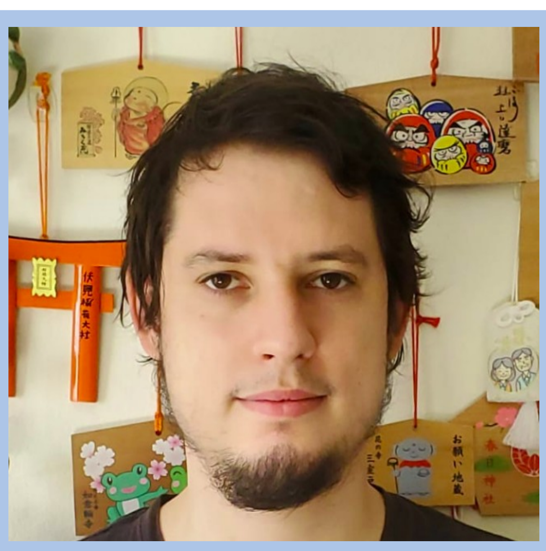

Grain coagulation during the protostellar collapse

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ABSTRACT

Dust grains play a major role in many astrophysical contexts. They affect the chemical, magnetic, dynamical, and optical properties of their environment, from galaxies down to the interstellar medium, star-forming regions, and protoplanetary disks. Their coagulation leads to shifts in their size distribution and ultimately to the formation of planets. However, although the coagulation process is reasonably uncomplicated to model and compute by itself, it is difficult to couple it with multidimensional hydrodynamics numerical simulations because of its high computational cost. We propose here a simple method for tracking the coagulation of grains at far lower cost. Given an initial grain size distribution, the state of the distribution at time t is solely determined by the value of a single variable integrated along the trajectory, independently of the specific path taken by the grains. Although this method cannot account for processes other than coagulation, it is mathematically exact, fast, inexpensive, and can be used to evaluate the effect of grain coagulation in many astrophysical contexts.

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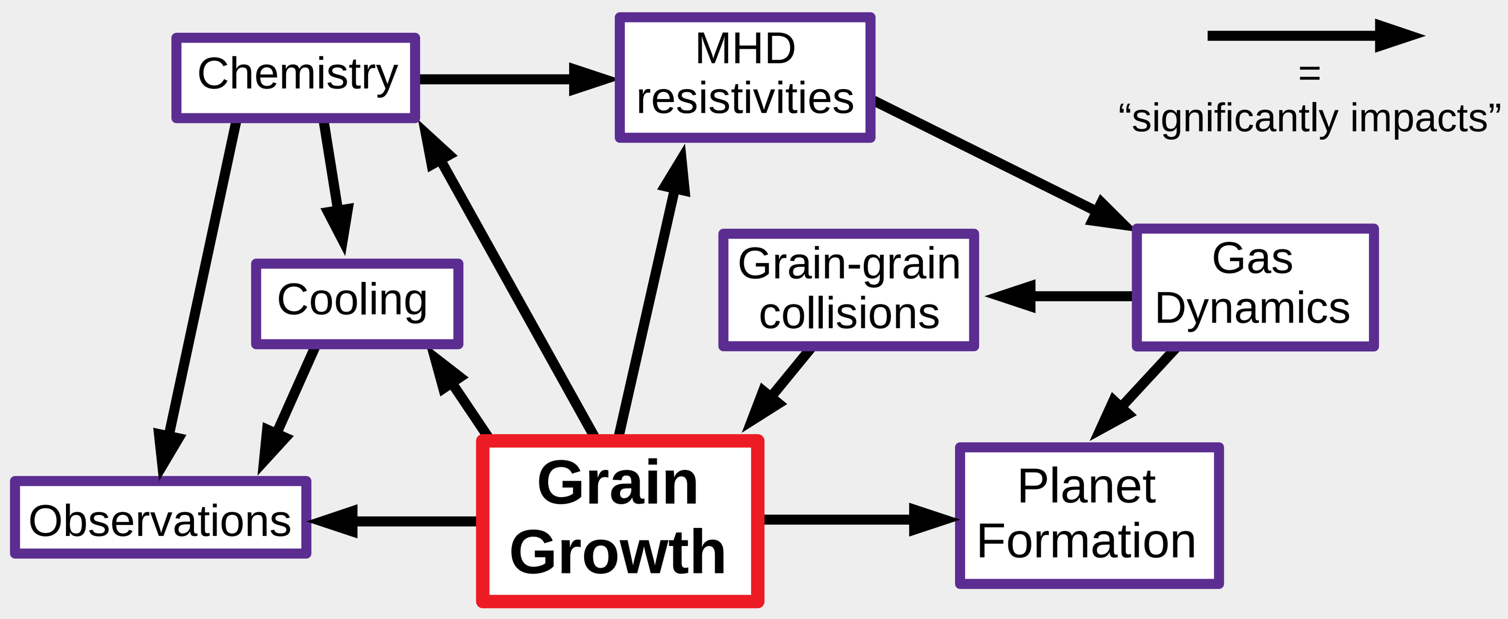
Intro & Methods

