

Feedback effects on the  
formation of first  
generation stars

-- Radiation Hydrodynamic  
Simulations--

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# Introduction

- Importance of star formation efficiency of first generation stars
  - Early reionization source ? (e.g. Sokasian et al. 2004 )
  - Observed NIR background radiation ? (e.g. Salvaterra & Ferrara 2004 )
- Feedback Processes

- Negative Feedback

- Strong negative feedback by H<sub>2</sub> photodissociation  
(e.g. Omukai & Nishi 1999; Glover & Brand 2001; Machacek, Bryan, & Abel 2001)
- Photoheating evaporates the low mass host clouds  
(e.g. Susa & Umemura 2004ab)

- Positive Feedback

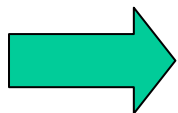
- SN shell fragmentation  
(e.g. Ferrara 1998 ; Johnson & Bromm 2005)
- Collapse of Remnant HII region  
(O'shea et al. 2005 ; Nagakura & Omukai 2005)

- H<sub>2</sub> shell surrounding HII region  
(Ricotti, Gnedin & Shull 2001)

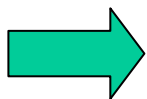
# H<sub>2</sub> photodissociation feedback in uniform gas cloud

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

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



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



**Uniform** low mass host clouds are totally photodissociated.

Omukai & Nishi 1999

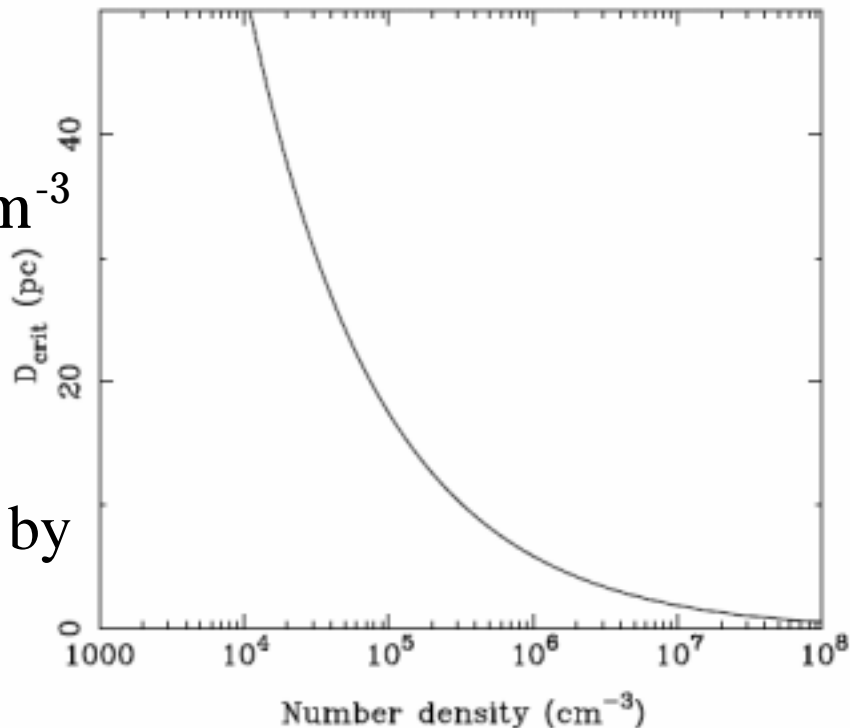
# H<sub>2</sub> photodissociation feedback on clumpy cloud

Glover & Brand 2001

$$D_{\text{crit}} \simeq 50 - 100 \text{ pc} @ n_{c0} \approx 10^3 \text{ cm}^{-3}$$



Dense clouds can survive the photodissociation feedback by first star in the host cloud.



