Testing star formation prescription in simulations

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Motivation

	Galactic Scale	Cloud Scale
resolution	~ 10 pc	sub-parsec
SF scheme	thermoturbulent	sink particle

What if there is an uncertainty in calculating turbulence at lower resolution?

What if this effect leads to lower SFEs on galactic-scale simulations?

different SFE → different disruption rate of SF clouds → different escape fraction / outflow rates → effect on reionization / galaxy formation

Quantity of interest: total SFE, growth rate of stellar mass

Star Formation Recipes: galactic scale

density-based scheme: "Dencon"

- minimum density
- converging flow
- free parameter: SFE / t_{ff}

thermo-turbulent scheme: "FK2"

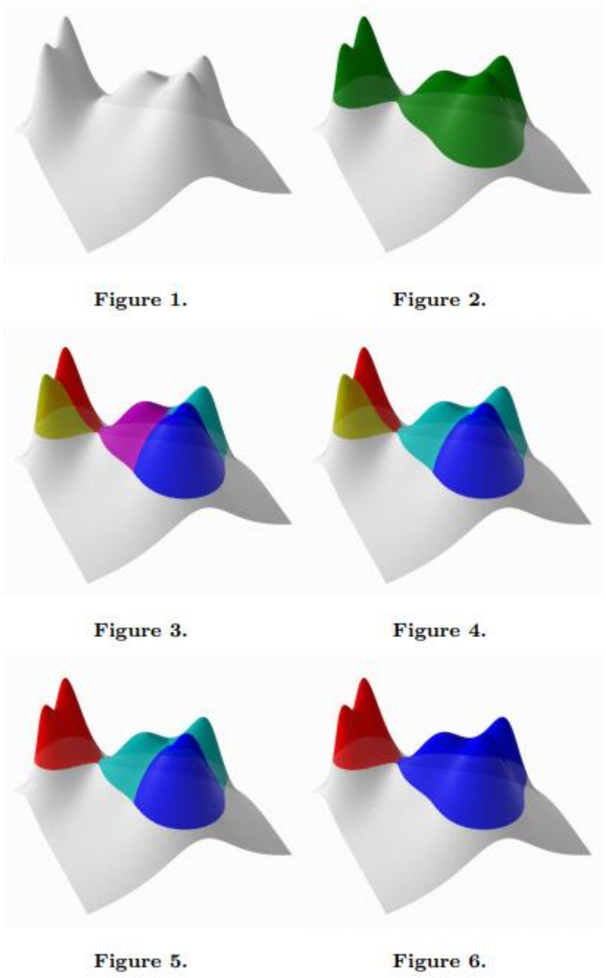
- converging flow
- turbulent Jeans length

when not resolved, stars are formed

- efficiency parameter ϵ

depends on α_vir, M

Star Formation Recipe: sink particle



Bleuler & Teyssier 2014, figures 1 - 6

1. Clumps are identified following steps in figures 1 – 6.

2. virial check + collapse check + proximity check

3. If all the tests are passed, a sink particle is formed.

4. When the sink particle exceeds a given threshold mass, the sink particle's mass is converted to a star particle.

free parameters

- ρ_{clump}: threshold density for a clumpfinder
- msink2star: controls star particles' mass resolution

Star Formation Recipe: sink particle

There are two possible choices for sink formation threshold density.

1. Truelove et al. 1997

$$\lambda_J = \sqrt{\frac{\pi c_s^2}{G\rho}} \geq 4\Delta x_{min} \rightarrow \rho_{sink} = \frac{\pi c_s^2}{16G\Delta x_{min}^2} = \rho_{Tr}$$

2. Gong & Ostriker 2012

- Larson 1969 & Penston 1969

$\rho_{LP}(r) = \frac{8.86 c_s^2}{4\pi G r^2}$ for an initially-static, gravitationally-unstable isothermal sphere

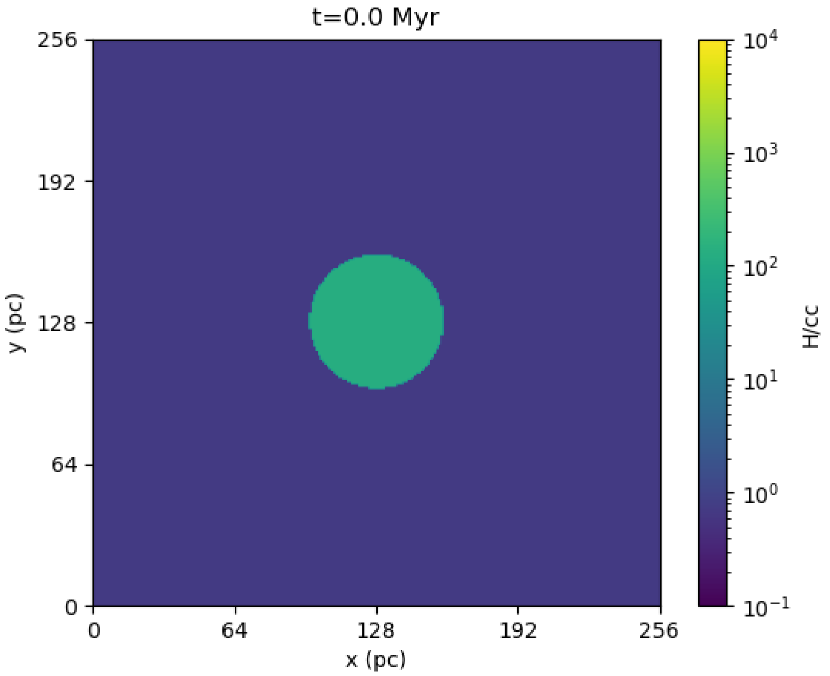
- $\rho_{sink} = \rho_{LP}(0.5\Delta x) = \frac{8.86 c_s^2}{\pi G \Delta x_{min}^2} \sim 14.4\rho_{Tr}$

