PopIII連星形成シミュレーションにむけて

- Toward Pop III binary formation simulations -

TOHOKU UNIVERSITY

Kazu Sugimura（Tohoku）

Theoretical Astrophysics
Tohoku University

Collaborators: T. Matsumoto（Hosei, Princeton）
T. Hosokawa（Kyoto）, K. Omukai（Tohoku）

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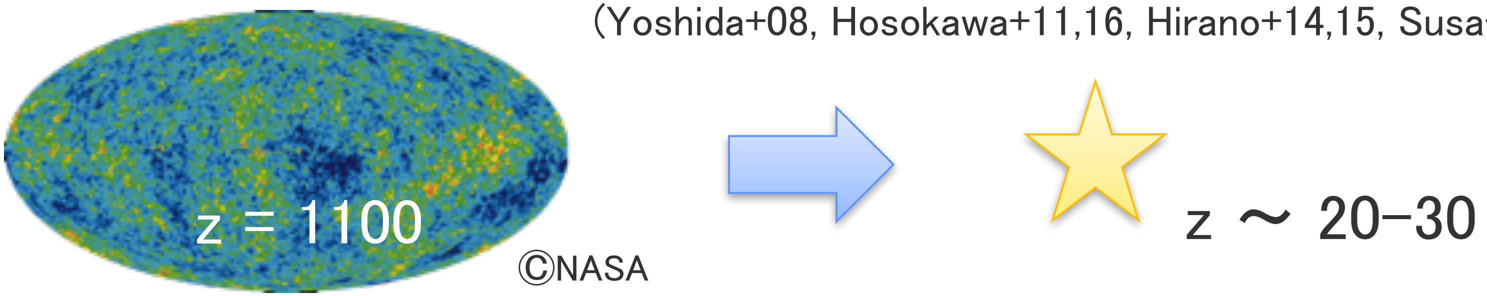
INTRODUCTION

Pop III binary formation

Yoshida-san’s talk
Machida-san’s talk
Matsukoba-san’s talk
Shima-san’s talk
Oda-san’s talk

- From Big Bang to first objects (= Pop III stars)

(Yoshida+08, Hosokawa+11,16, Hirano+14,15, Susa+14, etc.)



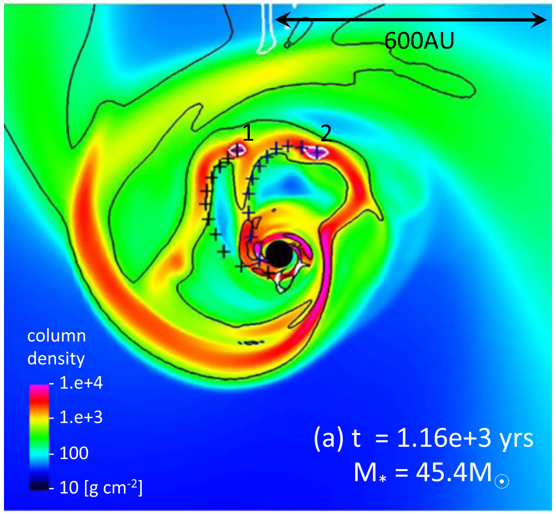
Understanding this process is one of the main objectives for theoretical astrophysics

- Are Pop III stars formed alone?

And, how is the property of binaries, if formed?
We know little about it...

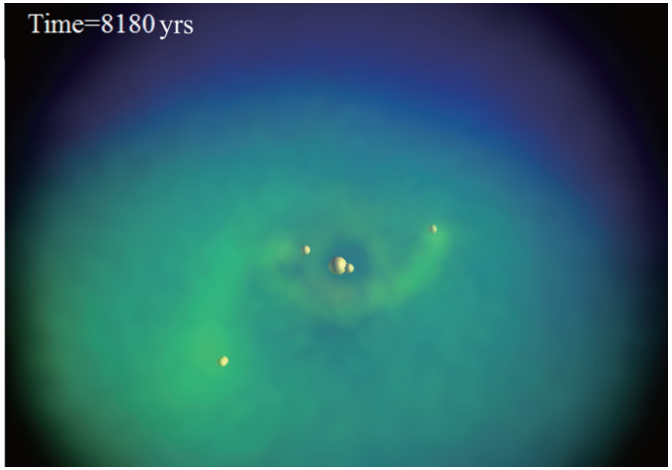
Pop III formation until the end of accretion: radiation feedback and fragmentation

Grid-base simulation
(spherical coords., Hosokawa+16)



- low resolution in outer region
- single radiation source

SPH simulation (Susa+14)



- low resolution in HII region
- diffusion of turbulence(?)

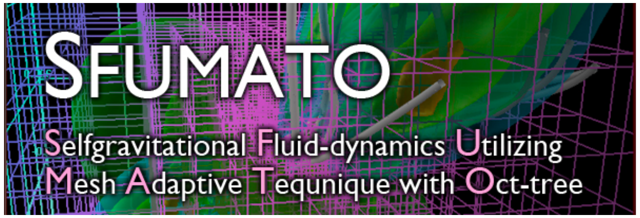
develop a new code, and then simulate Pop III binary formation

METHODS

Code development

Strategy for code development

- ✓ self-gravitational (M)HD
- ✓ AMR



(Matsumoto 2007)

- ✓ chemistry, cooling/heating
- ✓ protostellar radiation

Pop III physics

(Hosokawa+ 2016)

- ✓ Radiation transfer
- ✓ EUV, FUV

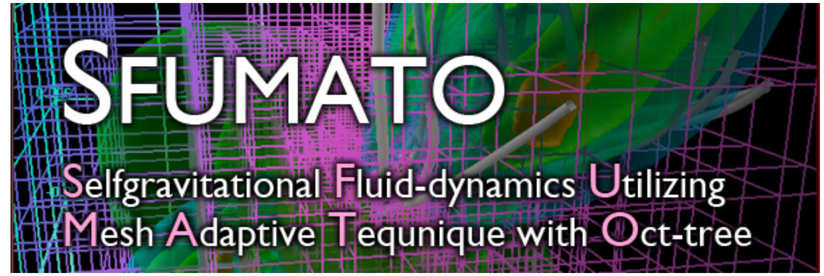
Adaptive Ray-Tracing

(Abel&Wandelt 2002)

New code for Pop III binary formation!!

