Formation of massive primordial stars controlled by the protostellar evolution

Takashi Hosokawa (Kyoto Univ.)

< References >

TH, Hirano, Kuiper, Yorke, Omukai & Yoshida (2016), ApJ

Hirano, TH, Yoshida, & Kuiper (2017), submitted

Nakatani, TH, et al. (2017), in prep.

3.Jun.2017@Florence

HMSF meeting @ Heidelberg, 2007

Key Questions

+ How massive the primordial (or PopIII) stars finally become?

+ What is the maximum mass of the primordial stars?
  Is it possible to seed SMBHs in the early universe?

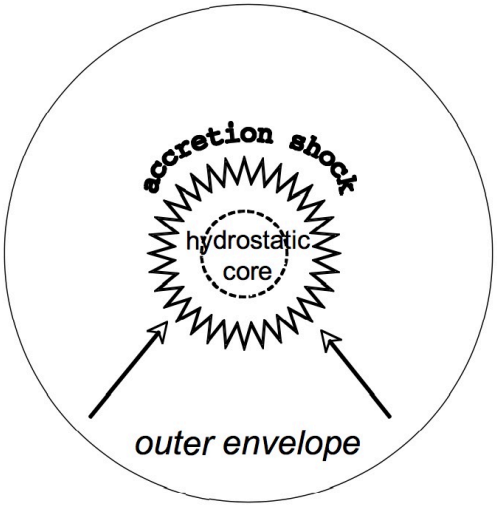
Study the late evolution in the accretion stage

two potential barriers against formation of very massive stars:
① radiative (UV) feedback, ② fragmentation

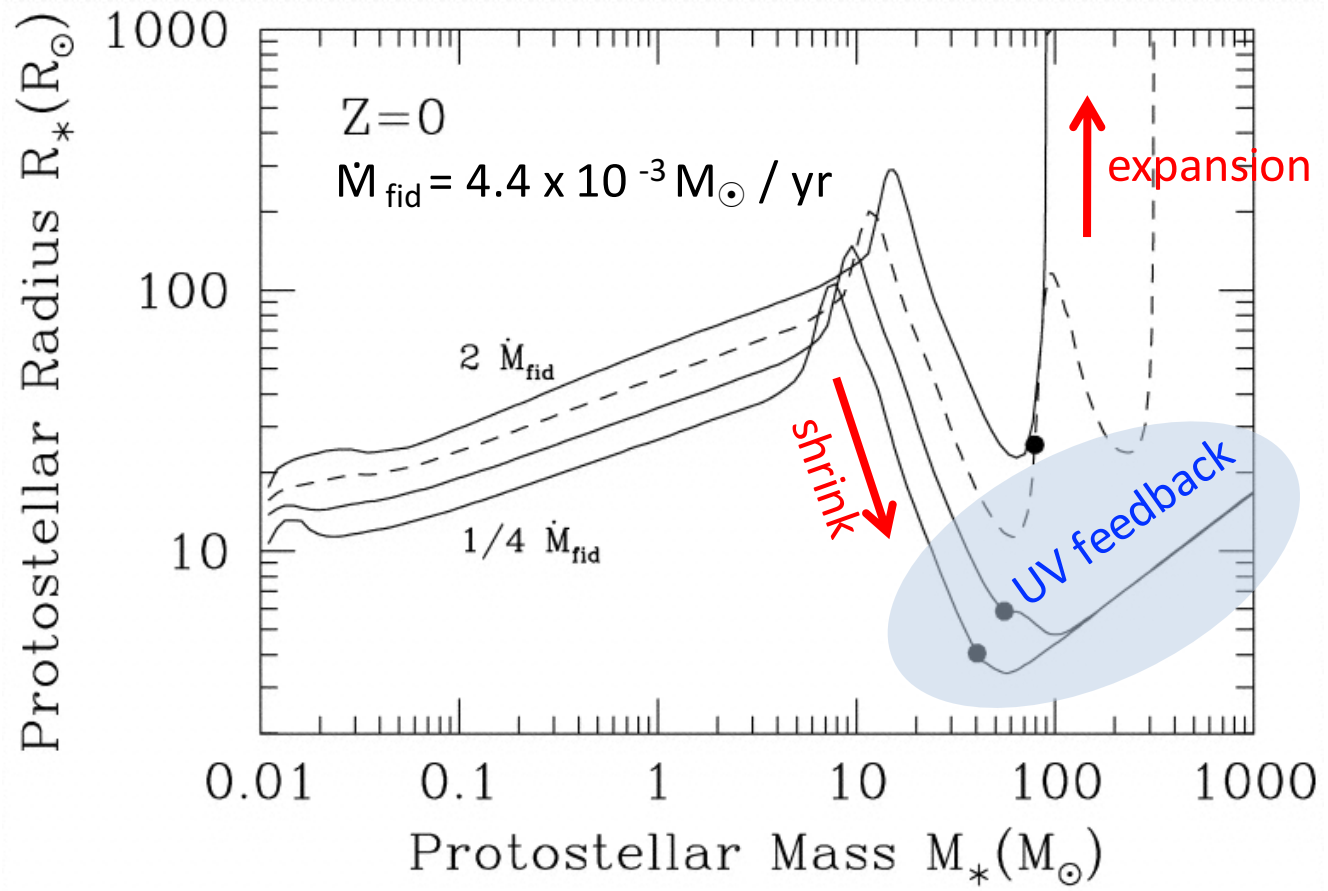
How serious?

