

# The First Cosmic Billion Years

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# DAVID

The **D**ark **A**ges **V**irtual **D**epartment

<http://www.arcetri.astro.it/twiki/bin/view/DAVID/WebHome>



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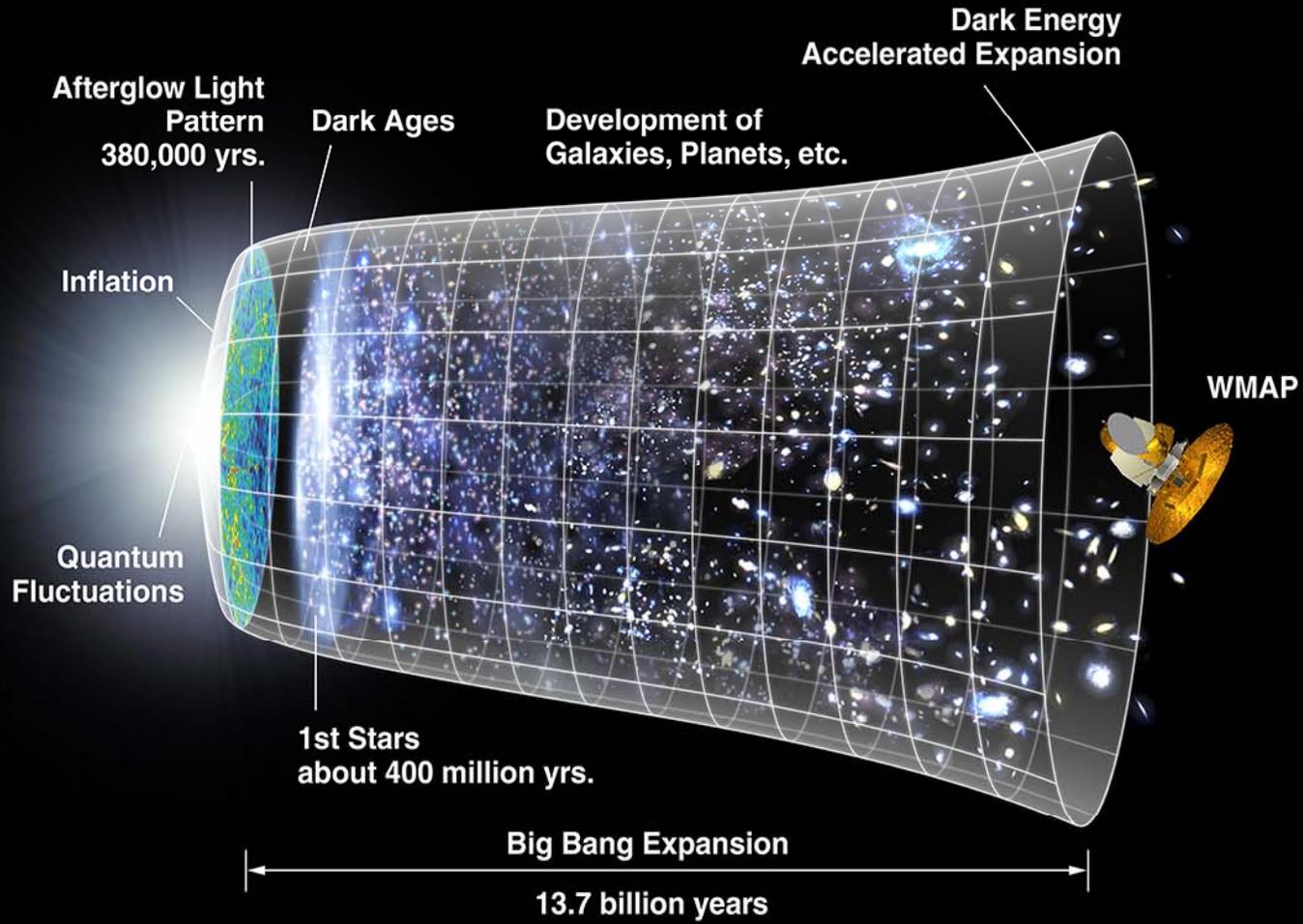


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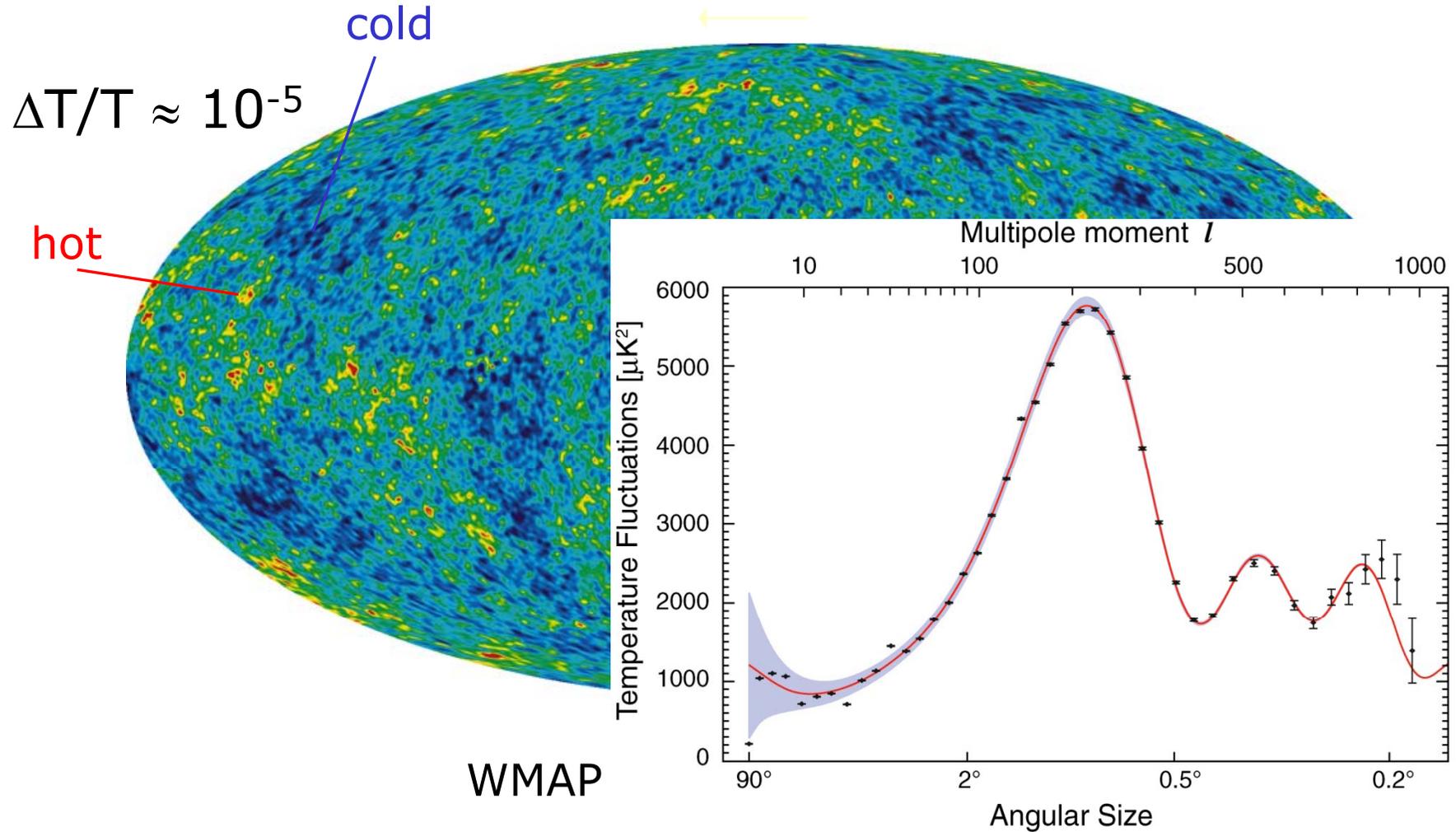
# First Gyr



