SF2A; ATELIER SIMULATIONS NUMÉRIQUES EN ASTROPHYSIQUE

The gaseous protocluster: better characterizing the initial conditions of stellar cluster formation?

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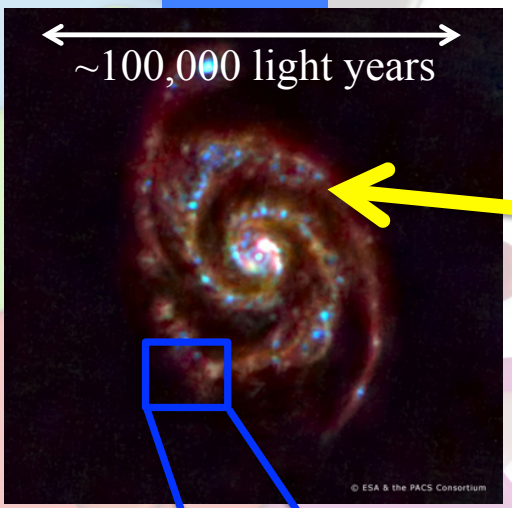
Context

Large Scale Structures

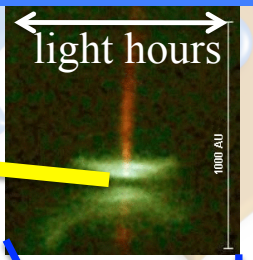
Interstellar Cycle and Star Formation

Planets

Galaxies

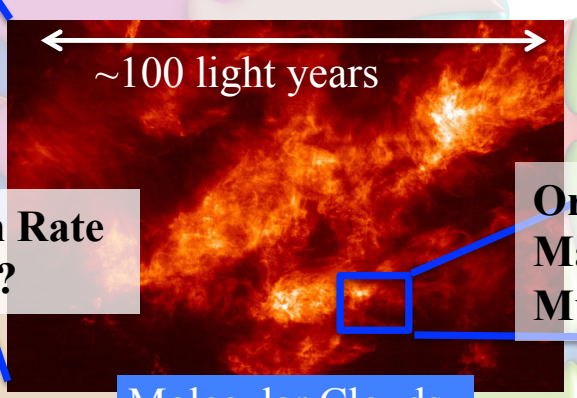


Stars and Accretion Disks



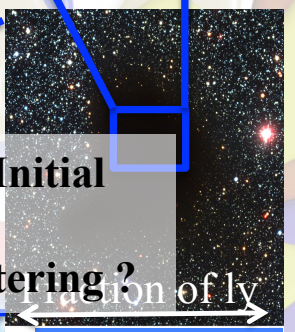
Feedback Efficiency ?

Protostars, Binarity Protoplanetary Disks ?



Molecular Clouds

Star Formation Rate and Efficiency ?



Dense Cores

Origin of the Stellar Initial Mass Function ? Multiplicity and clustering ?

Context

Main difficulties in star formation simulations

- Large range of temporal and spatial scales
- Strong coupling between several physical processes
- Difficult to simplify and isolate the problems

Outline

Star formation simulations

RAMSES MHD simulations (Teyssier 2002, Fromang+2006)

Physics

- 10^4 $M_\odot$
- $\rho = \rho_0/[1 + (r/r_0)^2]$,
  $\rho_0 = 800$ cc^{-1}
- cooling function
- turbulent Mach number 2.7-10

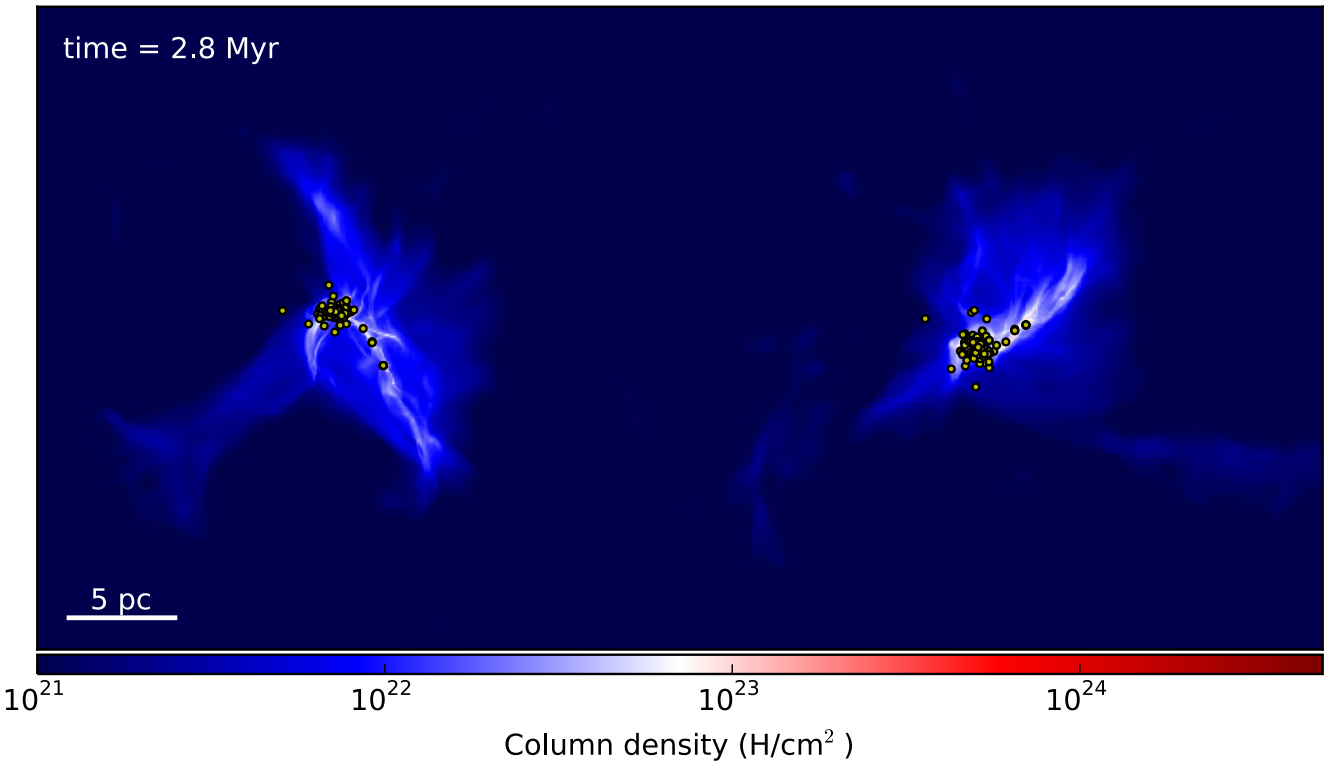
Numerics

- 30 pc computational box
- 128^3 base grid (0.23 pc)
- 7 AMR levels (0.002 pc $\sim$ 400 AU)
- sink particles

