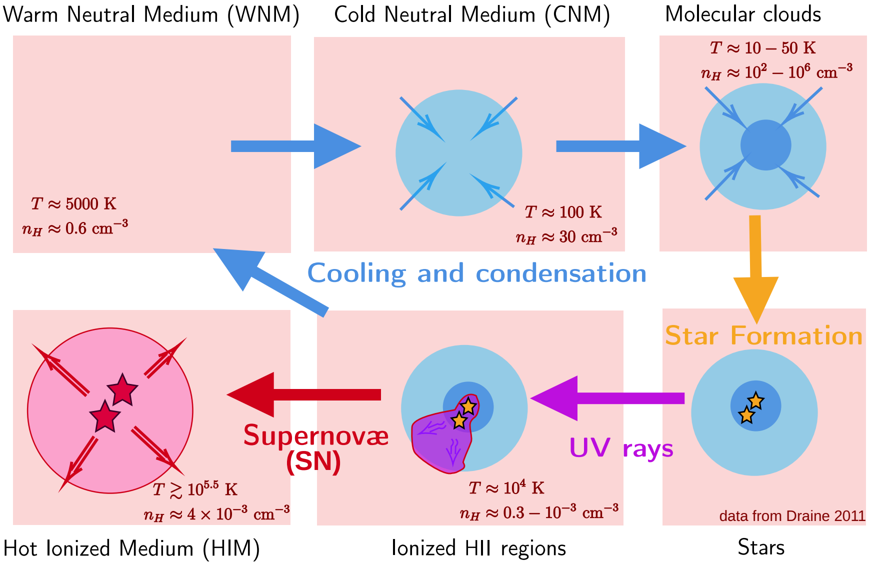
What is the contribution of gravity on the mass assembly of star-forming clouds?

Noé Brucy, Enrique Vázquez-Semadeni, Tine Colman, Jérémy Fensch, Ralf Klessen

SNO Ramses - Paris, 11/2025

The matter cycle in the ISM



Key questions when studying star formation at the Galactic / ISM scale

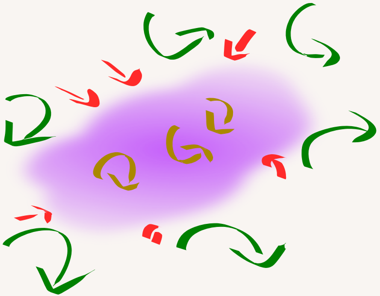
How do the the warm diffuse gaz condense into cold dense clouds?
From there, how do these clouds further condense to form stars?

Several answers one can get:

- It's all (or mainly) due to [insert your favorite process here] (usually to pick among gravity, turbulence or magnetic field)
- It's a bit of everything
- It depends

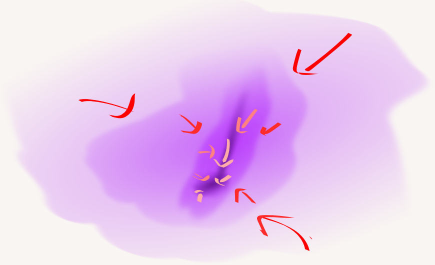
Mass assembly of molecular clouds and star formation

Turbulence-Driven



1. Turbulence shapes the density field
2. Small overdensities collapse because of gravity.

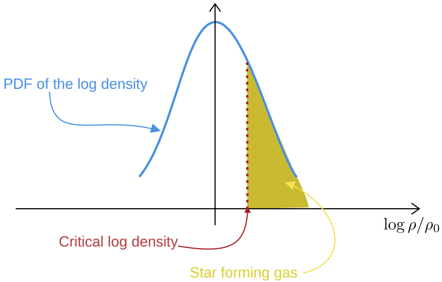
Gravity-driven (GHC)



- Gravity acts as a conveyor belt that drive gas accross density layers.

Hoyle 1953, Hartman+ 2001, Vazquez Sedameni 2009,2017,2019,2024

A bit more on Gravo-turbulent models



Krumholz & McKee 2005, Padoan & Nordlund 2008, Hennebelle & Chabrier 2011, Federrath and Klessen 2012.

