始原ガス円盤分裂による多重星系形成と数値計算の不定性

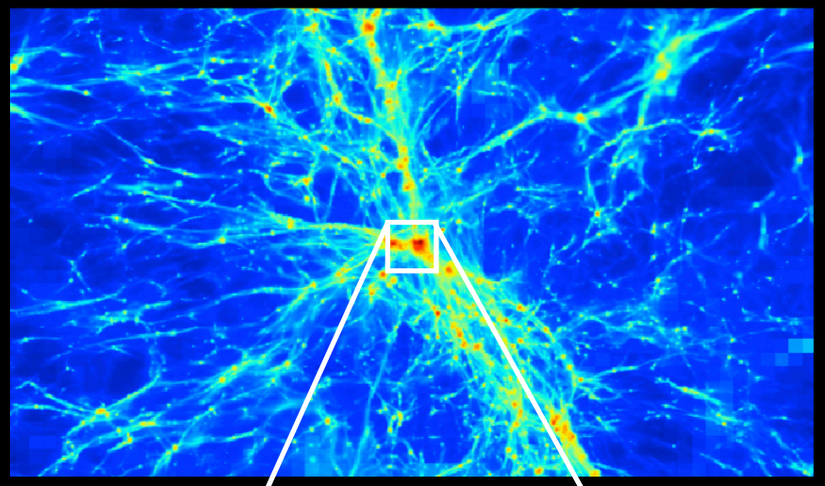
島 和宏 (京都大学)

共同研究者: 細川 隆史 (京都大学)

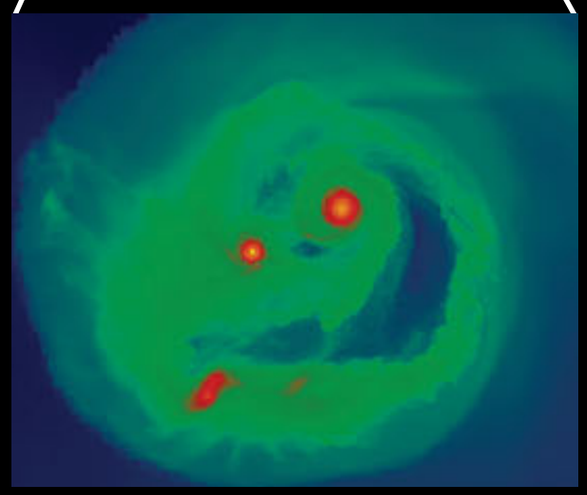
初代星・初代銀河研究会2019@名古屋

PopIII stars binary formation

Cosmological simulations

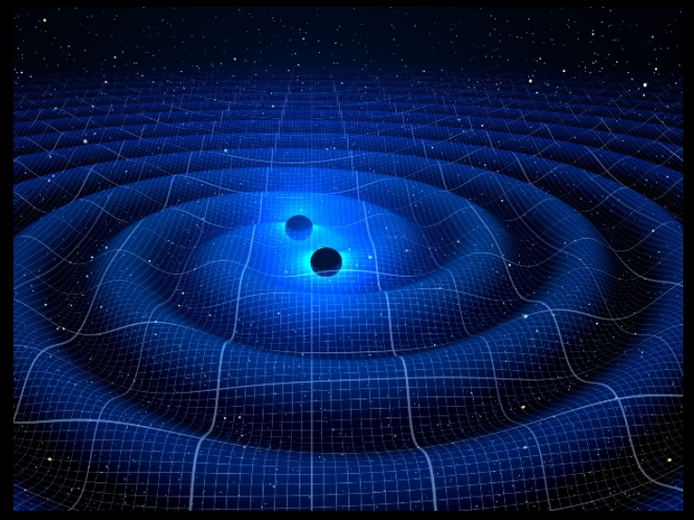


mini halo

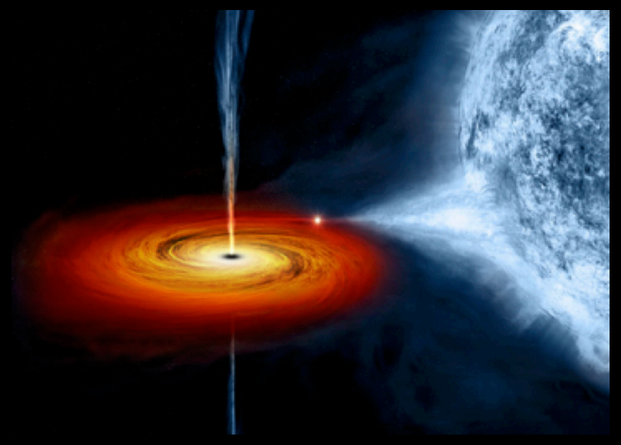


low mass star
survivors?

fragmentation
& binary formation ?