Star formation simulations

Star formation simulations often are initialized with a molecular cloud, or a piece of cloud

- cluster formation
- origin of the IMF
- star formation rate (SFR)
- star formation efficiency (SFE)



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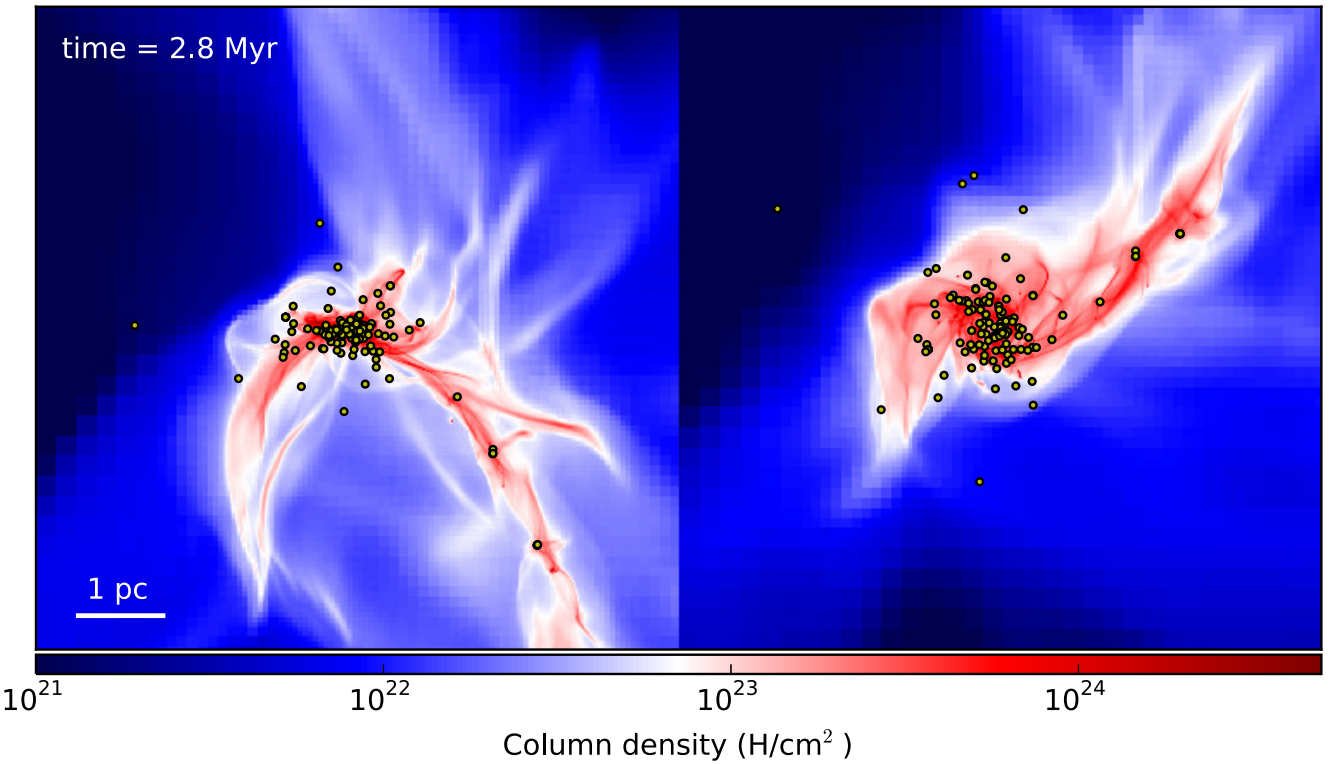

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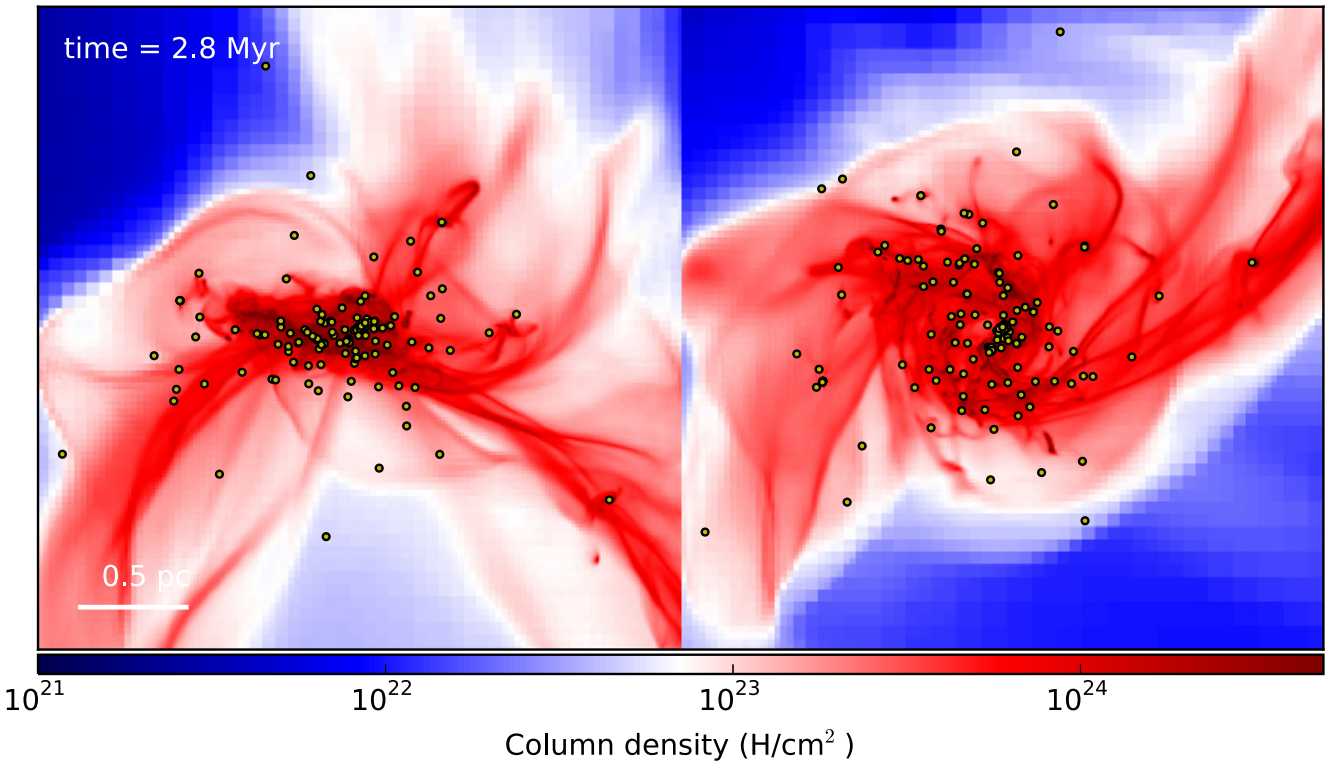
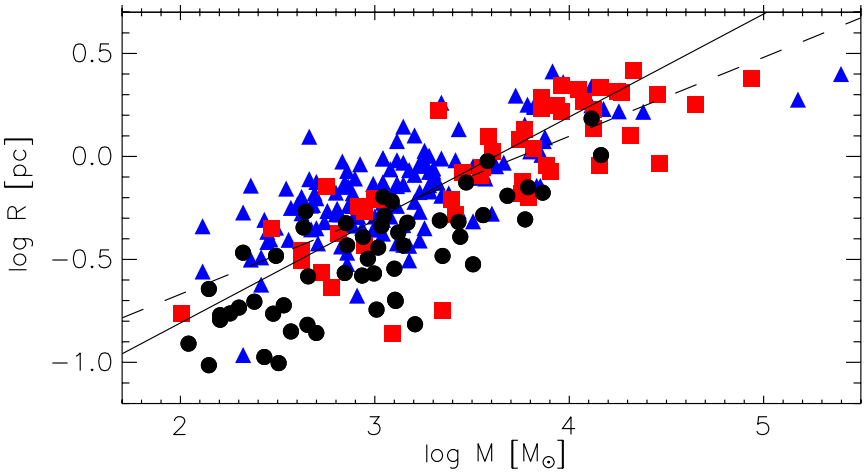


