Radiative Feedback of POPIII Stars

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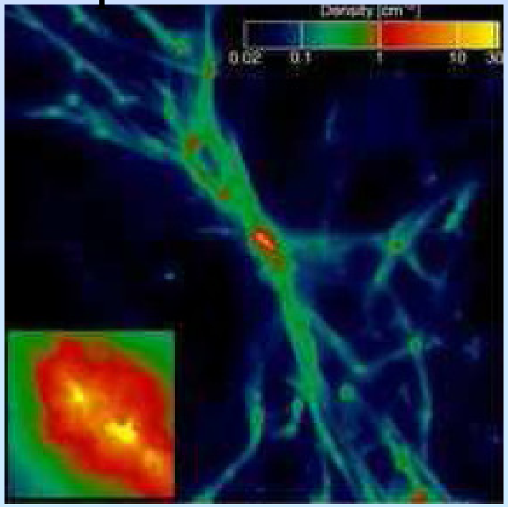
Radiative Feedback

- Micro Processes
  - photoionization
    - photoevaporation
    - enhance H2 formation
  - H2 dissociation by Lyman-Werner (LW) Band photons
    - H2 destruction
    - H2+, H- destruction
- Outcome
  - self-regulation of SF in the early universe
  - Source of reionization



Abel et al. 2006

Three phases of Radiative feedback from dark to luminous ages

- Phase I:

  local feedback from single POPIII（ionization+dissociation）

  e.g. Omukai & Nishi 1999; Glover & Brand 2001; Susa & Umemura 2006; Ahn & Shapiro 2006; Yoshida et al.(2006)

- Phase II:

  diffuse LW background (built up by many stars)

  e.g. Haiman et al. 1997; Ciardi et al. 2000; Oh & Haiman 2003 ; Mesinger ,Bryan, Haiman 2006

- PhaseIII:

  diffuse ionizing photon background →Reionization of the univ.

  e.g. Barkana & Loeb 2000; Kitayama et al. 2000,2001; Susa & Umemrua 2004ab

Local H_2 photodissociation feedback in uniform gas cloud

$$L_{LW} = L_{LW,0}\left(\frac{N_{H_2}}{10^{14}\,\mathrm{cm}^{-2}}\right)^{-3/4}$$

$$n_{H_2} = 0.88\times 10^{-26} x_e \left(\frac{L_{LW}}{4\pi r^2}\right)^{-1} T n^2 \,(\mathrm{equilibrium})$$

$$r_{sh} = 1\,\mathrm{kpc}\left(\frac{x_e}{10^{-4}}\right)^{-\frac{1}{3}}\left(\frac{L_{LW,0}}{10^{24}\,\mathrm{erg\,s^{-1}\,Hz^{-1}}}\right)\left(\frac{T}{10^3\,\mathrm{K}}\right)^{-\frac{1}{3}}\left(\frac{n}{1\,\mathrm{cm}^{-3}}\right)^{-\frac{2}{3}}$$

Uniform low mass host clouds are totally Photodissociated by single POPIII star.

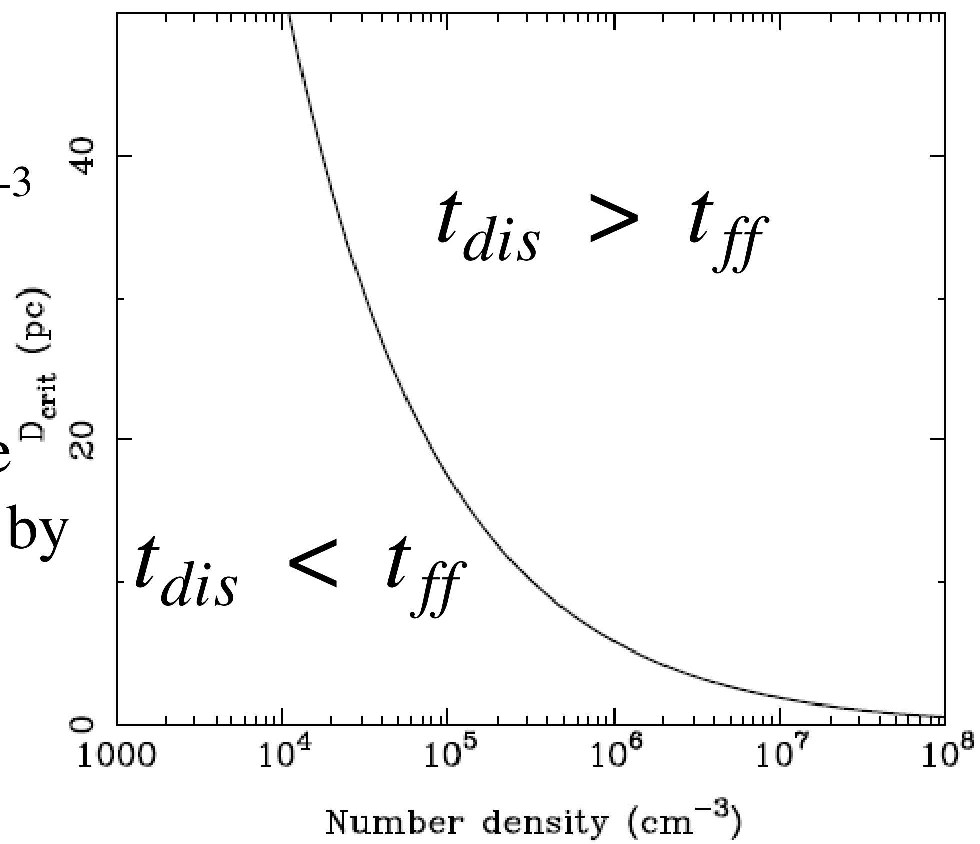
Omukai & Nishi 1999

H_2 photodissociation feedback on clumpy cloud

Glover & Brand 2001

D_{crit} ; 100pc@ n_{clump} » 10^3cm^{-3}

Dense clouds are able to survive the photodissociation feedback by another nearby star.



- Dynamically collapsing cloud ?
- Photoionization?

Photoionization Feedback

- Evaporation of low density cloud

  (e.g. Yoshida et al. 06)
- Survival of dense prestellar core

  (e.g. Abel et al. 06; Ahn & Shapiro 07)
- Once ionized → recollapse→HD→ low mass Fragments ?

