Planetesimal formation by sweep-up coagulation

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What is this about?

The early stages of planet formation are still poorly understood. In the incremental growth scenario, planetesimals form by sticking events between dust aggregates, but studies have revealed **barriers to the dust growth**, caused by e.g. grain charging, particle bouncing/ fragmentation, or rapid inward drift.

As a result, the growth is predicted to stop at millimeter to centimeter sizes instead of the kilometers needed for gravity to aid the accretion. The complexity of the physics involved has however long forced **major approximations** to the numerical dust evolution codes. Below, we improve some of these approximations and discuss their effects on the dust growth.

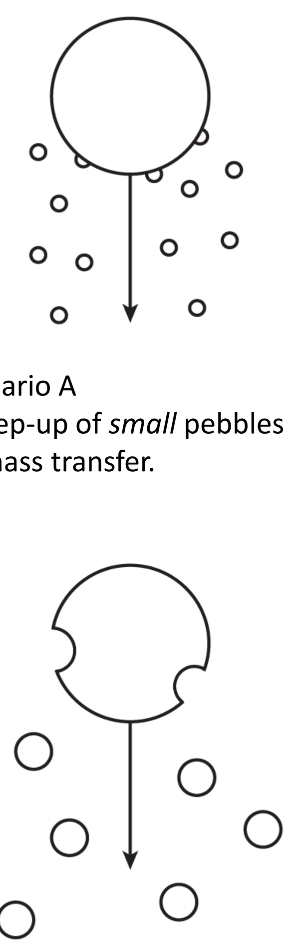
The improvements we have made include:

➢ More realistic dust collision modeling.

➢ The inclusion of impact velocity distributions for determining the collision outcome.

➢ The capability of particles of similar aerodynamic properties to clump together, increasing the rate of low-velocity collisions.

Planetesimal formation by sweep-up



Scenario A
Sweep-up of *small* pebbles by mass transfer.

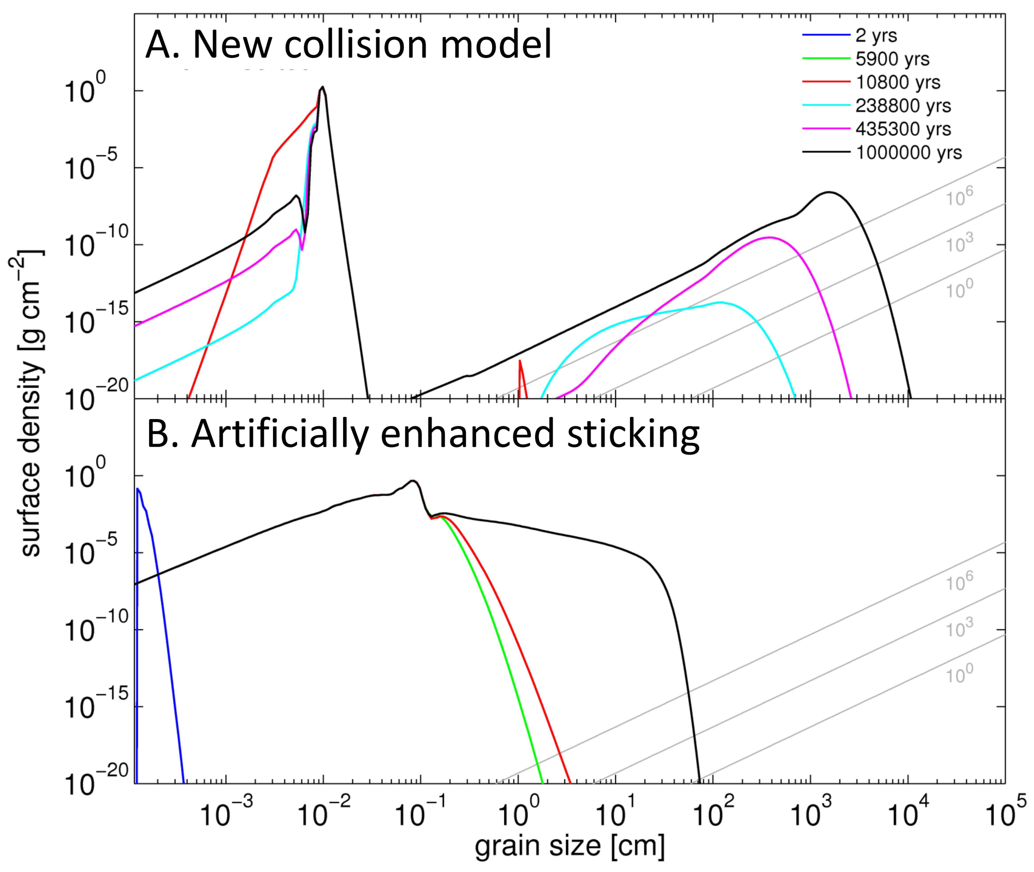
Scenario B
Erosion by *large* pebbles.

