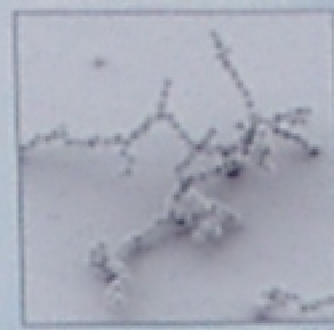
Microgravity Experiments Probing Collision Processes in the Solar Nebula

Demerese Salter (Leiden University, NL), Daniel Heißelmann (TU Braunschweig, GER), Germán Chaparro (Leiden University, NL), Guido van der Wolk (University of Groningen, NL),
Philipp Reißaus (Space Technology & Applications Division, Kayser-Threde GmbH, GER), Helen J. Fraser (Strathclyde University, UK), and Jürgen Blum (TU Braunschweig, GER)

Star Formation

Proto-Planetary Disks

Initial Grain Growth



Planetesimal Formation
(The Subject of our Experiment)

Planets

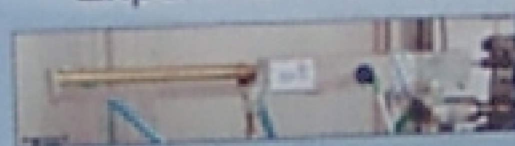
Abstract

We present results from our microgravity experiment to study particle collisions in the solar nebula during the European [illegible] Agency's 45th Parabolic Flight Campaign. Specifically, we [illegible] impact behavior at ambient temperatures of dust [illegible] assembled [illegible] 1.5 µm SiO_2 spheres) that measure 0.2-6 mm across [illegible] possess velocities of 16-18 cm/s. These properties roughly [illegible] proto-planetary disk that are initially supported by turbule[illegible] grow to centimeter sizes begin to settle to the midplane. T[illegible] the play between sticking probability, fragmentation [illegible], 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 (~10%), and only with very small agglomerates against a large target. Semi-elastic collisions appear to dominate all encounters (~80-90%) 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. This
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 (~20 µm/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 (~76% porous). Instead, the results are likely due to the larger, relative impact velocities for aggregate-aggregate collisions (~36-40 cm/s) versus the target impacts (~16-22 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 ≤ 16-22 cm/s can stick to much larger aggregates.
- Similarly sized aggregates with relative collision velocities ≥ 36-40 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.