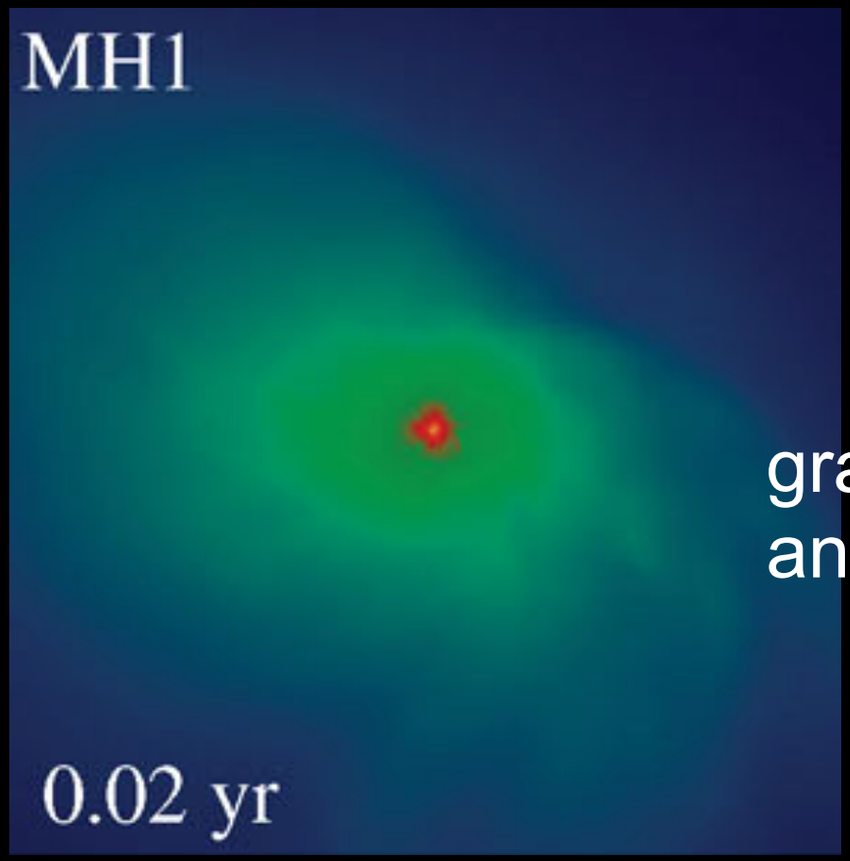
GW source?



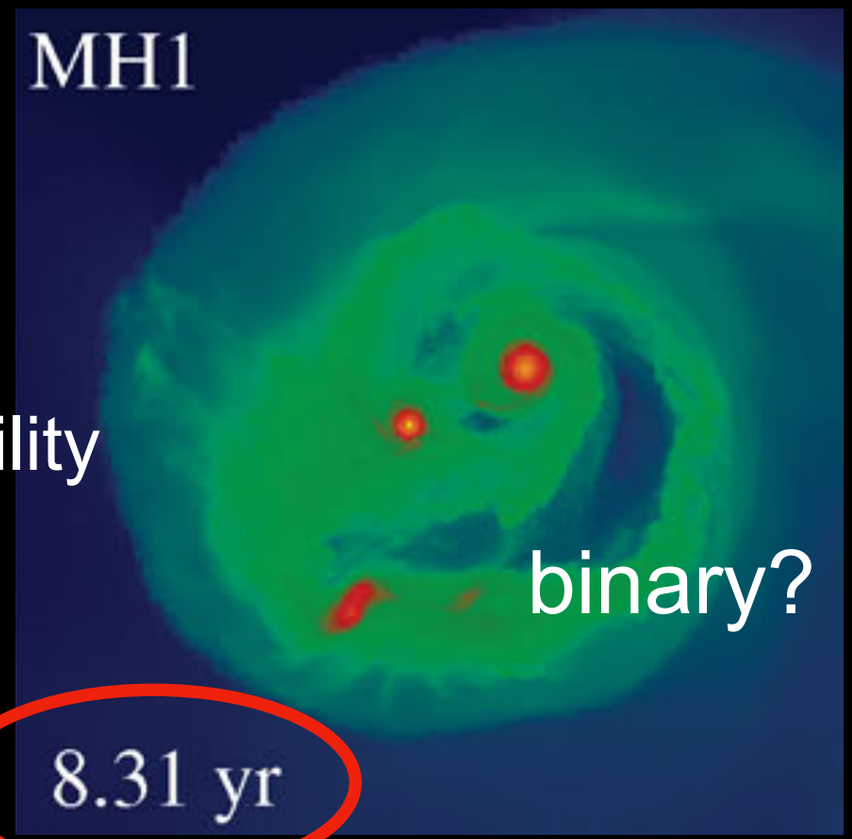
Fragmentation of primordial gas disk

collapse of primordial gas

(Greif et al. 2012)



gravitational instability
and fragmentation



only for ~10 yrs after the first protostar formation

-> A sub-grid model (sink particle) is necessary

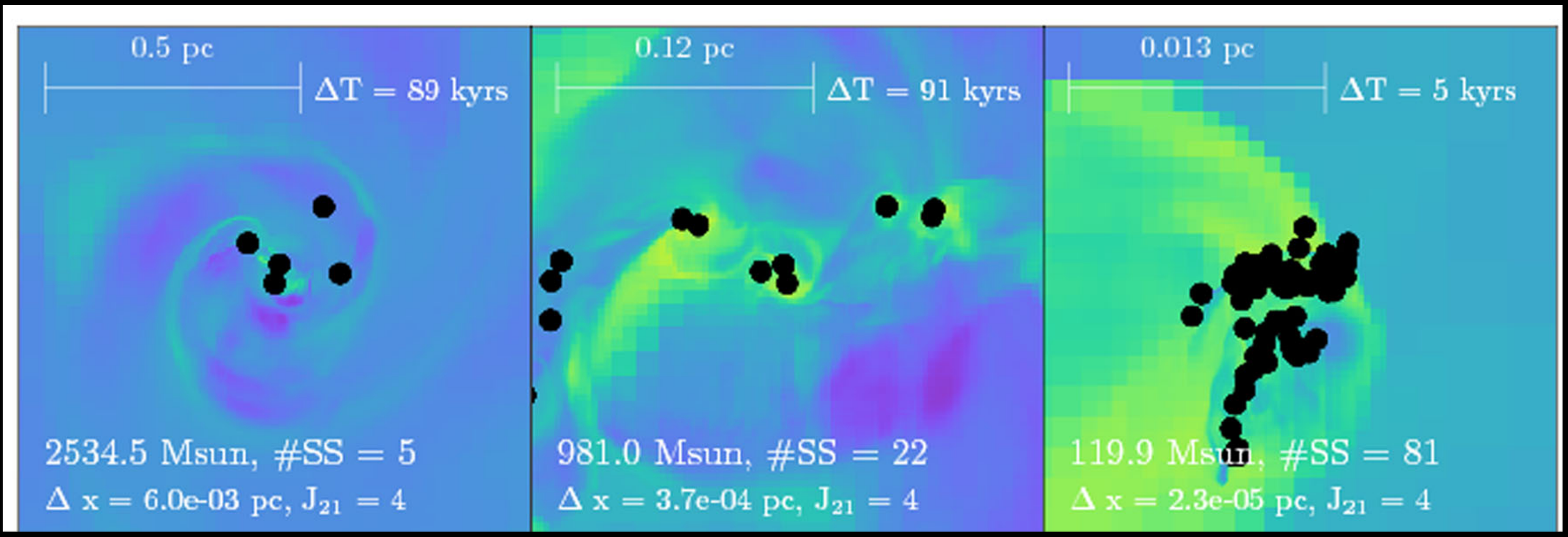
Resolution dependency with sink particles

