Star Formation: Then and Now, August 17, 2007

Star Formation in (very) High-z Proto-Galaxies

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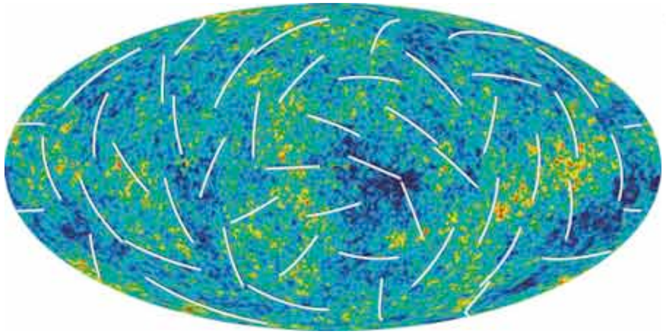
Star formation in proto-galaxies

- an important topic in observational cosmology

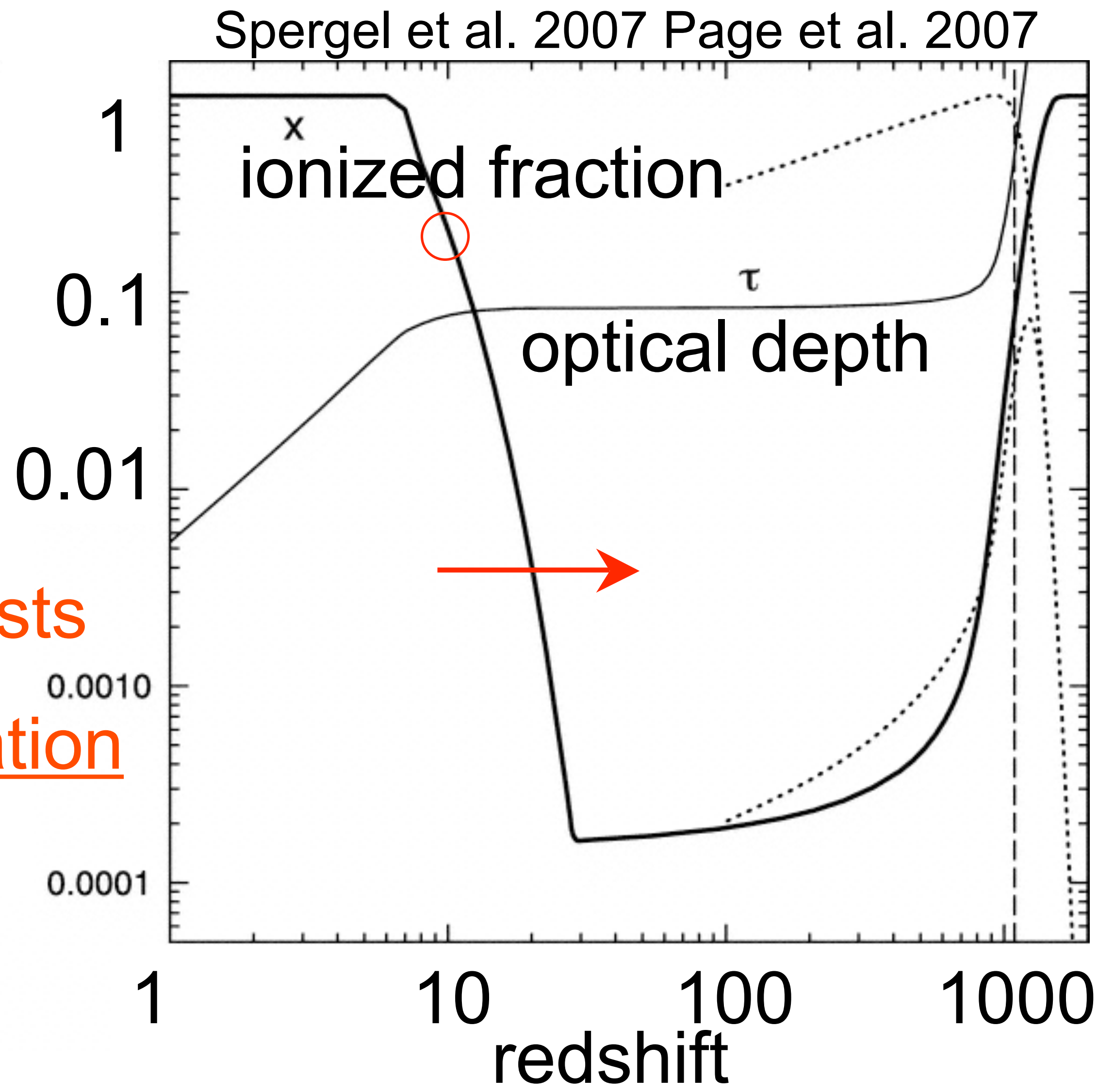


CMB polarization

measurement suggests

<u>significant star-formation</u>

<u>at z > 10.</u>



Sources of Hydrogen Reionization

- First stars
- Decaying particles, mini-quasars

Quasars

Normal galaxies

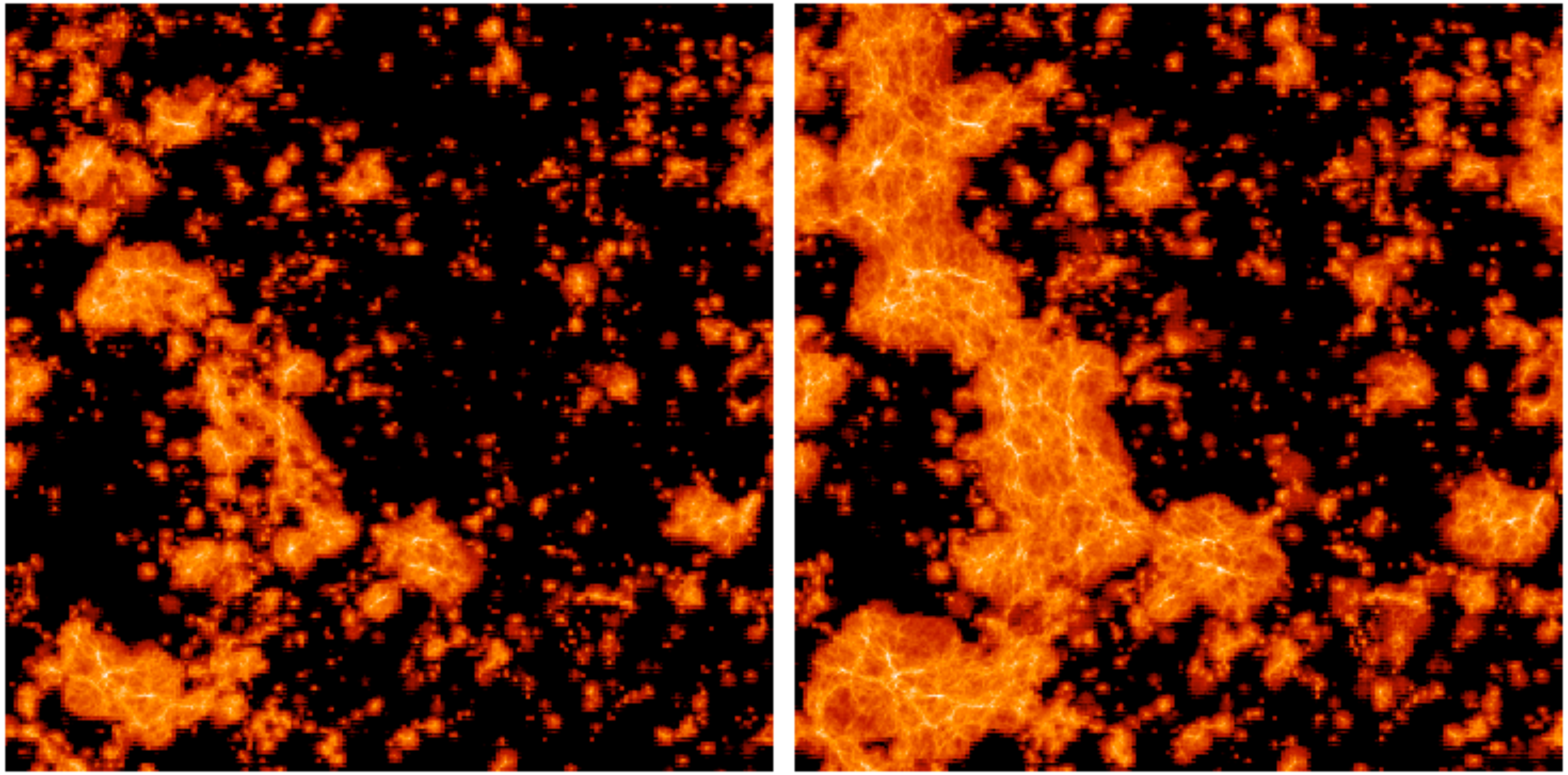
High-z dwarf (proto-)galaxies

with M = 10^7-10^{10} Msun

= ah-, yes, maybe, but...let's talk tomorrow

Reionization by the first galaxies

Trac & Cen 2007

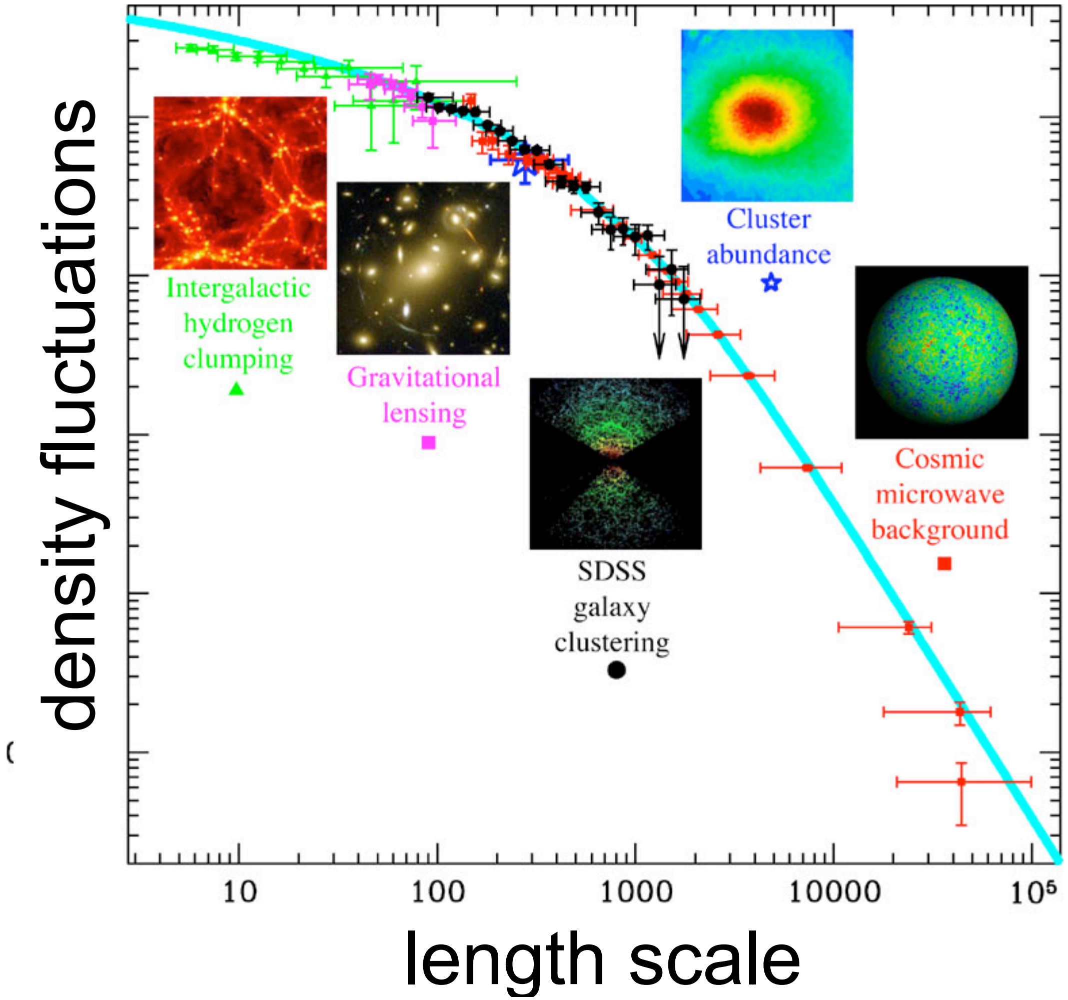


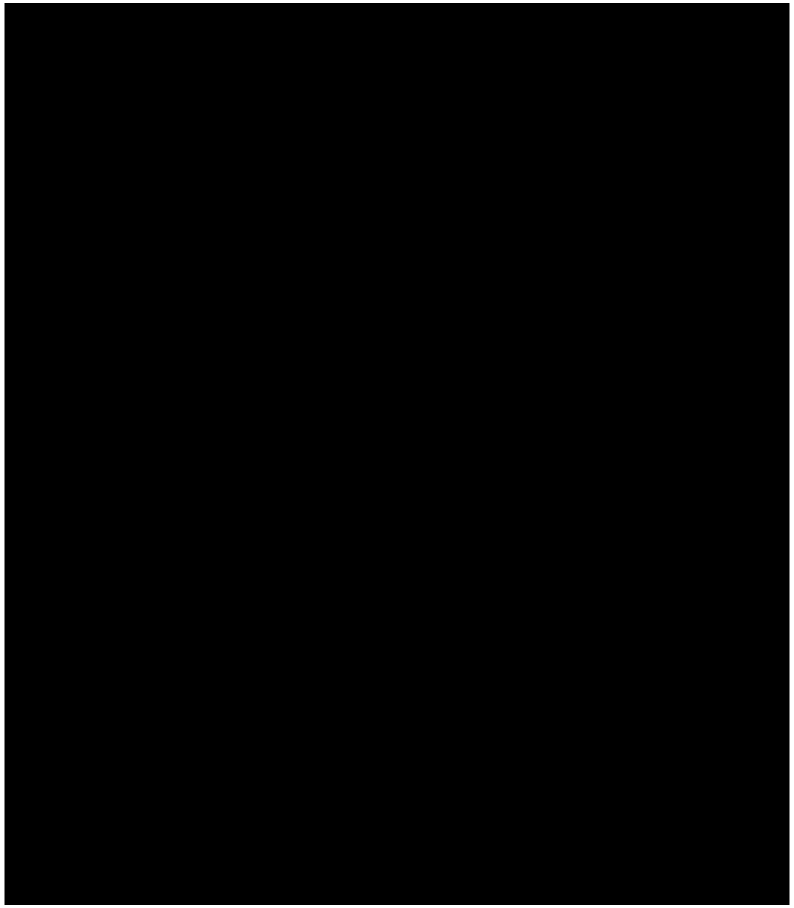
Please see also Iliev & Shapiro et al. (2005,6,7)
McQuinn et al. (2006,2007)

