MIGRATION OF SMALL BODIES TO THE EARTH.

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We investigated the present migration of bodies to the Earth from various regions of the Solar System and the sources of filling up the groups of near-Earth objects (NEOs). It was obtained that perihelia or aphelia of orbits of bodies that collided the Earth mainly lied near the Earth's orbit. The large number of objects should exist which orbits lie inside the orbits of Earth and Venus. Most of asteroids of the Amor group should have come from the asteroid belt.

The orbital evolution of 500 fictitious asteroids initially located near the 5:2 commensurability with Jupiter's motion was investigated by numerical integration of the equations of motion for the three-body problem (the Sun–Jupiter–asteroid) [1–3]. The obtained results showed that more than 1/6 of asteroid debris that entered into the 5:2 Kirkwood gap with the eccentricity \( e=0.15 \) can reach the orbit of the Earth in 100,000 yr. These debris may make an appreciable part of those H chondrite meteorites which age is less than 10 Myr. The mean times of migration of bodies to the Earth's orbit from other regions of the Solar System are greater than those from the 5:2 gap.

We investigated the variations in orbital elements of three gravitationally interacting objects moving around the Sun in initially close circular orbits. Masses of the objects were equal to that of Pluto. The investigations of the planar model showed [4] that the eccentricity of one of these objects could reach 0.4 during the age of the Solar System. The three-dimensional model and a larger number of interacting objects were considered in [5]. The obtained results indicate the possibility of migration of some bodies from the beyond–Neptune belt to the Neptune's orbit under the gravitational influence of the largest bodies of this belt. A small number of LL chondrite meteorites with the age \( t<8 \) Myr may be due to their long way from the belt.

Computer simulations of the evolution of disks that originally consisted of planets and 500 bodies located in various regions of the Solar System were carried out [6]. The bodies initially located in the Kirkwood gaps 5:2 and 3:1 and near the orbits of Earth, Mars, Jupiter, and Neptune were considered. The gravitational influence of planets was taken into account by the action (Tisserand) spheres method, that is two two-body problems were considered. The obtained results showed that amongst the bodies, which have come from the zone of the giant planets, the number of Earth–crossers is ten times greater than the number of only Mars–crossers and usually \( e>0.6 \). The number of Amor objects is greater than the number of Apollo objects. Therefore, most of Amor objects must have come from the asteroid belt.

During the last stages of the evolution of all considered disks, orbits of some bodies were located inside the orbits of Earth and Venus. The number of such bodies in the Solar System can be large and some of these bodies can migrate to the orbit of the Earth. At the late stages of the disk evolution near the orbits of the giant planets, we obtained gaps in the distribution of perihelia of objects initially located in the zone of Neptune.
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Perihelia or aphelia of bodies collided the Earth were located mainly near the Earth's orbit. The part of initial bodies collided the Earth was obtained to be about 6%, 1%, and 0.01% for the bodies initially located at the 3:1 and 5:2 gaps, and at the Neptune's zone, respectively. The total mass of planetesimals in the feeding zones of Uranus and Neptune could be equal to 100 Earth's masses. Therefore, a large amount of water could be delivered to the Earth during the accumulation of planets. The number of objects that impacted Venus was not significantly less than that impacted Earth.

The formula for a characteristic time up to a collision of k-th asteroid with the Earth, $T_k$, is presented in [7] for the case when the asteroidal semimajor axis, eccentricity, and inclination $i$ don't change, and the values of the argument of perihelion and the longitude of ascending node change considerably before a collision. Using this formula we obtained that the part of Earth-crossing objects (ECOs) with $100 \text{ Myr} \leq T_k \leq 1000 \text{ Myr}$ and the part of ECOs with $T_k \leq 115 \text{ Myr}$ are almost the same and are equal to 50%. Orbital elements of real ECOs can change significantly before their collisions with the Earth and the values of the time up to these collisions may differ much from the values of $T_k$ obtained for the fixed orbital elements. We found the average time up to the collision as $T=N/\sum(1/T_k)=40 \text{ Myr}$, where the sum is taken for $N$ known ECOs. The value of $T$ is 5 times less than the value of $T_k$ obtained for the mean values of $e$ and $i$ for ECOs. The number of ECOs with diameters $d>1 \text{ km}$ is considered to be greater than 500, so a time before a collision of one of such ECOs with the Earth is less than 100,000 yr.

The probability of ejection of a NEO into a hyperbolic orbit is ten times as large as the probability of its collision with the Earth, and most NEOs leave the Solar System in 10 Myr. Therefore, for most of bodies that collided the Earth, the time interval between obtaining the orbit intersecting the Earth's orbit and a collision with the Earth does not exceed 10 Myr.

The obtained appraisals show that asteroids which are ejected into the Kirkwood gaps due to the gravitational influence of the largest asteroids can make only some percents of NEOs. The larger number of bodies can be ejected into the gaps due to mutual collisions of asteroids. The mean disruption lifetimes for main-belt asteroids with diameters $d=100 \text{ km}$ are less than the age of the Solar System and for 1 m bodies can be less than 10 Myr. The mean time till the moment of the first collision of some asteroid of diameter $d'=0.1 \text{ d}$ is less than 10,000 yr. Therefore, small debris can frequently be ejected into the Kirkwood gaps.

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