Collision Dynamics of Decimetre Dust

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Introduction

Planets form in protoplanetary discs by accretion of km-sized objects, the planetesimals. The growth process of the planetesimals is not yet understood entirely. They grow from smaller dust particles, but gravity is not an important factor for individual particle interaction, as particles size and mass are still small. The models that try to describe planetesimal growth can roughly be divided into two main groups. One group describes growth by coagulation of particles through mutual collisions. However, bouncing and fragmentation might prevent further growth. Another group considers gravitational instabilities in areas of high particles densities, which can be generated in different ways, e.g. by the streaming instability (Johansen et al. 2007). Decimetre bodies are important for both groups of models. They are direct precursors to metre-sized bodies and are therefore relevant for coagulation models. Especially the threshold between bouncing and fragmentation is of interest. But they are also relevant for the second group of models, as they can easily be trapped in vortices where critical particle densities can lead to gravitational instability. We carried out collision experiments under microgravity conditions in the Bremen drop tower.

Experiment

Sample Preparation

The agglomerates are produced by pressing quartz powder into an aluminium mould. The quartz powder consists of irregular grains mainly in the size range between 1 and 5 µm. The cylindrical agglomerates have a height and diameter of 12 cm, a mean volume filling factor of about 0.44 and a mass of little over 1.5 kg.

Figure 1: Press with dust agglomerate

Experimental Setup

Experiments are carried out in the Bremen drop tower, which provides microgravity conditions ($\leq 10^{-6}$ g) for 4.7s. The experimental setup (see Fig. 2) is placed into a vacuum chamber ($p \leq 10^{-2}$ mbar). The dust agglomerates are placed on sample mounts. This setup is as close as possible to the collision geometry of spheres. When microgravity conditions are reached, the sample mounts are pulled down and the agglomerates are free. Then the agglomerates are accelerated by pistons. The collisions are observed by two perpendicular high-speed cameras (at 500 fps). An LED-system illuminates the collisions.