Protostellar Evolution

e.g., Omukai & Palla 03
TH & Omukai 09



the stellar evolution with accretion

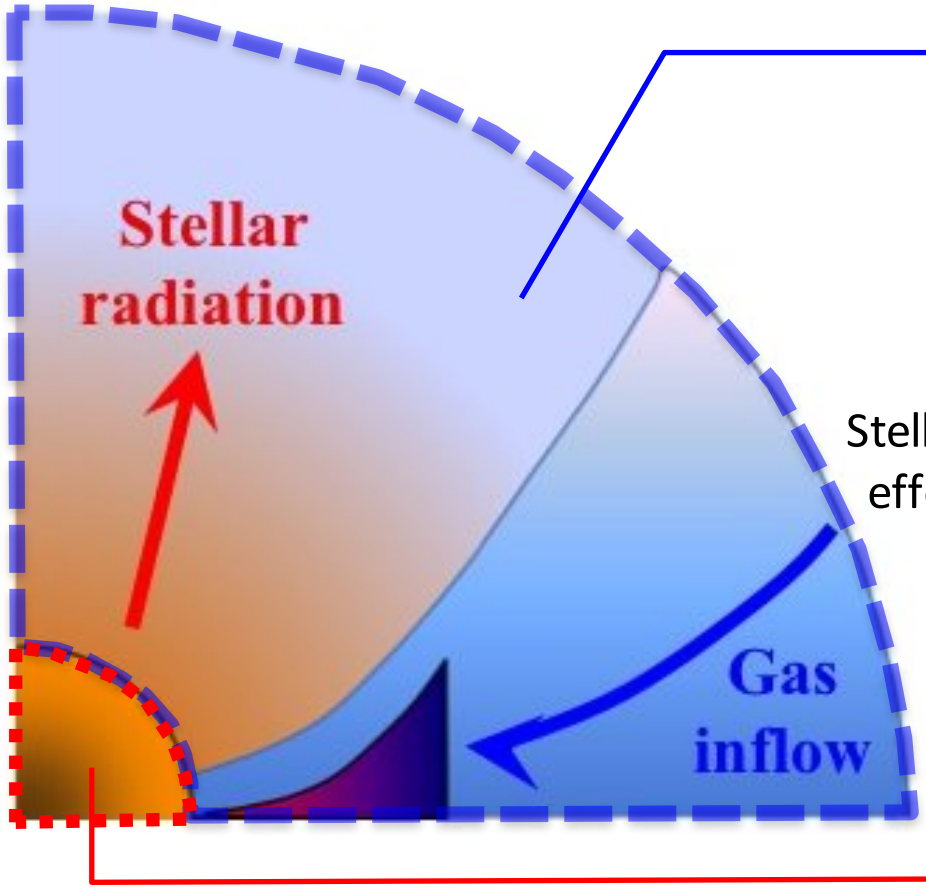


The UV feedback operates when a protostar contracts

The protostellar evolution controls the UV feedback effect

Our Approach

real-time coupling : radiation-hydro simulations + stellar evolution
(e.g., TH+11; Hirano, TH+14; TH+16)



Radiaion-hydro sims.
+ hydro + self-gravity
+ chemistry
+ heating/cooling processes
+ radiation transfer

Stellar luminosity
effective temp.

Accretion rate
onto the star

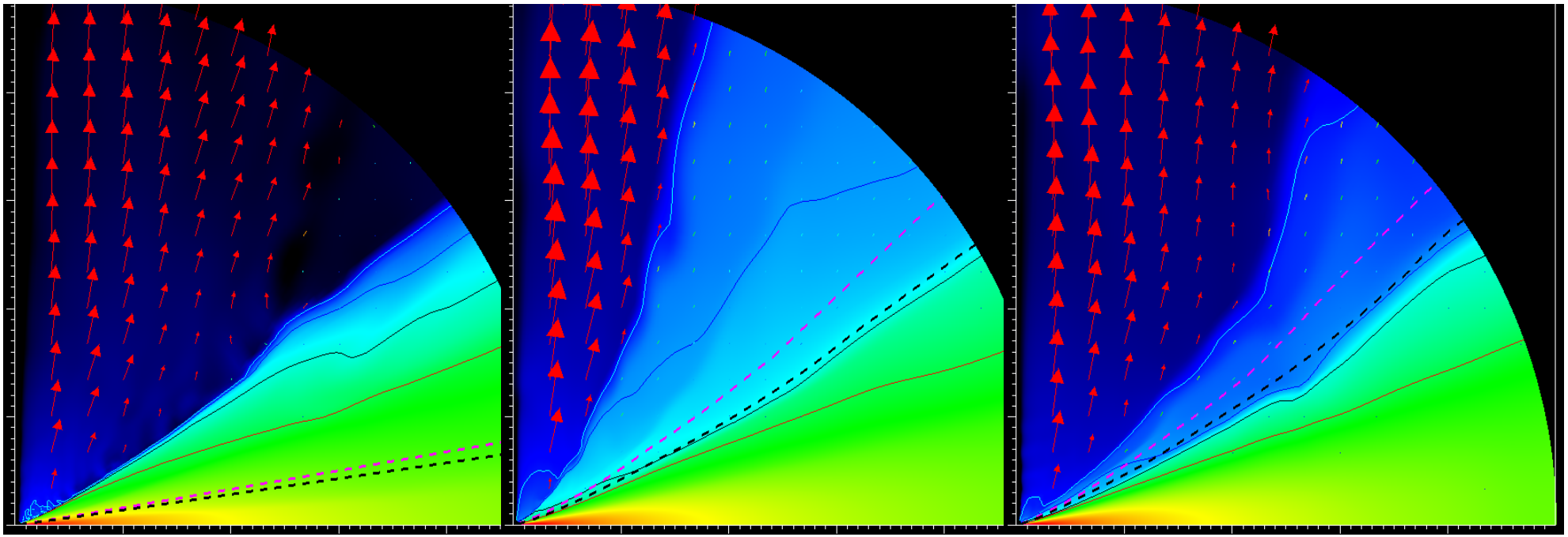
Protostellar Evolution
+ 4 stellar structure eqs.
+ mass accretion
+ nuclear fusion, convection