The gaseous protocluster

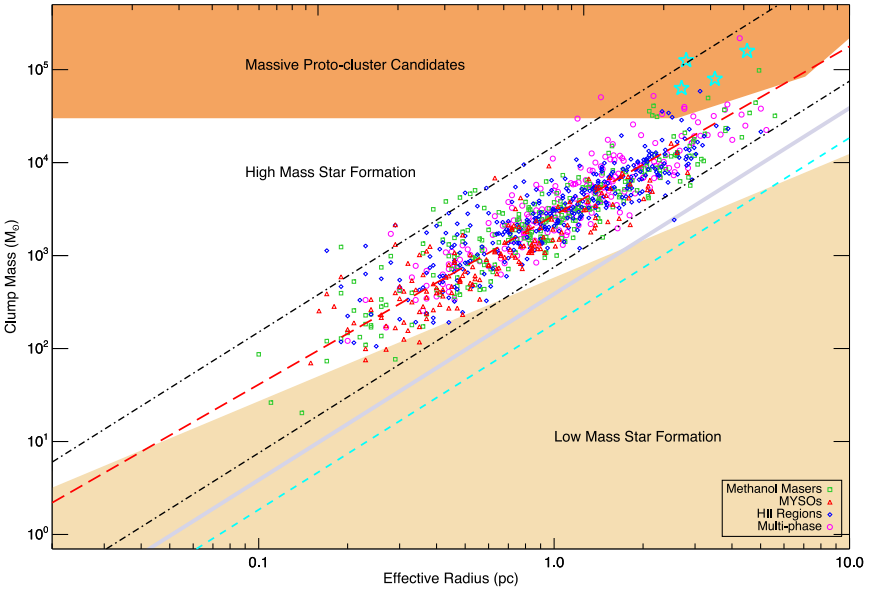
Star forming clumps from molecular and continuum observations

- $R \propto M^{0.38}$



Fall+ (2010)

- $M \propto R^{1.67}$



Urquhart+ (2014)

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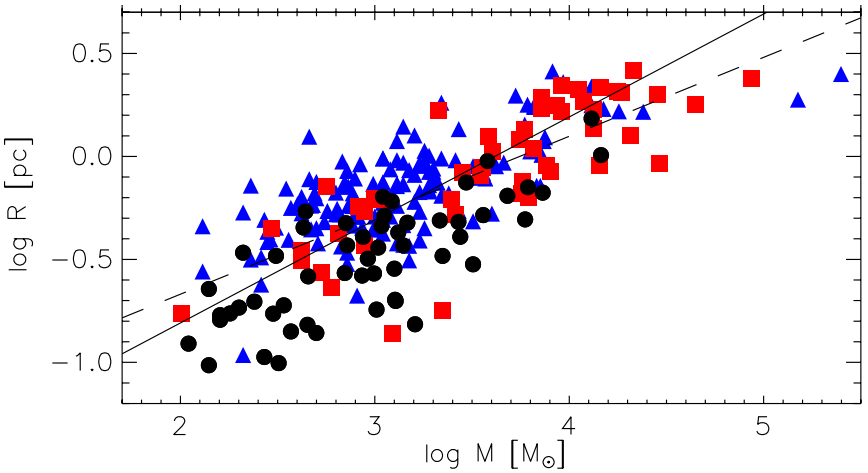

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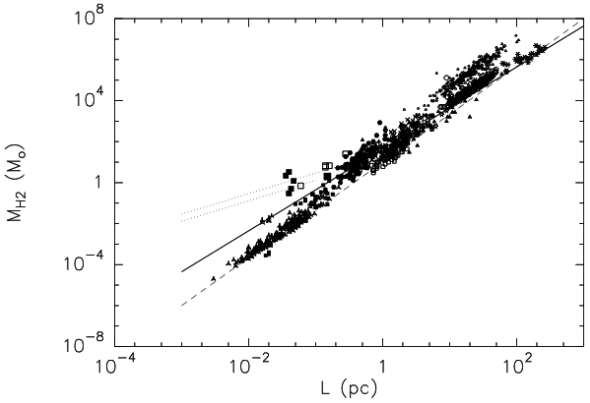

Larson's relation Hennebelle & Falgarone (2012)

