Abrasion of cm-sized dust agglomerates -

a source of small dust agglomerates in the protoplanetary disk

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1. The experiment

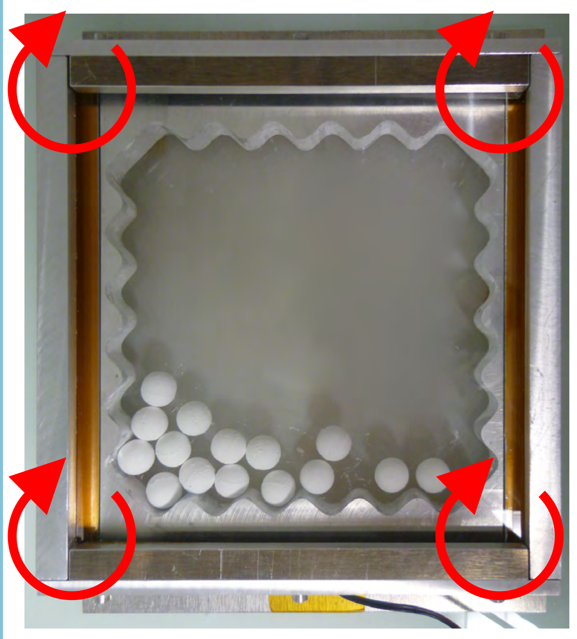

Figure 1: Image of the particle chamber prior to the flight a flight. The arrows illustrate the direction of the shaking.

The objective of this experiment is to study multiple bouncing collisions between cm-sized dust agglomerates. Bouncing collisions occur at velocities considerably below 1 m/s. In order to achieve low collision velocities, the experiment was conducted on a parabolic flight on 15 consecutive parabolas.

The agglomerates were pressed in a mold out of a silicate powder whose constituent grains were spherical with 1.5 µm diameter. The diameter, mass and volume filling factor of the agglomerates were 1.26 ± 0.04 cm, 1.06±0.04 g, and $\Phi = 0.53 \pm 0.04$.

15 agglomerates were placed in an evacuated chamber, which was rotated in order to generate collisions among the particles (see Figure 1). In order to study the influence of the collision velocities, the shaker frequency was increased over time so that the collision speed increased from 6 cm/s to 18 cm/s. The experiment was recorded in background illumination by a high-speed camera. Before it was possible to track individual particles or to analyze the evolution of their size, it was necessary to compensate the progressive pollution of the experiment chambers windows by image corrections.

2. Abrasion

Figure 2 shows the evolution of the average agglomerate size during the 13 parabolas at which the agglomerates were shaken. The colors at the bottom of the figure indicate the maximum velocity of the shaker in each setting, which corresponds to the typical collision velocities between the agglomerates (collisions between the agglomerates and the walls are typically 50% faster).

While the radius of the agglomerates stays constant for the first settings, their size decreases as soon as the shaker was in setting 3. However, these velocities were well below the fragmentation threshold velocity. Furthermore, it was not possible to identify a clear mass loss in individual collisions. Thus, we assume that this effect is an abrasive form of fragmentation, which occurs at considerably lower velocities than usual fragmentation.

In order to calculate the onset velocity of this effect, we measured the radius loss rate dr/dt and used the previously determined collision rate to estimate a radius loss per collision. A mass loss was found for the two fastest shaker setting. Based on these two velocities, we linearly extrapolated that abrasion starts at 12.3 cm/s collision velocity.

