ORBITAL EVOLUTION OF PHAETHON CLUSTER.

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Introduction: It is known that the Geminids meteor shower is associated with the near-Earth asteroid (3200) Phaethon. In [1], it was suggested that the asteroid (155140) 2005 UD is a fragment of the asteroid (3200) Phaethon. This point of view is discussed in [2]. In [3], it was concluded that the orbital evolution of asteroids (155140) 2005 UD and (225416) 1999 YC is similar to the orbital evolution of asteroid (3200) Phaethon. Analysis of the difference in orbital angular elements (longitudes of nodes and perihelions) excludes the separation of (155140) 2005 UD and (225416) 1999 YC from (3200) Phaethon in the recent past. Probably, these events took place more than 100 kyr ago. In [4], it is concluded that asteroids (155140) 2005 UD and (225416) 1999 YC are not members of the Phaethon–Geminids meteoroid complex.

Method: We have studied the orbital evolution of asteroids of the Phaethon cluster: (3200) Phaethon, (155140) 2005 UD and (225416) 1999 YC over 1 Myr in order to estimate the age of asteroid pairs. We use the term "Phaethon cluster" to distinguish it from the "Phaethon–Geminid meteoroid complex".

We used the Orbit9 software to study orbital evolution. Perturbations from eight major planets, the dwarf planet Pluto, the influence of the Yarkovsky effect, the contraction of the Sun, and relativistic effects were considered. The orbital elements for the epoch MJD 59000 (May 31, 2020) from the AstDyS were used as the initial ones.

The diurnal Yarkovsky effect was taken into account in the semi-major axis drift da/dt. For (3200) Phaethon, we used da/dt = –(6.9 ± 1.9)·10^{-4} au/Myr [5]. For (155140) 2005 UD, the drift da/dt was assumed to be zero since the angle of inclination of the asteroid's rotation axis to the plane of its orbit is $\varphi \approx 87°$ [6]. For (225416) 1999 YC, there are no estimates of the semi-major axis drift based on the observation results; therefore, an estimate was obtained for the absolute value maximum of the drift $|da/dt|_{max} = 7.8 \cdot 10^{-5}$ au/Myr using the normalization of the physical and dynamic parameters of the asteroid concerning the corresponding parameters of the (101955) Bennu [7, 8]. For (225416) 1999 YC, five variants of evolution were considered: $da/dt = 0, \pm 1/2 \cdot |da/dt|_{max}, \pm |da/dt|_{max}$.

Standard methods for determining the age of pairs of asteroids in close orbits include analysis of low relative-velocity close encounters of asteroids [9], analysis of minimum distances between orbits [10], analysis of the simultaneous approach of the lines of nodes and lines of the apses of the orbits of asteroids [11].

Results: Based on the simulation results, over 1 Myr in the past, no paired low relative-velocity close encounters were revealed for the asteroids of the Phaeton cluster. Analysis of the evolution of the distances between the orbits, calculated using the Kholshevnikov metrics [12], did not reveal close approaches of the orbits.

Analysis of the evolution of the differences in the longitudes of the ascending nodes $\Delta\Omega$ and the perihelion arguments Δg showed the following. The orbital convergence condition is not fulfilled for the pair (3200) Phaethon – (155140) 2005 UD over 1 Myr. The difference in the longitudes of the ascending nodes $\Delta\Omega \approx 0$ near 280 kyr ago, the difference in the perihelion arguments Δg librates relative to the value of 180° with an amplitude of 90°. The libration Δg to 180° is since both asteroids are in the metastable Lidov–Kozai resonance [13], which protects asteroids from very close encounters with planets. The perihelion argument is librated to 0° for (3200) Phaethon and 180° in the case of (155140) 2005 UD over 1 Myr in the past. This behavior of the perihelion argument excludes the orbits convergence for (3200) Phaethon and (155140) 2005 UD over 1 Myr in the past.

Asteroid (225416) 1999 YC is also in the metastable Lidov–Kozai resonance. Unlike (3200) Phaethon and (155140) 2005 UD, the perihelion argument of (225416) 1999 YC changes the libration position between 0° and 180°, which makes it possible to converge the orbit of (225416) 1999 YC as with the orbit (3200) Phaethon, and with the orbit (155140) 2005 UD. If the asteroid (225416) 1999 YC results from the fragmentation of the asteroid (155140) 2005 UD, the age of the pair may be 50 kyr or more. If (225416) 1999 YC is a fragment of (3200) Phaethon, then the age of the pair exceeds 100 kyr, which is consistent with the conclusions of [3].

Discussion: The results indicate the complex resonance dynamics of the Phaeton cluster. We have used the nominal orbits. To obtain reliable estimates of the age of pairs, considering the peculiarities of the stochastic orbital evolution of near-Earth asteroids, it is necessary to study the probabilistic orbital evolution of the Phaethon cluster.

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