Contents

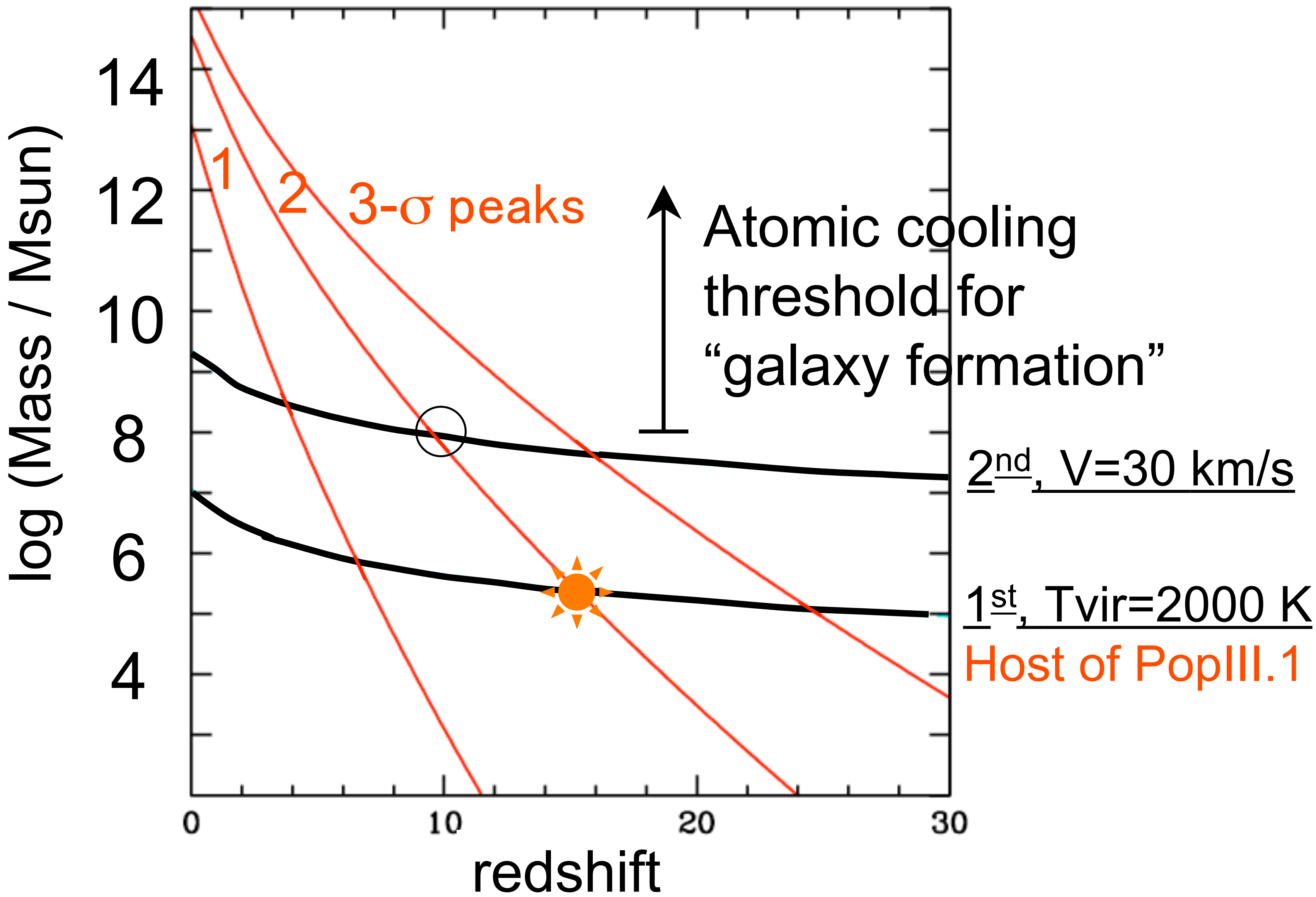
Hierarchical Structure Formation

Cold Dark Matter models predict "bottom-up"

