<u>Stellar Physics at Paris Observatory</u>

Star formation with RAMSES

Implementing new physics and performing challenging simulations

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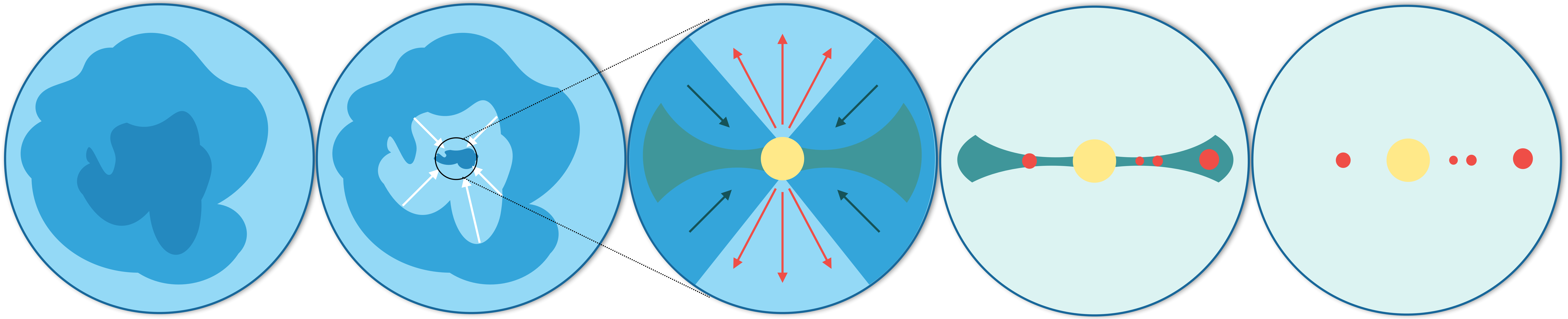
Ugo Lebreuilly 30/06/2022

Introduction The protostellar collapses



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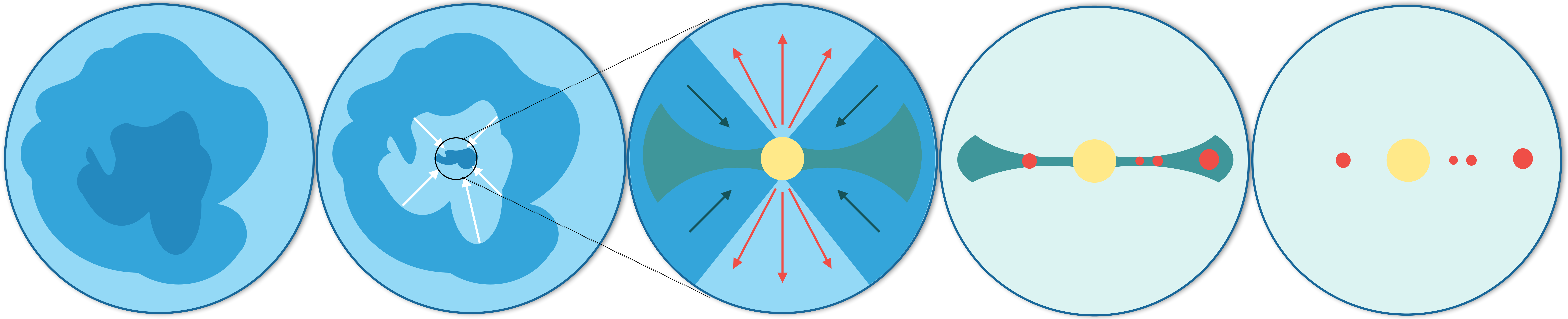

Jeans mass (Jeans 1902)

$$M_{\mathrm{core}} \geq \left(\frac{5k_{\mathrm{B}}T_{\mathrm{g}}}{\mu_{\mathrm{g}} m_{\mathrm{H}} \mathcal{G}}\right)^{3/2} \left(\frac{3}{4\pi\rho_0}\right)^{-1/2}$$

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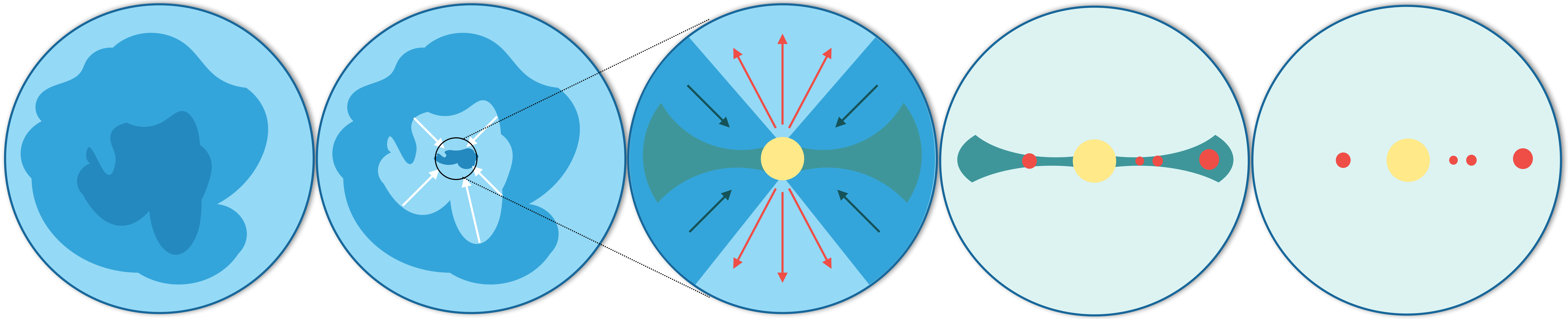
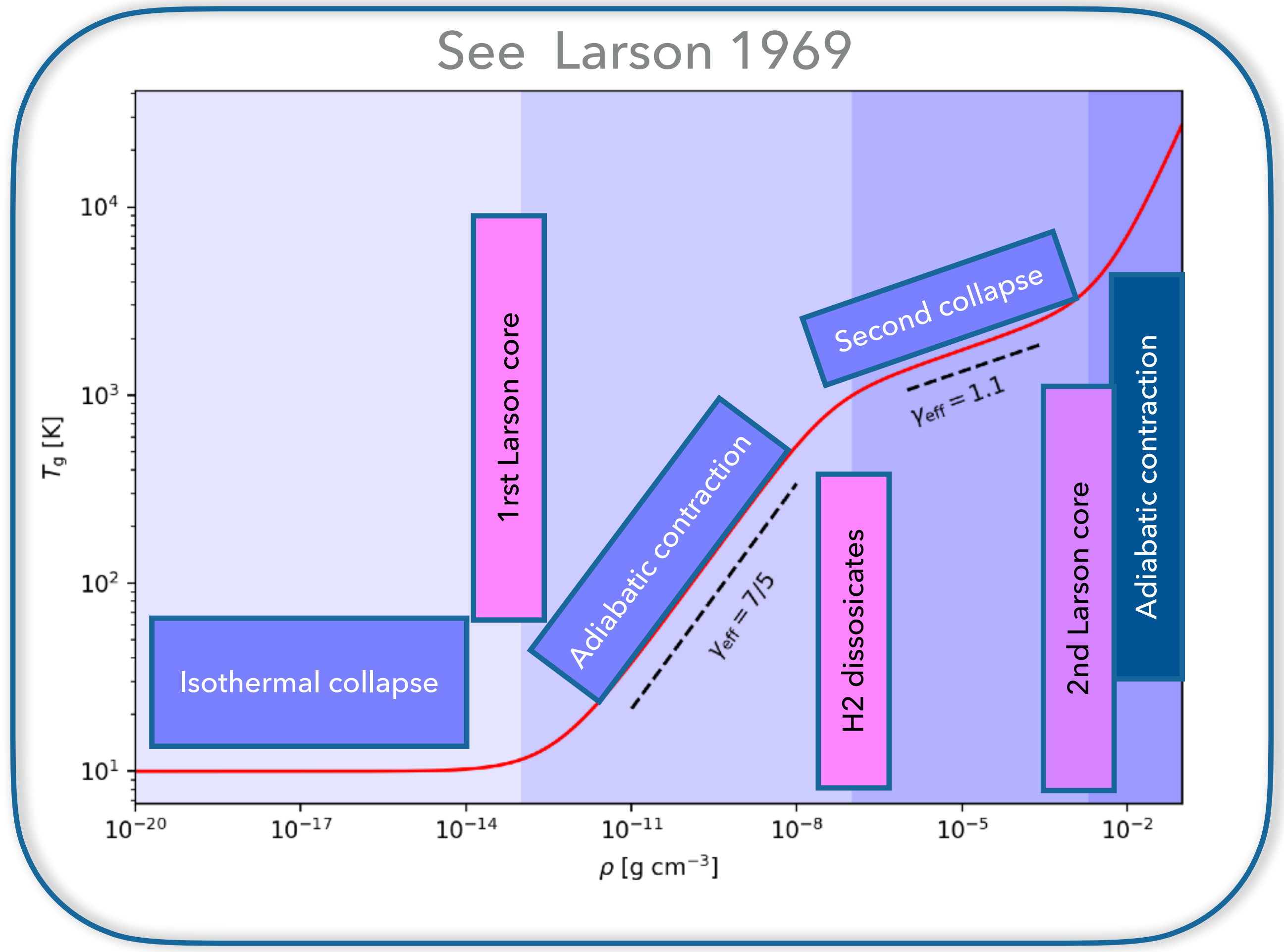


Free-fall timescale

$$t_{\rm ff} = \sqrt{\frac{3\pi}{32\mathscr{G}\rho_0}}$$

10 000 - 100 000 yrs

See Larson 1969



0

100 000 yrs

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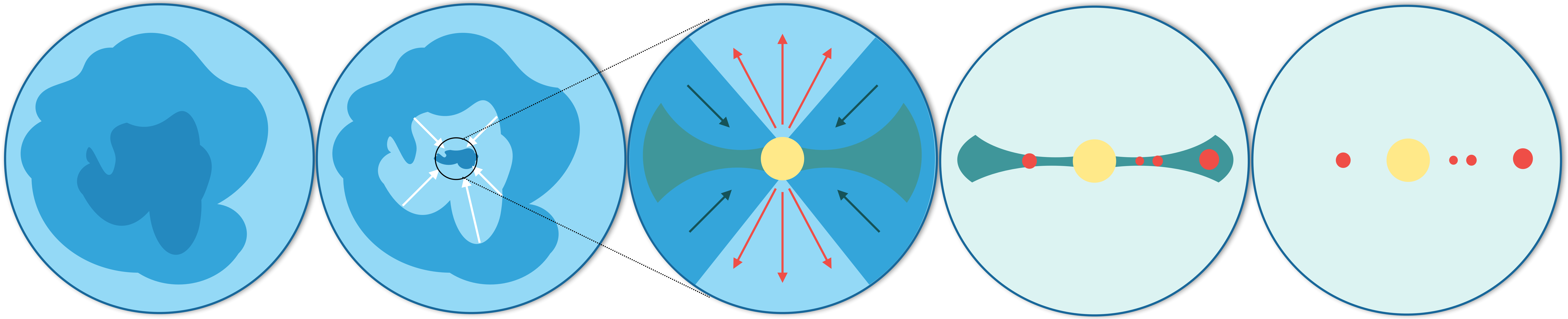

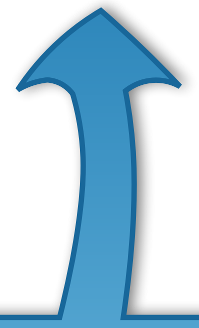

Accretion + Ejection

Protoplanetary disk

Matter ejected at the poles (winds and jets)

10 000 - 100 000 yrs

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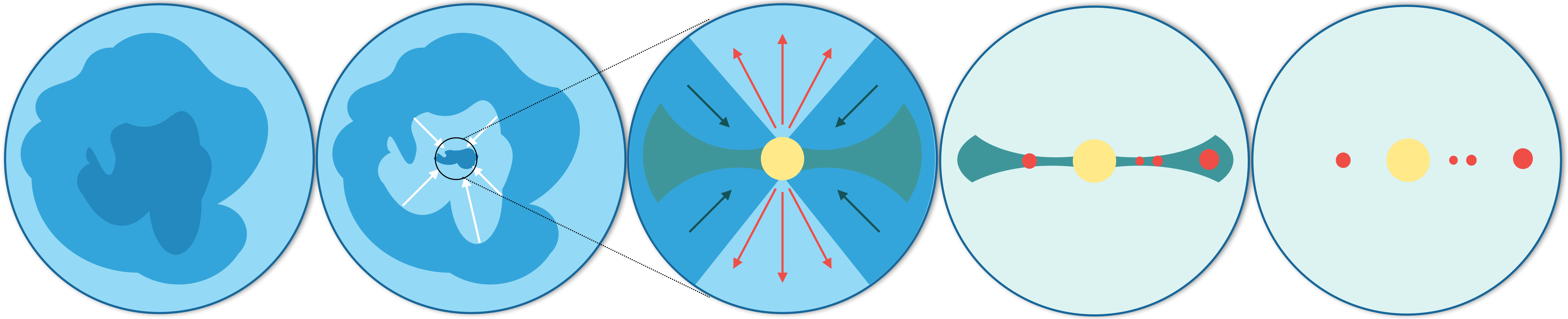


Protoplanetary disks

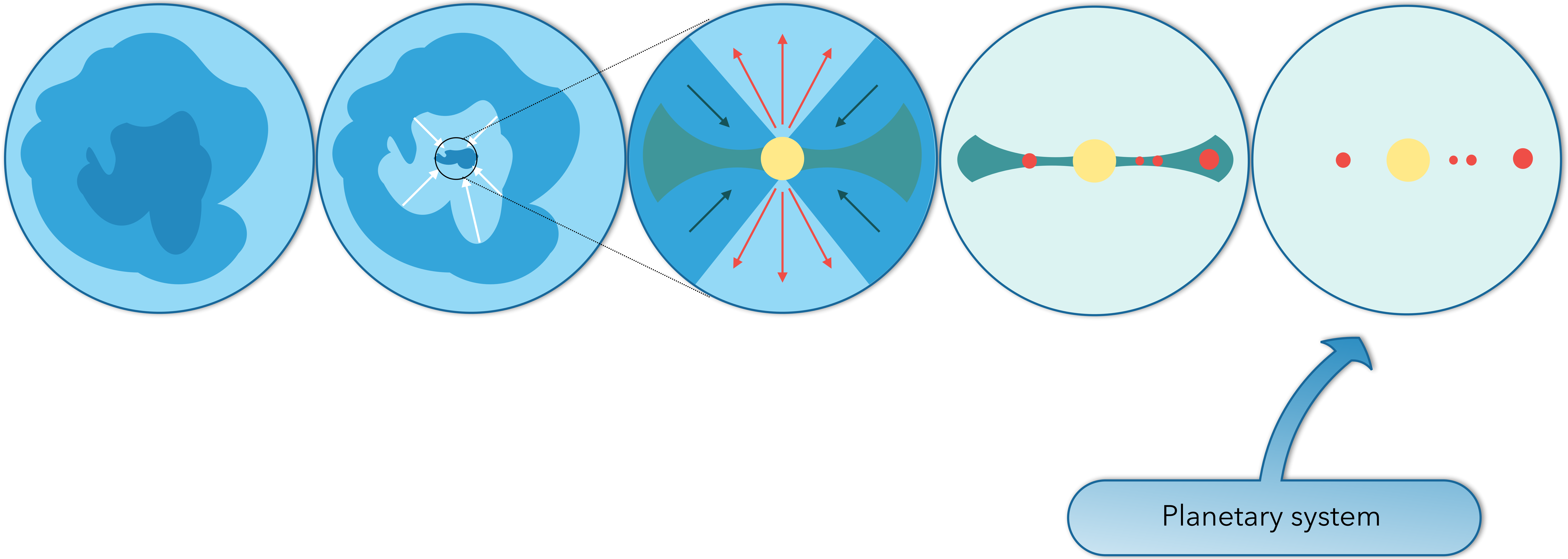
Quasi keplerian Gaz + dust

Planet formation by coagulation/fragmentation and accumulation of dust grains

Dispersal of the disk (Winds? Photo-evaporation?)

1 000 000 - 50 000 000 yrs

Introduction The protostellar collapses



Introduction A key component: dust

Interstellar dust grains

Distribution

1 % of the mass

Distribution in the diffuse ISM (MRN, Mathis et al., 1977)

$$\frac{\mathrm{d}n(s)}{\mathrm{d}s} \propto s^{-3.5}; s \in [5\,, 250] \ \ \mathrm{nm}$$

Larger grains in denser regions ?

1-10 microns in dense cores (Pagani et al., 2010)

10-100 microns around protostars (Kataoka et al., 2015; Sadavoy et al., 2018a, b, 2019; Galametz et al., 2019)

1-10 mm in protoplanetary disks

Crucial for

Observations : major tracer in star forming clouds

Dynamics : Coupled with the gas and also the magnetic field.

Thermodynamics : major cooling species and catalyser for molecule formation

Planet formation : dust grains are the building blocks of planets

But .. Dust is challenging to take into account numerically !

Introduction Dust is a numerical challenge

Difficulty 1 Dust grains are distributed in a spectrum of sizes -> Each dust size has a different dynamical evolution

Difficulty 2 Small grains are tightly coupled to the gas and large grains are completely decoupled (and very large grains are not in the fluid regime) -> 3 main regimes. No current method can handle all of them

Difficulty 3 Dust grain are coagulating and fragmenting during star formation -> Mass exchange between sizes modelled by a non-linear integro-differential equation.

Difficulty 4 Dust grains are typically charged and thus are coupled to the magnetic field

Methods Multifluid equations

(Saffman 1962)

$$\frac{\partial \rho_{\mathrm{g}}}{\partial t} + \nabla \cdot \rho_{\mathrm{g}} \vec{v}_{\mathrm{g}} = 0$$

$$\frac{\partial \rho_{\mathrm{d}}}{\partial t} + \nabla \cdot \rho_{\mathrm{d}} \vec{v}_{\mathrm{d}} = 0$$

$$\frac{\partial \rho_{\mathrm{g}} \vec{v}_{\mathrm{g}}}{\partial t} + \nabla (\rho_{\mathrm{g}} \vec{v}_{\mathrm{g}} \otimes \vec{v}_{\mathrm{g}} + P_{\mathrm{g}} \mathbb{I}) = \rho_{\mathrm{g}} \vec{f} + K \overrightarrow{\Delta v}$$

$$\frac{\partial \rho_{\mathrm{d}} \vec{v}_{\mathrm{d}}}{\partial t} + \nabla \rho_{\mathrm{d}} \vec{v}_{\mathrm{d}} \otimes \vec{v}_{\mathrm{d}} = \rho_{\mathrm{d}} \vec{f} - K \overrightarrow{\Delta v}$$

$$\frac{\partial E_{\mathrm{g}}}{\partial t} + \nabla \cdot (E_{\mathrm{g}} + P_{\mathrm{g}}) \vec{v}_{\mathrm{g}} = K \overrightarrow{\Delta v} \cdot \overrightarrow{\Delta v}$$

<u>Advantages:</u>

- Simple
- Complete (in the fluid approximation)

<u>Drawback:</u>

- 2 equations per dust species
- Not convenient in Lagrangian codes
- Intrusive for existing codes

Methods Dust and gas as one fluid

(Laibe & Price 2014a,b,c) See also Price & Laibe 2015; Lin & Youdin 2017; Hutchison et al., 2018 and Lebreuilly et al., 2019

Can we reformulate the multi-fluid equations using one fluid ?

