Searching for the First Stars

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Searching for the First Stars

I: Searching for Primordial Galaxies

w/ Raffaella Schneider (Arcetri), Andrea Ferrara (SISSA)

II: Searching for the first SNe

w/ Alex Heger (Los Alamos), Stan Woosley (UC Santa Cruz),
Piero Madau (UC Santa Cruz), Andrea Ferrara

III: Searching for Their Signatures Today

w/ Daisuke Kawata (Carnegie) Chris Brook (Laval),
Brad Gibson (Lancashire), Andrea Ferrara, Raffaella Schneider

Little bit of notation

Primordial => Z=0

Population III ? = ?

1. Z = 0
2. $Z < Z_{crit} = 10^{-4}$ solar
3. Cool via Molecular Hydrogen

“First Galaxies”

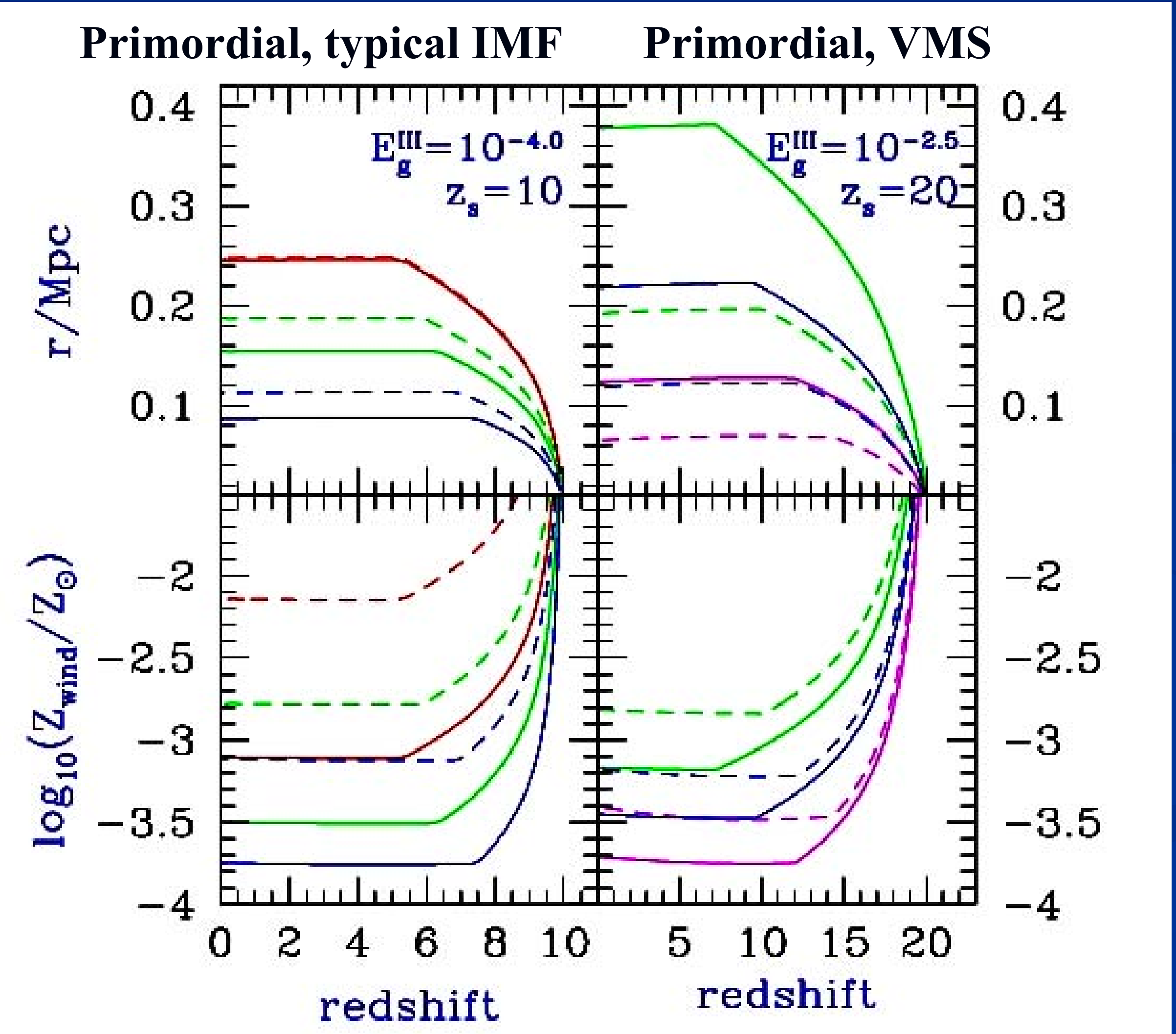
$T_{vir} \geq 10^4$ K, masses >~ $10^8\ M_{sun}[(1+z)/5]^{-3/2}$

• Oh & Haiman 2002: Such large primordial halos with first cool by Lyα into a disk, but would begin to form H_2 , thus a similar story may hold as in the smaller objects.

• Going to assume that the same story holds for all primordial ($Z < Z_{crit}$) objects, regardless of mass.

Method I: Search for Primordial Galaxies

ES, R. Schneider, A. Ferrara (2003)

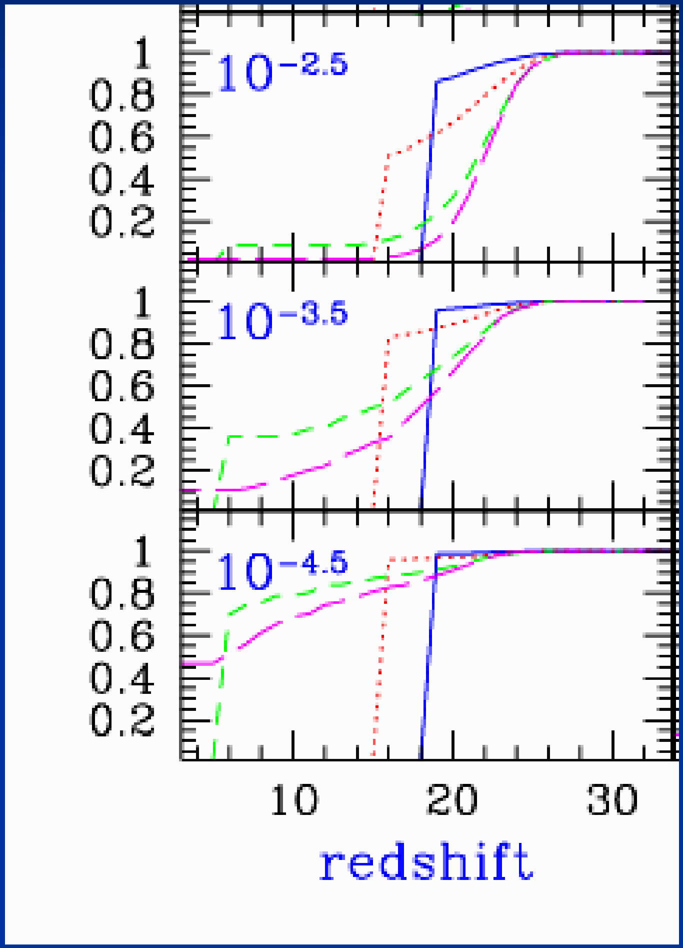


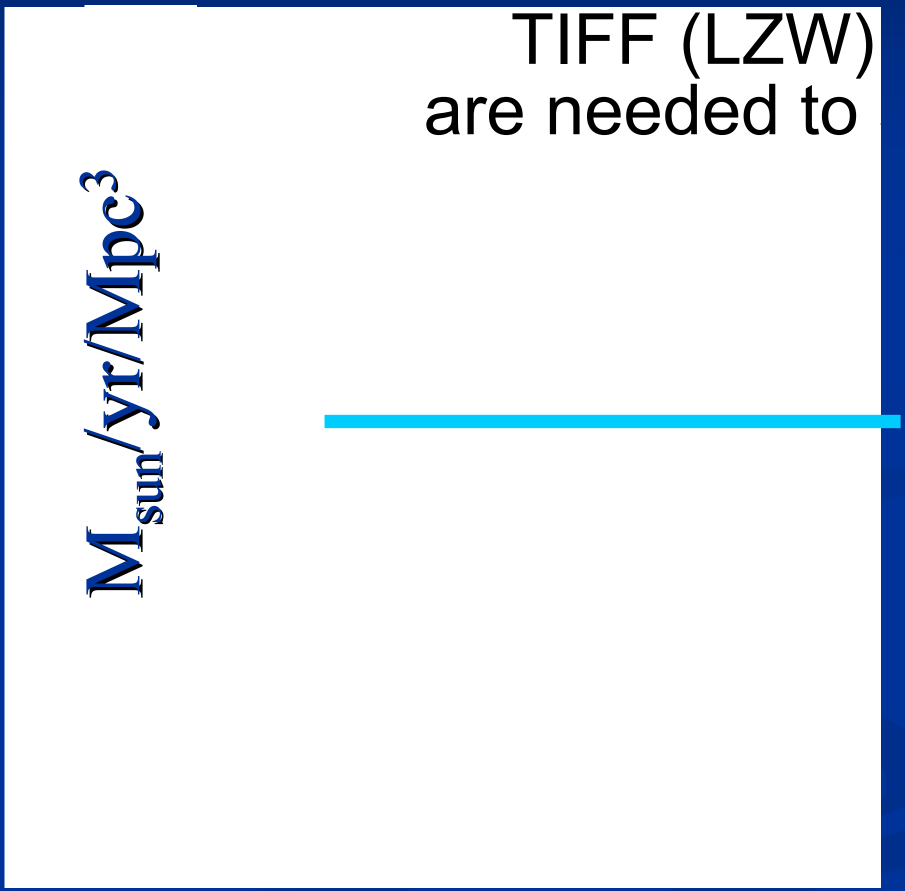
E_g = Kinetic Energy / Baryon Mass into Stars