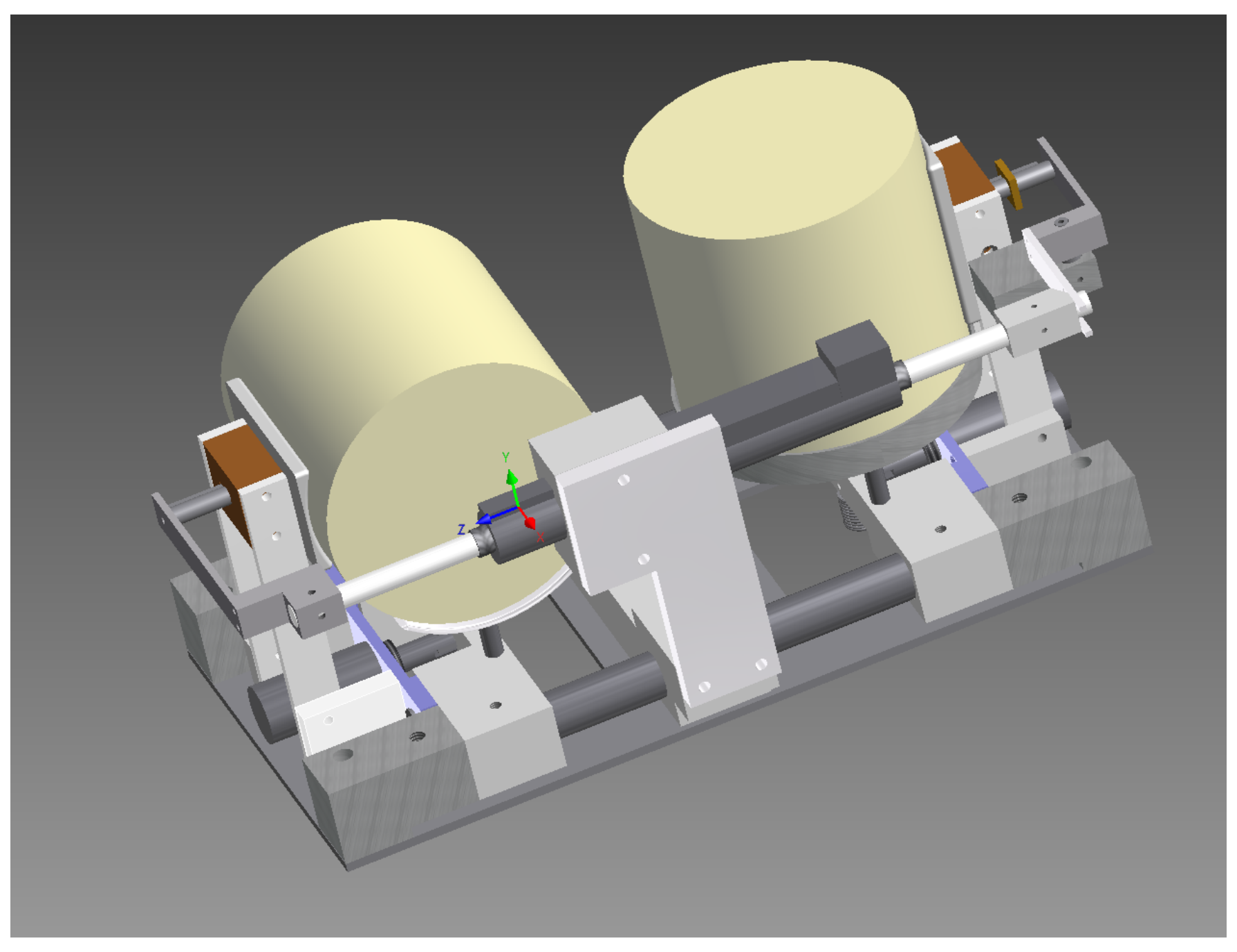