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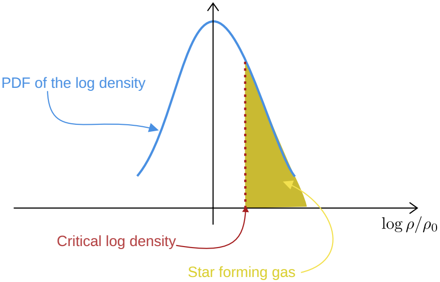

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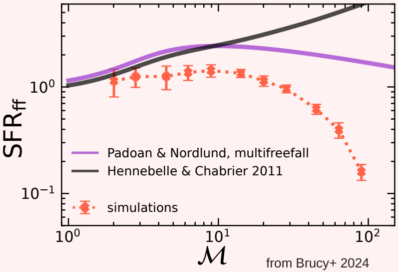
These models don't work at high Mach



from Brucy+ 2024

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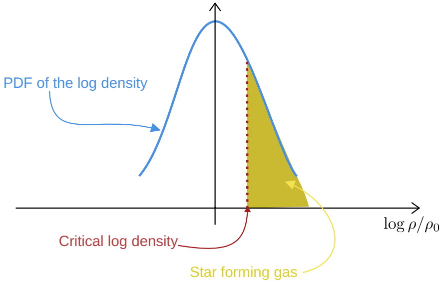

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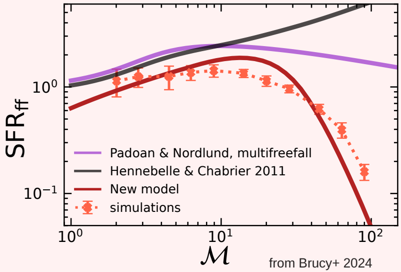
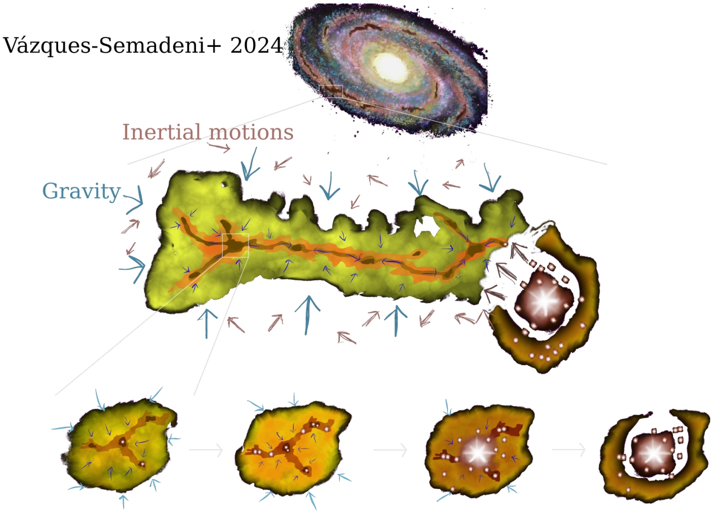


from Brucy+ 2024

Check new **Turbulent support** model: Hennebelle+2024, Brucy+ 2024.

A bit more on GHC



How to distinguish from the two paradigms?

In the Global Hierachical Collapse scenario, the **contribution** of the gravitational pull needs to be large.

For a given molecular cloud we need to quantify how much gas is:

- gravity-driven
- inflowing into the cloud

We can do it in simulations of the interstellar medium, by tracking the gas

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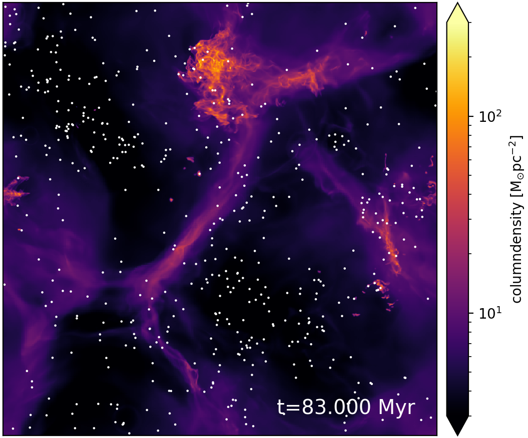
Application on a ISM simulation

