Growth and Transport of Dust Grains - How to Cross the Meter Size Barrier

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Background

The structure of the protoplanetary disk, the dust growth mechanisms and the effects of dust transport in the gaseous disk are intimately coupled. The interplay of these effects leads to what is conventionally called the *meter-size barrier*: gas drag effects and high collision velocities prevent the collisional growth of dust particles from proceeding beyond the size of at most a meter, if not less.

Observations of protoplanetary disks show two important facts: firstly these disks are rich in small dust during their whole lifetime. Secondly grains of millimeter or centimeter sizes are present in the outer parts of the disk even though theory expects grains of these sizes to disappear quickly due to inward drift.

Analytical solutions to growth, fragmentation and drift

The above mentioned interplay between many size-dependent effects and the physics of growth and fragmentation make dust evolution a complicated matter. In this presentation I will review results of a recently published code (see Birnstiel et al. [1]) from an analytical point of view. A semi-analytical toy model is derived which very well reproduces the size and spatial evolution of dust particles in protoplanetary disks.

These results are used to derive the profile of the dust surface density and the dust-to-gas ratio under different physical conditions. A dust size distribution which is limited by fragmentation can account for various observational facts:

- fragmentation replenishes the small dust sizes, thus keeping the disk rich in small dust during several millions of years
- fragmentation prevents particles from reaching sizes at which dust is quickly removed due to radial drift
- for a fragmentation dominated dust distribution, the analytical result for the dust surface density profile is proportional to $r^{-1.5}$ (see Fig. 1), in agreement with the minimum-mass solar nebula profile

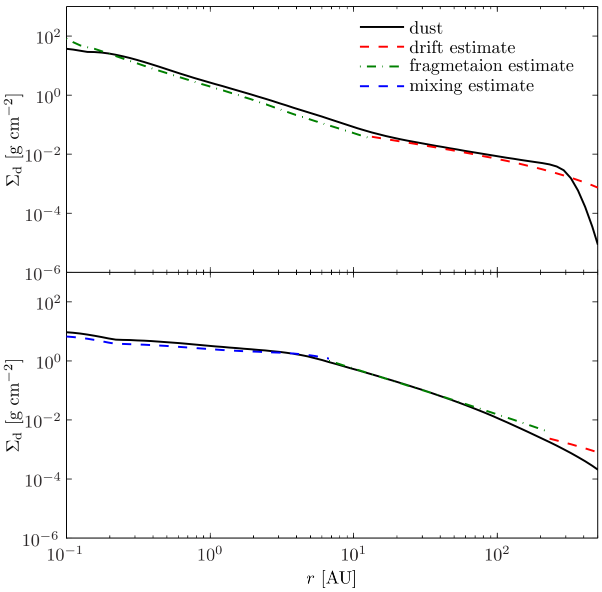

Figure 1: Comparison of detailed simulation results after 1 Myr of evolution (black solid line) and the analytically derived profiles from Birnstiel et al. (in prep.). The upper panel shows a simulation with a smaller strength of turbulence ($\alpha = 10^{-3}$), the lower one for stronger turbulence ($\alpha = 10^{-2}$). The different colors of the analytical profiles correspond to different physical conditions, depending on the upper size limit of the grain size distribution. The green line is the profile for a dust distribution whose upper size limit is set by fragmentation. The derived slope in this case is proportional to $r^{-1.5}$.

An updated collision model

While dust grain fragmentation can explain many observational facts, it does not explain the formation of larger bodies. One possible solution to this could be another mode of growth which is not properly accounted for in all current models of dust growth. Laboratory experiments such as Teiser and Wurm [2] or Kothe et al. [3] show that impacts of small projectiles at relatively high velocity are not necessarily erosive, but can cause a net growth of the target. We therefore put forward a new collision model

(Windmark et al., in prep.) which is based on physical considerations and calibrated by laboratory experiments to investigate wether growth over and beyond the meter size barrier is possible.

First results indicate that an environment with large amounts of small dust provides the perfect background for further growth with this mechanism. Particles of around cm-sizes are able to sweep up small dust even though the collision velocities are typically considered to be too high. The amount of large bodies produced in this way is limited by the fact that these bodies fragment upon similar-sized collision. This model thus has the potential to explain both the presence of large amounts of small dust and the existence of large bodies formed by collisional growth.

Outlook

Current investigation focusses on the sensitivity of this mode of growth with respect to parameters which are still weakly constrained by experiments. Future work will include the treatment of the composition of the dust grains to be able to track effects such as porous mantles on compact grains.

References

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