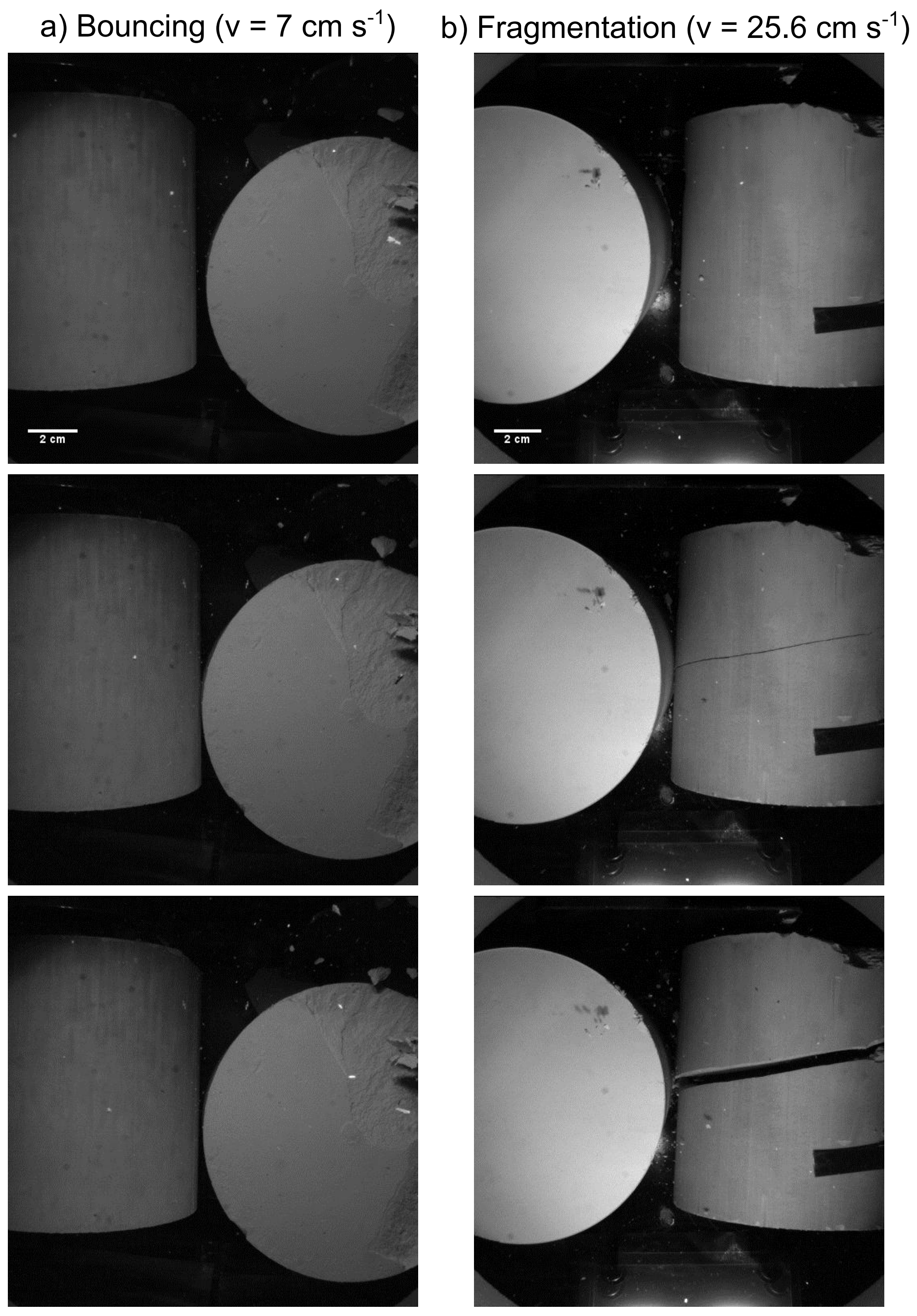