By implementing the results from the latest laboratory and numerical work into a **new collision model**, we discover a new type of planetesimal formation channel, sketched in the **left figure**.

Right figure (top): Growth proceeds by sticking collisions until the particles reach sizes of 100 micrometers, where bouncing starts, efficiently preventing further growth. After 10,000 years, we artificially introduce a handful of 1 cm particles. Because of the **mass transfer effect**, these "seeds" can grow to planetesimal sizes by sweeping up the small particles stuck at the bouncing barrier.

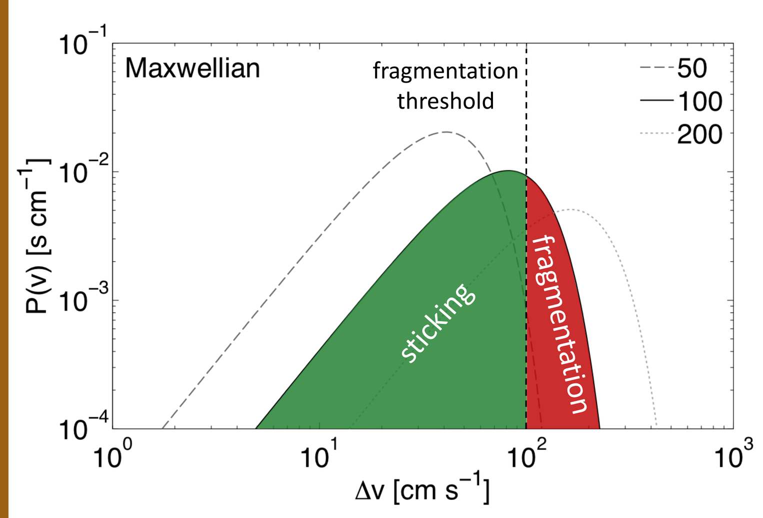
Right figure (bottom): In this simulation, we have as a test turned all the bouncing collisions into sticking ones. The average particle then grows to a larger size before fragmentation halts its growth. In this case, large particles can never form, because the smaller particles now carry enough collision energy to erode the larger particles instead of stick onto them in mass transfer collisions.

In the above examples, we showed that hindering the growth of most of the particles, a small number of lucky particles can grow into planetesimals.

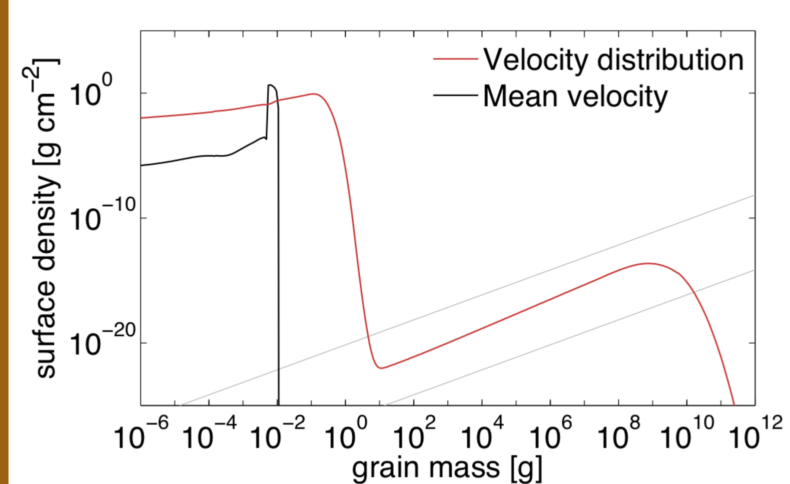


The dust grain size evolution for two different scenarios described in more detail in the text. The simulation follows the local growth at 3 AU in a Minimum Mass Solar Nebula for $\alpha = 10^{-3}$.

Formation of the first seeds



The Maxwellian velocity PDF for Δv_{rms} = 50, 100 and 200 cm/s, and its effect on the collision outcome.

