PROBABILITIES OF COLLISIONS OF MIGRATING SMALL BODIES AND DUST PARTICLES WITH PLANETS.

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1. Model of Migration of Small Bodies and Dust Particles: The orbital evolution of >30,000 bodies with initial orbits close to those of Jupiter-family comets (JFCs), Halley-type comets, long-period comets, and asteroids in the resonances 3/1 and 5/2 with Jupiter, and also of >20,000 dust particles produced by these small bodies was integrated [1-6] until all bodies or particles reached 2000 AU from the Sun or collided with the Sun. Based on a set of orbital elements during evolution, we studied the probabilities of collisions of migrating particles and bodies (during their dynamical lifetimes) with planets. For initial orbital elements close to those of Comets 2P/Encke, 10P/Tempel 2, 44P/Reinmuth 2, and 113P/Spitaler, a few bodies got Earth-crossing orbits with semi-major axes a<2 AU and aphelion distances Q<4.2 AU, or even got inner-Earth, Aten, or typical asteroidal orbits, and moved in such orbits for more than 1 Myr (up to tens or even hundreds of Myrs). From a dynamical point of view, the fraction of extinct comets among near-Earth objects can exceed several tens of percent, but, probably, many comets disintegrated into mini-comets and dust during a smaller part of their dynamical lifetimes if these lifetimes were large. The ACM presentation will be put on http://www.dtm.ciw.edu/ipatov/present.htm .

2. Probabilities of Collisions of Migrating Small Bodies with the Terrestrial Planets: The probability of a collision of Comet 10P with the Earth during a dynamical lifetime of the comet was $P_E \approx 1.4\cdot10^{-4}$, but 80% of this mean probability was due only to one body among 2600 considered bodies with initial orbits close to that of Comet 10P. For runs for Comet 2P, $P_E \approx (1\text{-}5)\cdot10^{-4}$. For most other considered JFCs, $10^{-6}<P_E<10^{-5}$. For Comets 22P/Kopff and 39P/Oterma, $P_E \approx (1\text{-}2)\cdot10^{-6}$; and for Comets 9P/Tempel 1, 28P/Neujmin 1 and 44P, $P_E \approx (2\text{-}5)\cdot10^{-6}$. For all considered JFCs, $P_E > 4\cdot10^{-6}$ even if we exclude a few bodies for which the probability of a collision of one body with the Earth could be greater than the sum of probabilities for thousands of other bodies. The Bulirsh-Stoer method of integration and a symplectic method gave similar results. The ratios of probabilities of collisions of JFCs with Venus, Mars, and Mercury to the mass of a planet usually were not smaller than those for Earth.

3. Probabilities of Collisions of Migrating Dust Particles with the Terrestrial Planets: For dust particles produced by comets and asteroids, P_E was found to have a maximum (~0.001-0.02) at $0.002 \le \beta \le 0.01$, i.e., at d~100 μm (this value of d is in accordance with observational data). These maximum values of P_E were usually (exclusive for Comet 2P) greater at least by an order of magnitude than the values for parent comets. Probabilities of collisions of considered particles with Venus were of the same order as those for Earth, and those for Mars were about an order of magnitude smalller. Depending on a source of dust, probabilities for Mercury can be smaller or greater than for Mars.

4. Probabilities of Collisions of Migrating Small Bodies and Dust Particles with the Giant Planets: Probabilities of collisions of considered particles and bodies with Jupiter during their dynamical lifetimes are smaller than 0.1. They can reach 0.01-0.1 for bodies and particles initially moved beyond Jupiter's orbit or in Encke-type orbits. For bodies and particles initially moved inside Jupiter's orbit, the probabilities are usually smaller than the above range and can be zero. Probabilities of collisions of migrating particles (exclusive for trans-Neptunian particles) with other giant planets were usually smaller than those with Jupiter. The total probability of collisions of any considered body or particle with all planets didn't exceeed 0.2.

5. Delivery of Water to the Terrestrial Planets: Using $P_E=4\cdot10^{-6}$ and assuming that the total mass of planetesimals that ever crossed Jupiter's orbit is about $100m_E$ [7-8], where m_E is the mass of the Earth, we obtained [1-2,6] that the total mass of water delivered from the feeding zone of the giant planets to the Earth could be about the total mass of water in Earth's oceans (similar conclusion was made in [9]). We supposed that the fraction of water in planetesimals equaled 0.5.

The ratio of the mass of water delivered to a planet by Jupiter-family comets and Halley-type comets to the mass of the planet can be greater for Mars, Venus, and Mercury, than that for the Earth. This larger mass fraction would result in relatively large ancient oceans on Mars and Venus.

References: [1] Ipatov S. I. and Mather J. C. (2003) *Earth, Moon, & Planets*, *92*, 89-98. [2] Ipatov S. I. and Mather J. C. (2004) *Annals of New York Acad. Sci.*, *1017*, 46-65. [3] Ipatov S. I. et al. (2004) *Annals of New York Acad. Sci.*, *1017*, 66-80. [4] Ipatov S. I. and Mather J. C. (2004) *Adv. in Space Res.*, *33*, 1524-1533. [5] Ipatov S. I. and Mather J. C. (2006) *Adv. in Space Res.*, *37*, 126-137. [6] Ipatov S. I. and Mather J. C. (2007) *Proc. IAU Symp. 236 "Near-Earth Objects, Our Celestial Neighbors: Opportunity and Risk"* (14-18 Aug. 2006, Prague), 55-64. [7] Ipatov S. I. (1987) *Earth, Moon, & Planets, 39*, 101-128. [8] Ipatov S. I. (1993) *Solar System Res., 27*, 65-79. [9] Ipatov S. I. (2001) *Adv. in Space Res.*, *28*, 1107-1116.