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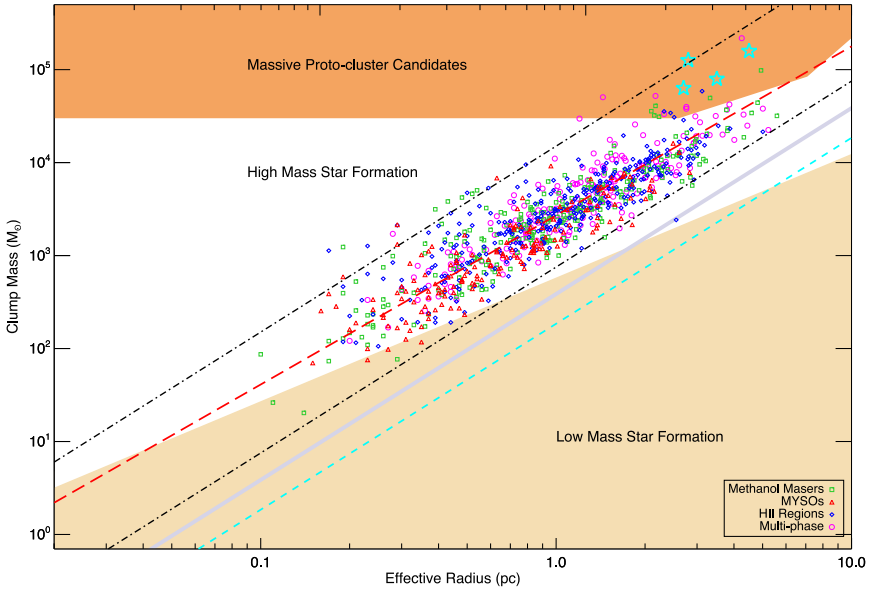

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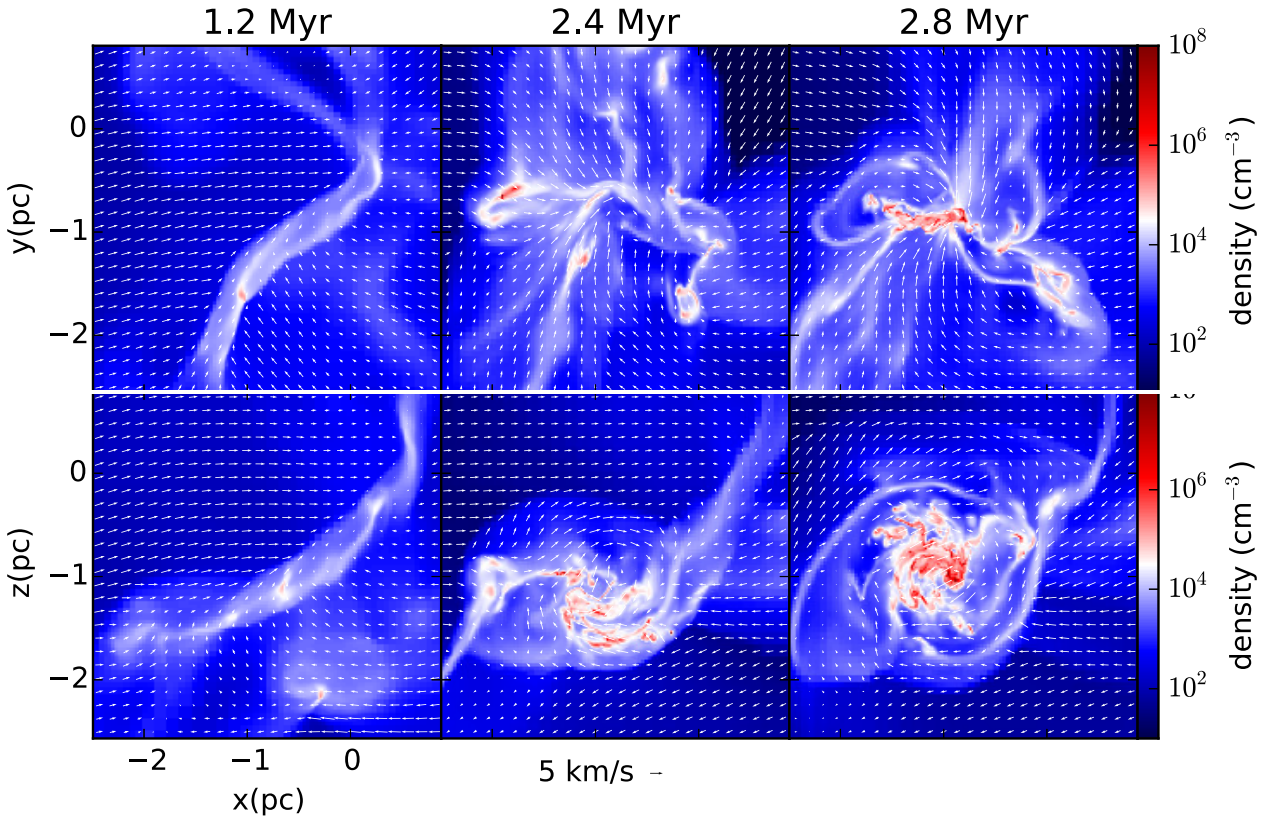
The gaseous protocluster

The gaseous protocluster!

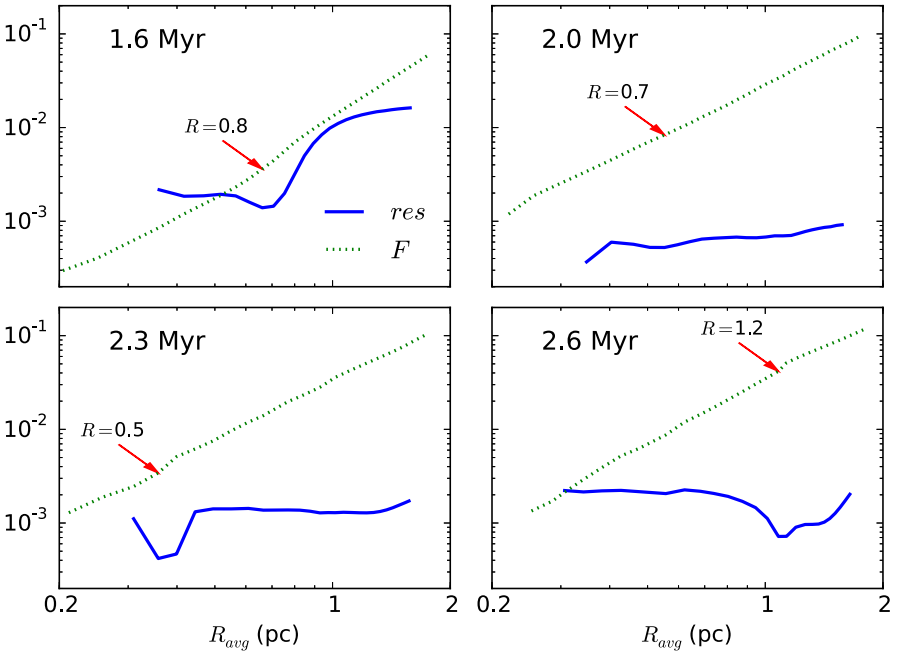
- The formation of dense structures inside molecular clouds
- The transition of flow properties