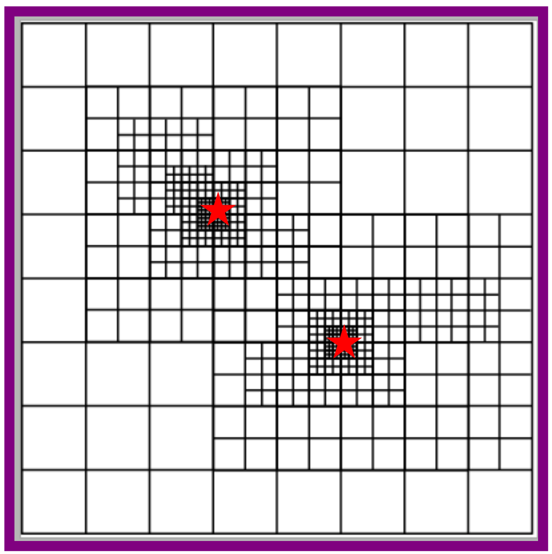
SFUMATO

(Matsumoto 2007)



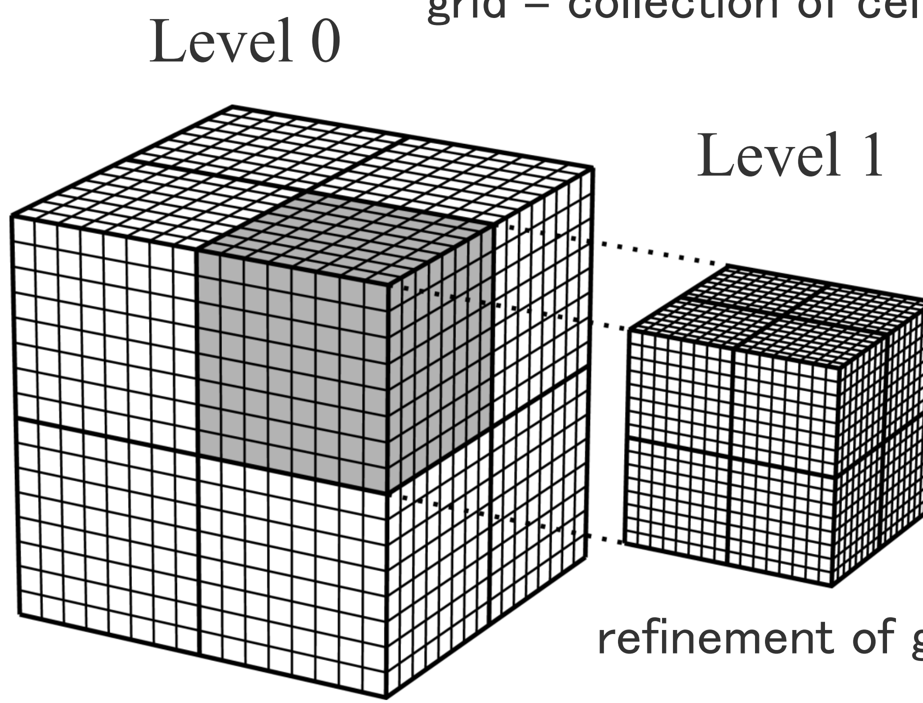
- **MHD (AMR)**

Adaptive Mesh Refinement
= high resolution where you need it



- **Seflgravity**
- **Resistivity**
- **Sink particle**

minimum unit = cell
grid = collection of cells



refinement of grid

Oct–tree type block structure

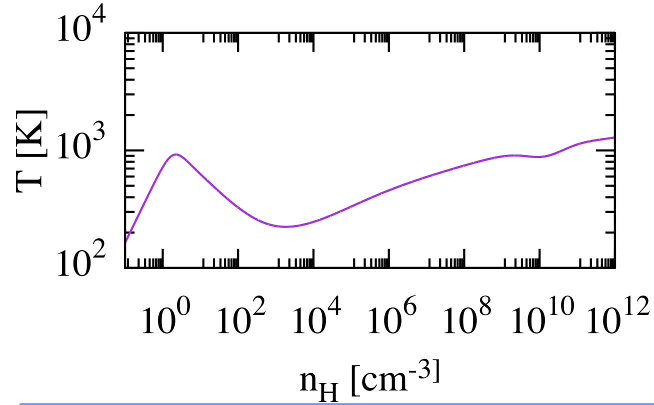
Microphysics model for Pop III formation

(c.f., Hosokawa+ 2016)

Prim. chem. model (H, H_2, e, H^+, H^-, H_2^+, (He))

- chemical reactions

  H photo-ion., H_2 photo-dis., H^- photo-det., H^+ rec.,
  H^-/H_2^+-channel & 3-body H_2 formation, etc.