One density $\rho \equiv \rho_{\mathrm{g}} + \rho_{\mathrm{d}}$

One advection velocity $\vec{v} \equiv \dfrac{\rho_{\mathrm{d}} \vec{v}_{\mathrm{d}} + \rho_{\mathrm{g}} \vec{v}_{\mathrm{g}}}{\rho}$

Several phases (gas and each dust sizes) $\epsilon \equiv \rho_{\mathrm{d}}/\rho$ and $\Delta \vec{v} \equiv \vec{v}_{\mathrm{d}} - \vec{v}_{\mathrm{g}}$

Note: Same as in magnetohydrodynamics (MHD) : ions, electrons and neutrals are all part of a monofluid.

Methods Monofluid, mass conservation

(Laibe & Price 2014a,b,c) See also Price & Laibe 2015; Lin & Youdin 2017; Hutchison et al., 2018 and Lebreuilly et al., 2019

$$\frac{\partial \rho_{\mathrm{g}}}{\partial t} + \nabla \cdot \rho_{\mathrm{g}} \vec{v}_{\mathrm{g}} = 0$$

$$\frac{\partial \rho_{\mathrm{d}}}{\partial t} + \nabla \cdot \rho_{\mathrm{d}} \vec{v}_{\mathrm{d}} = 0$$

$$\longrightarrow \frac{\partial \rho_{\mathrm{g}}}{\partial t} + \frac{\partial \rho_{\mathrm{d}}}{\partial t} + \nabla \cdot \rho_{\mathrm{g}} \vec{v}_{\mathrm{g}} + \nabla \cdot \rho_{\mathrm{d}} \vec{v}_{\mathrm{d}} = 0$$

$$\downarrow$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \vec{v} = 0$$

Remember : $\vec{v} \equiv \frac{\rho_{\mathrm{d}} \vec{v}_{\mathrm{d}} + \rho_{\mathrm{g}} \vec{v}_{\mathrm{g}}}{\rho}$

$$\frac{\partial \rho_{\mathrm{d}}}{\partial t} + \nabla \cdot \rho_{\mathrm{d}} \vec{v}_{\mathrm{d}} = 0 \longrightarrow \frac{\partial \rho \epsilon}{\partial t} + \nabla \cdot \left[\rho \epsilon \left(\vec{v} + (1-\epsilon)\overrightarrow{\Delta v}\right)\right] = 0$$

Methods Full monofluid equations

(in a Lagrangian formulation)

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -\rho(\vec{\nabla}\cdot\vec{v}),$$

$$\frac{\mathrm{d}\vec{v}}{\mathrm{d}t} = -\frac{\nabla P_\mathrm{g}}{\rho} + \vec{f} - \frac{1}{\rho}\nabla\cdot\left(\epsilon(1-\epsilon)\rho\overrightarrow{\Delta v}\otimes\overrightarrow{\Delta v}\right),$$

$$\frac{\mathrm{d}\epsilon}{\mathrm{d}t} = -\frac{1}{\rho}\vec{\nabla}\cdot\left(\epsilon(1-\epsilon)\rho\overrightarrow{\Delta v}\right)$$

$$\frac{\mathrm{d}\overrightarrow{\Delta v}}{\mathrm{d}t} = \frac{\nabla P_\mathrm{g}}{(1-\epsilon)\rho} - \frac{\overrightarrow{\Delta v}}{t_\mathrm{s}} - (\overrightarrow{\Delta v}\cdot\vec{\nabla})\vec{v} + \frac{1}{2}\nabla\left((2\epsilon-1)\overrightarrow{\Delta v}\cdot\overrightarrow{\Delta v}\right)$$
$$+(1-\epsilon)\overrightarrow{\Delta v}\times(\nabla\times(1-\epsilon)\overrightarrow{\Delta v}) - \epsilon\overrightarrow{\Delta v}\times(\nabla\times\epsilon\overrightarrow{\Delta v}),$$

$$\frac{\mathrm{d}e_\mathrm{g}}{\mathrm{d}t} = -\frac{P_\mathrm{g}}{\rho(1-\epsilon)}\nabla\cdot\left(\vec{v}-\epsilon\Delta\vec{v}\right) + (\epsilon\Delta\vec{v}\cdot\nabla)e_\mathrm{g} + \epsilon\frac{\overrightarrow{\Delta v}\cdot\overrightarrow{\Delta v}}{t_\mathrm{s}}$$

$$t_\mathrm{s} \equiv \rho_\mathrm{d}\rho_\mathrm{g}/(\rho K)$$

Advantages:

- 1 fluid (better for Lagrangian codes) because 1 resolution
- Still complete

Drawback:

- More complicated than before..
- Still intrusive for the code

See also Price & Laibe 2015; Lin & Youdin 2017; Hutchison et al., 2018 and Lebreuilly et al., 2019

Methods Monofluid, strong coupling regime

(Laibe & Price 2014a,b,c) See also Price & Laibe 2015; Lin & Youdin 2017; Hutchison et al., 2018 and Lebreuilly et al., 2019

Stopping time $t_\mathrm{s} \equiv \rho_\mathrm{d}\rho_\mathrm{g}/(\rho K) \approx \dfrac{\rho_\mathrm{grain} s_\mathrm{grain}}{\rho c_\mathrm{s}}$.

Stokes number $\mathrm{St} = t_\mathrm{s}/t_\mathrm{dyn}$, where t_dyn is the dynamical timescale of the gas.

In the ISM grains are 'small', we typically have St<1, we are in a strong coupling regime between the gas and the dust.

Methods Monofluid, strong coupling regime

(Laibe & Price 2014a,b,c)

See also Price & Laibe 2015; Lin & Youdin 2017; Hutchison et al., 2018 and Lebreuilly et al., 2019

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -\rho(\vec{\nabla}\cdot\vec{v}),$$

$$\frac{\mathrm{d}\vec{v}}{\mathrm{d}t} = -\frac{\nabla P_{\mathrm{g}}}{\rho} + \vec{f} - \frac{1}{\rho}\nabla\cdot\left(\epsilon(1-\epsilon)\rho\overrightarrow{\Delta v}\otimes\overrightarrow{\Delta v}\right),$$

$$\frac{\mathrm{d}\epsilon}{\mathrm{d}t} = -\frac{1}{\rho}\vec{\nabla}\cdot\left(\epsilon(1-\epsilon)\rho\overrightarrow{\Delta v}\right)$$

$$\frac{\mathrm{d}\overrightarrow{\Delta v}}{\mathrm{d}t} = \frac{\nabla P_{\mathrm{g}}}{(1-\epsilon)\rho} - \frac{\overrightarrow{\Delta v}}{t_{\mathrm{s}}} - (\overrightarrow{\Delta v}\cdot\vec{\nabla})\vec{v} + \frac{1}{2}\nabla\left((2\epsilon-1)\overrightarrow{\Delta v}\cdot\overrightarrow{\Delta v}\right)$$

$$+(1-\epsilon)\overrightarrow{\Delta v}\times(\nabla\times(1-\epsilon)\overrightarrow{\Delta v}) - \epsilon\overrightarrow{\Delta v}\times(\nabla\times\epsilon\overrightarrow{\Delta v}),$$

$$\frac{\mathrm{d}e_{\mathrm{g}}}{\mathrm{d}t} = -\frac{P_{\mathrm{g}}}{\rho(1-\epsilon)}\nabla\cdot\left(\vec{v}-\epsilon\Delta\vec{v}\right) + (\epsilon\Delta\vec{v}\cdot\nabla)e_{\mathrm{g}} + \epsilon\frac{\overrightarrow{\Delta v}\cdot\overrightarrow{\Delta v}}{t_{\mathrm{s}}}$$

$$\longrightarrow$$

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -\rho(\vec{\nabla}\cdot\vec{v}),$$

$$\frac{\mathrm{d}\vec{v}}{\mathrm{d}t} = -\frac{\nabla P_{\mathrm{g}}}{\rho} + \vec{f},$$

$$\frac{\mathrm{d}\epsilon}{\mathrm{d}t} = -\frac{1}{\rho}\vec{\nabla}\cdot\left(\epsilon t_{\mathrm{s}}\nabla P_{\mathrm{g}}\right)$$

$$\frac{\mathrm{d}e_{\mathrm{g}}}{\mathrm{d}t} = -\frac{P_{\mathrm{g}}}{\rho(1-\epsilon)}\nabla\cdot\vec{v}$$

Second order in Stokes

First order in Stokes/Decaying in a stopping time

Methods Monofluid, strong coupling regime

(Laibe & Price 2014a,b,c) See also Price & Laibe 2015; Lin & Youdin 2017; Hutchison et al., 2018 and Lebreuilly et al., 2019

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -\rho(\vec{\nabla} \cdot \vec{v}),$$

$$\frac{\mathrm{d}\vec{v}}{\mathrm{d}t} = -\frac{\nabla P_{\mathrm{g}}}{\rho} + \vec{f},$$

$$\frac{\mathrm{d}\epsilon}{\mathrm{d}t} = -\frac{1}{\rho}\vec{\nabla} \cdot \left(\epsilon t_{\mathrm{s}} \nabla P_{\mathrm{g}}\right)$$

$$\frac{\mathrm{d}e_{\mathrm{g}}}{\mathrm{d}t} = -\frac{P_{\mathrm{g}}}{\rho(1-\epsilon)}\nabla \cdot \vec{v}$$

<u>Advantages:</u>

Still one fluid.

Less intrusive for a code

Fewer equations (drift velocity directly computed from the force balance)

Easier to implement

<u>Drawback:</u>

Incomplete (St<1).

Methods Monofluid in strong coupling regime

(With multiple species)

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -\rho(\nabla \cdot \vec{v}),$$

$$\frac{\mathrm{d}\vec{v}}{\mathrm{d}t} = -\frac{\nabla P_{\mathrm{g}}}{\rho} + \vec{f},$$

$$\frac{\mathrm{d}\epsilon_k}{\mathrm{d}t} = -\frac{1}{\rho}\nabla \cdot \left(\epsilon_k T_{\mathrm{s},k} \nabla P_{\mathrm{g}}\right), \forall k \in [1, \mathcal{N}],$$

$$\frac{\mathrm{d}e_{\mathrm{g}}}{\mathrm{d}t} = -\frac{P_{\mathrm{g}}}{\rho(1-\mathscr{E})}\nabla \cdot \vec{v} + \left(\mathscr{E}\mathscr{T}_{\mathrm{s}}\frac{\nabla P_{\mathrm{g}}}{(1-\mathscr{E})\rho} \cdot \nabla\right) e_{\mathrm{g}},$$

With $\mathscr{E} \equiv \sum_{l=1}^{\mathcal{N}} \epsilon_l$, $T_{\mathrm{s},k} \equiv \frac{t_{\mathrm{s},k}}{1-\epsilon_k} - \sum_{l=1}^{\mathcal{N}} \frac{\epsilon_l}{1-\epsilon_l} t_{\mathrm{s},l}$ and $\mathscr{T}_{\mathrm{s}} \equiv \frac{1}{\mathscr{E}} \sum_{l=1}^{\mathcal{N}} \epsilon_l T_{\mathrm{s},l}$

Advantages:

- Still one fluid.
- Less intrusive for a code
- Fewer equations (drift velocity directly computed from the force balance)
- Easier to implement

Drawback:

- Incomplete (St<1).

Numerical implementation in RAMSES

Reminder for a pure gas

Conservative form

$$\frac{\partial \mathbb{U}}{\partial t} + \nabla \cdot \mathbb{F}(\mathbb{U}) = 0$$

$$\mathbb{U} \equiv \left(\rho_{\mathrm{g}}, \rho_{\mathrm{g}}\mathbf{v}_{\mathrm{g}}, E_{\mathrm{g}}\right);\ \mathbb{F}(\mathbb{U}) \equiv \left(\rho_{\mathrm{g}}\mathbf{v}_{\mathrm{g}}, \rho_{\mathrm{g}}\mathbf{v}_{\mathrm{g}} \otimes \mathbf{v}_{\mathrm{g}} + P_{\mathrm{g}}\mathbb{I}, \mathbf{v}_{\mathrm{g}}(E_{\mathrm{g}} + P_{\mathrm{g}})\right)$$

Integral over a control volume

$$\int_{x_{\mathrm{left}}}^{x_{\mathrm{right}}} \left(\mathbb{U}\,(T) - \mathbb{U}\,(0)\right) \mathrm{d}x + \int_0^T \left(\mathbb{F}(x_{\mathrm{right}}) - \mathbb{F}(x_{\mathrm{left}})\right) \mathrm{d}t = 0$$

Godunov Scheme (Godunov 1959) & Riemann problem

$$\mathbb{U}_i^{n+1} = \mathbb{U}_i^n - \left(\mathbb{F}_{i+1/2}^{n+1/2} - \mathbb{F}_{i-1/2}^{n+1/2}\right)\frac{\Delta t}{\Delta x};\ \mathbb{F}_{i\pm1/2}^{n+1/2} = \mathbb{F}^{\star}\left(\mathbb{U}_i^n, \mathbb{U}_{i-1}^n\right)$$

Stability constrain (Courant et al., 1928)

$$\Delta t \equiv C_{\mathrm{CFL}} \frac{\Delta x}{c_{\mathrm{fastest}}}$$

Numerical implementation in RAMSES

Now with the dust (see Lebreuilly et al., 2019)

Conservative form

$$\frac{\partial \mathbb{U}}{\partial t} + \nabla \cdot \mathbb{F}_{\mathrm{H}}(\mathbb{U}) + \nabla \cdot \mathbb{F}_{\Delta}(\mathbb{U}) = 0$$

$$\mathbb{U} \equiv \left(\rho, \rho \mathbf{v}, E, \rho_{\mathrm{d},k}, \ldots\right); \mathbb{F}_{\mathrm{H}}(\mathbb{U}) \equiv \left(\rho \mathbf{v}, \rho \mathbf{v} \otimes \mathbf{v} + P_{\mathrm{g}} \mathbb{I}, \mathbf{v}(E + P_{\mathrm{g}}), \rho_{\mathrm{d},k} \mathbf{v}, \ldots\right); \mathbb{F}_{\Delta}(\mathbb{U}) \equiv \left(0, 0, \frac{P_{\mathrm{g}}}{\gamma - 1} \frac{\mathscr{E} \mathscr{T}_{\mathrm{s}}}{1 - \mathscr{E}} \frac{\nabla P_{\mathrm{g}}}{\rho}, \rho_{\mathrm{d},k} \frac{T_{\mathrm{s},k} \nabla P_{\mathrm{g}}}{\rho}, \ldots\right)$$

We perform the integration in two distinct steps (operator splitting)

1. We treat the ‘barycentre’ terms (almost already done in RAMSES)
2. We treat the differential advection of the dust terms represented by the flux : $\mathbb{F}_{\Delta}$

The dust ‘source’ term $\nabla \cdot \mathbb{F}_{\Delta}(\mathbb{U})$ is computed in two steps

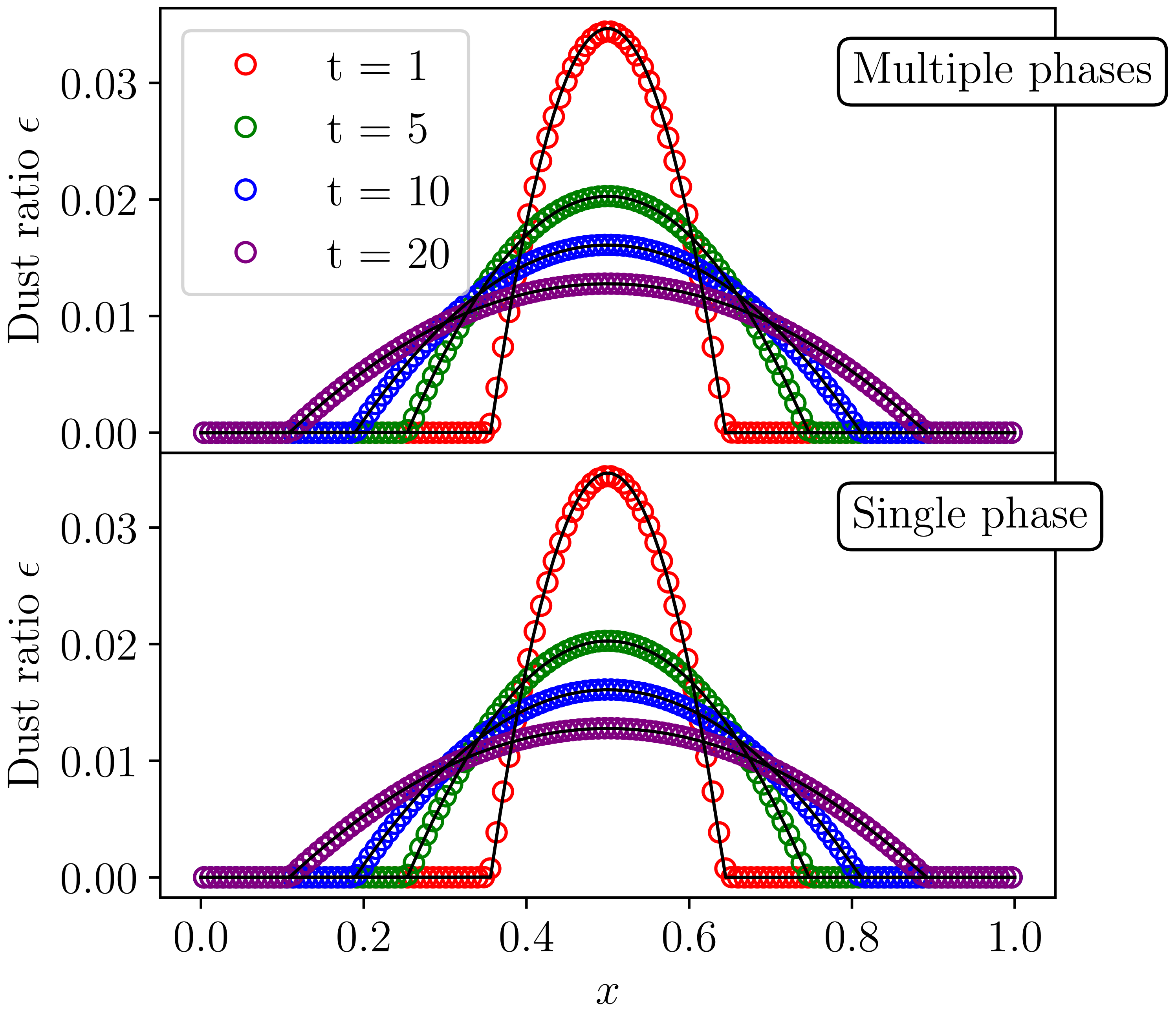
1. Predictor step : variables computed at cell interfaces and half timesteps (using slope limiters and finite differences)
2. Flux computed by solving a Riemann problem a cell discontinuities and added in a conservative way using the Godunov scheme

Note that this is exactly what was already done for the gas fluxes !