The similar approaches have been explored in the business of present-day star formation (e.g., Kuiper & Yorke13; Baraffe+17)

Photoevaporationg proto-planetary disks w/ a wide variety of metallicity

$Z = 10^{-4} Z_\odot$ $Z = 10^{-0.5} Z_\odot$ $Z = 10^{+0.5} Z_\odot$

low Z → high Z

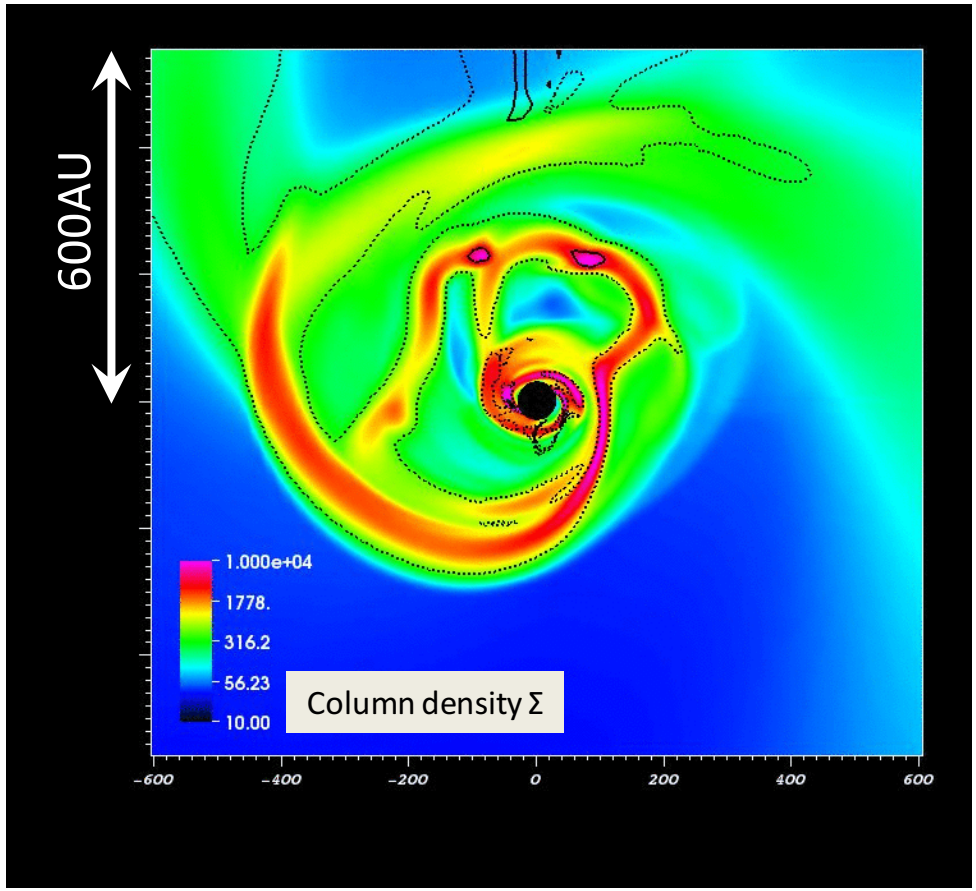


See Poster #63, presented by Riouhei Nakatani

Fragmentation, and massive stars?