1-zone calc. w/ our chem. model

- cooling/heating processes

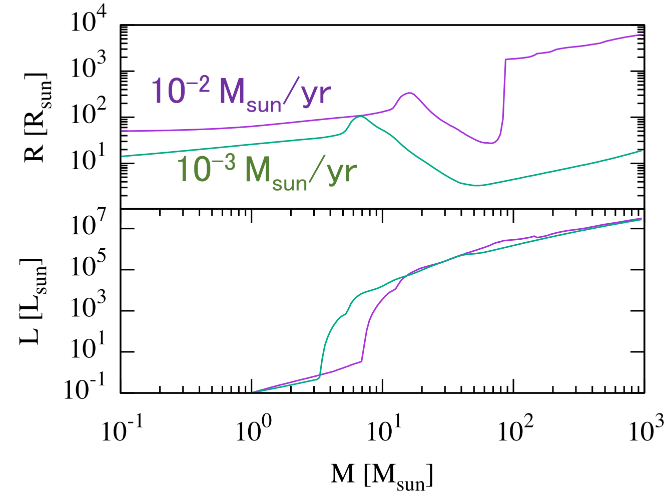
  H photo-ion heat., H^+ rec. cool., Lyα cool, free-free cool.,
  H_2 line cool (w/ f_{esc}), chemical heat/cool, etc.

Pop III proto-stellar radiation

- pre-calculated table of the results from stellar evolution code

  (M, Mdot) → (L, R) or (L, T_{eff})

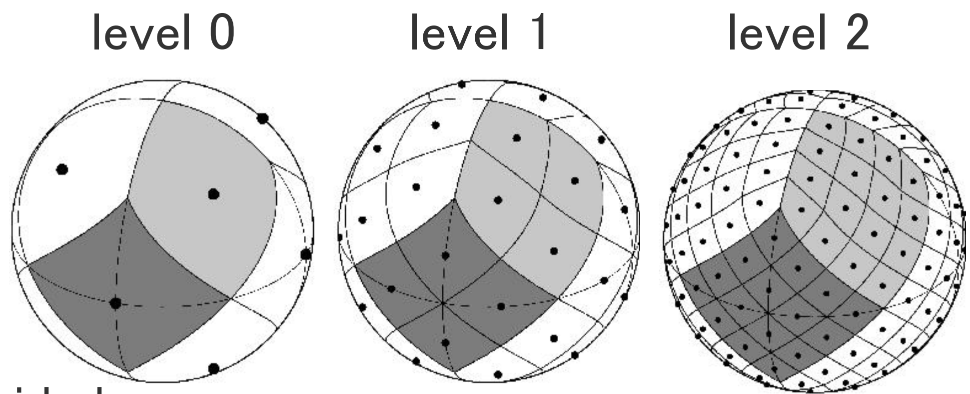
- extension to on-the-fly calculation with stellar evolution code is straightforward



Pop III star evolution model

(≠ Authentic Radiation Transfer; Nakamoto, Umemura, Susa 2001)

A(d)RT Method

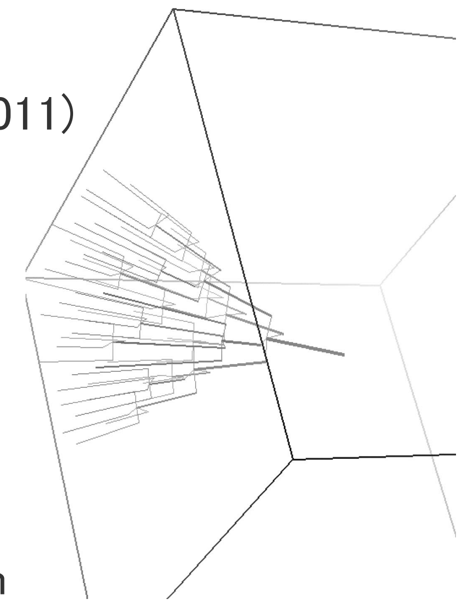


HEALPix (Górski+ 2005)

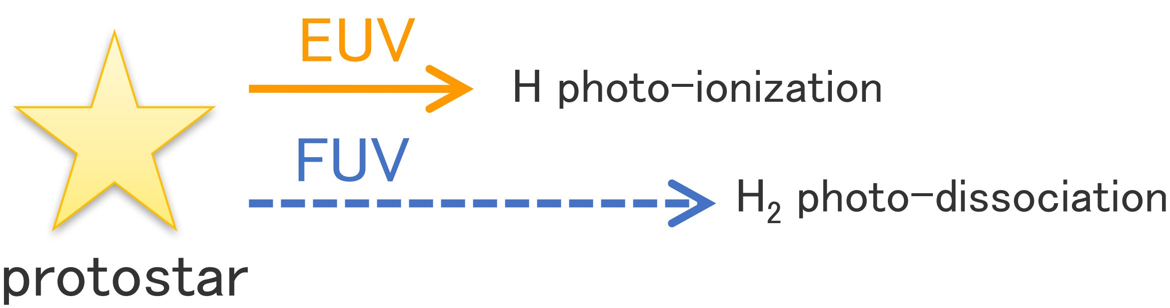
- originally for CMB analysis
- divide sphere into 12 x 4^{level} patches
- function: (level, ID) -> (θ , ϕ) is provided

ART (Adaptive Ray Tracing) method

(Abel&Wandelt 2002, Wise&Abel 2011)



- Rays are split with HEALPix to ensure the minimum # of rays penetrating each cell surface
- Using this method for RT of EUV/FUV photons



Preliminary!!