  (e.g. Uehara & Inutsuka 00; Greif & Bromm 06)

Radiation hydrodynamics simulations

Need systematic understanding of physical processes

Numerical Methods

H. Susa, PASJ 58, 445 (2006)

- Tree
- SPH
- RT of Ionizing photons by Ray Tracing
- RT of Lyman-Werner photons by Ray Tracing (Self-Shielding function)

$$F_{LW} \propto f_{sh}(N_{H_2}) = \left(\frac{N_{H_2}}{10^{14} cm^{-2}}\right)^{-3/4} \quad \text{if } N_{H_2} > 10^{14} cm^{-2}$$

- Implicit solver for reactions and energy equation
- H_2 (no HD, unfortunately)
- Everything parallelized utilizing MPI

FIRST

240 nodes

480 CPU ＋

240 Blade-GRAPE

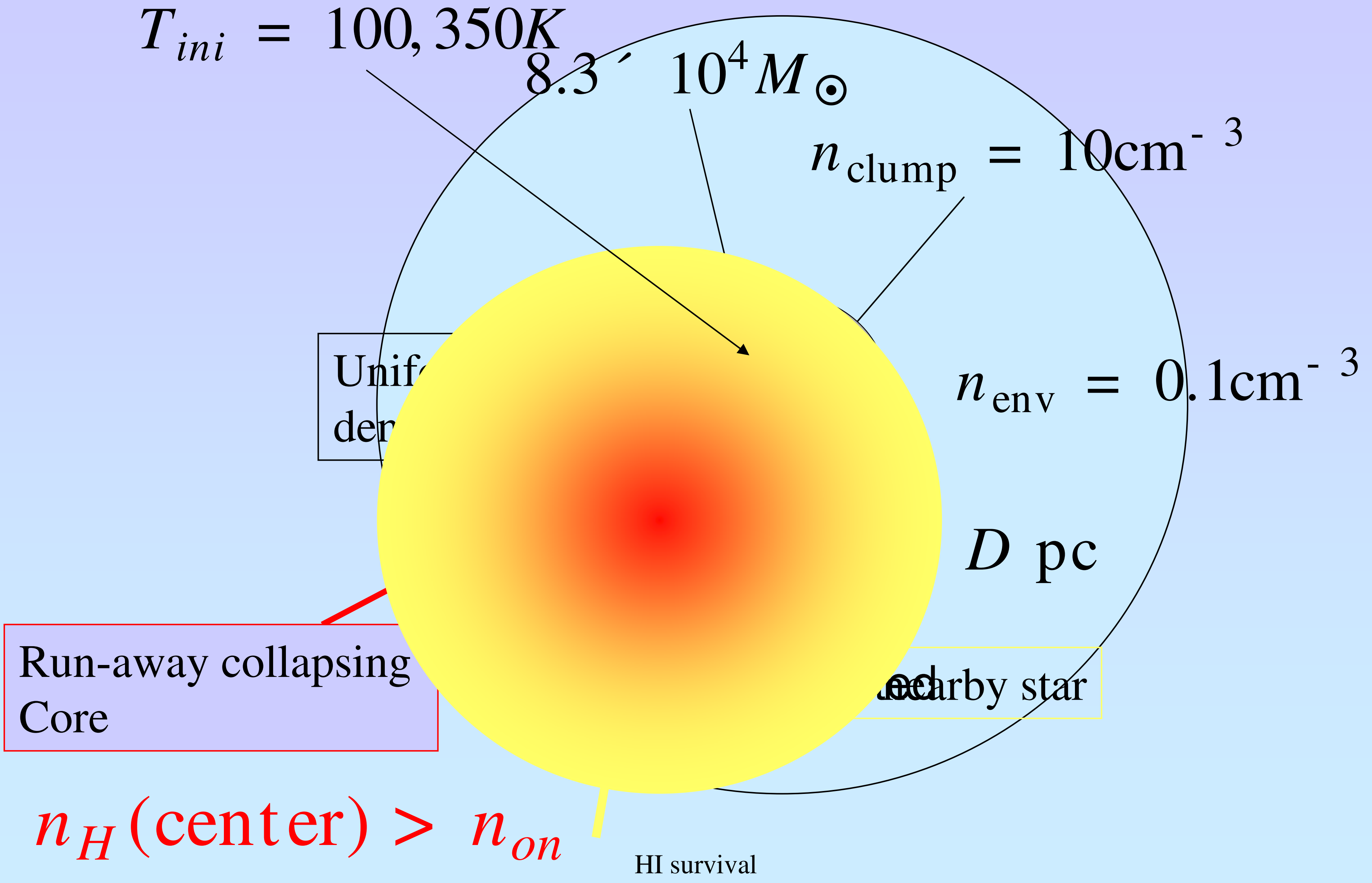
480 Xeon : 2.9 Tflops