Figure 2: Experimental Setup (Deckers and Teiser 2013)

Results and Discussion



a) Bouncing (v = 7 cm s^{-1}) b) Fragmentation (v = 25.6 cm s^{-1})

Figure 3: Example for a bouncing and a fragmenting collision (Deckers and Teiser 2013)

Critical Fragmentation Velocity

The linear and rotational motion are derived from the images of both cameras. The kinetic energy of an agglomerate is defined as $E_{kin} = 1/2\ (m v^2 + I_x^2 \omega_x^2 + I_y^2 \omega_y^2)$, with the two moments of inertia around perpendicular axes I_x and I_y. The error of the kinetic energy is calculated using the method of error propagation. The threshold between bouncing and fragmentation lies at a kinetic energy of 15.7 mJ (the collision velocity v lies at 16.2 cm s^{-1}), this corresponds to a specific kinetic energy of 5 mJ kg^{-1}.

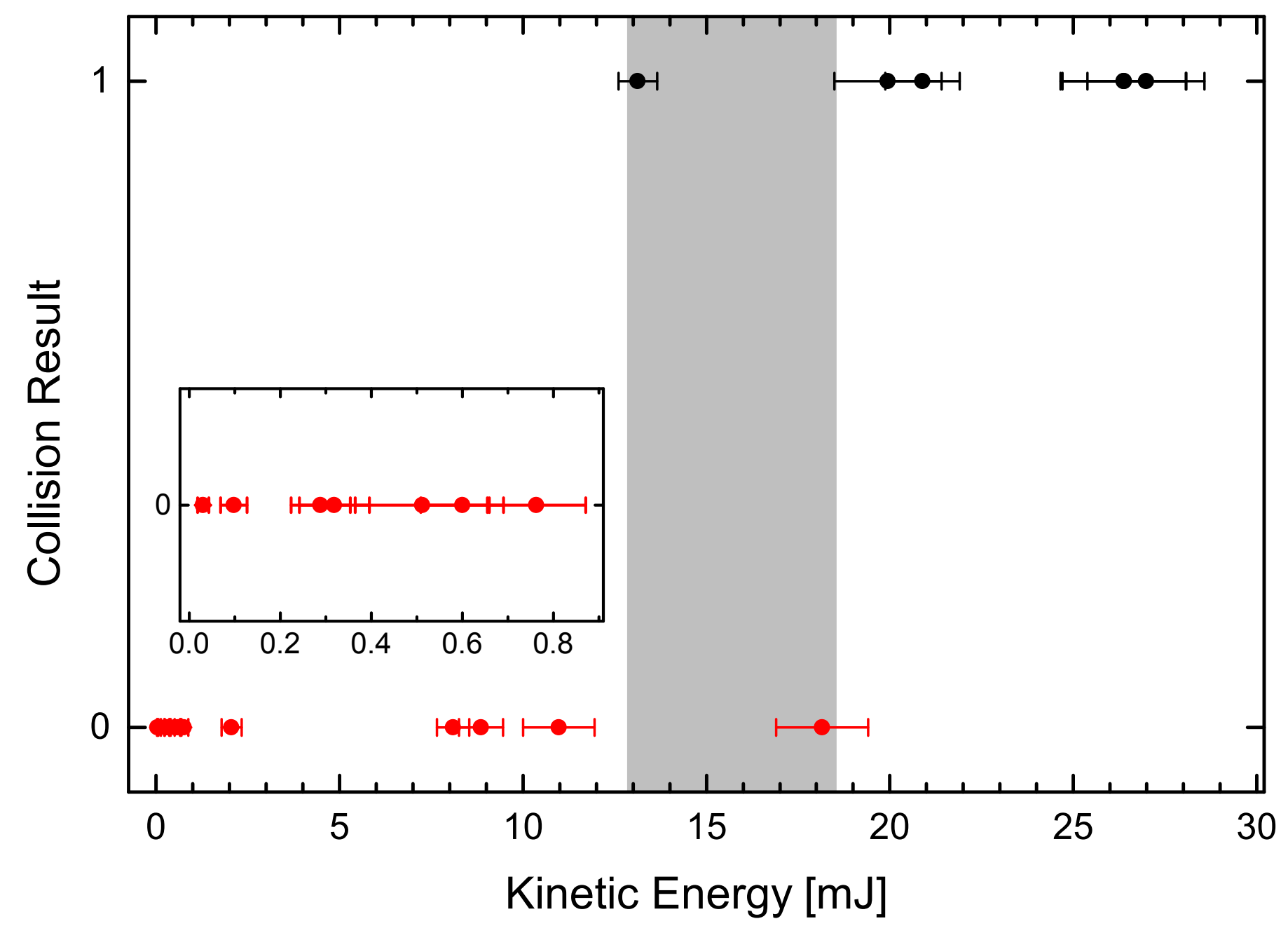


Figure 4: Results of the collisions (bouncing = 0, fragmentation = 1, Deckers and Teiser 2013)

Coeffecient of Restitution

The coefficient of restitution e is here defined by the ratio of the kinetic energy after and before the collision. In this way the rotational movement of the agglomerates is included into the calculation. The coefficient of restitution decreases with increasing collision energy. Schräpler et al. (2012) predict a power law for the dependency of e on the collision velocity, according to a solid state model by Thornton & Ning (1998). This power law is shown in Fig. 5 (blue dashed line).