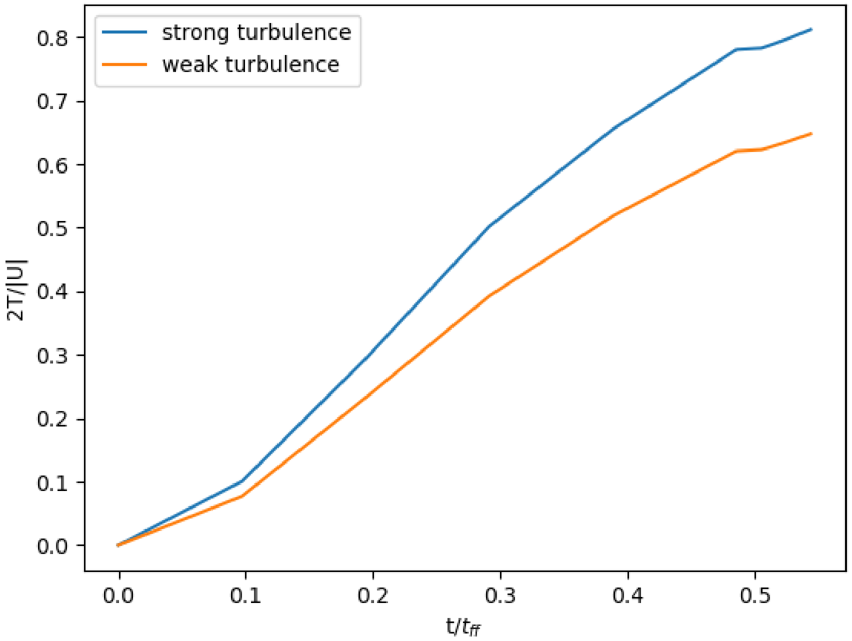
Simulation Setup

- $T_{cl} = 30\ K,\ r_{cl} = 30\ pc,\ \rho_{cl} = 100\ H/cc,\ t_{ff} \sim 5.1\ Myr$
  $\rho_{clumpfind} = 0.1\rho_{sink}$, msink2star = $10^3 M_{\odot}$
- develop turbulence for 0.5 t_{ff} without gravity

→ control the first star's formation time

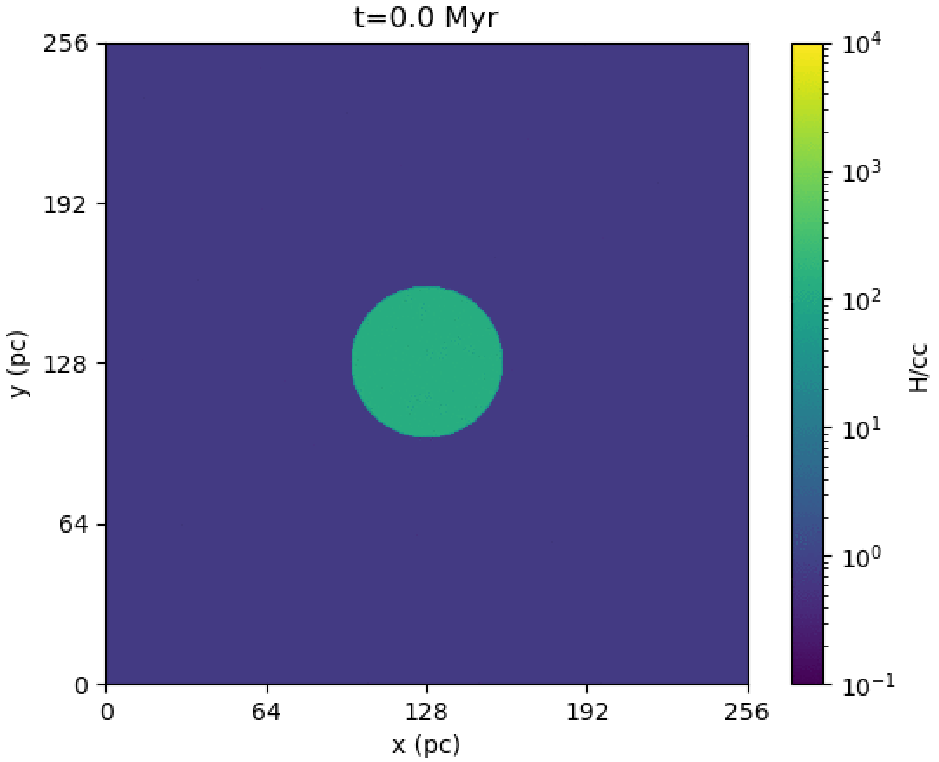
Simulation name	Δx_{min} (pc)	ρ_{sink} (H/cc)
sink_1pc	1	4821.6
sink_0.5pc	0.5	19286.4
sink_0.25pc	0.25	77145.6





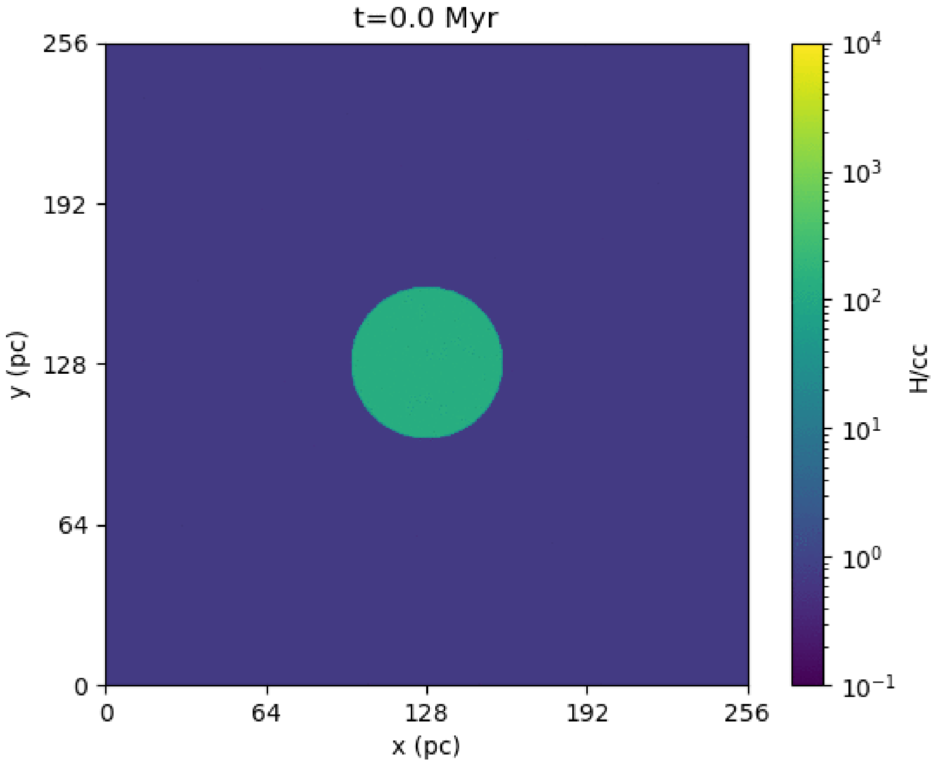
Simulation Setup

sink_0.5pc, weak turbulence



Most stars are formed and clustered at the center.