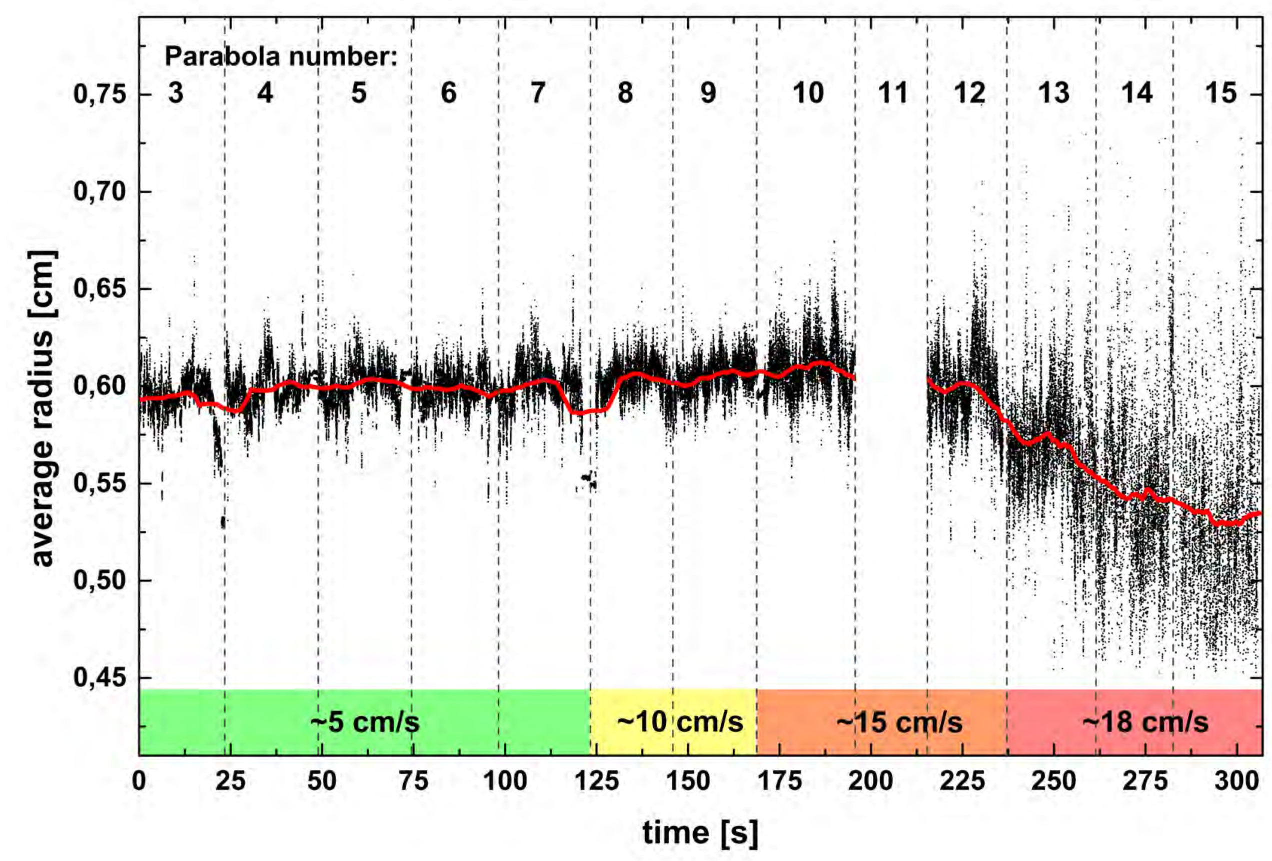

Figure 2: Evolution of the average agglomerate radius. The color bars at the bottom indicate the four different shaker settings and the red curve represents the moving average of the data points. The scattering during the last parabolas is caused by the increasing pollution of the windows, which could not be compensated entirely.

3. Discussion

Theoretical models and simulations have shown that the growth of planetesimals can be prohibited by various effects.

One of these obstacles is the so called “bouncing barrier”. The yellow areas of the parameter plots in Figures 3 and 4 indicate the regime in which agglomerates do no longer stick at each other. Growth simulations have shown that particles can grow up to this size where further mass gain is prohibited by bouncing. Typical time scales on which this size is reached are on the order of a few thousand years (e.g. Zsom et al. 2010) or even faster. Abrasion might be an effect that helps to overcome this barrier by producing fragments, which can add to the growth process again.