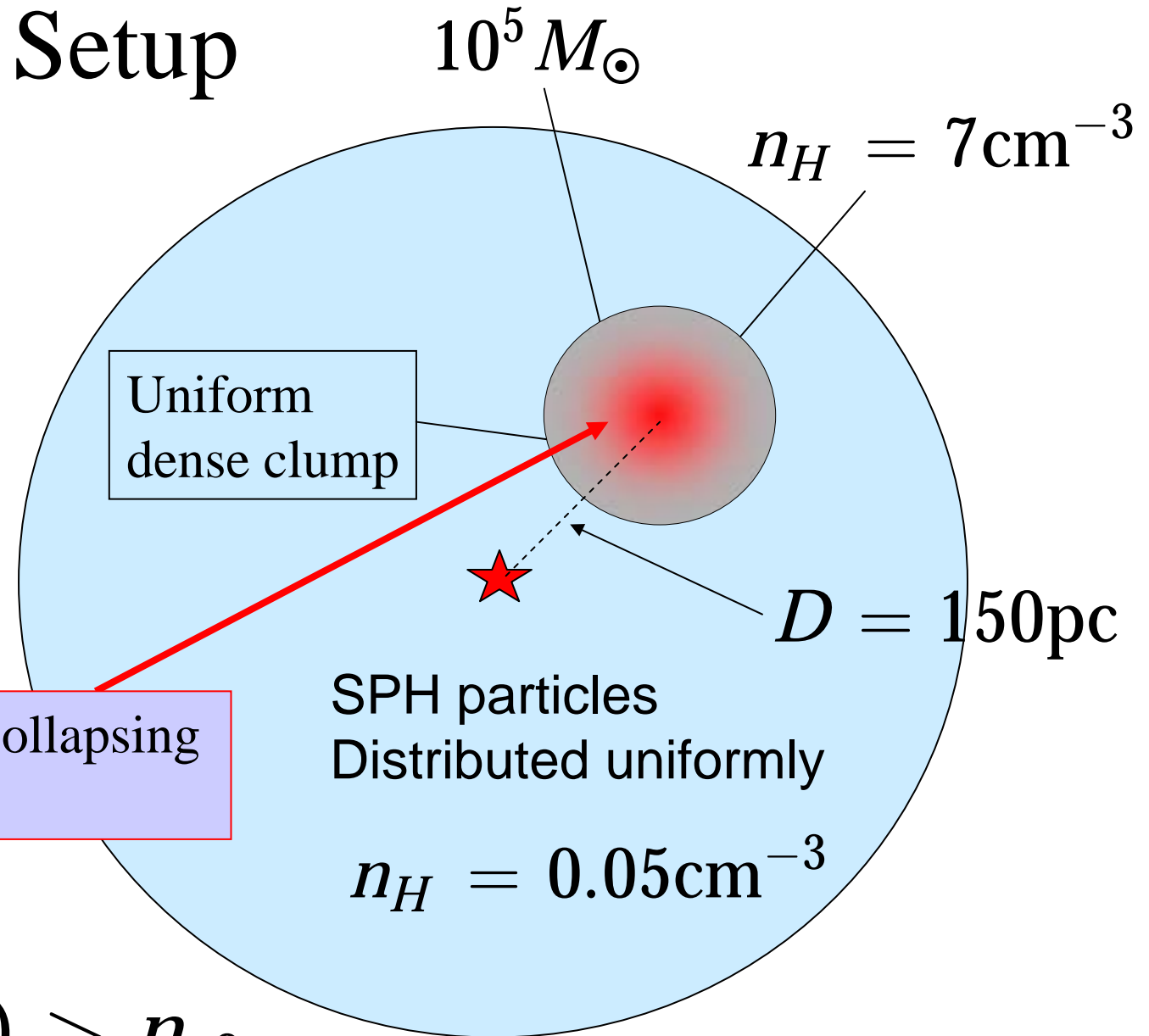
- Hydrodynamics ?
- Dynamically collapsing cloud ?
- Coupling of the photoheating/photionization with photodissociation?

*Radiation hydrodynamic simulations with ionization and photodissociation*

# Numerical Methods

- Parallel Tree
- SPH
- New RT solver
- Implicit solver for reactions and energy equation
- H<sub>2</sub> (still no He) + Self-Shielding function
- On-the-Spot approximation (Case B recom.)
- Multiple sources ( ~ 100 )
- Any Spectrum
- Passed basic tests of propagaion of IF