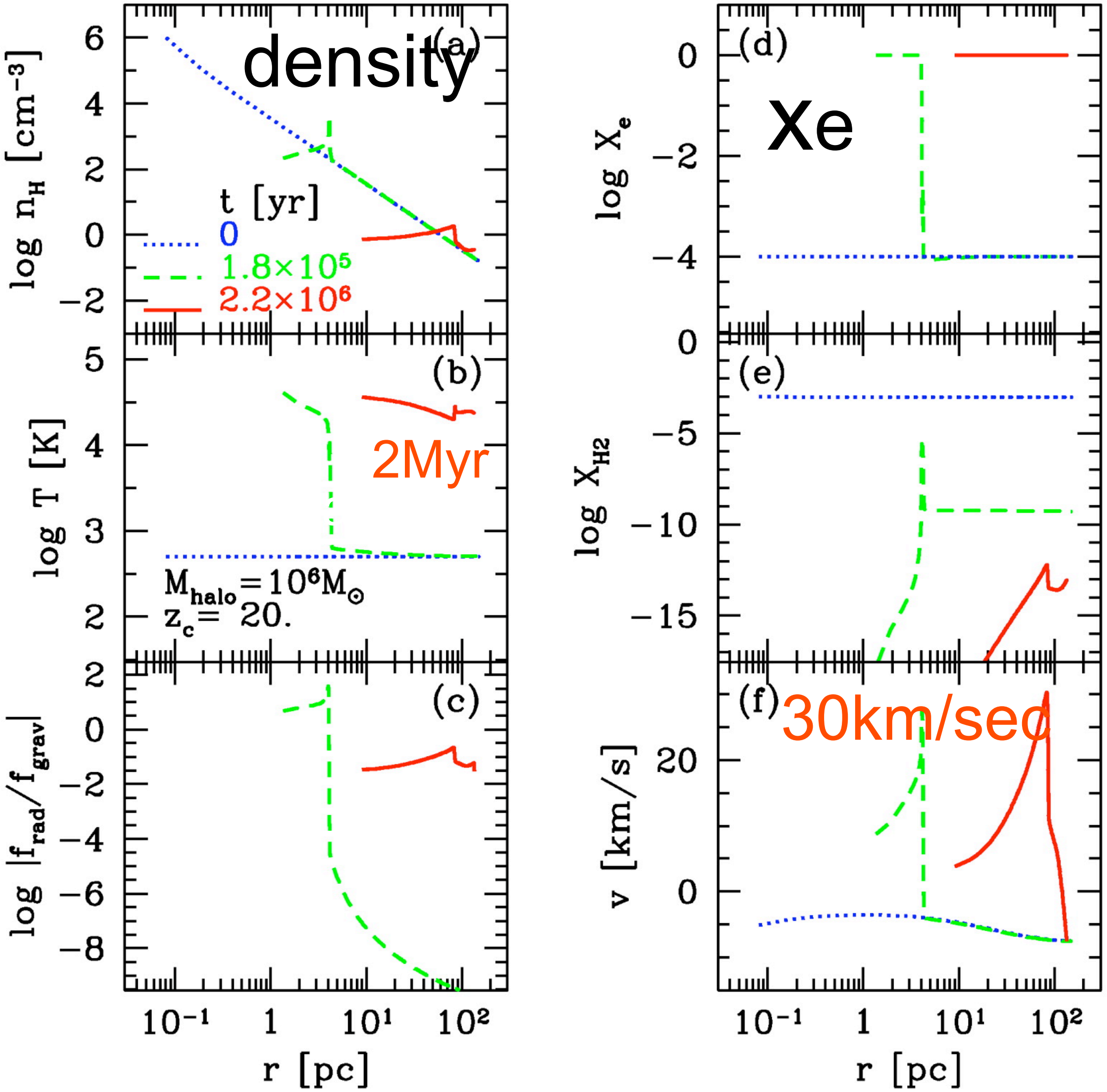


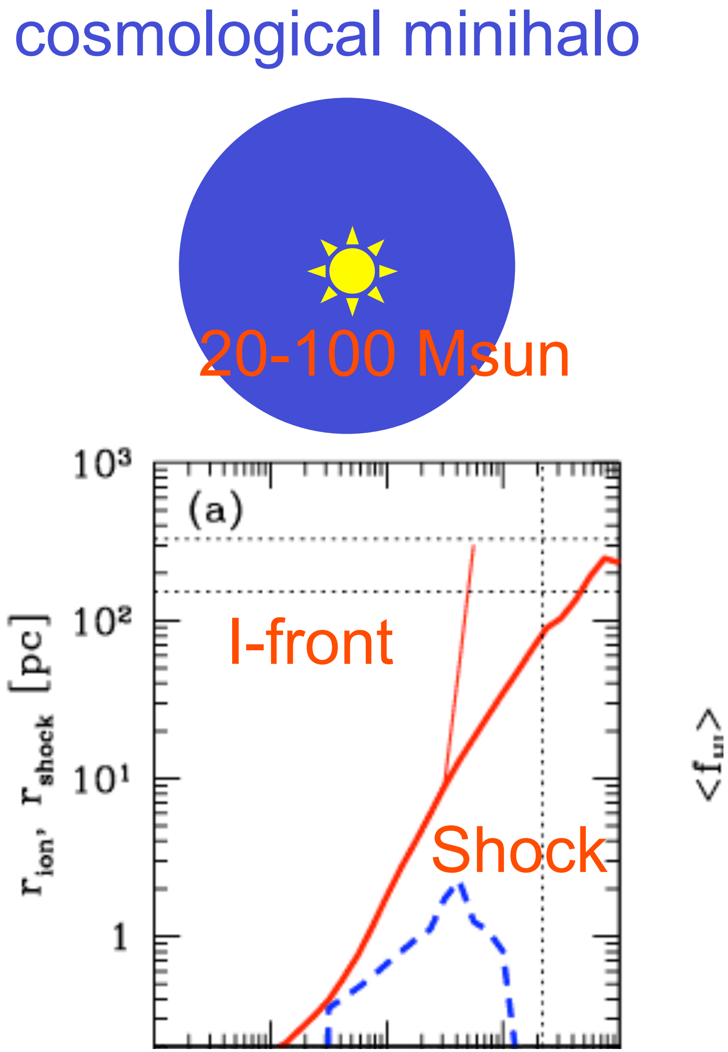


Halo mass evolution in CDM models



Feedback effect 1: Radiation

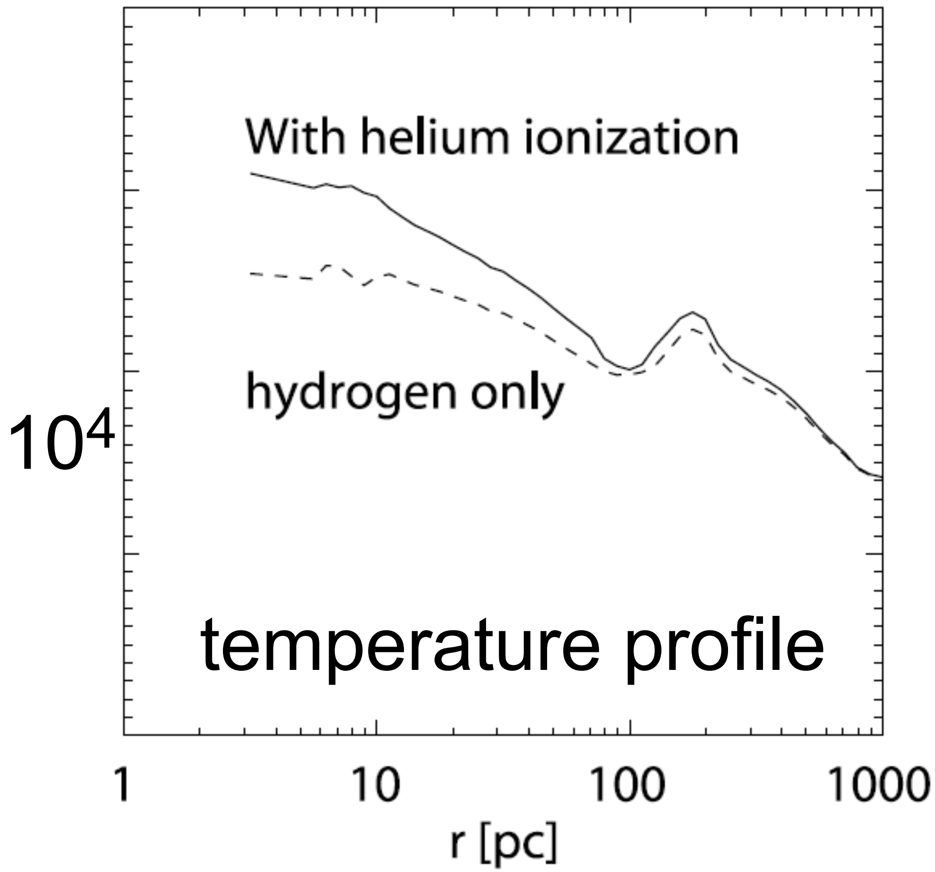


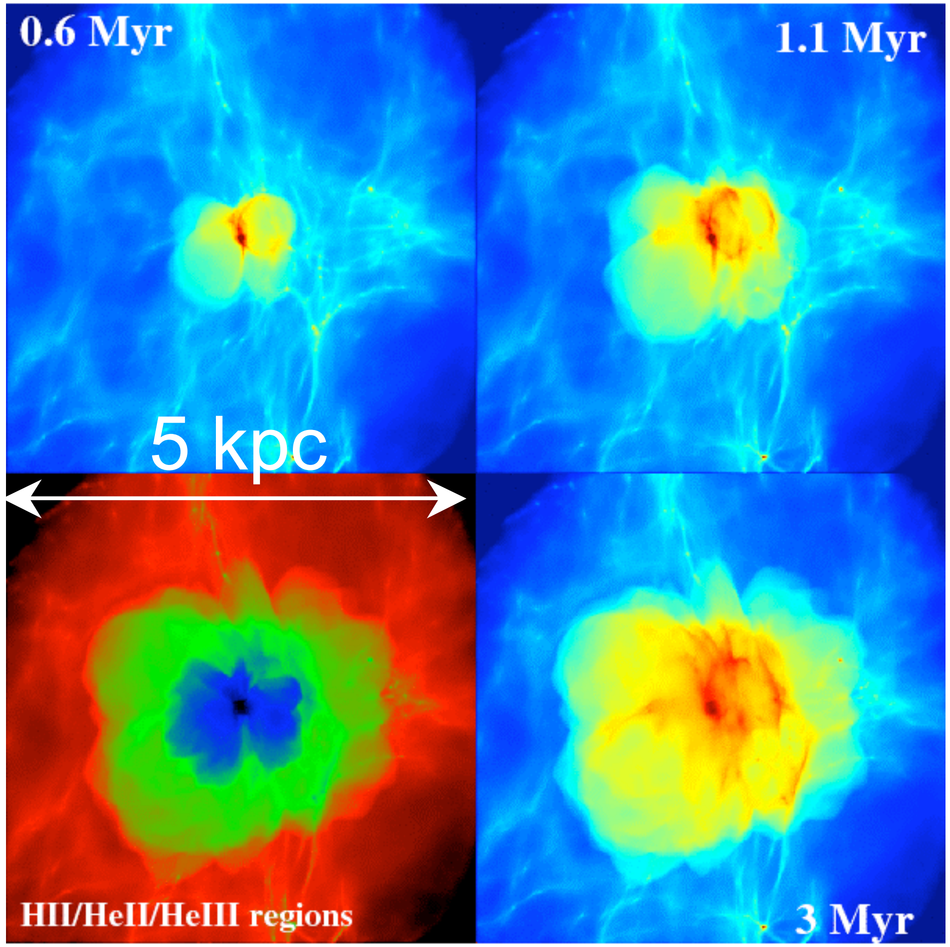


