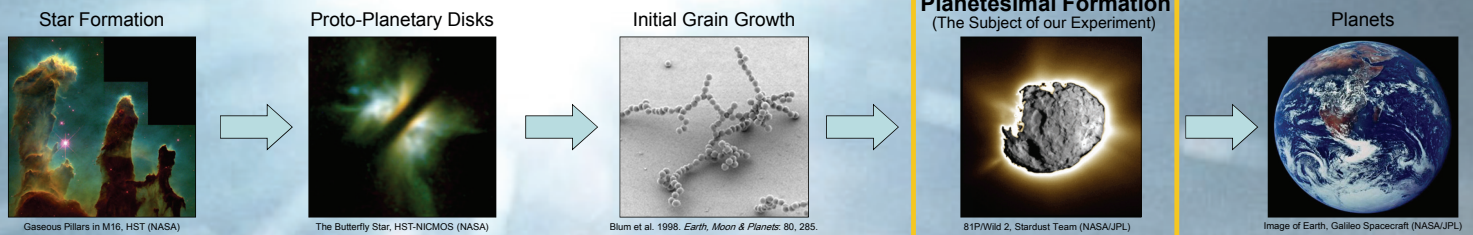


Microgravity Experiments Probing Collision Processes in the Solar Nebula

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Abstract

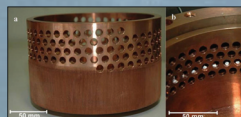
We present results from our microgravity experiment to study particle collisions in the solar nebula during the European Space Agency's 45th Parabolic Flight Campaign. Specifically, we investigate the impact behavior at ambient temperatures of dust aggregates (assembled from 1.5 μm SiO_2 spheres) that measure 0.2-6 mm across, are 85% porous, and possess velocities of 16-18 cm/s. These properties roughly simulate grains in the proto-planetary disk that are initially supported by turbulent gas, but as they grow to centimeter sizes begin to settle to the midplane. Throughout this period, the play between sticking probability, fragmentation efficiency, mass exchange, and compaction behavior

during encounters will help shape disk lifetime and the effectiveness of planet formation via grain growth. Using a vacuum chamber setup during parabolic flight, we began by firing individual agglomerates at a large target of similar, but denser dust structure. We followed with individual aggregate on aggregate collisions. We recorded over 100 separate impacts at 107 frames per second during 33 minutes of combined weightlessness. In this initial run, we observed a very low sticking probability ($\sim 10\%$), and only with very small agglomerates against a large target. Semi-elastic collisions appear to dominate all encounters ($\sim 80\text{-}90\%$) with occasional fragmentation observed.

Experiment Setup



ESA's 45th Parabolic Flight Campaign
Bordeaux, France (Oct 2006)



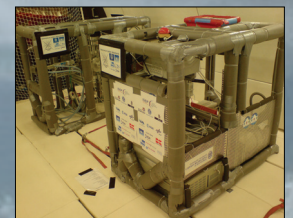
A rotating storage device (a), with particles (b) loaded in individual, and 180° opposite, compartments.



Hydraulic pistons accelerate the particles toward the center of the vacuum chamber where the collisions are captured on video.



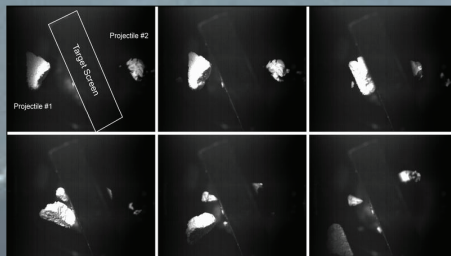
The central target with the two particle guiding tubes located in the center of the chamber.



On board: The experiment rack (back) and the support rack (front).

Recorded Image Sequences

Frames showing aggregate and target collisions. Left of target, a fragmentation; right, a semi-elastic collision.

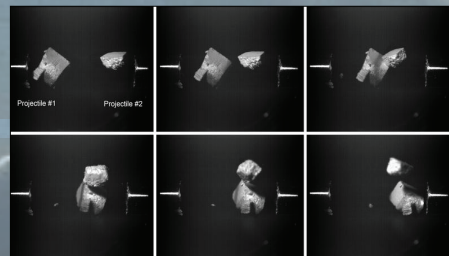


Vacuum chamber (0.3 mbar)

Ambient temperatures (300K)

Low velocities (16-18 cm/s)

Time-series of a semi-elastic aggregate on aggregate collision. All frames measure approximately 4 mm across.



High-resolution, 107 fps camera

mm-sized dust agglomerates

Microgravity conditions

Performance: The experiment design was consistent and accurate in firing the dust agglomerates. The deviation of imparted velocities from the intended velocity was small.

Particle trajectories were well constrained by the guiding tubes, and collisions were centered in the field of view. More than 100 separate collision events were observed.

Semi-Elastic Collisions

The majority of collisions (roughly 80-90%) resulted in semi-elastic rebounding events. On average, only 15% of the translational energy is conserved during most events. This is likely due to aggregate compaction—a property that can not be extracted from the video data due to limited resolution ($\sim 20 \mu\text{m}/\text{pix}$, which is about 10-15 mono layers).

Fragmentation

Fragmentation occurred in 10% of the aggregate-aggregate collisions, but played a much smaller role during particle-target impact events. This occurs despite the larger hardness factor due to a higher dust volume filling number for the target ($\sim 76\%$ porous). Instead, the results are likely due to the larger, relative impact velocities for aggregate-aggregate collisions ($\sim 36\text{-}40 \text{ cm/s}$) versus the target impacts ($\sim 16\text{-}22 \text{ cm/s}$), as well as the geometry of the target, which simulates a larger particle that can fracture inside, absorbing additional collision energy without fragmenting.

Sticking

Sticking was observed in 10% of all particle-target collisions, but only when the sticking particles were sub-millimeter-sized fragments. In some aggregate-aggregate collisions, sticking was observed, but in these cases the sticking may be electrostatic in nature; and thus these events warrant further investigation.

Conclusions

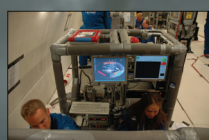
The sticking and fragmentation statistics suggest that we are probing a critical transition region for the collision velocities of dust agglomerates.

- ✓ Small aggregates with relative collision velocities $\leq 16\text{-}22 \text{ cm/s}$ can stick to much larger aggregates.
- ✓ Similarly sized aggregates with relative collision velocities $\geq 36\text{-}40 \text{ cm/s}$ could mark the onset of fragmentation.
- ✓ Relative aggregate sizes are important for constructive versus destructive growth.
- ✓ The majority of fragmentation and sticking events for particle-target events occurred at small impact angles.

We are unable to build planetesimals in the lab yet, but our experimental setup is capable of consistently and accurately launching cold agglomerates for detailed collision studies over a large range of high and low velocities, in order to test theoretical models of planetesimal formation, and approach more realistic simulations.

Future Work

Ground-based fragmentation studies of high velocity (dust and ice) collisions at low temperatures (140-220 K) will be performed in preparation for future flights. Plans for these additional microgravity experiments include low, cryogenic temperature dust studies (80-140 K) followed by the inclusion of water ice at cryogenic temperatures.



For additional information regarding this poster or this project, contact Demereze Salter at:

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Or to view movies taken during the flight, see:

www.strw.leidenuniv.nl/~parabolic