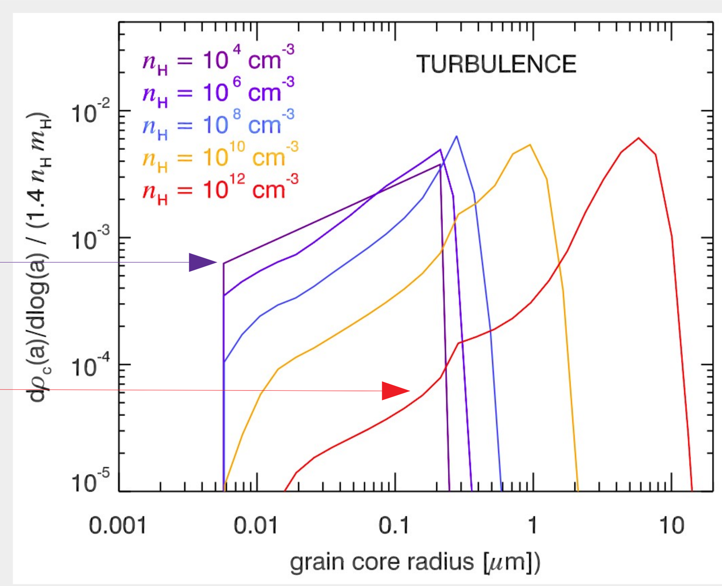
The importance of grain growth in star formation



Grains **do grow** during the protostellar collapse:

From MRN size-distribution (<250 nm) in the envelope…

… to ~ 10 µm in the disk !



Results from Guillet et al. (2020) [3] in a one-zone model

Tweaking the equation of coagulation

$$\frac{d\rho}{dt}(m,t) = -\int_0^\infty m K(m,m') n(m,t) n(m',t) dm' + \frac{1}{2}\int_0^m m K(m-m',m') n(m-m',t) n(m',t) dm'$$

Density variation of grain of mass m = destruction by coagulation with m'
+ creation by coagulation between m-m' and m'

"Easy" to solve but computationally expensive !

After some clever algebraic manipulations

$$\frac{dx}{d\chi}(m,t) = C * I(m,x,t)$$

Normalized grain quantity

Constant

Integral over distribution

Environment-only dependent variable:
Density, Temperature, Dust-to-gas ratio, time...

$$d\chi = n_H^{\frac{3}{4}} T^{-\frac{1}{4}} d_g dt$$

Coagulation = 1D process parametrized by χ

User's manual: how to use in simulations ?

1. Tabulate size-distributions for several values of χ → **use Ishinisan*** !
2. Calculate χ in your simulation (inexpensive !),
3. Read the corresponding size-distribution from the pre-calculated table,
4. Do physics with grains !

