# The Bouncing Barrier in Protoplanetary Discs: Experimental Studies

Protostars and Planets VI

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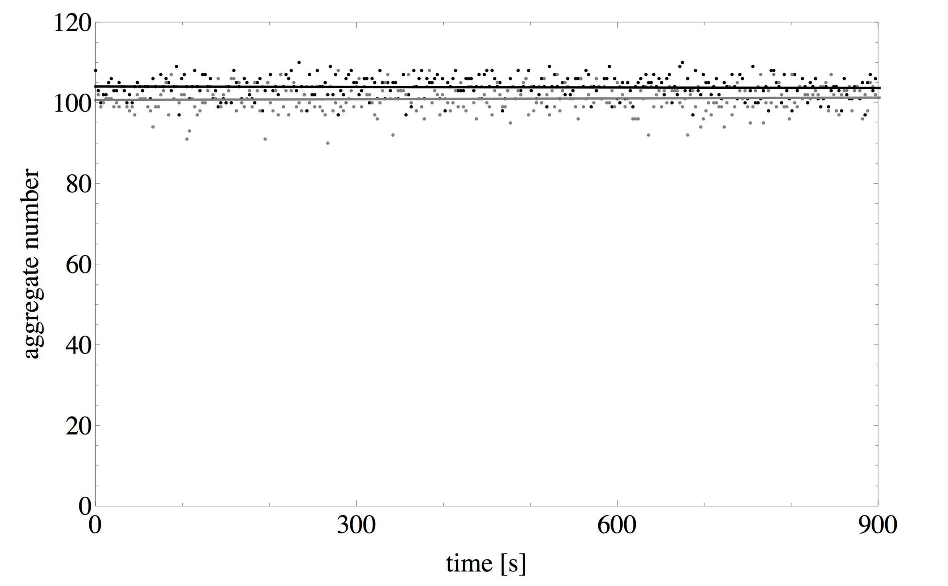
**ABSTRACT**

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 lead to the notion of a bouncing barrier for which growth gets stalled. Here, we present long term laboratory experiments on the outcome of repeated aggregate collisions at the bouncing barrier. About 100 $SiO_2$ dust aggregates of 1 mm in size were observed interacting with each other. Collisions occured within a velocity range from below mm/s up to cm/s. Aggregates continuously interacted with each other over a period of 900 s. During this time more than half a million collisions occured. More than 4000 collisions were analyzed in detail. No temporal stable net growth of larger aggregates was observed even though individual collisions were found to be sticking. Larger ensembles of aggregates sticking together formed but were disassembled again during the further collisional evolution. The concept of a bouncing barrier supports the formation of planetesimals by seeded collisional growth as well as by gravitational instability favouring a significant total mass being limited to certain size ranges. Within our parameter set the experiments confirm that bouncing barriers are one possible and likely evolutionary limit of a self consistent particle growth. This poster is based on the article (and references within) T. Kelling, G. Wurm and M. Köster, Experimental Study on Bouncing Barriers in Protoplanetary Discs, MNRAS (submitted), 2013