# Setup

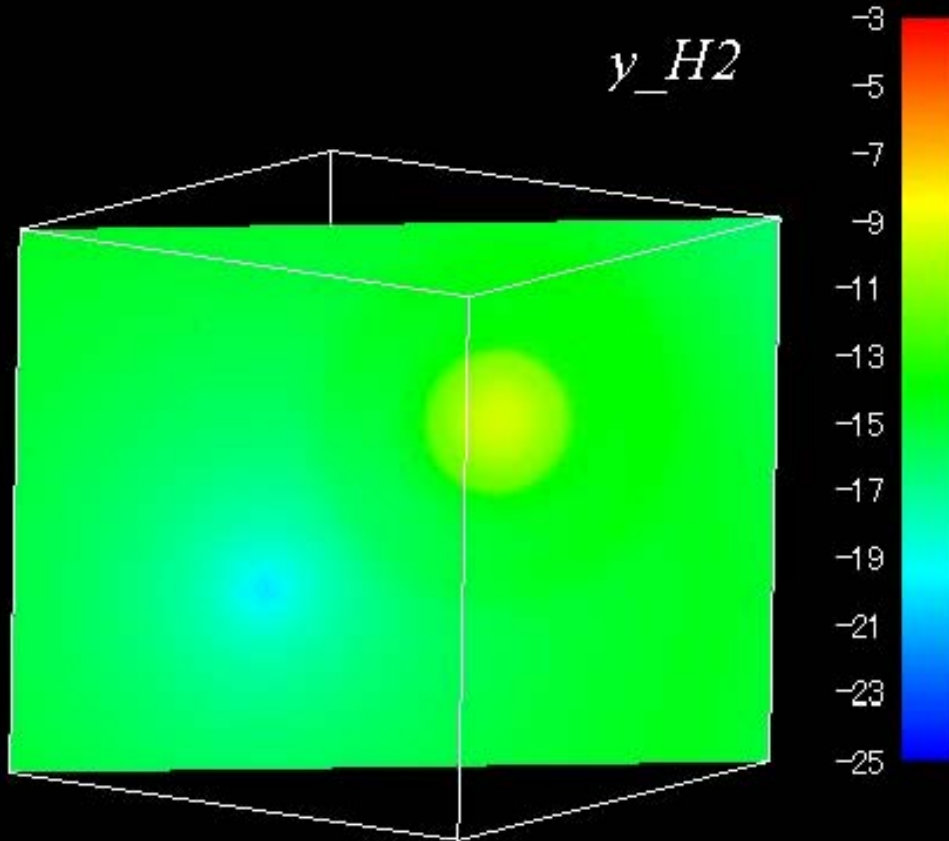


$$n_H(\text{center}) > n_{c0}$$

# Failed Collapse (No ionization)

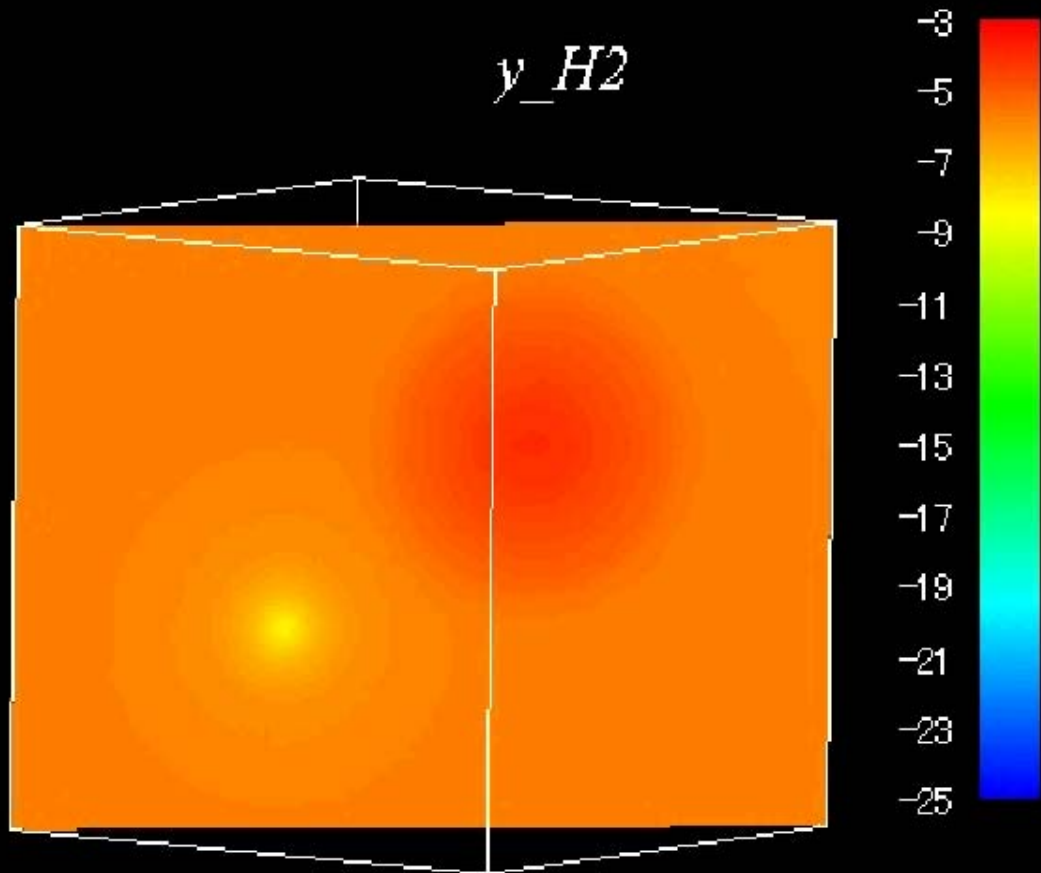
$$n_{c0} = 10^2 \text{ cm}^{-3}$$

$$N_* = 100 \quad (D = 15 \text{ pc})$$



LW photons sweep the dense core and prevent the cloud from collapsing.

# Survived prestellar core (ionization)



$$n_{c0} = 10^2 \text{ cm}^{-3}$$