Radiation-hydro. sim. by Kitayama, NY, Susa, Umemura (2004, ApJ)

Early HII/HeIII region

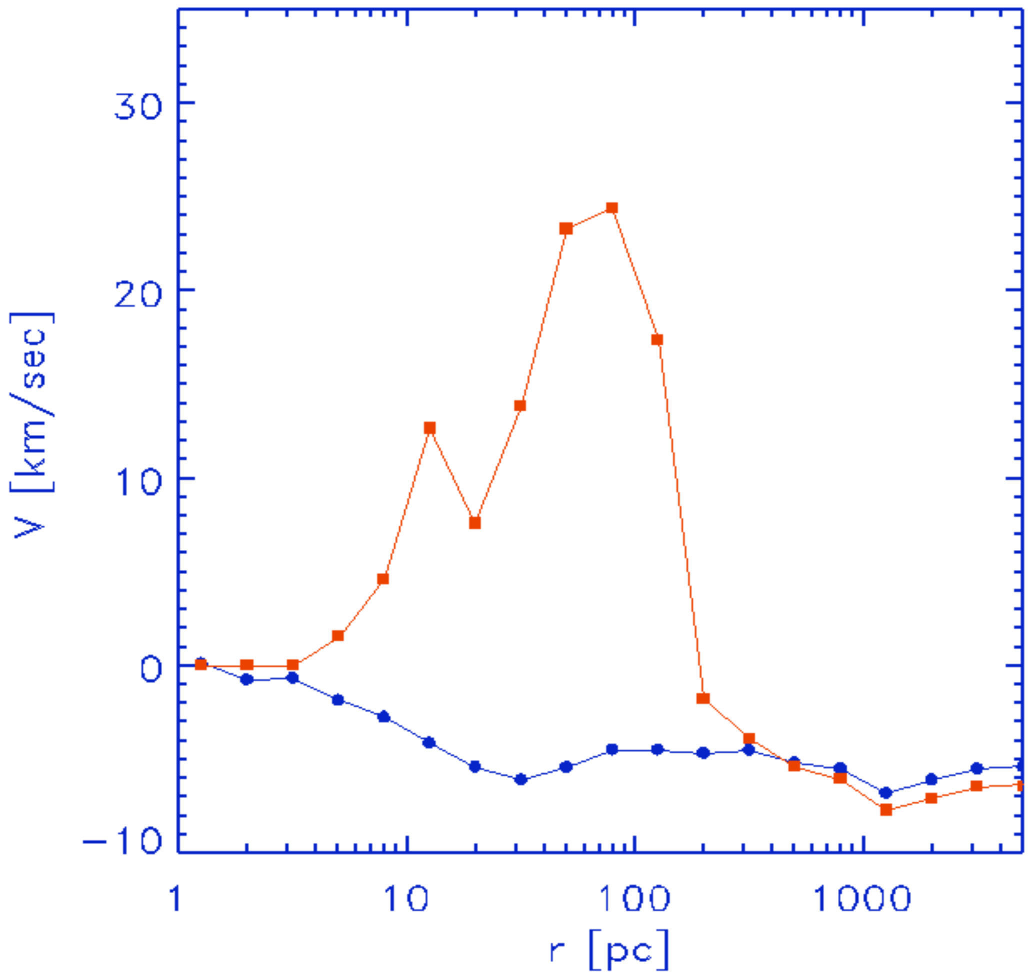
A massive primordial star heats the gas to > 10^4 K





NY, Oh, Kitayama, Hernquist (2007, ApJ)
Radiation-hydrodynamics calculation
See also Abel+07, Johnson+07, Whalen+07