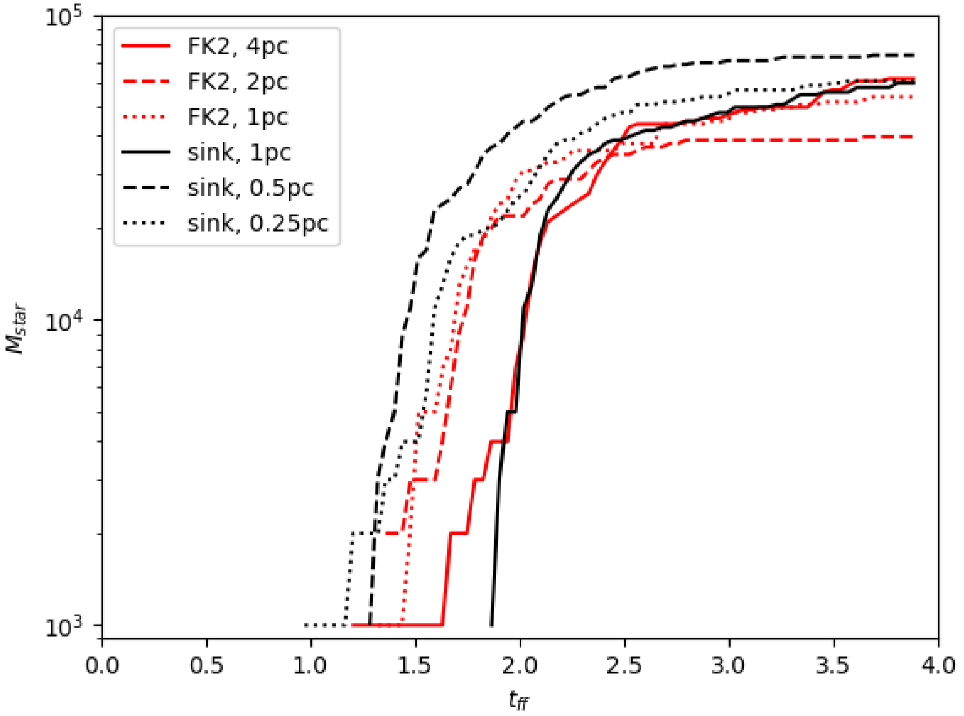
sink_0.5pc, strong turbulence

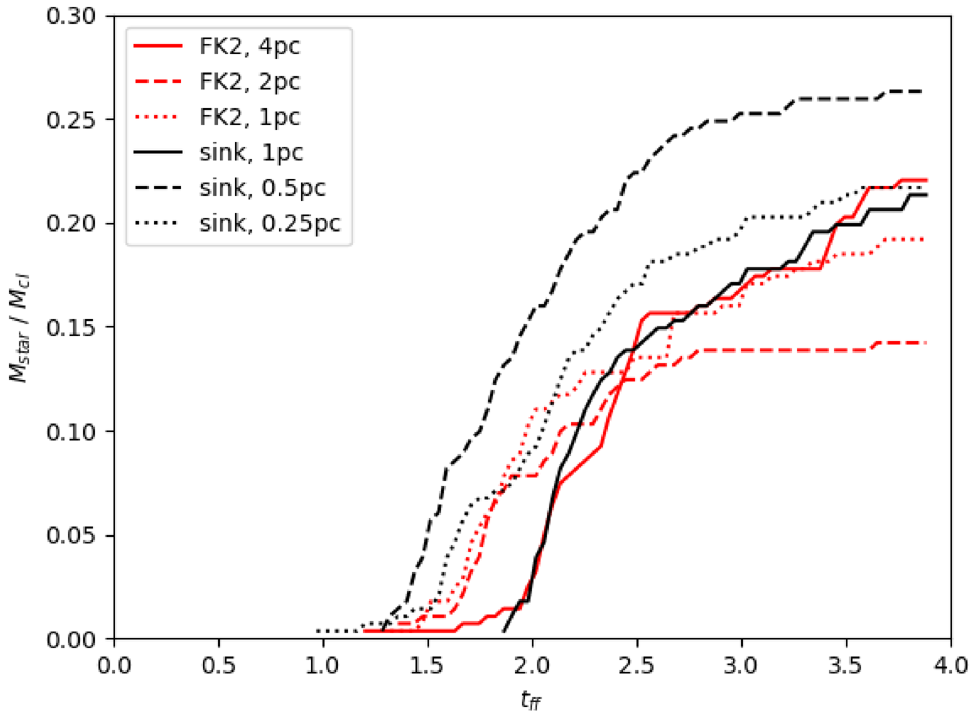


Stars are scattered across a larger region.

Preliminary Results

Strong turbulence case



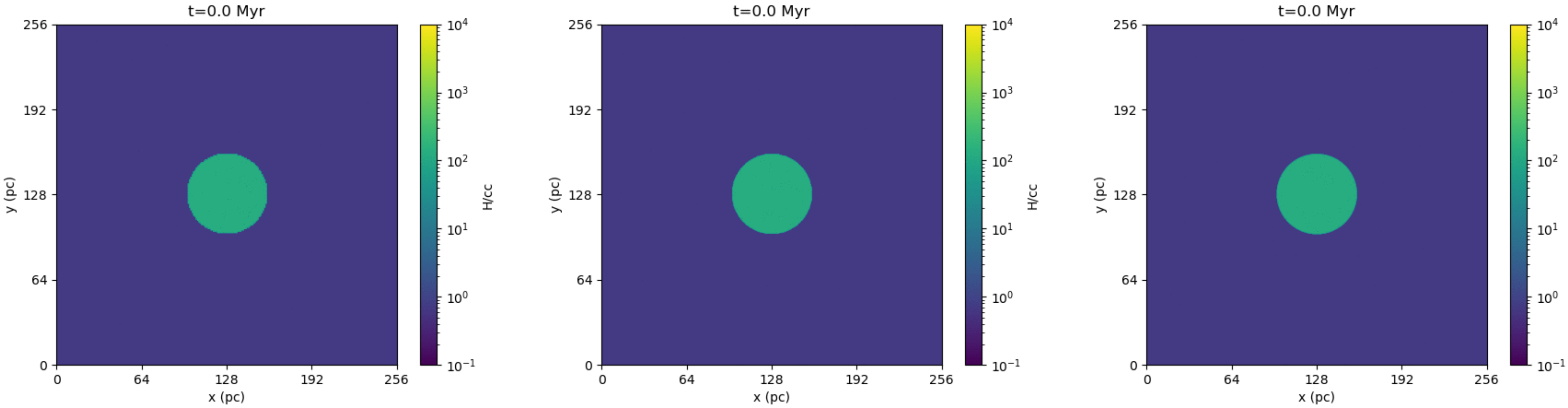


- SFE is higher in simulations with sink particles, but results are very resolution-dependent.
- The total SFE: (20, 26, 22)% in sink (1, 0.5, 0.25)pc, (23, 14, 19)% in FK2 (4, 2, 1)pc