Blade-GRAPE: 8.7 Tflops

Memory: 512GB

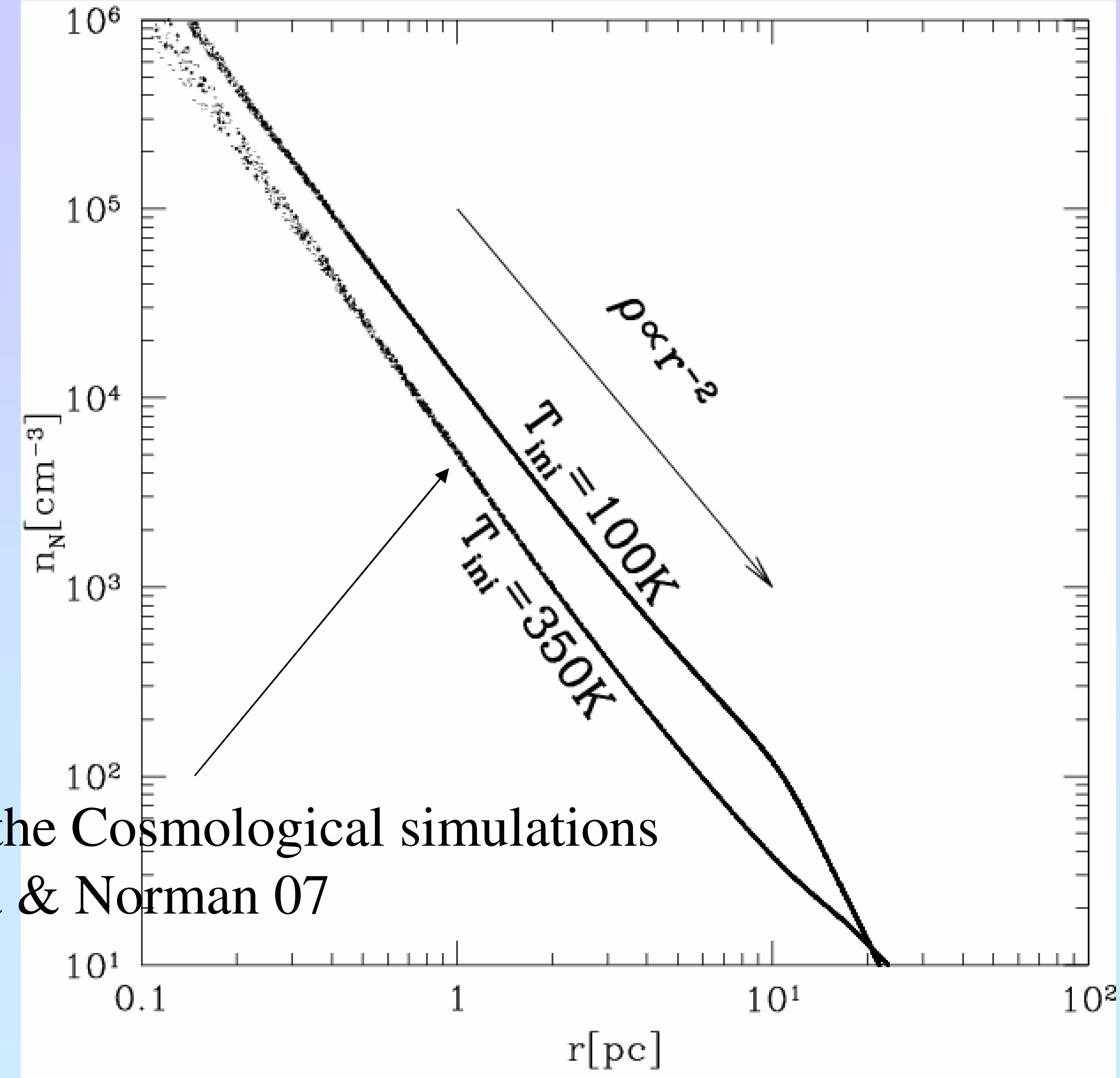
Now available

Setup



$T_{ini} = 100, 350K$
$8.3\times 10^4 M_\odot$
$n_{clump} = 10 cm^{-3}$
Unif
den
$n_{env} = 0.1 cm^{-3}$
D pc
ednearby star
Run-away collapsing Core
$n_H(center) > n_{on}$
HI survival

Difference due to Tini



Closer to the Cosmological simulations
By O'shea & Norman 07

HI survival

Parameters

$N_{SPH} = 524288$

Property of the Source Star

$120 M_{\odot}$ $4.6 R_{\odot}$ 9.92×10^4 K

With/without ionizing radiation

$D = 10\text{pc} - 150\text{pc}$

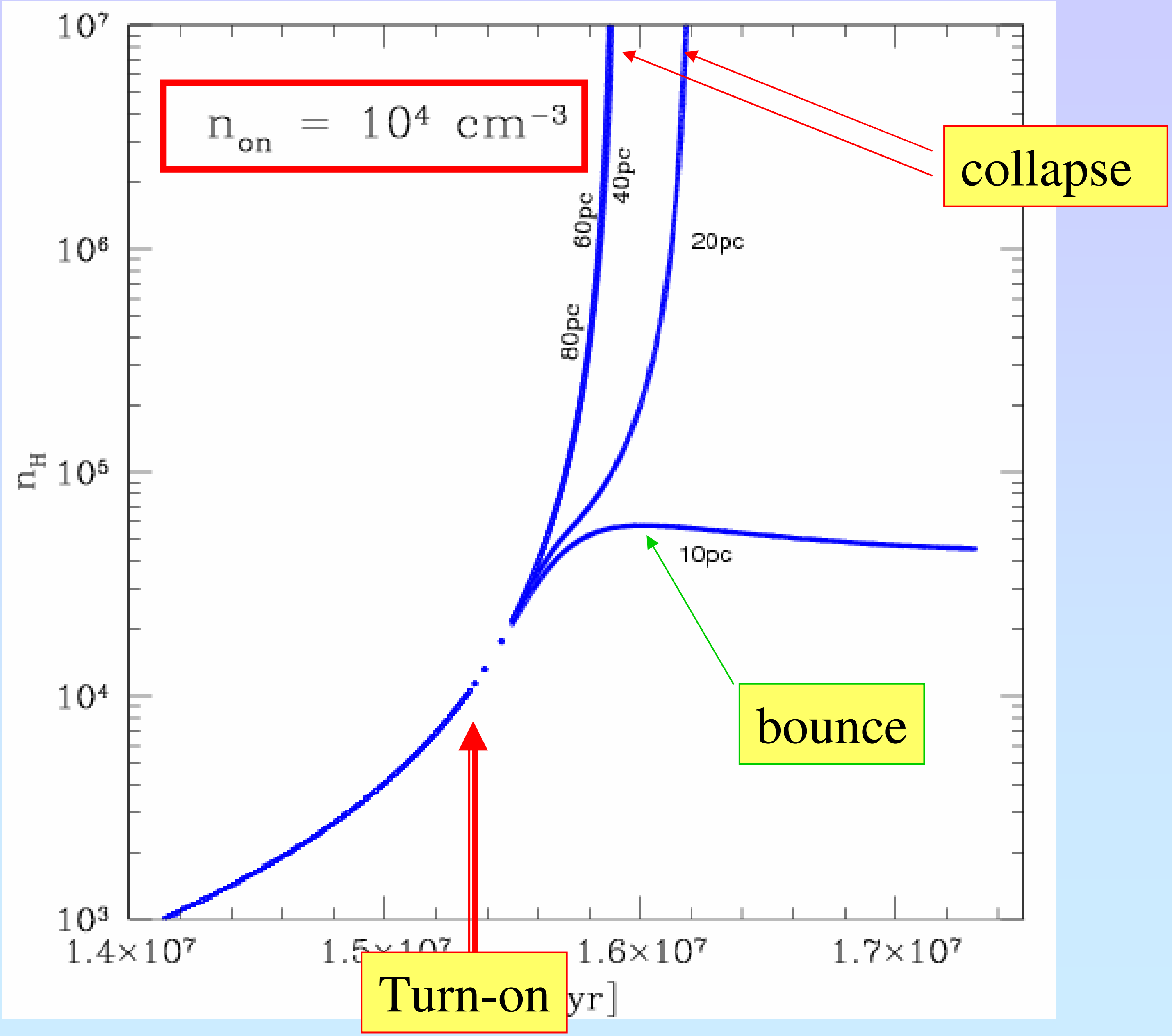
c.f. size of the first star forming halos are several $\times$ 10pc