The gaseous protocluster

Infalling motion dominates in the envelope, while rotation dominates inside the proto-cluster.

$$F(R) = \int_{V(R)} -\mathbf{v} \cdot \mathbf{r} \rho dV$$



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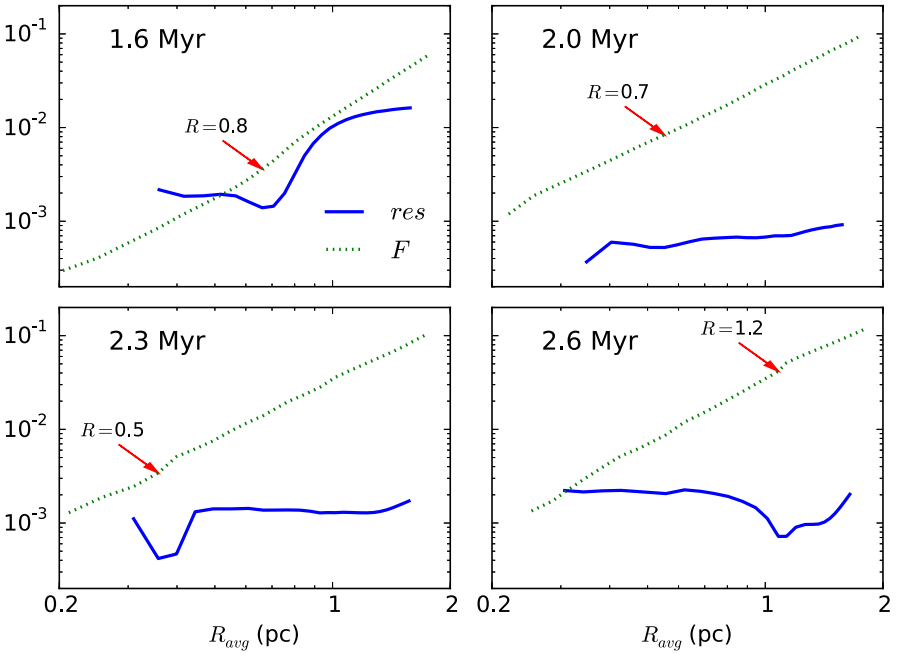


in the collapsing cloud

$$\rho v_{inf} 4\pi r^2 \propto r^0$$

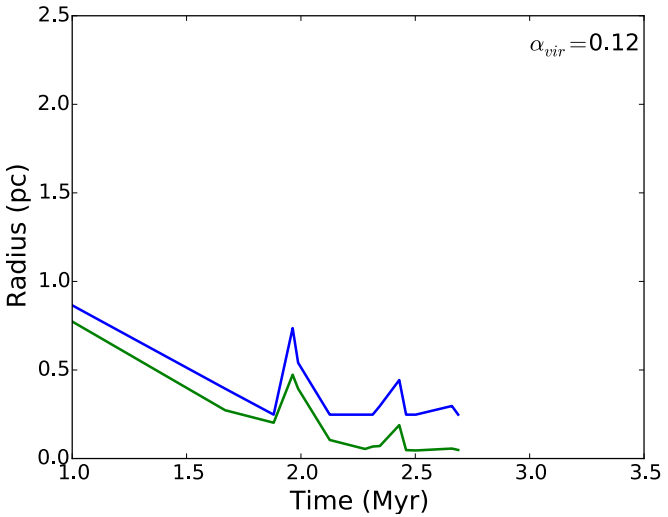
$$\int \rho v_{inf} r dV \propto R^2$$

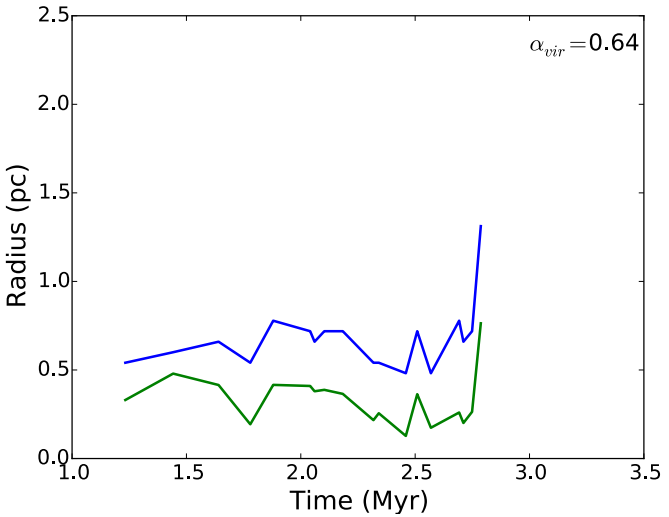
in the cluster

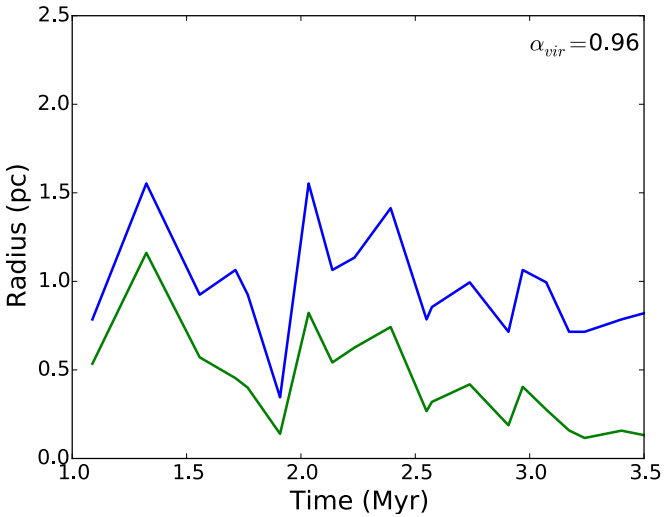
$$d_r(\rho v_{inf} 4\pi r^2) = \dot{\rho} 4\pi r^2 \propto r^2$$