Hot gas in a small halo
gone with the wind…



The photo-ionized gas escapes out at

V ~ 30 km/sec

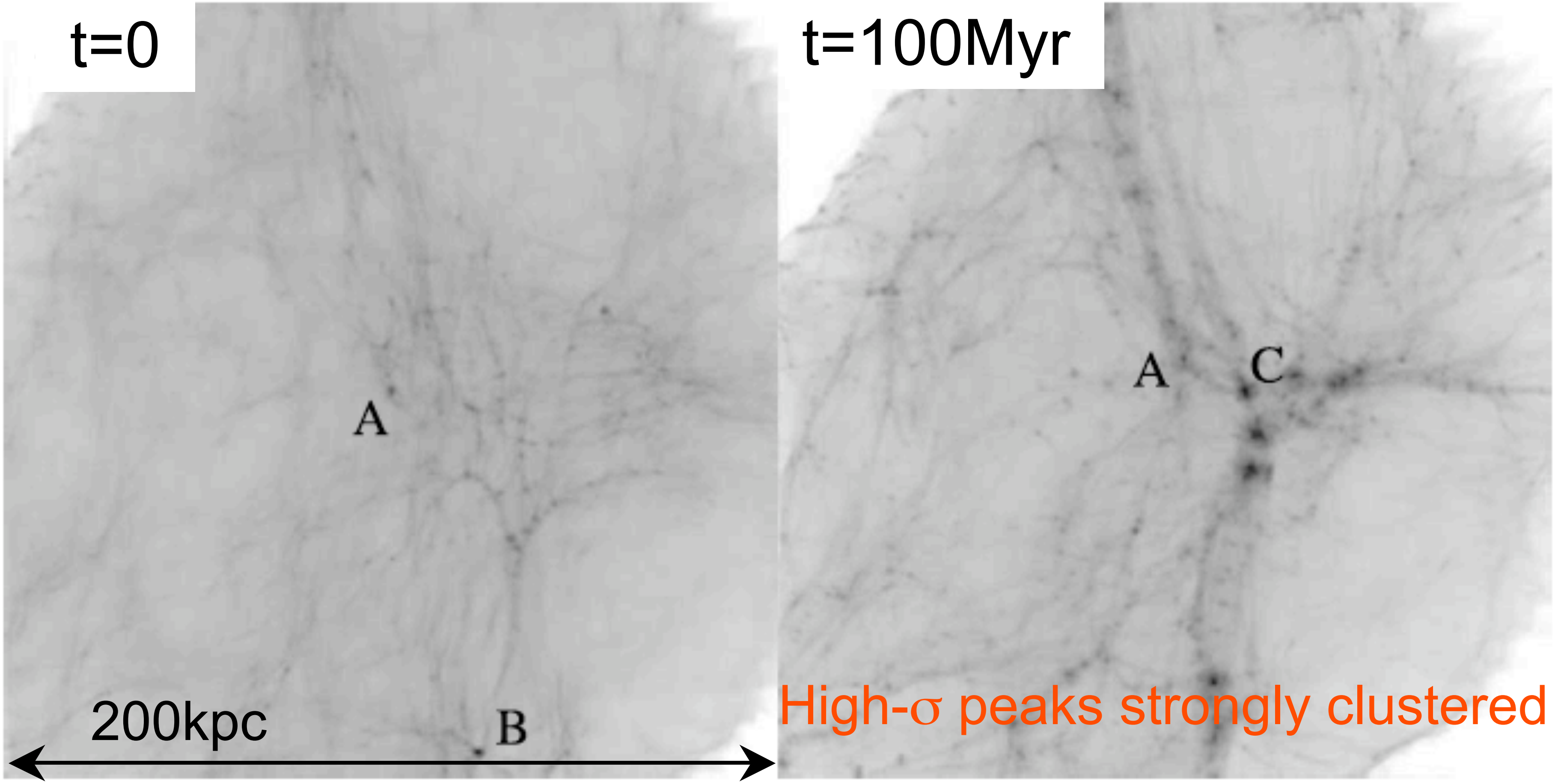
whereas the halo circular velocity is

Vc ~ 3 km/sec

= zero-baryon fraction in the end

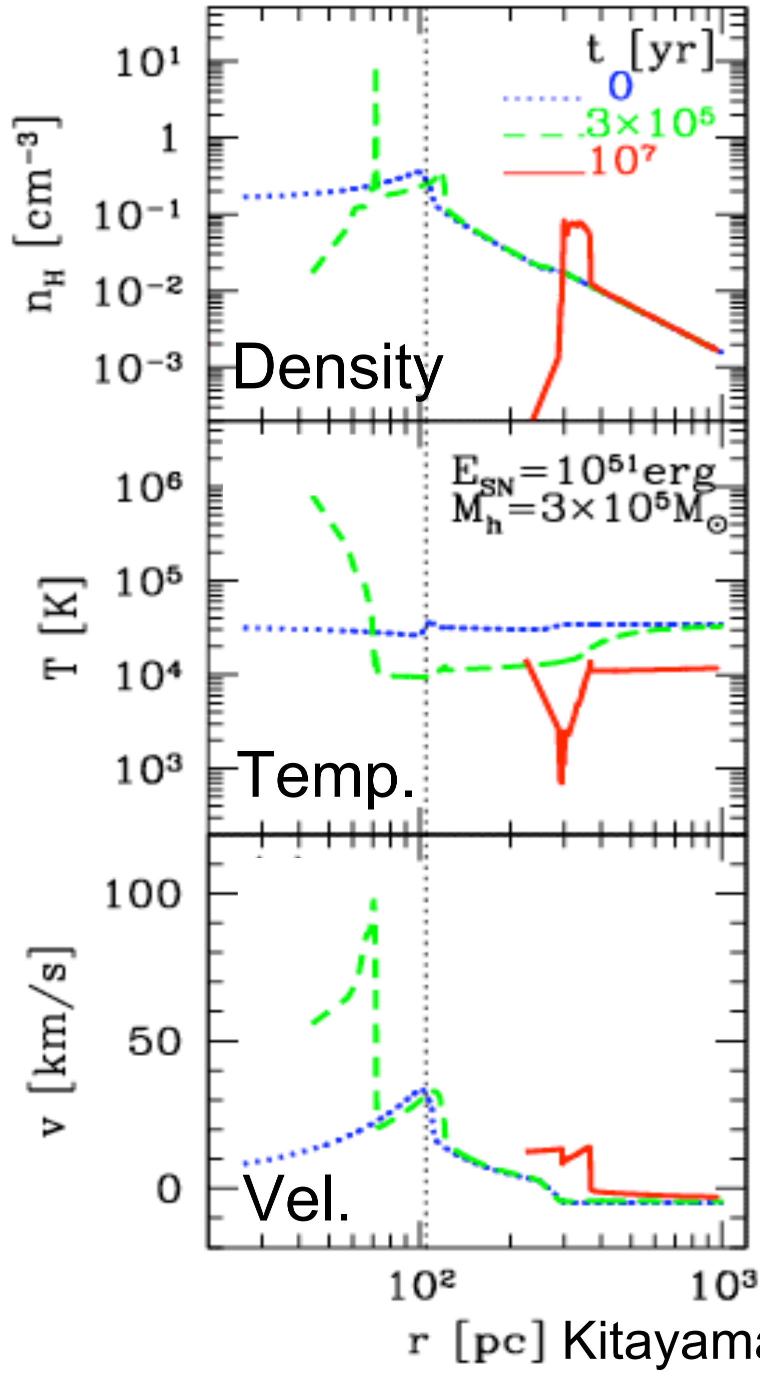
NY, Oh, Kitayama, Hernquist (2007, ApJ)

Evolution of dark matter density field



Gravitational potential gets deeper in time,
and eventually captures the outgoing gas, but …

Supernova feedback



Point explosion in a pre-existing cavity (HII region).