# STRUCTURE FORMATION: INITIAL CONDITIONS

*Komatsu+2008*

## COSMIC MICROWAVE BACKGROUND



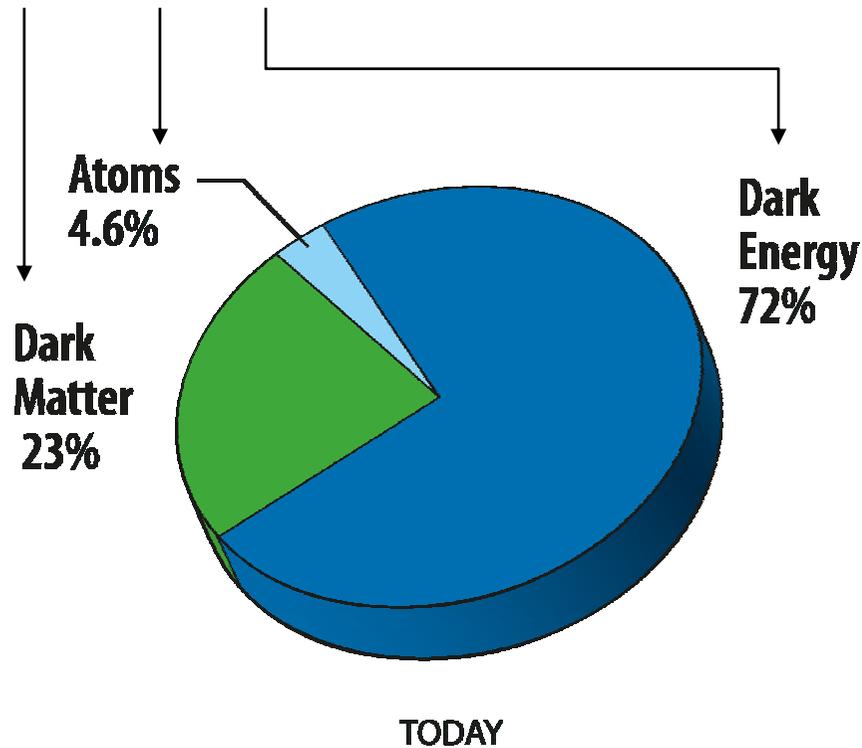
# STRUCTURE FORMATION: INITIAL CONDITIONS

*Dunkley+ 2008*

## COSMIC CONTENT

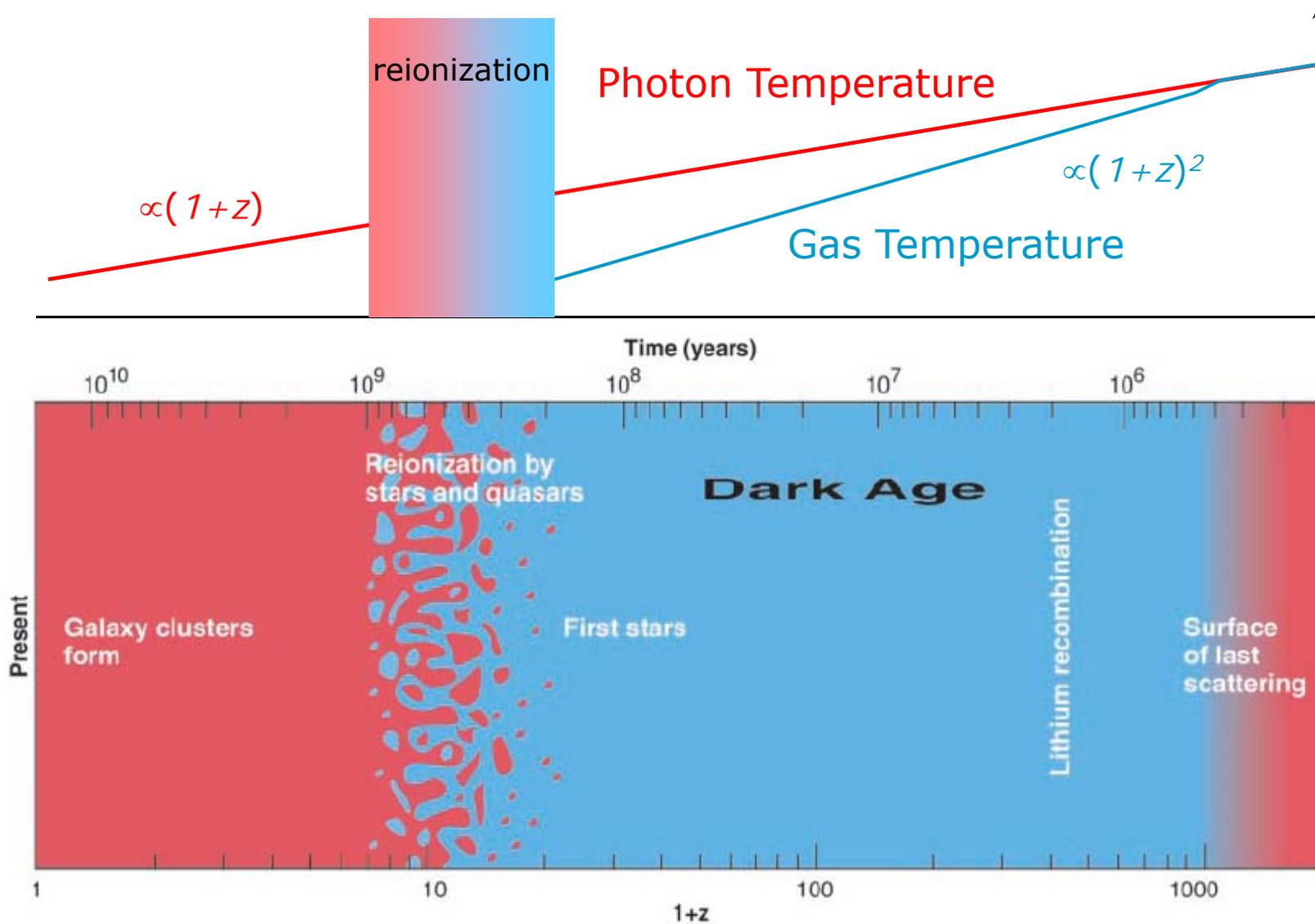
$$\text{DEF: } \Omega_X = \rho_X / \rho_{\text{cr}} \quad \rho_{\text{cr}} = 3H^2 / 8\pi G$$