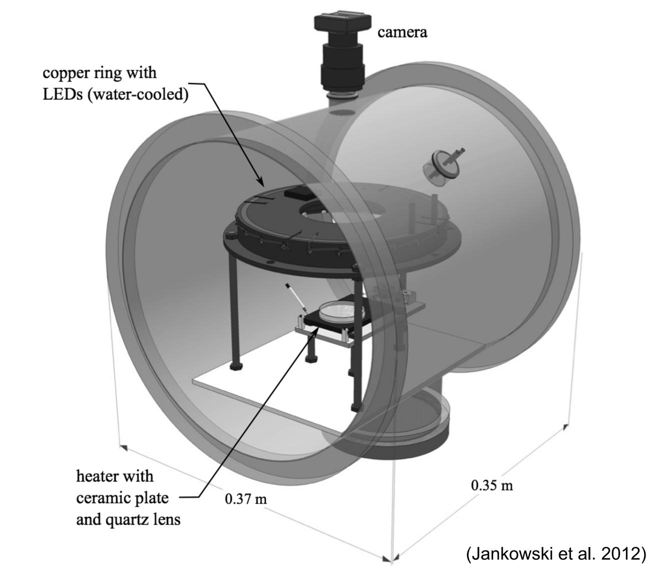

**CONCLUSION**

We study a total of over half a million collisions for 100 aggregates or 1000 collisions per mm-aggregate in the mm/s to cm/s regime. We find sticking and detachment but no large aggregate that survived for long. In the end 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.

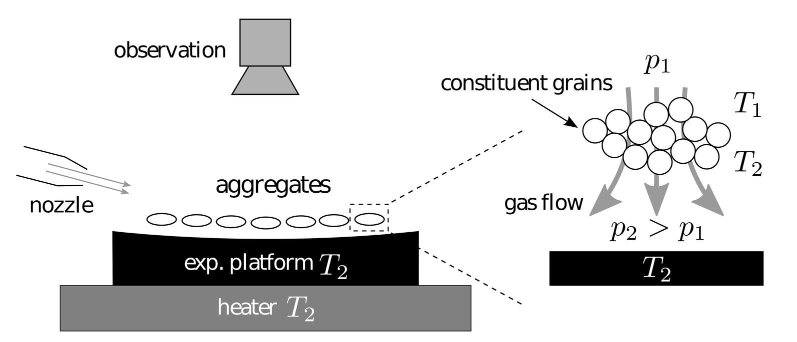



(dark grey 3.1 mm/s mean collision velocity; light grey: 6.3 mm/s mean collision velocity)