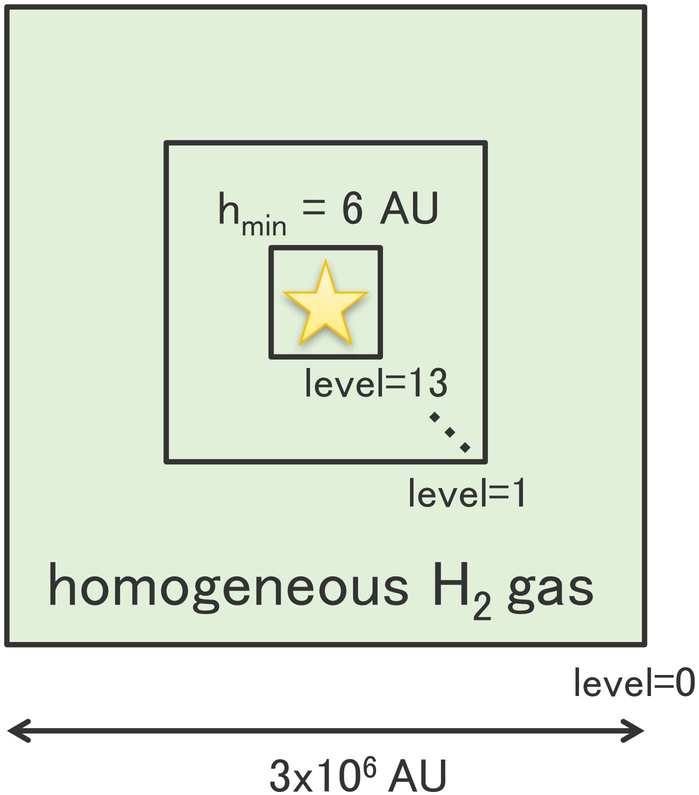
RESULTS

Early results from test calculations

Tests for radiation feedback: set-up

Basic set-up

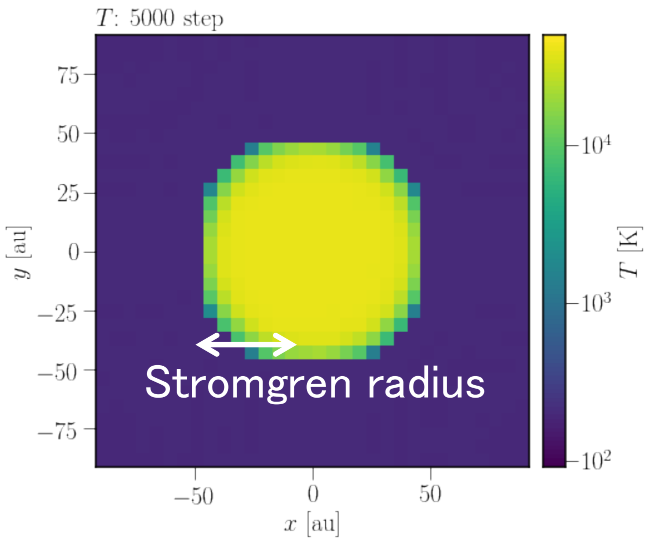
- central radiation source (Pop III star)
- initially homogeneous H_2 gas
- nested grid with level_max = 13
  (cell size in ith level: $h(i) = h(0)/2^i$)
- resolution at each level:
  (8x8x8) x (8x8x8)
  # of cells   # of grids

