PROBABILITIES OF COLLISIONS WITH THE EARTH AND THE MOON OF PLANETESIMALS MIGRATED FROM OUTSIDE THE ORBIT OF MARS

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The model and initial data used for calculations: Below I study the migration of planetesimals from different distances from the Sun to the Earth and the Moon. Such studies allow one to understand better the delivery of water and volatiles to the Earth and the Moon. Earlier we studied migration of bodies with initial orbits close to known Jupiter-family comets [1-5] and migration of planetesimals from the zone with initial semi-major axes from 4.5 to 12 AU [6]. In most new calculations, initial semi-major axes a_o of planetesimals varied from a_m to a_m+2.5 AU with a number of initial planetesimals proportional to $a_o^{1/2}$. In other runs, initial semi-major axes of all initial planetesimals equaled to r_f. For different runs, a_m and r_f varied from 2.5 to 40 AU with a step equaled to 2.5 AU. Initial eccentricities e_o of planetesimals equaled to 0.05 or 0.3. Initial inclinations i_o equaled to e_o/2 rad. The mean eccentricities equaled to 0.3 could be reached due to mutual gravitational influence of planetesimals during evolution of a disk of planetesimals in the feeding zone of the giant planets [7-8]. The gravitational influence of 7 planets (from Venus to Neptune) or of 5 planets (from Venus to Saturn) was taken into account. The symplectic code from the Swift integration package [9] was used. The orbital elements of the migrated planetesimals were recorded in computer memory with a step of 500 years. Based on these arrays of the orbital elements, similar to the calculations presented in [1-6], I calculated the probabilities p_E and p_M of collisions of planetesimals with the Earth and the Moon.

Results of calculations: The probabilities of collisions of planetesimals initially located beyond Jupiter's orbit with the Earth and the Moon calculated for 250 planetesimals can differ by more than a factor of several tens for different runs with similar orbits. While considering thousands of planetesimals with $5 \le a_\mathrm{m} \le 10$ AU, the mean value of p_E could be larger than 2×10^{-6} by at least a factor of several. It means that if most of the mass of planetesimals in the feeding zone of Jupiter and Saturn was in a large number of relatively small planetesimals, then for estimates of the delivery of material from this zone to the Earth one may use the values of p_E about 10^{-5}. On average, for initial planetesimals in the region at 20 - 40 AU from the Sun, the value of p_E could be about 10^{-6}. This region also could play a valuable role in migration of icy bodies to the Earth. For planetesimals initially located in the asteroid belt, the probabilities of their collisions with the Earth were about 10^{-4}-10^{-2}, i.e., were much greater than for planetesimals initially located beyond Jupiter's orbit. The ratio of the probabilities of collisions of considered planetesimals with the Earth to those with the Moon was mainly in the range from 16 to 17. At e_o=0.3 probabilities p_Sun of collisions of planetesimals with the Sun were 0.17 for a_m=2 AU, 0.04 for a_m=2.5 AU, and 0.76 for r_f=2.5 AU. For all other runs, p_Sun<0.01, and p_Sun=0 for most runs for a_m or r_f not less than 5 AU.

Most of the planetesimals from the Jupiter's feeding zone were ejected into hyperbolic orbits in a few Myr under the gravitational influence of Jupiter and Saturn. Most of collisions with the Earth of bodies initially located in the zone at 5-30 AU from the Sun took place in less than 20 Myr. This testifies in favor of that the planetesimals from beyond Jupiter's orbit could fall onto the Earth and the Moon in the process of their growth, and the matter, including water and volatiles, delivered from beyond the orbit of Jupiter was incorporated into the internal layers of the Earth and the Moon. The delivery of matter to the Earth and the Moon from the zone of Uranus and Neptune depended on when these giant planets acquired large masses and began to move in orbits close to their present orbits. After the planetesimals from this zone began to experience a significant influence of these giant planets, the typical time until the fall of the planetesimals onto the Earth and the Moon often did not exceed 20 Myr, but a small fraction of the planetesimals could fall onto the Earth during hundreds of Myr.

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