10^9 M_{sun} 10^8 M_{sun}
10^7 M_{sun} 10^6 M_{sun}

Z/10^{51} erg ~ 2, SNeII, SNeγγ

Chemical Feedback

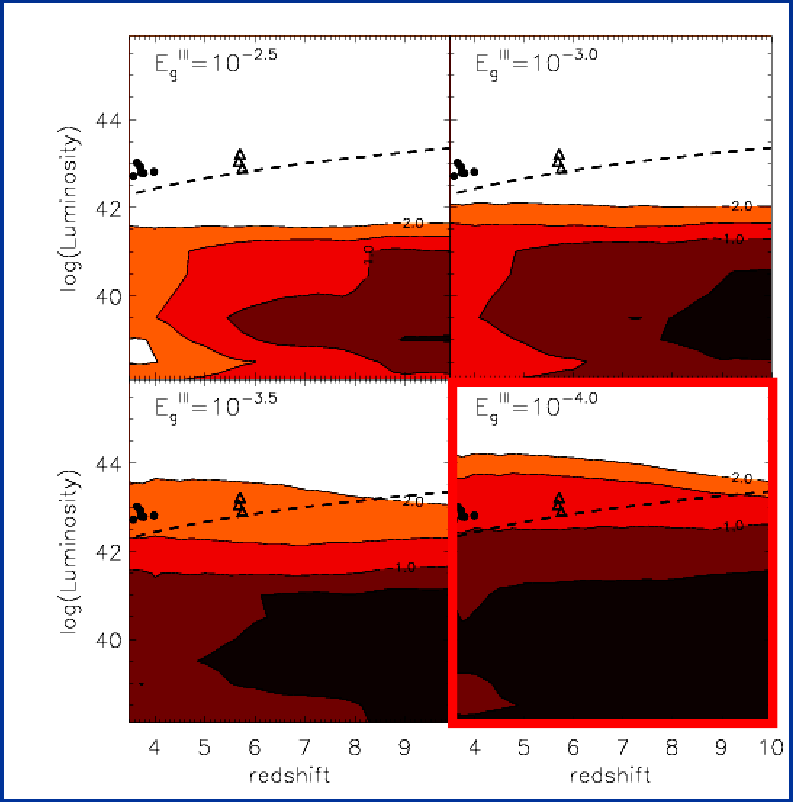




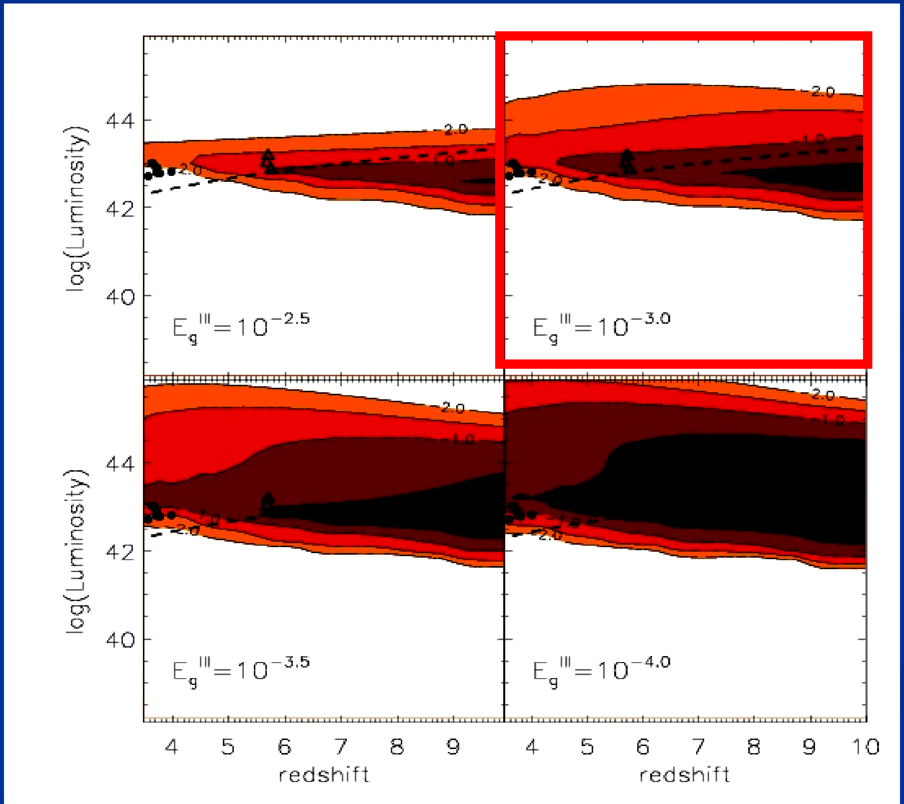
ES, Schneider, Ferrara (2003)

Observability

Lyman-Alpha Detection Probability



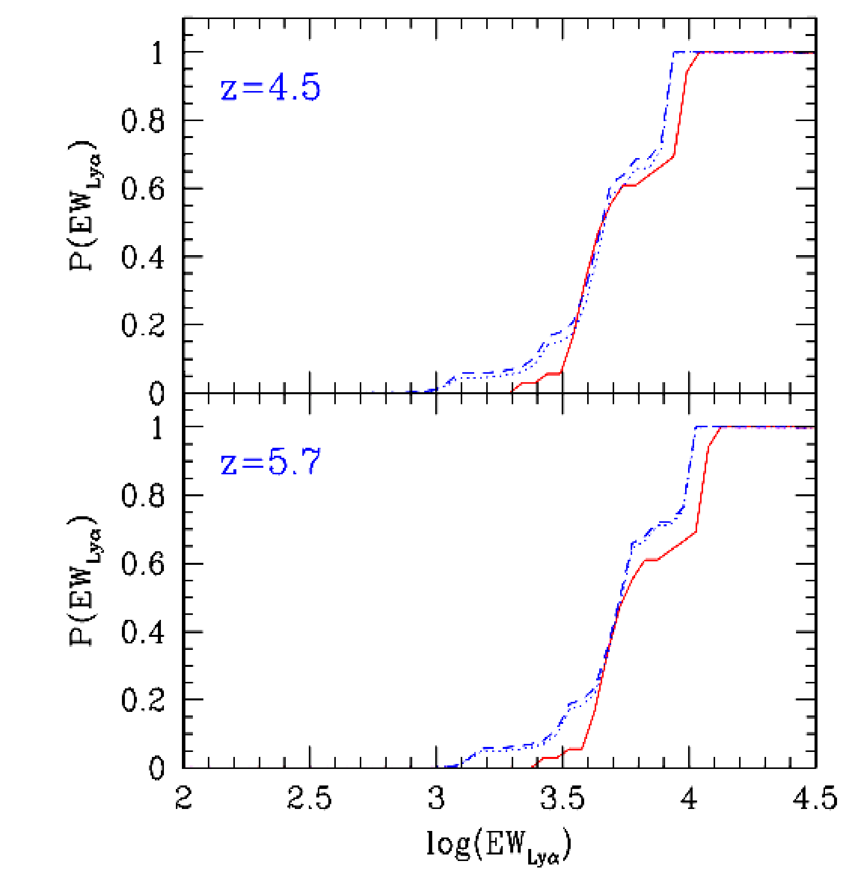
Primordial, typical IMF



Primordial, VMS

Very massive or not, Z=0 stars are hot

High EWs



ES, Schneider, Ferrara (2003)

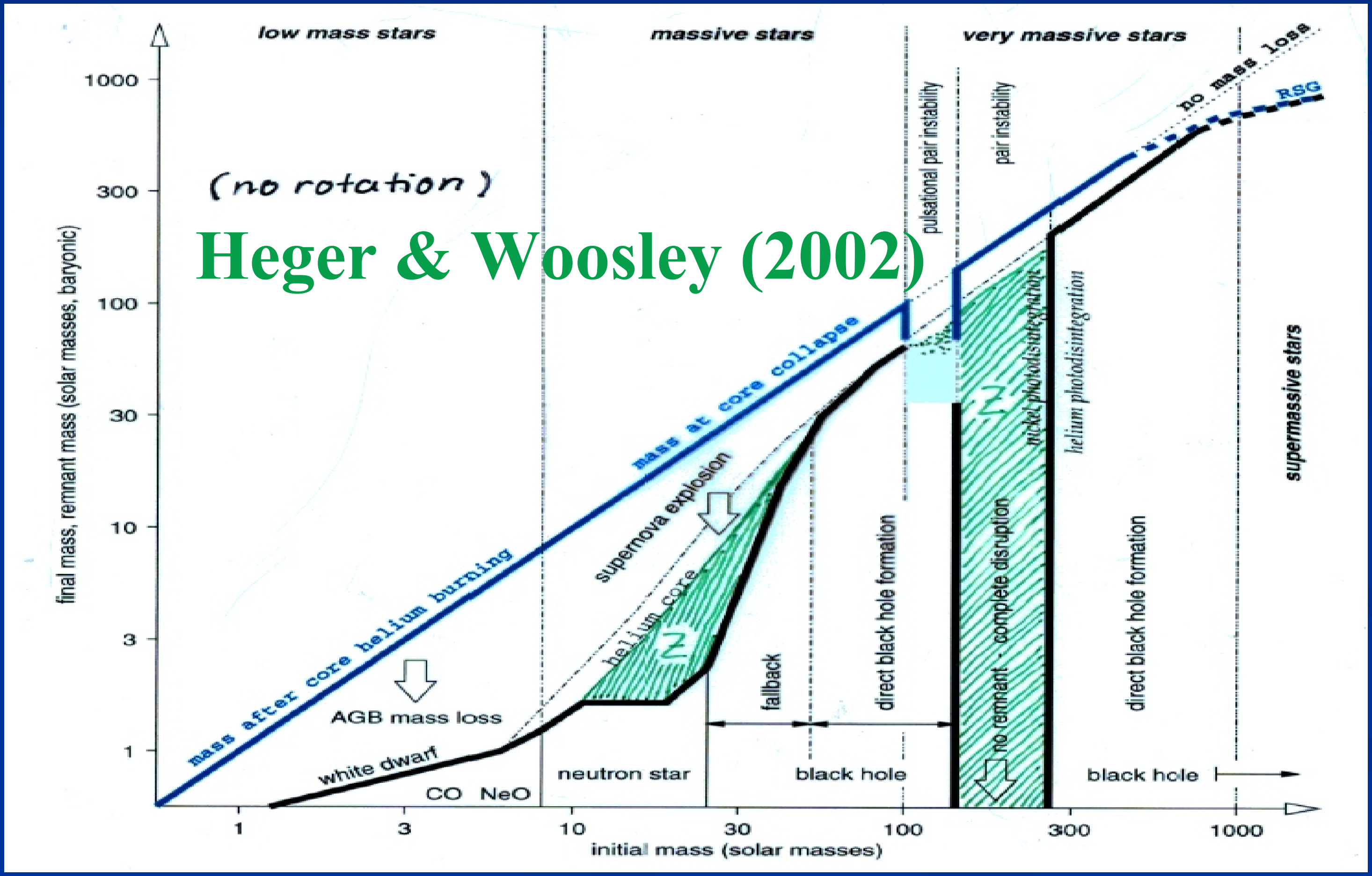
HeII lines

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Tumlinson, Shull, Venkatesan (2003),
See also Schaerer (2003), Oh, Haiman, & Rees (2001)

Method II: Search for their SNe

ES, P. Madau, S. Woosley, A. Heger, A. Ferrara (2005)



Pair Production Supernovae


γγ->e+e-
H/He

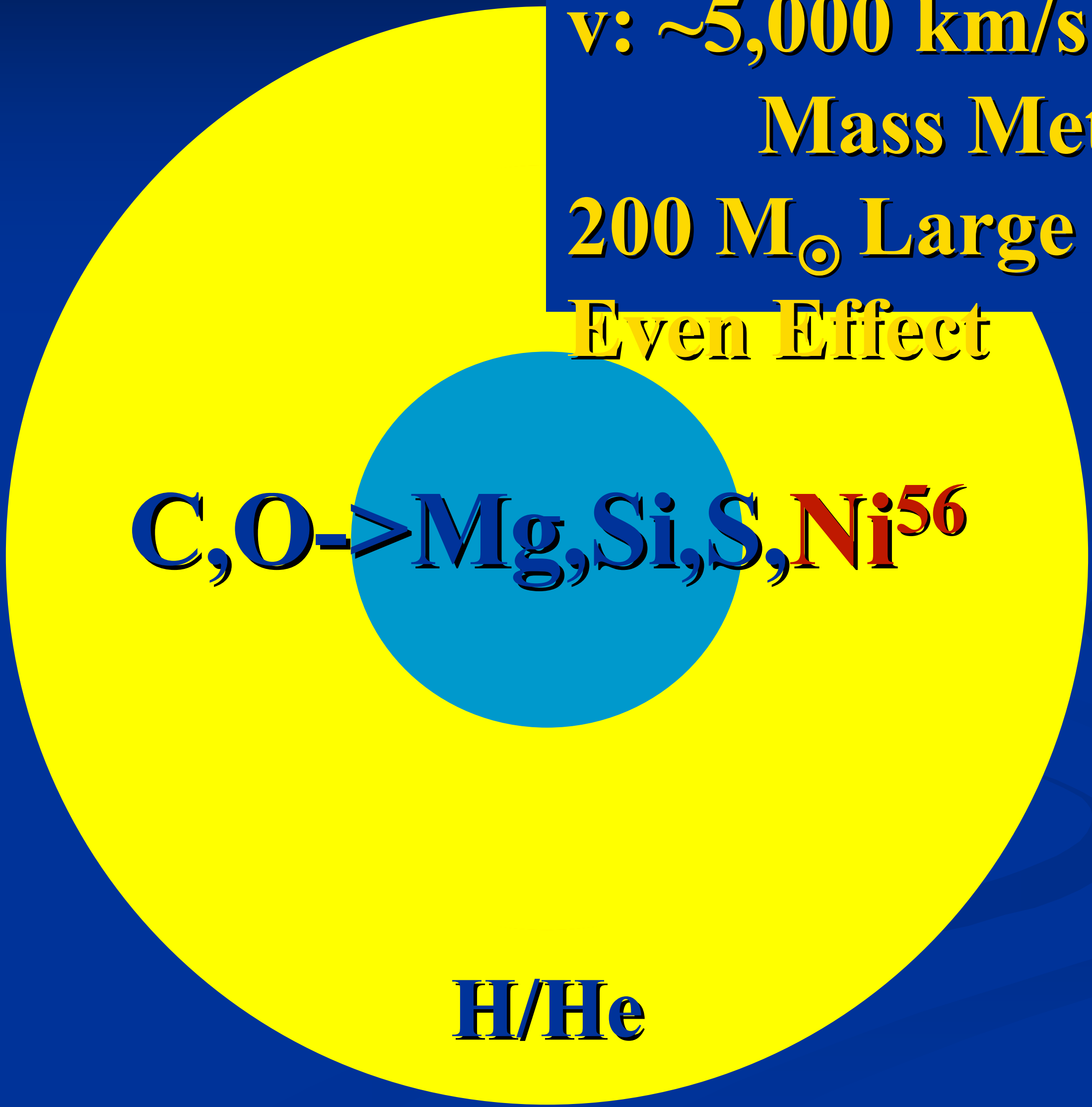
Quick Facts:

E_{kin}: 10-100x10^{51} ergs

Mass: 140-260 $M_{\odot}$

v: ~5,000 km/s

Mass Metals: 20-200 $M_{\odot}$ Large Odd-Even Effect



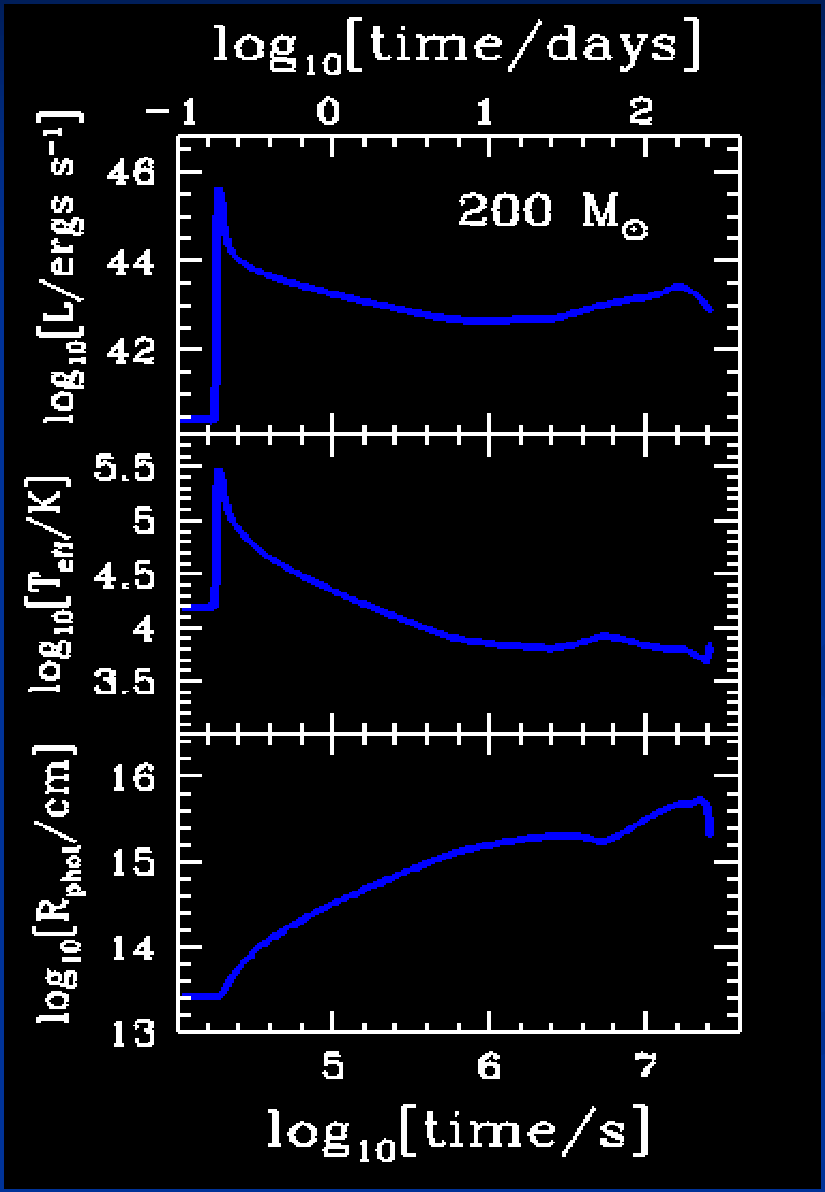
What do PPSNe look like?

ES, P. Madau, S. Woosley, A. Heger, A. Ferrara (2005)

Kepler, implicit (1-D) hydrodynamic code

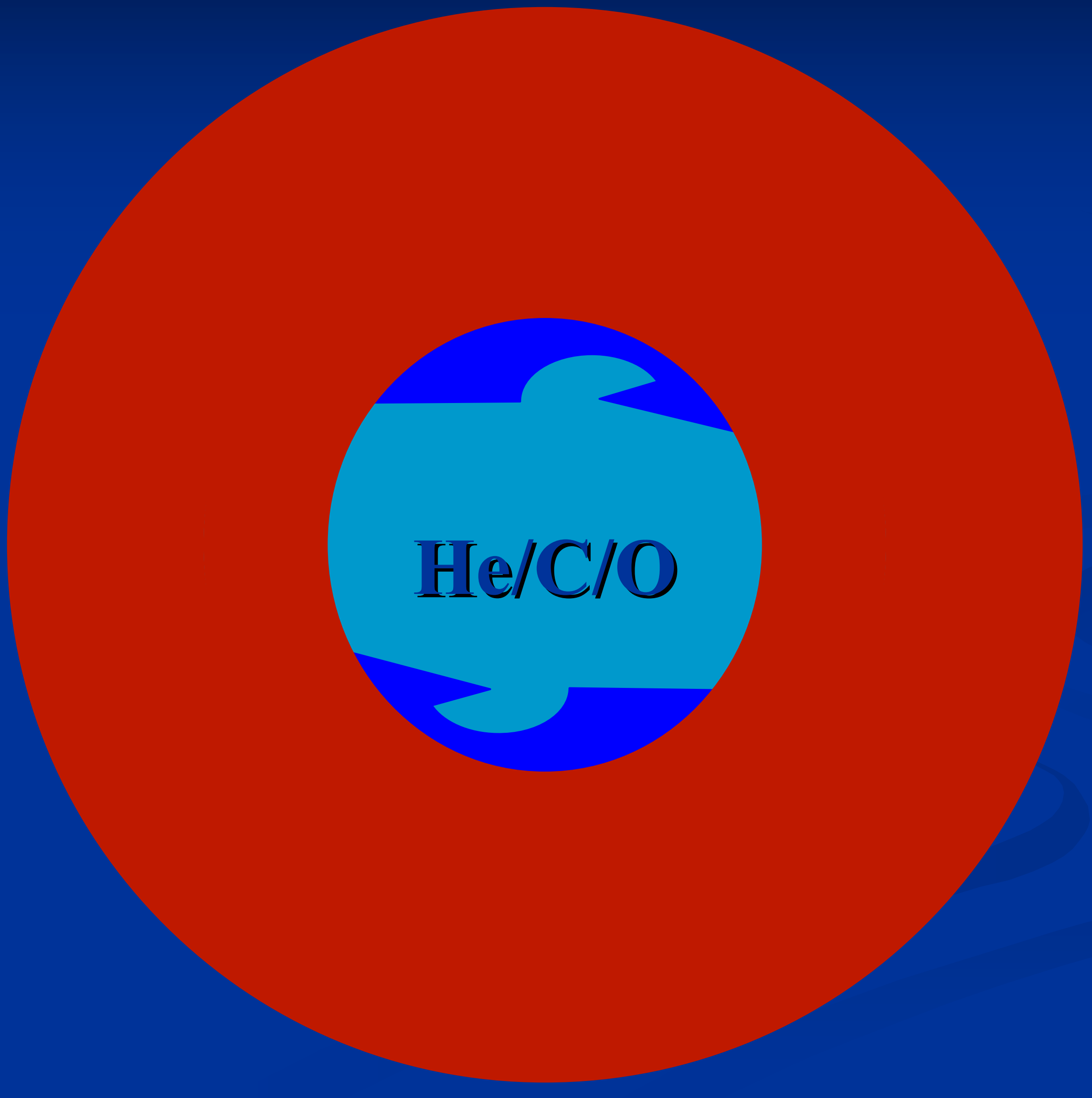
Single-temperature radiative diffusion, grey opacity. Includes radioactive decay.