**SETUP**



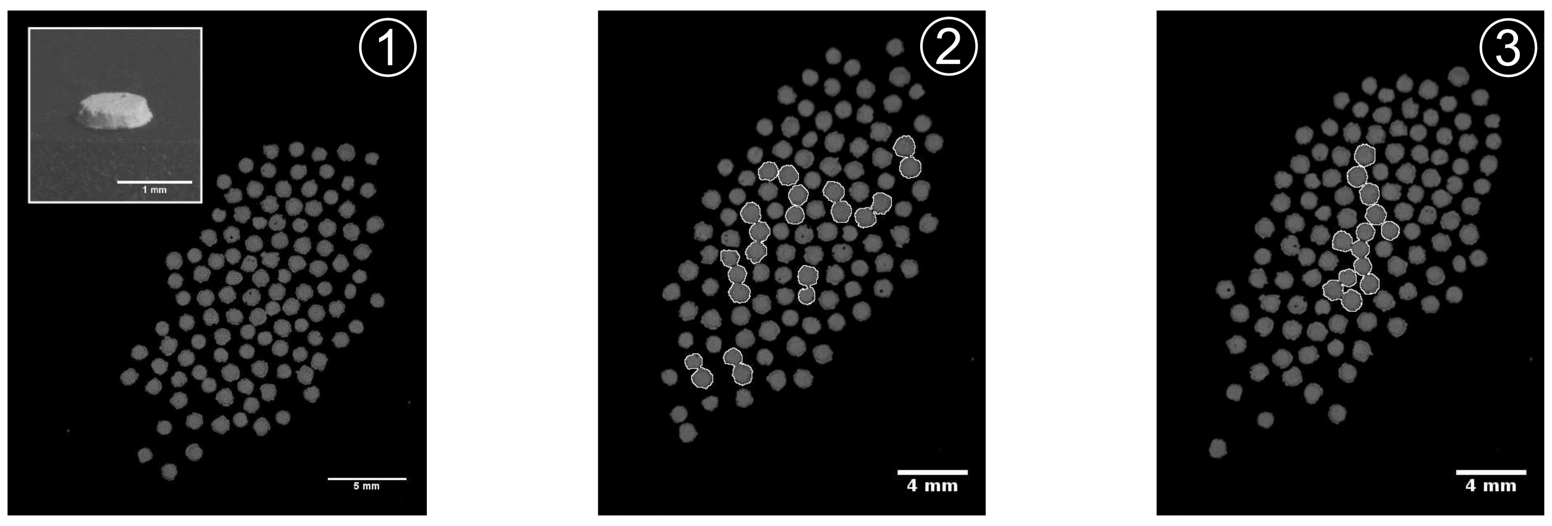

Experimental setup. A heater is placed within a vacuum cham- ber. About 100 aggregates are placed upon the heater and the pressure is evacuated to 15 mbar. A high speed camera (high speed recording phase) or a digital camera (long term recording phase) records the ensemble from above




The aggregates are levitated by a Knudsen compressor effect over the heater and the slightkly concave experimental platform. Aggregates are heated from below and cool on their top: There is a thermal gradient over the particles. Knudsen 1909 found that gas creeps along a micro-tube with thermal gradients from cold to warm. On the ourlet of the micro-tube an overpressure is created (Knudsen compressor effect). Dust aggregates have pores and act as collection of micro-tubes. Overpressure below the aggregates let them hover. Muntz et al. 2002 found that the overpressure at intermediate Knudsen numbers is

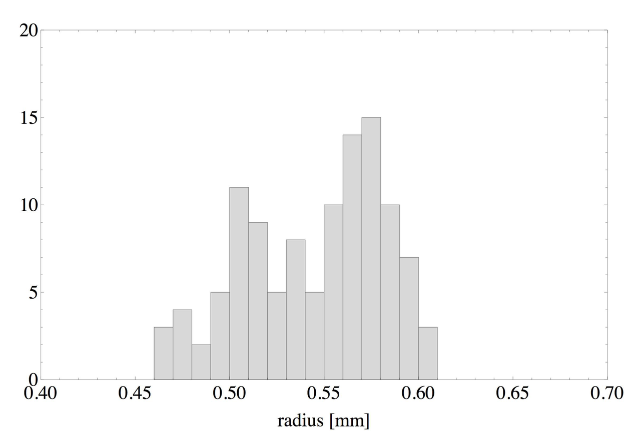
$$\Delta p = p_{avg} \frac{\Delta T}{T_{avg}} \frac{Q_T}{Q_P}$$

Random motions of the aggregates with mm/s 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 splitted in two phaes: 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 990 seconds in total. This allows to track the evolution of the aggregate ensemble.

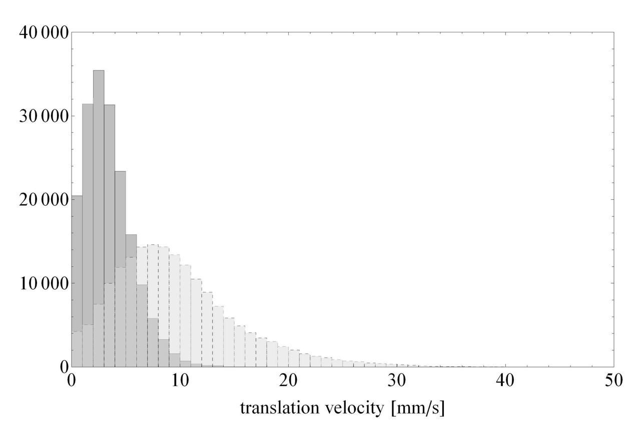



1) Dust aggregates used in the experiments with an microscope image of one aggregate; 2) Random image during the high speed recording phase showing all attached aggregates; 3) Largest aggregate formed during the high speed recording phase.