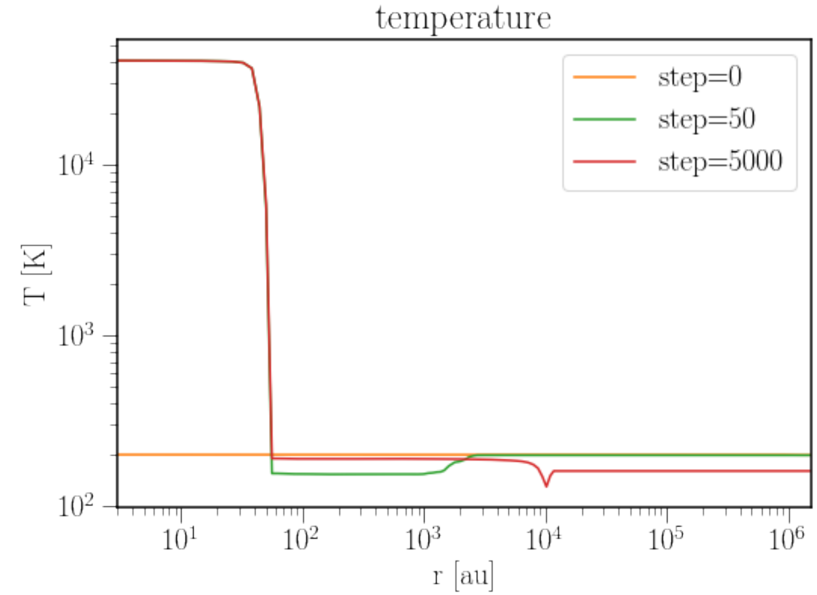


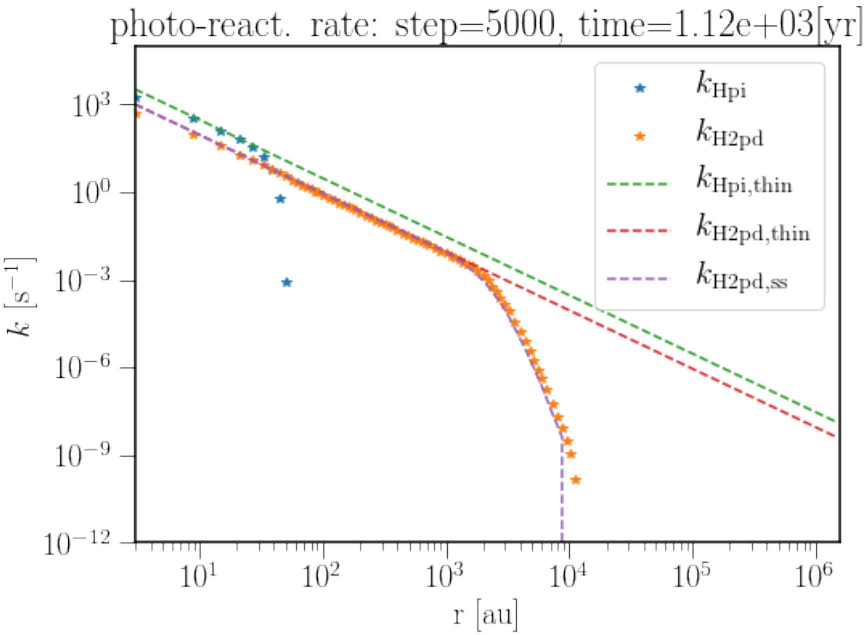
Model parameters

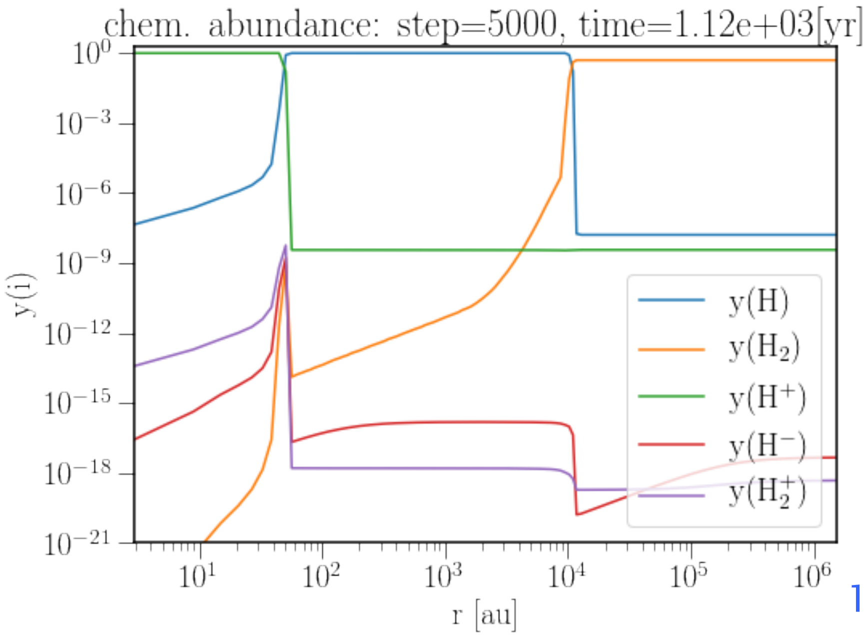
- $n_H = 10^9\ cm^{-3}$, T_{gas} = 200K
- $L = 6x10^5\ L_{sun}$, T_{eff} = 9000K ← Pop III star (100 M_{sun} & $10^{-3}\ M_{sun}/yr$)