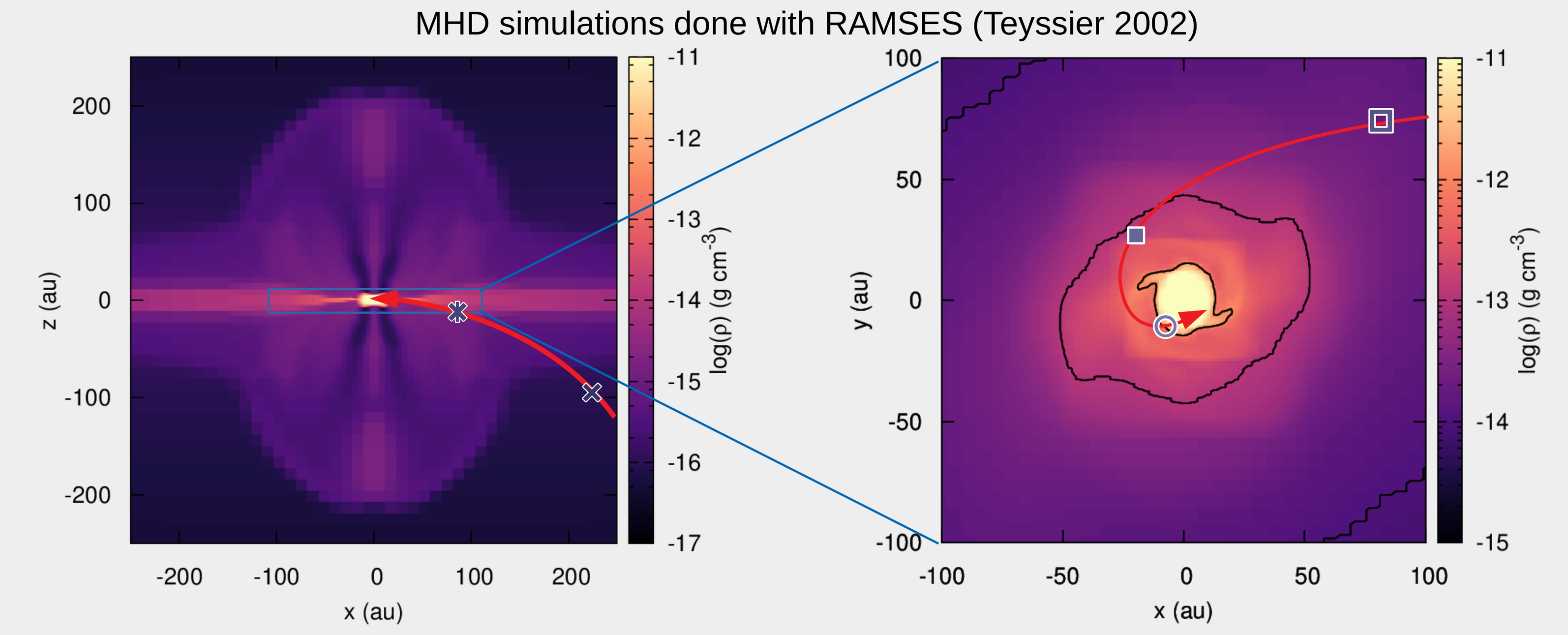
Mathematically accurate and self-consistent !

* https://bitbucket.org/pmarchan/ishinisan
(you can also use it to post-process your simulations !)