higher resolution

0.5 pc

0.12 pc

0.013 pc



(Regan and Downes 2018)

5 sinks

22 sinks

81 sinks

physical ? or numerical ?

Grid code + sink particle

(Regan and Downes 2018)

2 NUMERICAL FRAMEWORK

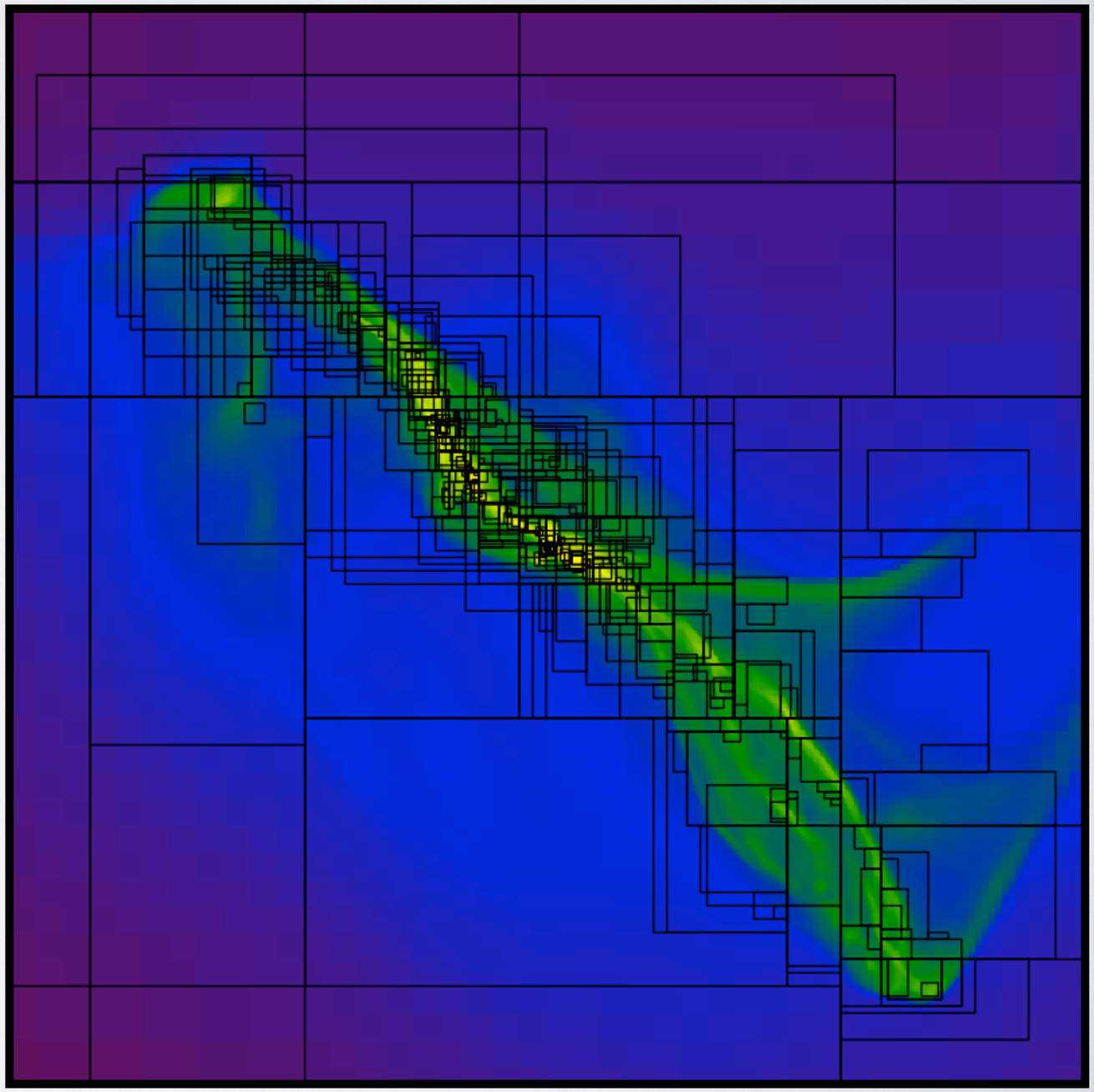
In this study, we have used the publicly available adaptive mesh refinement code ENZO[1] to study the fragmentation properties of gas within haloes irradiated by a background LW field. Into ENZOwe have added a new star particle type, which we have dubbed `SmartStar`. We now describe both components.

Similar to the prescriptions described by Federrath et al. (2010), we only form sink particles when the following criteria are met:

(i) The cell is at the highest refinement level.
(ii) The cell exceeds the Jeans Density.
(iii) The flow around the cell is converging along each axis.
(iv) The cooling time of the cell is less than the freefall time.
(v) The cell is at the minimum of the gravitational potential.

