MIGRATION OF DUST PARTICLES TO THE TERRESTRIAL PLANETS. S. I. Ipatov, *University of Maryland, USA (siipatov@mail333.com)*, J. C. Mather, *NASA/GSFC, Greenbelt, MD, USA*.

Introduction: There are a lot of papers on migration of dust (see references in [1-2]). In contrast to papers by other scientists, we study the orbital evolution of dust particles for a wider range of masses of asteroidal and cometary particles and consider also migration of dust particles produced by comets 10P and 39P.

Model: We integrated [1-2] the orbital evolution of about 12,000 asteroidal, cometary, and trans-Neptunian dust particles under the gravitational influence of planets, the Poynting-Robertson drag, radiation pressure, and solar wind drag, varying the values of the ratio β between the radiation pressure force and the gravitational force from $\leq$0.0004 to 0.4 (for silicates, such values correspond to particle diameters between $\geq$1000 and 1 microns). The considered cometary particles started from comets 2P, 10P, and 39P. A few hundred of particles were considered in each run. In our runs orbital elements were stored with a step of d_t of $\leq$20 yr for asteroidal and cometary particles and 100 yr for trans-Neptunian particles. The planets were assumed to be material points; however, using orbital elements obtained with a step d_t, we calculated the mean collision probability of a particle with the planet during the particle lifetime P=P_Σ/N, where P_Σ is the probability for all N considered particles. The relative error per integration step less than 10^{-8} was adopted. The integration continued until all of the particles either collided with the Sun or reached 2000 AU from the Sun.

Collision probabilities of dust particles with planets: The probability P of a collision of an asteroidal dust particle with the Earth was found [2] to have a maximum ($\sim$0.001-0.02) at 0.002$\leq\beta\leq$0.01, i.e., at diameters of particles $d\sim$100 μm. This is in accordance with cratering records in the lunar soil and also with particles record on the panels of the Long Duration Exposure Facility, which showed that the mass distribution of dust particles encountering Earth peaks at d=200 μm. At β>0.01 collision probabilities of asteroidal particles with the terrestrial planets decreased with growing β. For Venus these probabilities didn't differ much from those for Earth, whereas for Mars they were by an order of magnitude smaller at $\beta\geq$0.01 compared to Earth, and nearly similar to those for Earth at $\beta\sim$0.0004-0.001.

Collision probability P of a particle started from Comet 10P with a terrestrial planet sometimes differed by a factor of several from that for an asteroidal particle of the same size. In turn, for Comet 2P dust debris, the P values were found usually smaller than for asteroidal and 10P particles: for Earth at 0.002$\leq\beta\leq$0.01, P was by an order of magnitude smaller for 2P particles than for asteroid particles. For 2P particles at some β, P is by a factor of 2 or 4 greater for Venus than for Earth.

For trans-Neptunian and 39P particles, maximum values of the probability of collisions with the Sun (0.2-0.3) were reached at $0.05\leq\beta\leq0.1$. For $\beta\geq0.05$, the fraction of trans-Neptunian particles collided with the Sun was less than that of asteroidal particles by a factor of 4-6.

Probabilities of collisions of trans-Neptunian particles with Earth and Venus at 0.01$\leq\beta\leq$0.2 were $\sim(0.3-4)\cdot10^{-4}$ and were usually less than those for asteroidal particles by a factor of less than 4. The ratio of values of time T during which a particle has perihelion less than 1 AU for asteroidal particles to the values of T for trans-Neptunian particles was about 3-7 at $\beta\geq$0.1 and about 20 at $\beta=0.05$. The mean values e_m and i_m of eccentricities and inclinations at distance R=1 AU from the Sun were mainly greater for trans-Neptunian particles than those for asteroidal particles. Nevertheless, the ratio P/T was greater for trans-Neptunian particles. It may be caused by that perihelia or aphelia of migrating trans-Neptunian particles more often were close to the orbit of the Earth, or the fraction of Earth-crossing trans-Neptunian particles with small e and i was greater (though e_m and i_m were greater) than for asteroidal particles.

Probabilities P_E of collisions of trans-Neptunian and 39P dust particles with the Earth were usually smaller by a factor of several or more than those for asteroidal and 10P particles of the same size. At β=0.0001 one 39P particle moved in an Earth-crossing orbit located inside Jupiter's orbit for 6 millions of years, and the values of P and T for this run were much greater than those for other 39P runs. For 39P particles greater than 1000 μm, one need to consider many thousands of particles in order to get reliable statistics because for such runs the probability of a collision of one particle with the terrestrial planets can be greater than the total probability of collisions of thousands other particles. Comet 39P is located outside Jupiter's orbit ($a\approx$7 AU), and studies of the orbital evolution of dust particles produced by this comet help to better understand migration of trans-Neptunian particles to the terrestrial planets at small β. At 0.01$\leq\beta\leq$0.2 the values of P_E for trans-Neptunian dust particles were similar to those for 39P particles ($\sim10^{-4}$), but the times in Earth-crossing orbits for trans-Neptunian particles were smaller by a factor of several than those for 39P particles. Due to a small fraction of large (>1000 μm) particles that can move in Earth-crossing orbits for a long time, it may be possible that the probability of a collision of such trans-Neptunian particle with the Earth can be of the same order of magnitude as that for d<50 μm, but much more runs are needed for accurate estimates.