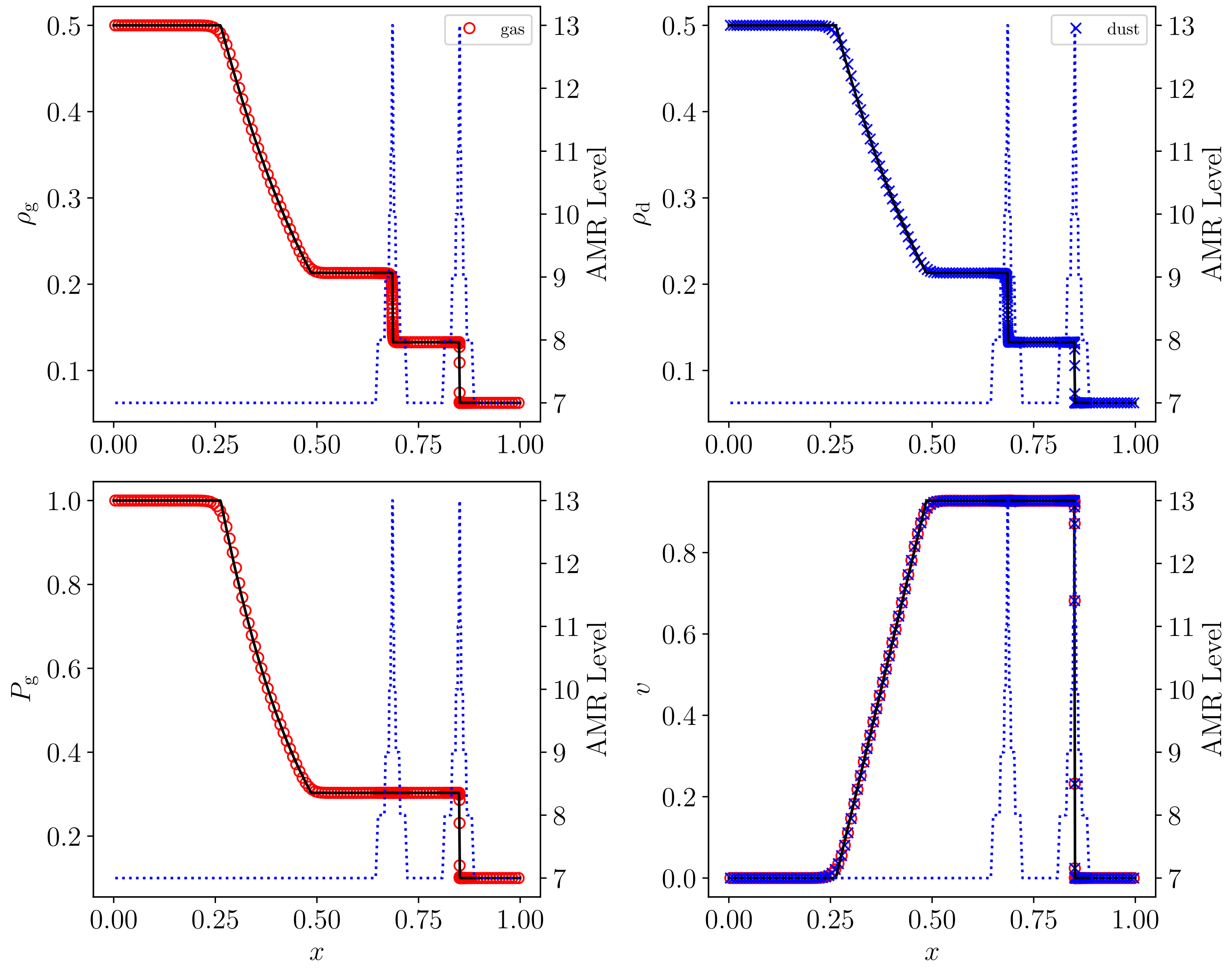
Numerical implementation in RAMSES

Validation tests (see Lebreuilly et al., 2019)

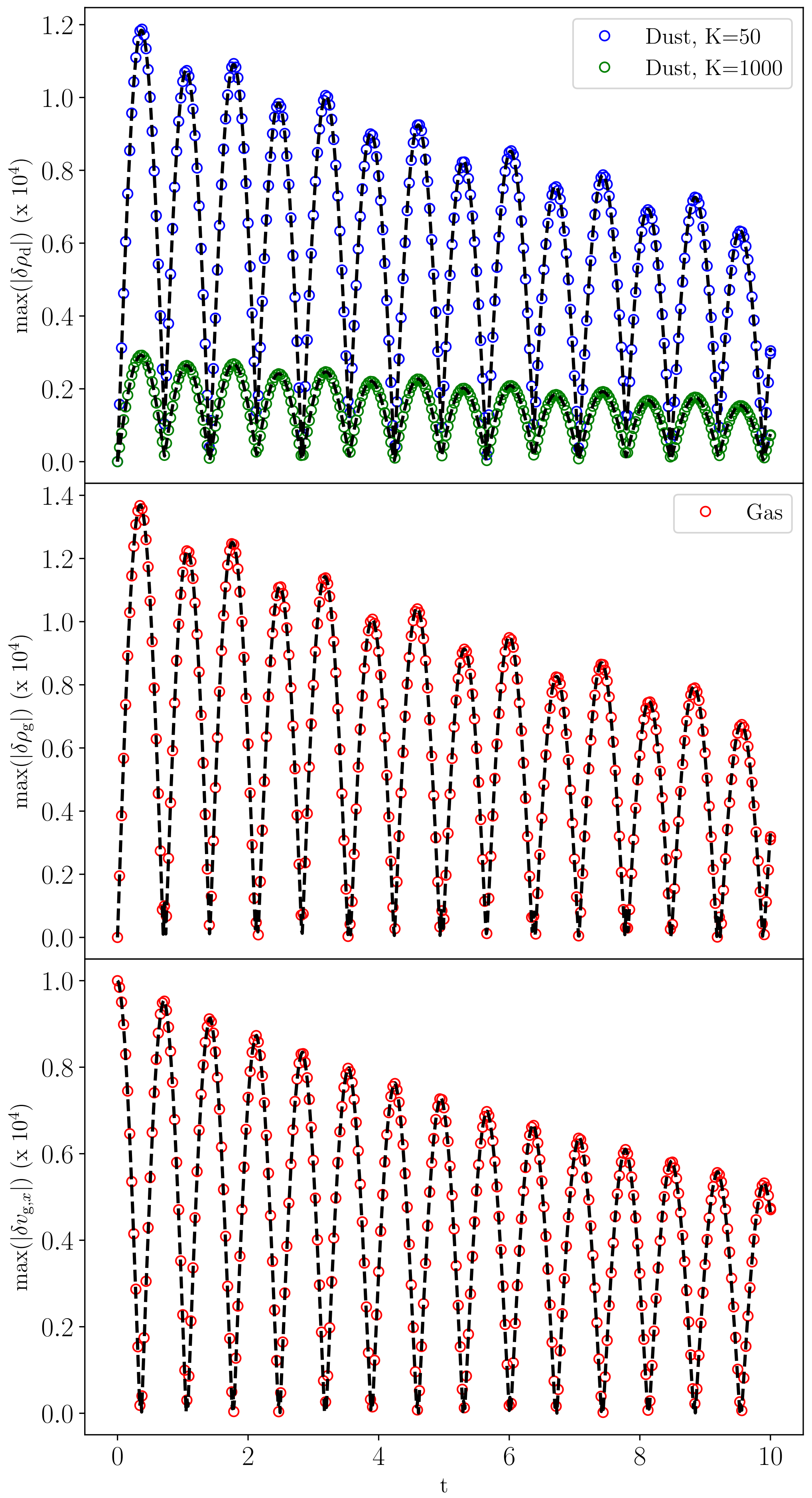
Diffusion (DUSTYDIFFUSE)



Shock (DUSTYSHOCK)



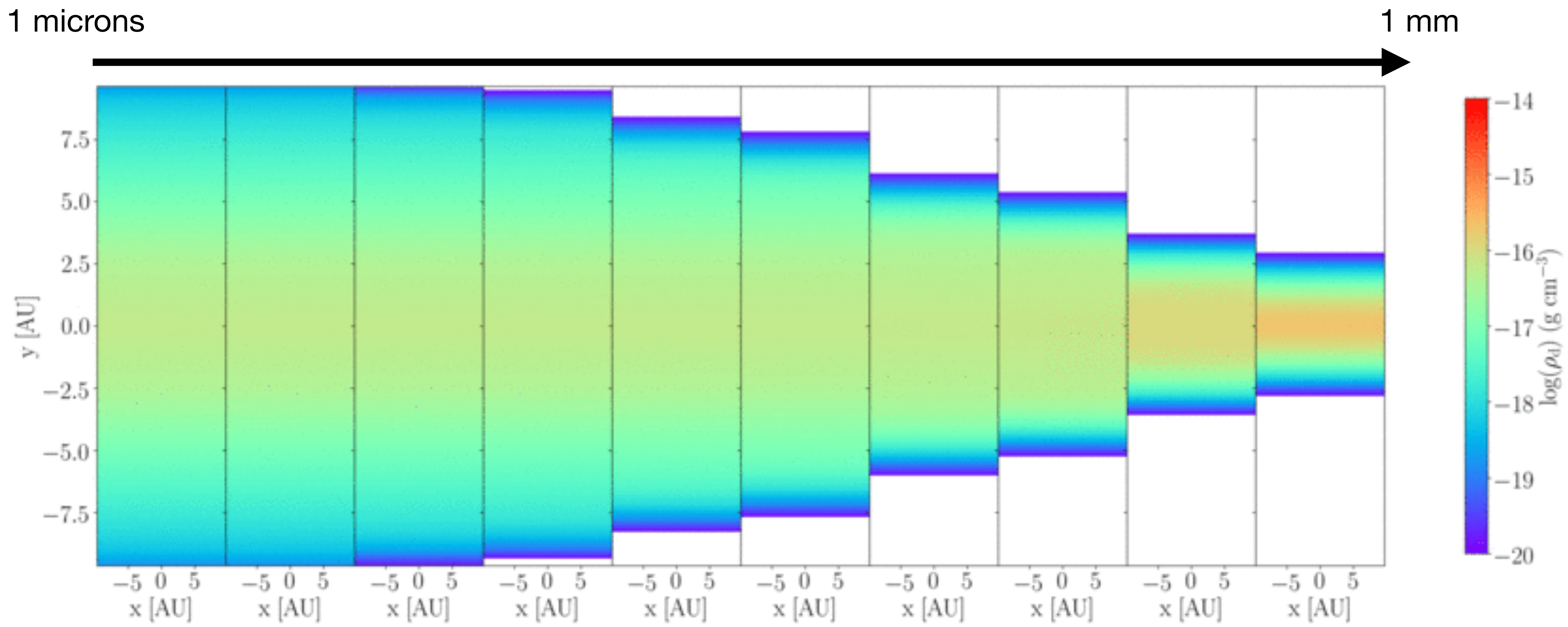
Damping of sound waves (DUSTYWAVE)



Numerical implementation in RAMSES

Validation tests (see Lebreuilly et al., 2019)

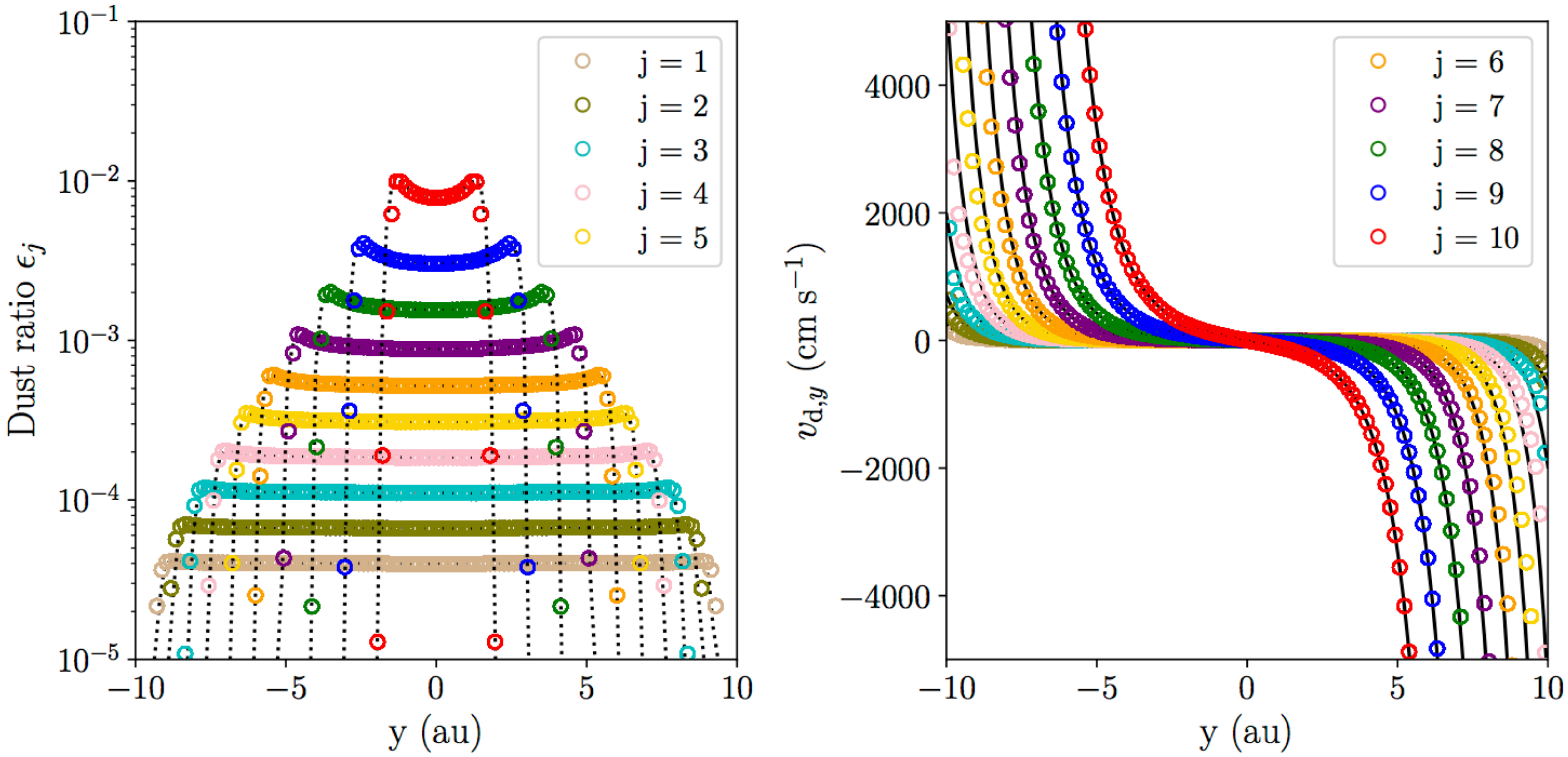
Settling in protoplanetary disks



Numerical implementation in RAMSES

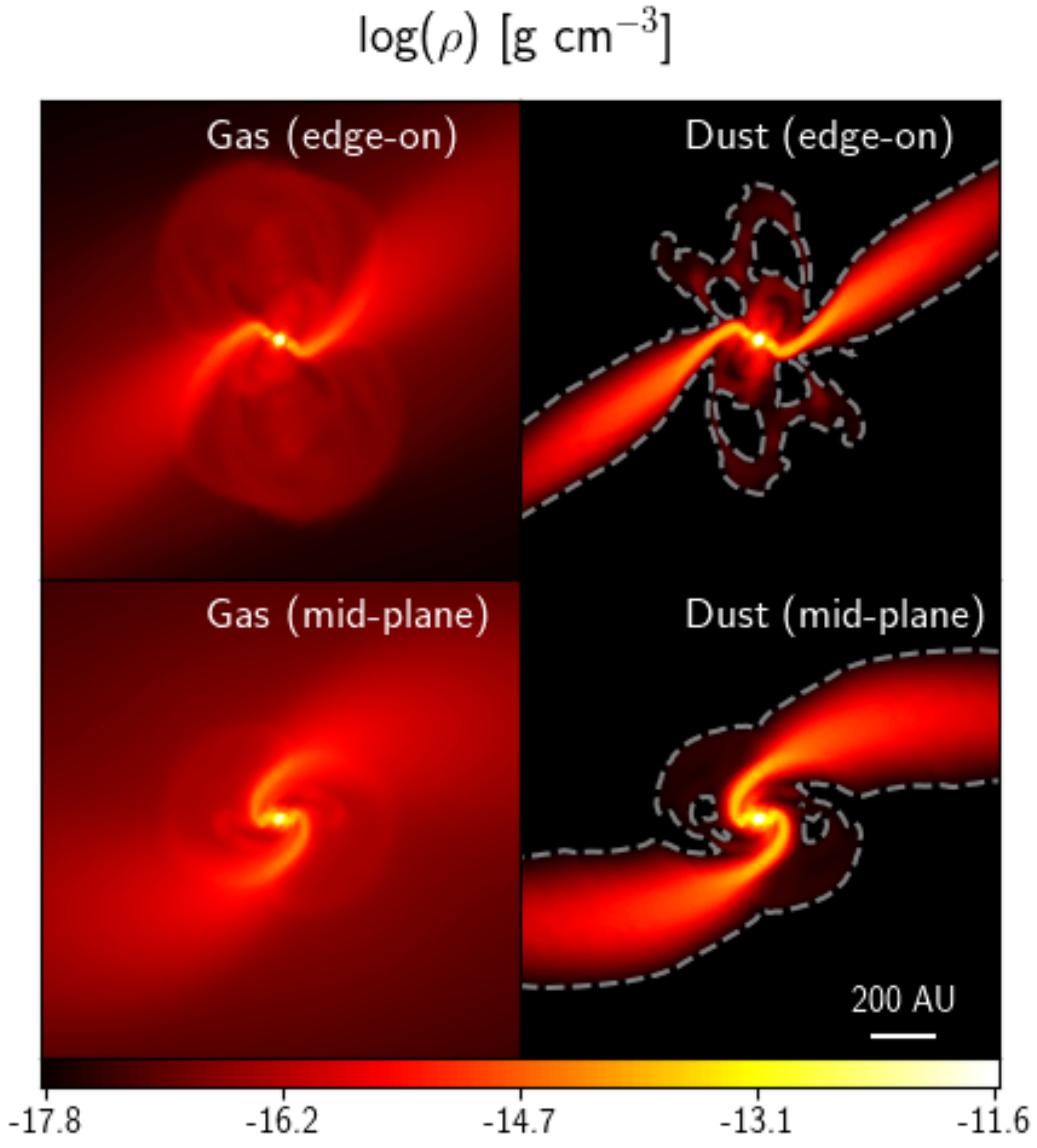
Validation tests (see Lebreuilly et al., 2019)