AMR:
ADAPTIVE-MESH REFINEMENT

- create and destroy grid patches dynamically (block-structured)
- grids at multiple resolutions
- multiple refinement criteria:
  - density (gas or dark matter)
  - gradients, shocks
  - cooling time
  - Jeans length
  - refine regions around particles
- easy to create new criteria



The Enzo Project

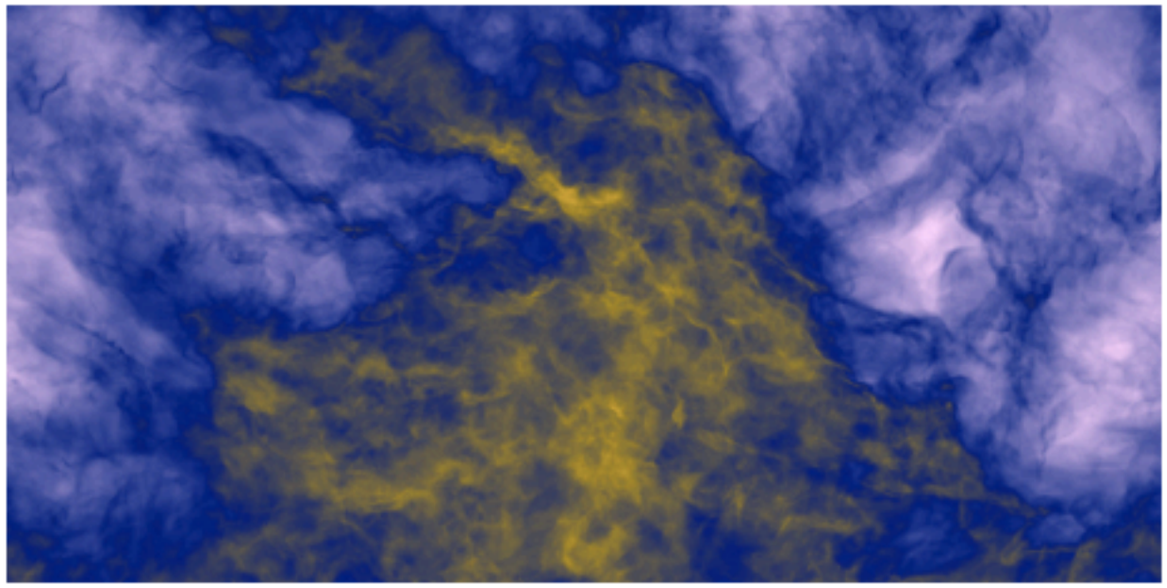
Enzo v2.6 is now available!

August 2, 2019: Enzo 2.6 has been released. View the Release Notes!

What is Enzo?

Enzo is a community-developed adaptive mesh refinement simulation code, designed for rich, multi-physics hydrodynamic astrophysical calculations.

Enzo is freely available, developed in the open, with a strong support structure for assistance. Simulations conducted with Enzo have been featured in numerous refereed journal articles, and it is capable of running on computers from laptop to Top500.



Getting Enzo

Enzo can be obtained in several places, corresponding to the degree of stability and development accessibility.

Let's go! »

Help!

There are several places to get help with Enzo, from mailing lists to documentation to online tutorials and recordings of workshop presentations.

Help me out! »

Developing

Enzo is developed in the open by a community of developers from different institutions. Contributions, fixes, and changes are all welcomed!

Develop! »

Community

There are several places to get help with Enzo, from mailing lists to documentation to online tutorials and recordings of workshop presentations.

Engage »

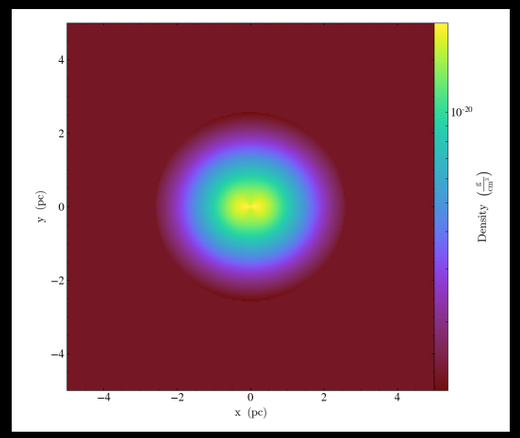
https://enzo-project.org/

Initial conditions

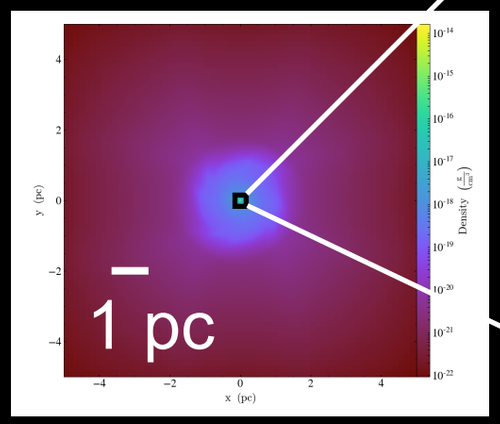
(an ideal rotating sphere)

