Shock heating of dusts and icy planetesimals due to bow shocks in protoplanetary disks

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In protoplanetary disks, planetesimals grow to planets through mutual collisions and accretions. The gravitational interactions among planetesimals increase the eccentricities of their orbits. Especially, large planeteimals have high eccentric orbits and supersonic velocities relative to the nebular gas. Small silicate particles in the nebular gas are heated and could be melted by passages though the bow shocks of such planetesimals [1-3]. It is proposed that the planetesimals perturbed by Jovian mean-motion resonances are the promising source of shock waves that form chondrules in chondritic meteorites because the shocks give short-time-scale heating of dust grains appropriate for the formation of chondrules [1]. In the previous studies on the planetesimal excitation, however, the velocities obtained were at most 8 kms^{-1} in the asteroid belt, which is insufficient to account for the ubiquitous existence of chondrules. Recently Nagasawa et al. [4] reexamined the effect of Jovian resonances, taking into account the secular resonance in the asteroid belt caused by the gravity of the gas disk. They found that the velocities of planetesimals relative to the gas disk exceed 12 kms^{-1} and the heating region is restricted to a relatively narrowband (1.5-3.5 au). These results suggest that chondrules were produced effectively in the asteroid region.

The planetesimal bow shocks also lead to heating of the planetesimal itself. Tanaka et al. [5] presented that icy planetesimals with radii larger than 100 km suffer from significant evaporation even outside the snow line. In [5], we focused on the oligarchic growth stage of propoplanets, in which planetesimals have velocities of 1-5 kms^{-1} relative to the gas due to stirring by protoplanets. In this study, we investigate the evaporation of planetesimal in the stage of the formation of gas giant planets. In such a stage, the evaporation of planetesimal proceeds much more effectively because of the stronger shocks and the evaporation time is much shorter than the disk lifetime of 10^6 yr. The evaporated H_2O vapor from the planetesimal surface recondenses as it cools and form a large amount of icy fine grains. During the evaporation of icy planetesimals, the silicate dust is also expected to be released from the planetesimal surface by the strong flow of the disk gas. This process provides a large amount of chondrule precursors. Our results may also relate to the origin of crystalline silicate observed in various comets and protoplanetary disks. The planetesimal bow shocks also lead to chemical reactions among various evaporated molecules. We propose a possibility that we can diagnose the shock heating and evaporation of icy planetesimals, using observations of lines of the molecules in the protoplanetary disks.

References

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