Collapse of Particle Filaments

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Introduction

The planetesimal formation process is one of the major uncertainties in theoretical planet formation models. The gravitational collapse of locally over-dense regions is a robust scenario to explain the observational constrains from the remnants of planetesimals in the Solar System.

In my work, I numerically investigated the formation of planetesimals by gravitational instability on two different spatial scales using the Pencil-Code. This way I could resolve the formation of planetesimals from particle overdensities in large filaments down to the scales close to the final solid object.

Method:

- Pencil-code: partial differential equation solver for compressible magnetohydrodynamical equations
- Shearing box set up with Lagrangian super-particles

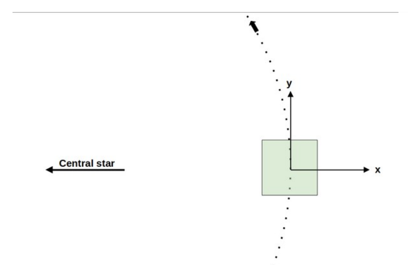

Fig. 1: Illustration of a shearing box.

Simulations setup:

- Dust filament:
  - 2D shearing box with L=0.2H
  - No gas pressure gradient
  - Particles random velocity distribution
- Cloud collapse:
  - 3D shearing box with L=0.01H
  - Particle collisions modeled using a Monte Carlo approach
  - Particles initially at rest

Collapse and Evolution of Particle Filaments

I tested the influence of the numerical resolution, the relative strength of gravity, and the initial clumping on the initial distribution of planetesimals by studying the gravitational collapse of a particle filament.

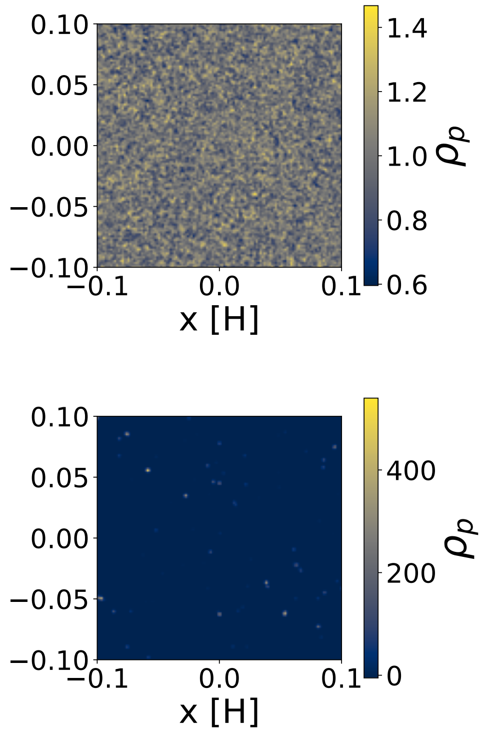

Fig. 2: Particle density distribution in the beginning (upper plot) and shortly after the first planetesimals have formed.

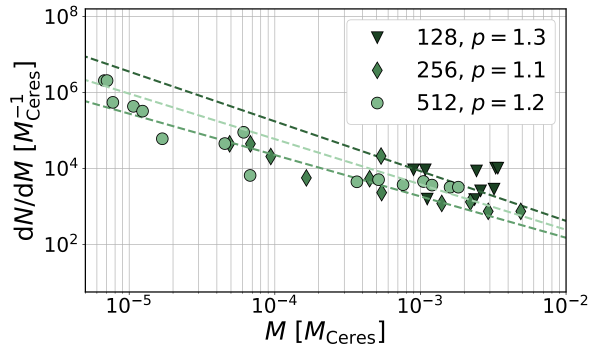

Fig. 3: Differential mass distribution for three different resolutions represented by different colours and markers. The mass distribution is fitted well with a power law $dN/dM_{pl} \propto M_{pl}^{-p}$ plotted as dashed lines.

Diagnostic:

- Visually determine snapshot shortly after planetesimals have formed.
- Planetesimals are identified using the FellWalker-Algorithm. This algorithm sorts all points in data set above a threshold by following different lines of steepest ascent.
- Size distribution is found by using

$$\left.\frac{\mathrm{d}N}{\mathrm{d}M_p}\right|_i = \frac{2}{M_{p,i+1} - M_{p,i-1}}$$

Conclusions:

- The number of planetesimals increases with increasing resolution while the minimum mass decreases.
- There is a general trend for lower mass planetesimals for lower relative strength of gravity.
- At a distance from 3 AU from the central star typical planetesimal radii are found to be between 9km to 110km.

Collapse of a cloud

I simulated the collapse of a particle cloud in the Pencil-code. This way, I was able to study the influence of the gas and dust interaction on the collapse by varying the friction time scale.

Diagnostic:

The collapse is followed by calculating the potential energy U of all particles.

$$U = -\frac{M^2 \mathrm{G}}{N}\sum_{j=1}^{N}\frac{1}{r_j}$$

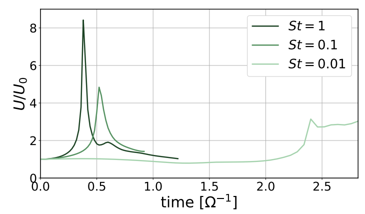

Fig. 4: Overview of the potential energy evolution with time for different Stokes numbers. The peak in U corresponds to end of the cloud collapse.

Conclusions:

- At high resolutions collisions were not modelled correctly (see box on the right for more information).
- Almost all mass of the cloud ends up in the final objects. In most simulations a binary system was formed.
- Collisional cooling and friction between gas and particles prolong the collapse process.

Limit in collision treatment in Pencil:

- Code uses collision probability of particles in same grid cell
- Number of particles is limited at 5×10^6
- At high resolutions: not enough particles in a cell to calculate probability ▶ no collisions take place

Take Home Message

Filament collapse:

- Differential mass distribution of initial planetesimals formed in absence of a radial gas pressure gradient is well-represented by a power-law $dN/dM_{pl} \propto M_{pl}^{-p}$, with p = 1.27 ± 0.08.
- The power-law slope is independent of the investigated parameters

Cloud collapse:

- Gas drag plays a role at the start of the collapse process
- Collisions mainly play a role for small Stokes numbers.

References:

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