Introduced in Colman+2025

Stratified ISM box simulation

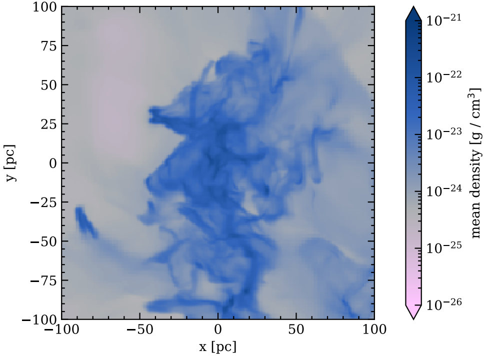
- Stratified kpc box
- ISM cooling/heating
- Supernova and HII radiation
- Resolution 4 pc - 1 pc
- Sinks form at $2.34 \cdot 10^{21}$ g·cm^{-3} (10^3 cm^{-3})



Setup: Iffrig+2015,Cooling+2018, Brucy+2020,2023, Colman+2022,2025

What are we looking at

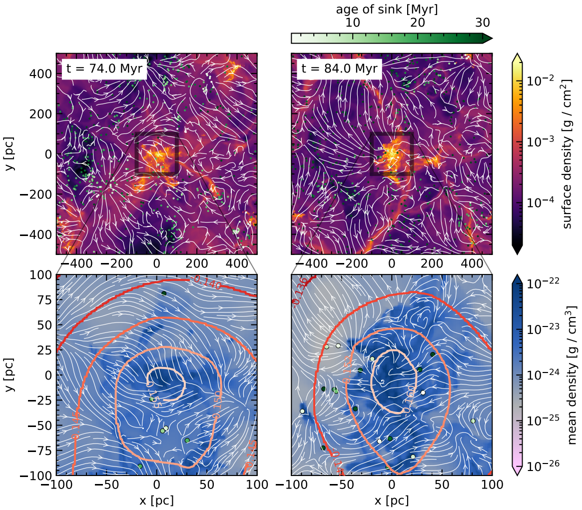
- A giant overdensity of gas
- Lifetime ≈ 15 Myr
- Density: from 10^{-23} to $4 \cdot 10^{-21}$ g·cm^{-3}
- CNM mass: $2 \cdot 10^5\ M_\odot$
- Size: ≈ 200 pc
- Velocity dispersion: 9 km·s^{-1}



Method

Resimulation of the life of a molecular cloud

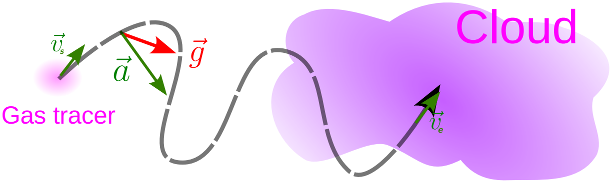
- From $t_i = 74$ Myr to $t_f = 84$ Myr
- At t_i, introduction of one tracer per cell
- Recording of the force experienced by the tracers



Method

Cloud-in-cell tracers particle

How do we recognize gravity-driven inflowing gas?



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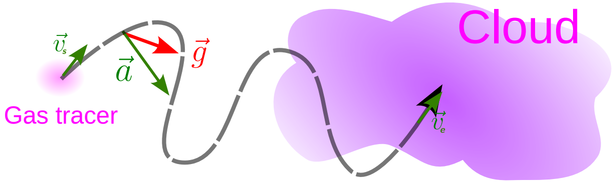

$$\vec{a}_{\mathrm{grav}}(t_s, t_e) = \frac{\int_{t_s}^{t_e} \vec{g}\, \mathrm{dt}}{t_e - t_s} \quad (1)$$

$$\vec{a}_{\mathrm{other}}(t_s, t_e) = \frac{\int_{t_s}^{t_e} \vec{a}\, \mathrm{dt}}{t_e - t_s} - \vec{v}_{\mathrm{grav}}(t_s, t_e) \quad (2)$$