$$C_l = C_l \{ \Omega_{\text{dm}}, \Omega_{\text{b}}, \Omega_{\Lambda} + \tau, h, w + 4 \text{ "spectral" pars} \}$$



# STRUCTURE FORMATION: INITIAL CONDITIONS

## THE DARK AGES



# The First Galaxies/Stars

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# STRUCTURE FORMATION

L=1 Mpc

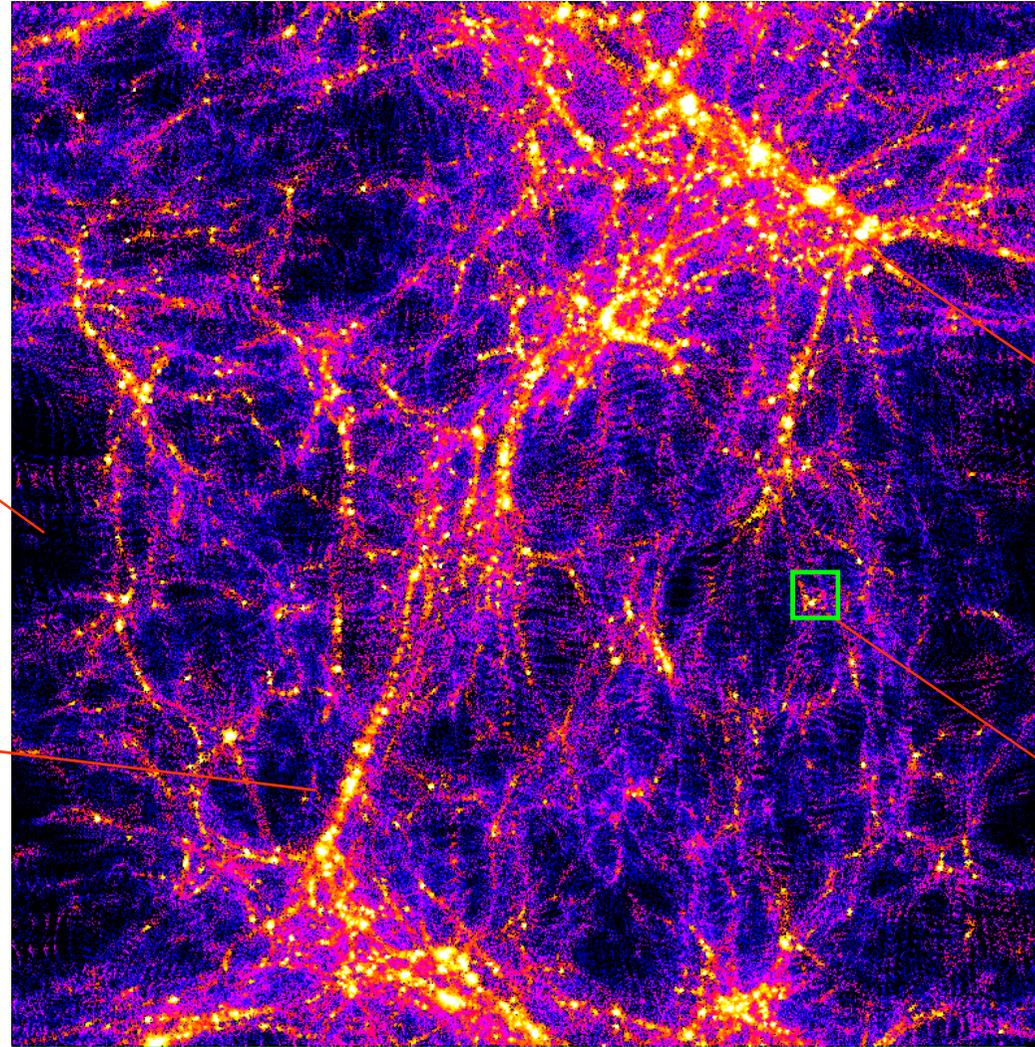
Redshift  $z=10$

Voids

Galaxy Cluster

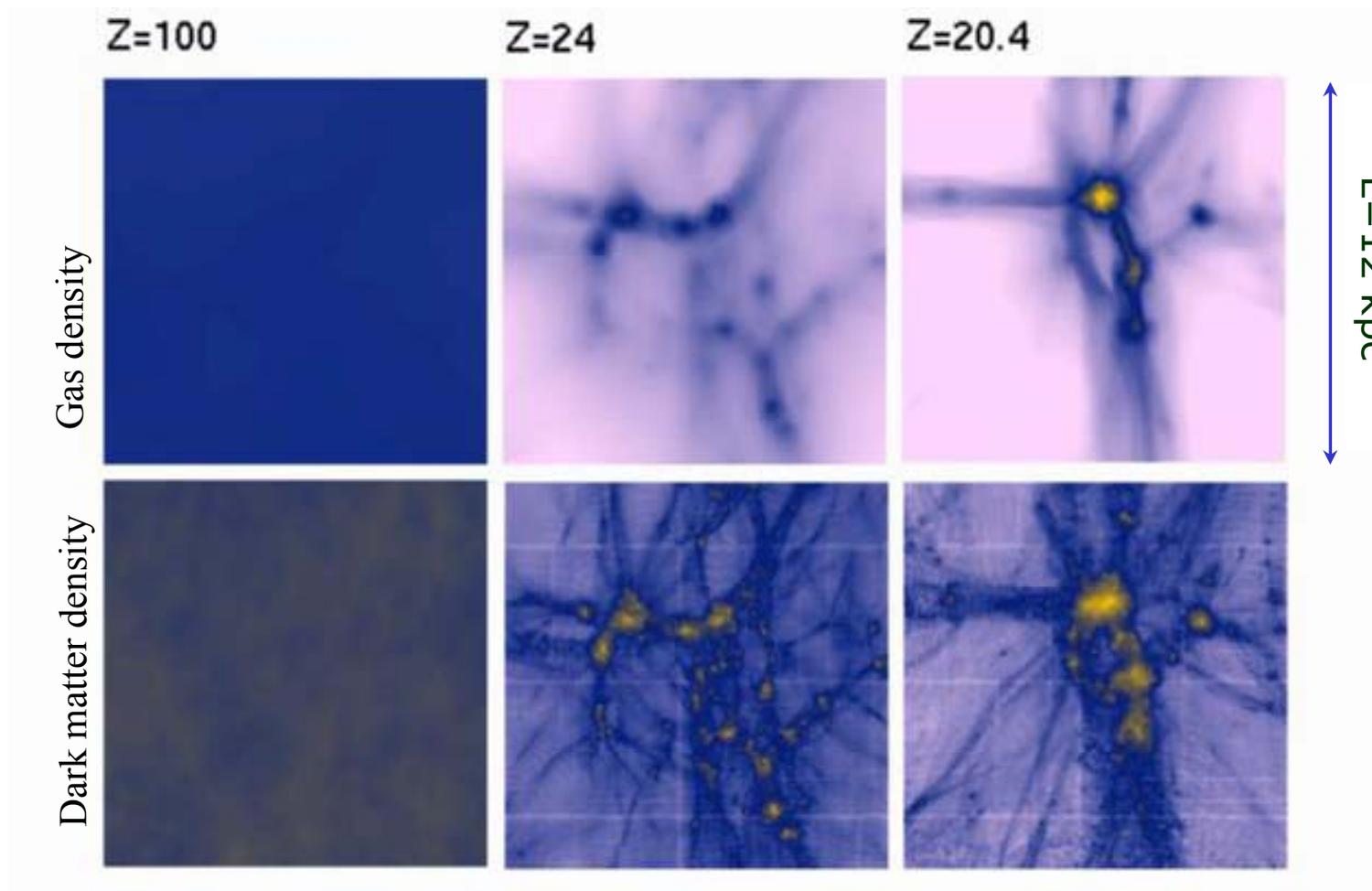
Filaments

First Galaxies



DM overdensity  $\Delta \equiv \rho / \langle \rho \rangle$

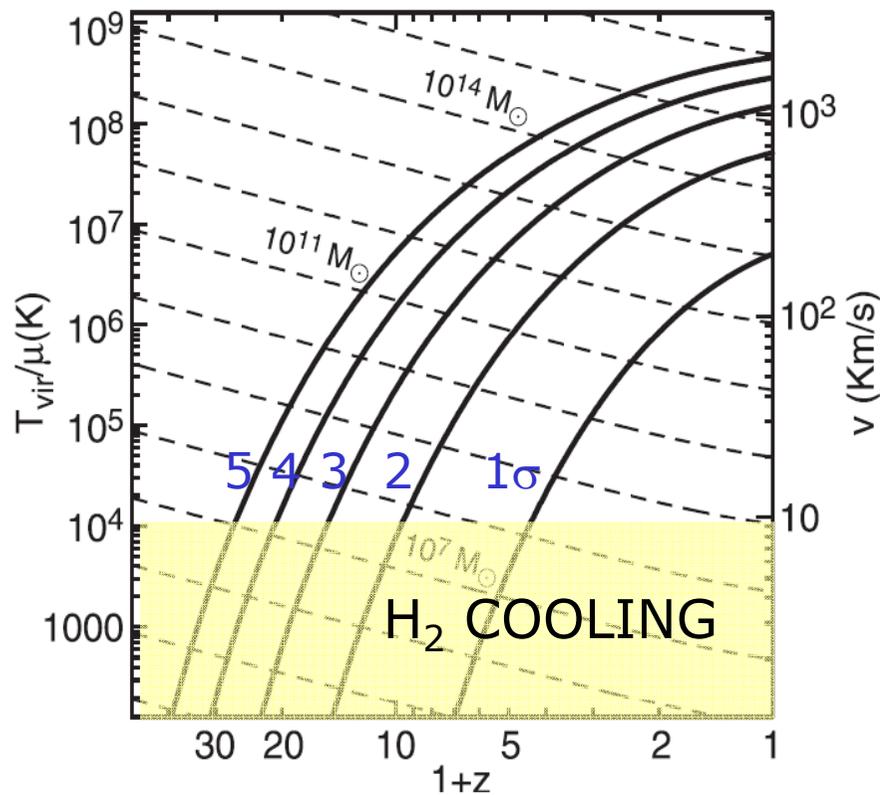
COLLAPSE