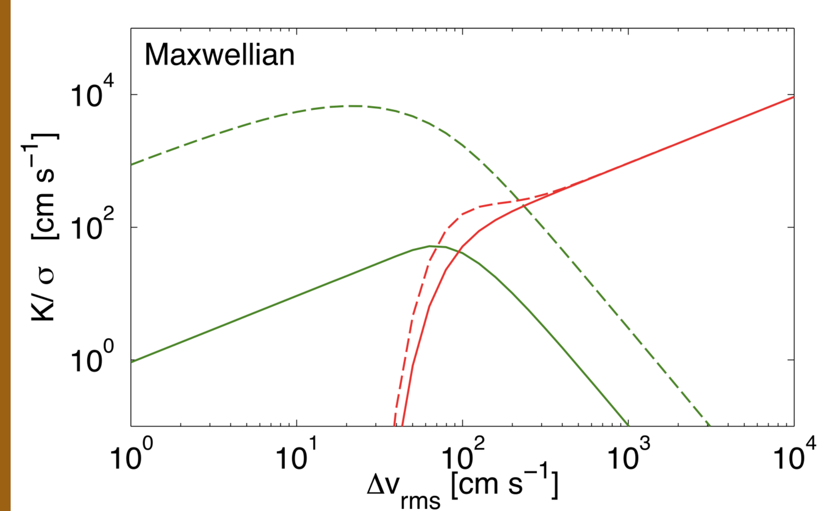


The dust size distribution after 50,000 years with and without velocity distribution considered.

Left figure (top): In the abovementioned sweep-up simulations, the first seeds where created artificially. However, if a **velocity distribution** is considered instead of only a mean velocity, multiple collision outcomes can occur for a given particle pair. Even at high mean velocities, sticking therefore becomes a possibility.

Left figure (bottom): As a result of the velocity distribution, the collision barriers are **smeared out**, when some particles can grow by only interacting in low-velocity sticking collisions, while others fragment immediately in high-velocity fragmenting events. The most **lucky particles can grow** significantly larger than the average grain, and these seeds can continue to grow by sweeping up the surrounding, smaller particles.

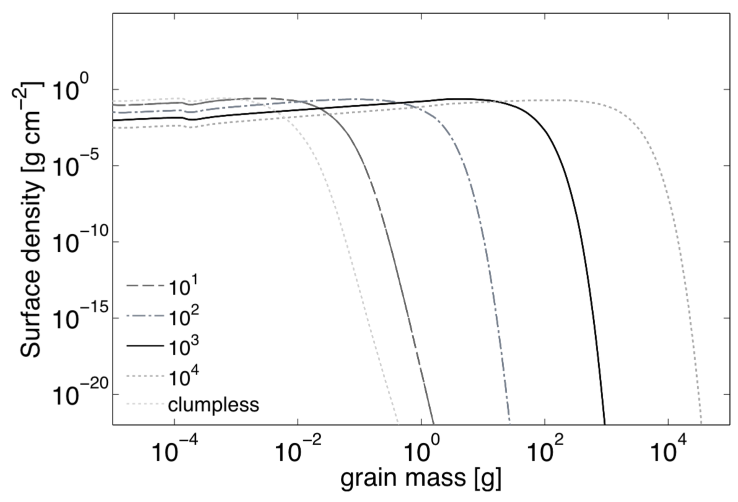
Growth in turbulent clumps



The velocity-integrated kernel calculated for the sticking (green) and fragmenting (red) collisions, with (dashed) and without (solid) clumping.

Left figure: A number of turbulent effects can cause dust grains to cluster. In these clumps, the densities can be very high, while the relative velocities are low. This means that the low-velocity sticking collisions are boosted significantly, while the fragmenting ones are less affected. The result is a **change in the equilibrium** between the sticking and fragmentation rates.

Right figure: If the clustering is significant, the average dust grain will be able to grow larger than in the absence of clustering. For realistic clumping strengths, this can cause grains to grow more massive by several orders of magnitude, which is relevant for the enabling of for example streaming instabilities.



The resulting steady-state distribution for various degrees of clumping.

We find that:

➢ Using a more realistic collision model has a big impact on the dust evolution, and growth of planetesimals via sweep-up coagulation becomes a possibility.

➢ Velocity distributions can enable the formation of the first planetesimal seeds by smearing out the growth barriers.

➢ Turbulent clustering can cause larger grains to form by shifting the equilibrium between sticking and fragmenting collisions.

For more information, see Windmark et al. (2012), A&A, 540, A73 and Windmark et al. (2012), A&A, 544, L16.

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If you have any questions or comments, feel free to ask me here or send me a mail at:

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