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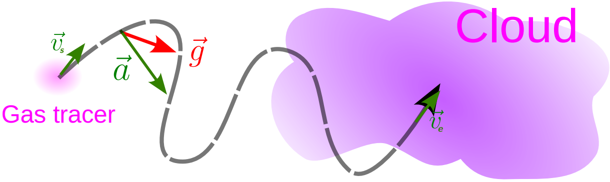

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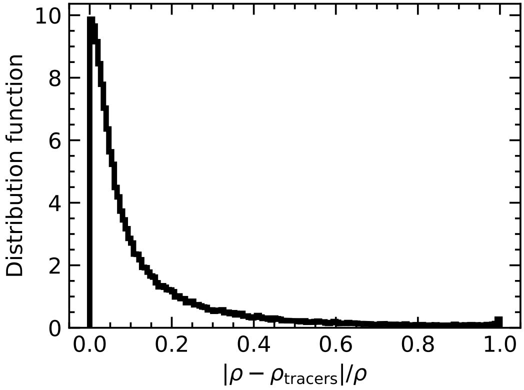
Gravity-driven: gravity contributed to more than 50 % of the resulting integrated acceleration

$$a_{\mathrm{grav}} > a_{\mathrm{other}}$$

Tracers in Ramses?



- We use velocity-advected tracers (Pichon+2011, Dubois+2012)
- Known for their lack of accuracy (Genel+2013)
- Other technique: Monte-Carlo tracers (Cadiou+2018) → not suited for force recording
- We quantify the error on the density

Error $<$ 15 % for 70 % of the tracers' mass.

Tracers in Ramses?

Changes in the code: tracers_memory branch

Goal: Gravitational contribution to the acceleration

- Make it possible to initialize "classical" tracers (again)
- Add new particle arrays (`vp_grav`, `vp_prev`, `ap_grav`)
  - Declaration
  - Allocation
  - Communication
  - I/O (dump & re-read)
- Update the new arrays with grav contribution (`move_fine` and `synchro_fine`)
- Repair and adapt `amr2cube` and `part2cube`

Thanks to the headers, the new arrays are directly read by Osyris.

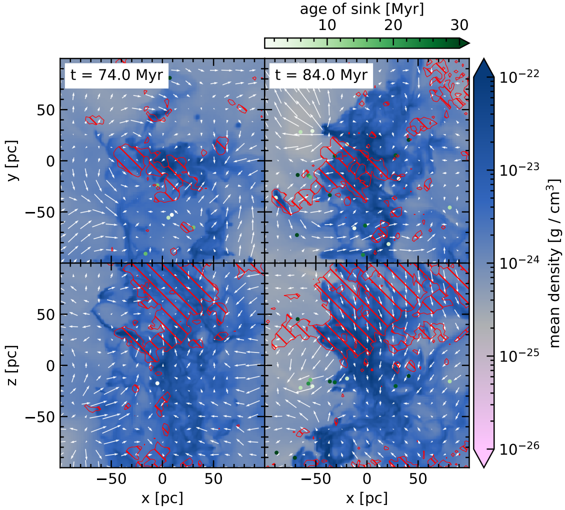
In green: Useful fixes that were ported in Ramses Vanilla.

Gravity-driven accretion

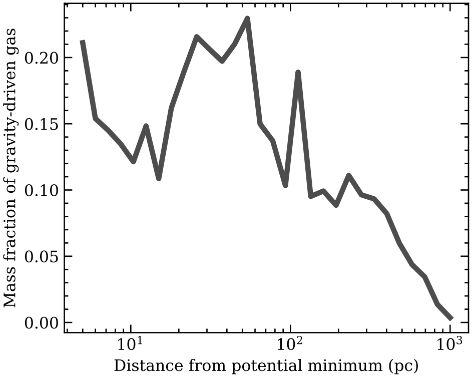
Where is the gravity-dominated gaz coming from?