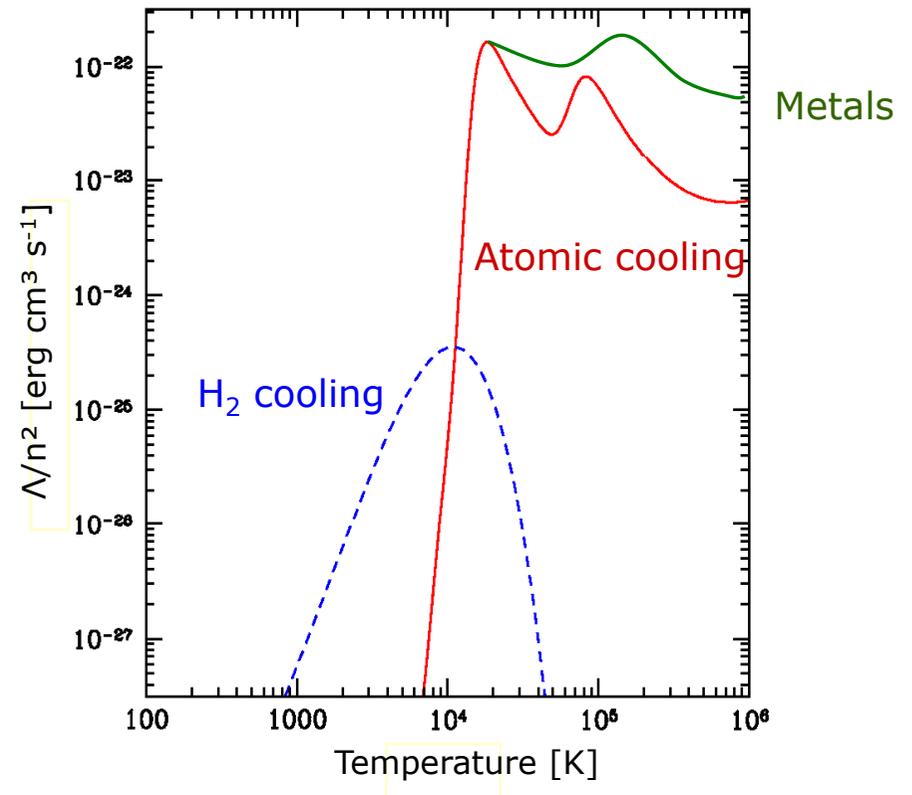
GAS COOLING

$$T_{vir} = 485\text{K } h^{2/3} \left( \frac{M}{10^4 M_{\odot}} \right)^{2/3} \left( \frac{1+z_{vir}}{100} \right)$$

DM halos virial temperature



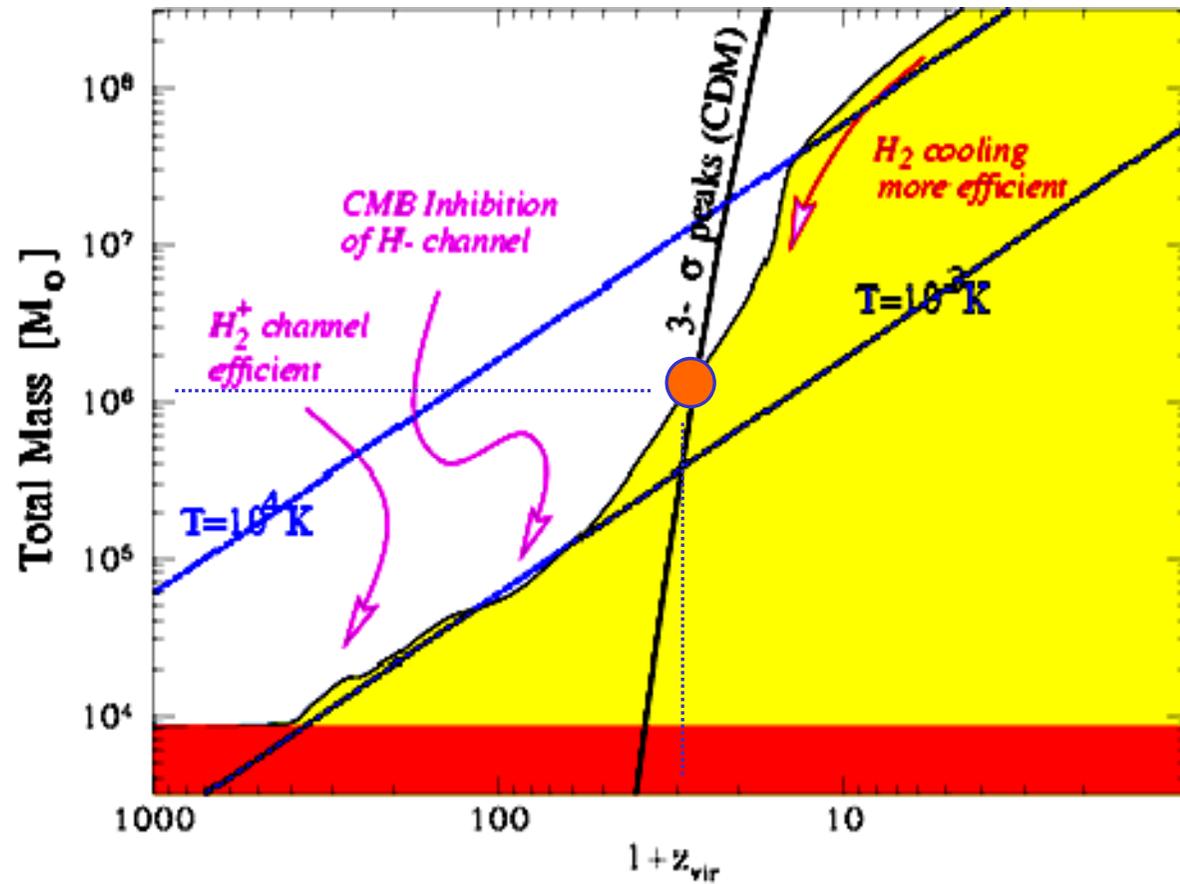
Cooling function (primordial)