$n_{on} = 10^2 : 10^5 \text{cm}^{-3}$

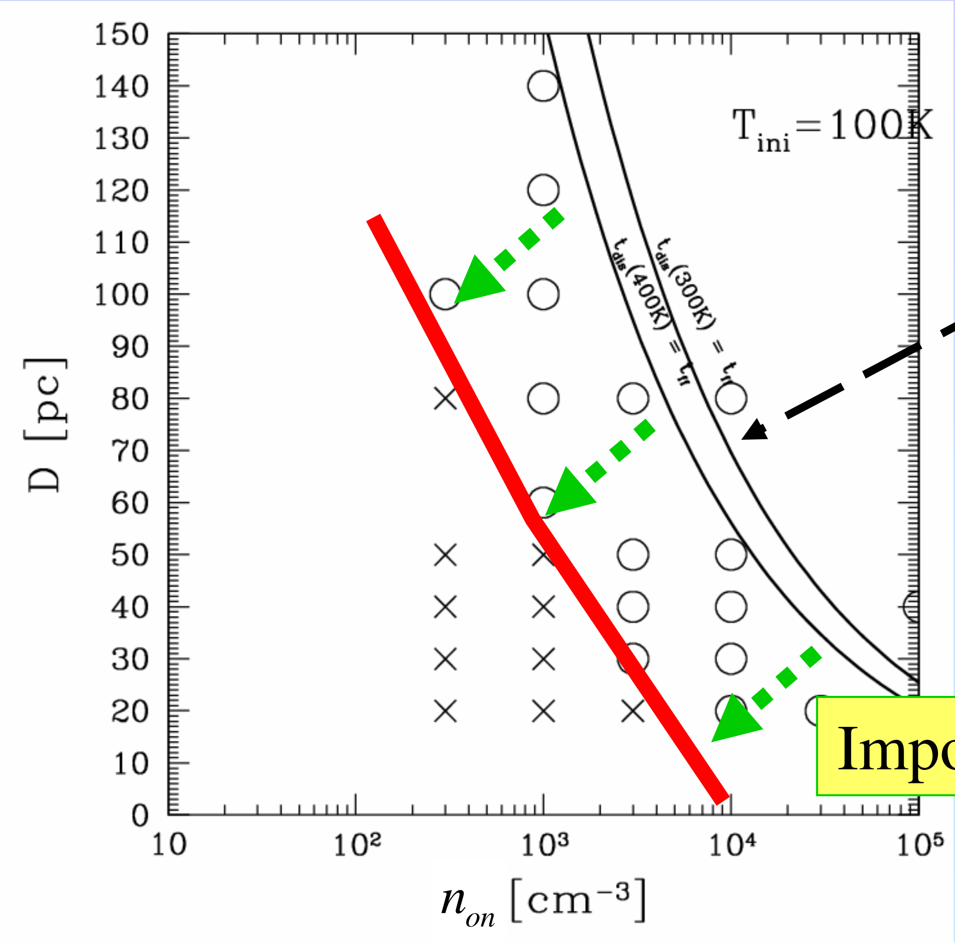
Effects of LW radiation

Susa 2007 ApJ **659** 908

Time evolution of Central density



Summary of Runs



$$t_{dis} = t_{ff}$$

Importance of dynamical effect

LW + Photoionization

Susa & Umemura ApJ **645**L 93

Susa & Umemura in prep.

Photoevaporation (less dense core)

- The I-front propagates as R-type
- Whole cloud is ionized/heated up to 1e4 K before the hydrodynamic reconfiguration.
- All of the gas is photoevaorated since V_esc < 10 km/s

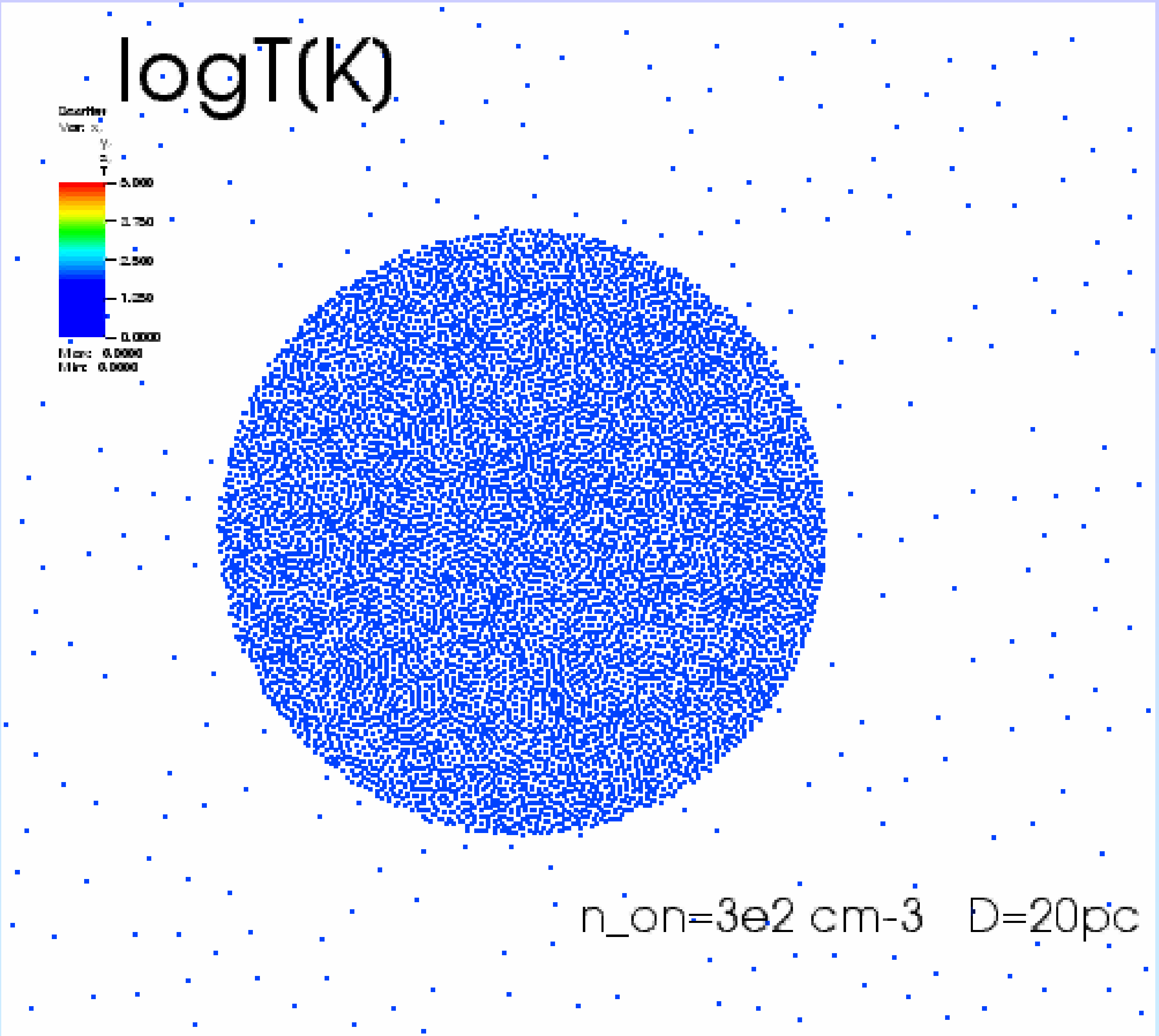
Self-shielding condition for Static Core