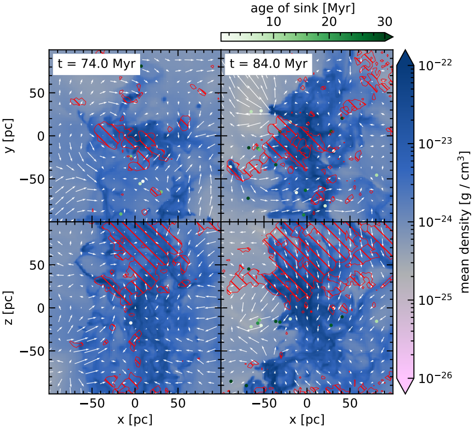
- Density slices
- Red = > 20 % of gravity-dominated tracers
- White dots = new stars

Answer: A bit from everywhere, with self-gravity dominated gaz in the midplane and a significant contribution from the Galactic fountain.



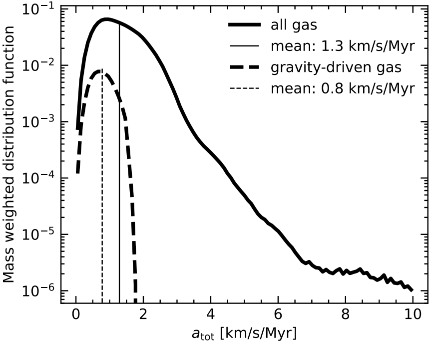
Mass fraction of gravity-driven gas





A fraction of 10-20 % of the gas is gravity-driven up to 100 pc from the center of the cloud

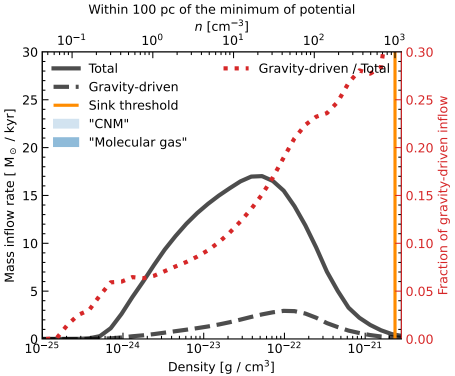
But gravity-dominated gaz is slow

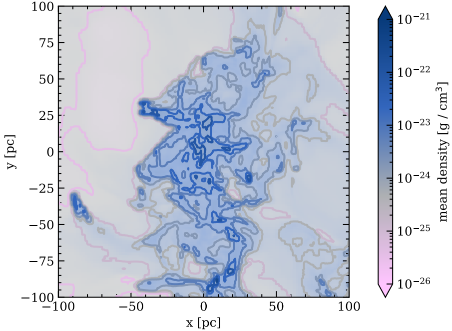


Supernova driven gaz can reach several hundreds of km/s while gravity infall is limited to 8 to 10 km/s.

Can it has a significant contribution to the clouds' mass assembly?

Mass flow towards across isodensity lines

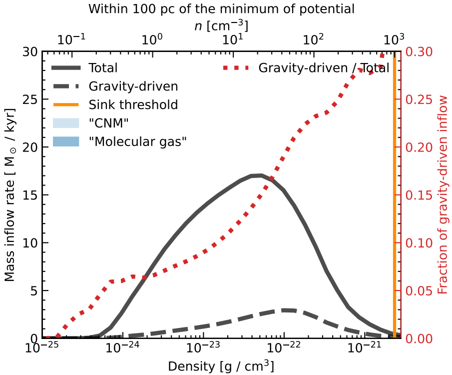


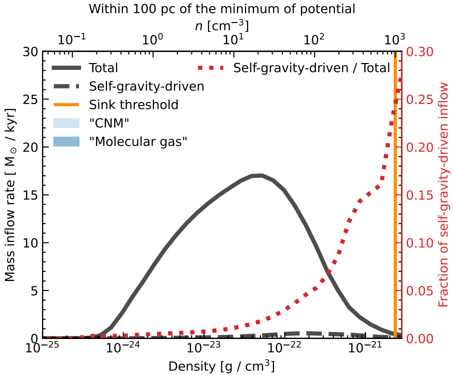


10 % of the gas inflowing onto the GMC is gravity-driven. This fraction rise to 30 % inside the clouds.