TH, Hirano, Kuiper et al. 2016, ApJ

Evolution over ～100 yrs



Contour: Toomre Q parameter
solid: Q=0.1, dotted: Q=1.0

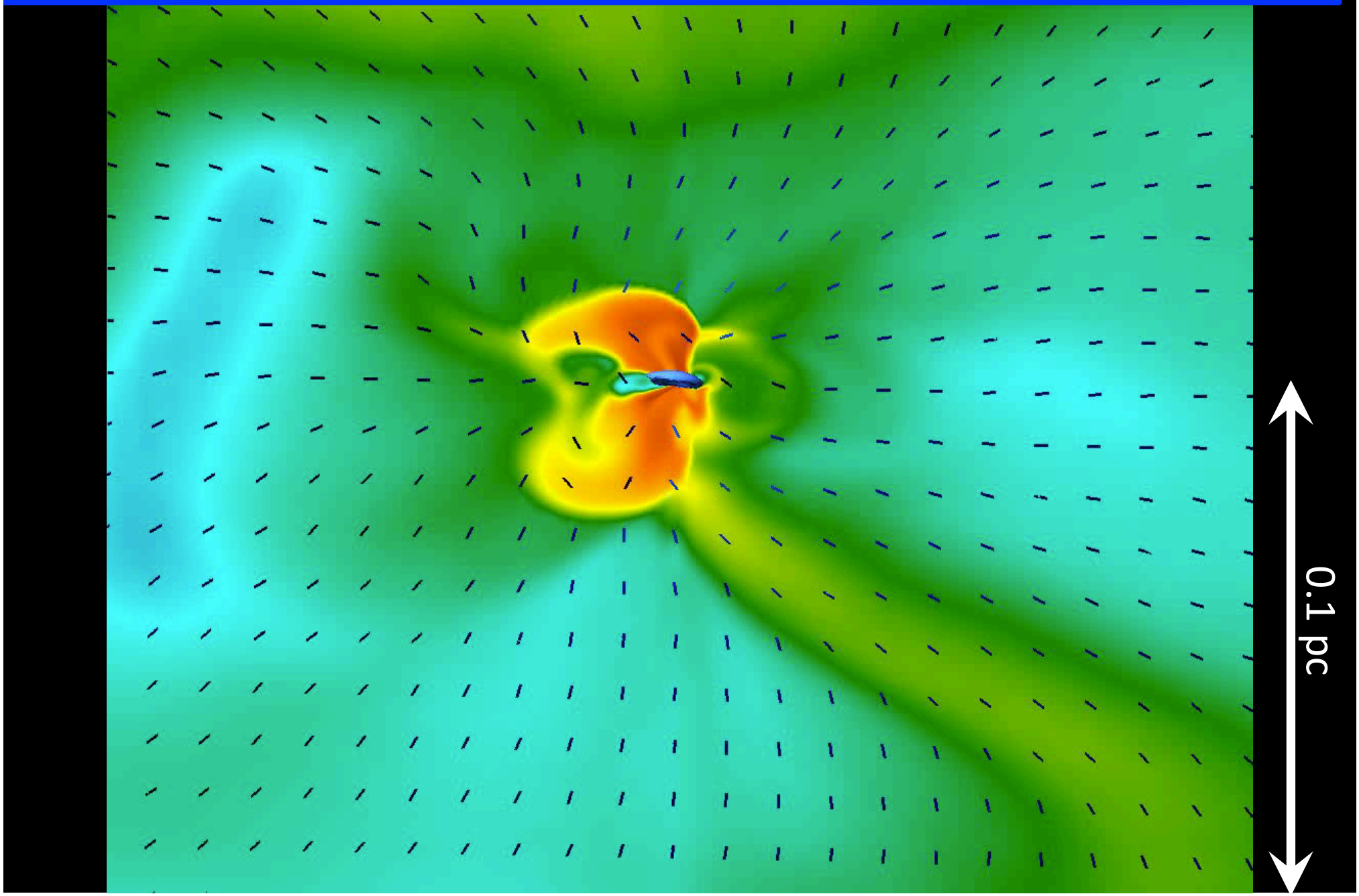
Disk Fragmentation

Difficult to get massive stars?
because the accreting gas is divided into multiple stars ("starvation")

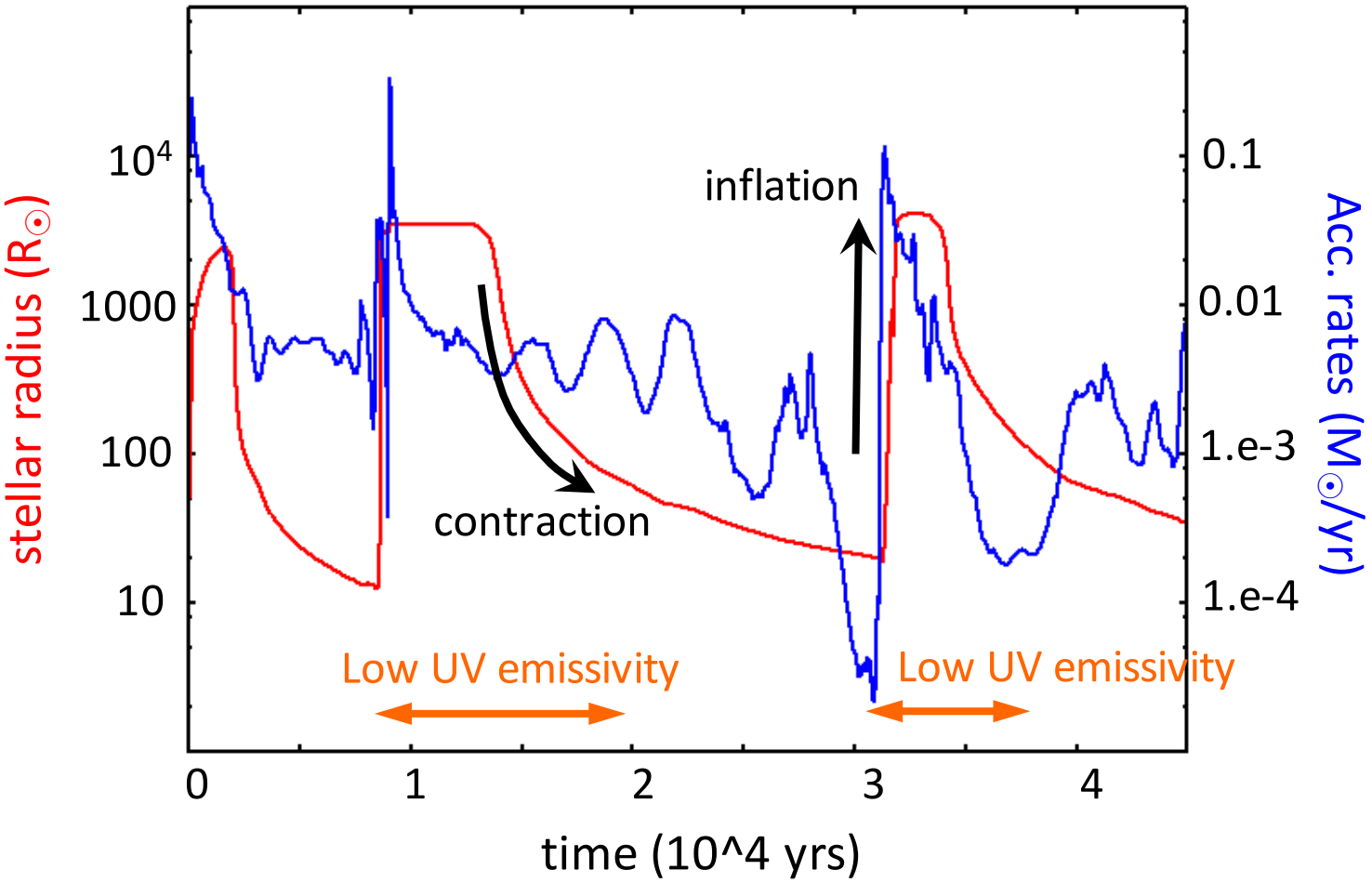
disk fragmentation
↓
migration of fragments
↓
episodic accretion