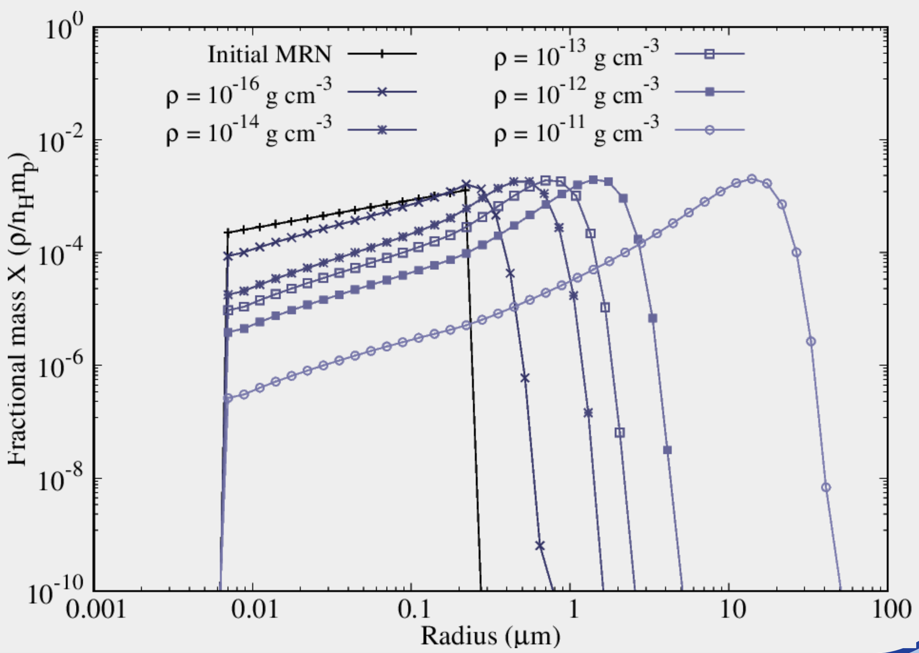
Results

Grain coagulation in MHD simulations

MHD simulations done with RAMSES (Teyssier 2002)

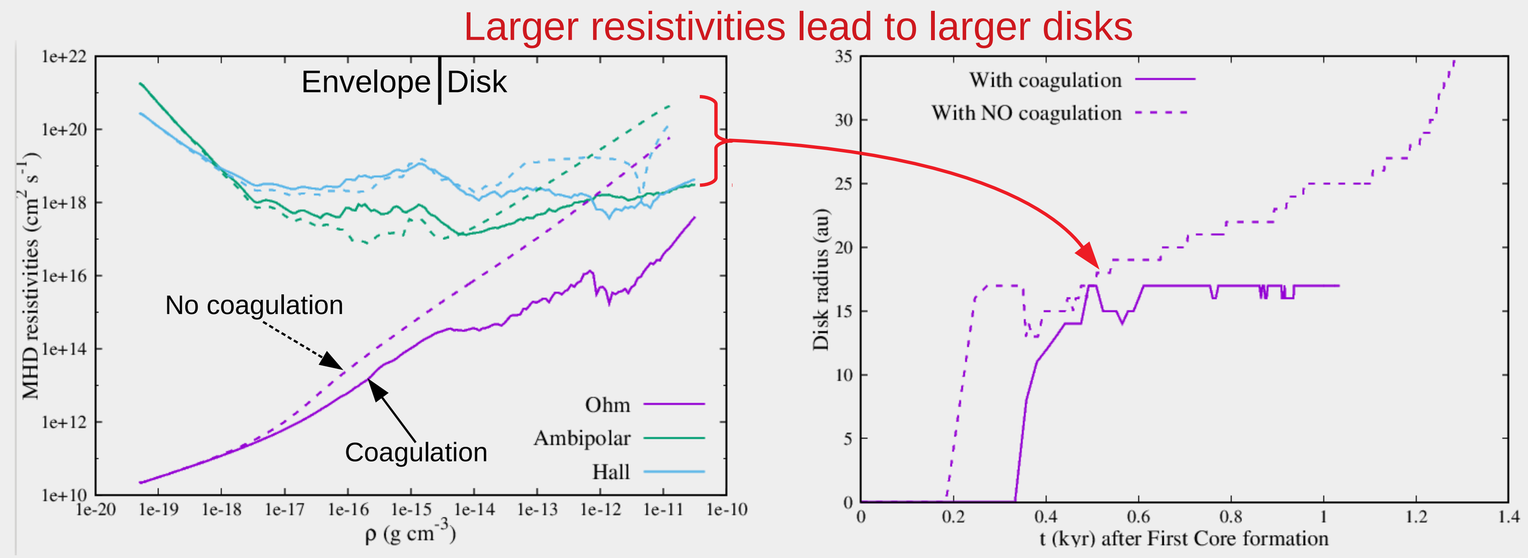


The grain size-distribution does not evolve much in the envelope, but grows rapidly to > 10 µm size in the first hydrostatic core and the disk !