$$N_* = 100 \quad (D = 15 \text{ pc})$$

- Formation of H<sub>2</sub> shell
- Implosion ?

# H<sub>2</sub> shell and N<sub>H<sub>2</sub></sub> from the source

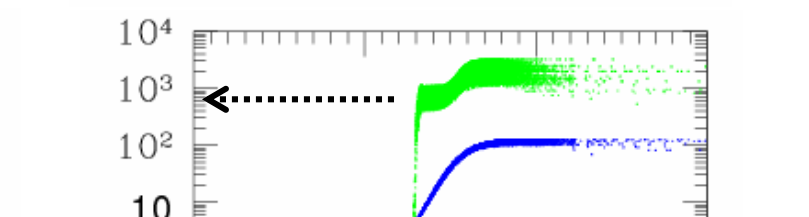
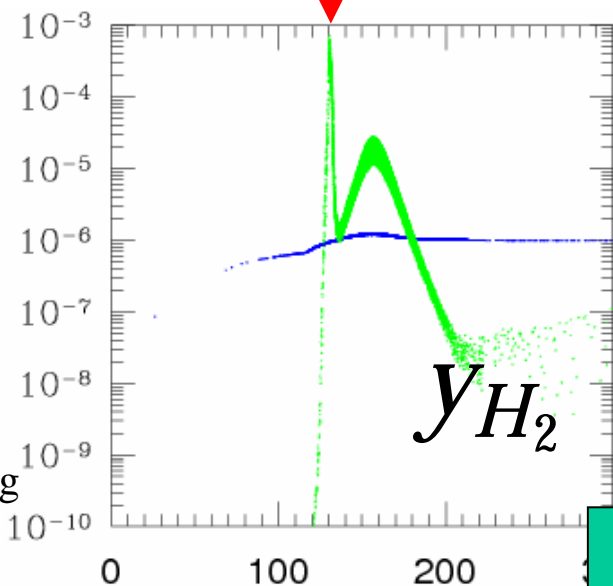
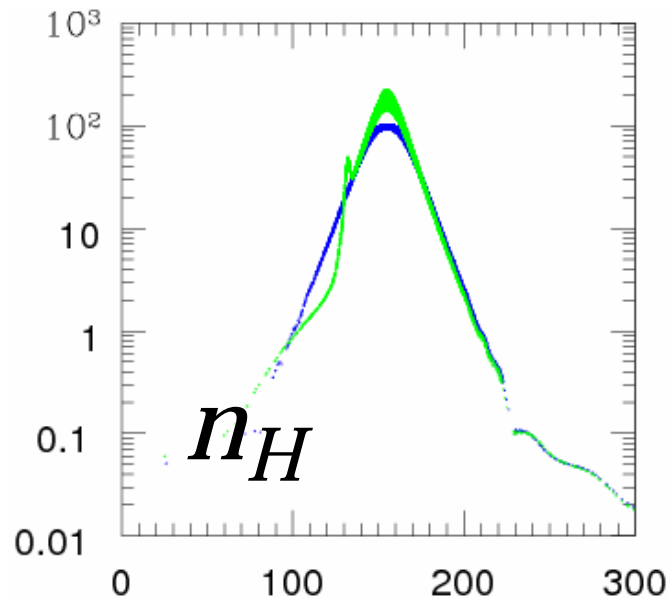
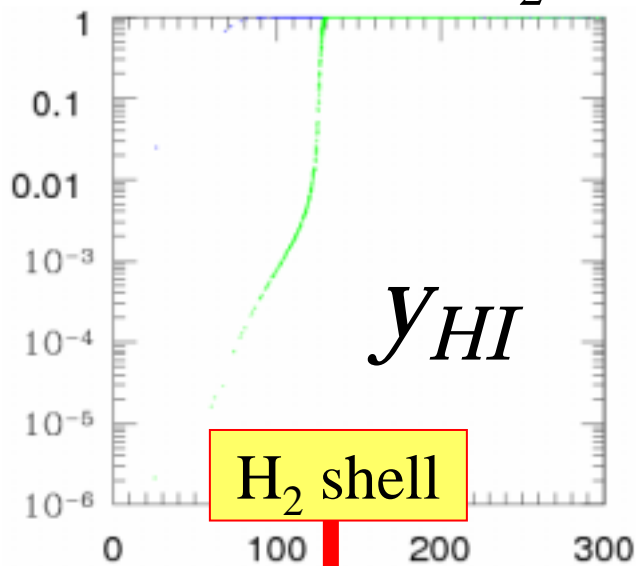
$$n_{c0} = 10^2 \text{ cm}^{-3}$$