Settling in protoplanetary disks

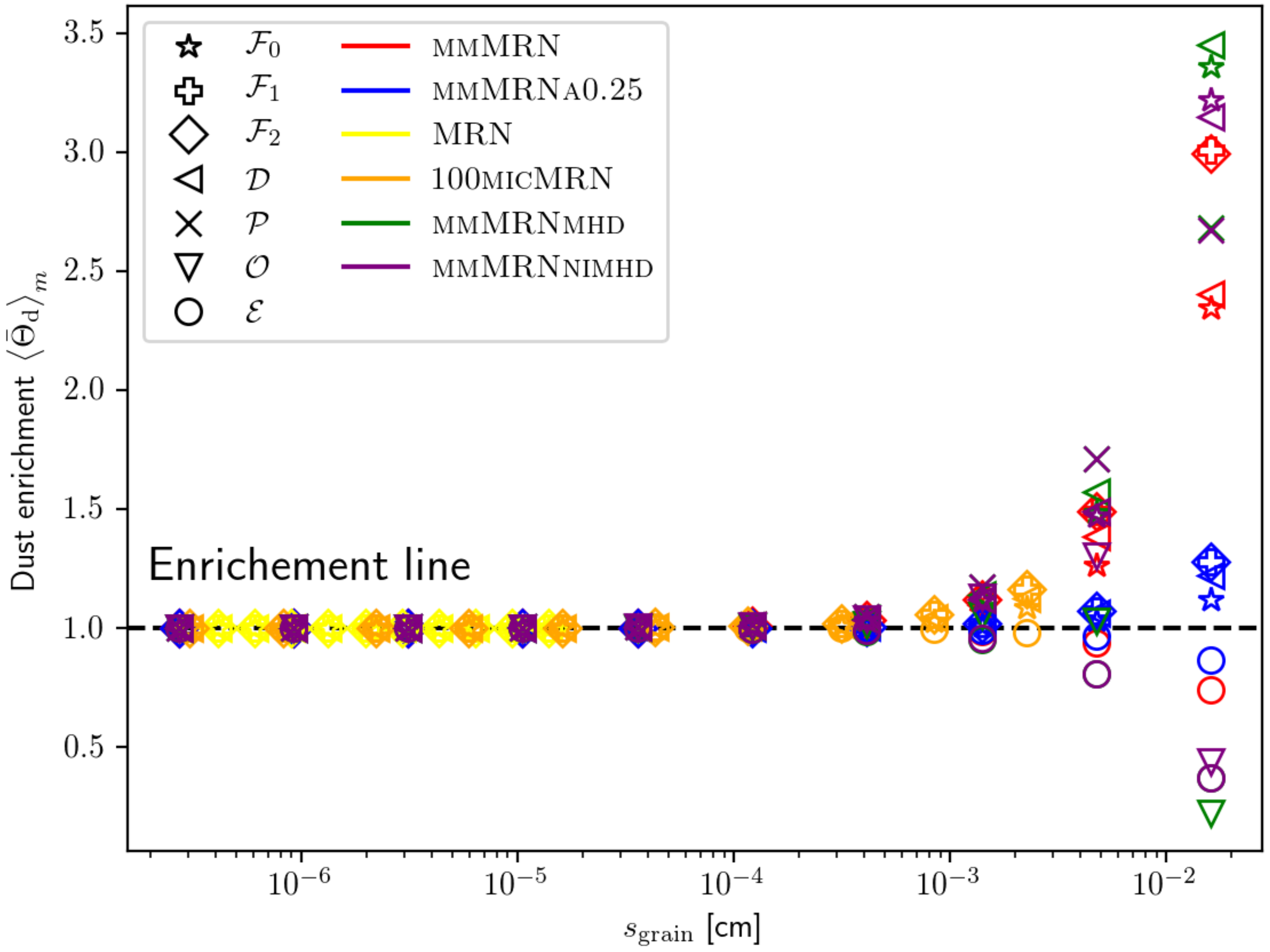


Application The protostellar collapse (see Lebreuilly et al., 2020)

Gas (left) and dust (right) densities

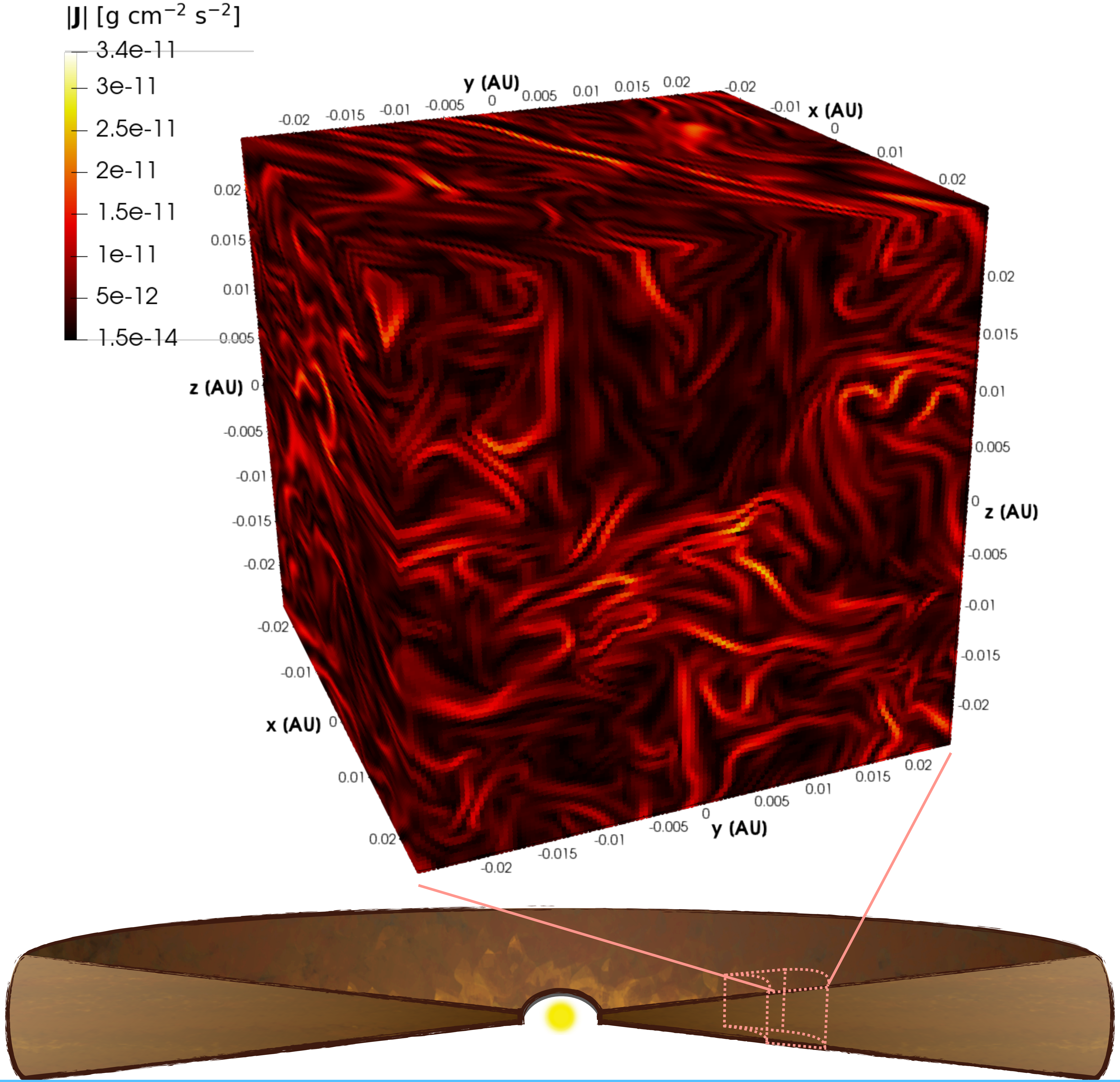


Dust enrichment in the different objects

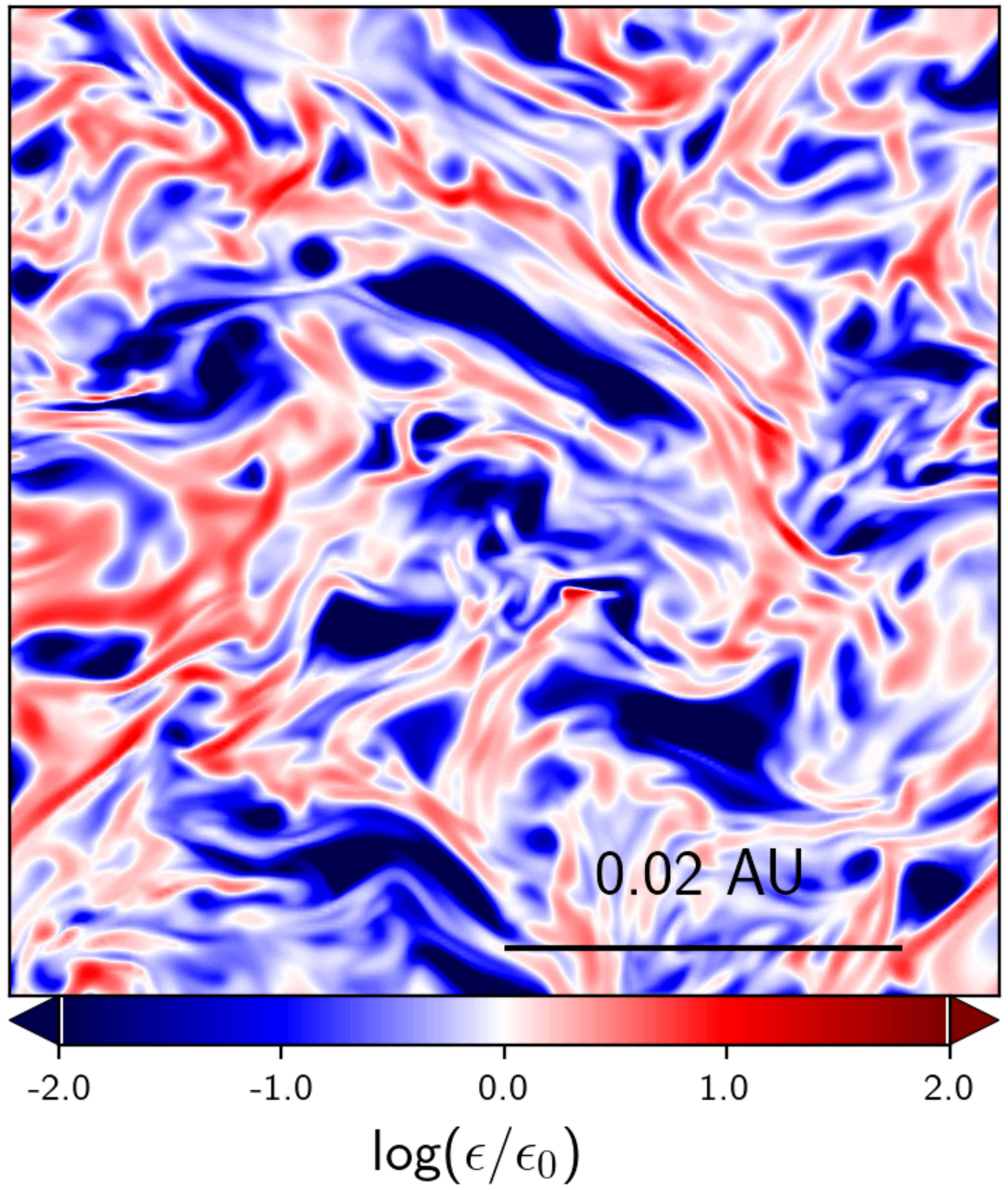


Application Current sheets in protoplanetary disks (Lebreuilly et al., sub)

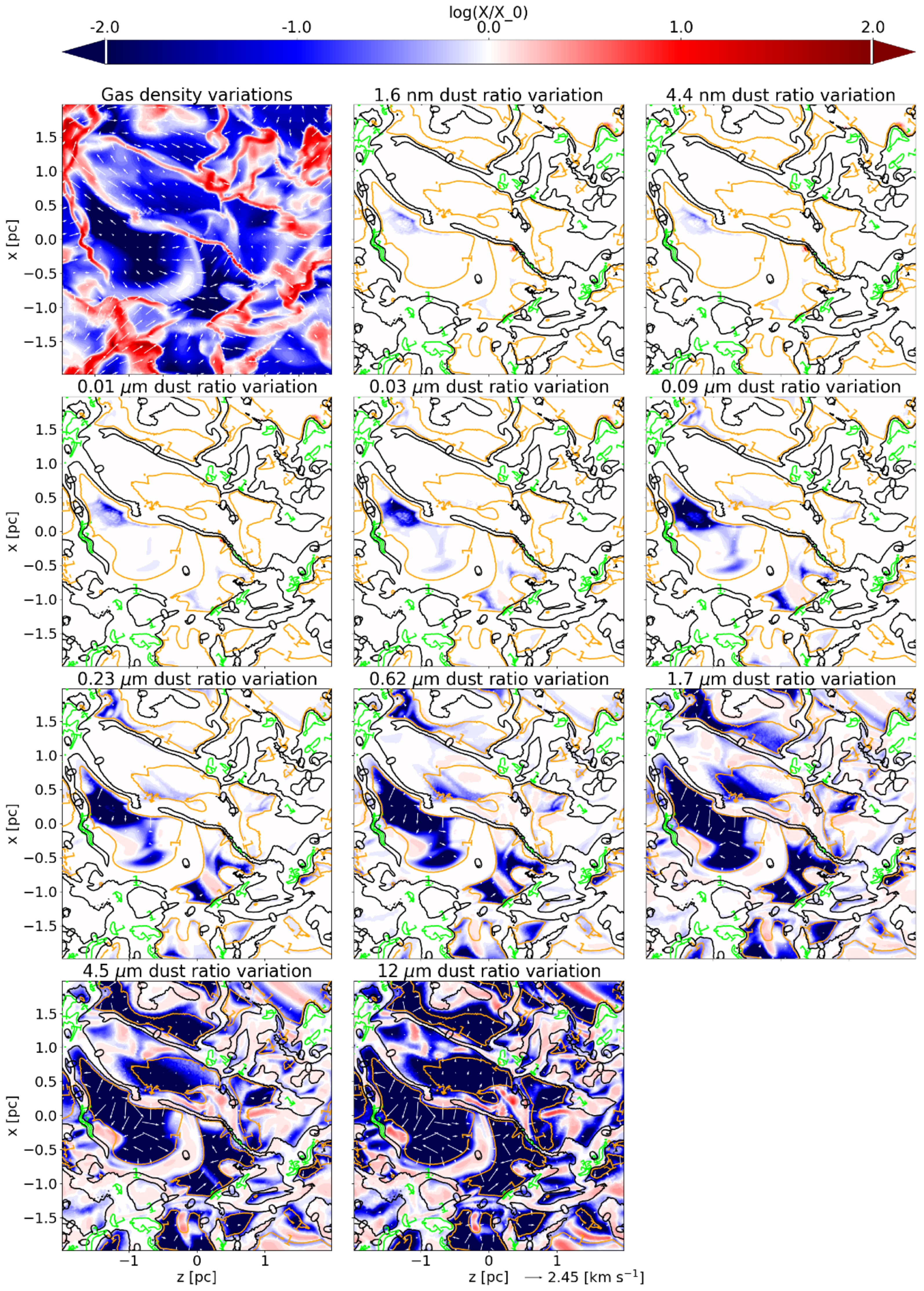
Current sheets

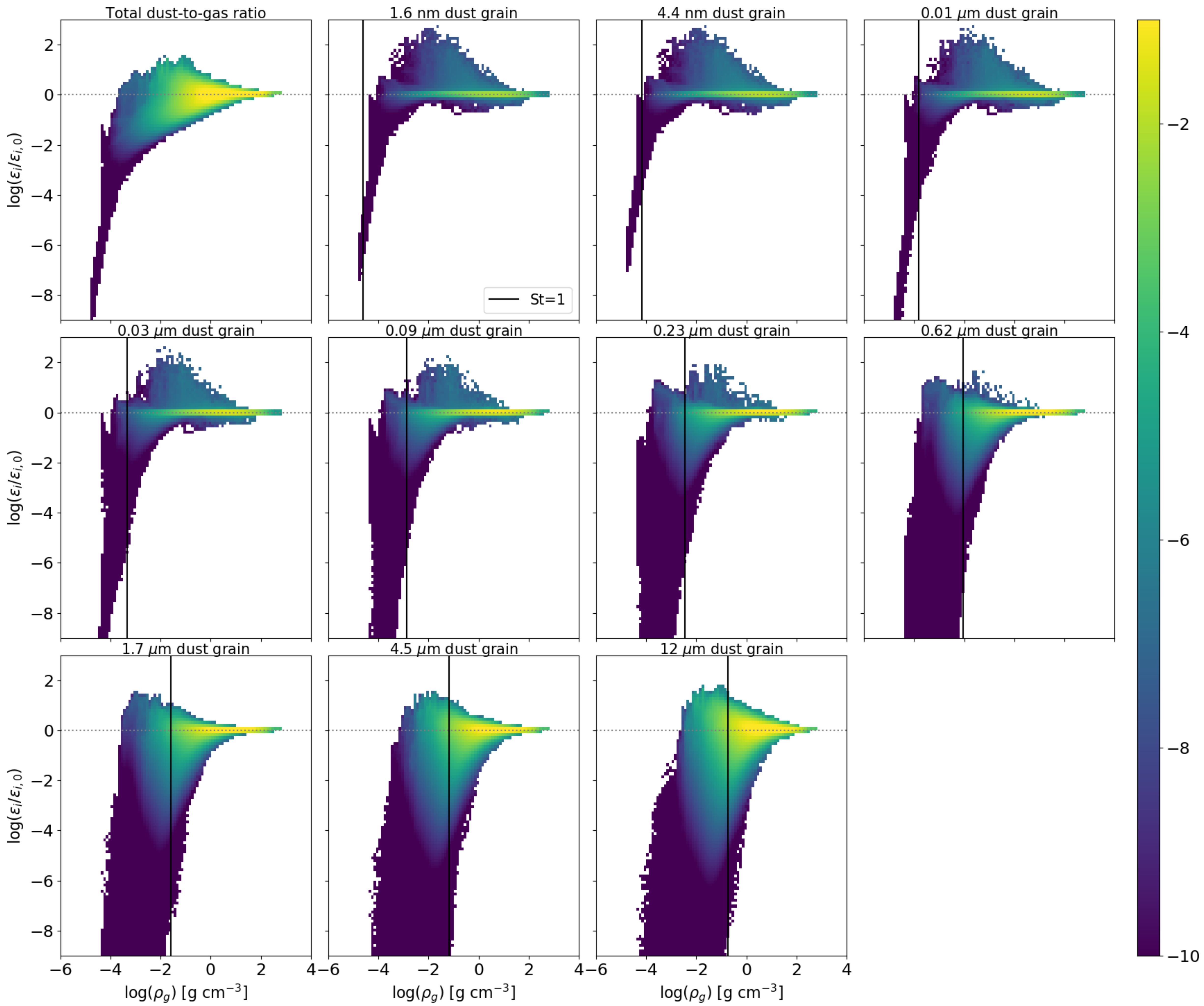


Dust concentration variations in the current sheets



Application Turbulent molecular clouds (Commerçon et al, in prep)





Next stage Dust growth

There are two possibilities to take into dust growth.

1.Solve the full coagulation equation (Smoluchowski) that considers mass exchange between bins.

2.Only follow the evolution of the peak of the distribution: “monodisperse growth”

While I am used to both methods. The first one is still tricky in 3D so I’ll present only the second one.