Stratified potential vs Self-gravity

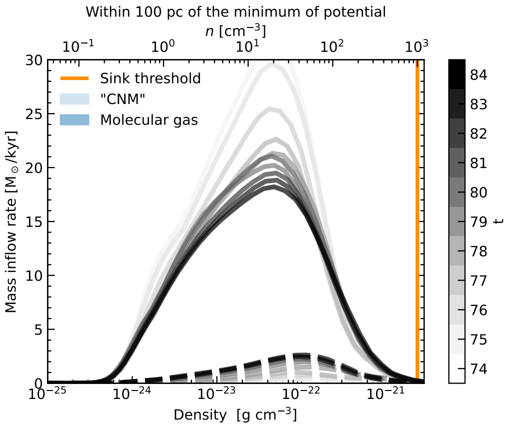
Proxy: looks at gas for which the movement parallel to the plane is gravity-driven

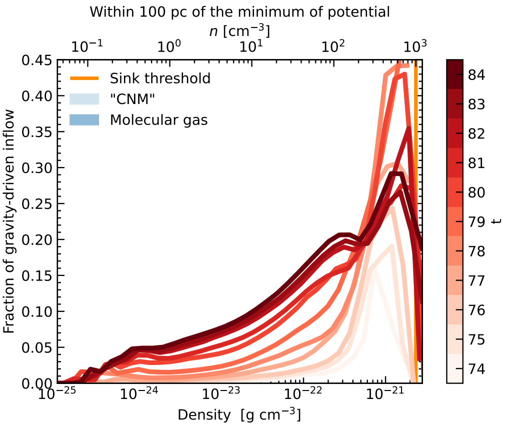




Stratified potential dominates the gravity-driven gas at large scales while self-gravity is stronger in dense regions

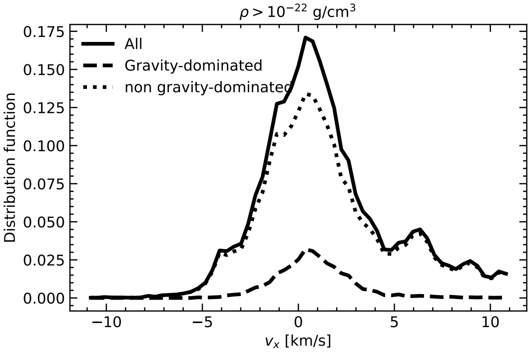
Time evolution





The fraction of gravity-driven increases as the integration time increase

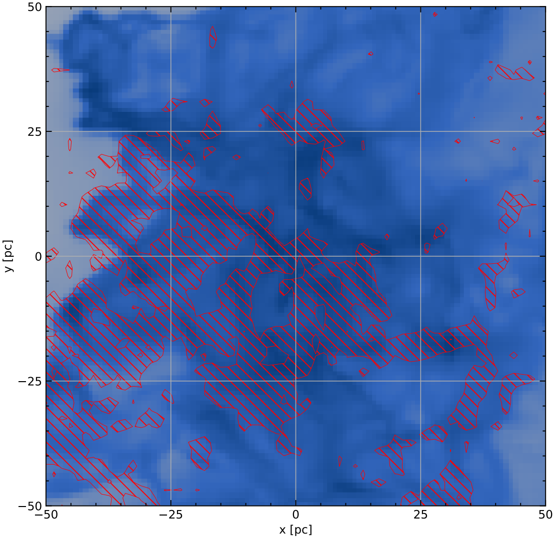
Contribution of the gravity-driven gas to the linewidth

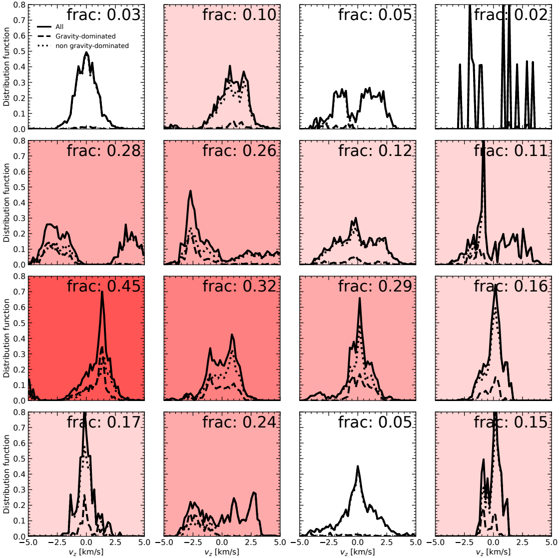


- Linewidth over a 100 pc wide area
- Gravity-driven gas: 10 % of the variance of the velocity
- No change of the FWHM

