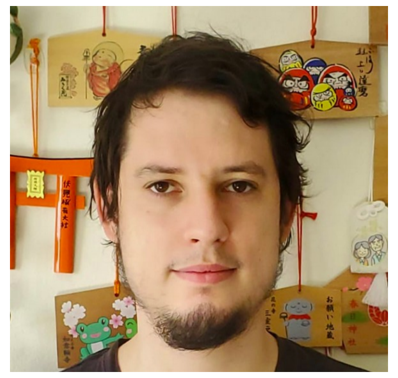

Grain coagulation during the protostellar collapse

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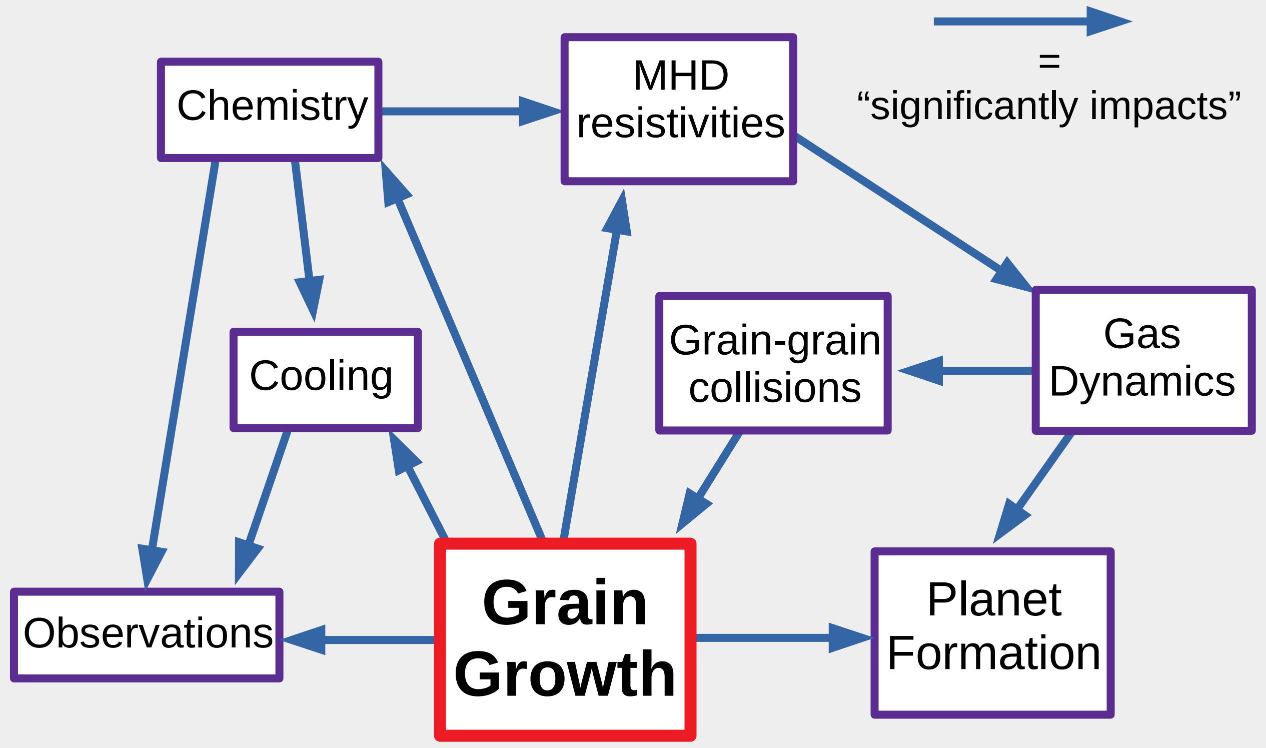
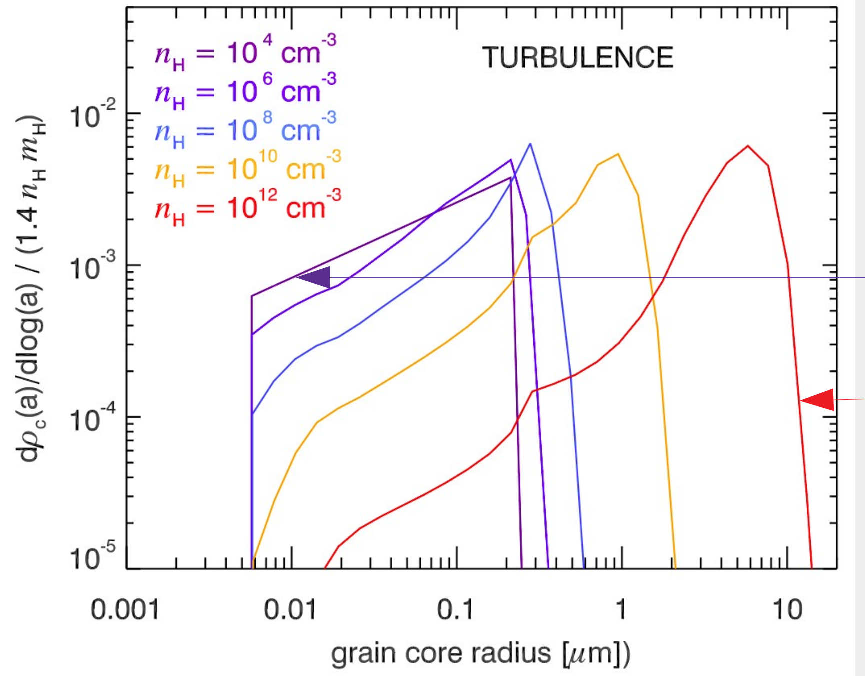
The importance of grain growth in star formation





