Accretion of proto-planetesimals through microgravity collisions of dust aggregates.

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Introduction: Proto-planetesimals forming in the early disk have obstacles to overcome if they are to accrete into planets and must do so quickly [1]. Collisions between these bodies may play an important role in determining whether or not growth or disruption occurs depending on a number of definable collision parameters [2], [3]. Van der Waal's forces are much more dominant than self-gravity in these size regimes and could play a major role in the early formation stages of aggregates [4]. We are characterizing the strengths, properties, and outcomes of centimeter sized clusters of aggregates with collisions in numerous free-fall experiments. Experimental constraints on material properties, aggregates properties, and collision parameters will lead to more informed formation models since almost no observational data exists.

Experiment: Based on input from solar nebula models a laboratory-based microgravity dust collision experiment was developed for a drop tower at the Technische Universität Braunschweig, Germany. Using two high-speed (1000 fps) cameras in stereo and in free-fall with the center of mass of the projectile and target we can easily track particles and outcomes with tracking software. We collided 1.0 – 1.6 mm dust aggregates with clusters of these aggregates at a range of velocities and mass ratios. The aggregates were created by sieving 0.5-10 µm SiO_2 dust, and the free-fall occurs in a reasonable vacuum of ~0.1 mbar. The average mass of a projectile is 2.2 mg for 1 mm aggregates, and 0.5 mg for the 800 µm aggregates. In Figure 1 are both a SEM picture of the dust and an image of the aggregates after sieving [5]. These aggregates are placed in a cup and dropped (Figure 2), but are only held together by their collective sum of surface forces (van der Waal's). We analyze the results of 264 microgravity collisions occurring at velocities of 1 – 160 cm/s with target-impactor mass ratios of 5:1 to 400:1 and using two aggregate sizes (800 µm, 1 mm).

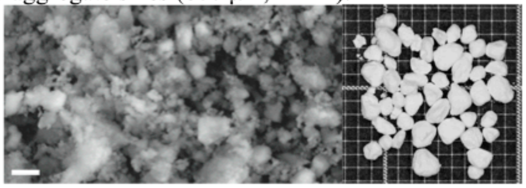

Fig. 1 (left) Poly-dispersed SiO_2 (0.5-10 µm) scale bar is 2 microns [5], (right) which is sieved into aggregates of 1-2 mm (1 mm gridlines).

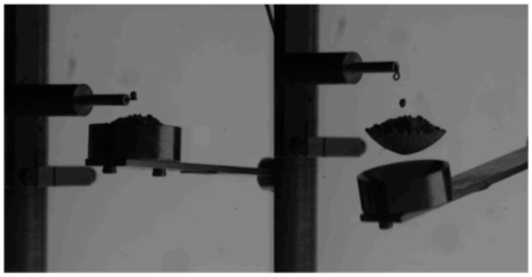

Fig. 2 Experimental apparatus set-up, (left) the upper solenoid releases a single aggregate to strike (right) the cluster released from the lower solenoid with a timed delay to set the impact velocity. For scale the cup is 2.5 cm across horizontally, and the falling aggregate's diameter is 1 mm.

Results: The free-fall experiments were conducted in a vacuum but the residual atmosphere caused air drag, which became significant when much smaller mass ratios were used. This effect worsened substantially when we switched to the 800µm aggregate size, particularly for target-impactor ratios of 5:1 – 10:1. As such we were unable to obtain results for this mass range, however, the remaining sets of data are indeed quite usable. From the 264 drops about 20-30% of them have usable rebound trajectories of the projectile giving us the coefficient of restitution (CoR). Although the drop tower's free-fall time is only ~0.5 seconds with a 1000 fps camera we get about 500 frames which is enough in most cases to see a definitive result (sticking, fragmenting). A large number of the low-velocity collisions resulted in sticking between the target and impactor. Nearly all of the high-energy impacts disrupted or fragmented the target.

Coefficient of restitution. The energy lost in a collision due to heat, separation of surface and chemical bonds, changes in internal structure, induced spin or motion; the CoR is a crude but real gauge of the material, dynamical, and physical properties effecting the outcome of collisions. Our focus is accretion, so we wish to understand if it is possible to have a high enough sticking efficiency to lead to accretion for our chosen particle sizes and radii. Figure 3 is the CoR's for roughly 50 of the experiments at various impact speeds up to 1.5 m/s, at these velocities no cluster can remain intact, heavy fragmentation is probable, but large fragments can survive in all but the most devastating impacts.

Sticking and fragmentation thresholds. In nearly all experiments obtaining a clear result was possible, and they were grouped for simplicity into three main categories: sticking, bouncing, and mass loss. Figure 4 shows the outcomes of the collisions color and symbol coded for clarity. Mass loss represents outcomes including: erosion of the target, fragmentation, and any other outcome that resulted in the target losing mass after impact.

Discussion: We present the coefficient of restitutions and sticking thresholds for low-velocity collisions and we will also present the comparison of the impact energies to the specific collision energy of fragmentation Q* for aggregates of this size. The results indicate that the outcomes of the collisions have a heavy dependence on the mass ratios of the target cluster and projectile. We find sticking occurs at mass ratios larger than 40:1, but only for low velocities ≤ 3 cm/s, clear boundaries exist for bouncing up to 30 cm/s, and fragmentation at ~50 cm/s and up, with total disruption occurring above 1.5 m/s. In this collisional accretion experiment we see fragmentation of the cluster at any velocity is possible depending on the mass ratio. Since the strength of the cluster essentially scales inversely with μ, growth by collisions to sizes beyond 5 – 10 mm might require very low velocities during this stage of formation.

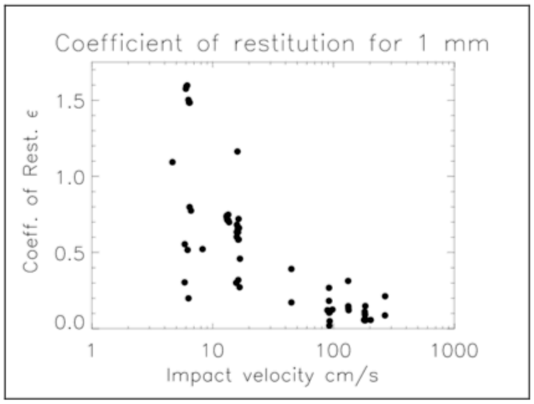

Fig. 3 Coefficients of restitutions for collisions where a rebound occurred for the 1 mm aggregates only. Higher than 1 is possible due to added rotational energy caused by release of projectile by the solenoid-controlled launcher.

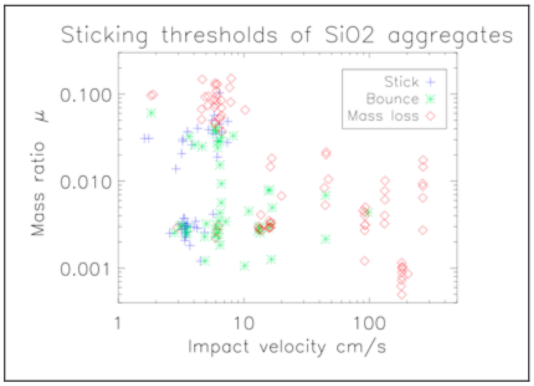

Fig. 4 The sticking and fragmentation thresholds for the 1mm aggregate collisions. Blue pluses indicate sticking, red diamonds represent mass loss (fragmentation, disruption, erosion etc.). Green asterisks indicate bouncing has occurred.

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