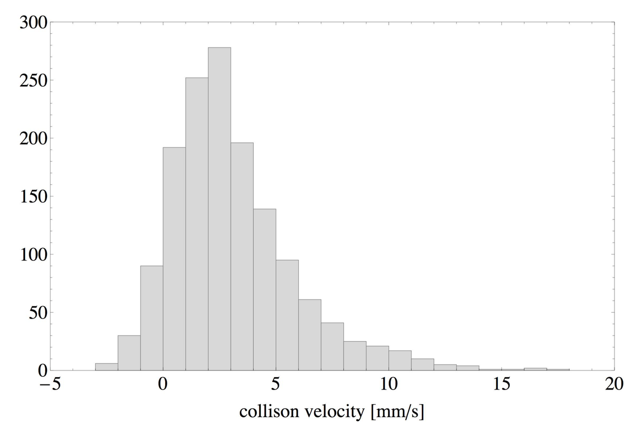
**EXPERIMENTAL PARAMETERS**



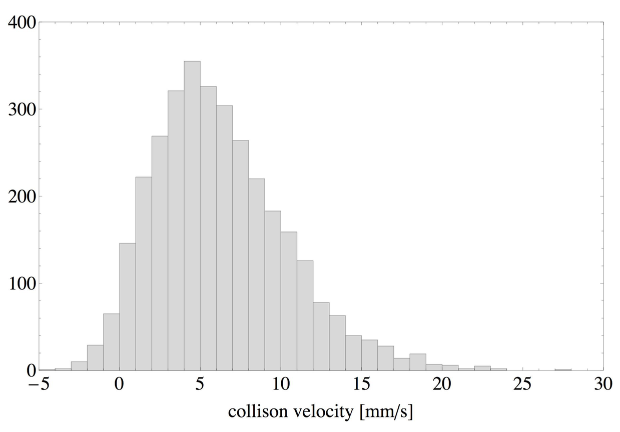

Size distribution of the aggregates (2d equivalent radii).




Translation velocity distribution of the aggregates with (light grey, dashed) and without excitation (dark grey, solid). The translation velocity is determined from frame

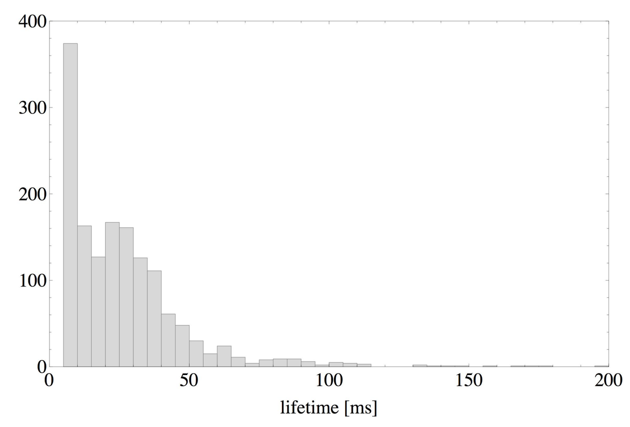



Collision velocity distribution without excitation. A negative velocity means that the two aggregates move away from each other but collide due to rotation.

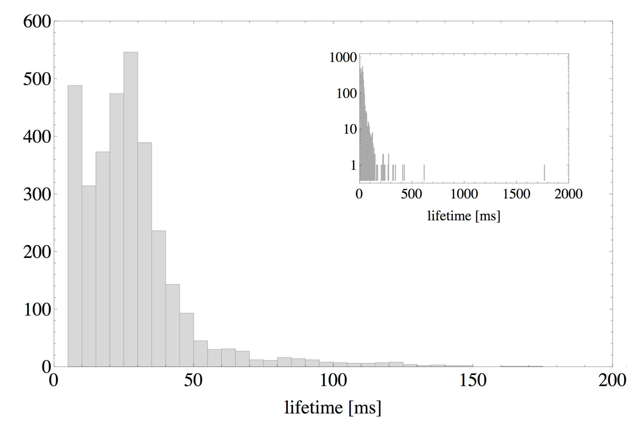



Collision velocity distribution with excitation. A negative velocity means that the two aggregates move away from each other but collide due to rotation.