MASS OF FIRST GALAXIES

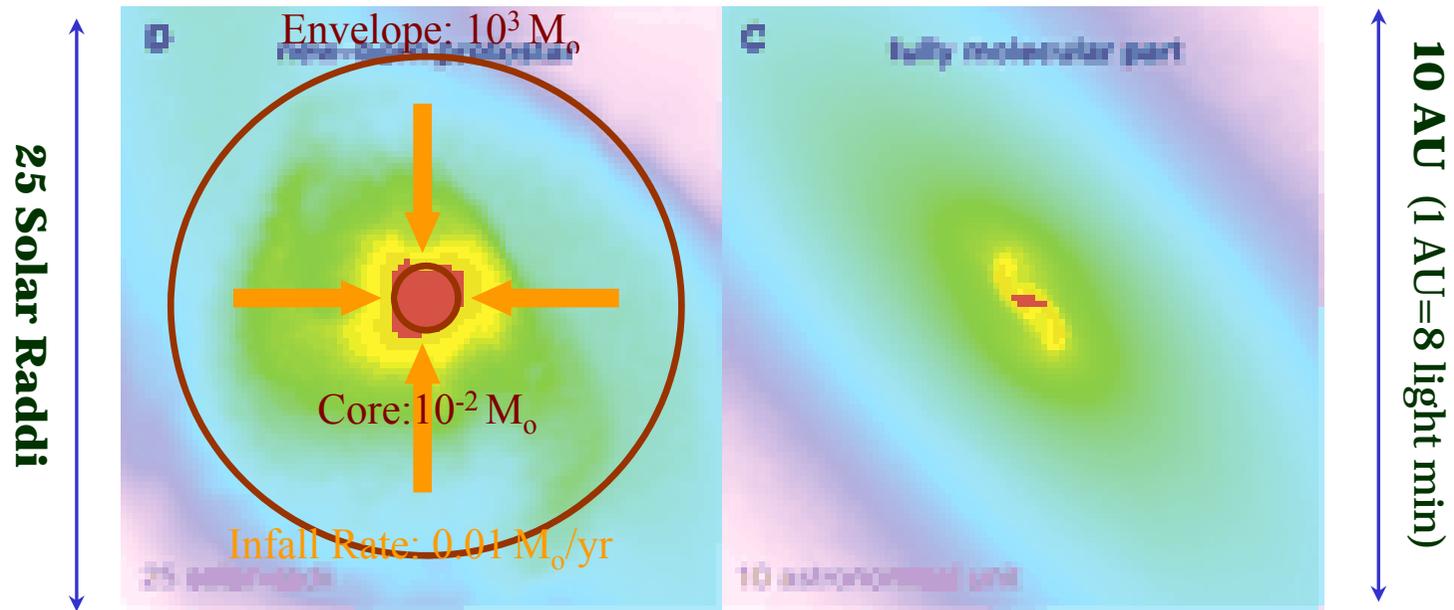
$$t_{\text{cool}} = 3kT/2n\Lambda(T) < t_H = H^{-1}(z)$$