Even a single supernova (not star-burst) *completely destroys the host.*

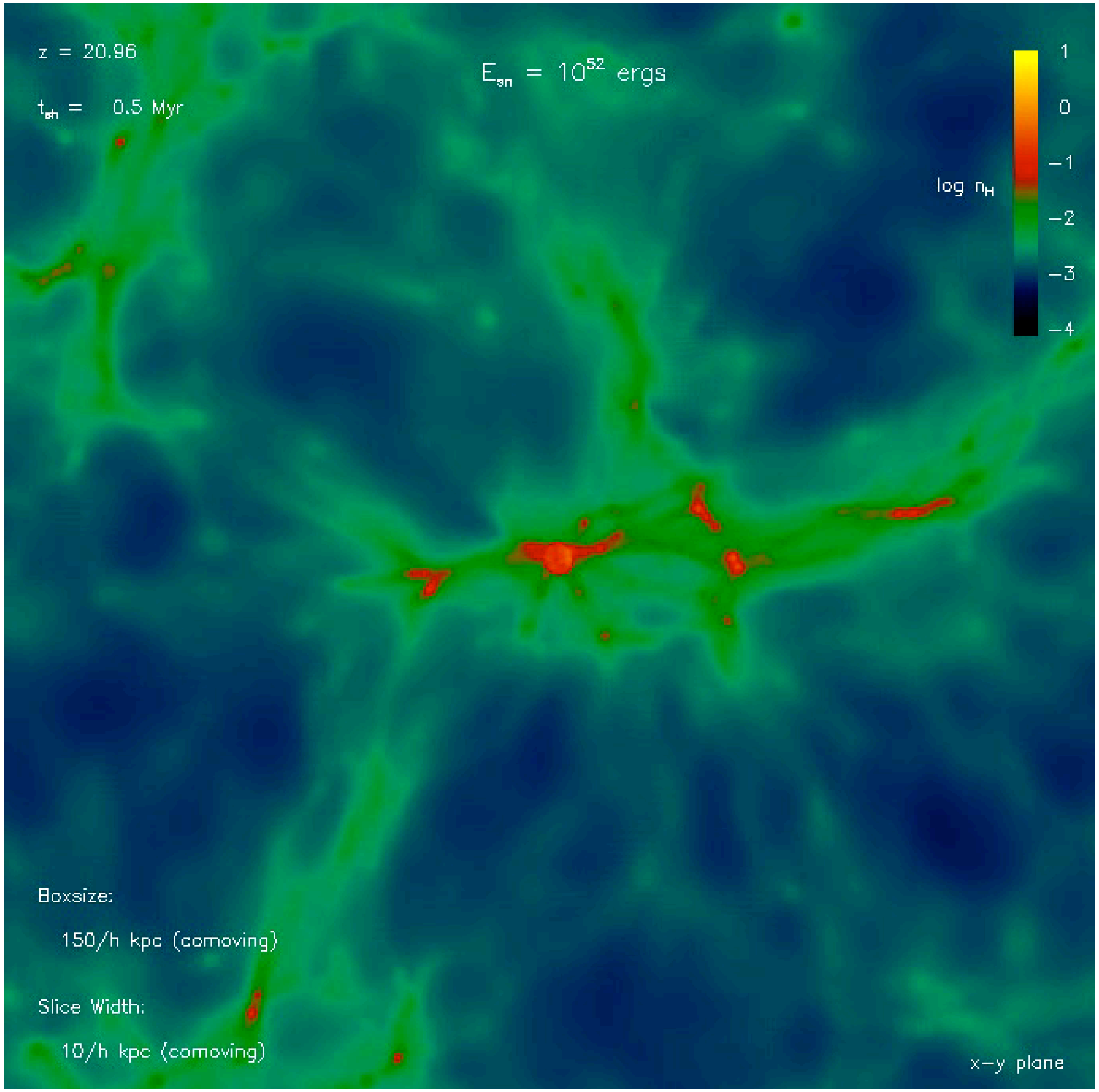
Gas velocity ~ 50-100 km/sec

SNR cools by brems, atomic line, and by Compton cooling (Sunyaev-Zeldovich effect).

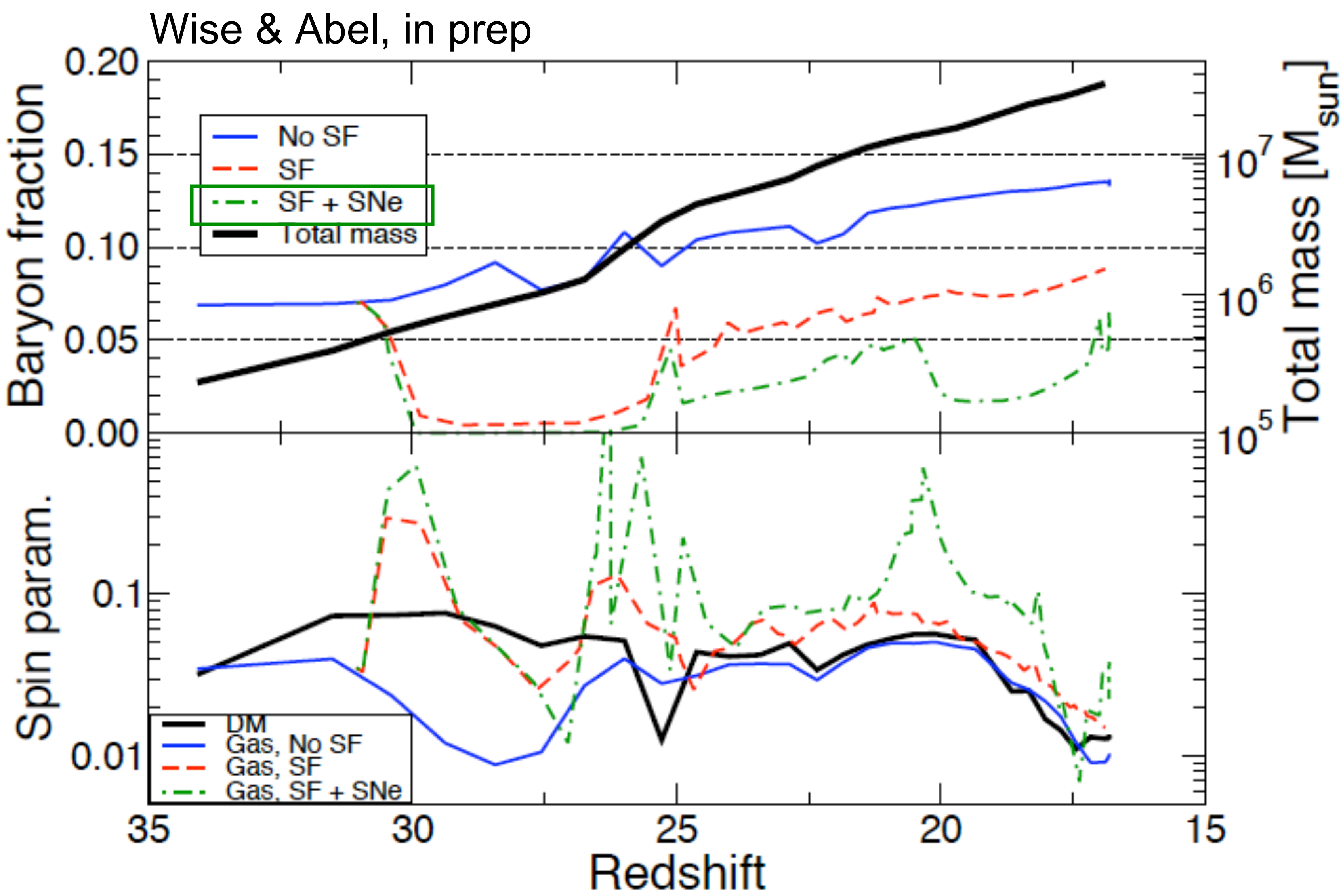
Kitayama & Yoshida (2005, ApJ)

Complete disruption of a halo

Simulation by Greif, Johnson, Bromm & Klessen (2007)