Preliminary Results

Strong turbulence case

higher spatial resolution

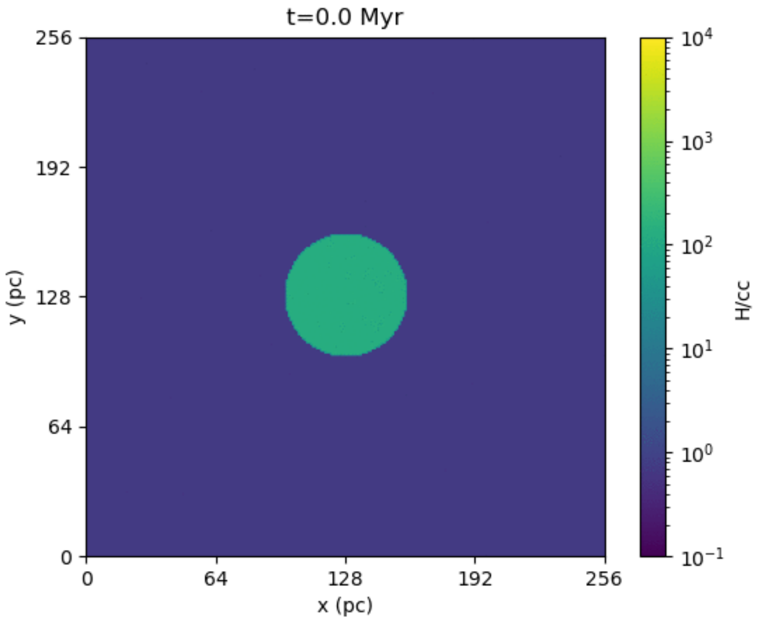


- The number of sink particles increases with increasing resolution. Since stars are formed from sink particles, they cover larger region as resolution increases.

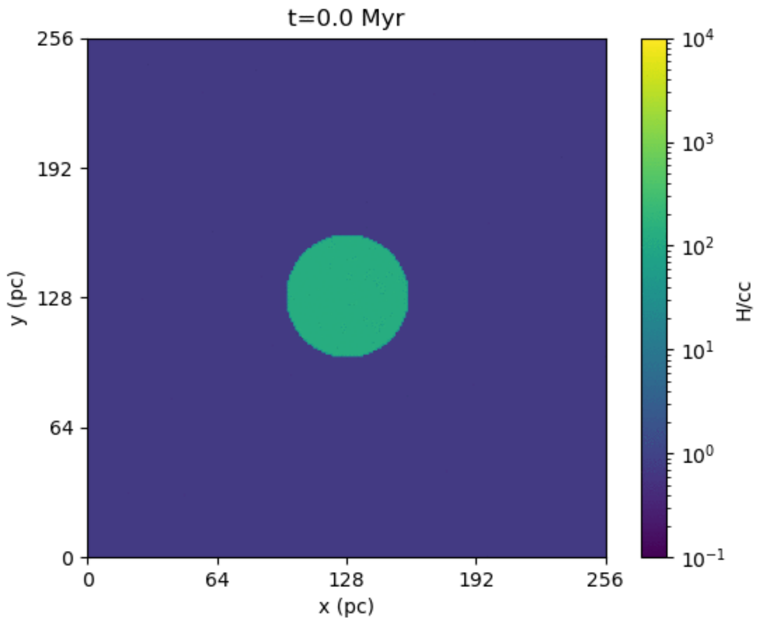
- The birth places of sink particles at the early stage in 0.5, 0.25 pc runs are similar to each other. However, they are different at the later stage. ← Sink particles change gas dynamics.