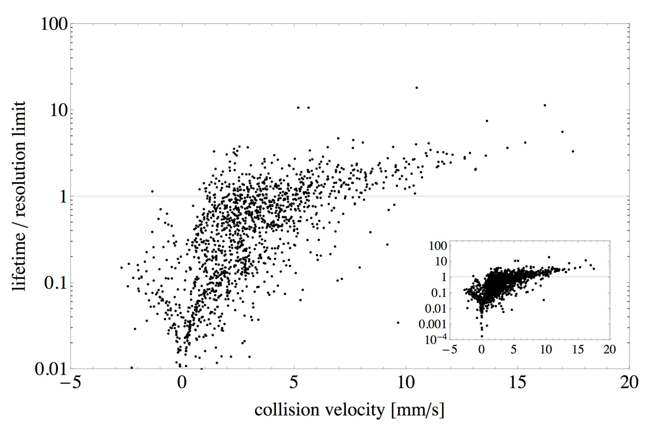
**DERIVED PARAMETERS**

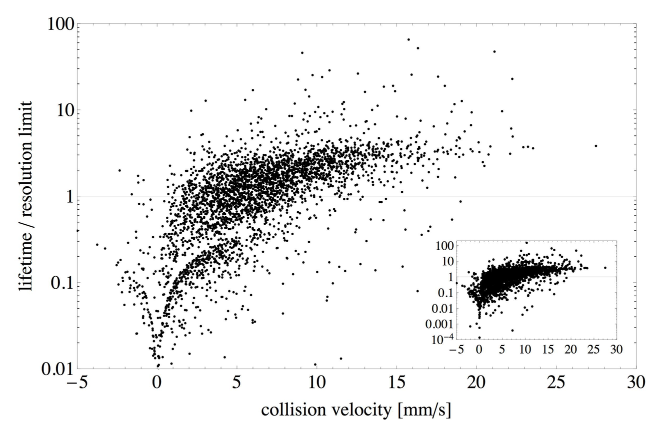



Distribution of the lifetimes (particles visually in contact) of grown aggregates (highspeed recording phase, no excita- tion).



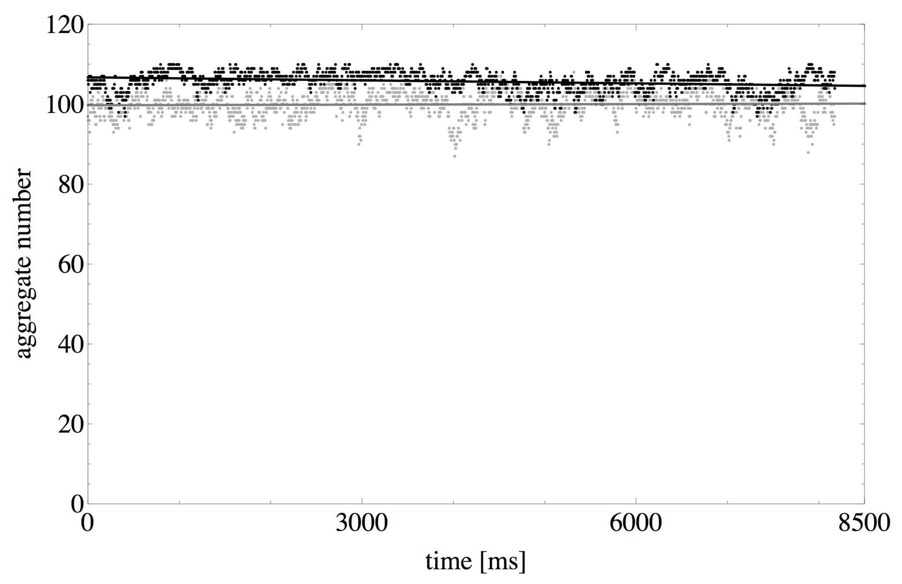

Distribution of the lifetimes (particles visually in contact) of grown aggregates (long term recording phase, no excita- tion).