Tests for rad. FB: case of fixed gas density with $n_H = 10^9$ cm^{-3}

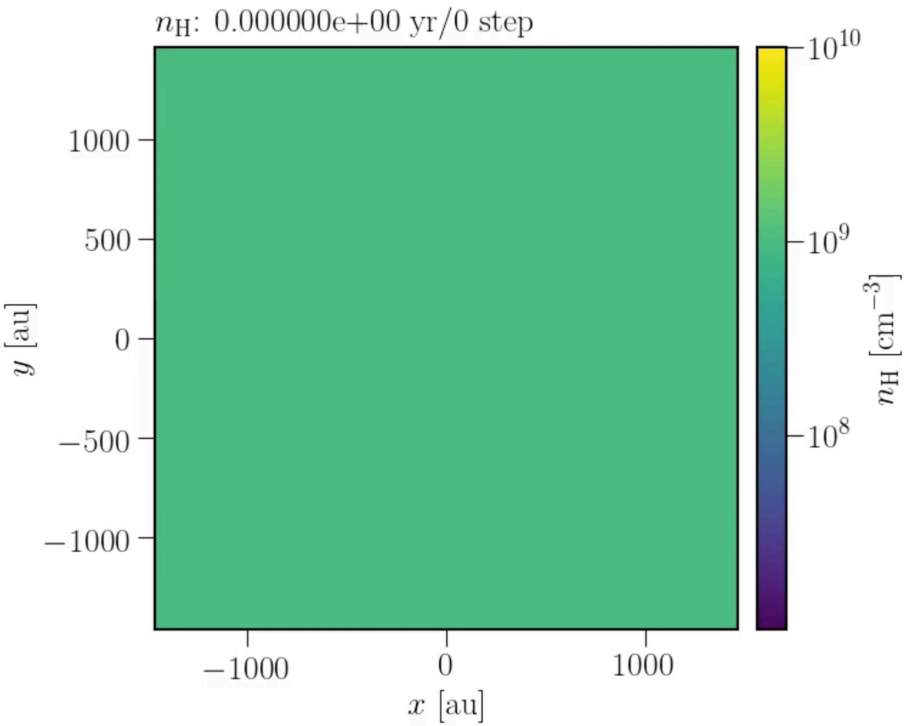


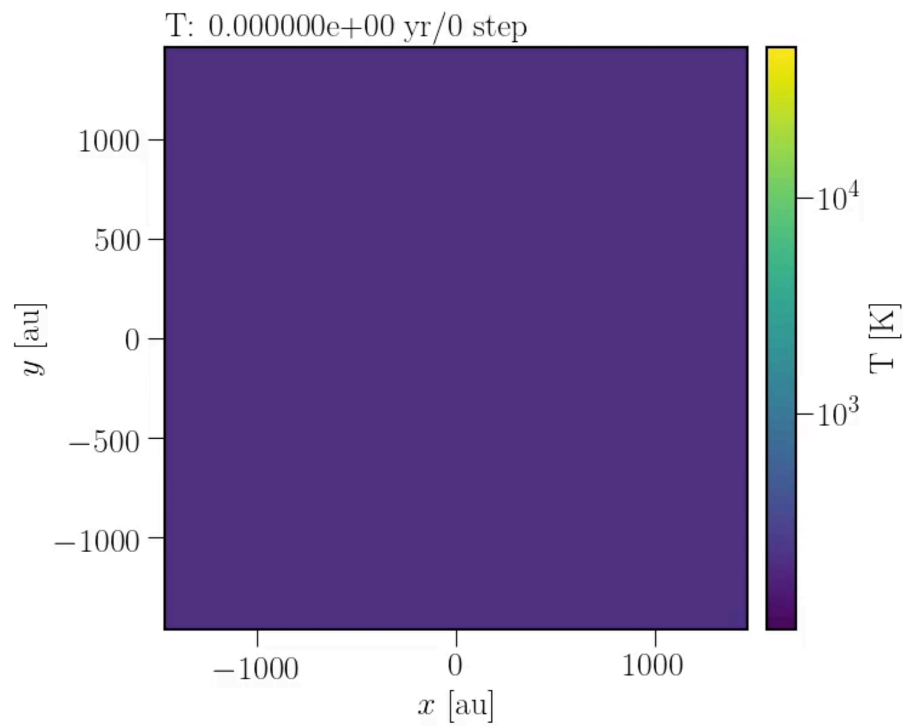






Tests for rad. FB: case of initial gas density with $n_H=10^9$ cm^{-3} (w/ HD update)





Expansion of HII bubble seems properly calculated

Tests for collapse of rotational Bonor–Ebert spheres: set-up

- initial density profile:

  1.2 x Bonor–Ebert sphere (T=200K)

- minimum cells per one Jeans length: 8

- maximum AMR level: 13

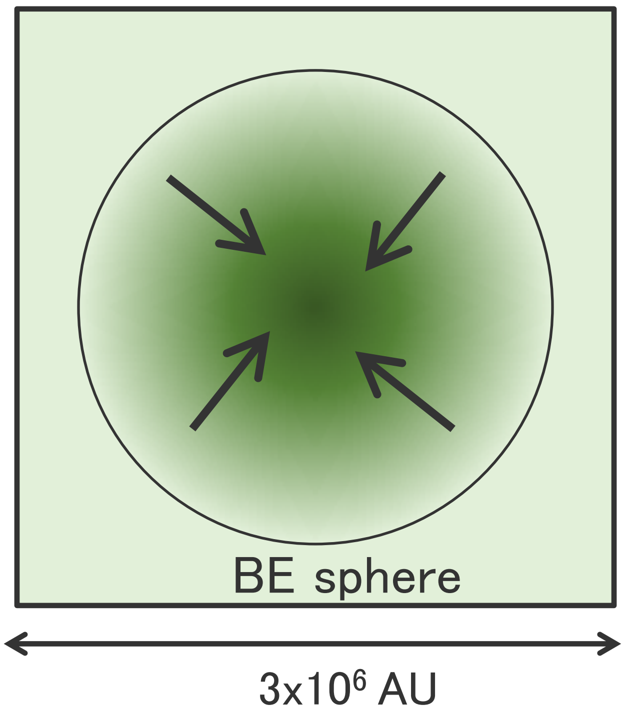
  → minimum cell size: 6 AU

- sink formation density: 10^{12}cm^{-3}

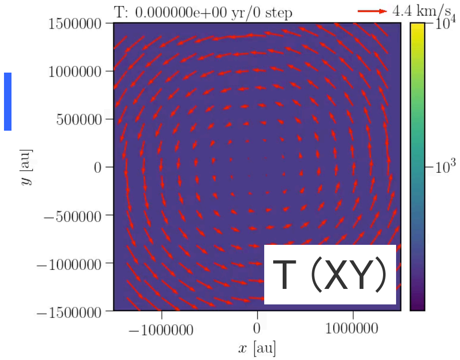
- initial rigid rotation:

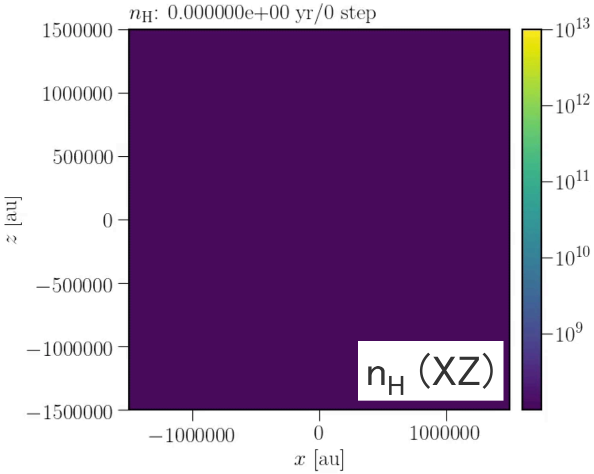
  β = (rotation energy)/(gravitational energy)