$$N_* = 1$$

Blue: Just after the light is turned on

Green: after 1 million yrs

Spatial distribution along the line which contain the source and the center of the clump.



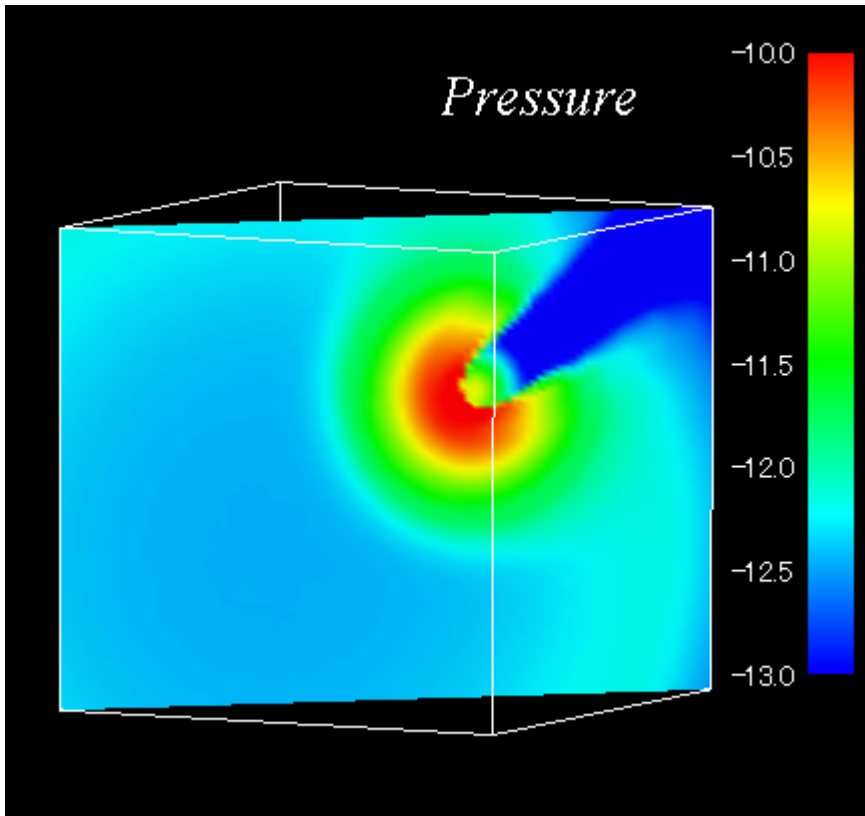
$$N_{H_2} (\text{shell}) \approx 10^{17} \text{ cm}^{-2}$$

$$10^{14} \text{ cm}^{-3}$$

Reduce LW flux by factor 200

# Implosion?

Pressure distribution



$$@ n_H \simeq 10^3 \text{ cm}^{-3}$$

$$t_{ff} \simeq 10^6 \text{ yrs}$$

$$t_{sound} \simeq \frac{10 \text{ pc}}{10 \text{ km} \cdot \text{s}^{-1}} \simeq 10^6 \text{ yrs}$$

External pressure helps the contraction

# Summary

- We perform 3D RHD simulations of the feedback effects on first generation stars.
- In the presence of ionizing photons from POPIII stars, the thin but opaque "H2 shell" is formed just behind the ionization front, and it significantly diminishes the incident flux of LW photons.
- If the surrounding materials are ionized, effects of implosion becomes important.
- In the absence of ionizing photons, shielding of LW photons is still very important, but it basically shutdown the SF in neighbor clumps.
- In order to evaluate the present effects in cosmological context, we need simulations with more realistic cosmological setup .