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A new collision model to overcome barriers

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Abstract

We present a new collision model where the results from the latest laboratory experiments are combined with a physical approach that allows us to follow the dust-size evolution from micron-sized grains up to kilometer-sized planetesimals. We take account of various types of collisional outcomes such as bouncing, erosion from monomers and fragmentation with mass transfer, in which only one of the particles fragments and a fraction of it is added to the surface of the other particle. [1, 2, 3]

We investigate not only the effect from the model calibrated by the laboratory experiments, but also the importance of different model parameters like the size of the fragmentation and bouncing regions and the mass transfer efficiency. Our new model is powerful enough to quickly test how sensitive the outcome depends on changes of the parameters. The aim is to determine under which circumstances planetesimal formation due to collisional growth is possible.

We find that growth through the *bouncing* and *fragmentation* barriers is possible, and that fragmentation with mass transfer allows for boulders of several hundred meters in size to be formed by sweeping up the mm-sized dust trapped at the bouncing barrier. These large boulders could possibly constitute the first generation of planetesimals.

1. Previous work on dust growth

In the core accretion scenario, micron-sized dust in the protoplanetary disk collides and sticks to form successively larger aggregates and finally kilometer-sized planetesimals. The study of the dust-size evolution in the protoplanetary disk has so far primarily been done using simplified collision models with only sticking and fragmentation. The dust grains coagulate rapidly up to the meter-size barrier, where the aggregates either fragment in equal-sized collisions or are lost due to rapid inwards migration. [4]

Recent laboratory experiments have shown many more different collisional outcomes to be possible, such as different bouncing collisions and fragmentation with mass transfer [1, 5]. Monte Carlo simulations based on these latest results have found a bouncing barrier at mm-sizes, at which the grain growth is halted even before it reaches the fragmentation barrier. [6]

2. The new collision model

We introduce a new physically based dust collision model to be used with continuum codes, which has the advantage compared to Monte Carlo codes that it can also trace rare collision events in a statistical fashion. We find that these rare events may even be crucial for the planetesimal formation. With the continuum approach, the dust is also resolved well at all dust sizes, allowing for all types of dust interactions without any biases. It is also fast enough to be used to follow the global dust evolution in the whole disk.

The new collision model is based on the latest laboratory work and includes mass-dependent fragmentation and sticking threshold velocities [7, 8, 9]. We also introduce a new collision energy division scheme using the center-of-mass energies which allows the experimental results to be extrapolated to large size ratios, and also provides a natural division between fragmentation with mass transfer and destructive fragmentation. Also included are growth neutral bouncing events and erosion from monomers. The model can be reduced to a couple of physically motivated parameters that can be studied individually in order to determine their importance for the dust growth.

3. Summary and Conclusions

We find that it is possible to grow through the bouncing barrier thanks to sticking events during collisions with large size-ratios. Because many particles pile up at the bouncing barrier, they provide a large reservoir of particles that can be swept up by mass transfer events by the few larger ones that have managed to pass over. In the end, the balance between sweep-up and destructive, mutual collisions determines the final size of the large bodies. In this way, it is possible to produce planetesimals of several hundred meters in size.

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