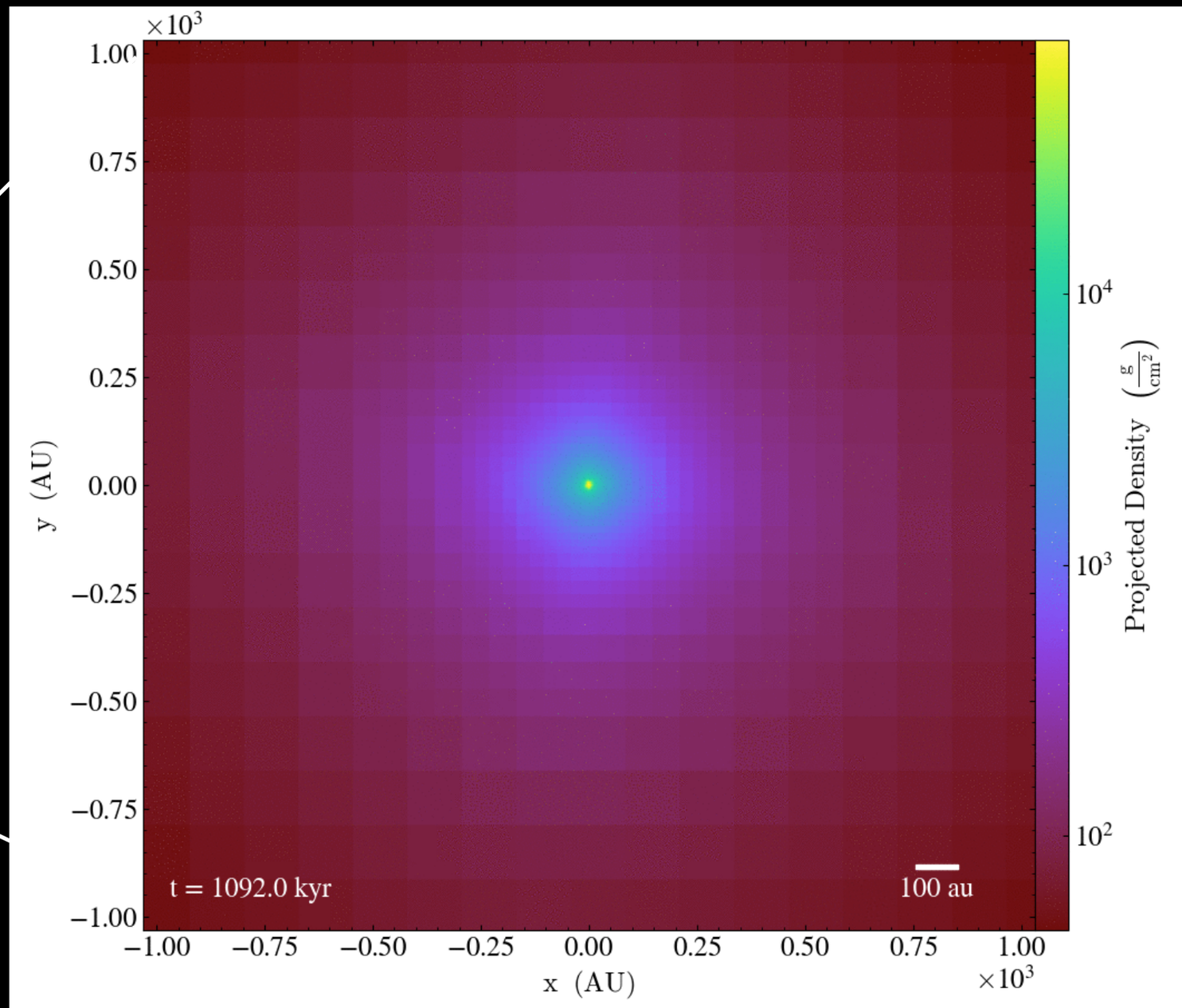
cloud mass = 1.8 x 10^{4} [Ms]
mean density = 1.7 x 10^{-20} [g/cc]
rotation speed = 2.6 x 10^{-14} [rad/s]

(density, x-y plane)