We consider one species: but of varying size $s_d\left(\vec{r},t\right)$

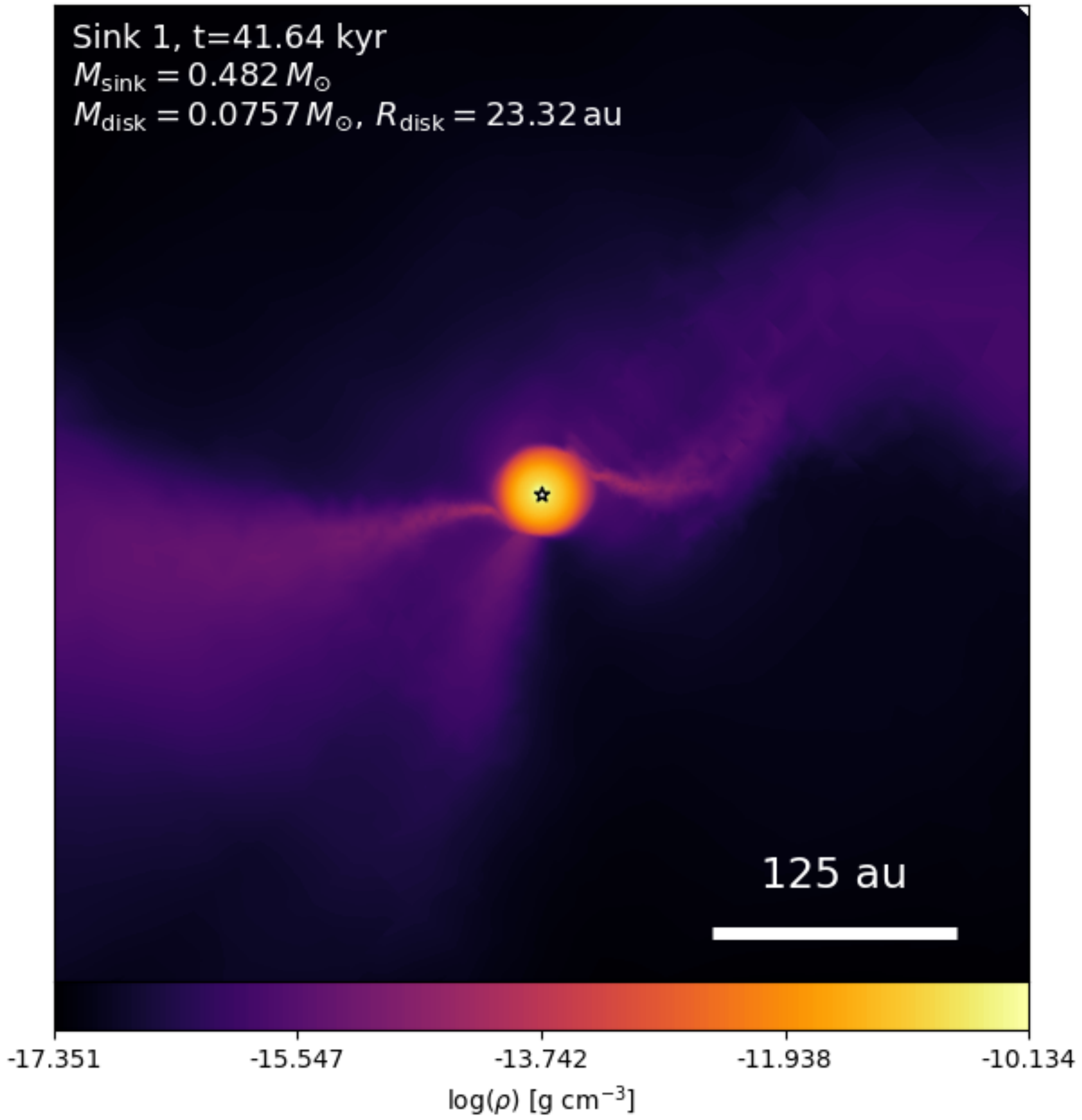
$$\frac{\partial \rho_d\ s_d}{\partial t} + \nabla \cdot \rho_d\ s_d \overrightarrow{v}_d = A_{\mathrm{gain,loss}} \frac{\rho_d\ s_d}{t_{\mathrm{growth}}},$$ we also advect dust grain as passive scalars at $\overrightarrow{v}_d \neq \overrightarrow{v_g}$

<u>What we can get from that:</u>

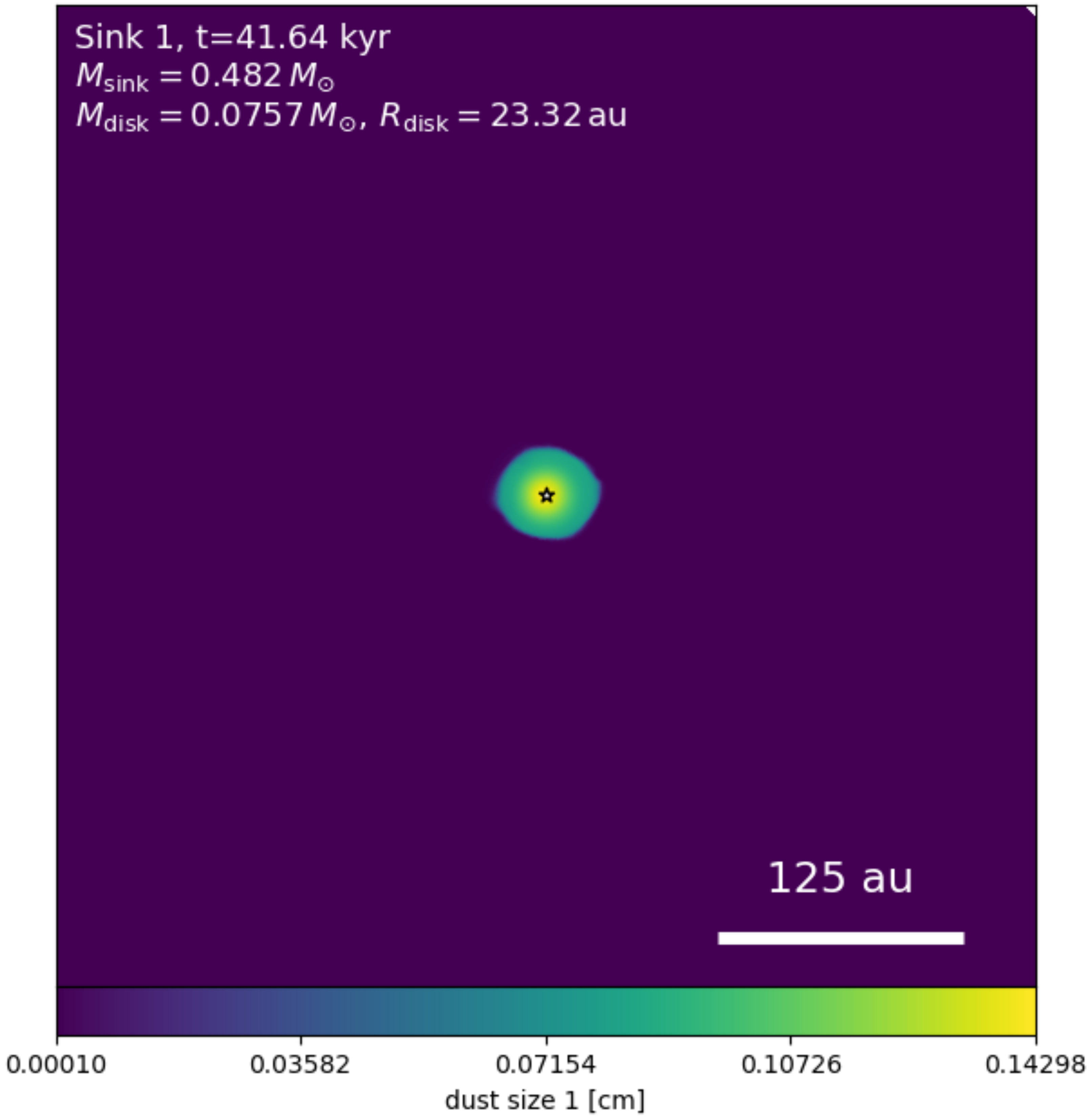
1. Typical grain size (in terms of mass)
2. Dust mass content of disks
3. Spatial repartition of large dust grains
4. Better synthetic observations

Next stage Dust growth

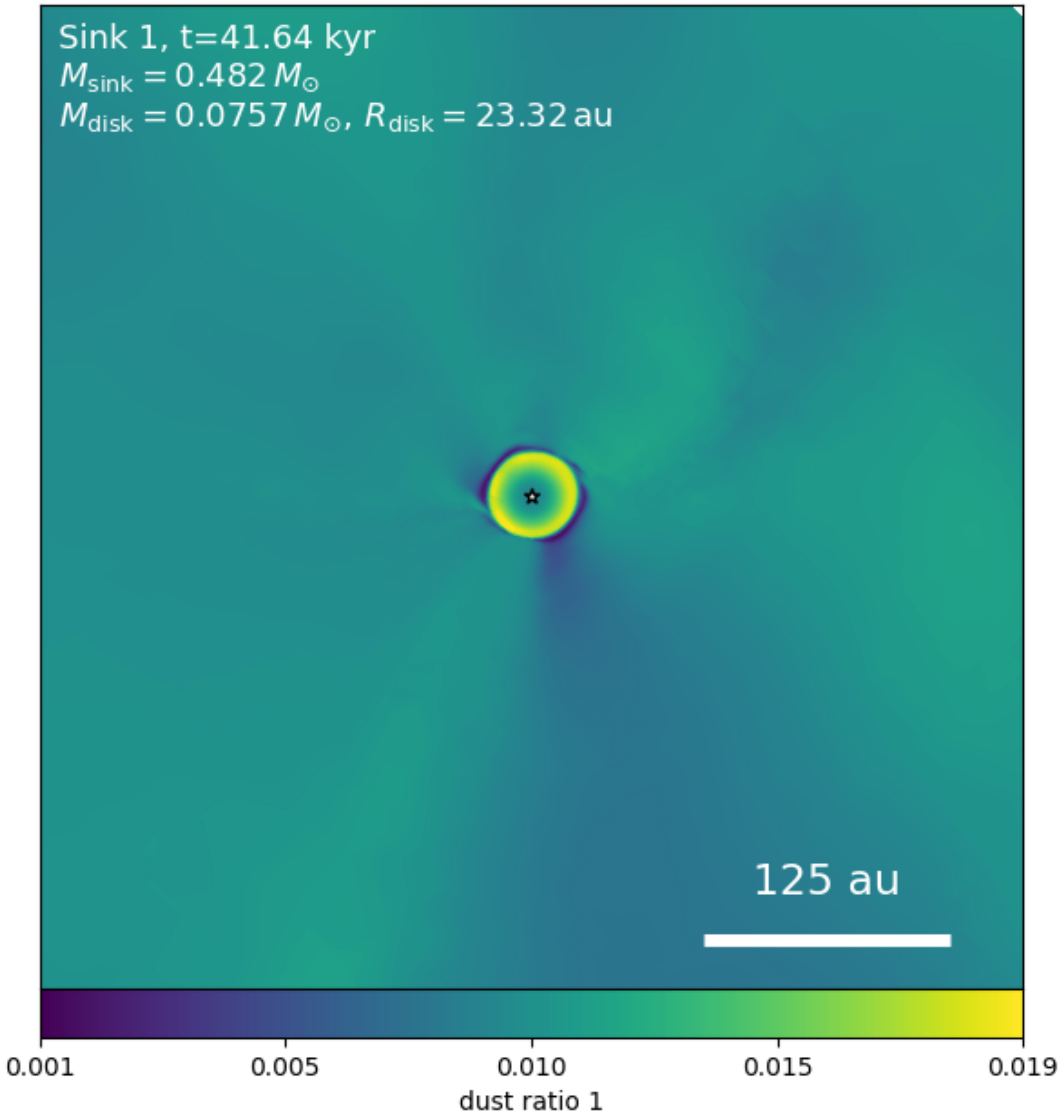
Gas density



Dust size



Dust-to-gas ratio



PRACE Synthetic populations of protoplanetary disks

Goals

1. To generate synthetic self-consistent populations of disks and constrain (statistically) the initial conditions of planet formation
2. To predict the internal structure (gas, temperature, magnetic field) of protoplanetary disks
3. To predict the dust content (in mass and size) of protoplanetary disks
4. To provide a physical interpretation of young disk observations

Methods

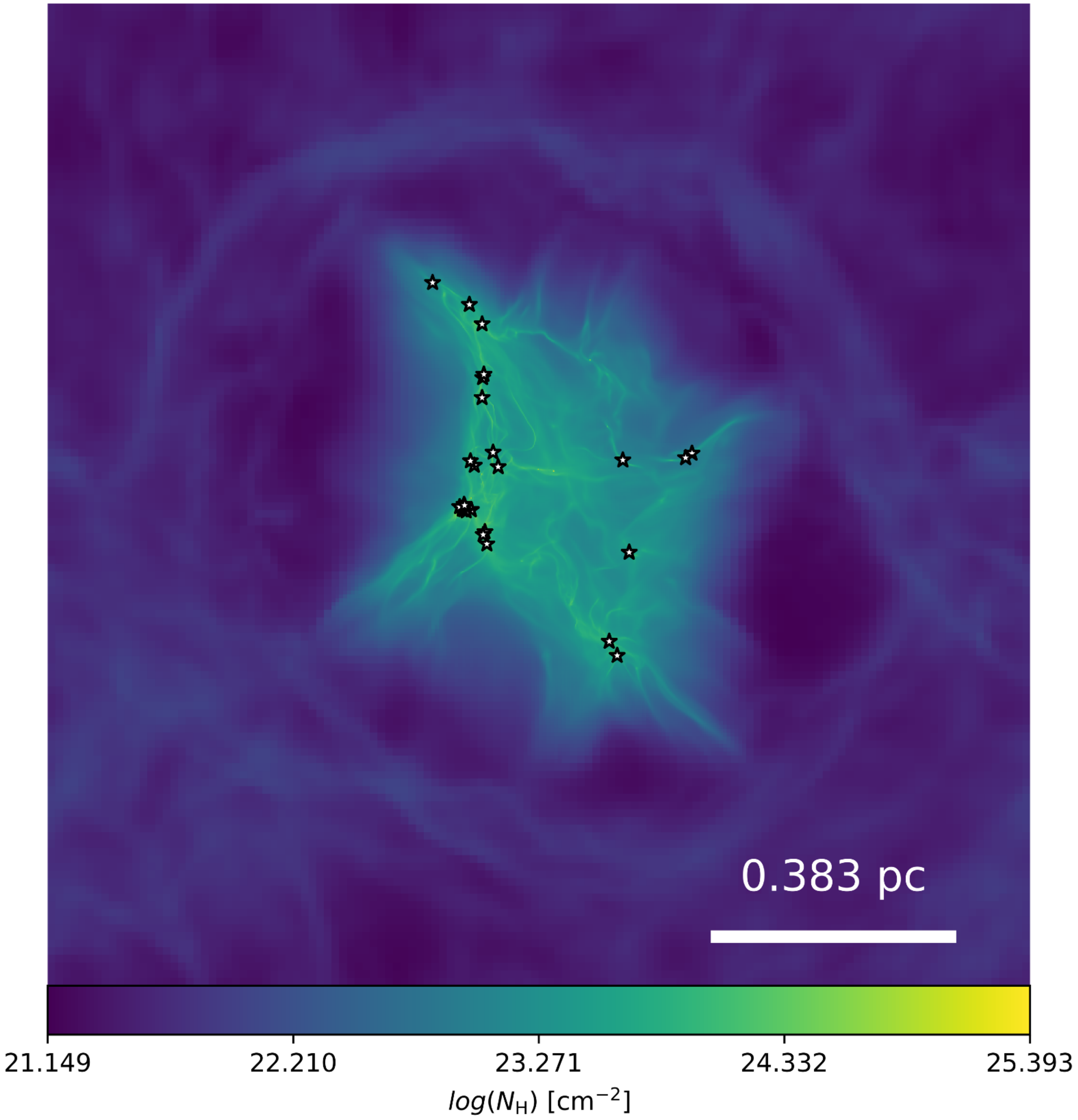
Several clump collapse calculations with different initial conditions (magnetic field, Mach number, size, mass) and physical processes (non-ideal MHD, radiative feedback, dust)
Rezooms on some specific disks to get the internal structure !
Synthetic observations with radiative transfer code

Ressources

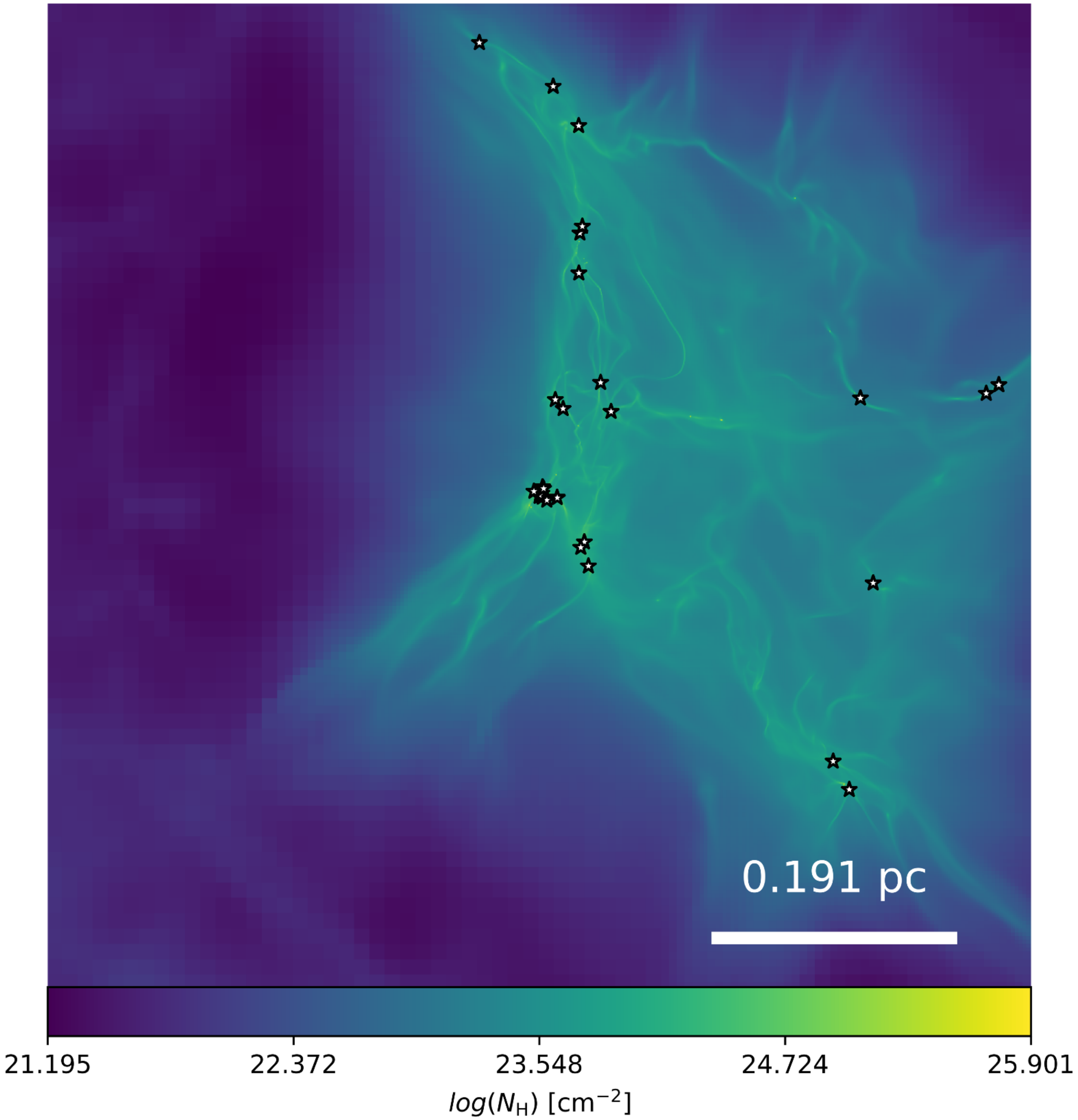
32.7 million CPU hours (so far ~70% used) on the JUWELS cluster
-1 Run is about 3-4 million CPU hours on ~1000 CPUs.