PPSN Evolution

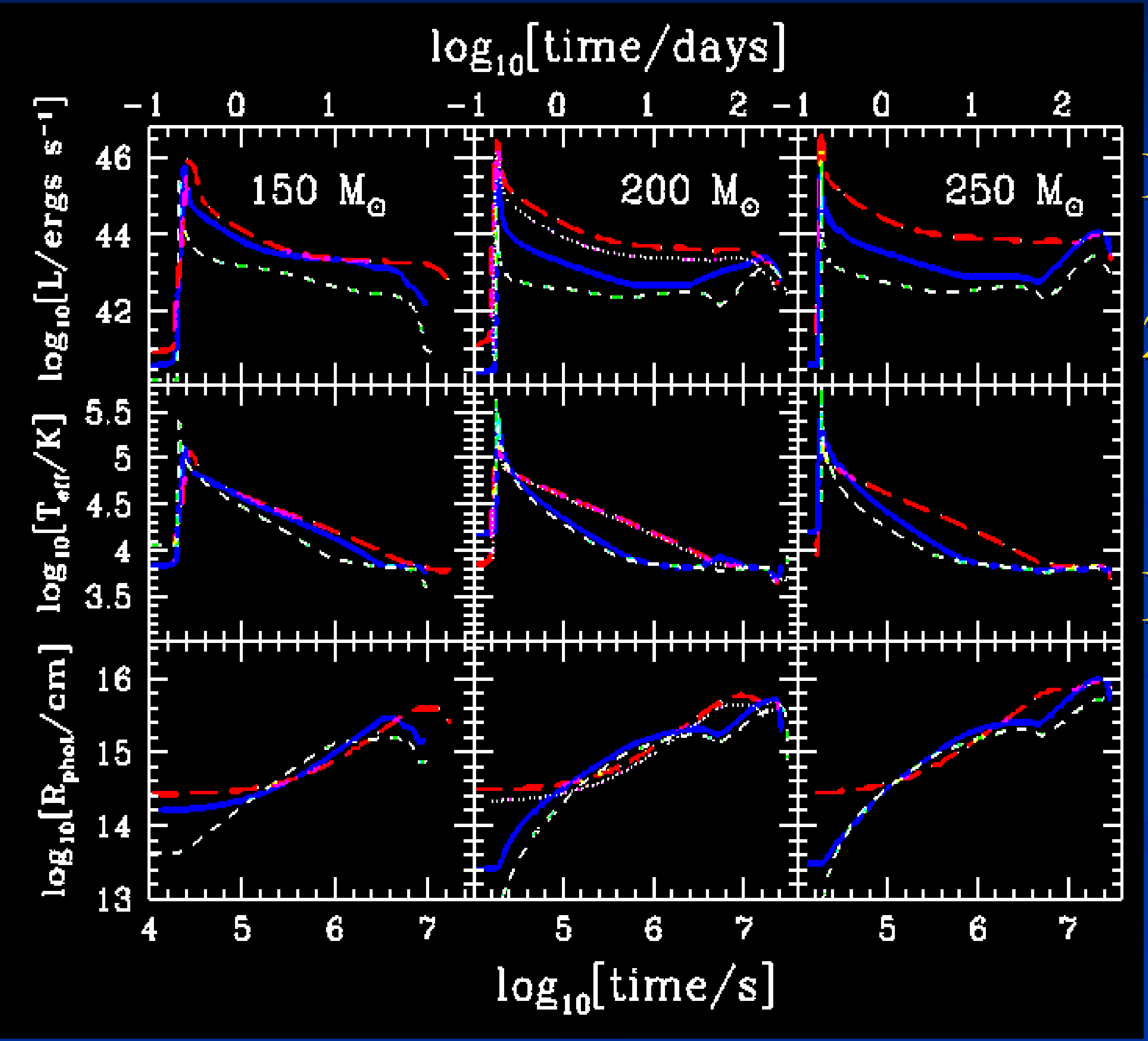


1. Breakout
2. Adiabatic Expansion + H recombinations
3. Ni^{56} decay
4. Becomes optically thin


He/C/O
H/He


He/C/O

PPSN Evolution

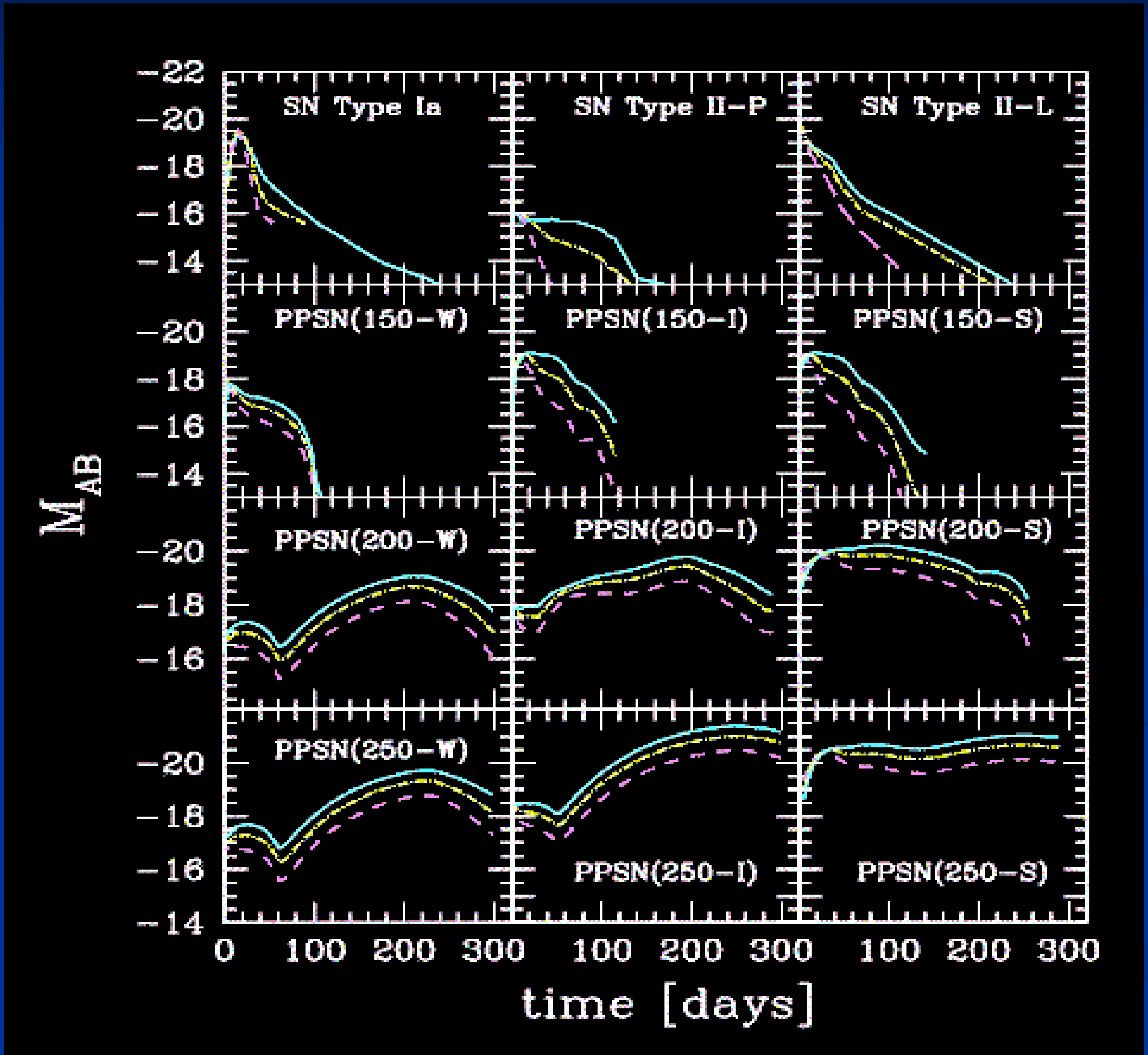


Dependent on:

1. Progenitor Size
2. Ni^{56} Mass

Mixing is key

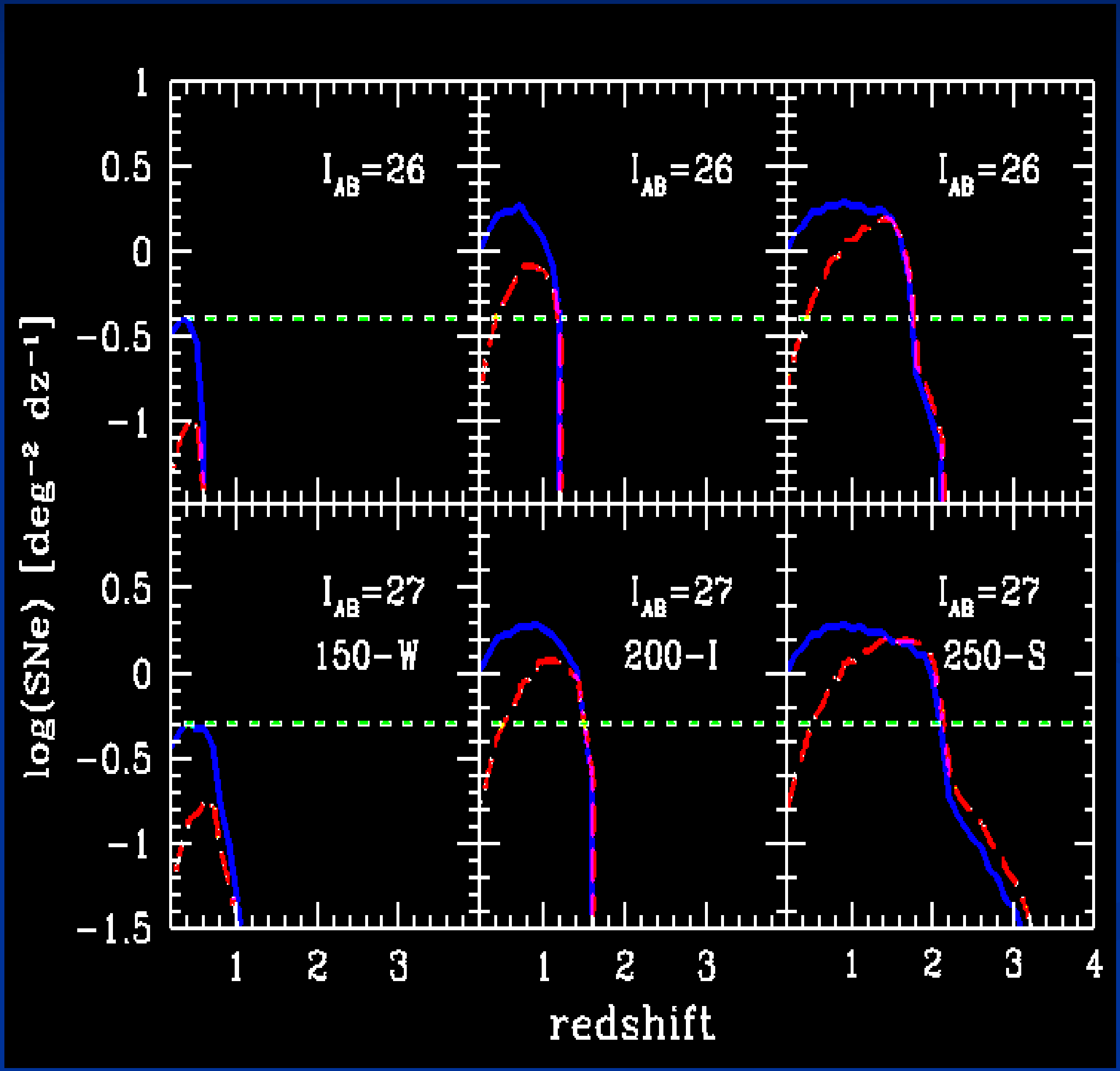
PPSN Lightcurves



V-band, B-band, U-band

1. **Not Always Brighter**
2. Long Evolution Times
3. Hydrogen

Visible PPSNe: I-band



$0.01\ M_{sun}/yr/Mpc^3$

$0.01 \times SFR_{obs}$

IfA Deep Survey:

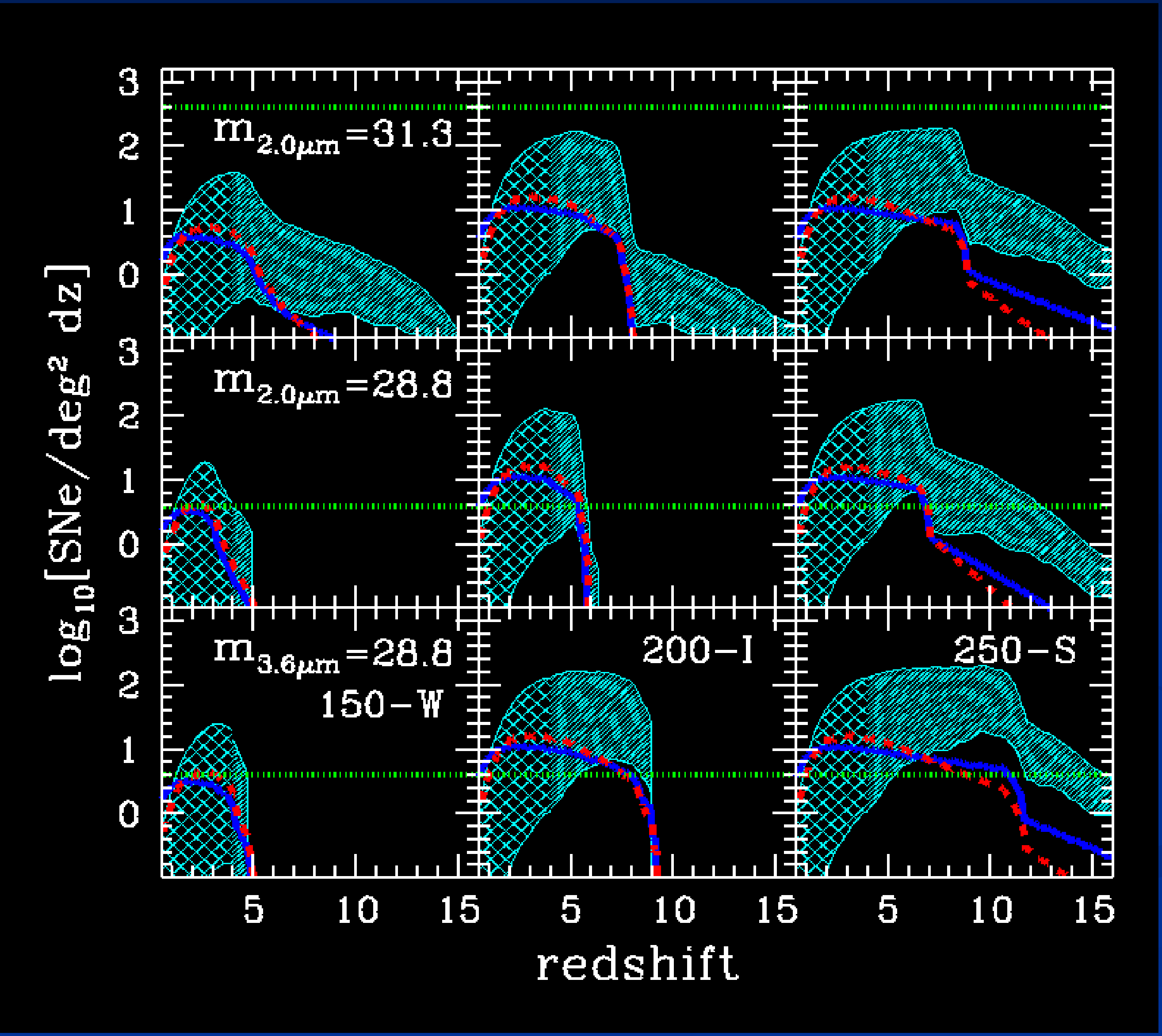
$I_{AB} > 26$, 2.5 deg^2

COSMOS:

$I_{AB} > 27$, 2 deg^2

(general survey)

Visible PPSNe: NIR



JWST Detections

$0.01\ M_{sun}/yr/Mpc^3$

$0.01 \times SFR_{obs}$

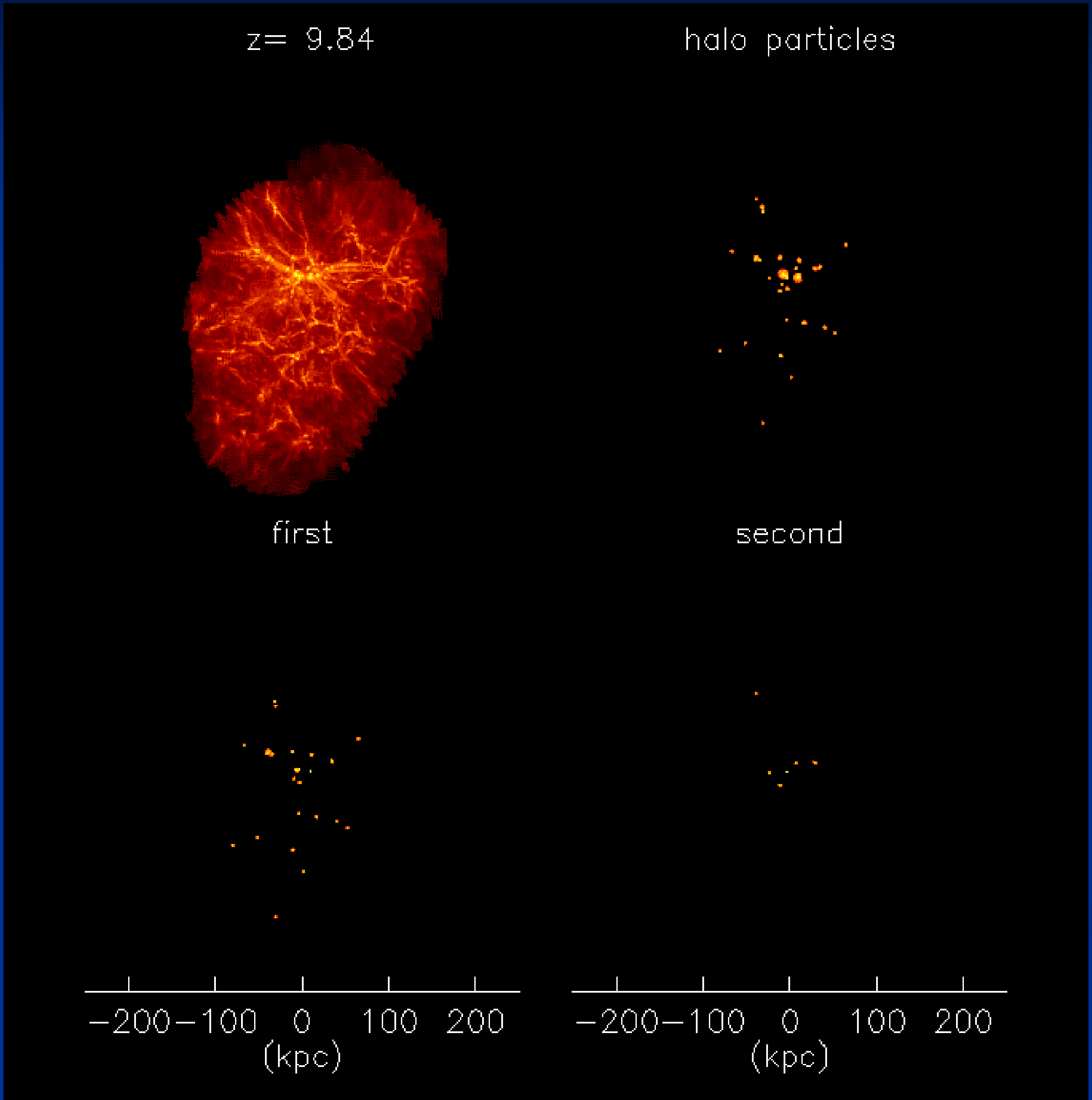
Method III: Search for Their Signatures Today

ES, D. Kawata, C. Brook, R. Schneider, A. Ferrara, B. K. Gibson (2006)

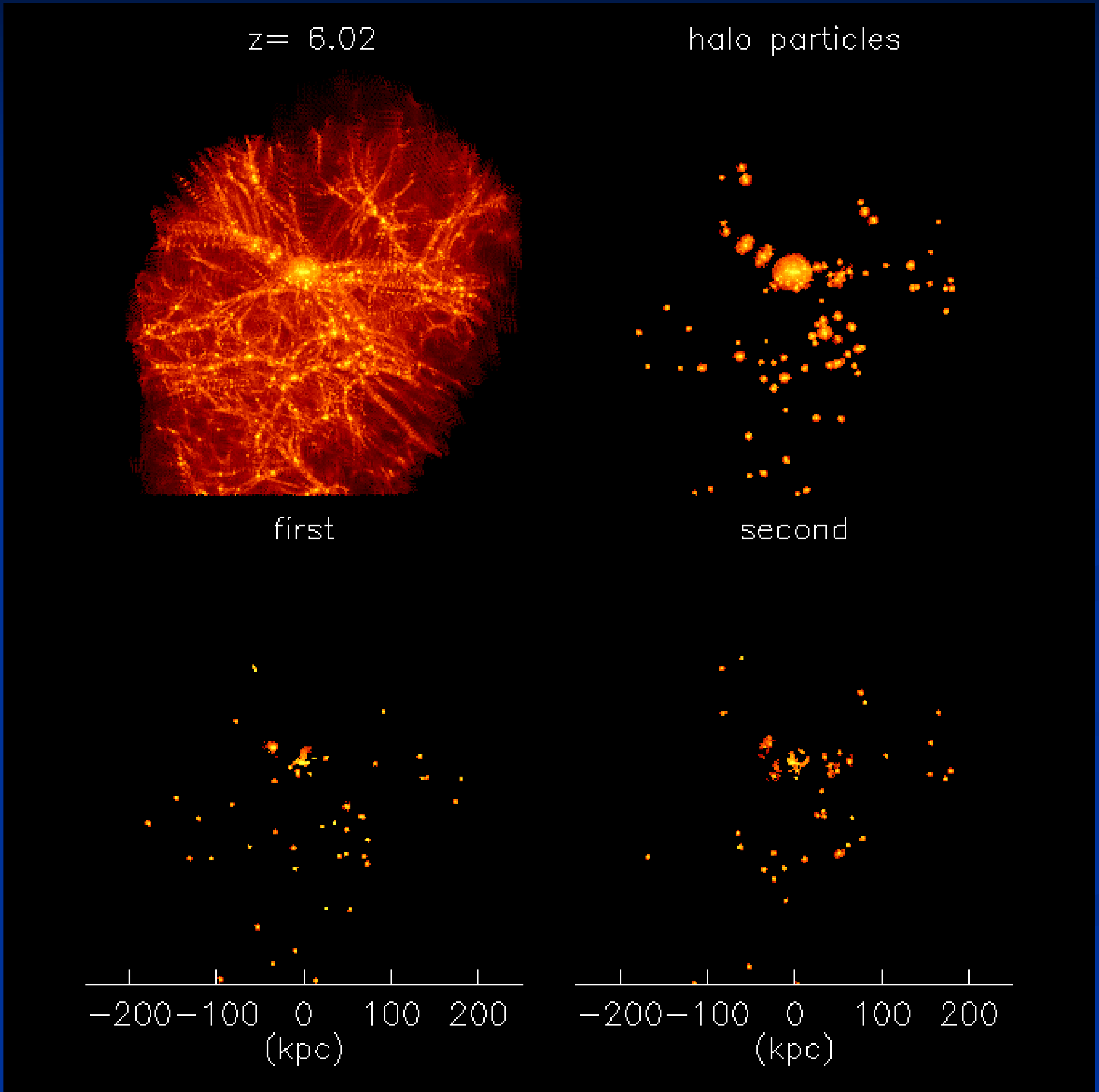
Although the oldest stars should be near the center of the galaxy, does extended primordial SF history change spatial distribution?

- ΛCDM "zoom in" sim. of $8\times10^{11}\ M_\odot$ galaxy.
- DM simulation with $7\times10^{5}\ M_\odot$ particles.
- Pick out all objects above 10^4 K limit.
- Use 1D model (varying wind efficiency) to find positions of metal-free stars.