$$M \sim 10^6 M_{\odot}$$



$$z \sim 30$$

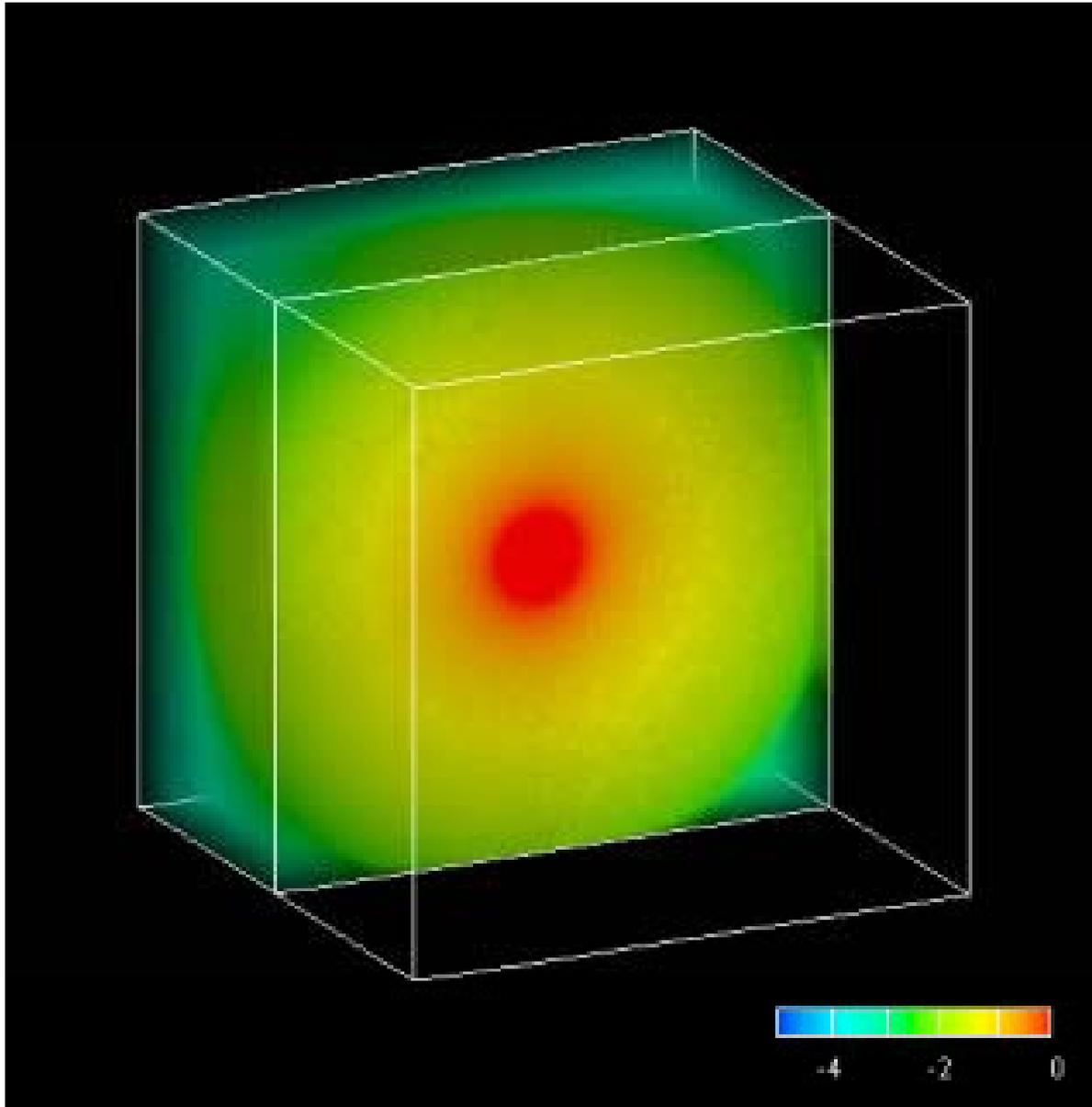
FIRST STARS ARE MASSIVE



Density Maps

## SUPERNOVAE AND METAL ENRICHMENT

*Mori, AF & Madau 2001*

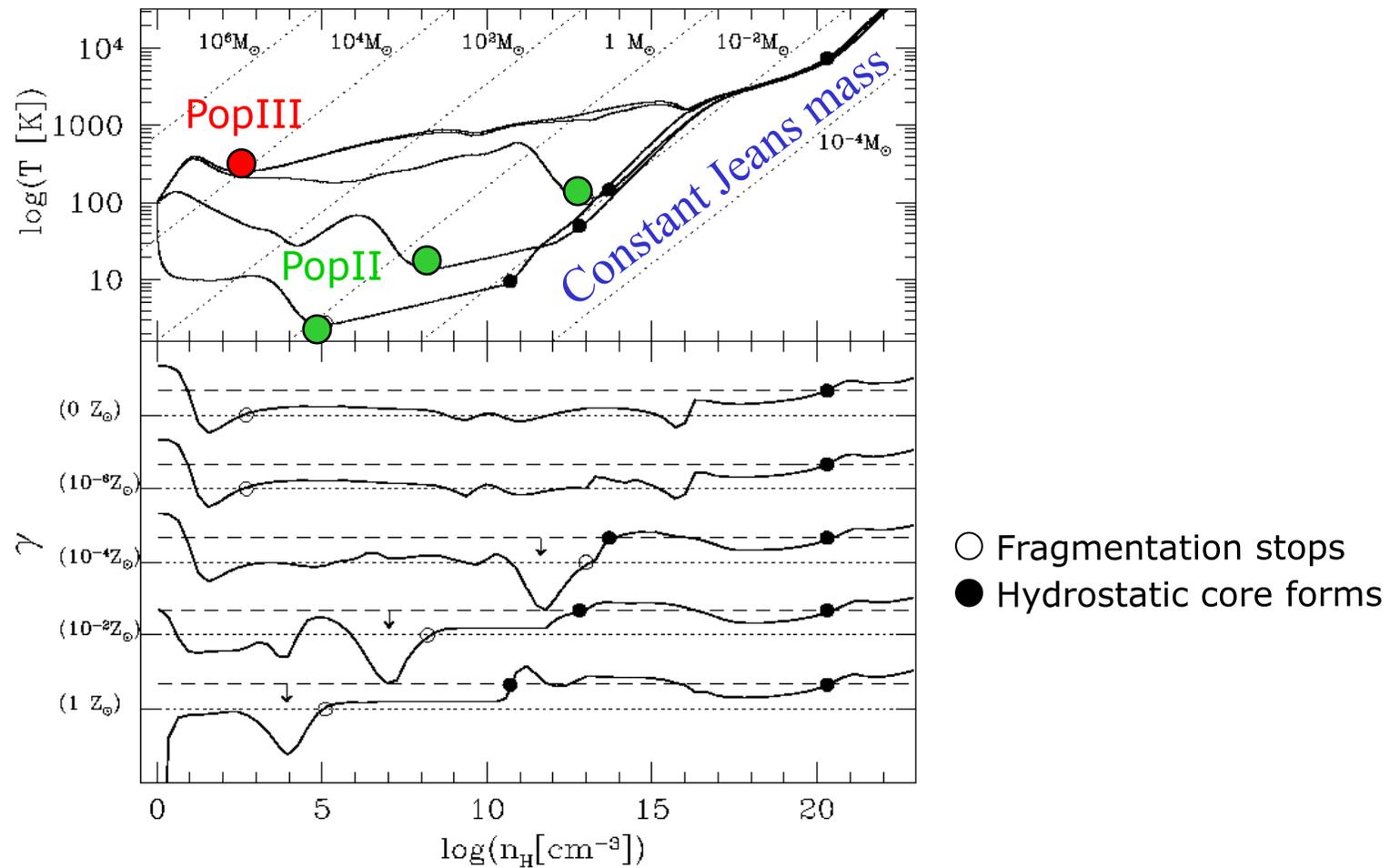


- $M=10^8 M_{\odot}$
- $t = 0 - 175 \text{ Myr}$
- $\text{Log}(\text{gas density})$
- Box size: 3 kpc  $\rightarrow$  12 kpc