Preliminary Results

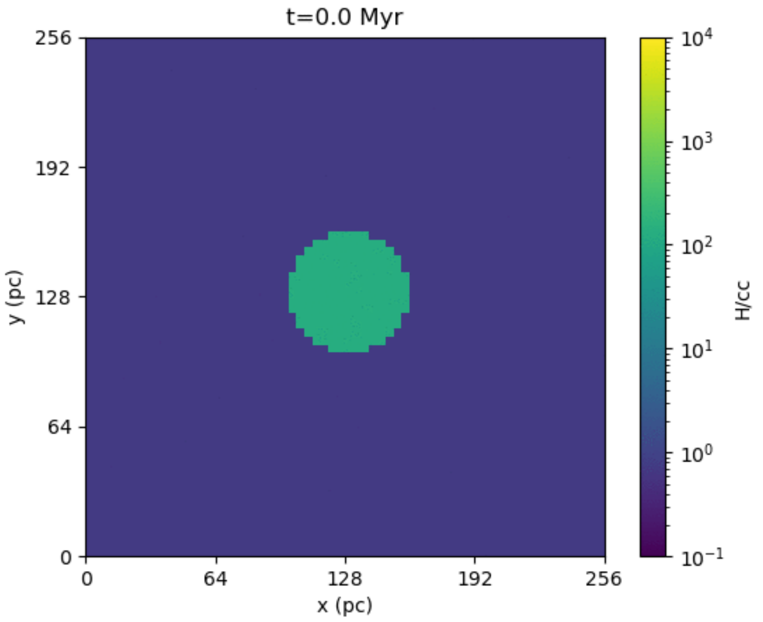
Strong turbulence case



sink_1pc



FK2_1pc

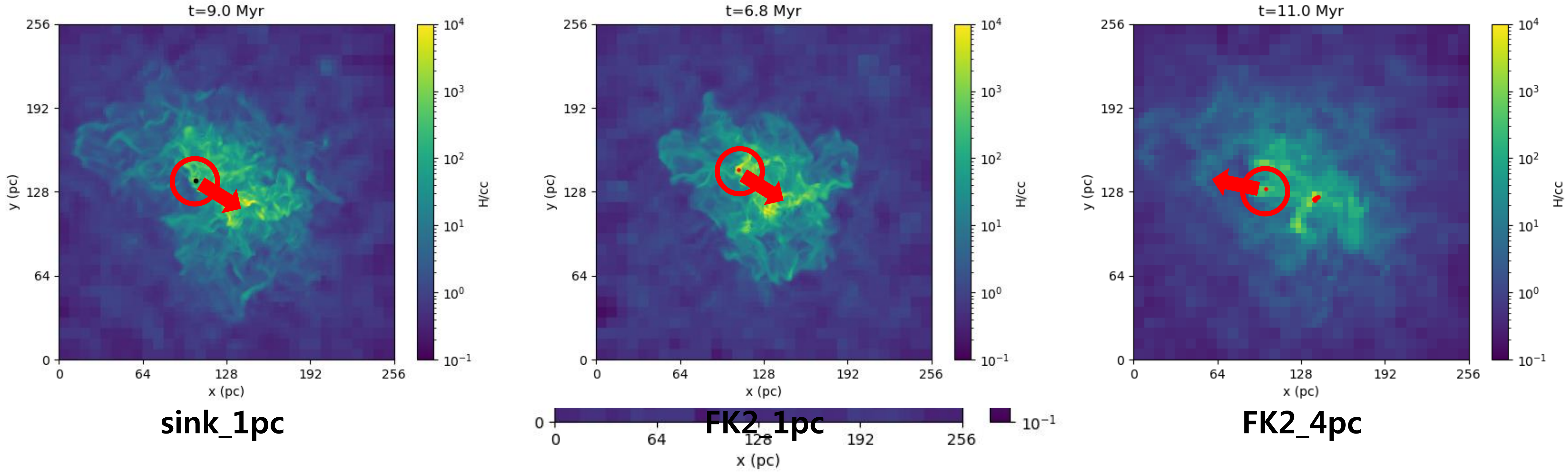


FK2_4pc

- The birth places of stars in sink_1pc and FK2_1pc seem to be similar.
- Due to an uncertainty in calculating turbulence, stars in FK2_4pc have different distributions.

Preliminary Results

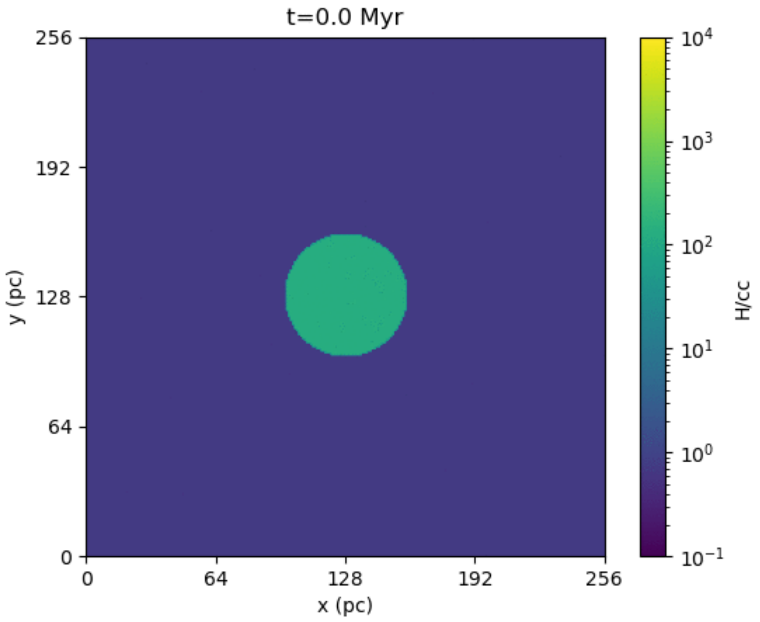
Strong turbulence case



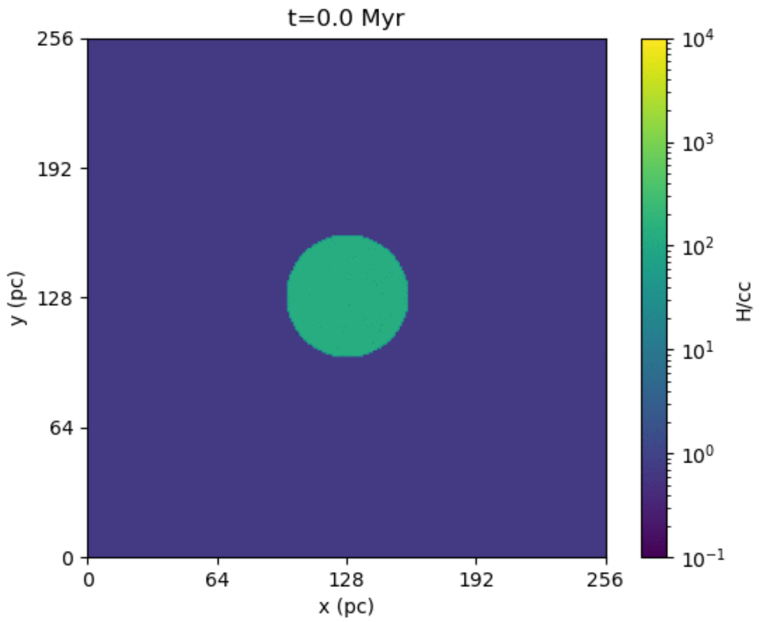
- The sink / star inside the red circle in sink_1pc and FK2_1pc move inward.
- However, in FK2_4pc, the star inside the red circle moves outward.