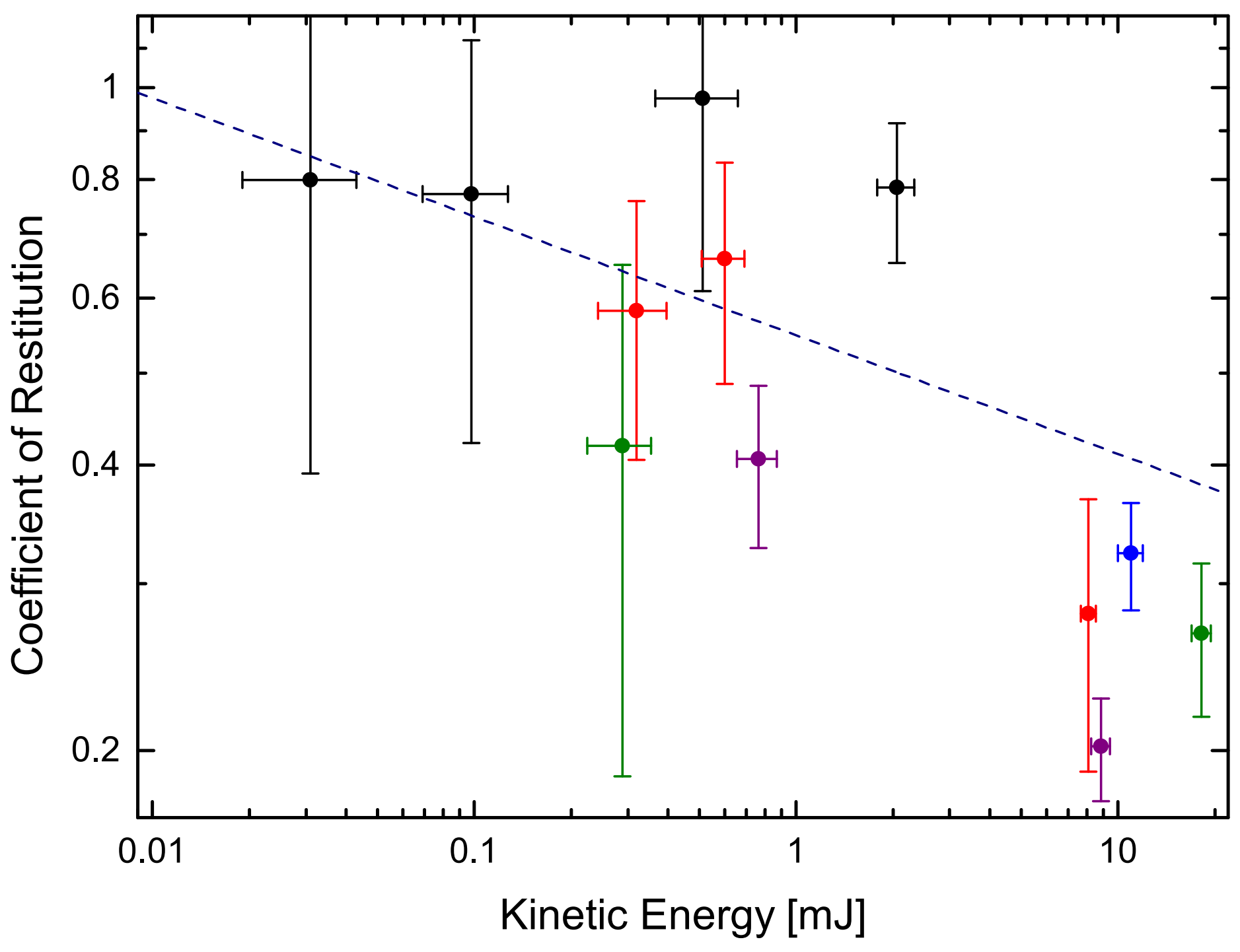


Figure 5: Coefficient of Restitution (same symbols = multiple collisions, Deckers and Teiser 2013)

Astrophysical Applications

Protoplanetary Discs:

The threshold velocity of 16.2 cm s^{-1} is much lower than the collision velocity for mutual collisions expected in protoplanetary discs (around 10 m s^{-1}). This means that decimetre bodies are destroyed in mutual collisions and smaller fragments are likely produced. Observations show the presence of these small dust grains in protoplanetary discs. Aggregates might still grow by sweeping up the small fragments.

Planetary rings:

Particles in ring systems mainly consist of water ice. Although the physical properties of water ice and dust differ significantly, the coefficient of restitution is mainly determined by the surface properties, that means regolith covered ice particles (common in ring systems) and dust agglomerates have a similar coefficient of restitution. Furthermore, the collision velocities in ring system are in the same range investigated in our experiments.

References

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Acknowledgements

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