To assess the importance of this effect, an abrasion time scale has to be estimated. If reaccretion of dust is neglected, this can be done by numerically solving Smoluchowski's equation, assuming a monodisperse mass distribution of the agglomerates and an abrasion that can be described by a power law, similar to the onset of fragmentation. In the absence of better knowledge, we assume that the strength of abrasion is linear between its onset and a maximum value, which is reached just before the agglomerates fragment. The velocities were calculated for three different nebula models. The solution is only applicable in the abrasion regime. The calculated time scales $t_{1/2}$ on which the dust agglomerate size would be reduced by a factor of two are between 16000 and 22000 years, and thus considerably longer than the time in which these agglomerates were formed.

While these calculation neglects further growth of the agglomerates, the time scales illustrate that the fragments, which are produced during this process, might form new agglomerates by direct sticking (e.g. Kothe et al. 2013) or add to the larger agglomerates by mass transfer (e.g. Meisner et al. 2014). These potential growth paths are indicated in Figure 4.

The small dust fragments might also be a source of small dust grains, which are observed in the spectral energy distribution of protoplanetary disks (e.g. Testi et al. 2014). This effects adds to the common explanation that these grains are replenished by the fragmentation of agglomerates and lifted into the atmosphere of the disks by turbulence.

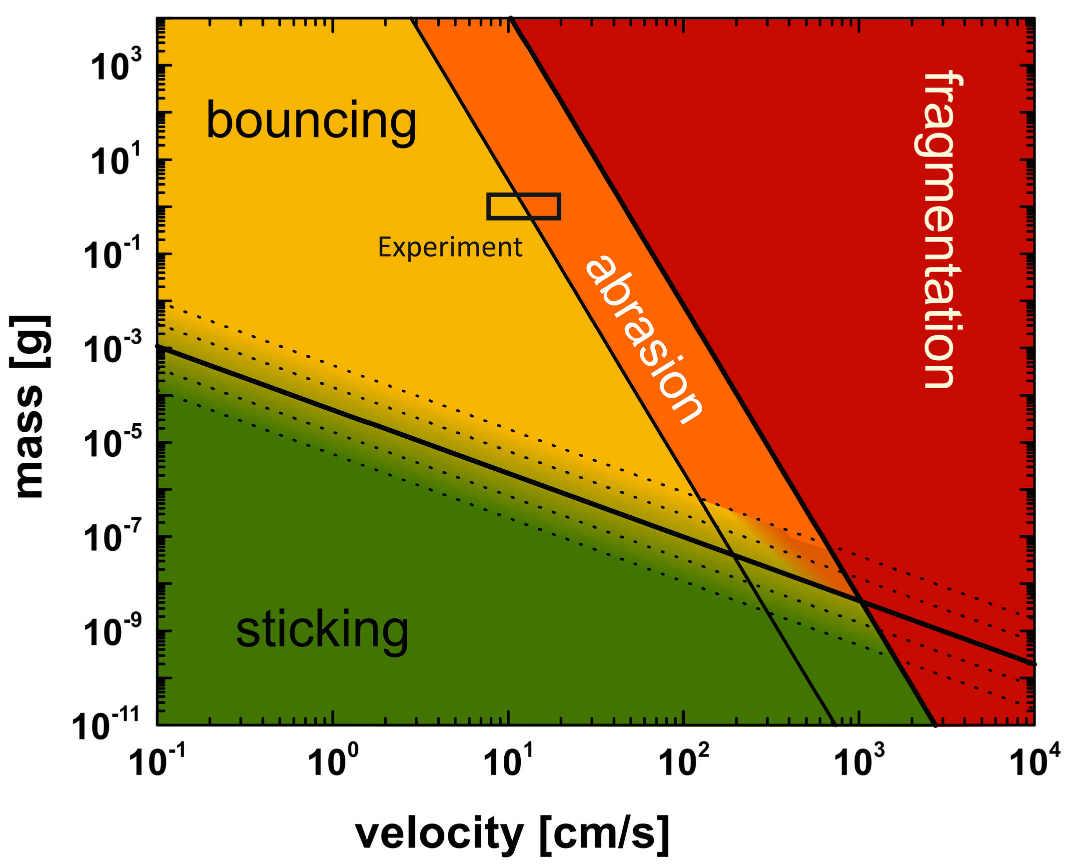

Figure 3: Experiment based collision model for porous dust agglomerates ($\Phi \approx 0.3$-0.5). The model predicts the outcome of collisions between equal sized agglomerates and originally distinguished between sticking, bouncing, and fragmentation (Güttler et al., 2010). Kothe et al. (2013) introduced a transition regime between sticking and bouncing. Based on the results of this work, abrasion was added to the model (Kothe et al., in prep. a). The power law has been adopted from the fragmentation threshold (Windmark et al., 2012a, Kothe et al., in prep. b).

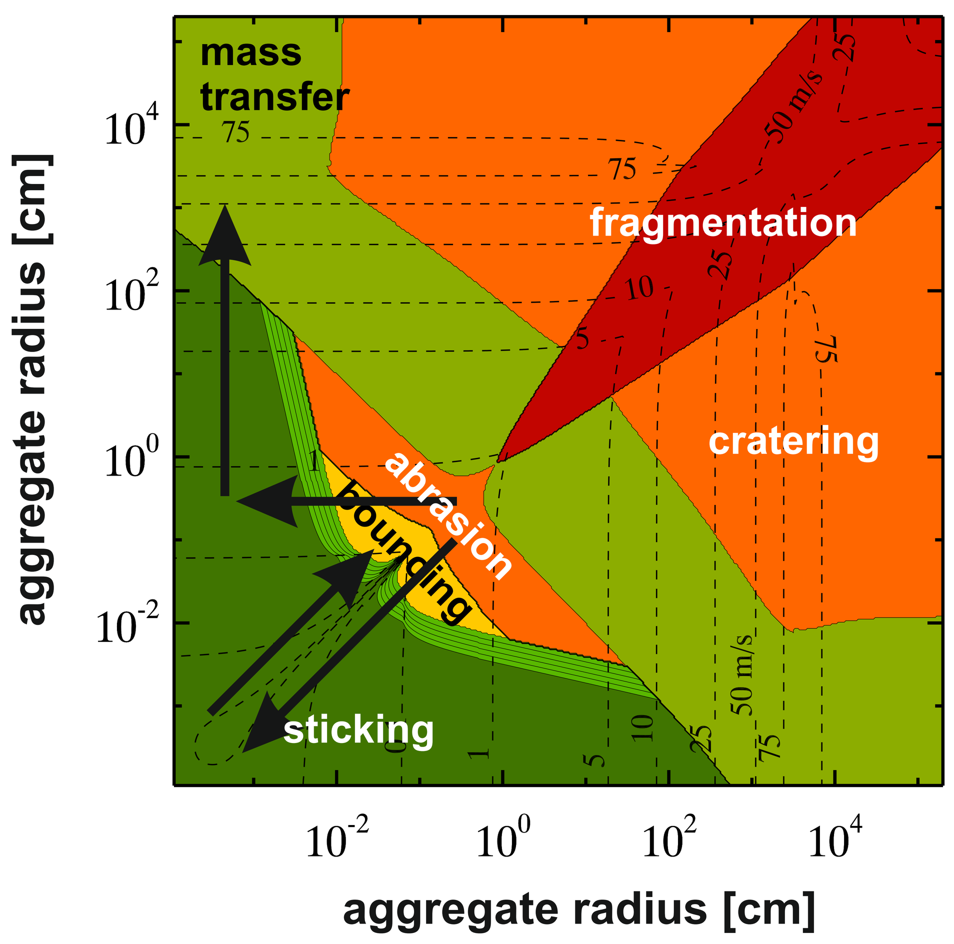

Figure 4: Collision model for collision partners with arbitrary size ratio. The underlying collision velocities are based on the minimum mass solar nebula model (Weidenschilling. 1977). To predict the outcome of the collisions between different sized agglomerates, we look at the collisions in their center of mass frame and calculate the outcome for each collision patner(see Windmark et al., 2013a).

References

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