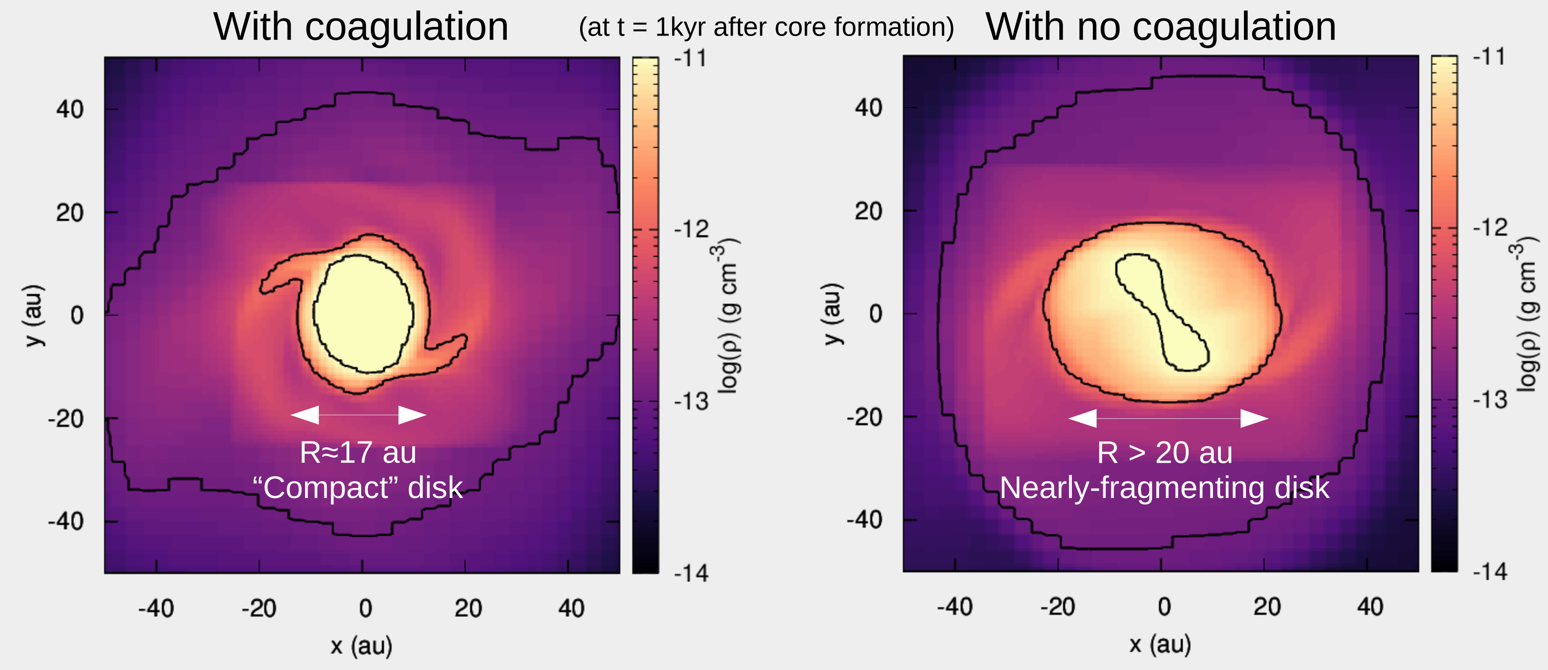


Impact on MHD resistivities and gas dynamics

Larger resistivities lead to larger disks



With coagulation (at t = 1kyr after core formation) With no coagulation



Conclusions

- Grain coagulate during the protostellar collapse.
- They impact many aspects of star formation.
- Coagulation is expensive to compute, this method makes it affordable.
- It unlocks a larger range of grain physics in numerical simulations.

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[1] Marchand P., Guillet V., Lebreuilly U., Mac Low M.-M., 2021, A&A 649, 50
[2] Marchand P., Guillet V., Lebreuilly U., Mac Low M.-M., 2022, A&A *in press*
[3] Guillet V., Hennebelle P., Pineau des Forêts G., Marcowith A., Commerçon B., Marchand P. 2020, A&A 643, 17