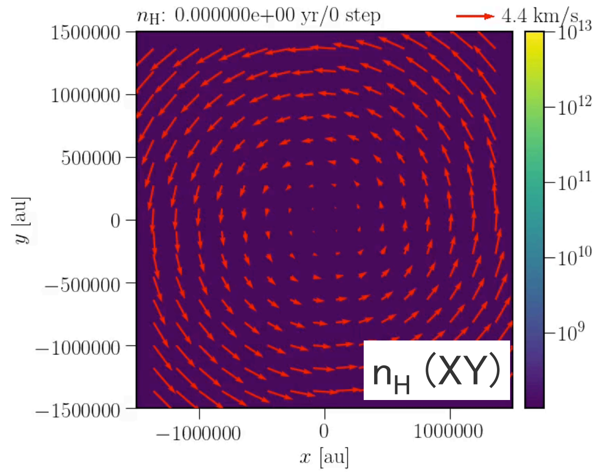
  = 0.003, 0.01, 0.1

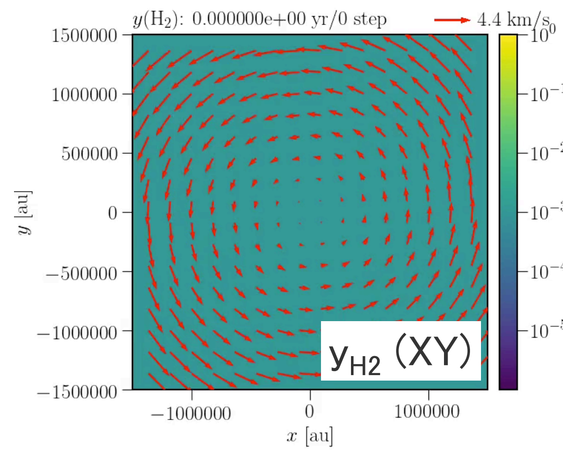


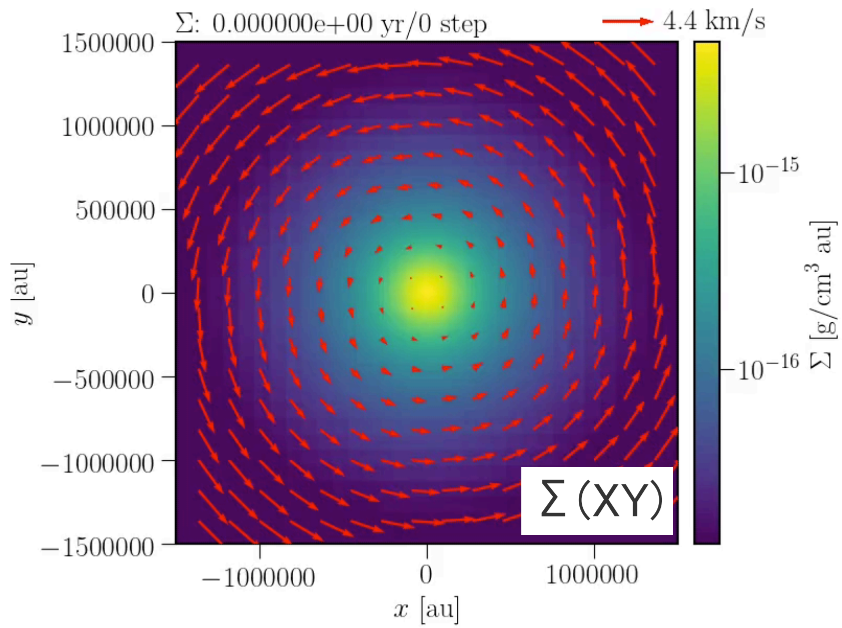
Tests for collapse of rotational BE spheres: $\beta = 0.01$ case