Preliminary Results

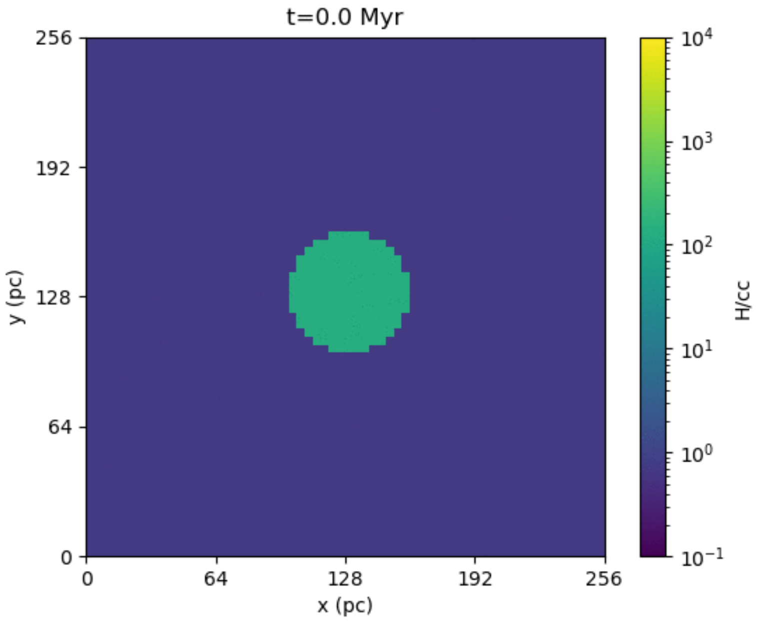
Strong turbulence case



sink_1pc



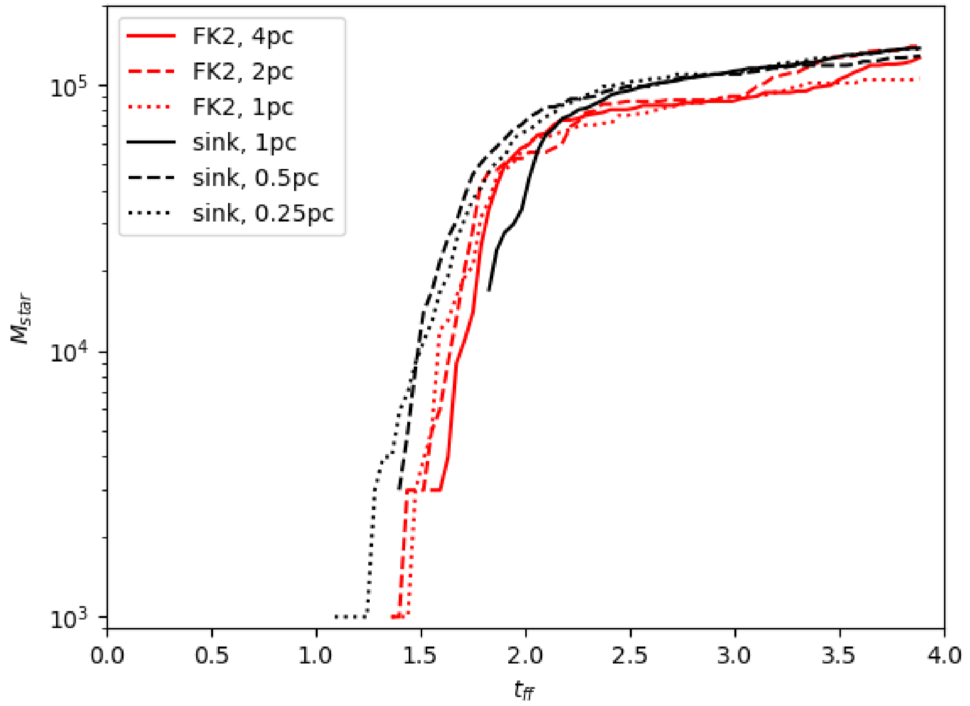
FK2_1pc

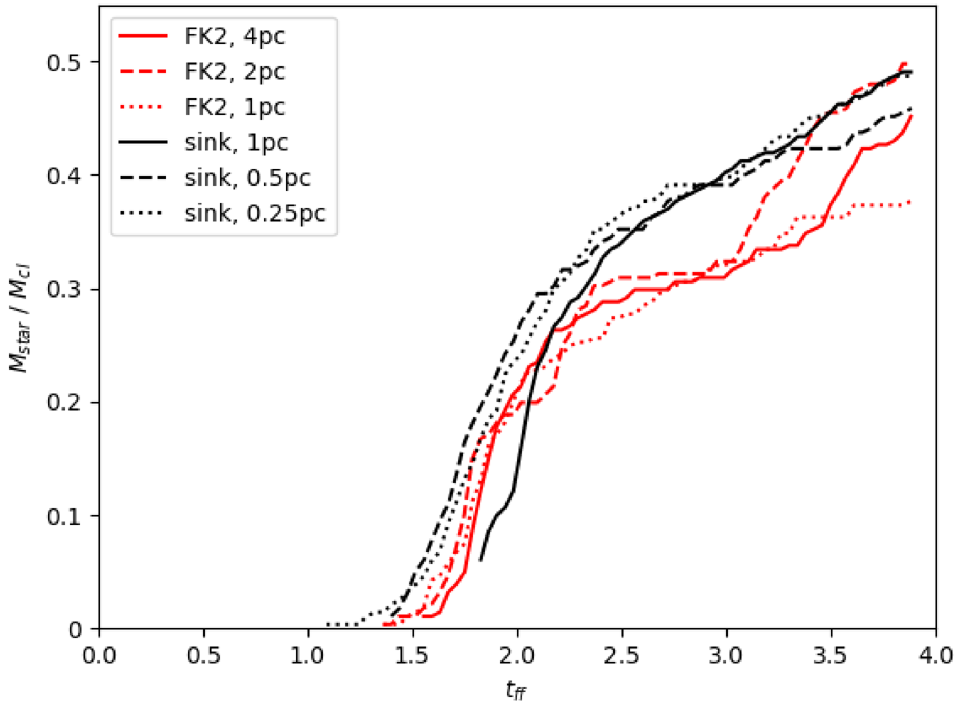


FK2_4pc

Preliminary Results

Weak turbulence case



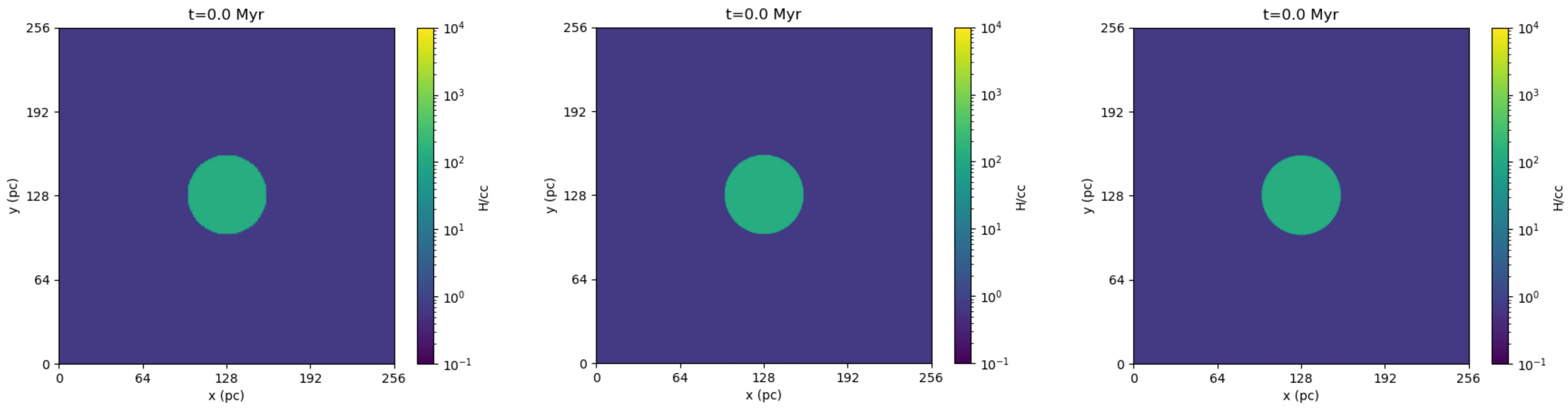


- SFEs in simulations with sink particles are comparable to those using the thermo-turbulent scheme.
- The SFHs in simulations with sink particles become much more resolution-independent.
- The total SFE: (49, 46, 49)% in sink (1, 0.5, 0.25)pc, (45, 50, 38)% in FK2 (4, 2, 1)pc