See Lebreuilly et al., (2021) for a similar previous work

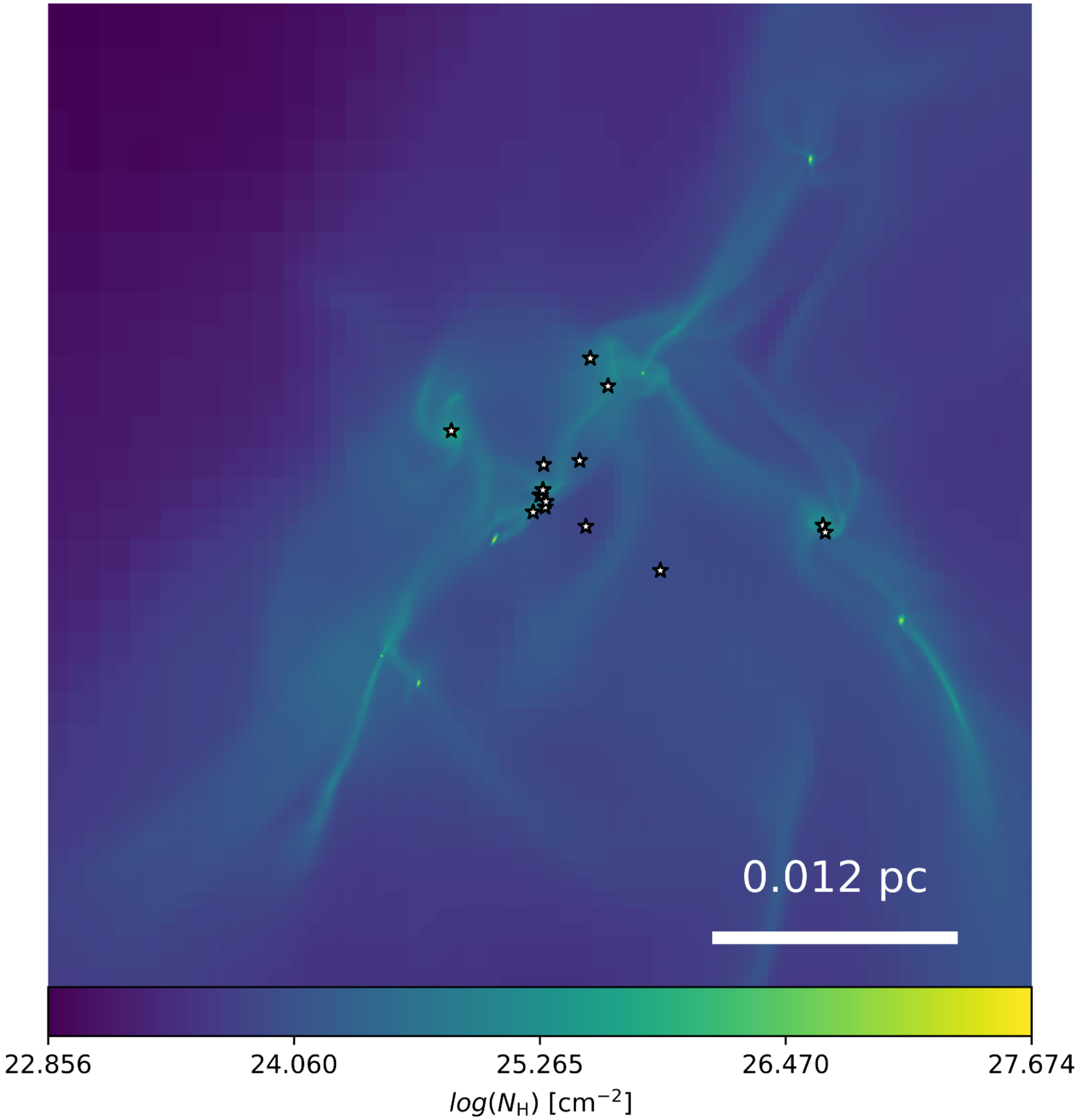
PRACE Synthetic populations of protoplanetary disks



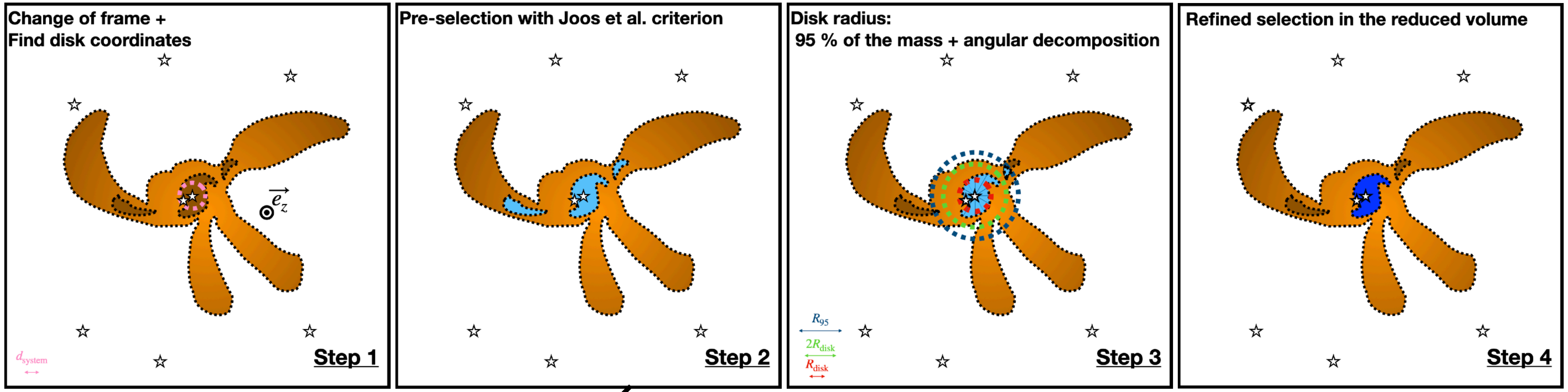
PRACE Synthetic populations of protoplanetary disks