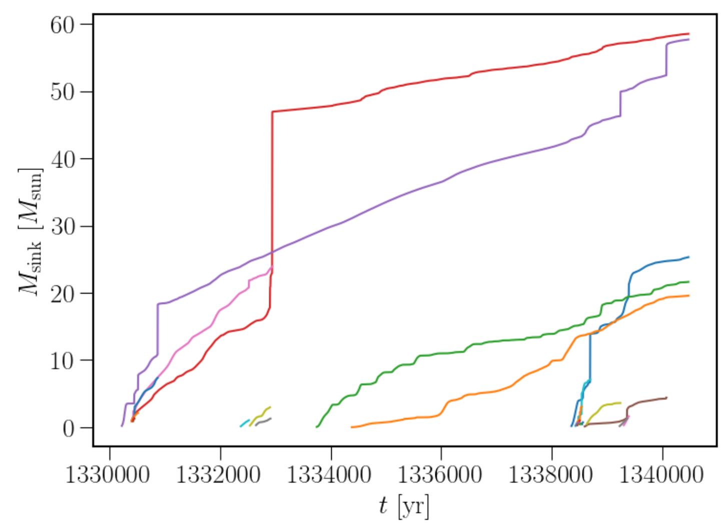






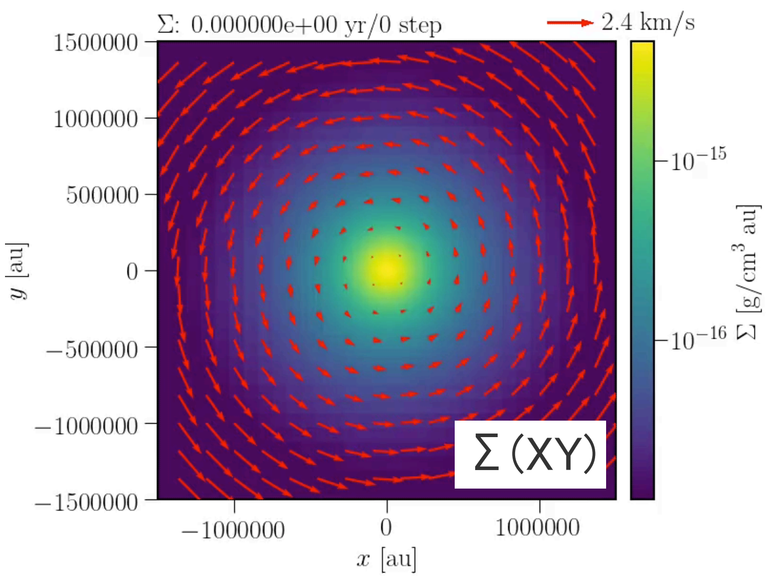


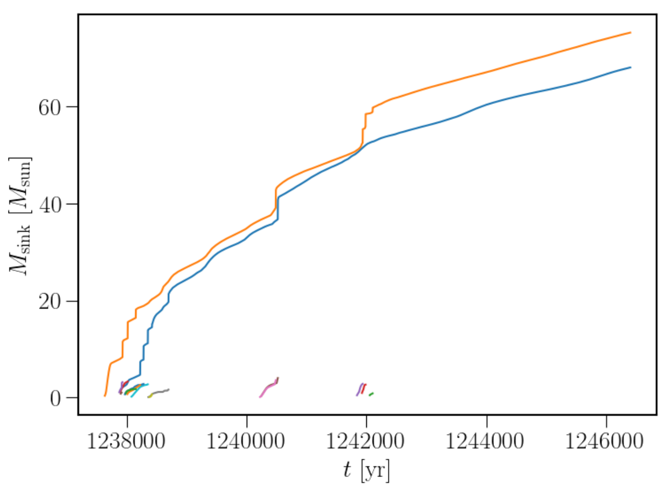
sink mass evolution



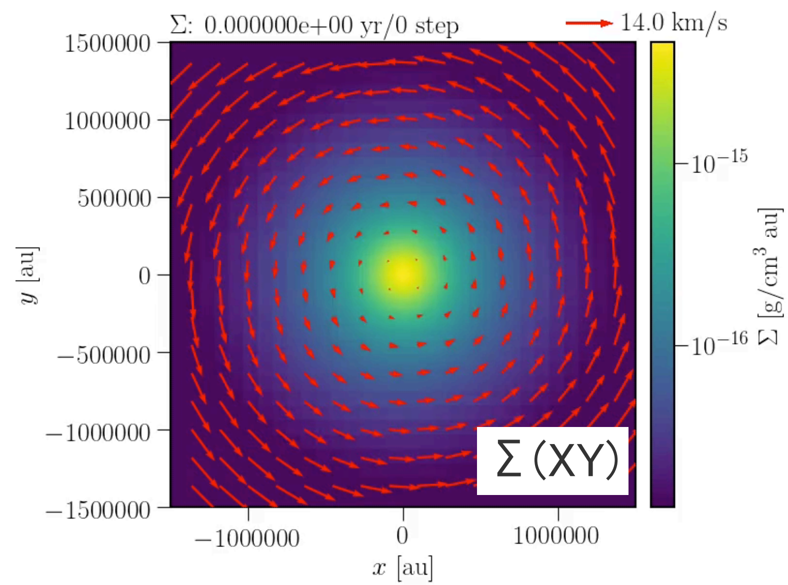
Tests for collapse of rotating BE spheres: β = 0.003 & 0.1 cases

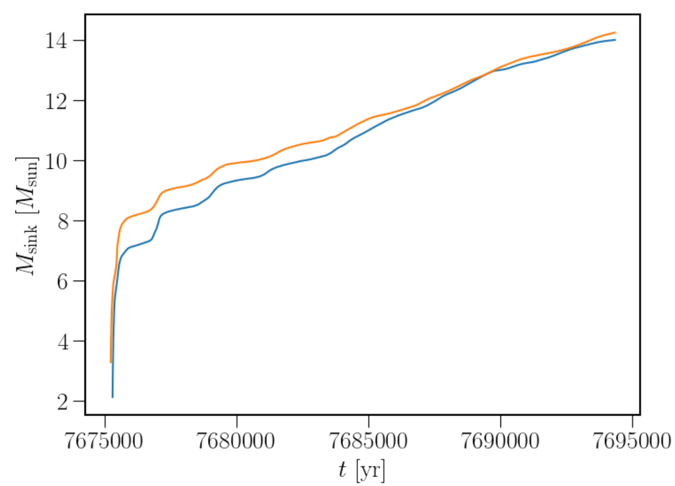
β =0.003





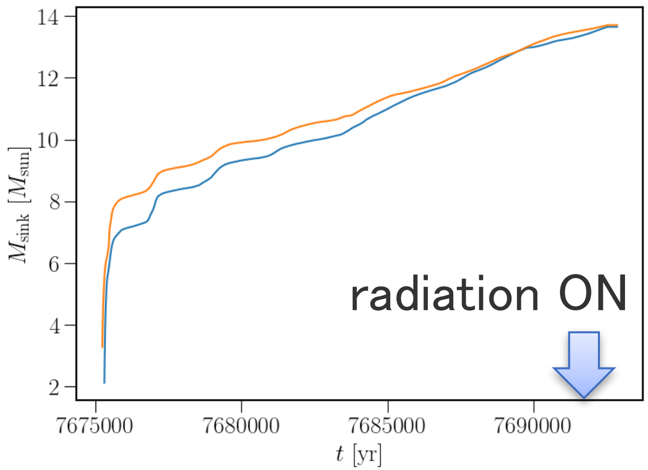
β = 0.1





Tests for collapse of rotating BE spheres: rad. FB test

case of β =0.1



blue: density

red: EUV

- Test radiation FB by turning on radiation at some time
- Assume strong radiation from each sink particle

← Pop III star with 100 M_{sun} & 10^{-3} M_{sun}/yr

SUMMARY & FUTURE PLAN

Summary

Aim of the project

- simulating Pop III binary formation

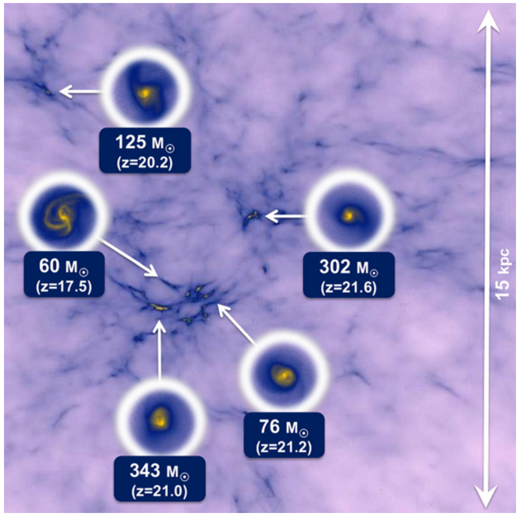
Current status

- development of code with AMR + Pop III phys. + RT almost done
- testing the code with a problem of collapse of rotational BE sphere

Future plan

- to make sure that the code properly calculates the radiation feedback from protostars
- to perform simulations from cosmological initial conditions

→ Pop III binary formation from Big Bang!



Hirano+14