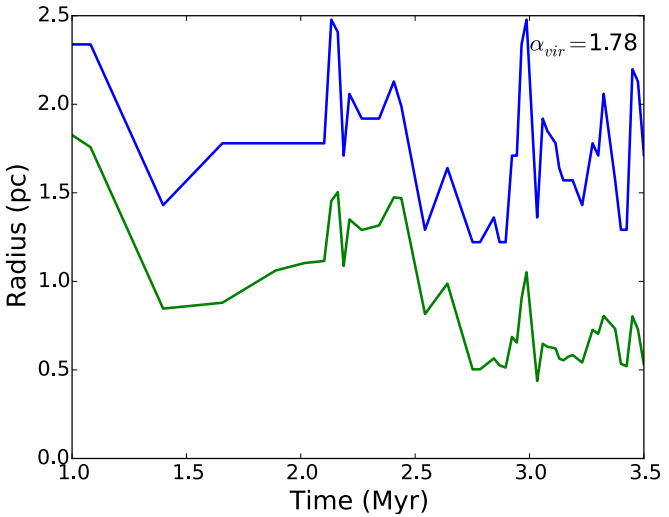
$$\int \rho v_{inf} r dV \propto R^5$$

The gaseous protocluster









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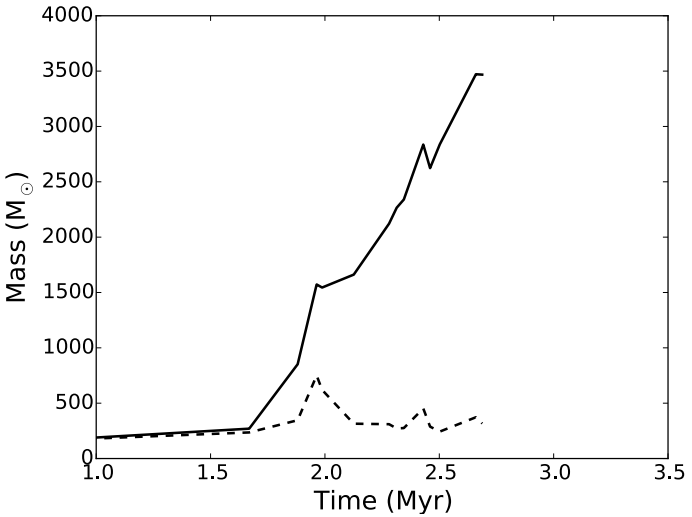
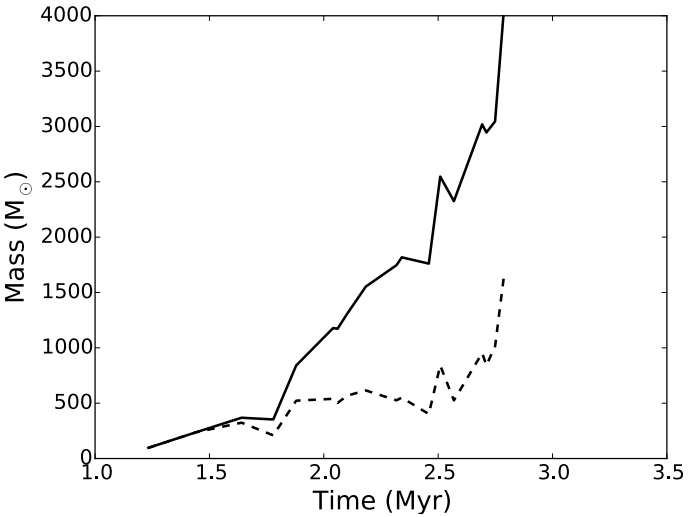
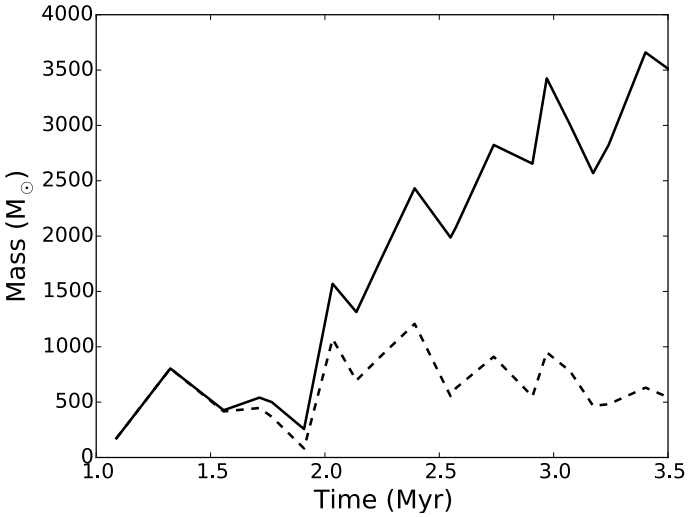
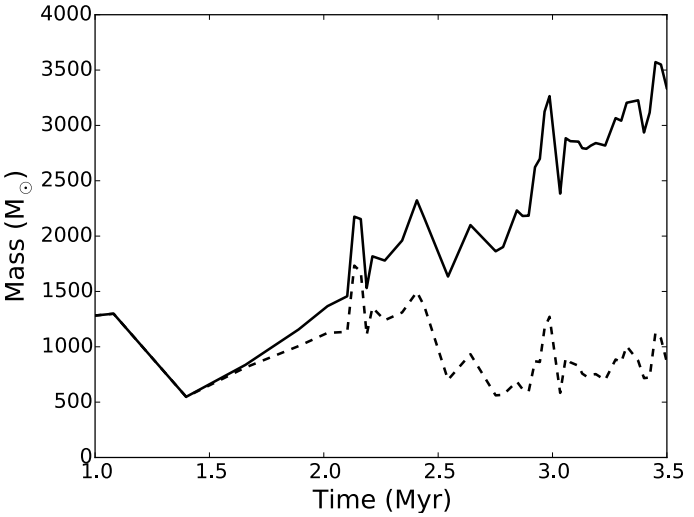