PRACE Synthetic populations of protoplanetary disks



PRACE Disk extraction



$$v_\phi > 2v_r$$

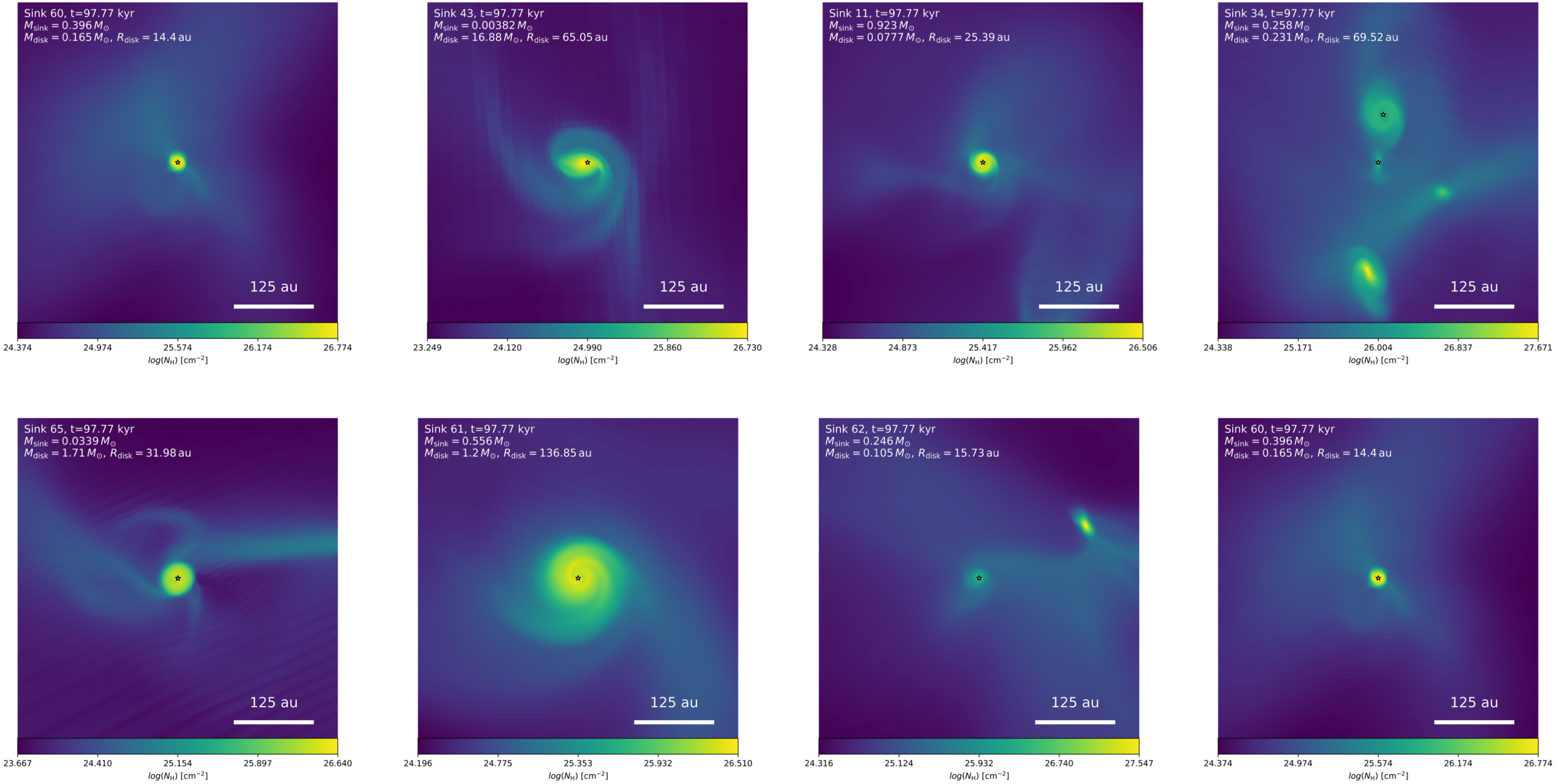
$$v_\phi > 2v_z$$

$$\frac{1}{2}\rho v_\phi^2 > 2P_{\text{th}}$$

$$n > n_{\text{thre}} = 10^9\ \text{cm}^{-3}$$

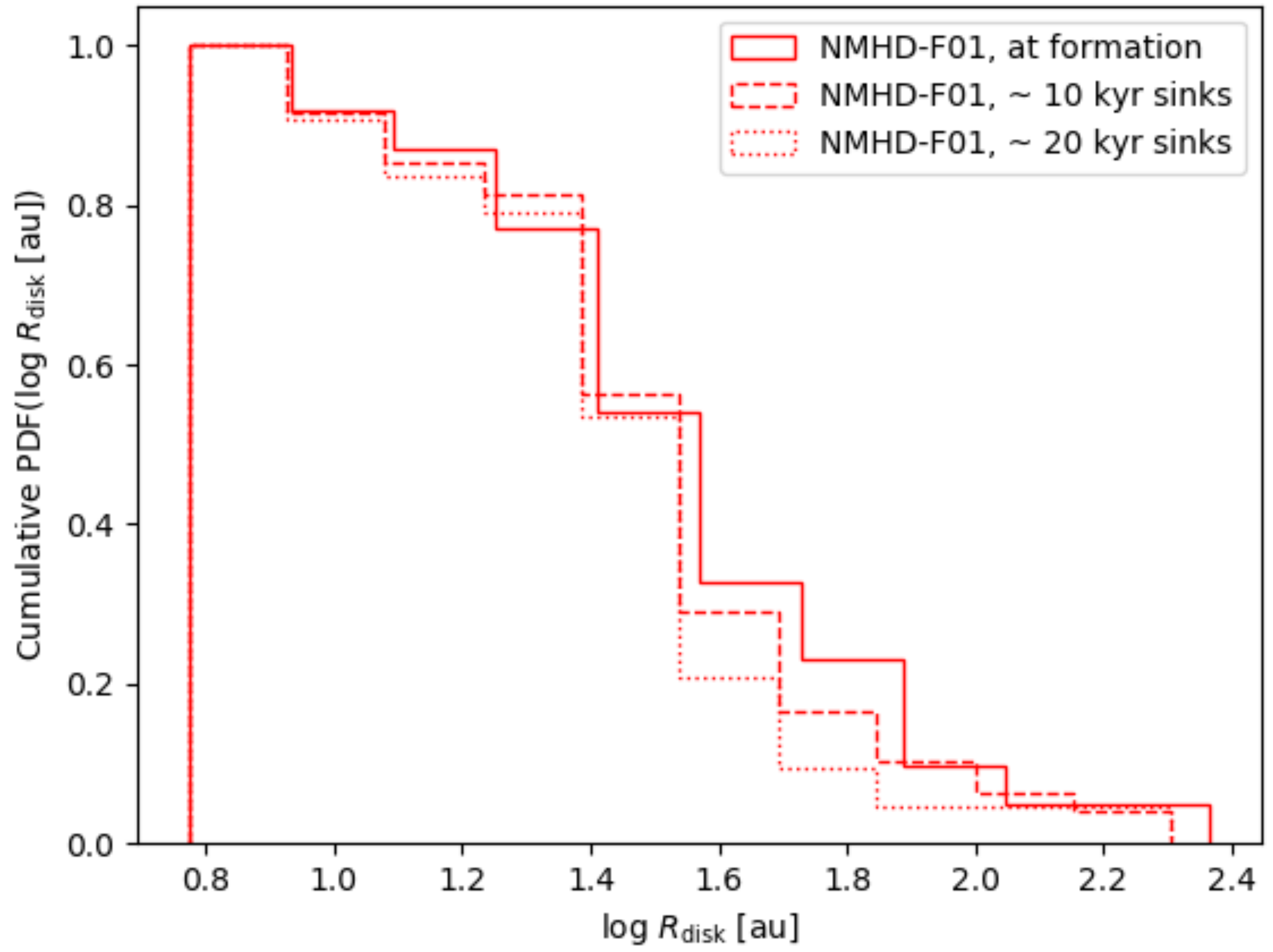
Joos et al., 2012

PRACE Disks variety

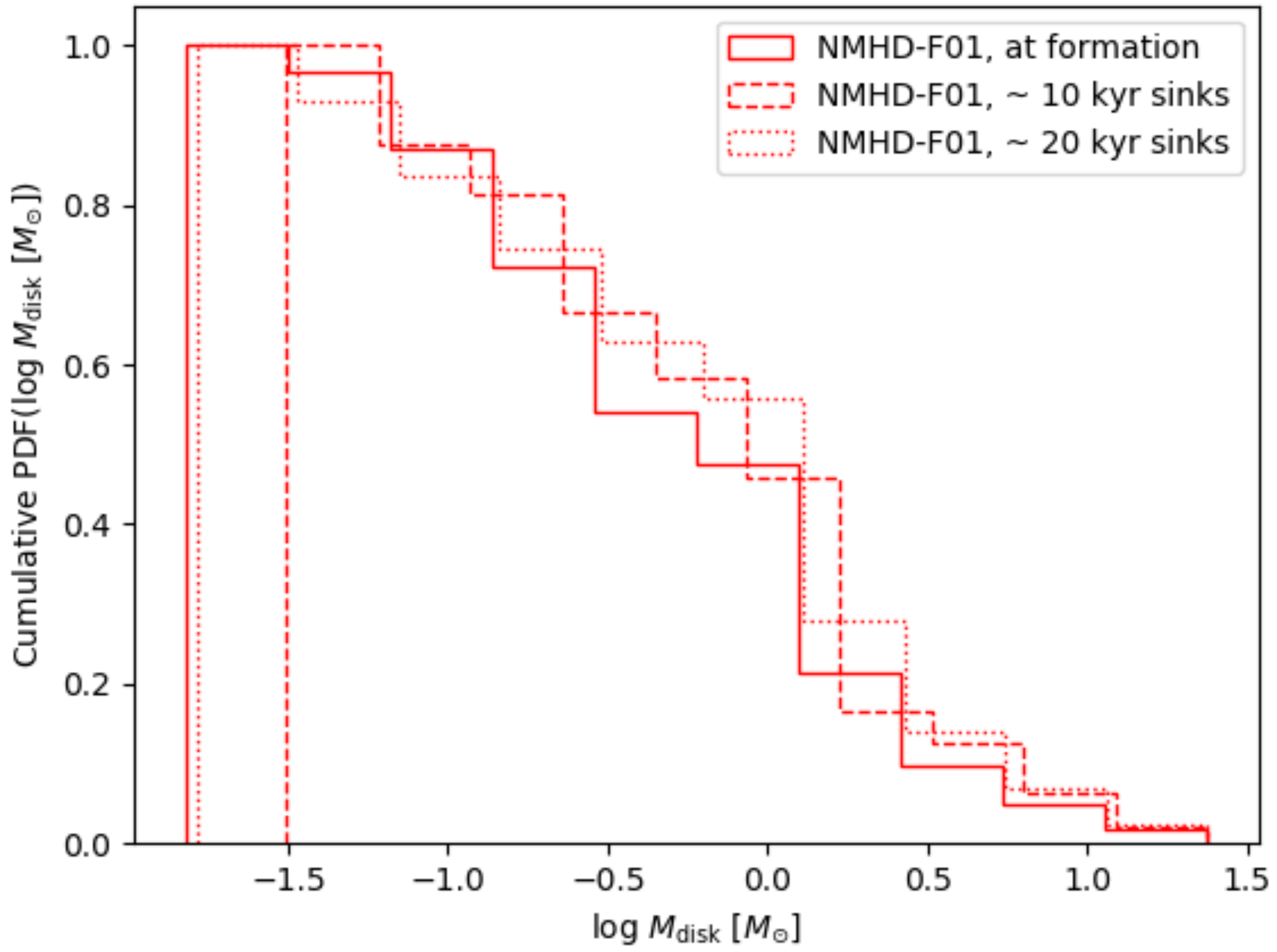


PRACE Disk populations

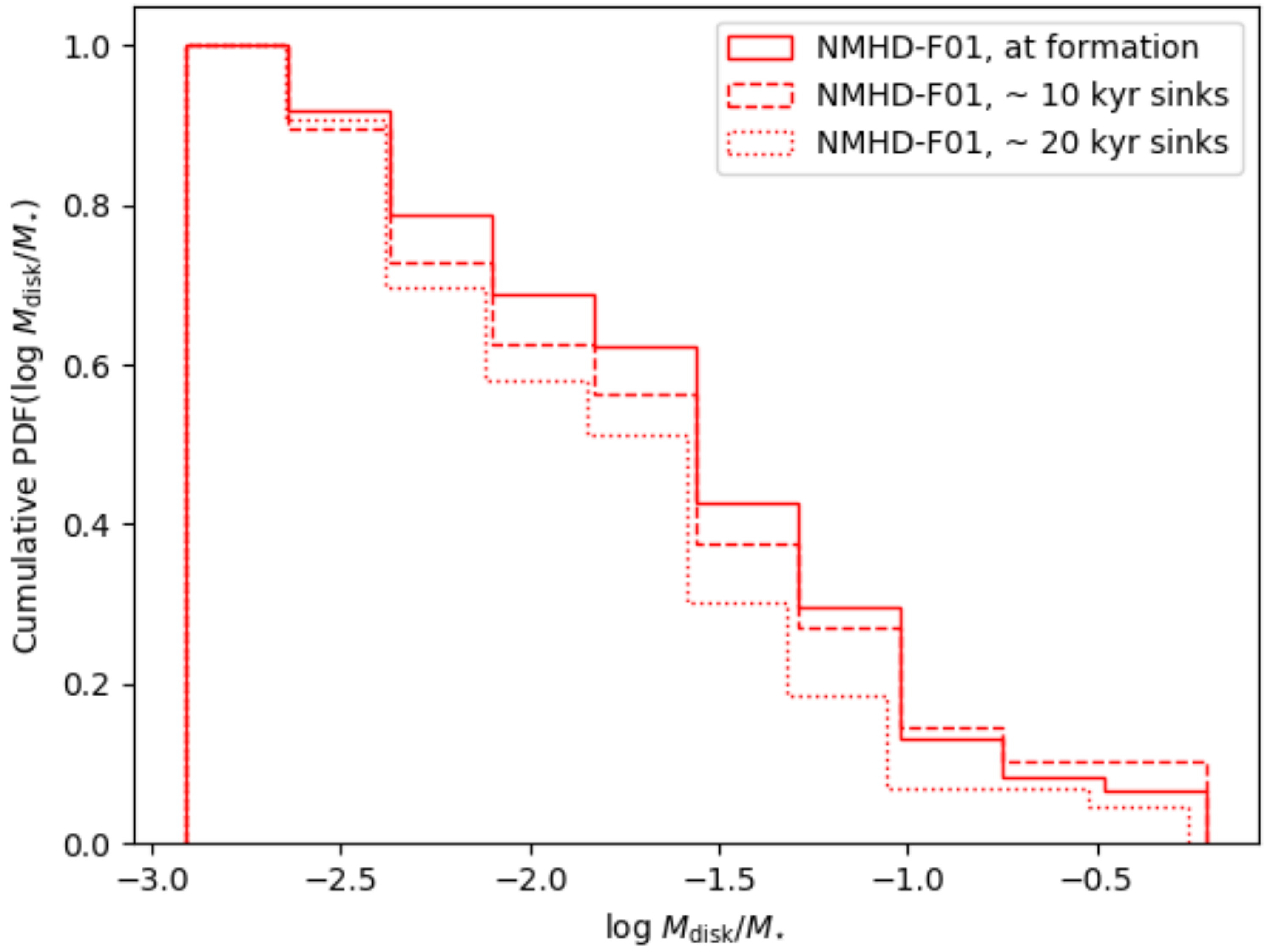
Disks radius



Disks masses

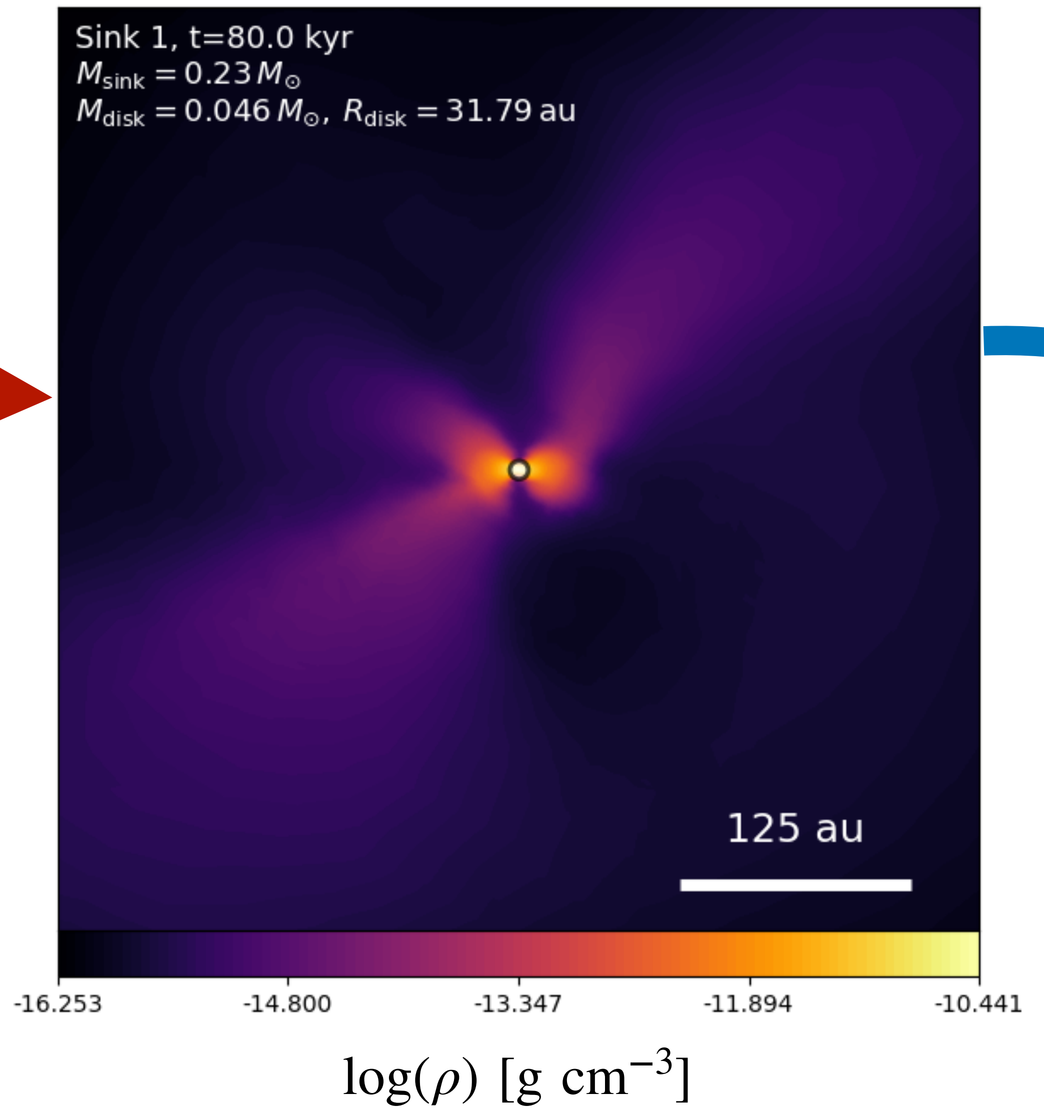


Disks/star mass ratios



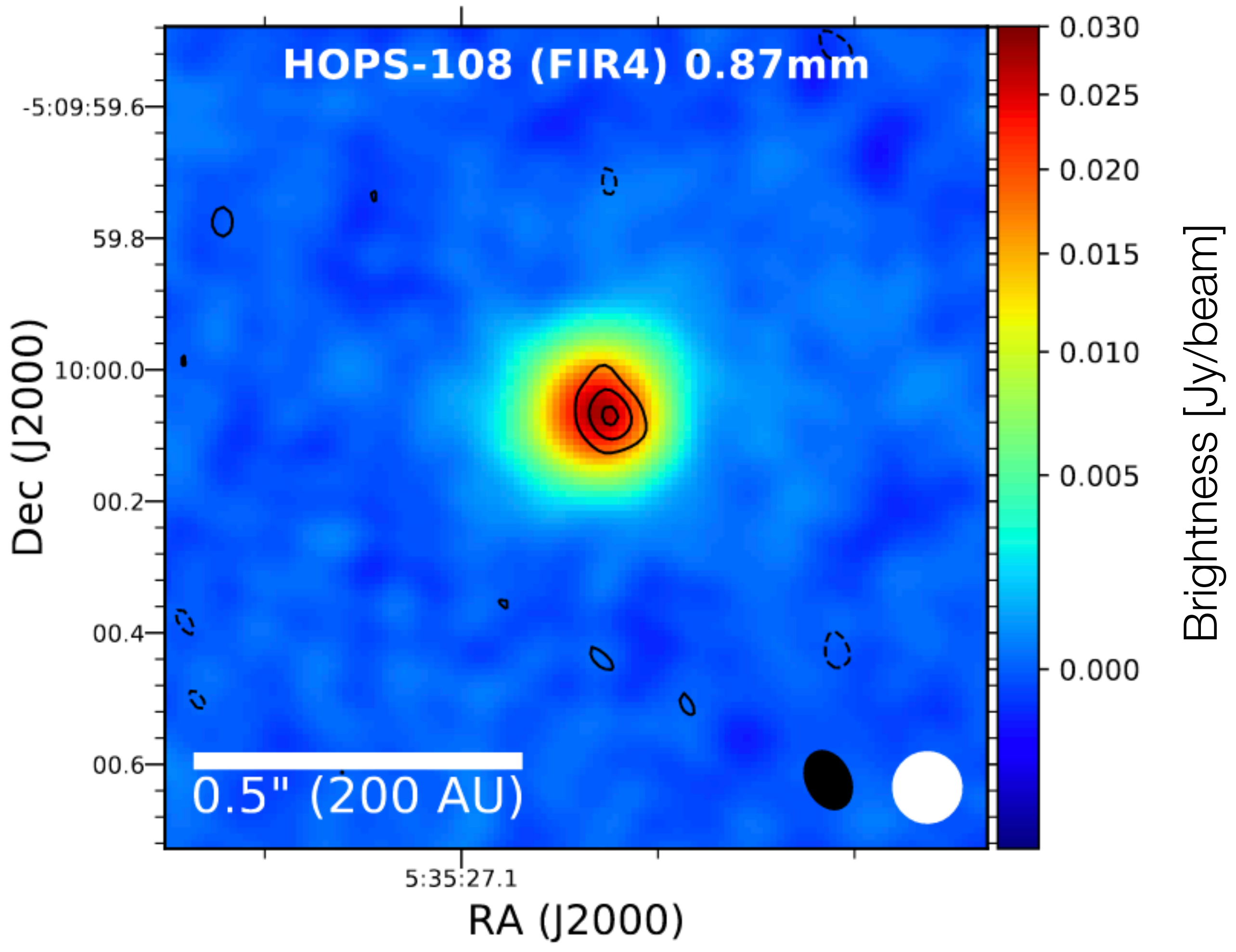
PRACE Synthetic observations

Improving the model?



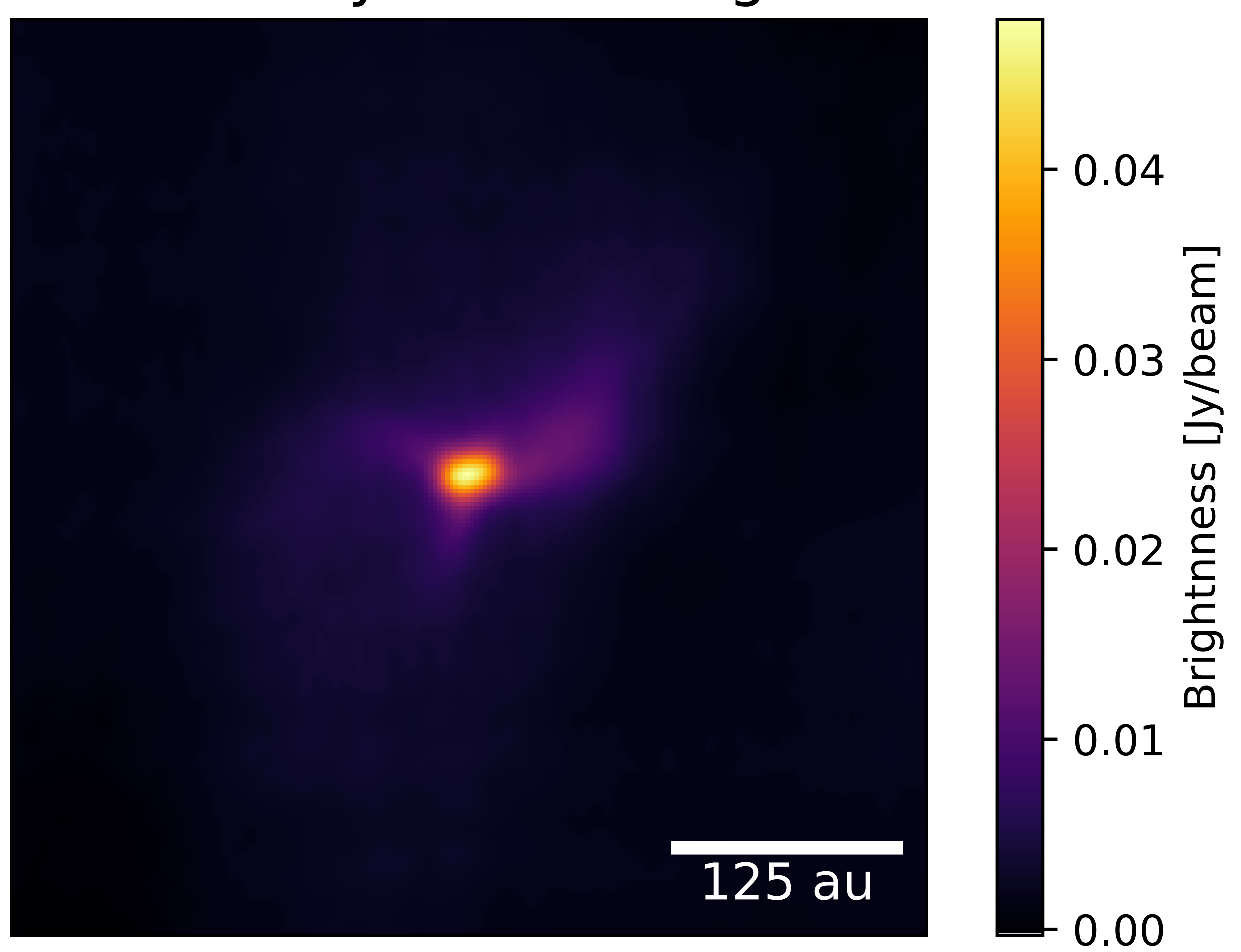
Synthetic observations
with RADMC-3D (Dullemond et al., 2012)
+ CASA (Mc Mullin et al., 2007)

VANDAM survey (e.g. Tobin et al., 2019)