very rapid mass accretion
for short durations

Extinction and re-formation of HII regions are repeated.
Mass accretion is not efficiently stopped by such intermittent feedback



Accretion burst & inflating protostar



Accretion burst makes the star bloated. And the star remains bloated for thousands yrs

stellar radius～10AU

→

Low UV emissivity

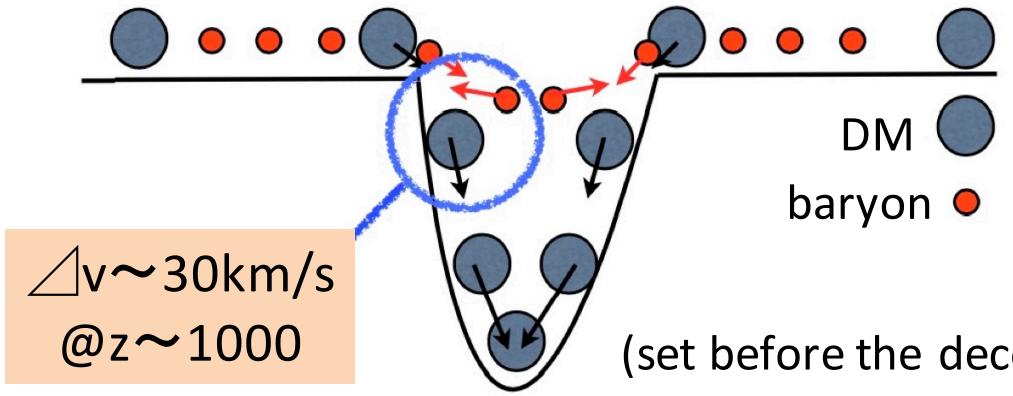
UV feedback is weakened

This helps forming massive stars

Extremely massive stars for extreme cases?

dark matter – baryon relative motions

(Tseliakhovich+Hirata10)



⊿v～30km/s @z～1000

(set before the decoupling)

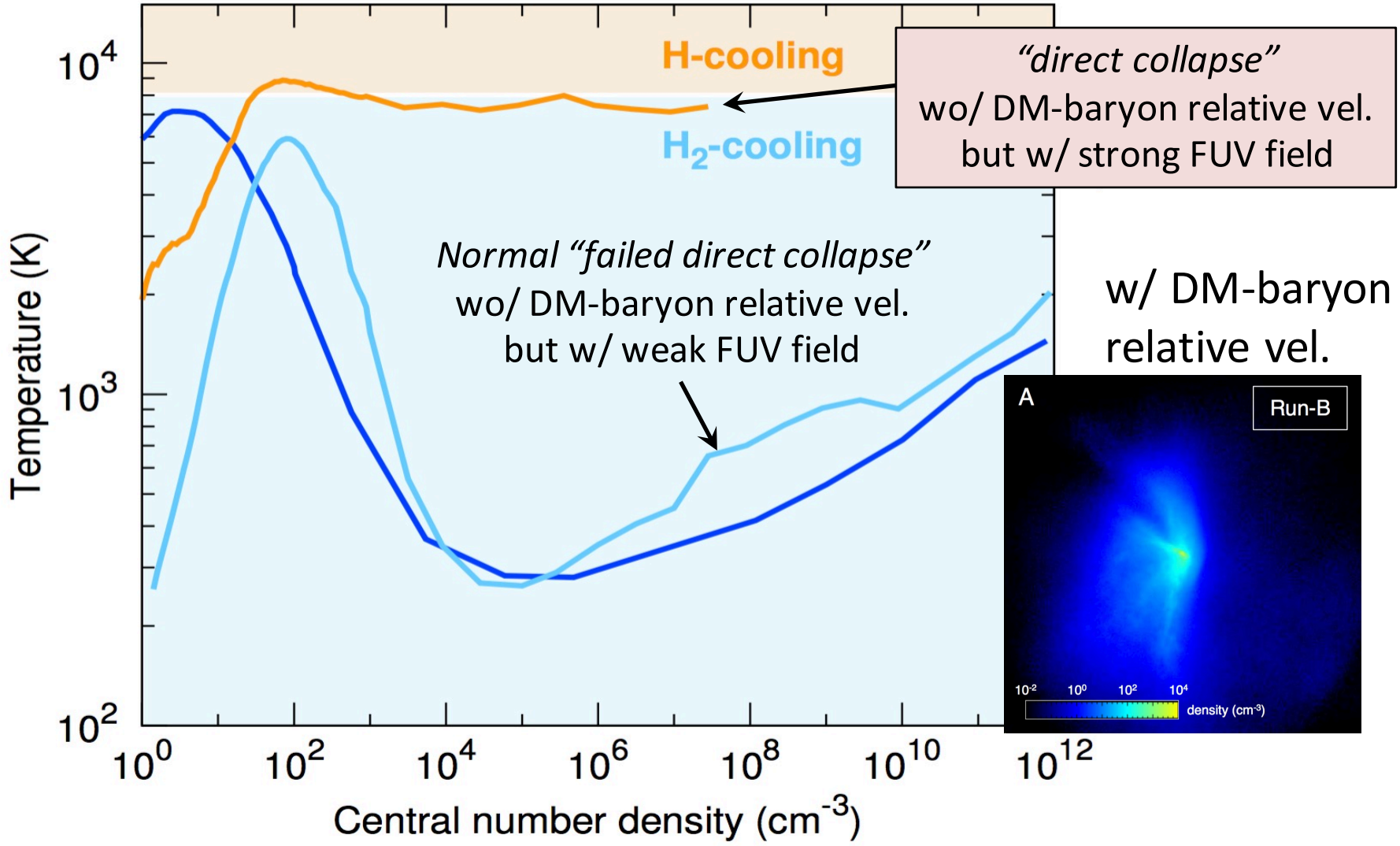
Normal PopIII star formation occurs with some **delay**