Evolution of the size-distribution

Envelope : < 250 nm

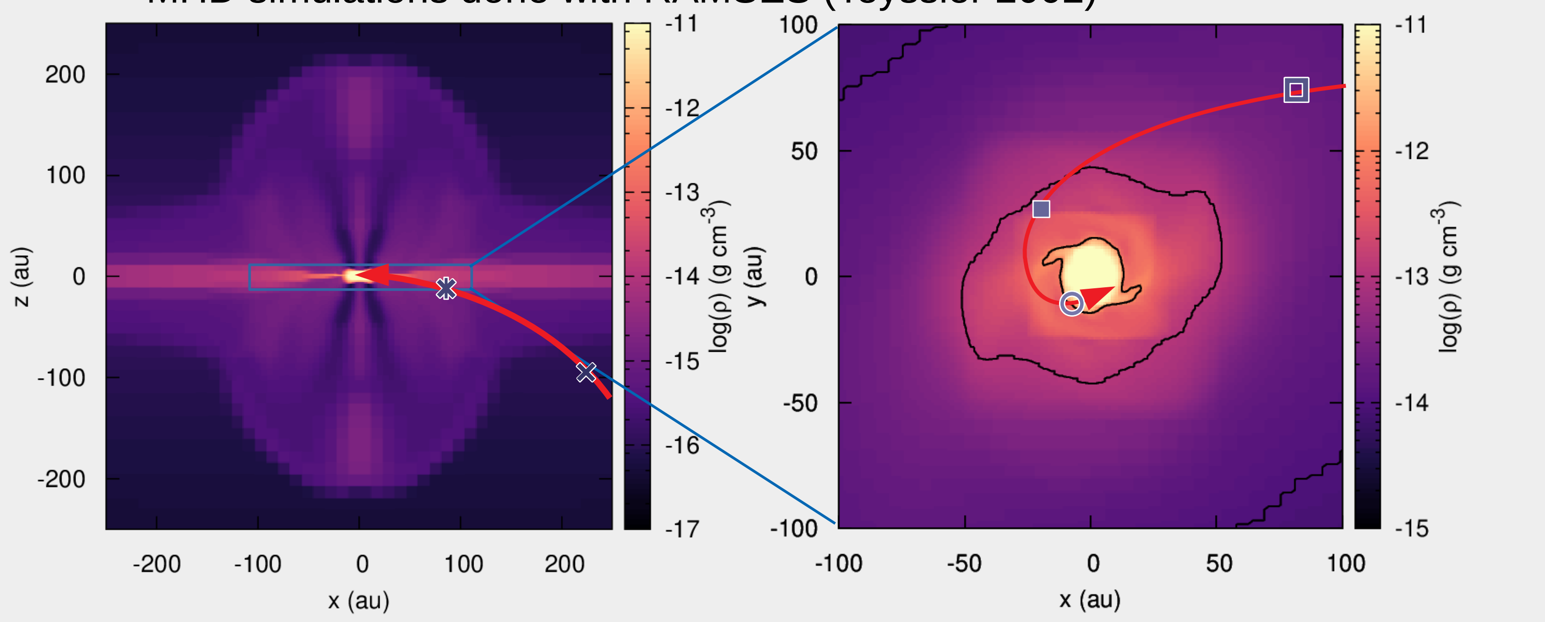
Disk : ~ 10 µm

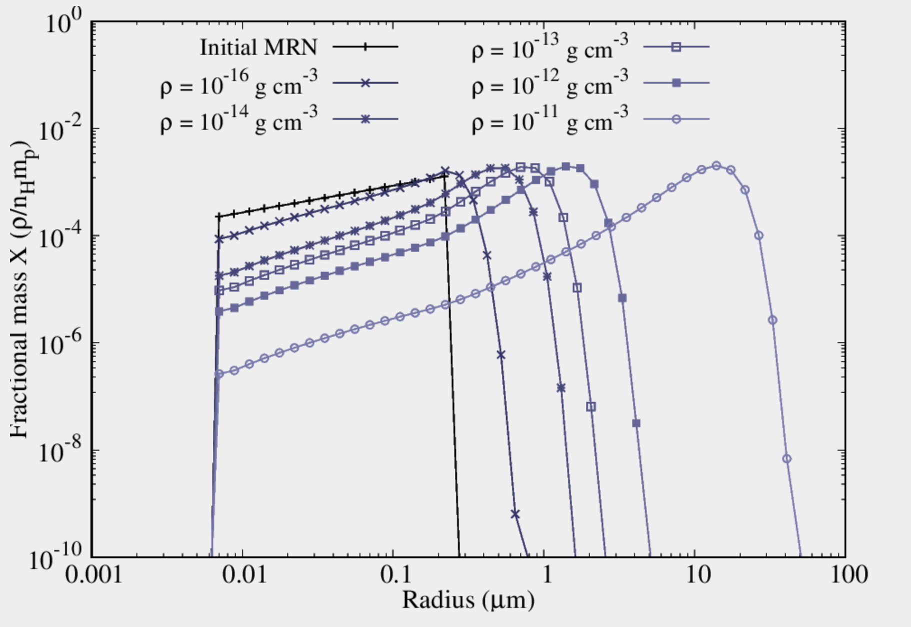
Results from Guillet et al. (2020) in a one-zone model

Grains **do grow** during the protostellar collapse

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 !

Tweaking the equation of coagulation

Smoluchowski equation of coagulation (1916)