Interstellar particles can be effective in destruction of trans-Neptunian dust particles through collisions, especially with grains between 9 μm and 50 μm, as it is argued in [3]. Larger particles may survive because interstellar grains are too small to destroy them in a single impact. Since the total mass of the trans-Neptunian belt exceeds that of the asteroid belt by more than two orders of magnitude, and the derived in our model mean residence times ratio in orbits with perihelion distance q<1 AU for asteroid and trans-Neptunian particles is less than 20 at $\beta\geq$0.05, then for $d\sim$1-10 μm the fraction of trans-Neptunian dust of the overall dust population can be significant even at R<3 AU.

Distribution of migrating dust particles: Based on our runs, we studied [2] the distribution of spatial density n_s (i.e., the number of particles per unit of volume) near ecliptic over distance R from the Sun. For asteroidal particles, n_s quickly decreases with an increase of R. So asteroidal dust particles cannot explain the constant spatial density of dust particles at $R\sim$3-18 AU. At such distances, many of the dust particles could have come from the trans-Neptunian belt and from comets. In our runs at $\beta\geq$0.05, spatial density n_s of trans-Neptunian particles near ecliptic at R=1 AU was greater than at R>1 AU. At 0.1$\leq\beta\leq$0.4 and 2<R<45 AU (at β=0.05 for 11<R<50 AU) for trans-Neptunian particles, n_s varied with R by less than a factor of 4, but at R=5 AU it was smaller by at least a factor of 2 than at 15 AU.

Velocities of dust particles: Ipatov et al. [4-5] studied how the solar spectrum is changed by scattering by dust particles. Positions of particles were taken from the runs of migration of dust particles. For each such stored position, we calculated many ($\sim10^2$-10^4 depending on a run) different positions of a particle and the Earth during the period P_{rev} of revolution of the particle around the Sun, considering that orbital elements do not vary during P_{rev}. Three different scattering functions were considered [2]. For each considered position, we calculated velocities of a dust particle relative to the Sun and the Earth and used these velocities and the scattering function for construction of the solar spectrum received at the Earth after been scattering by different particles located at some beam (line of sight) from the Earth. The direction of the beam is characterized by elongation ϵ and inclination i. Particles in the cone of 2° around this direction were considered. In each run, particles of the same size (at the same β) and the same source (i.e., asteroidal) were studied. Ipatov et al. [5] and Madsen et al. [6] compared the rotation curves, i.e., plots of velocities of Mg I line (at zero inclination) versus elongations ε (measured eastward from the Sun), with the observational plots obtained by Reynolds et al. [7]. The rotation curves obtained for different considered scattering functions were similar for 30°<ε<330°, the difference was greater for more close direction to the Sun. The difference between different plots for different sources of dust was maximum at ε between 90° and 120°. In our opinion, the main conclusion of the comparison of such curves is that asteroidal dust doesn't dominate in the zodiacal light and a lot of zodiacal dust particles were produced by high eccentricity comets (such as comet 2P Encke). Significant contribution of cometary dust was considered by several other authors. For example, based on cratering rates from an ensemble of Earth- and Lunar-orbiting satellites, Zook [8] estimated that the cometary contribution to the near-Earth flux of particles is $\sim$75%.

Conclusions: Probabilities of collisions of migrating asteroidal and cometary dust particles with the terrestrial planets during the lifetimes of these particles were maximum at diameter $d\sim$100 μm, which is in accordance with the analysis of microcraters.

Cometary dust particles (produced both inside and outside Jupiter's orbit) are needed to explain the constant spatial density of dust particles at 3-18 AU. The spatial density of migrating trans-Neptunian particles near Jupiter's orbit is smaller by a factor of several than that beyond Saturn's orbit. Only a small fraction of asteroidal particles can get outside Jupiter's orbit.

Comparison of velocities of particles obtained in our runs with the results of observations also show that only asteroidal dust particles cannot explain these observations, and particles produced by high-eccentricity comets (such as Comet Encke) are needed for such explanation.

Several our recent papers are presented on astro-ph.

References: [1] Ipatov S. I., Mather J. C., and Taylor P. (2004) *Annals of the New York Acad. of Sciences, 1017*, 66-80. [2] Ipatov S. I. and Mather J. C. (2005) *Advances in Space Research*, in press. [3] Liou J.-C., Zook H. A., Dermott S. F. (1996) *Icarus*, *124*, 429-440. [4] Ipatov S. I. et al. (2005) *LPSC XXXV*, abstract #1266. [5] Ipatov S. I. et al. (2005) *BAAS*, late abstracts of AAS 206 Meeting, #449, in press. [6] Madsen G. J. et al. (2005) *this abstract book*. [7] Reynolds R. J., Madsen G. J., Moseley S. H. (2004) *Astrophys. J.*, *612*, 1206-1213. [8] Zook H. A. (2001) in: Peucker-Ehrenbrink, B. and Schmitz, B. (Eds.) *Accretion of extraterrestrial matter throughout Earth's history*, Kluwer, New York, 75-92.