A theoretical model for the collisional sticking probability of cosmic dust aggregates

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In protoplanetary disks, pairwise collisional growth of dust aggregates composed of submicron-sized grains is a key process that ultimately leads to planet formation. Understanding collisional outcomes is therefore essential, and the collisional behavior of dust aggregates has been investigated through both laboratory experiments (e.g., Blum & Wurm 2008) and numerical simulations (e.g., Arakawa et al. 2023; Oshiro et al. 2025). Low-velocity collisions can result in bouncing rather than sticking under certain conditions. As bouncing may limit dust growth in protoplanetary disks, quantifying the threshold between sticking and bouncing is crucial for understanding pathways to planet formation.

Here we propose a semi-analytic model for the sticking probability in collisions between spherical dust aggregates. Arakawa et al. (2024) showed that the collisional compression of dust aggregates can be modeled using elastoplastic spheres. Assuming that the energy required to separate two aggregates in contact is governed by a weakest-link model (e.g., Weibull 1939), we derive the sticking probability and the coefficient of restitution as functions of collision velocity, aggregate radius, and volume filling factor. We demonstrate that the model reproduces the numerical results of Oshiro et al. (2025). Furthermore, the model predicts a threshold velocity for bouncing of ~ 0.1–1 m/s for (sub)mm-sized aggregates with volume filling factors of 20%. This prediction is broadly consistent with aggregate sizes and filling factors inferred from astronomical observations (e.g., Ueda et al. 2024). In this presentation, we summarize the essence of the model and discuss several astronomical applications.