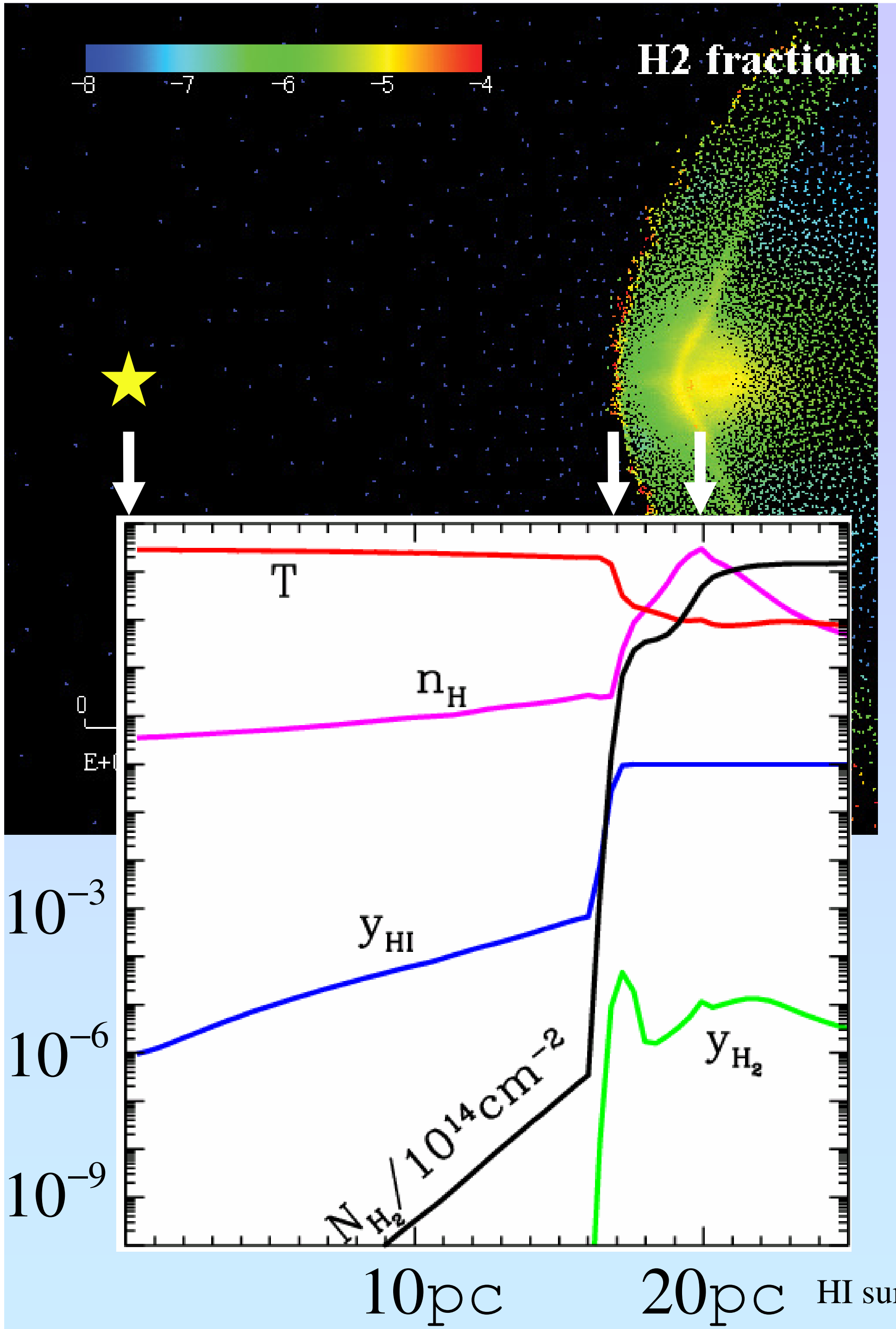
$$\dot{N}_{\rm ion}(\pi r_{\rm core}^2/4\pi D^2) < 4\pi r_{\rm core}^3 n_{\rm core}^2 \alpha_{\rm B}/3$$

$$n_{\rm core} > \left(\frac{3\dot{N}_{\rm ion}}{16\pi D^2 a_1 \alpha_{\rm B}} \sqrt{\frac{G m_{\rm p}}{\pi}} \right)^{2/3}$$

$$= \; 5.1 \ {\rm cm}^{-3} \left(\frac{\dot{N}_{\rm ion}}{10^{50}{\rm s}^{-1}} \right)^{2/3} \left(\frac{D}{20{\rm pc}} \right)^{-4/3} \left(\frac{a_1}{1{\rm km \ s}^{-1}} \right)^{-2/3}$$

