The Effect of Dynamical Friction on Formation of the Terrestrial Planets

Junko Kominami[1], Shigeru Ida[2]

[1] Earth and Planetary Sci.,T.I.Tech., [2] Dept. of Earth and Planetary Sci., Tokyo Inst. of Tech.

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We investigated the possible strength of the dynamical friction that can reproduce the terrestrial planets, that is, the strength that does not inhibit the orbital crossing but sufficiently damp the eccentricities of the planets after coagulations on reasonable timescales about a hundred million years. We found out that the dynamical friction with such strength is exerted by planetesimals with total mass comparable to the mass of protoplanets or disk gas with 0.1 - 1% mass of the minimum mass model. Based on the results we discuss the overall history of the terrestrial planet accretion.

We performed the N-body simulation of terrestrial planet accretion, including the effect of dynamical friction from planetesimals and residual disk gas.

It is considered that terrestrial planets are formed by runaway accretion of planetesimals followed by giant impacts between the runaway protoplanets. As a result of runaway accretion, ten to twenty Mars-sized protoplanets are formed in the terrestrial planet region with several Hill radius separation (Kokubo & Ida 1998,2000). The orbits of the protoplanets are nearly circular.

The following stage is the accetion of the protoplanets. The eccentricities of their orbits may be pumped up by the long term mutual gravitational force and/or the gravity of the giant gaseous planets, so that orbit crossing starts (Chambers et al. 1996, Ito & Tanikawa 1999, Nagasawa et al. 2000). The orbit crossing results in the coagulation of the protoplanets. The accretion lasts till the planets become about the size of the Earth (Chambers & Wetherill 1998).

However, the N-body simulation shows that the final eccentricity of the planets are around 0.1, which is about 10 times higher than that of the Earth and Venus (Chambers & Wetherill 1997).

Because the eccentricities during the orbital crossing are so high, the collisional damping cannot damp the eccentricities sufficiently. In order to reproduce the present terrestrial planets, we need another damping mechanism. An important damping mechanism that has not been taken into account in the previous N-body simulations, is gravitational interaction with small planetesimals leftover from the accretion, and partly dissipated disk gas (Stewart & Wetherill 1988,Ward 1993).

We included such gravitational interaction as dynamical friction force (Chandrasekhar 1943) for orbital integration and carried out the N-body simulation. We found out that the final mass of the planets, spacial distribution, and eccentricity depend on the strength of the dynamical friction. If the friction is too weak, the final eccentricity is too high. If it is too strong, eccentricity of the protoplanets cannot be pumped up, resulting in not enough orbital crossing. Small planets with low eccentricities are formed with small separation.

We investigated the possible strength of the dynamical friction that can reproduce the terrestrial planets, that is, the strength that does not inhibit the orbital crossing but sufficiently damp the eccentricities of the planets after coagulations on reasonable timescales about 100 million years. We found out that the dynamical friction with such strength is exerted by planetesimals with total mass comparable to the protoplanets mass or disk gas with 0.1 – 1 % mass of the minimum mass model. Based on the results, we discuss the overall history of the terrestrial planet accretion.