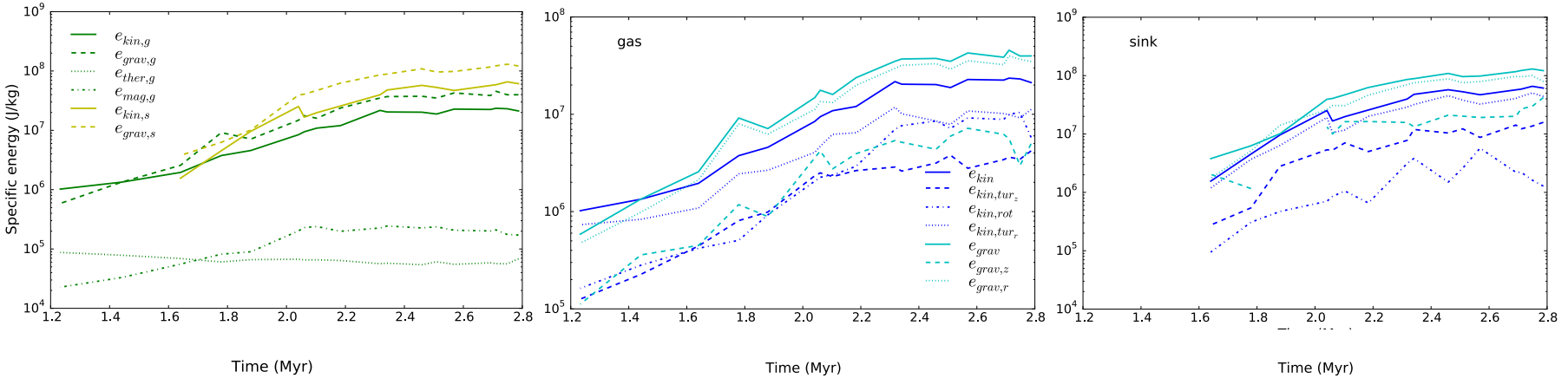




Energy properties

- The gaseous protocluster is in virial equilibrium
- So is the sink particle cluster

gas sink kinetic gravitational



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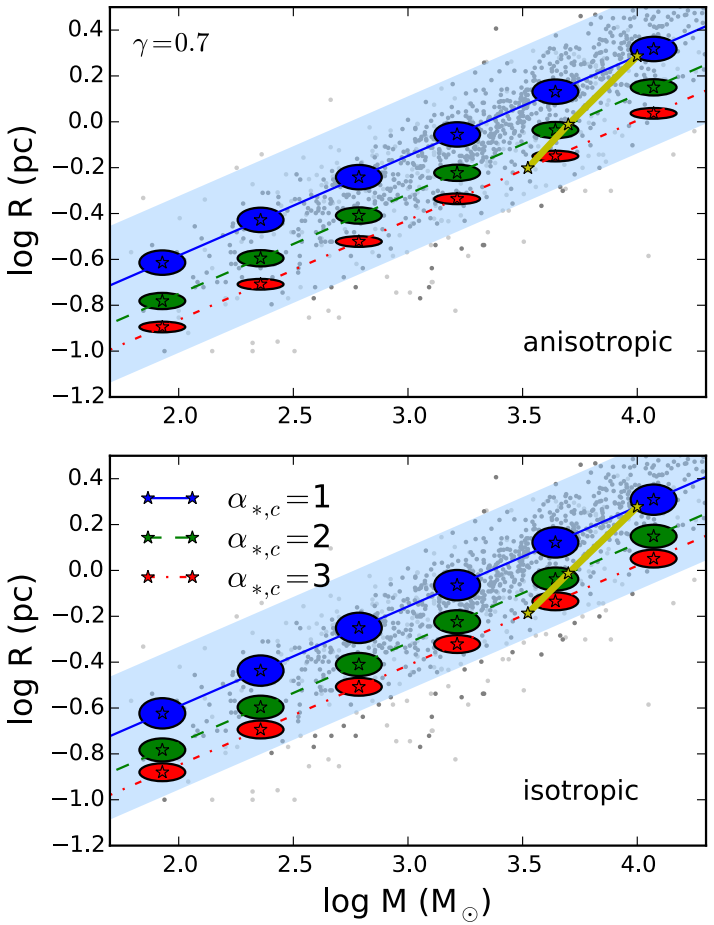
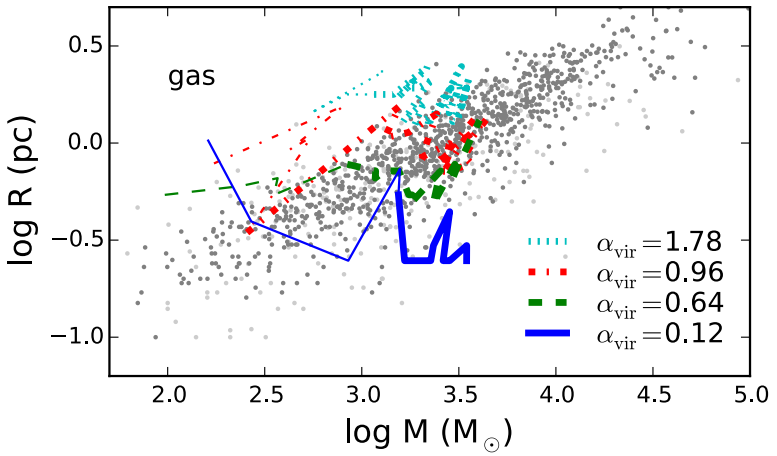
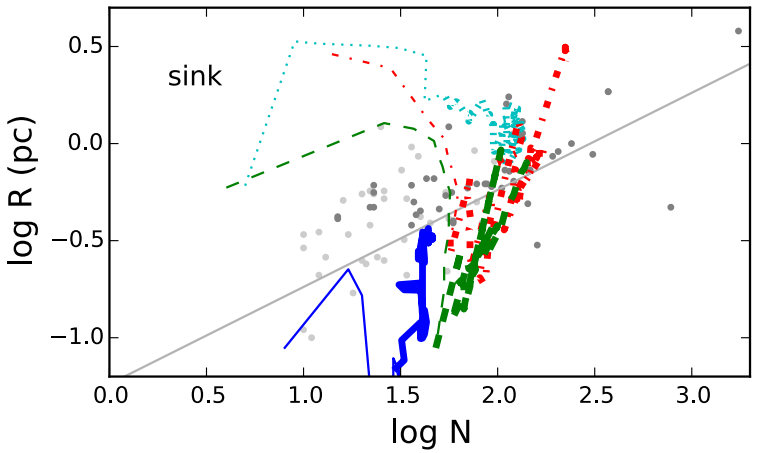
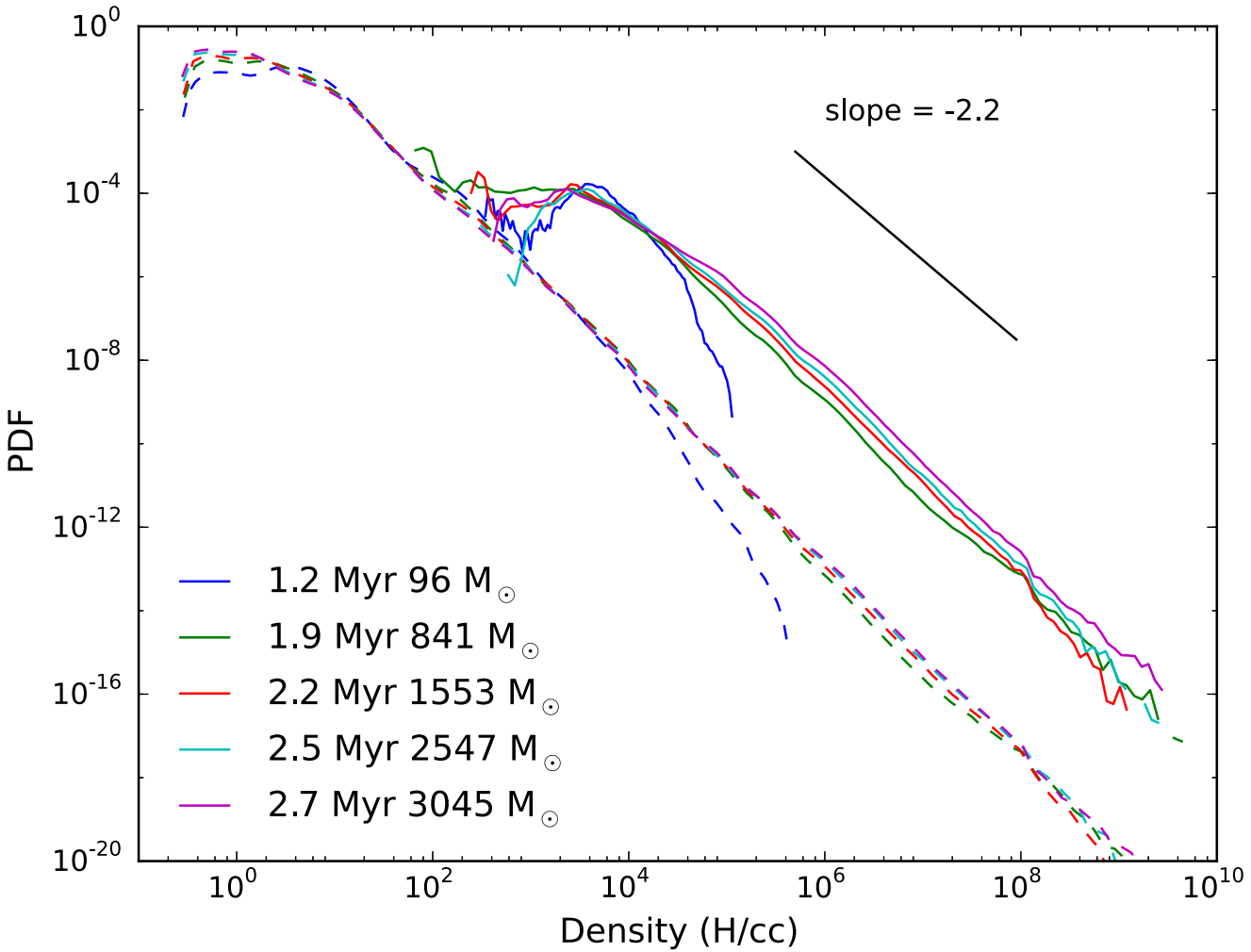