collapse





Resolution dependency test

with sink particles v.s. with smart stars

run1: refinement level = 12

r_sink = 1.5e-04 pc = 31 AU

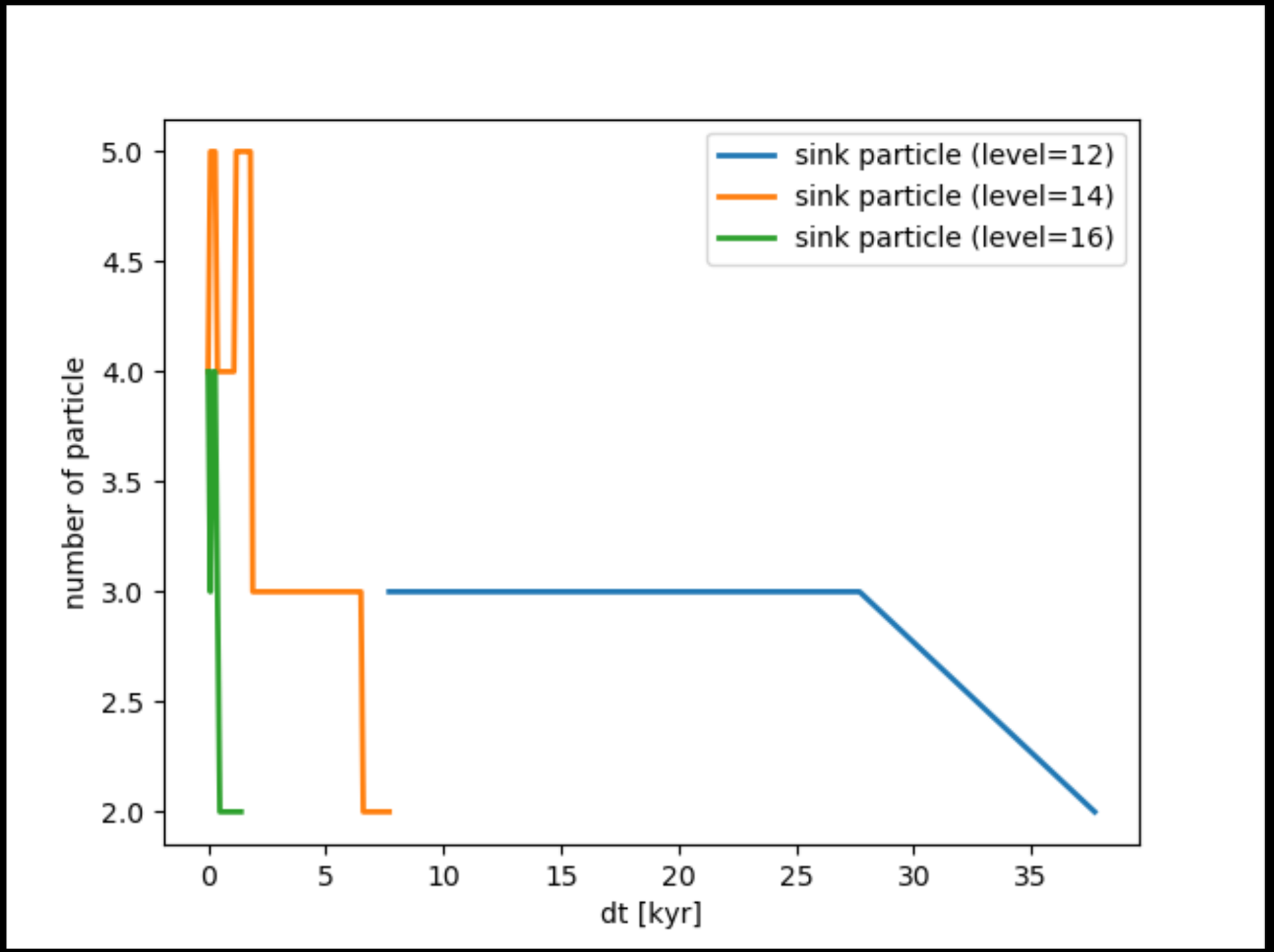
run2: refinement level = 14

r_sink = 7.6e-05 pc = 8 AU

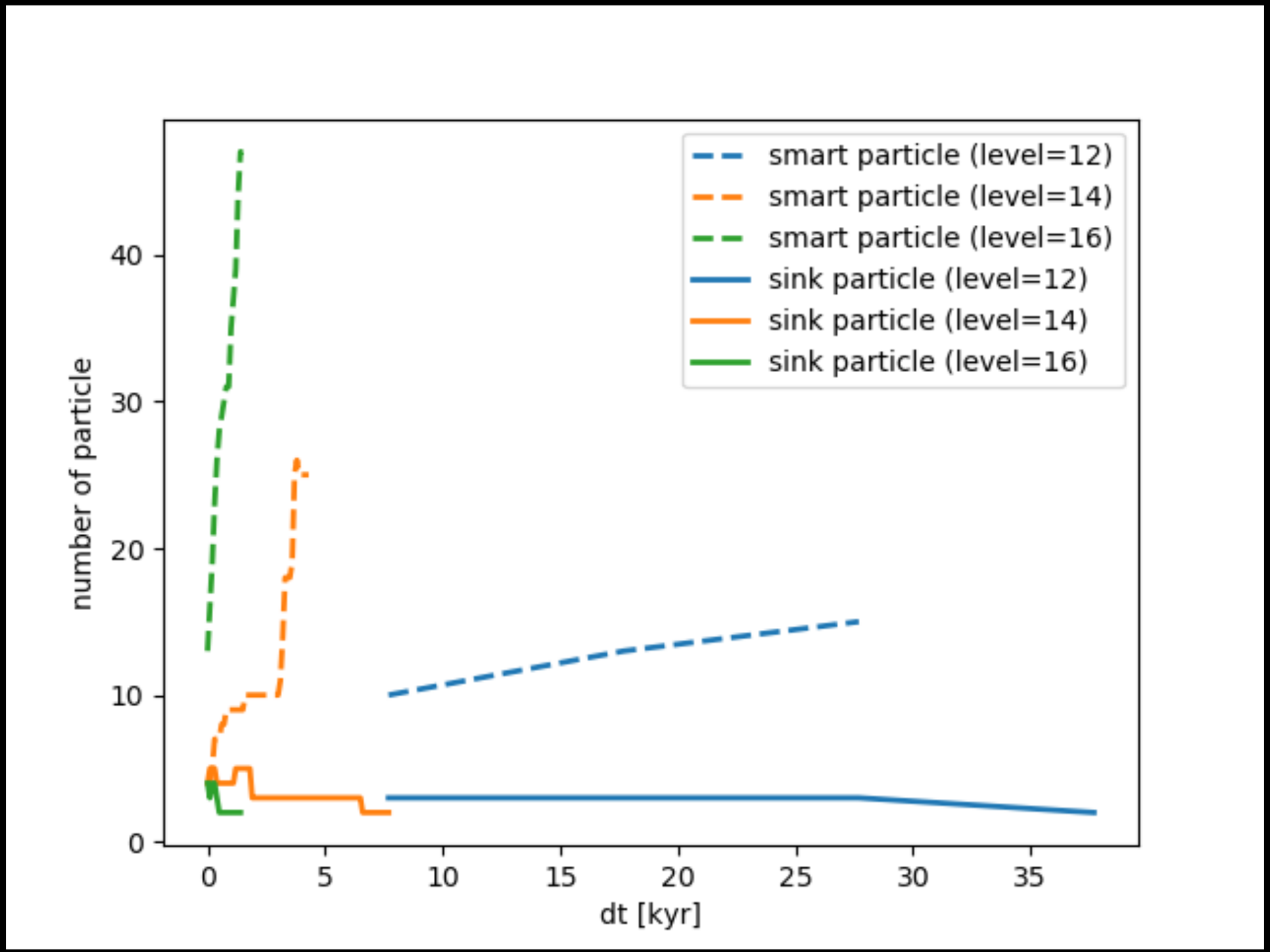
run3: refinement level = 16

r_sink = 3.8e-05 pc = 1 AU

The number of particles v.s. time

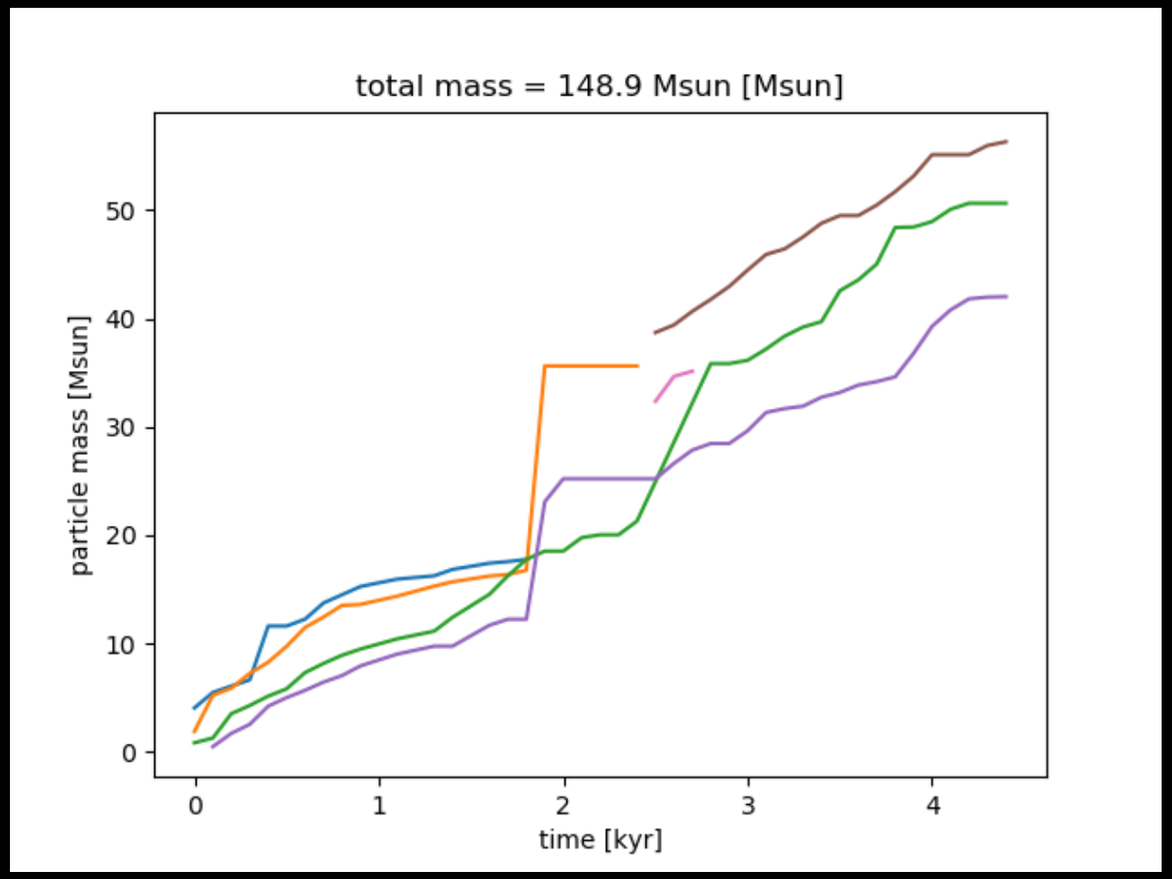


The number of particles v.s. time

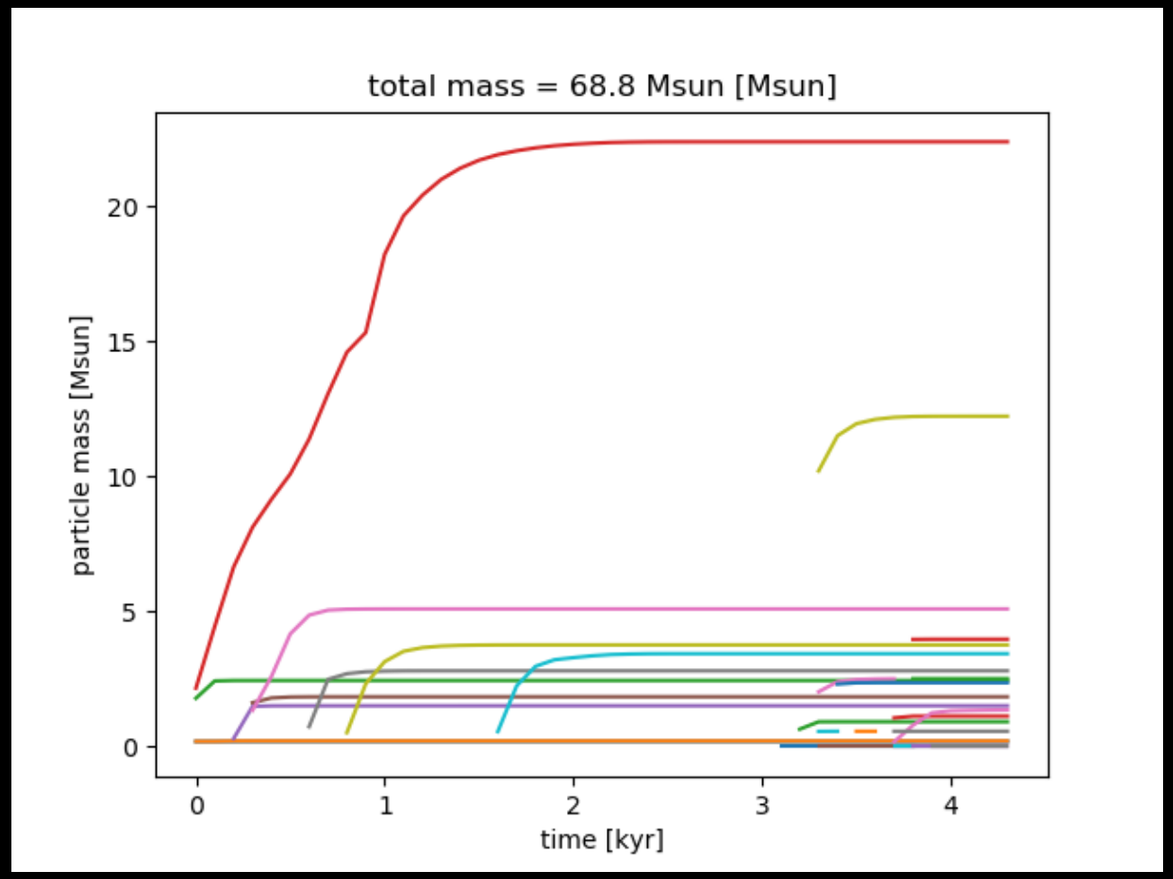


What is the difference?