(e.g., Stacy+11; Greif+11)

But what happens w/ much larger ⊿v? (e.g., Tanaka+Li 14)
Significantly delayed star formation w/ very massive host halo?

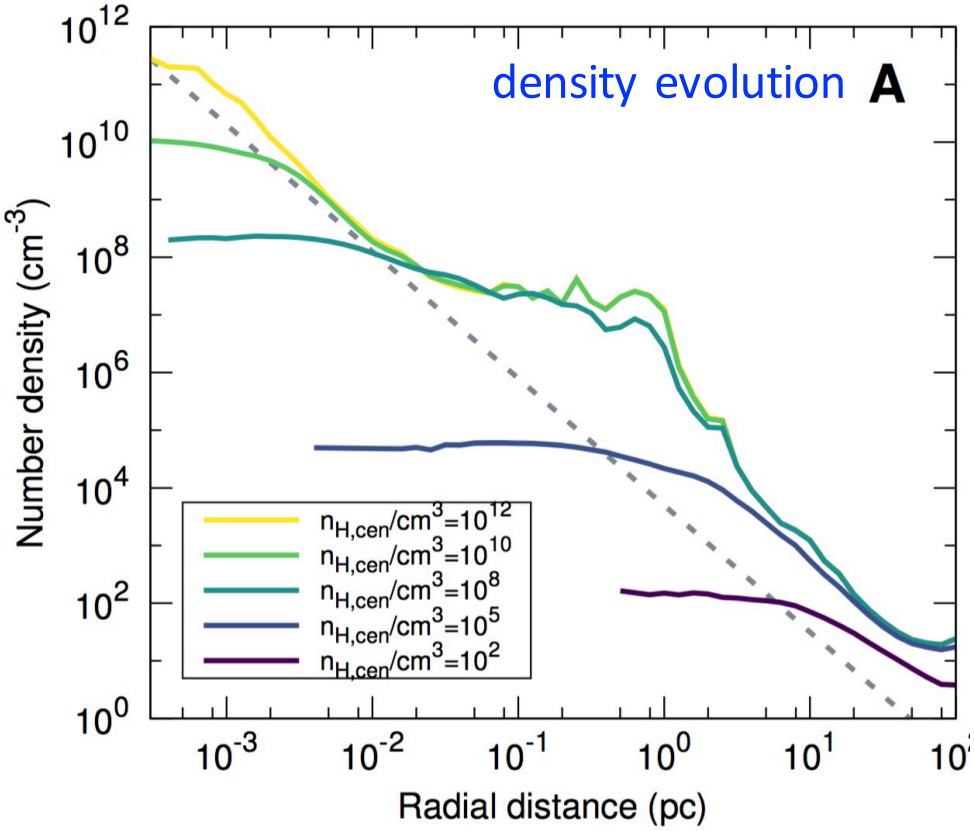
(also see Anna Schauer's talk after the lunch)