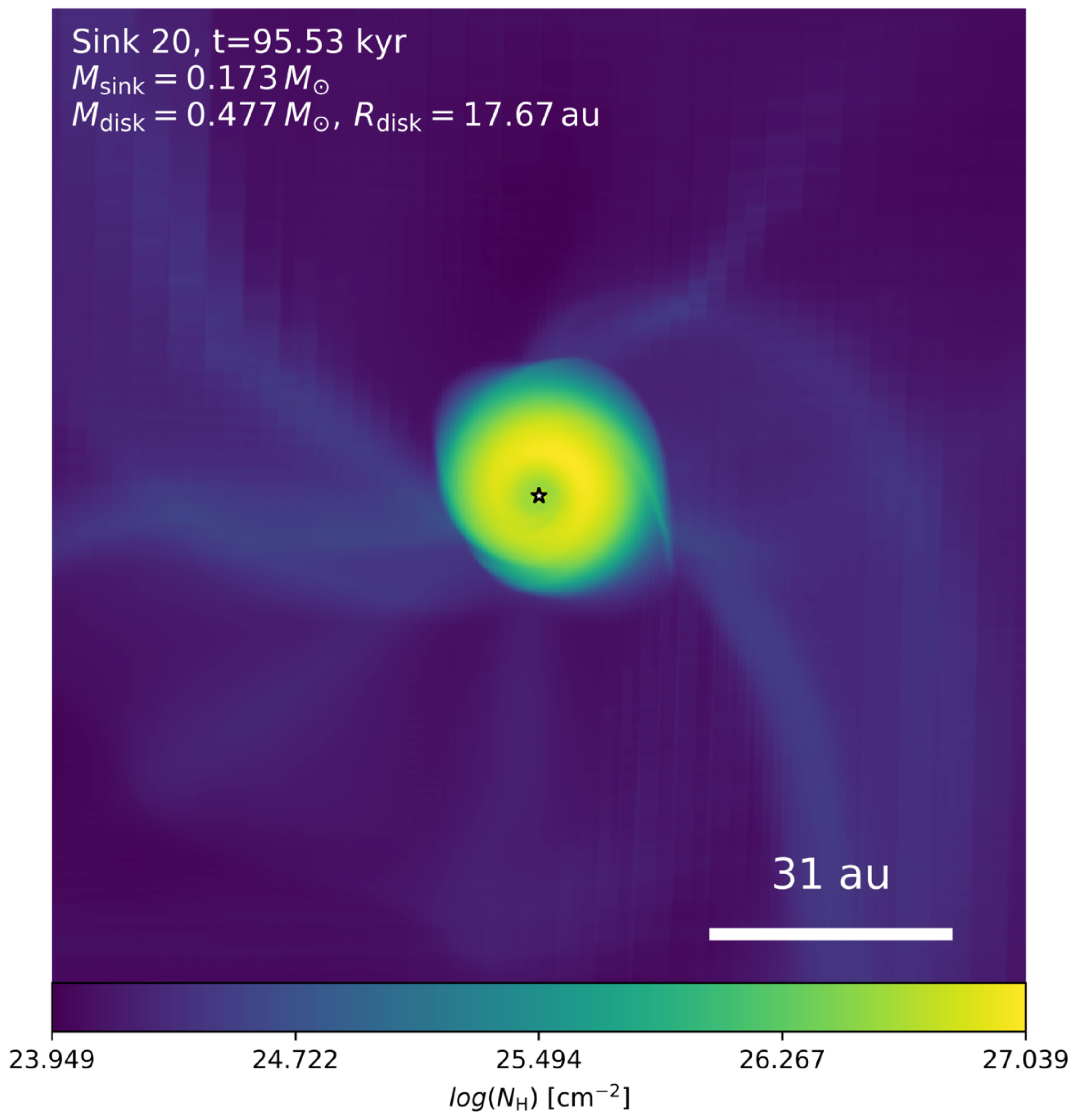
Comparison

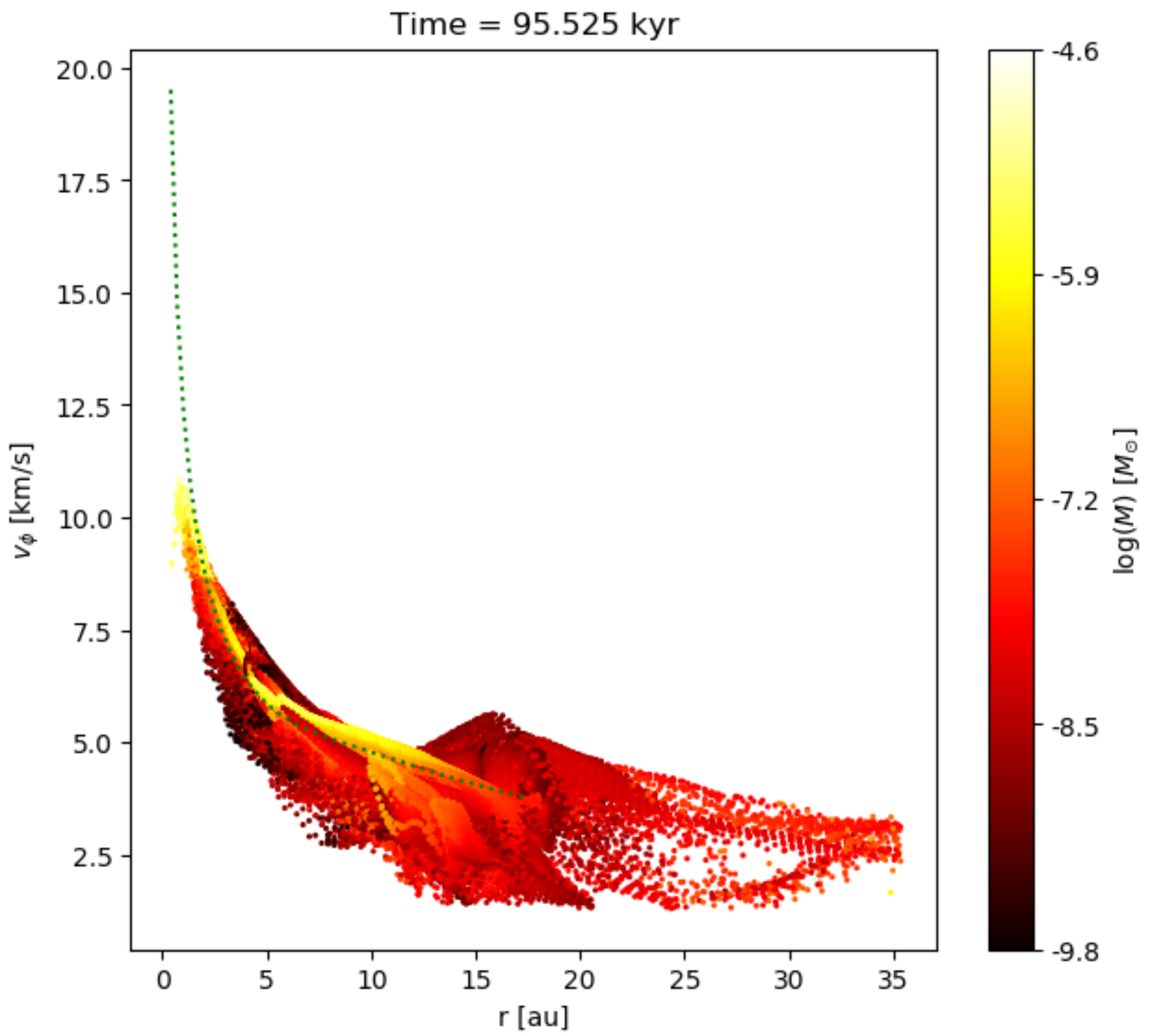
CASA synthetic image

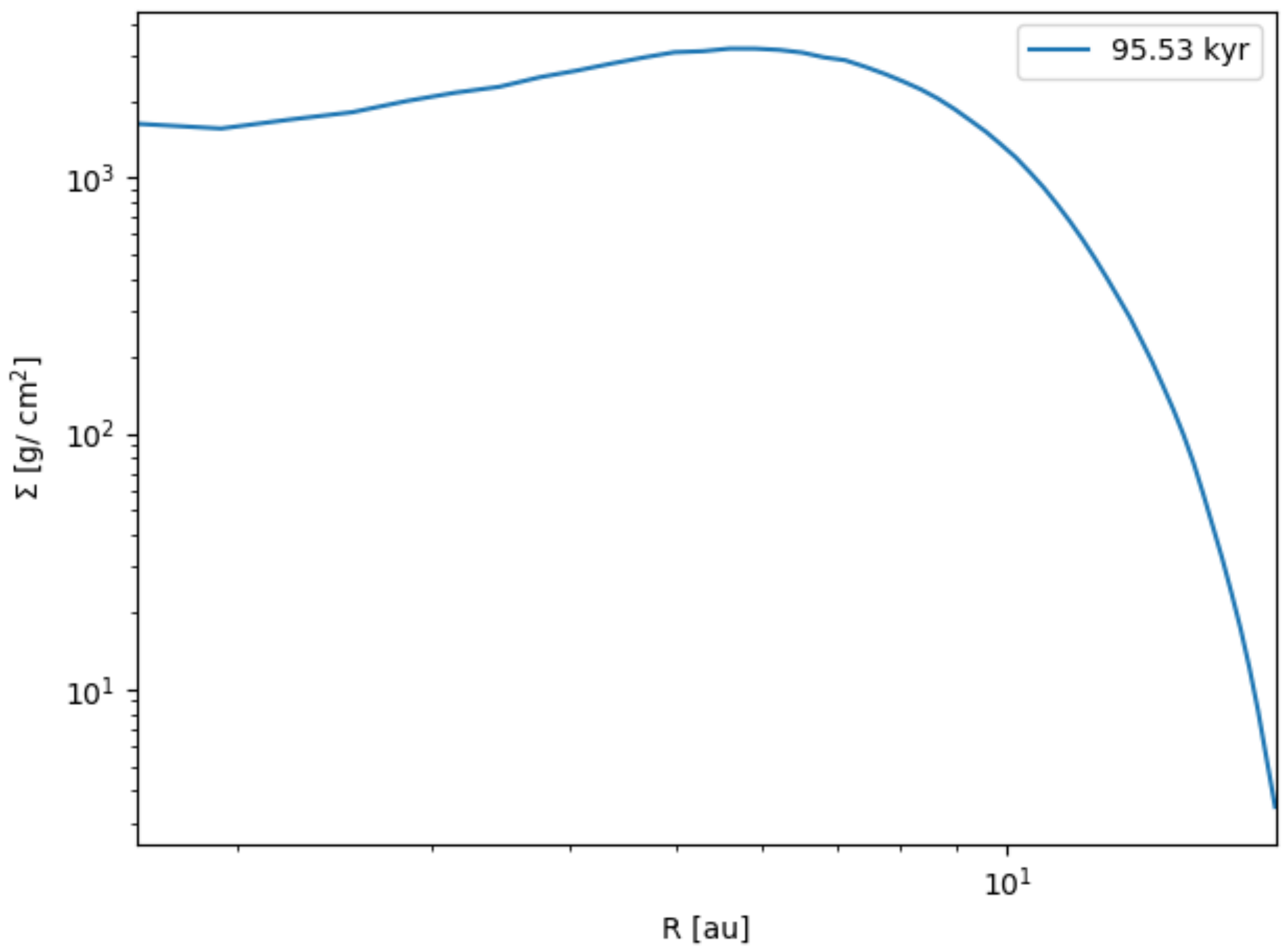


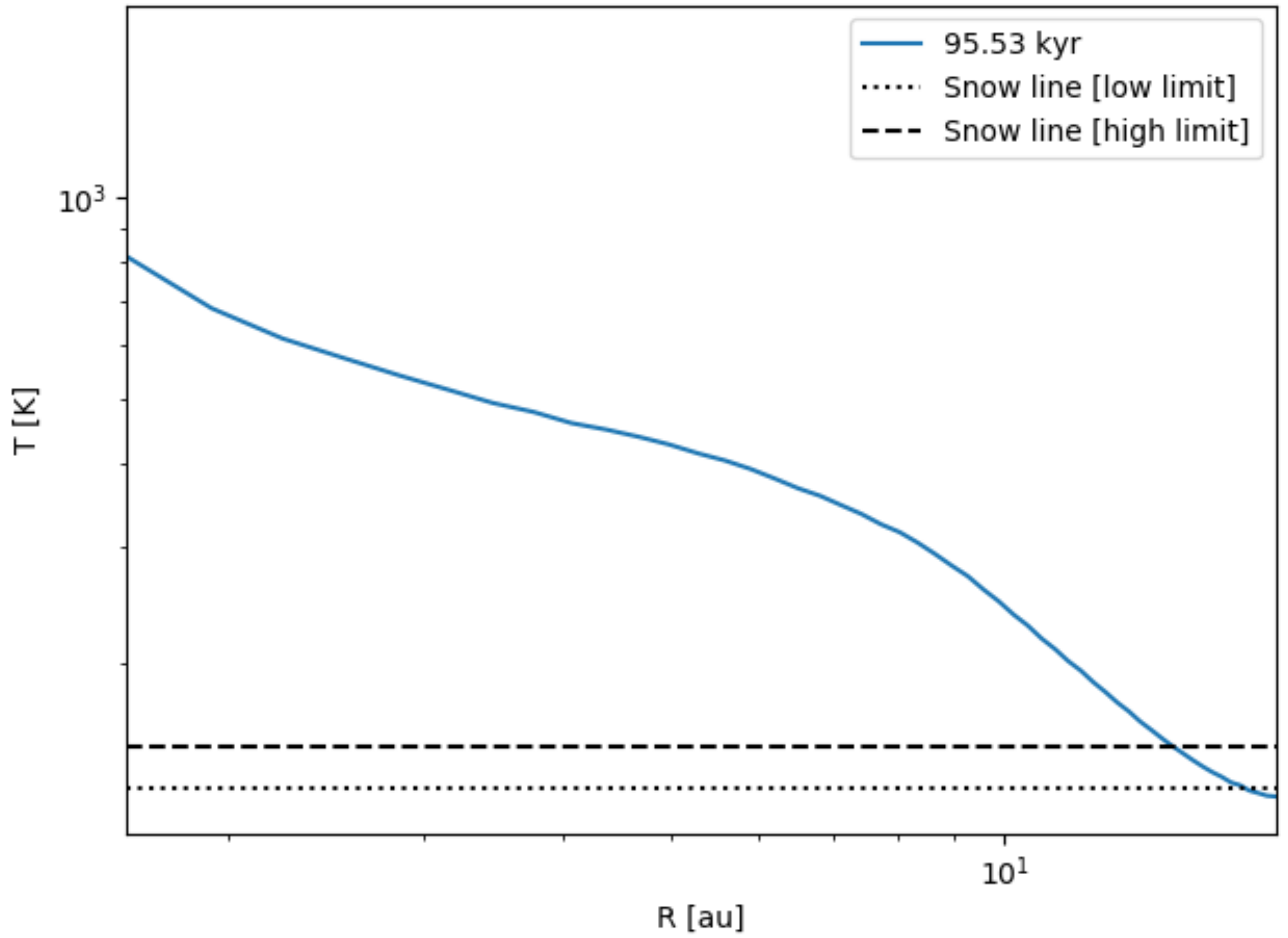
ALL CREDITS for the synthetic obs go to Tung Ngo Duy

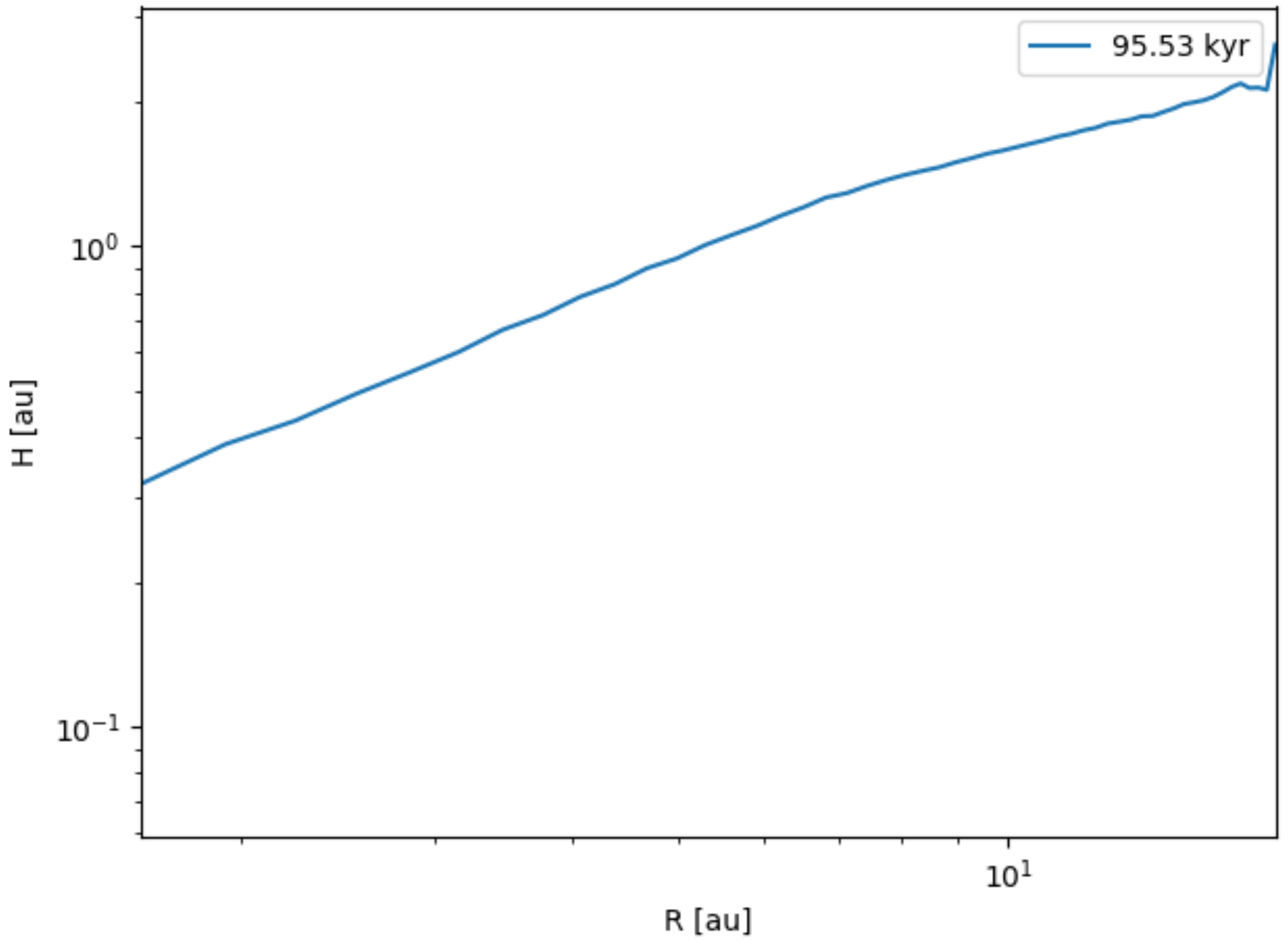
PRACE Rezooms





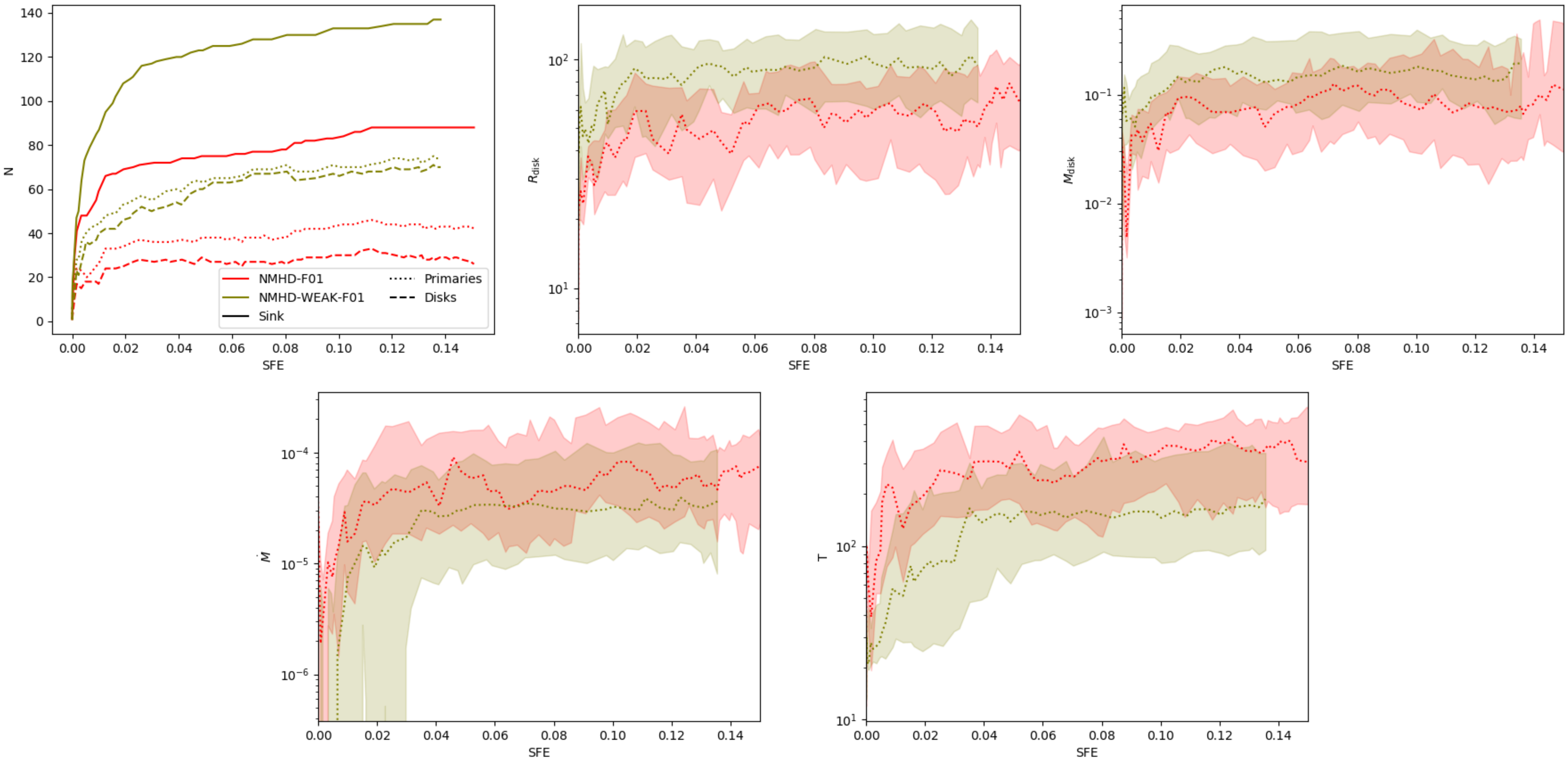






PRACE Impact of the magnetic field

WEAK FIELD = FIDUCIAL / 5



PRACE Synthetic populations of protoplanetary disks

How to get PRACE time?

https://prace-ri.eu/hpc-access/calls-for-proposals/

Call for proposals every 6 months (spring and autumn)

Proposal (template available at the previous link): mine was about 17 pages.

1. Key scientific contribution (for example disk populations in my case)
2. Detailed plan, justification for the ressources, scientific overview of the project
3. Code presentation, performances, ressources needed & data management
4. Detailed presentation of the HPC performances of the code (strong, weak scaling on the setup proposed)
5. Work plan : Gantt chart, publication plan, communication plan

Why/When asking a PRACE?

If a lot of ressources are needed -> You can do a lot with PRACE time. It's about 10 times what the CPU time I was used to get.

If you can propose something useful for the community (in my case catalogues of disks and clumps to compare with observations)

My experience

Ask help from people who got a PRACE in the past !

Time consuming: needs preparation and requires a perfect work plan.

Summary

DUSTY RAMSES

We have implemented dust (dynamics and growth) in RAMSES.
We have extensively tested the implementation
We have been using this module in the context of:

- Protostellar collapse
- Protoplanetary disks
- Turbulent molecular clouds

PRACE "Synthetic populations of protoplanetary disks"

We can now predict the initial properties of protoplanetary disks self-consistently in massive protostellar clumps (as a function of B, Mach, the cloud size, …)
For the community: future open access of the simulations http://www.galactica-simulations.eu/db/
(previous ones published in Lebreuilly et al., 2021 are already there)