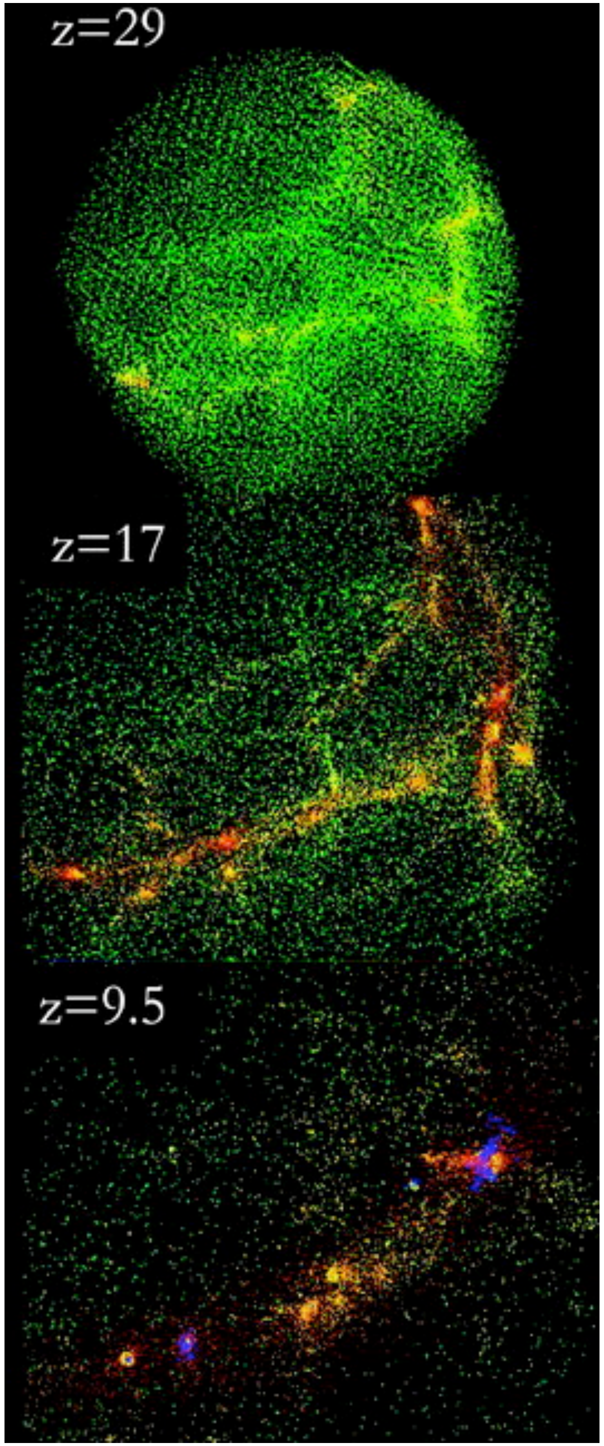


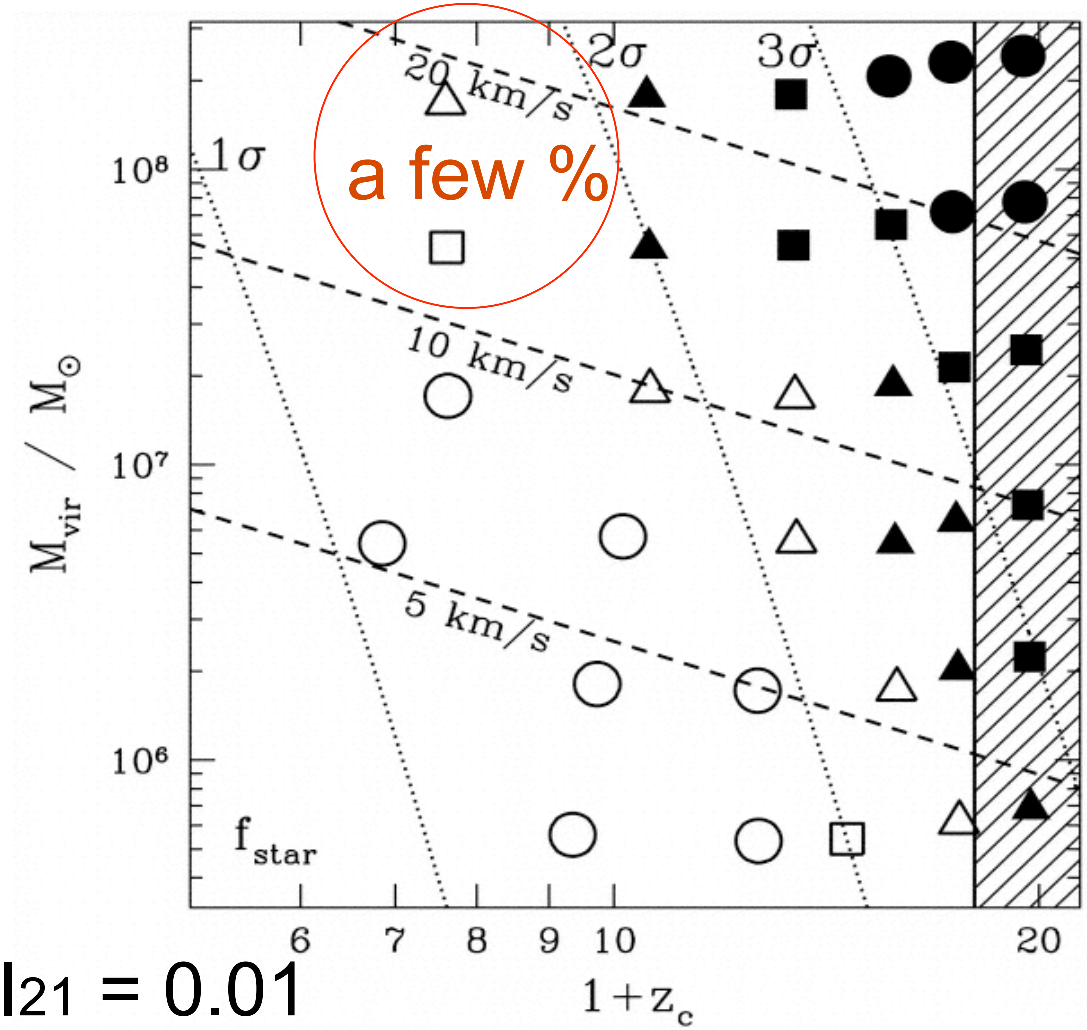
Re-incorporation of the gas



Irradiation by cosmic UV background

Simulation by Susa & Umemura (2004)