Preliminary Results

Weak turbulence case

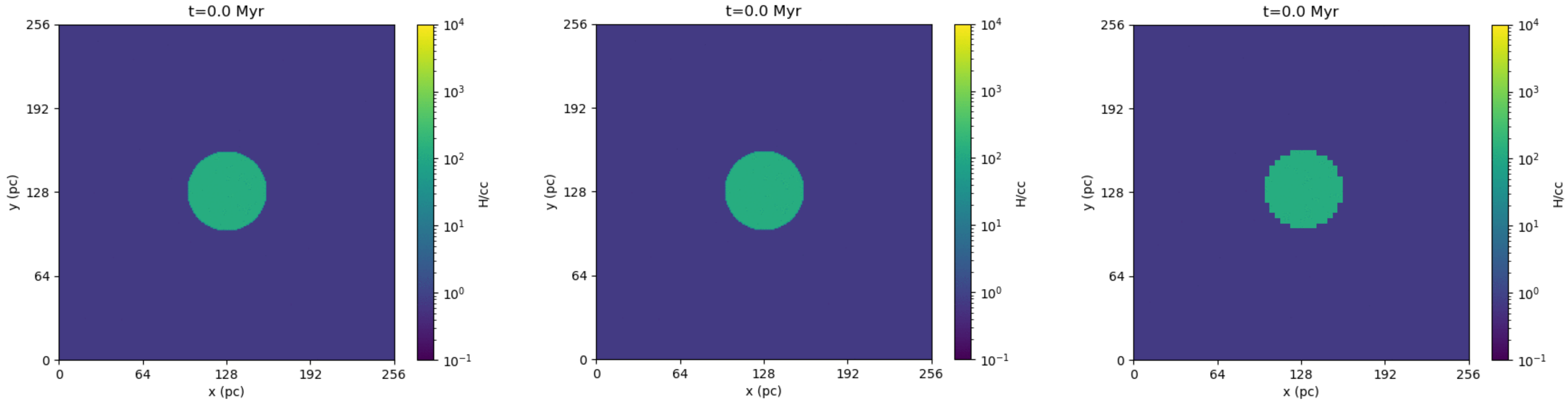
higher spatial resolution



- Although the total SFEs and the SFH histories show a better convergence in the weak turbulence case, the birth places of sink particles do not show better convergence.

Preliminary Results

Weak turbulence case



sink_1pc **FK2_1pc** **FK2_4pc**

- Again, just like what is found in strong turbulence case, stars in FK2_4pc have different distributions while stars in sink_1pc and FK2_1pc are distributed in a similar way.

Conclusions

- The thermo-turbulent SF scheme seems to have a good agreement with sink-based SF algorithm.
- SFEs are higher in simulations with sink particles at stronger turbulence. But they are comparable when the turbulence is weak.
- The SFHs show a better convergence between simulations with sink particles. The converging trend is more resolution-independent in weak turbulence cases.
- The resolution independency of sink-based SF algorithm doesn’t mean that stars are formed at the same places. It is because sink particles change dynamics of their surround gas.
- The sink formation is delayed in the lowest resolution. (Any suggestion?)

Future Work

- Cosmological zoom-in simulations targeting at $10^{8-9}M_{\odot}$ DMHs using sink particle algorithm with spatial resolution of 1-2 pc

- Why $10^{8-9}M_{\odot}$ DMHs?

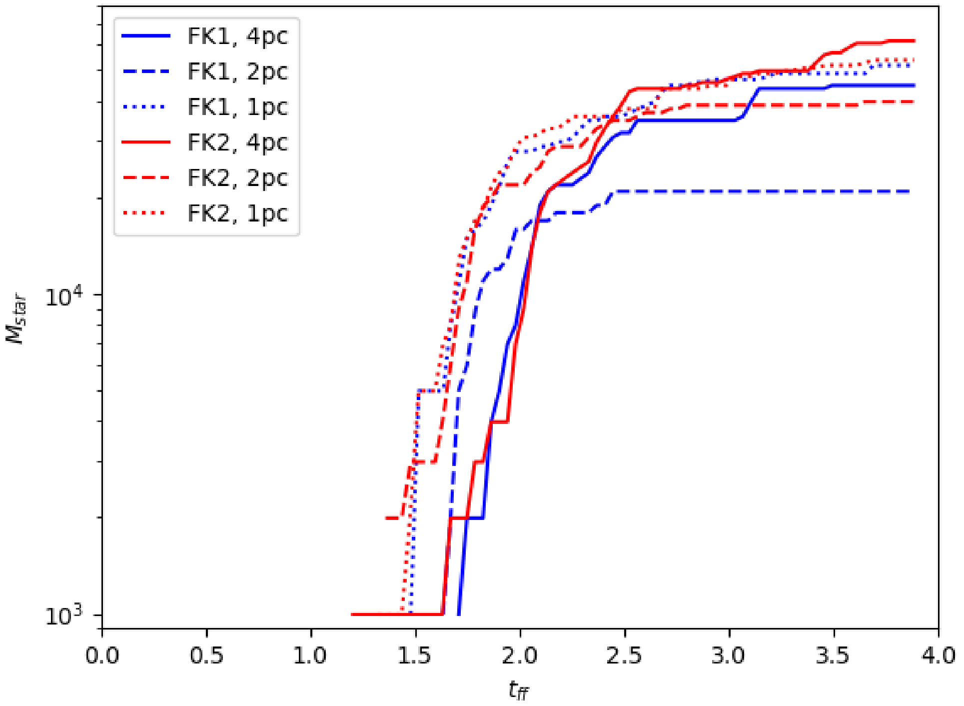
→ They are thought to have a huge impact on reionization.

