Collision Simulations of Compressed Icy Dust Aggregates: Probing the Sticking-Bouncing Boundary

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Understanding the collisional evolution of dust aggregates is crucial for unravelling planetesimal formation. Recent millimeter-wave polarimetric observations suggest the existence of relatively compact icy dust aggregates (e.g., Zhang et al. 2023). Compact dust aggregates not only stick or fragment upon collision but also bounce (e.g., Güttler et al. 2010). Some previous simulations have shown that the bouncing collisions have a significant effect on dust growth in protoplanetary disks (e.g., Zsom et al. 2010; Dominik & Dullemond 2024).

However, the conditions under which bouncing occurs are not well understood. Previous experiments with SiO_2 aggregates (e.g., Kothe et al. 2013) or icy aggregates (e.g., Schräpler et al. 2022) have shown that larger aggregates are more likely to bounce at lower velocities. In contrast, previous collision simulations of icy dust aggregates have indicated that larger aggregates are more likely to bounce, but do not show a significant velocity dependence (Arakawa et al. 2023).

In this study, we performed a suite of collision simulations of moderately compact icy dust aggregates with various impact velocities, aggregate radii, and filling factors between 0.4–0.5 (Oshiro et al. 2025). Unlike previous simulations, we generate compact aggregates by compressing fluffy aggregates — known as ballistic cluster-cluster aggregates (BCCAs) — mimicking the natural process through which compact aggregates form. Icy particles in the aggregates are treated as adhesive elastic spheres, and we solve the equations of motion for all constituent particles (Wada et al. 2007).

As a result, we confirm that for compressed BCCA aggregates, the mass threshold for bouncing depends on the impact velocity for all tested filling factors, in qualitative agreement with previous experiments. We also find that the threshold aggregate mass for bouncing decreases sharply with increasing the aggregate filling factor. An energy analysis reveals that approximately 90% of the initial impact energy is dissipated during the collision, resulting in a restitution coefficient of about 0.1.

Using our results from collision simulations, we estimate the effect of the bouncing barrier on dust growth in protoplanetary disks. Dust aggregates stop growing at sizes of the order of 100 μm, almost independently of other factors such as radial distance from the central star or gas surface density. This value is in agreement with millimeter-wave polarimetric observations (Kataoka et al. 2015). Although bouncing-limited aggregates are too small to trigger the streaming instability (Lim et al. 2025), their concentration within the smallest turbulent eddies can still lead to planetesimal formation (Cuzzi et al. 2001).