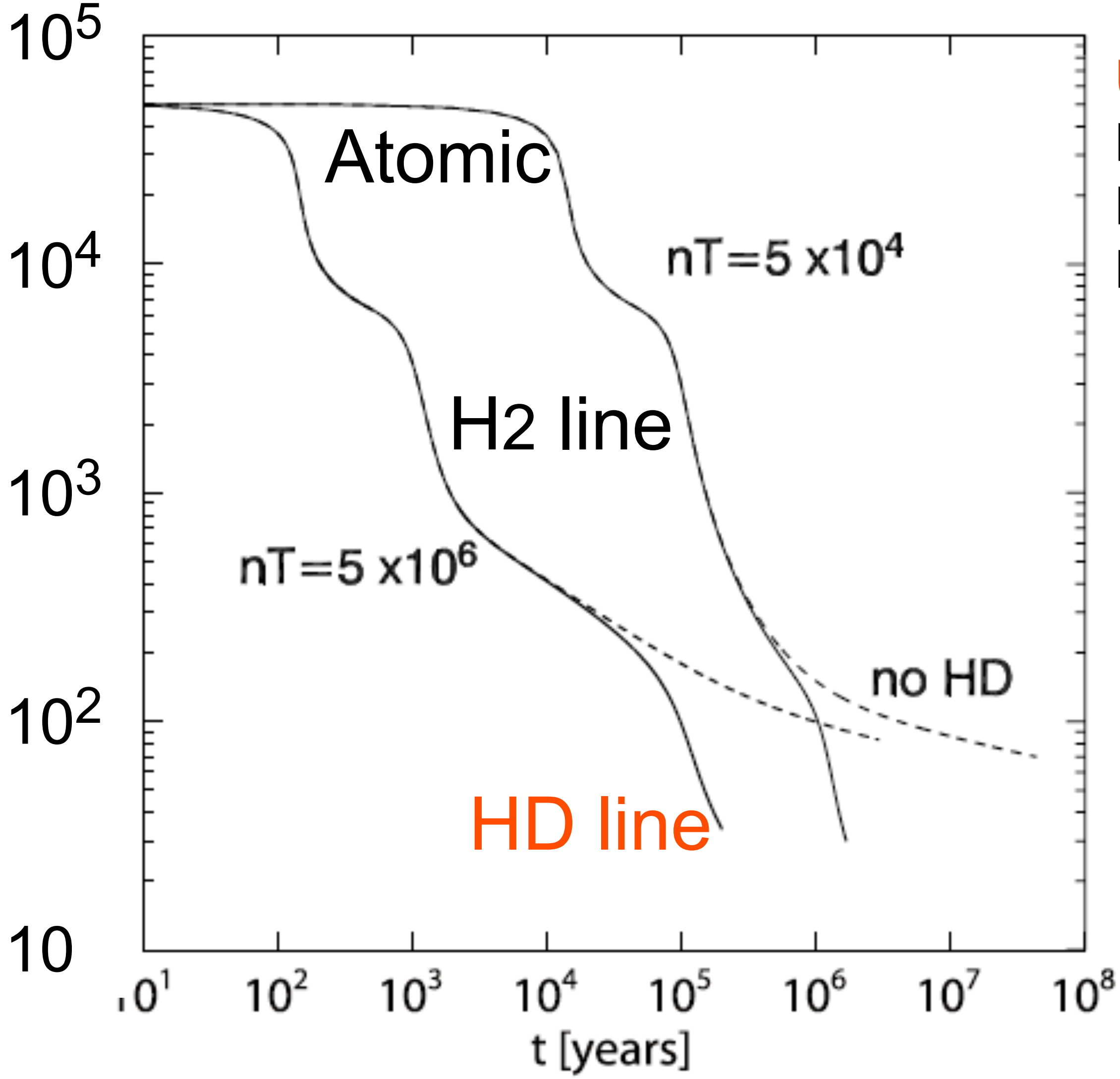


I_{21} = 0.01

Formation Part

SF in a re-ionized gas: cooling

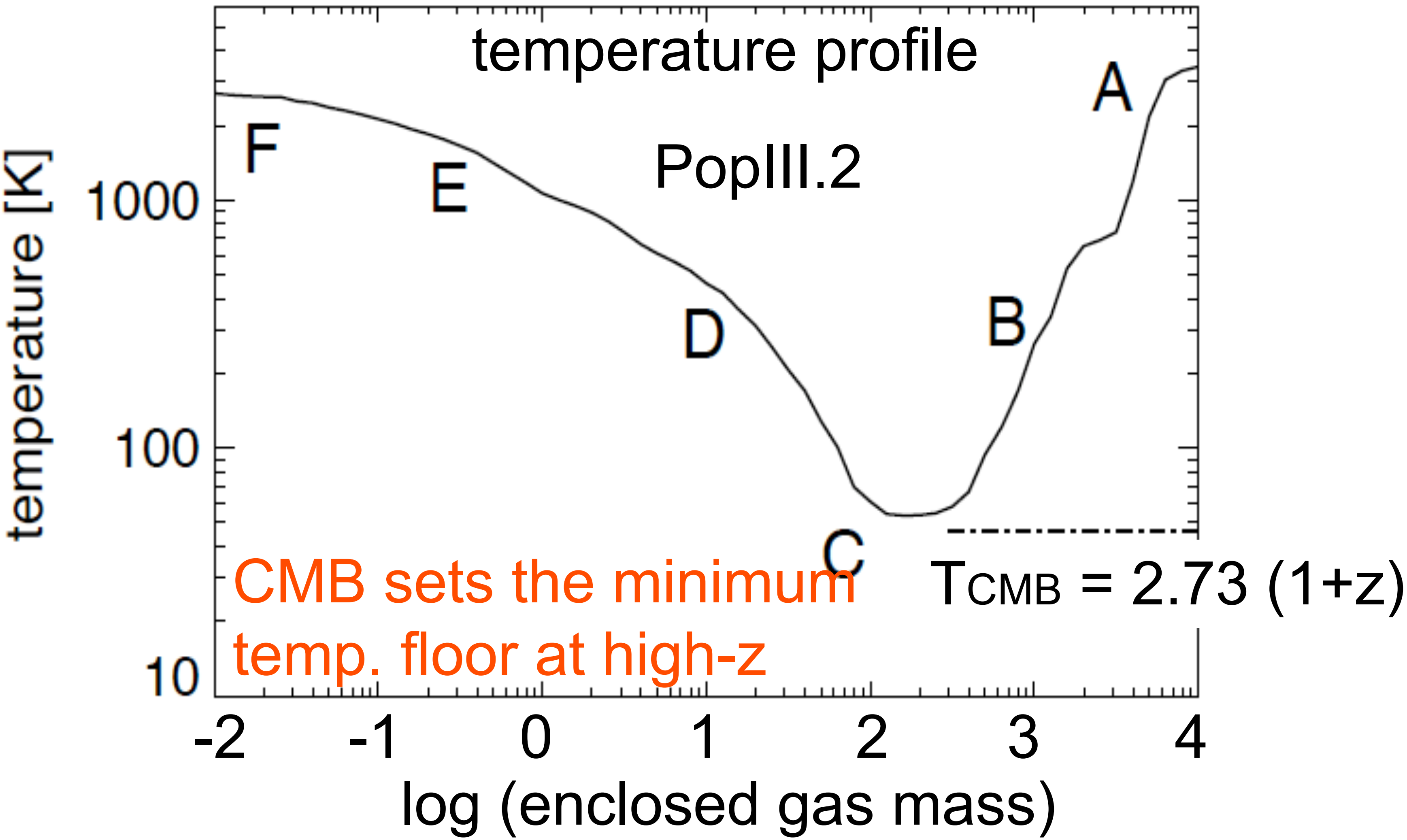
Temperature evolution of an isobarically cooling gas



Uehara & Inutsuka (2000)
Nakamura & Umemura (2002)
Nagakura & Omukai (2005)
NY, Oh, Kitayama, Hernquist

HD cooling brings the gas temperature to a few 10 K even without metals

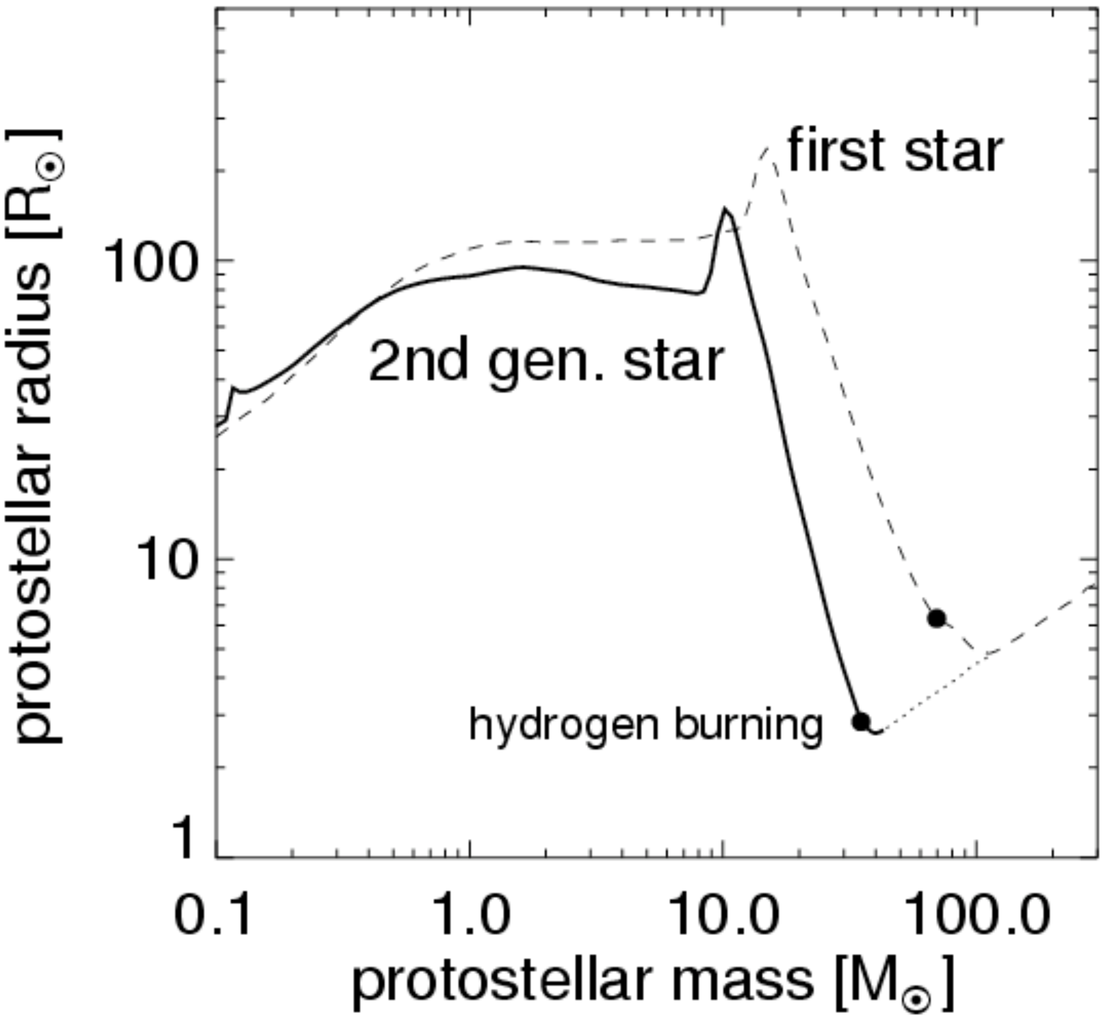
SF in a re-ionized gas: cloud structure



NY, Omukai, Hernquist (2007, ApJL)

SF in a re-ionized gas: proto-stellar evolution

NY, Omukai, Hernquist (2007, ApJL)



Envelope has a low T

Parent cloud mass
~ 40 Msun
(smaller at lower z)

M_{ZAMS} ~ 40 Msun

Conclusions

It is well-known that stellar feedback effects
(radiative, supernova) are strong in low-mass systems.
At (very) high-z, even a single star can affect significantly
by reducing the host halo's baryon fraction to
a few percent level for/over a Hubble time.

SF in proto-galaxies are inefficient under
a cosmic UV background at z>6. (c.f. galactic satellite)

Primordial stars in a reionized gas are likely massive
(rather than very massive).
CMB plays a role in SF@high-z!
Metals won't affect much unless dust exists.