Disrupted Core by shock





HI survival

H2 shell formation & Enhancement of H2 in the core

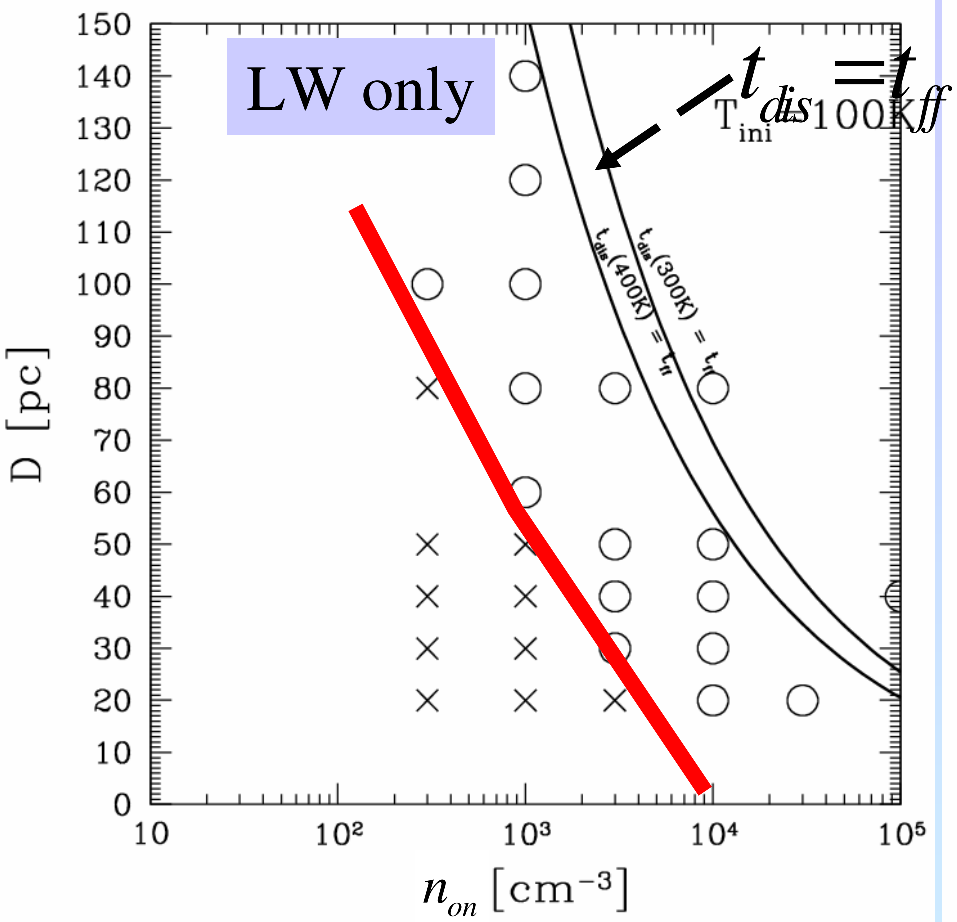
Competing effects

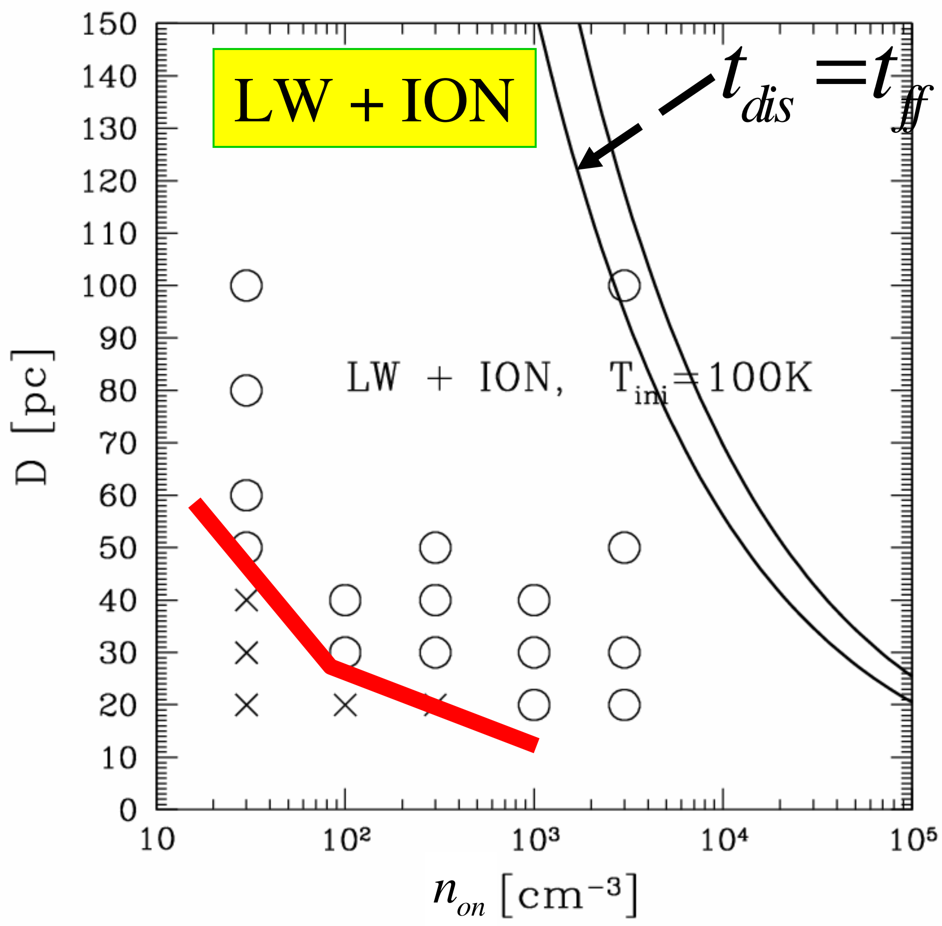
- H2 dissociation
- Photoevaporation (thermal pressure / shock)

↕

- Self-shielding (LW / ionizing photons)
- Enhanced H2 formation in the core by mild shock (→Ahn & Shapiro 07)
- H2 shell formation