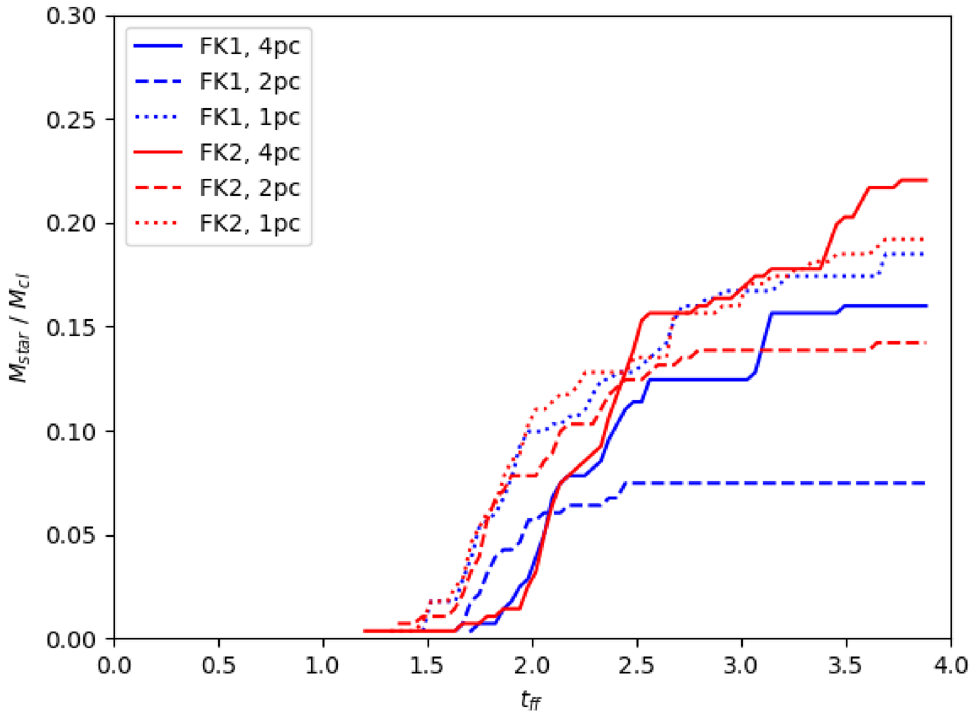
- What resolution is needed to use sink particle algorithm on galactic scale simulations?

Thank you

Appendix: FK1

Strong turbulence case

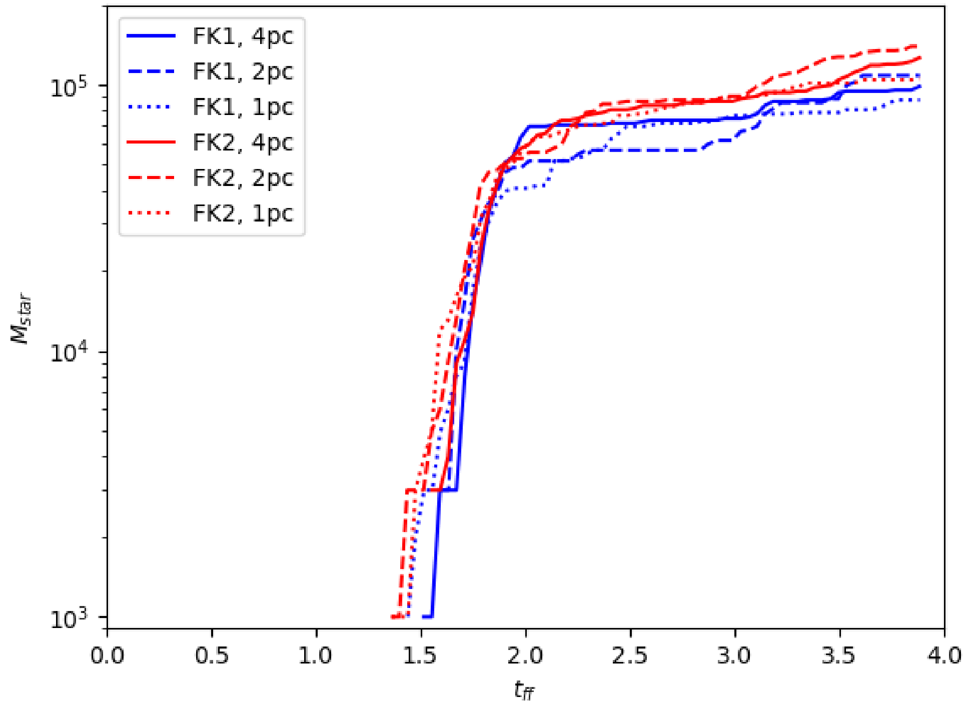


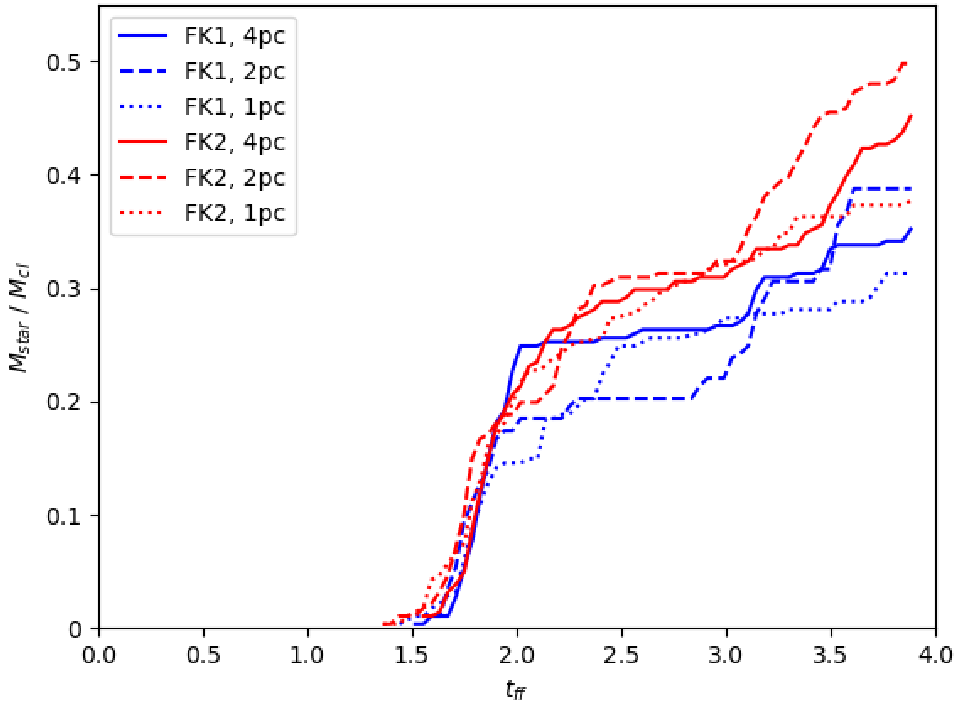


- Both the total stellar mass and the growth history don’t converge.

Appendix: FK1

Weak turbulence case





- The total stellar mass seems to converge between different resolutions, but the SFH are very different.