At 100pc scale, the contribution of gravity-driven gas to the linewidth is negligible

Perspective: towards an observational criterion

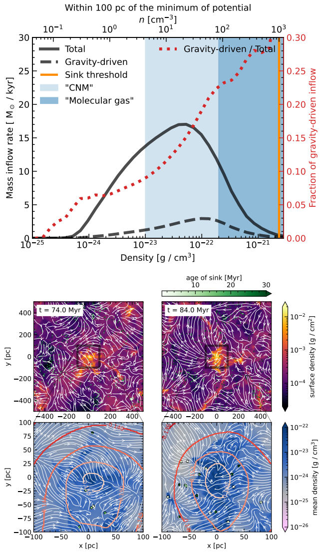




Conclusions

Paper under review: Brucy+ 2025 (Open Journal of Astrophysics)

- Global Hiearchical Collapse happens, with gravity-dominated gas up to 100 pc from the center of the cloud,
- Only 10 % on the inflowing gas is gravity-dominated → **not the main driver of cloud mass assembly**.
- The fraction of density inflowing gas progressively increases with density

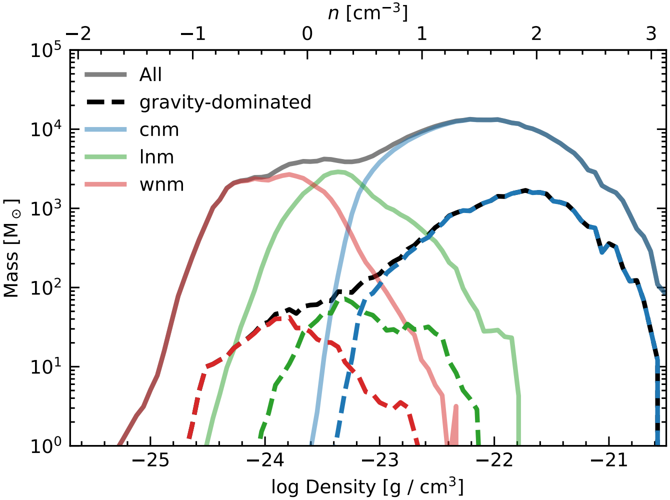


Perspectives

- Do a statistical study, look at larger and small scales
- Derive a criterion that can be used in observations

Phase decomposition

based on temperature



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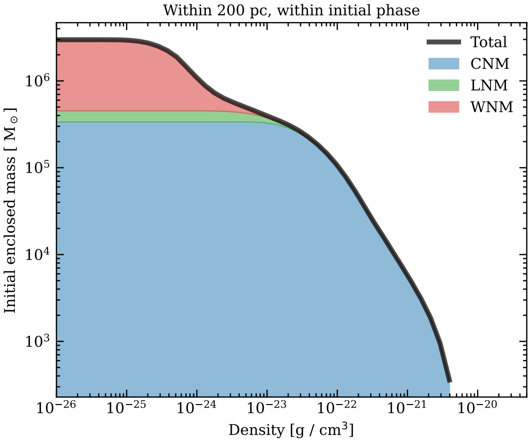

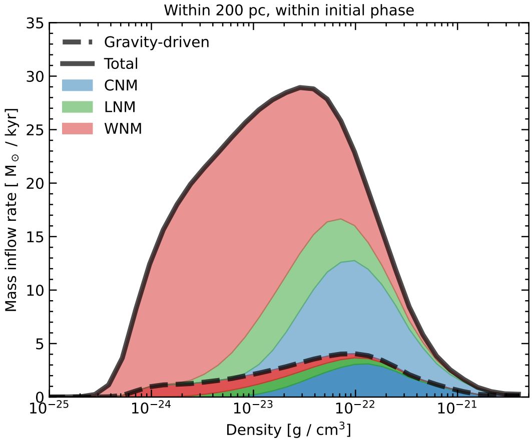

Cloud properties