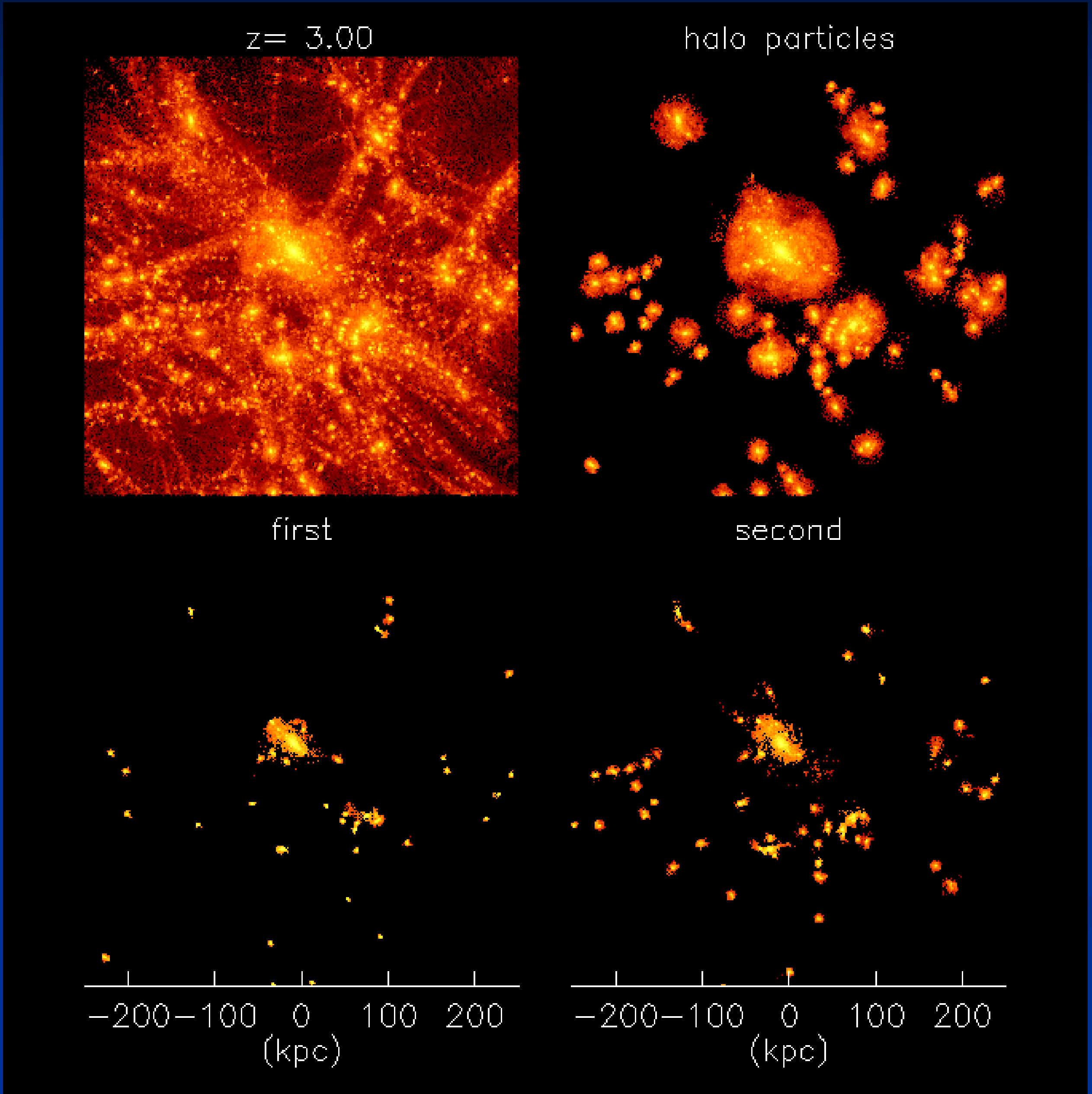
Milky Way Implications



Milky Way Implications



Milky Way Implications



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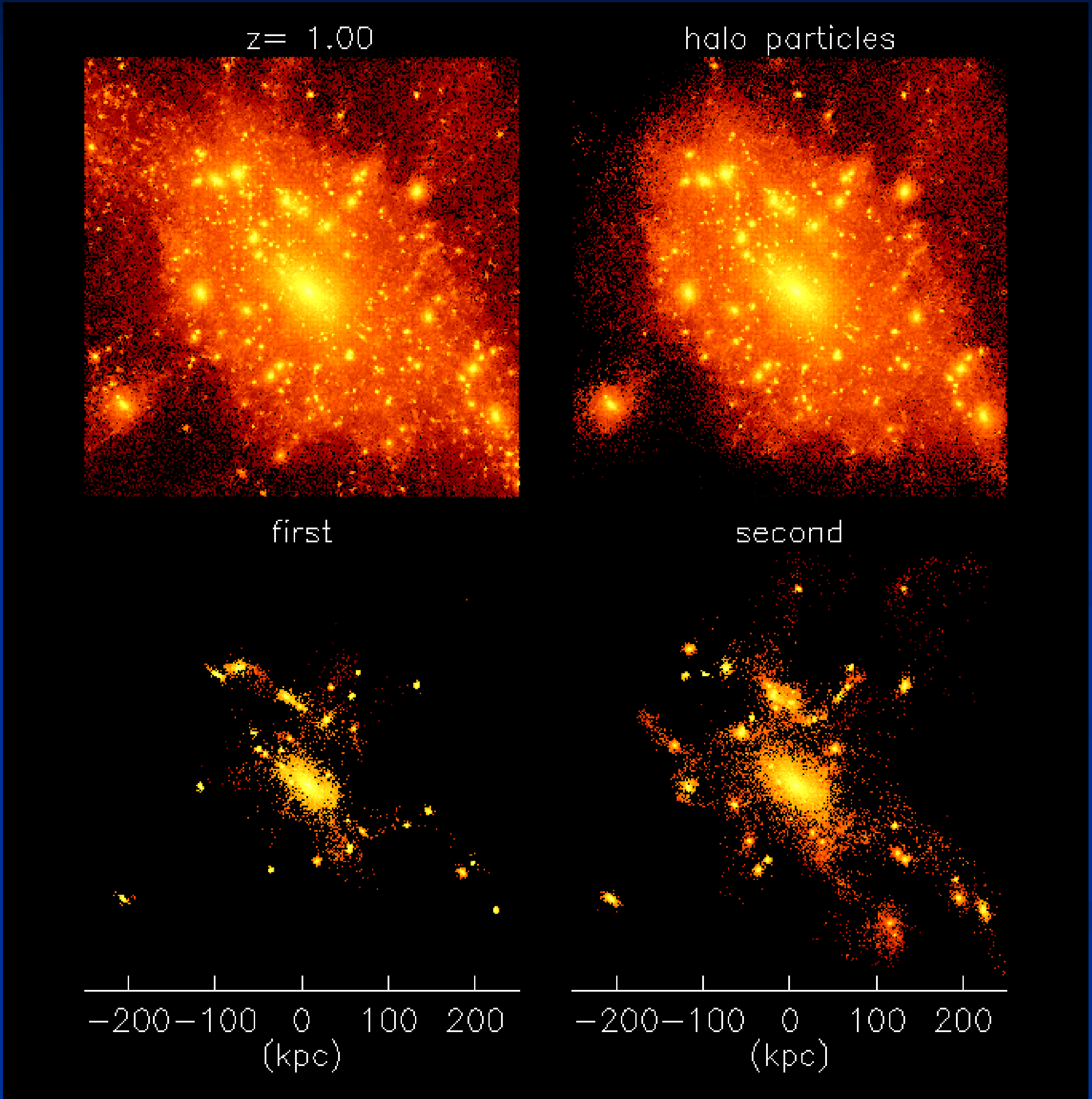
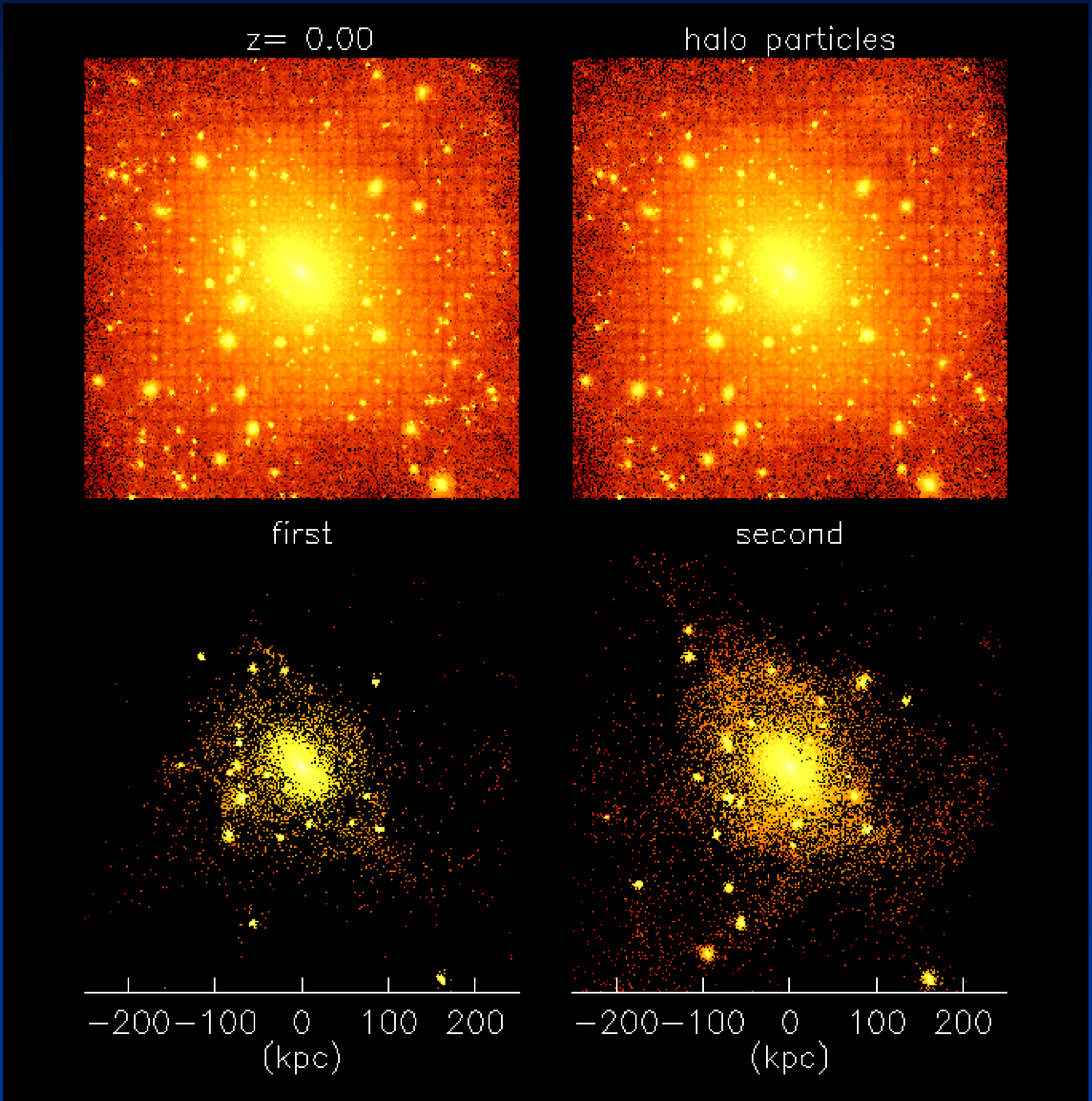
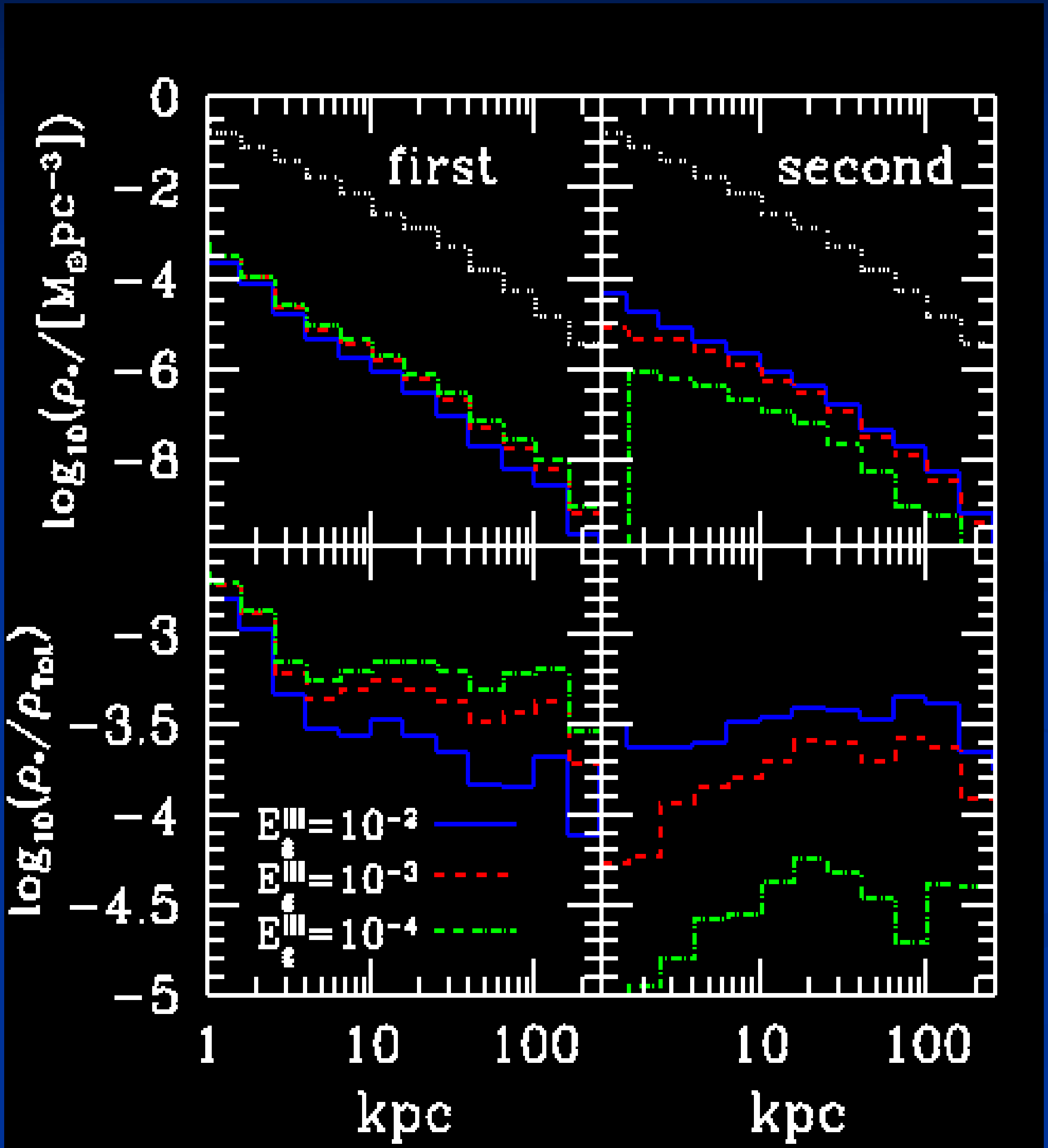


