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Evaporation of icy planetesimals due to planetesimal bow shocks in a protoplanetary disk

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In a protoplanetary disk, planetesimals grow to planets by mutual collisions and accumulations. The gravitational interactions among the planetesimals increase eccentricities of the planetesimal orbits. When a relative velocity between the disk gas and planetesimal exceeds a sound velocity of the gas, a bow shock wave is produced on the leading side of the planetesimal.

It has been shown that heating by the planetesimal bow shocks in the nebular gas played a key role in formation of particles found in meteorites and interplanetary dust. For instance, the shock heating leads to formation of chondrules, millimeter-scale igneous silicate spheres in chondrites, by melting dust in the protoplanetary disk (e.g.,Hood 1998; Weidenschlling et al. 1998; Ciesla et al. 2004; Miura and Nakamoto 2002). Furthermore, it is possible by a planetesimal bow shock to form various types of cosmic crystals, which are fine silicate crystals observed in chondritic meteorites and interplanetary dust particles (Miura et al. 2010).

So far, the attention has mainly been paid on thermal evolutions of dust particles in the shocked region in the previous studies. However, we note a possibility that the planetesimal bow shock leads to heating and evaporation of the planetesimal itself. A similar process is found in ablation of the planetesimals penetrating through the atmosphere of a protoplanet (e.g., Podolak et al. 1988; Pollack et al. 1986). Heating and resultant evaporation by the planetesimal bow shocks will suppress growth of planetesimals. Furthermore, cooling of the vapors thus produced will form small dust particles by re-condensation. Those dust clouds in the disk may be found in the infrared spectra of the protoplanetary disks.

In the present study, we focus on the planetesimal heating and evaporation by the planetesimal bow shocks. We evaluated the surface temperature and evaporation rate of the planetesimal using a simple model of planetesimal evaporation by the planetesimal bow shock. We applied the model of the planetesimal evaporation to the formation stage of protoplanets. Our results show that the icy planetesimals evaporate efficiently in the planetary oligarchic stage (Kokubo and Ida 2002), where strong shocks are generated by the gravitational perturbations from the protoplanets. The results suggest that the growth of a protoplanet is suppressed owing to the insufficient accretion of planetesimals onto the protoplanet. There may be an influence on the chemical conposition in the asteroid region because the vicinity of asteroid belt (2-4 AU) corresponds to the region where the evaporation is effective.

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