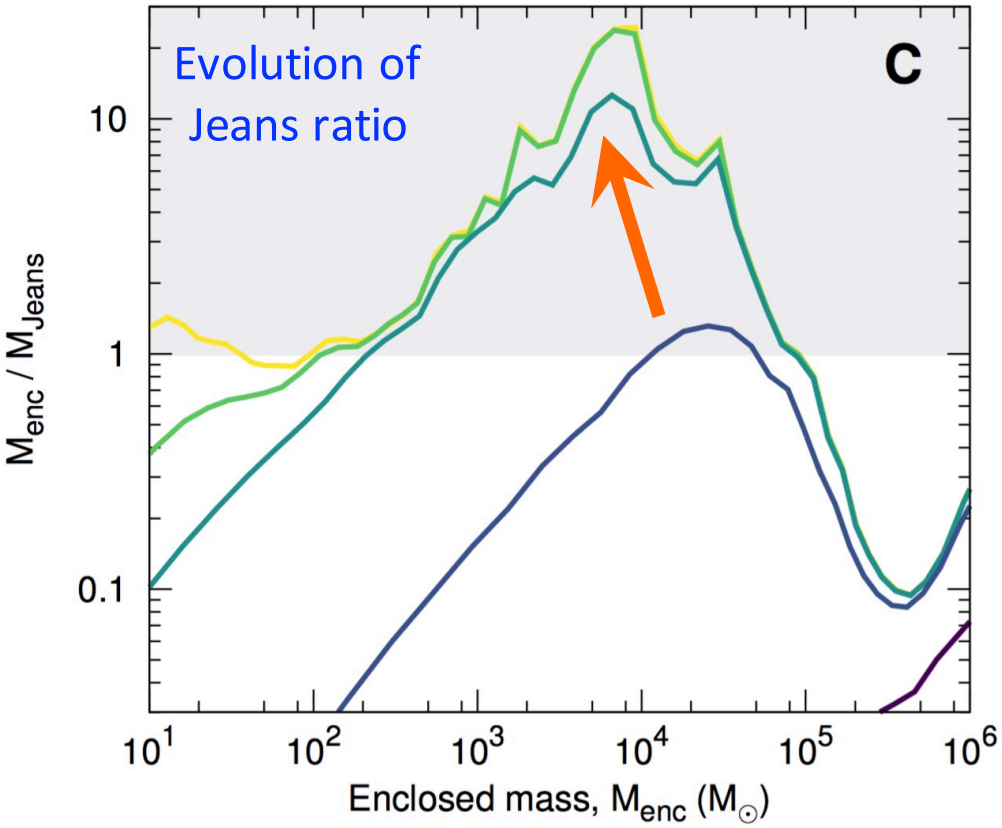
Cosmological Simulation



Temperature drops at some point because H2 molecules form without nearby strong FUV source → no rapid accretion? $\dot{M} \propto T^{1.5}$