Milky Way Implications

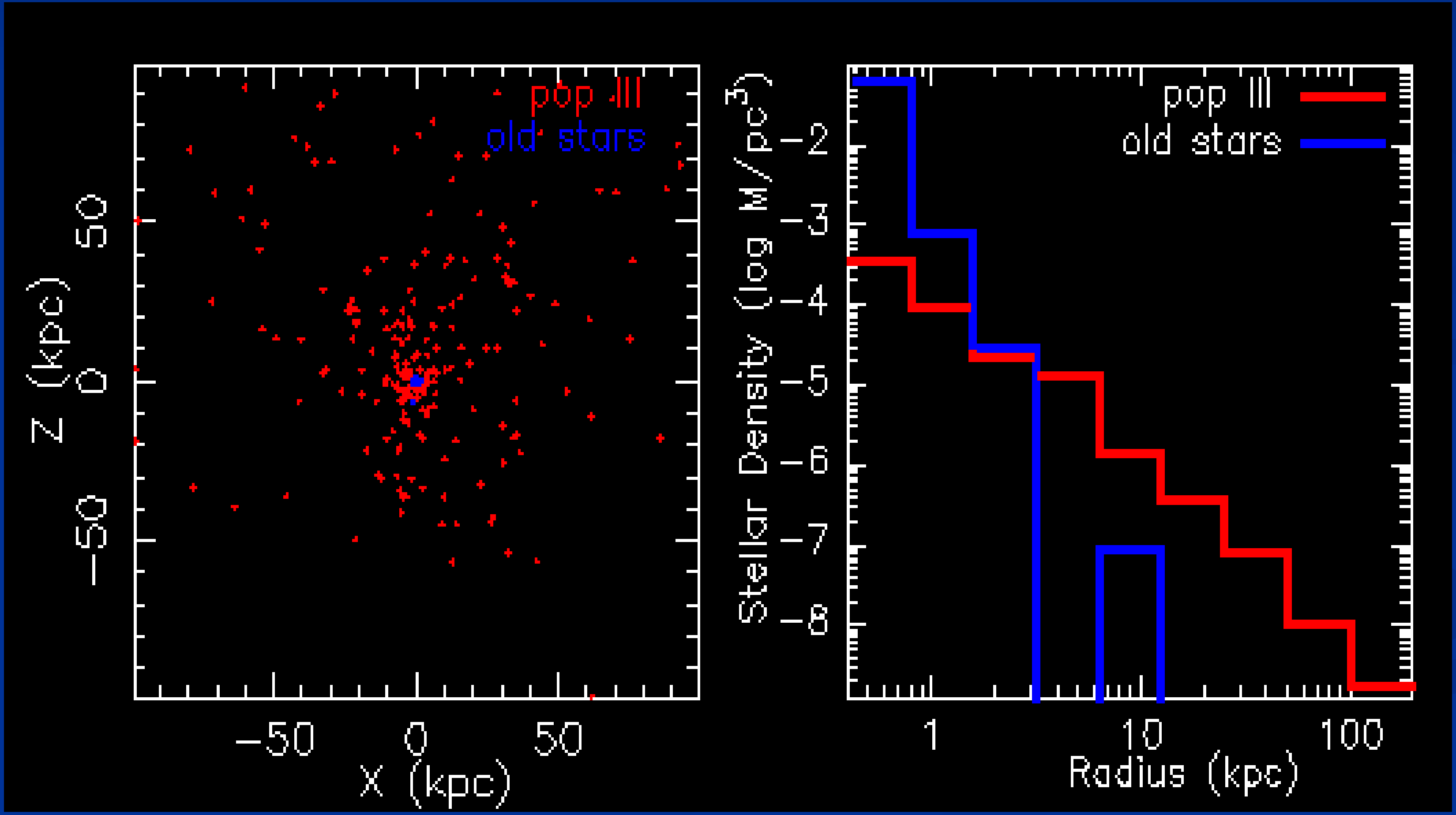


Milky Way Implications

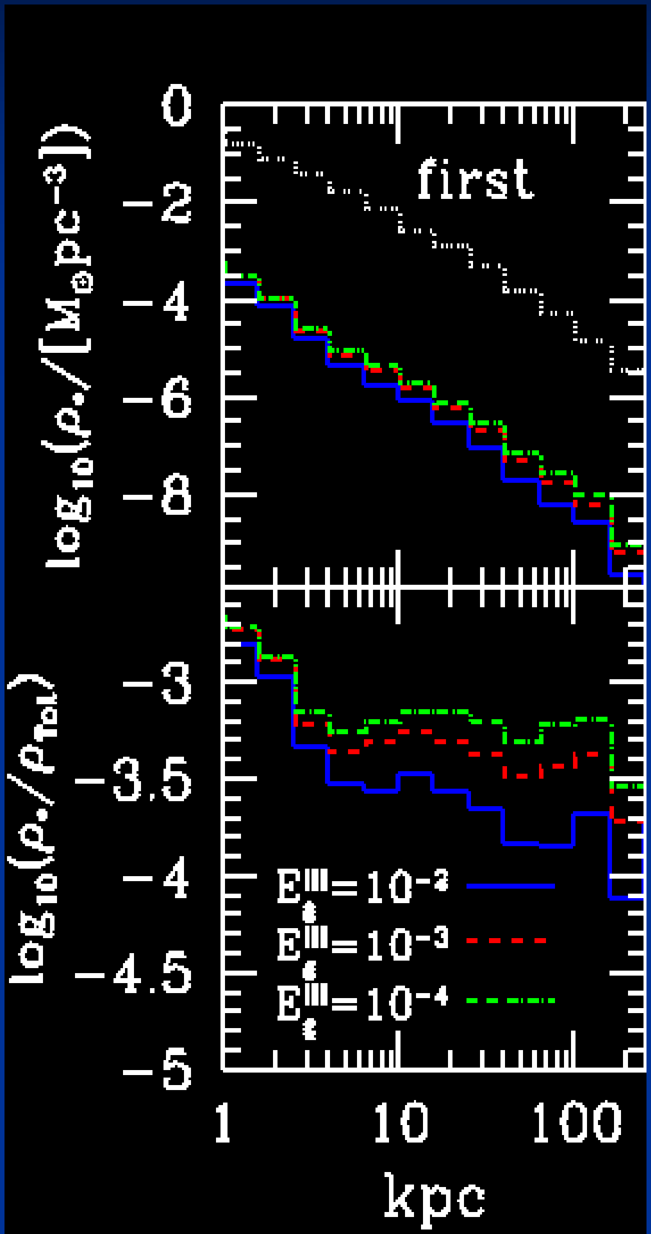


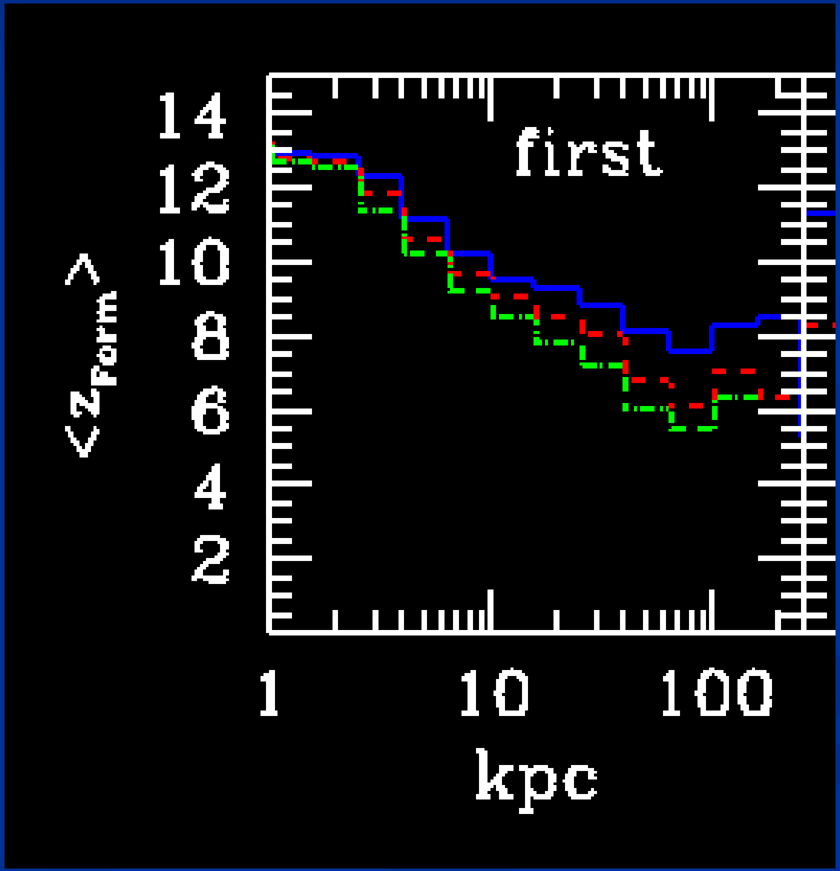
Lots of 1st stars end up in the solar Neighborhood

Full SPH calculations DM: $8x10^6$ $M_\odot$



Milky Way Implications





Limits on Mass function:

No Metal free observed stars: M_{min} ¤ 0.8 $M_{\odot}$

Limits for nucleosynthesis:

Odd even effect not observed

<1/2 Fe from Pop III is from PPSN

Metallicity distribution function of halo stars, etc… have important implications for PopIII star formation.

Conclusions

I First Galaxies:

- The transition from metal-free to normal is **definitely** extended
- Thus metal-free galaxies are **probably** observable at z <5
- the smallest emitters, high equivalent widths, HeII

II Pair-production Sne

- Distinguished by: Hydrogen lines, **slightly** brighter than Ia, **long evolution times -- possibly with 2 local maxima**
- Detectable in I band in present SNe searches out to z ~ 2
- **~ 1 deg, 3 year, NIR** surveys can set limits out to z~6 or beyond

III Searches in the Galactic Halo

- Metal-free stars and their products end up everywhere
- **The Halo is a great place to look**
- Lack of metal-free stars argues for high mass, lack of odd even effect constrains PPSNe

Conclusions

I First Galaxies:

- The transition from metal-free to normal is **definitely** extended
- Thus metal-free galaxies are observable with JWST/TMT at z <10
- the smallest emitters, high equivalent widths, HeII

II Pair-production Sne

- Distinguished by: Hydrogen lines, **slightly** brighter than Ia, **long evolution times -- possibly with 2 local maxima**
- Detectable in I band in present SNe searches out to z ~ 2
- **~ 1 deg, 3 year, NIR** surveys can set limits out to z~6 or beyond

