An improved model for grain growth in the outer parts of protoplanetary discs

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ISIMA project 2011

Hamilton, 12/06/2012
The mm-size problem at 100 AU

Circumstellar disc: Gas + Dust

Observations:
- detection of mm-cm size objects in the outer part of discs.
The mm-size problem at 100 AU

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T-Tauri Hydra disc

Wilner et al. 2005
Introduction

Theory:

models for grain growth take into account:
  gas-dust coupling
  coagulation/fragmentation processes

Results:

- mm size objects difficult to grow in the outer part
- even if successful growth: radial drift

Birnstiel, 2011
Brauer et al., 2008
GrOG: Growth Of Grains

A new coagulation-fragmentation solver for grains evolution at a fixed radius in a circumstellar disc.

Recipe for cooking grains:

- take a disc with gas profile $\sim 1/r$ at $r = 100$ AU
- consider as ICs a gaussian distribution of grain sizes centered at 10 $\mu$m
- calculate collisional velocities
- solve for the coagulation/fragmentation equations.
Coagulation/Fragmentation equation:
Coagulation/Fragmentation equation:

\[ \frac{dm}{dt} = \int_{s_{\text{min}}}^{s} \frac{dn(s')}{ds} m(s') \Delta v(s, s') A(s, s') \epsilon ds' \]
Coagulation/Fragmentation equation:

\[
\frac{dm}{dt} = \int_{s_{\text{min}}}^{s} \frac{dn(s')}{ds} m(s') \Delta v(s, s') A(s, s') \epsilon ds'
\]

- Number of particles of size $s$
- Mass of particles of size $s$
- Collisional velocity
- Cross section area
- Coagulation/fragmentation probability
The fiducial model: Brauer et al. 2007

- collisional velocity: maximal between
  - radial drift
  - vertical settling
  - brownian motion
  - turbulence

Fragmenting probability: $$p_f(\Delta v) = \left(\frac{\Delta v}{v_f}\right)^\psi \Theta(v_f - v) + \Theta(v - v_f)$$

with $$\psi = 2.0$$ and $$v_f = 30 \text{ m/s}$$

- Coag. probability = 1 - Frag. probability

- Mass redistribution after fragm. $$n(m) \, dm \propto m^{-\xi} \, dm$$

with $$\xi = 1.83$$ from lab. experiments (Mathis et al. 1977)
Coagulation
Fragmentation
Coagulation
Fragmentation
... and cooking all together

![Graph showing size distribution](image-url)
Tail Model

Idea: the collisional velocity is not given by a single value but by a probability distribution function.

3D convolution of gaussians with:
- center given by $(v_{rd}, 0, v_{vs})$
- width given by turbulence + brownian motion
Tail Model

The Coagulation/Fragmentation probability is given by the convolution between the pdf and a step function.
Tail Model

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Tail Model

Coagulation
Fragmentation
Coagulation efficiency

Brauer Model

Tail Model
Coagulation efficiency

Maximal size: the Tail Model gains more than one order of magnitude (factor of ~20)
Conclusions

We present a new code, GrOG, to study the evolution of grains in circumstellar discs. GrOG passed standard tests and is able to reproduce previous results.

We present the Tail model, an improvement in the collisional velocity description.

The Tail model leads to the formation of larger grains (mm-size problem at 100 AU).