Early Stages of Planetesimal Formation in Microgravity Experiments

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Abstract
The formation of planetesimals in the protoplanetary disk begins with accretion of micron-sized particles into cm-scale objects. These so-called “pebbles” then must find a way to accrete into the km-scale planetesimals. Planetesimals grow into planets through their mutual gravitational attraction, while pebbles are too small for gravity to allow pairs to accrete and too large for electrostatic forces to strongly bind them together. Pebble accretion into planetesimals likely involves collective effects allowing for gravitational instabilities. We have carried out a series of experiments on various microgravity platforms to study the outcomes of collisions of sub-cm particles with each other and with dust particles. We present here an overview of our results which show weakly bound aggregates at very low collision velocities (< 1 cm/s) and accretion of dust onto larger objects at collision velocities ~ 10 cm/s, depending on the collisional environment.

Impacts Into Regolith and Mass Transfer
The COLLIDE (Collisions Into Dust Experiment) and PRIME (Physics of Regolith Impacts in Microgravity Experiment) on orbital and suborbital platforms and on parabolic airplane flights perform impacts of cm-scale projectiles into a 2-cm-deep bed of simulated planetary regolith at speeds below 1 m/s in microgravity. Outcomes of these impacts include (1) ejecta production, (2) rebound of impactor, (3) adhesion of impactor to target regolith bed, and (4) transfer of regolith particles to the surface of the impactor. Outcomes 1 and 3 can occur in the same impact, and outcomes 1, 2, and 4 can occur in any combination. In order to better study mass transfer events (outcome 4), we developed a small, laboratory-drop-tower-based experiment. The short duration of the drop prevents a full impact and rebound, so we begin with the projectile already in contact with the target surface and pull it away from the surface with a spring once the experiment is in free-fall. While this configuration produced mass transfer events, an analysis of the various factors affecting collisional outcomes indicate that the initial impact compression of the target material, only achievable in longer-duration microgravity flights, is a strong contributor to producing these accretion events (Jarmak et al. 2019, Figure 1).

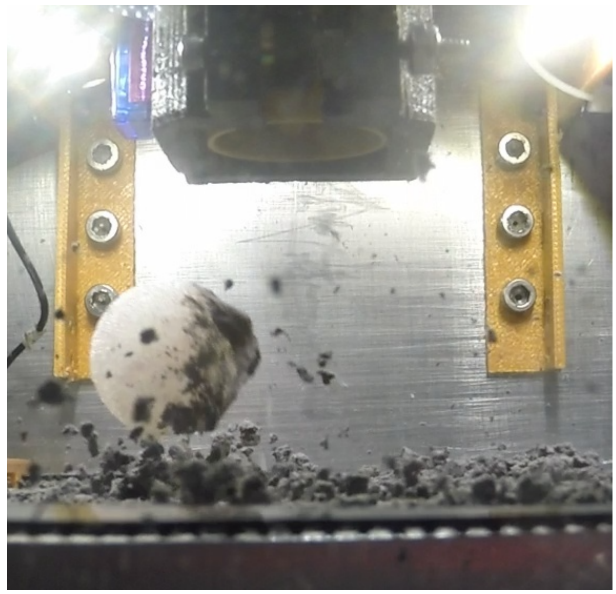

Figure 1: This still frame from a parabolic flight experiment shows a mass transfer event between a 10 g coated quartz marble and simulated Orgueil meteoritic material with a size range of 125-250 µm.

Summary and Next Steps
Long-duration and low-noise-level microgravity environments provided on suborbital, orbital, and free-floating parabolic platforms have shown the possibility of significant mass transfer between particles in a collisional environment. Laboratory-based experiments support these results, but more data in long-duration platforms are needed. We will present our results obtained so far and identify the highest-priority next steps for experiments and simulations.

References
Jarmak, S. G. et al. 2019. DPS Meeting, Geneva, Switzerland.