The Bouncing Barrier in Protoplanetary Discs: Experimental Studies

Thorben Kelling, Marc Köster and Gerhard Wurm

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ABSTRACT

For dust aggregates in protoplanetary discs a transition between sticking and bouncing in individual collisions at mm to cm size has been observed in the past. This points to a notion of a bouncing barrier for which no net growth was found. This is a perfect demonstration of a bouncing barrier, though in our experiments it would need with the corresponding collision velocities. A value above one indicates sticking while for values below one no statement about sticking and bouncing can be given.

RESULTS/CONCLUSION

We study a total of over half a million collisions for 100 aggregates or 1000 collisions per mm-aggregate in the mm to cm regime. We find sticking and detachment but no large aggregate that survived for long. The overall trend is and no net growth was found. This is a perfect demonstration of a bouncing barrier though in our experiments it might be better called a detachment barrier.

The aggregates are levitated by a Knudsen compressor effect over the heater and the slightly concave experimental platform. Aggregates are heated from below and cooled on their top: There is a thermal gradient over the particles. Knudsen 1900 found that gas creeps along a micro-tube with thermal gradients from cold to warm. On the outlet of the micro-tube an overpressure is created (Knudsen compressor effect). Dust aggregates have pores and act as collection of micro-tubes. Overpressures below the aggregates let them hover.

Munzt et al. 2002 found that the overpressure at intermediate Knudsen numbers is 

\[ \Delta P = \left( \frac{m}{2 \pi k T} \right)^{1/2} \alpha \frac{2 \pi D}{c} \]

\[ \text{(Knudsen compressor effect)} \]

As a result of the experimental observation, the aggregates are visualized in the high speed recording phase with 200 fps which allows the tracking and analysis of individual aggregates and collisions and a long term recording phase where every 3 seconds the ensemble is recorded for 960 seconds in total. This allows to track the evolution of the aggregate ensemble.

Random motions of the aggregates with the mm are visible and collisions are frequent. The nozzle is used to excite the ensemble resulting up to several cm/s translation velocities. The experiment is split in two phases: A high speed recording phase with 200 fps which allows the tracking and analysis of individual aggregates and collisions and a long term recording phase where every 3 seconds the ensemble is recorded for 960 seconds in total. This allows to track the evolution of the aggregate ensemble.

EXPERIMENTAL PARAMETERS

- Size distribution of the aggregates (two equivalent radii).
- Translation velocity distribution of the aggregates with (light grey, solid) and without excitation (dark grey, solid). The translation velocity is determined from frame
- Collision velocity distribution without excitation. A negative velocity means that the two aggregates move away from each other but collide due to rotation.
- Collision velocity distribution with excitation. A negative velocity means that the two aggregates move away from each other but collide due to rotation.

DERIVED PARAMETERS

- Distribution of the lifetimes (particles visually in contact) of grown aggregates (highspeed recording phase, no excitation).
- Distribution of the lifetimes (particles visually in contact) of grown aggregates (long term recording phase, no excitation).

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