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

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

Normalized grain quantity

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

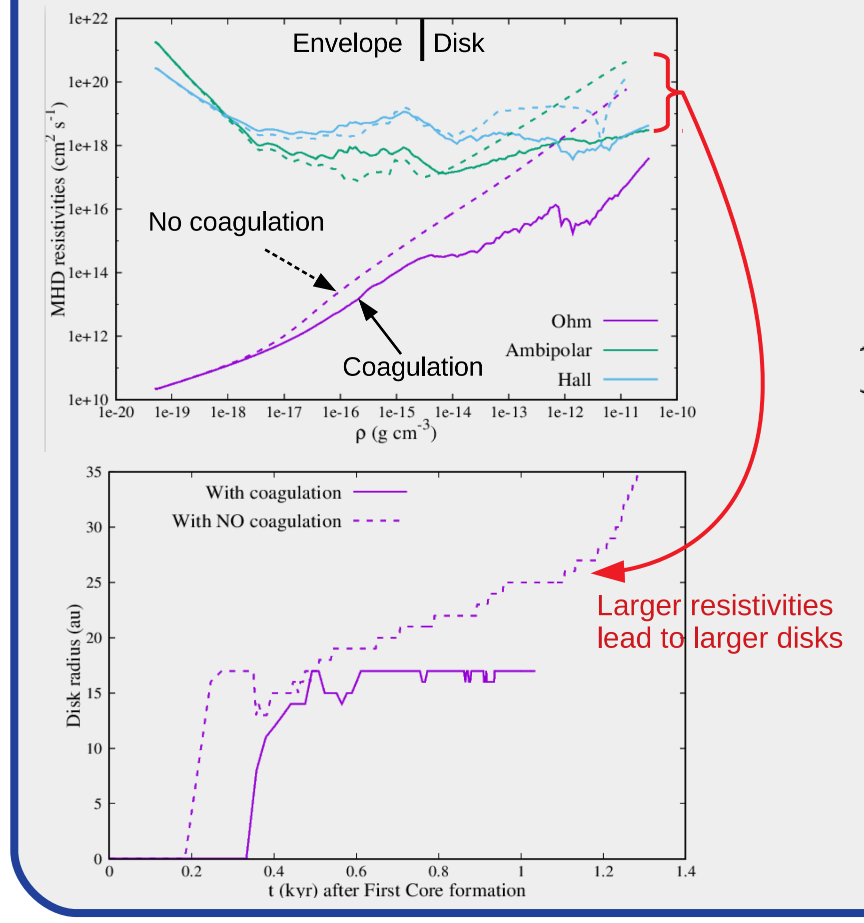
Integral over distribution

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

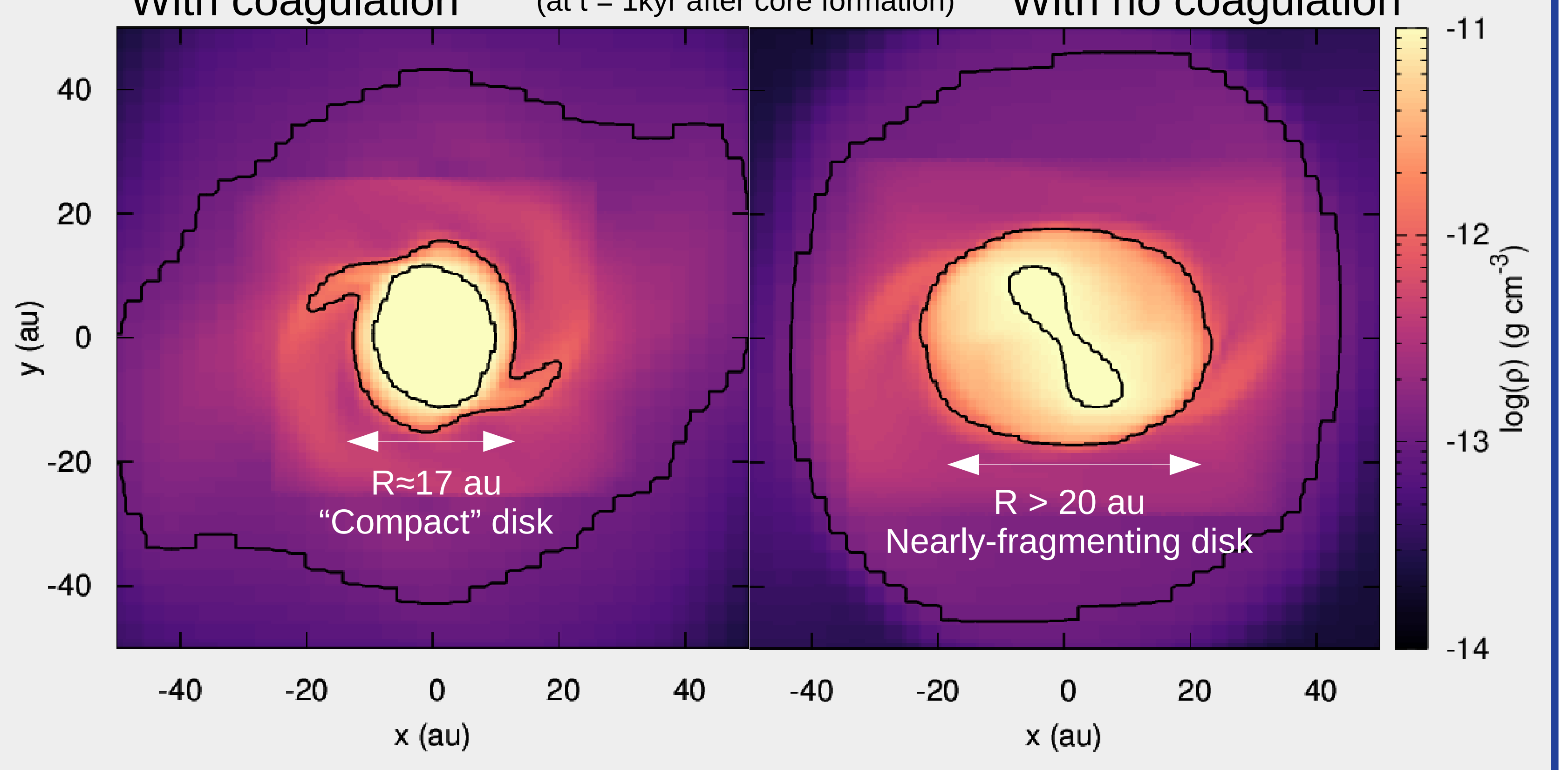
$$\boxed{d\chi = n_H^{\frac{3}{4}} T^{-\frac{1}{4}} d_g\, dt}$$

Coagulation =
1D process parametrized by χ

Impact on MHD resistivities and gas dynamics



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



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 !)

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.

References

Guillet et al. 2020, A&A 643, 17
Marchand et al. 2021, A&A 649, 50
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