Summary of Runs (n_{on}-D plane)

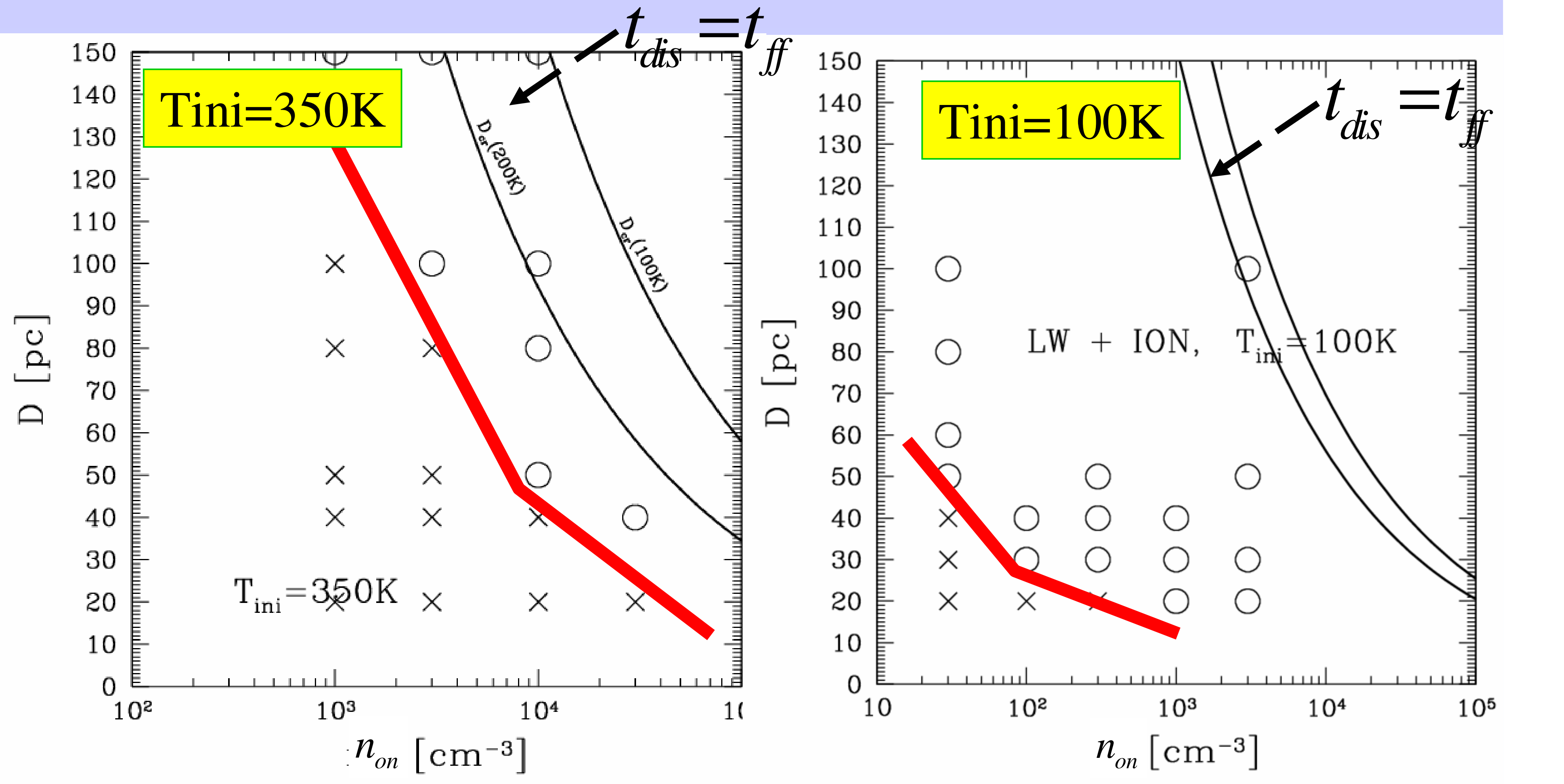




Effects of photoionization alleviates the negative feedback of photodissociation

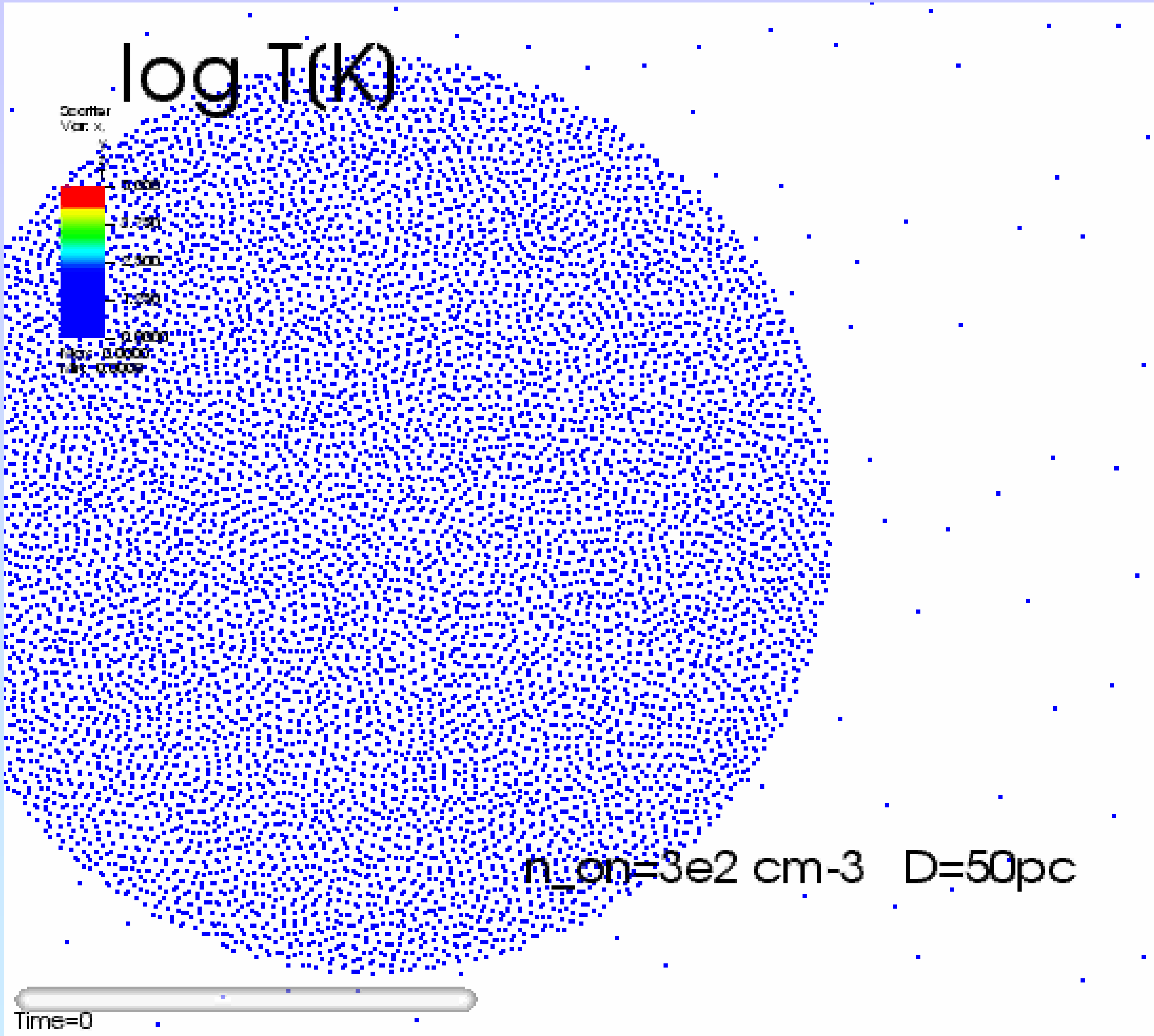
HI survival

Effects of Tini (n_{on}-D plane)



Larger Tini → smaller core radi → stronger feedback effects

Survived HI Core & Lost Envelope

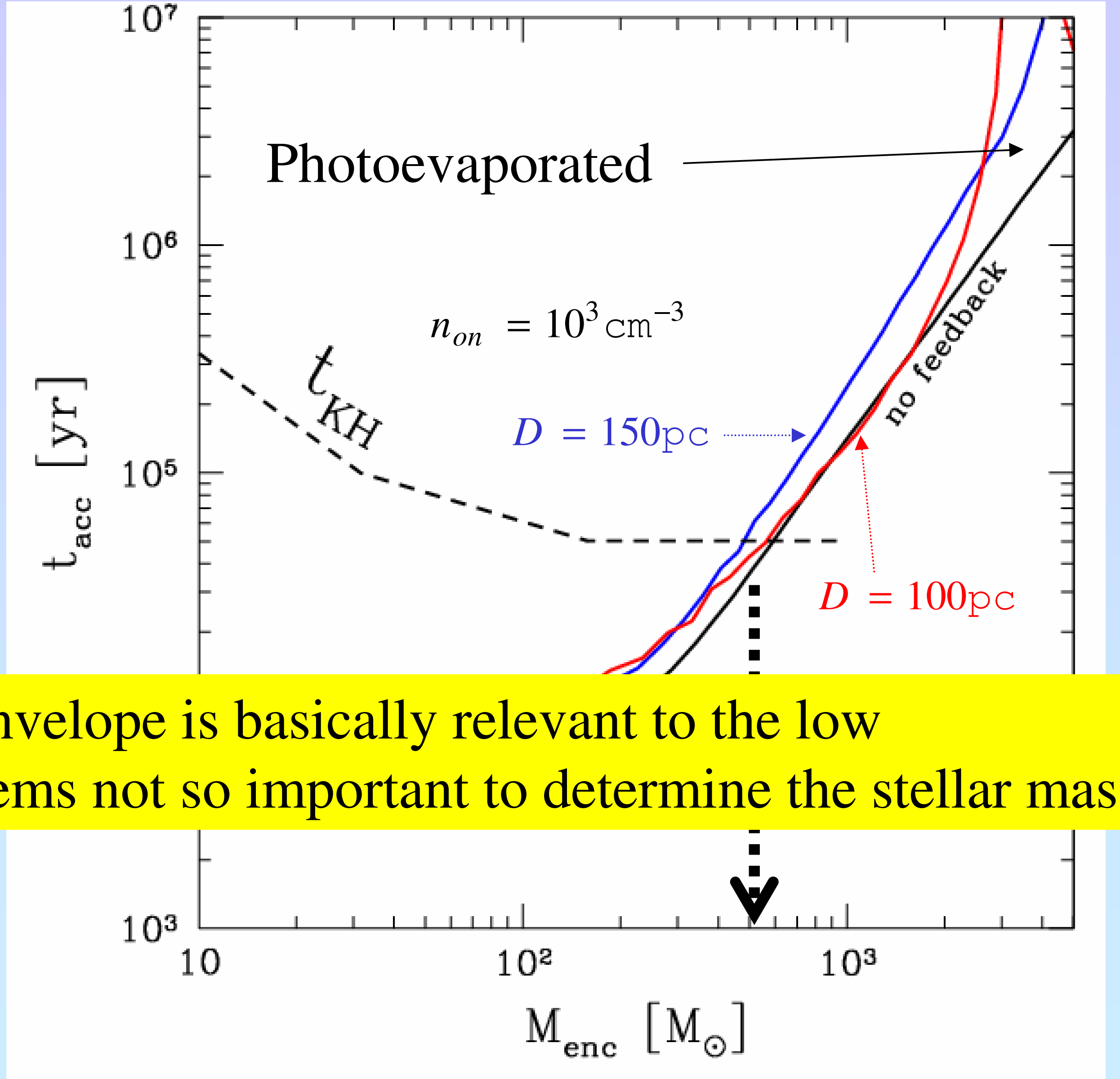


Accretion time vs. tKH (preliminary)

$$t_{acc} \equiv \frac{M_{enc}}{4\pi\rho r^2(-v_r)}$$

t_{KH}

Kelvin Helmholtz



Photoevaporation of envelope is basically relevant to the low density envelope →seems not so important to determine the stellar mass?

O'shea & Norman 07

Summary

- We perform 3D RHD simulations on POPIII radiative feedback
- Local feedback by POPIII stars are not so destructive as expected before.
- Photoionization alleviates the negative effects by LW photons.
- Collapses of self-gravitating prestellar cores (n_H ♦ 10^3 /cc) are not reverted even if another star is formed in its neighbor (D〜 100pc).