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Revised fragmentation model of planet-sized collisions

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In the process of planet formation, collisions between planetesimals or a planetesimal and a protoplanet occur frequently and let them grow up. Recent studies (e.g., Kobayashi and Tanaka 2009) suggest that the upper limit on the mass of planets varies by the amount or size of fragments scattered by such collisions. Therefore, in order to develop the more accurate theory of planet formation, it is important to investigate how destructive each collision is under various conditions. The critical impact energy for catastrophic disruption Q_{D*}, where the largest remnant has half the target mass, has been well investigated under various conditions (e.g., Benz and Asphaug 1999), and only this value has been regarded as important for the planet formation to date. However, there are some doubtful points in the accuracy of this value because of the low-resolution simulations and unclearness of the analytical method. Moreover, according to Kobayashi and Tanaka 2009, the collisions with less than critical impact energy are also important for planet formation. Although they presumed that the total mass of fragments is linear with the impact energy, its dependence on impact energy has not been examined.

We systematically performed the hydrodynamic simulations of collisions with various impact energies in SPH method, and reexamined Q_{D*} and investigated a relation between total mass of ejected material and impact energy. In our simulations, bodies with different size collide against 100km- and 10km-diameter bodies at different speed, and the amount of the total mass of ejected material can be calculated. In addition, we checked the dependence on the resolution and performed simulations in high enough resolution, and analyzed with the original analytical method, that can be recognized objectively.

We found that the Q_{D*} value we derived is about one order of magnitude smaller than that of the previous work (Benz and Asphaug 1999). This means collisions between planetesimals or a planetesimal and a protoplanet are more destructive than before.

In the case of collisions with impact energy less than Q_{D*}, contrary to the expectation of Kobayashi and Tanaka 2009, the total mass of fragments is not linear with the impact energy due to the curvature of the target. On the other hand, in the case of collisions with very low impact energy, the effect of the curvature is so slight that the total mass of fragments is linear with the impact energy. Considering these two facts, the fragmentation model can be built on such a small scale.

Moreover, since we improved the existing SPH code, it became possible to evaluate the collisions where the not gravity but material strength is dominant; the size of target is less than 1km-diameter. Then, we are going to show this result.

Keywords: planet formation, fragmentation, planetesimals