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Sticking of Dust Aggregates at Low Velocities

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Abstract

We have performed experiments to determine the threshold velocity between sticking and bouncing for millimeter-sized porous dust aggregates. Here, we will present the results of collisions in the relevant velocity regime and its implications on our understanding of the formation of planets.

1 Planet Formation

The formation of planetesimals, the precursors of planets, takes place in disks of gas and dust around young stars. Initially, the (sub-)micrometer-sized dust grains in the disk collide with very low velocities, stick together and form larger, fractal aggregates. As the aggregates grow, they also start to decouple from the gas, which causes them to collide with higher velocities. At first, this leads to restructuring of the collision partners, but at some point it causes the aggregates to bounce off each other instead of sticking together (see review by Blum and Wurm (2008) and references therein).

Over the past years numerous laboratory experiments have been performed to study the outcome of collisions between aggregates of various sizes and with different relative velocities. Güttler et al. (2010) developed a model to predict the outcome of a collision depending on the porosity, mass and velocity of the colliding aggregates, using the results of laboratory experiments as well as theoretical assumptions where no experimental data was available. Based on this, Zsom et al. (2010) ran 1D local box simulations to investigate the largest size to which aggregates can grow according to the model. Their results showed that the dust would only grow to sizes of about a centimeter, but more importantly also revealed the relevance of several combinations of mass and velocity of colliding aggregates for the growth evolution that had not been studied experimentally yet. One example are millimeter-sized aggregates with a mass of about 10^{-4} g that collide with approximately 1 mm s^{-1}. The growth model predicted aggregates colliding with a velocity slower than this to stick to each other, while faster aggregates were assumed to bounce.

2 Experimental setup

To reach the required collision velocities, we introduce an ensemble of dust aggregates into a vacuum chamber. Under microgravity conditions, they move randomly through this chamber, undisturbed by accelerations, but are slowed down due to repeated inelastic collisions. For further details on the experimental setup, see the talk "Free Collisions at Low Velocities" by Weidling et al.

3 Results

We have analyzed three experiments, one with 0.5 to 1.5 mm and two with 1.0 to 2.0 mm diameter dust aggregates so far (Weidling et al., 2011). They were part of the experiments conducted in the Drop Tower in Bremen in June 2010, where we examined different aggregate sizes and properties in a total of 40 experiments.

Here, we will present the collisional properties of 125 single collisions with relative velocities between 2 mm s^{-1} and 2 m s^{-1}. Seven of the collisions between the smaller aggregates led to sticking of the aggregates, which we could observe for the first time for millimeter-sized aggregates under controlled conditions (see Fig. 1). While in one case one of the smaller aggregates fragmented at 1.7 m s^{-1}, all the other collisions that we observed led to bouncing.

We will introduce a transition regime between perfect sticking and perfect bouncing, as the velocities at which aggregates stuck together scatter over more than one order of magnitude. To determine the velocities enclosing the transition zone, we adapt a collision model by Thornton and Ning (1998) for our aggregates by accounting for the porosity of the aggregates and the nature of the monomers it consists of. Finally, we

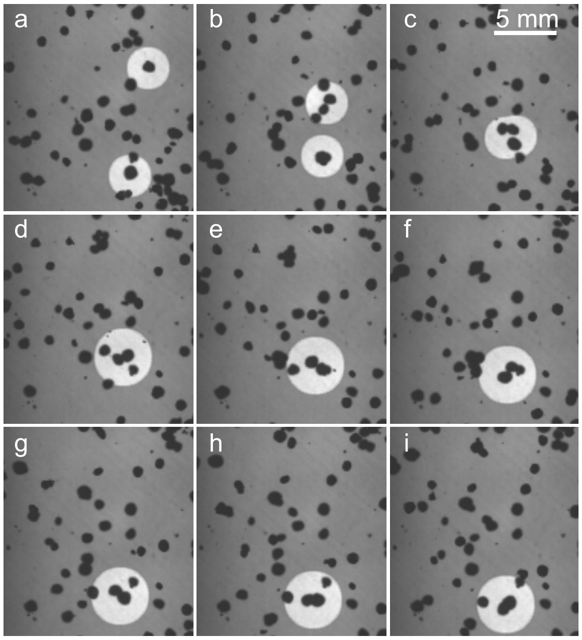

Figure 1: Image sequence of a collision between two dust aggregates with a relative velocity of 9 mm s^{-1} leading to sticking. The time between the images is 0.4s.

will discuss the implications of the results on the collision model.

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