Cloud Collapse w/ large ◿v

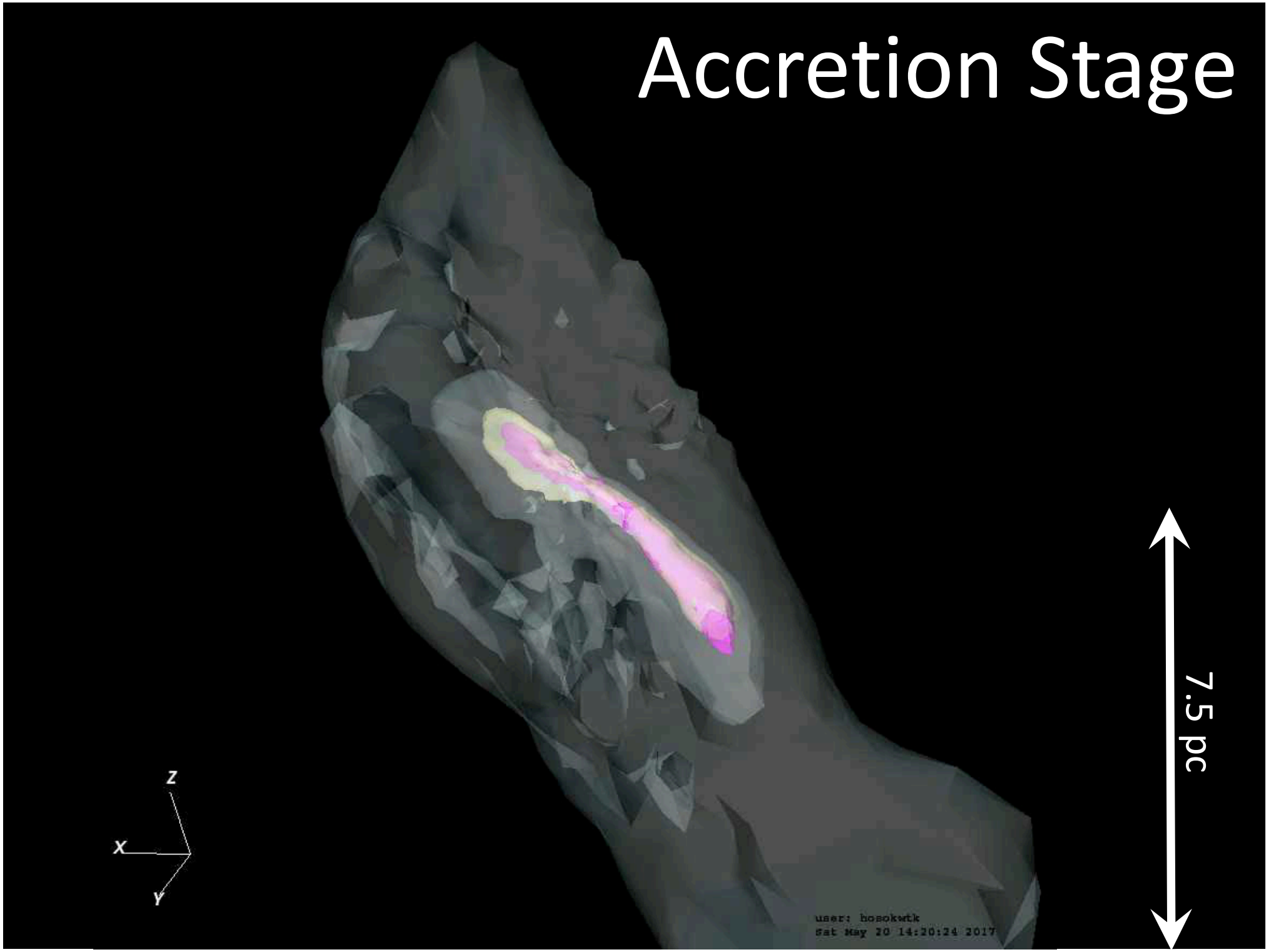




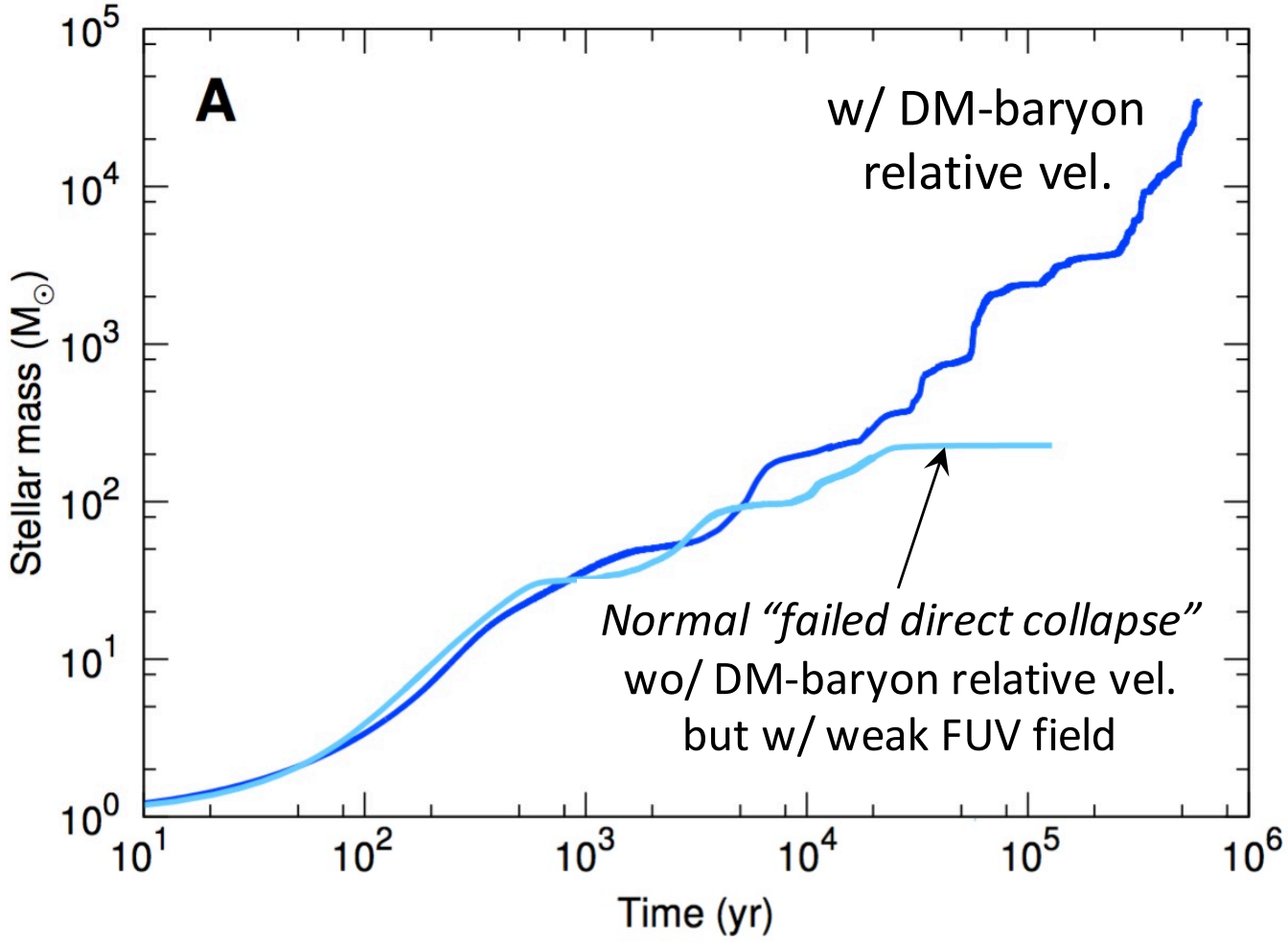
Rapid mass inflow into a very massive host halo w/ $M_{halo} \sim 10^7 M_\odot$ (x10 larger than the normal case)

$\Longrightarrow$

Very dense accretion envelope
→ very rapid accretion rate
(c.f. present-day high-mass SF)


Accretion Stage
Z
X
Y
user: hosokwtk
Sat May 20 14:20:24 2017
7.5 pc

Stellar Mass Growth



Stellar mass exceeds 3 x $10^4 M_\odot$ within the stellar lifetime, < Myr.
Evolution is qualitatively different w/ large DM-baryon relative vel.

Summary

Protostellar evolution

key to control the UV feedback from massive primordial stars

+ Episodic accretion in massive star formation should cause the drastic change of the protostellar evolution and feedback.

+ (large) DM-baryon relative velocity leads to a particular mode of forming very massive primordial stars → seeding SMBHs?