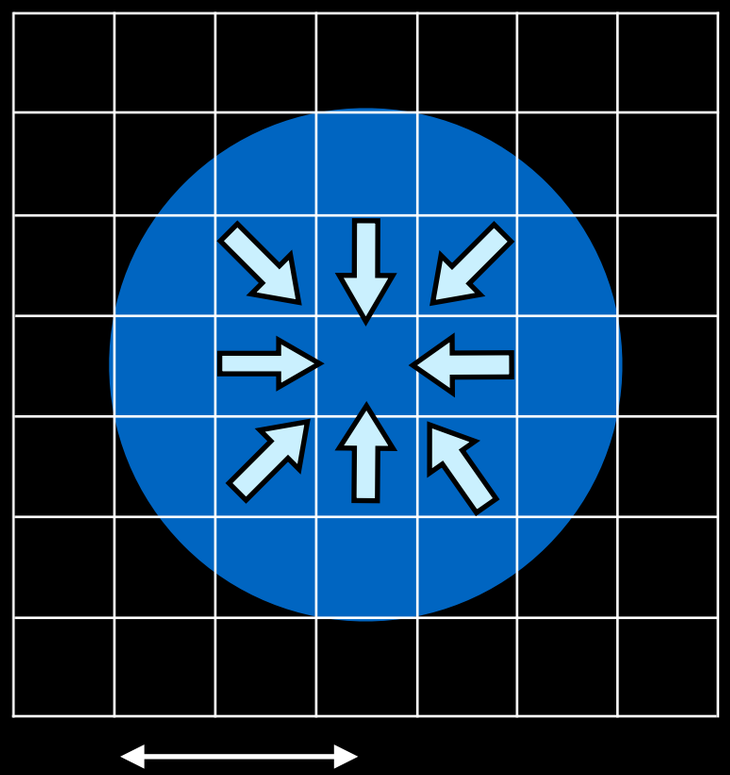
sink particle



smart star



Sink particle creation (Federrath et al. 2010)



sink radius

$$r_{acc} \sim \lambda_J$$

+ on the highest level of refinement

+ over density

+ converging flow

+ not within the radius of an existing sink

+ gravitational potential minimum

$$\phi_{center} \leq \phi(i,j,k)$$

(additional checks)

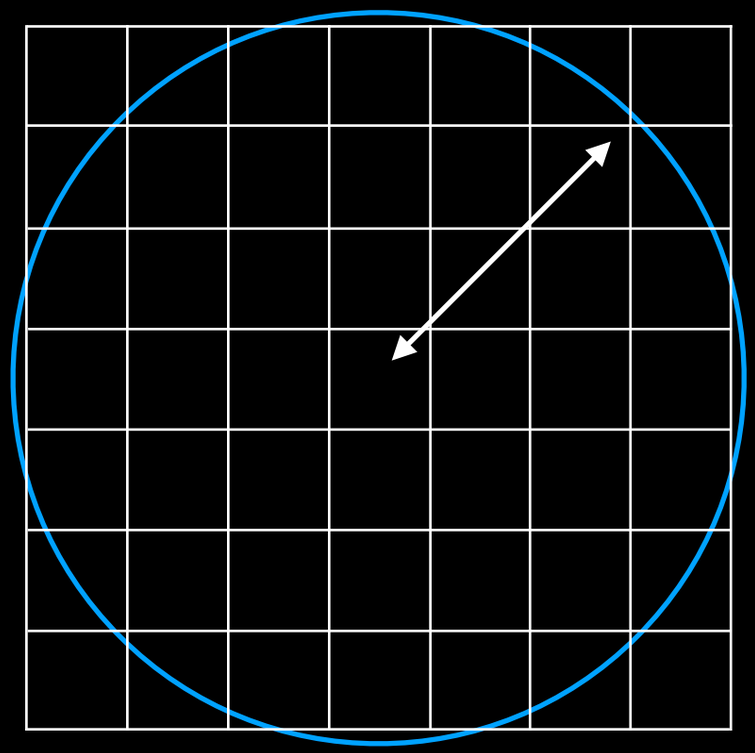
+ Jeans-unstable

$$|E_{grav}| > 2\,E_{th}$$

+ is bound

$$E_{grav} + E_{th} + E_{kin} < 0$$

Gas accretion into sinks (Federrath et al. 2010)



sink radius

$$r_{acc} \sim \lambda_J$$

criteria for gas accretion

$r_i < r_{acc}$ (within the radius)

$\rho_{gas} > \rho_{crit}$ (overdense)

$v_{rad} < 0$ (incoming)

$e_{kin} + e_{grav} < 0$ (bound)

Summary

We performed simulations of primordial gas disk fragmentation varying the resolution with two different sub-grid model.

sink particle v.s. smart star

Both of them are based on the same model (Federrath et al. 2010).
However, the results are different.
(the number of formed particles, the mass evolution)