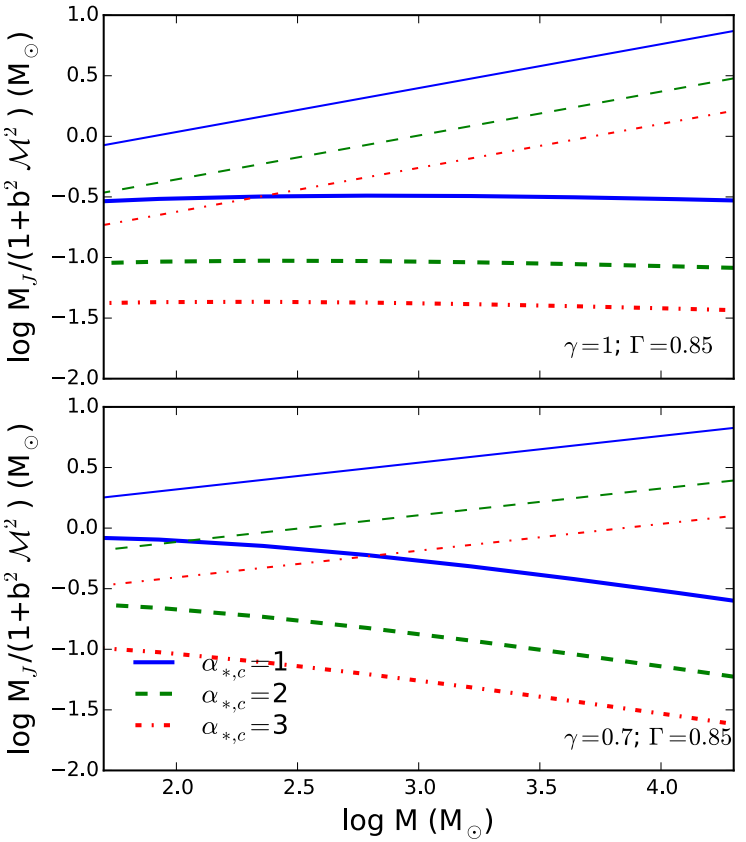
Energy properties

The density PDF inside the gaseous protocluster



Conclusions and outlook

- Stars do not form uniformly in molecular clouds
- Porotcluster conditions different from molecular clouds
- Observed protocluster mass-size relation reproduced by simulation and a viral model
- Starting with a more realistic and economic initial condition to study cluster formation
- Towards a more realistic cluster with stellar feedback: jet, ionizing radiation, supernovae



L & H 2016, A&A, 591, A30
L & H 2016, A&A, 591, A31