_{415992}$ [au/Myr]				
	-1.9×10^{-4}	-9.5×10^{-5}	0	9.5×10^{-5}	1.9×10^{-4}
-1.1×10^{-4}	-8 314 ± 41 -8 451 ± 174 56%	–8 116 ± 40 –8 319 ± 104 59%	–7 927 ± 39 –8 088 ± 157 56%	–7 750 ± 37 –7 901 ± 156 52%	–7 583 ± 35 –7 577 ± 185 48%
-5.5×10^{-5}	–8 432 ± 41 –8 594 ± 153 52%	–8 229 ± 41 –8 384 ± 146 58%	–8 035 ± 40 –8 220 ± 143 58%	–7 851 ± 38 –8 033 ± 134 55%	7 678 ± 36 –7 749 ± 188 50%
0	-8 552 ± 41 -8 623 ± 199 45%	-8 345 ±41 -8491±172 55%	-8 146 ± 40 -8 343 ±104 58%	-7 956 ± 39 -8 115 ± 161 57%	-7 776 ±37 -7 948±141 53%
5.5×10^{-5}	–8 675 ± 42 –8 637 ± 224 34%	–8 464 ± 41 –8 616 ± 157 51%	–8 260 ± 41 –8 403 ± 160 57%	–8 063 ± 39 –8 260 ± 130 58%	–7 878 ± 38 –8 051 ± 144 55%
1.1×10^{-4}	–8 804 ± 43 –8 771 ± 262 29%	–8 584 ± 41 –8 625 ± 210 42%	–8 377 ± 41 –8 533 ± 165 54%	–8 176 ± 40 –8 360 ± 110 58%	–7 984 ± 39 –8 149 ± 160 57%

Table 2. Estimates of the age of the (320025) 2007 DT76 – (489464) 2007 DP16 in years

$\left(\frac{da}{dt}\right)_{320025}$ [au/Myr]	$\left(\frac{da}{dt}\right)_{489464}$ [au/Myr]				
	-3.2×10^{-4}	-1.6×10^{-5}	0	1.6×10^{-5}	3.2×10^{-4}
-1.6×10^{-4}	-24 747 ± 2 373 -25 028 ± 2 995 67%	-29 560 ± 417 -26 832 ± 1 602 0.0060%	no low relative-velocity close encounters	no low relative-velocity close encounters	no low relative-velocity close encounters
-0.8×10^{-5}	-21 027 ± 1825 -20 979±2 548 76%	-27 550 ± 1 793 -27 291 ± 2 505 16%	no low relative-velocity close encounters	no low relative-velocity close encounters	no low relative-velocity close encounters
0				no low relative-velocity close encounters	no low relative-velocity close encounters
0.8×10^{-5}	-16 811 ± 1 140 -16 370 ± 1 763 77%	-21 027 ± 1 825 -20 991 ± 2 542 76%	-27 553 ± 1 791 -27 982 ± 1 663 16%	no low relative-velocity close encounters	no low relative-velocity close encounters
1.6×10^{-4}	-15 455 ± 966 -14 923 ± 1 385 74%	-18 563 ± 1 387 -18 318 ± 1 997 78%	-24 743 ± 2 373 -25 036 ± 2 970 66%	-29 547 ± 418 -27 868 ± 1 455 0.0061%	no low relative-velocity close encounters

The age estimate of the pair (87887) 2000 SS286 - (415992) 2002 AT49 ranges from 7.58 ± 0.035 to 8.8 ± 0.043 kyr depending on the drift rate of the semimajor axes.
The minimum age estimate corresponds to the variant in which for the first asteroid (87887) 2000 SS286 the drift velocity of the semimajor axis of the asteroid is $da/dt = -1.1\cdot10^{-4}$ au/Myr, and for the second asteroid (415992) 2002 AT49 it is $1.9\cdot10^{-4}$ au/Myr. The maximum estimate corresponds to the drift velocities of $1.1\cdot10^{-4}$ au/Myr and $-1.9\cdot10^{-4}$ au/Myr, respectively.
Our estimate is close to the estimate of 7.4 ± 0.3 kyr obtained in [5].

Estimates of the age of the in years from the analysis of low relative-velocity close encounters

Estimates of the age of the pair in years from the analysis of minimum distances between orbits

Part of variants with low relative-velocity close encounters: $\Delta r < 10R_H$ and $\Delta v < 4V_{esc}$

For the pair (320025) 2007 DT76 – (489464) 2007 DP16 integration interval was 30 kyr.

The age estimate ranges from 15.4 ± 0.96 to 29.5 ± 0.04 kyr.
The age of this pair significantly depends on the value of the semimajor axis drift.

We did not find low relative-velocity close encounters for some variants.

In [5], the age is estimated for this pair – more than 10 kyr.

References:

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