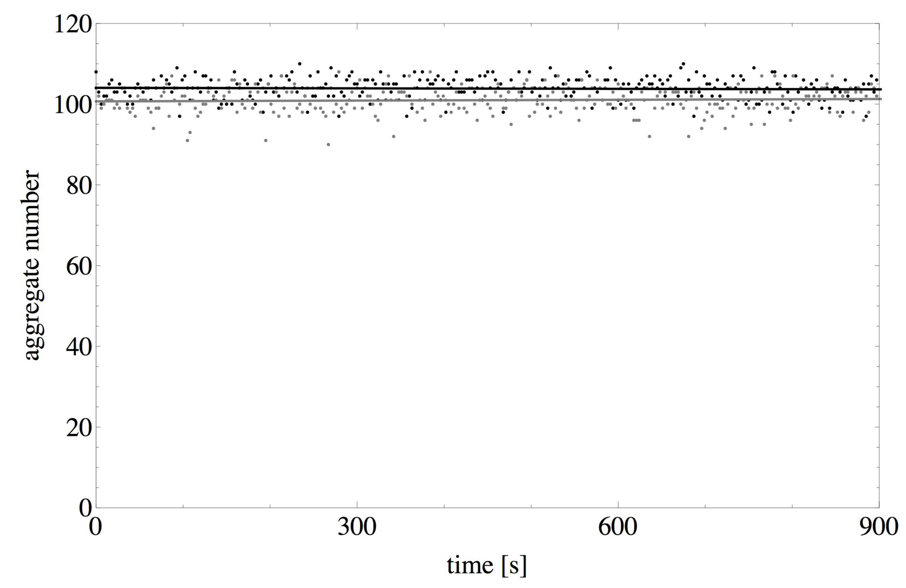




Our spatial and time resolution is limited in the experiments. Depicted here is the relation of the lifetime of grown aggregates (visually in contact) to the reolustion time (which is the time a potential bouncing event would need with the corresponding collision velocities). A value above one indicates sticking while for values below one no statement about sticking and bouncing can be given.

**RESULTS/CONCLUSION**

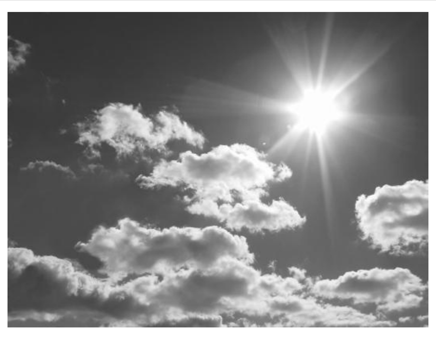



Total number of aggregates during the high speed recording phase (dark grey: no excitation; light grey: with excitation). The solid lines are linear fits to the data.




Total number of aggregates during the long term recording phase (dark grey: no excitation; light grey: with excitation). The solid lines are linear fits to the data.

We study a total of over half a million collisions for 100 particles or 1000 collisions per mm-aggregate. We find sticking and detachment but no large aggregate that survived for long. In the end 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 parameters of the dust – µm grain size, mm aggregate size, mm/s collision velocities – are close to values expected in protoplanetary discs. Applied to a disc our simulation experiment would suggest that – without a seed – no further growth would be possible over the discs lifetime in the terrestrial planet forming region. If seeded growth or gravitational instabilities feeding on the mm or cm particles would kick in to form planetesimals remains to be seen. However, a bouncing (or detachment) barrier at mm to cm size is very likely an important milestone in planetesimal formation.



This poster is based on the article (and references within)

**T. Kelling, G. Wurm and M. Köster, Experimental Study on Bouncing Barriers in Protoplanetary Discs, MNRAS (submitted), 2013**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