Particle coagulation and satellitesimal formation in a jovian subnebula

Ryuhei Shimazawa[1]; Kiyoshi Kuramoto[2]

[1] Earth and Planetary Sci., Hokkaido Univ; [2] Earth and Planetary Sci., Hokkaido Univ.

The regular satellites of the jovian planets are believed to be formed in subnebulae surrounding these planets. In the Jovian system, the Galilean satellites have nearly the same masses and orderly orbital separations and show monotonic increase in ice abundance with orbital radius, allowing the reconstruction of the density and temperature profiles of jovian subnebula. Because its spatial and evolutionary time scales are much different from those of the solar nebula, it is not obvious whether or not the processes explaining the planet formation in the solar nebula can also account the satellite formation by scale transformation. In this study, we made numerical analyses on the processes of particle growth in a reconstructed jovian subunebula (Mosqueira and Estrada, 2003).

As well known in solar nebula studies, particles contained in nebula gas have drift motion toward the central body (Jupiter) and equatorial plane. Because the subnebula is characterized by high surface density, small spatial scale, and short orbital period, the drift motion tends to be faster than that in the solar nebula. The drift motion is estimated by adapting the two component fluid approximation taking particles as a fluid component (Watanabe and Ida, 1998) for small particles, the solution of a single body motion modified by gas drag (Adachi et al., 1976) for large particles, and their extrapolation for medium-sized particles.

The inward drift is fastest at the particle size about 10 cm with velocity about 100 m/s in the orbital region of the Galilean satellites. It takes from several days to nearly one month for a particle to fall into Jupiter if the maximum speed is kept. So, the formation of satellitesimal requires rapid growth of particle across such size associated with high drift velocity. Here we call a particle with radius larger than 10 m satellitesimal, which has orbital motion nearly decoupled from the gas motion.

Because of relative motion, particles may collide and thereby coagulate into larger particles. This process is analyzed by numerical integration of coagulation equation. For simplicity, we assume homogeneous mixture of gas and particles with mixing ratio of the solar composition. Relative motion between particles is given by difference in their motions relative to gas, and their collisional cross section is given by geometrical one assuming spherical shape. The initial mean radius of particles is taken 1 micron meter. The coagulation equation is numerically integrated by use of the moving batch scheme (Inaba et al., 1999).

Numerical results show that 1 mm-size particles are formed after four month and they rapidly grow to nearly 10 m size in the next month at the region of Ganymede's orbit. This rapid growth is caused by the sharp increase in drift speed with particle size beyond 1 mm. The net orbital drift is negligible (smaller than 0.1 orbital radius) during the particle growth. At the region of Callisto's orbit, however, it takes much longer time for particle growth due to initial low special density and thereby most of particles may be lost from this region without forming satellitesimals.

The result for the region of Callisto's orbit demonstrates that the satellitesimal formation may be inhibited when the fraction of solid component is small. Because the subnebula is formed at the final stage of planet formation, its bulk composition should be different from the solar composition. If the solid component is depleted, the satellite formation would not occur due to the particle drift to Jupiter during slow particle growth. Imperfect sticking and collisional fragmentation of particles possess the same effect. As observed in the current jovian atmosphere, however, the jovian subnebula may also be enriched in heavy elements. If this is the case, the Galilean satellites would be formed through the ``in situ'' particle coagulation and the subsequent accretion of satellitesimals.