III Searches in the Galactic Halo

- Metal-free stars and their products end up everywhere
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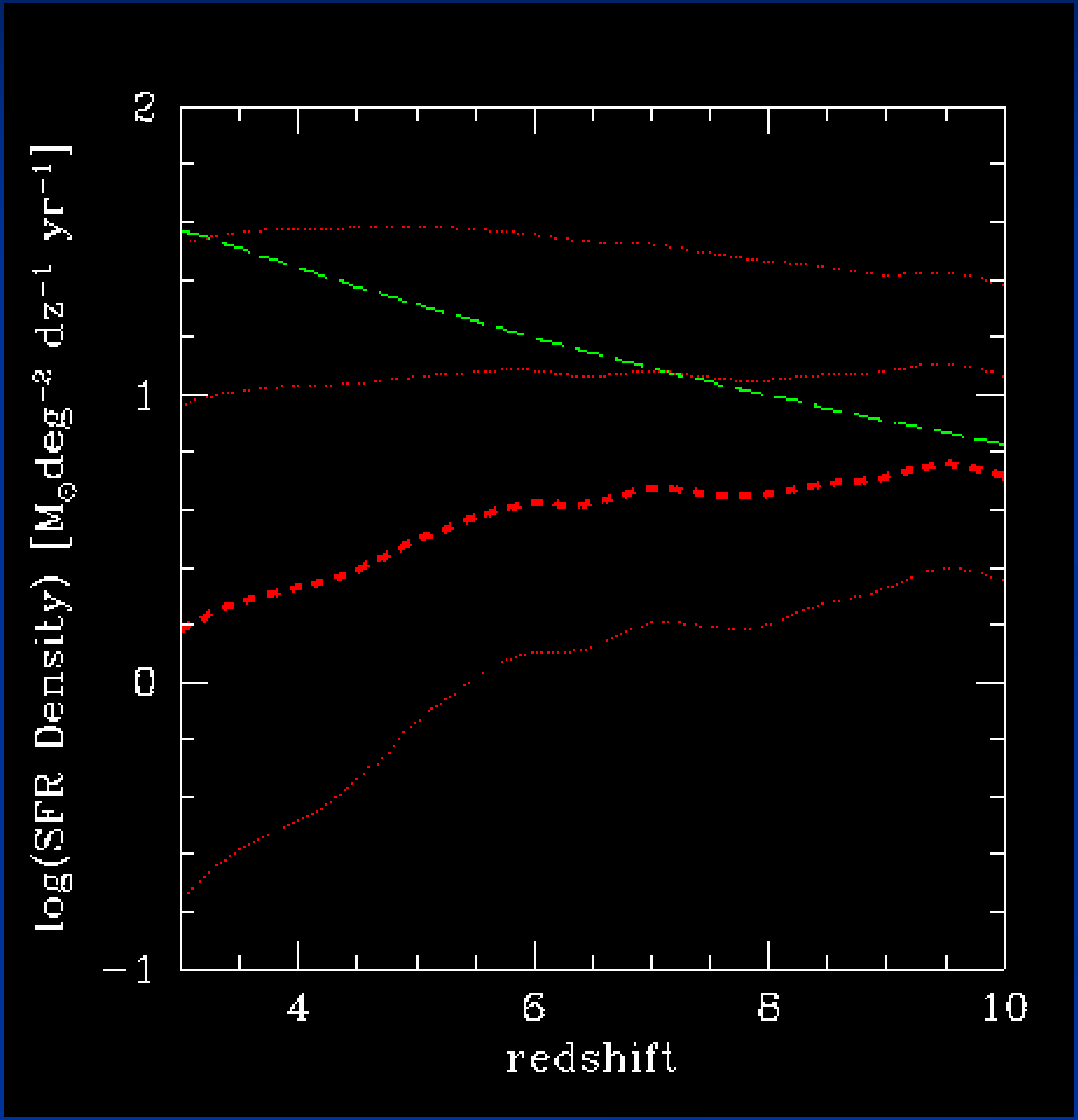
Number of Sneγγ in our models

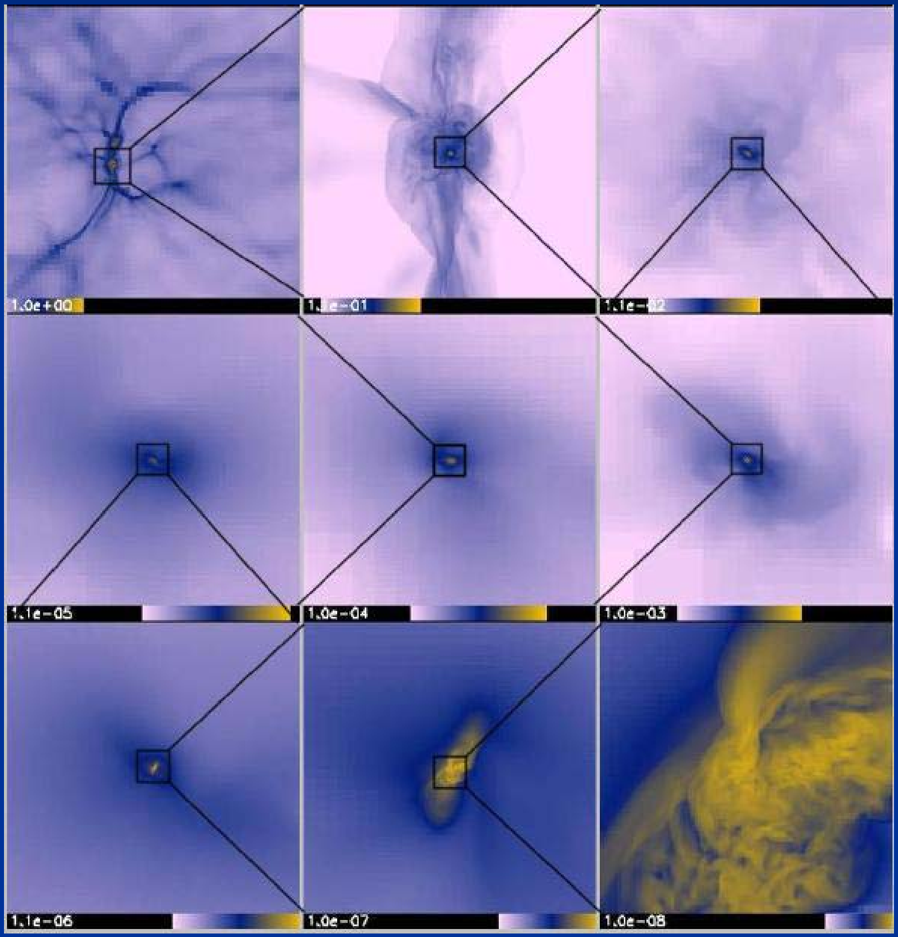


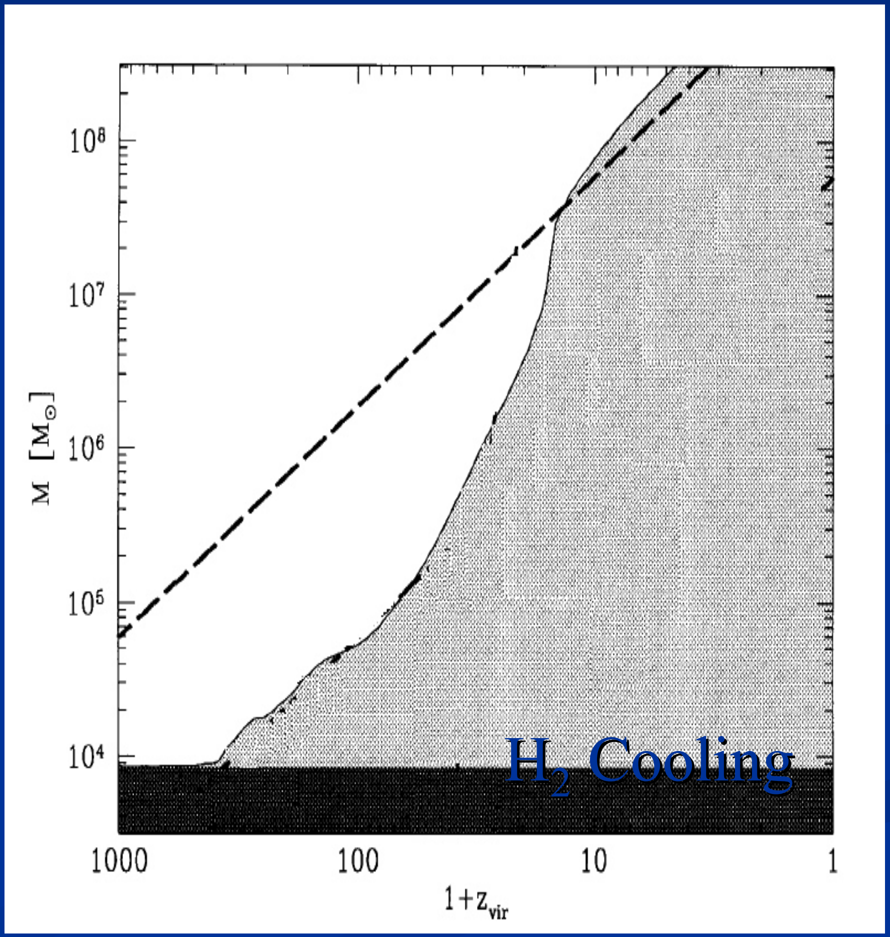
Assume 1 Sneγγ per 1000 M_{sun} of stars

1/100 M_{sun}/yr

Fiducial $E_g = 10^{-3}$

The 1st Objects: Why Massive?

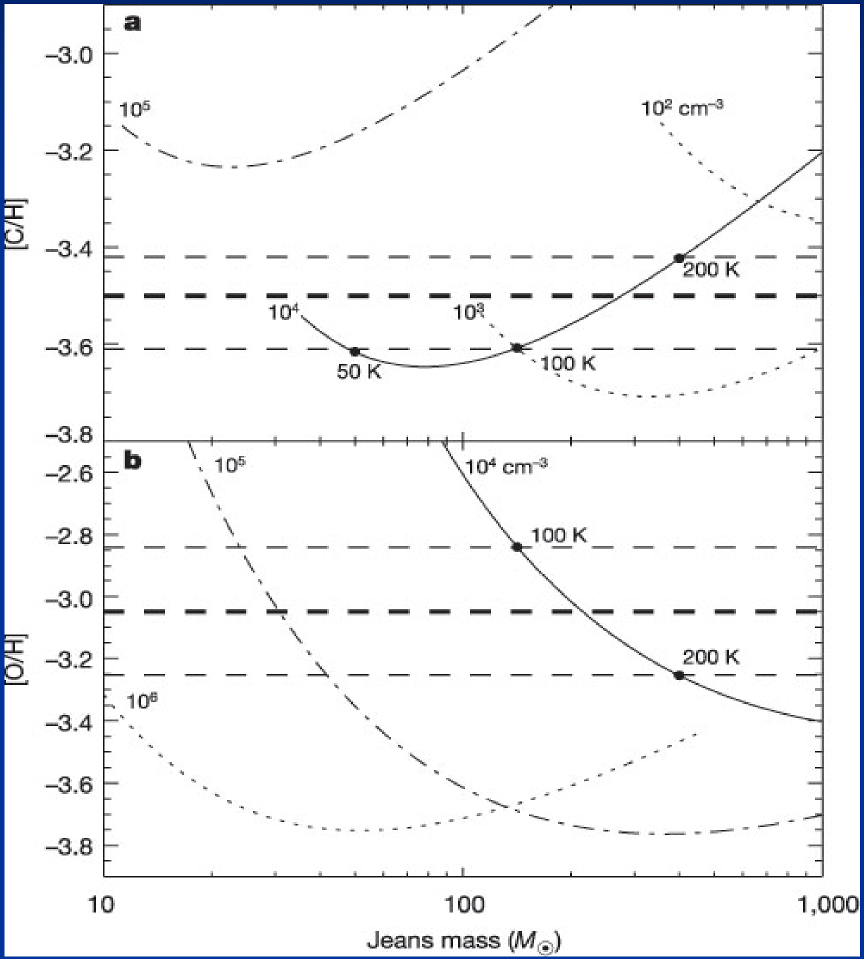




Abel, Byran, Norman (2001)

Tegmark, Silk, Rees, Blanchard, Abel, & Palla (1997)

Critical Metallicity



V. Bromm & A. Loeb (2004)

At typical density of 10^4 cm^{-3} & T of 100 K OI and CII are the primary coolants

~ 10^{-4} Z_{sun}

" Critical Metallicity"

WE DON'T SEE THEM