$z = 9$

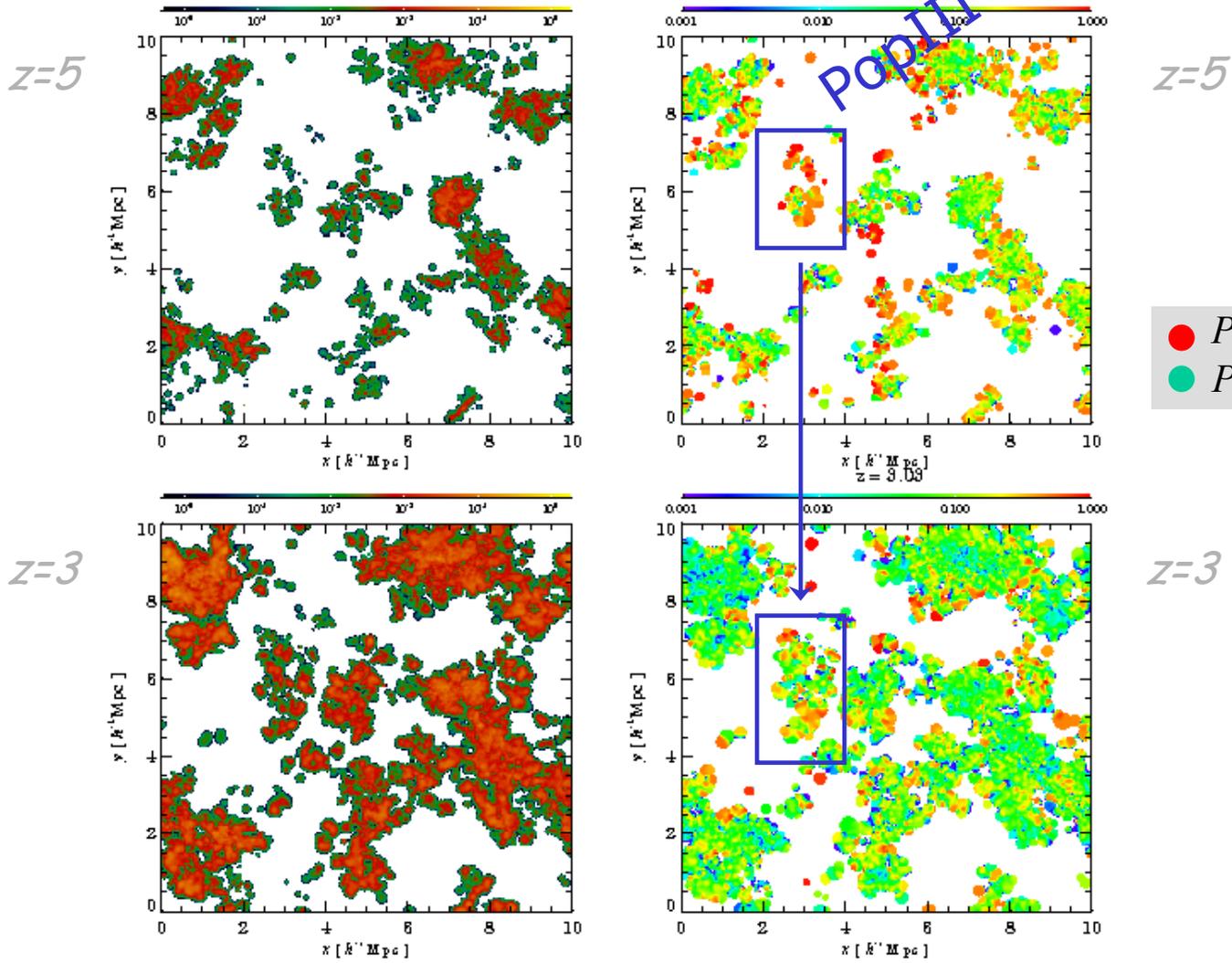
METAL INDUCED FRAGMENTATION

Metallicity:  $Z = M_Z/M_H$  ( $Z_\odot = 0.02$ )



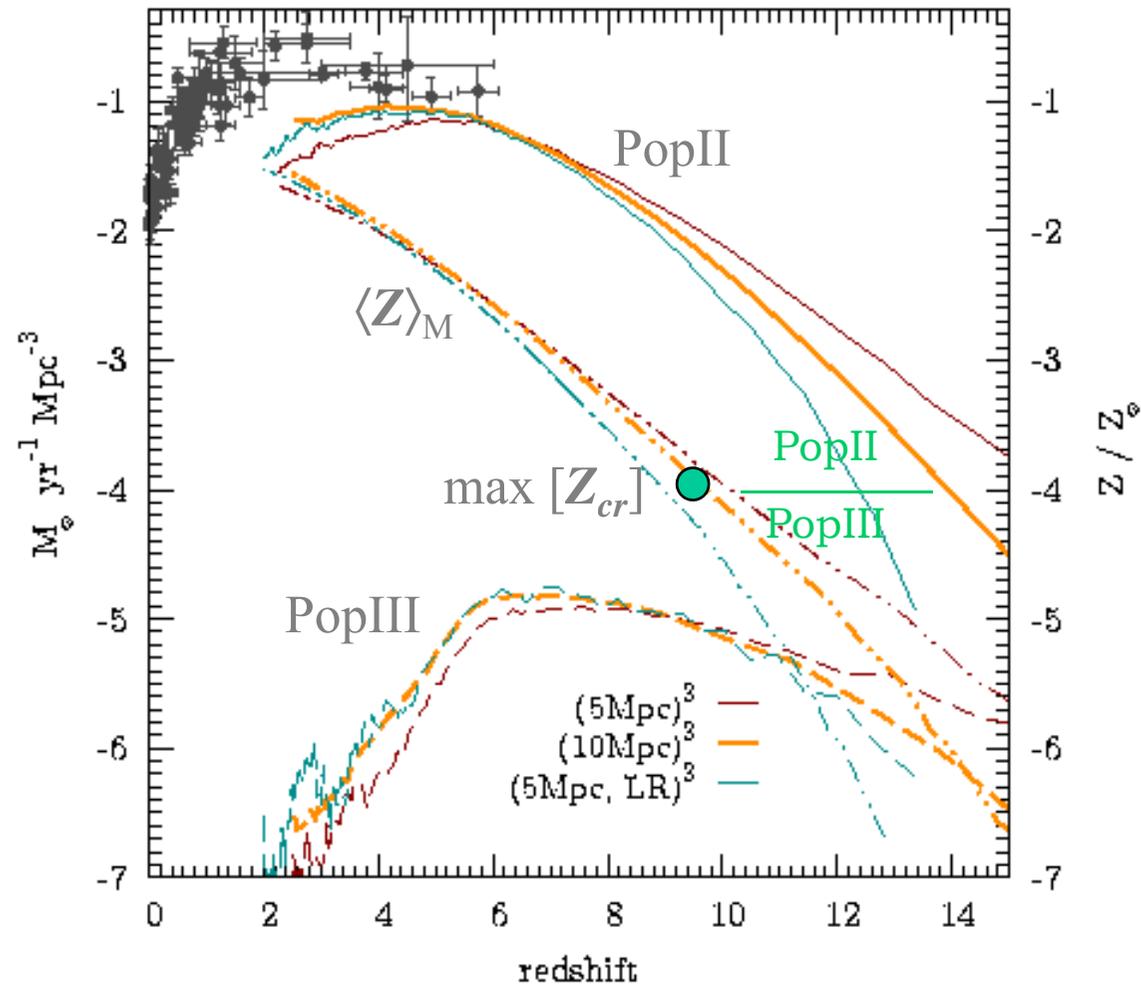
COSMIC POPIII/POP II TRANSITION

Total Metallicity



Fraction of Pop III forming sites

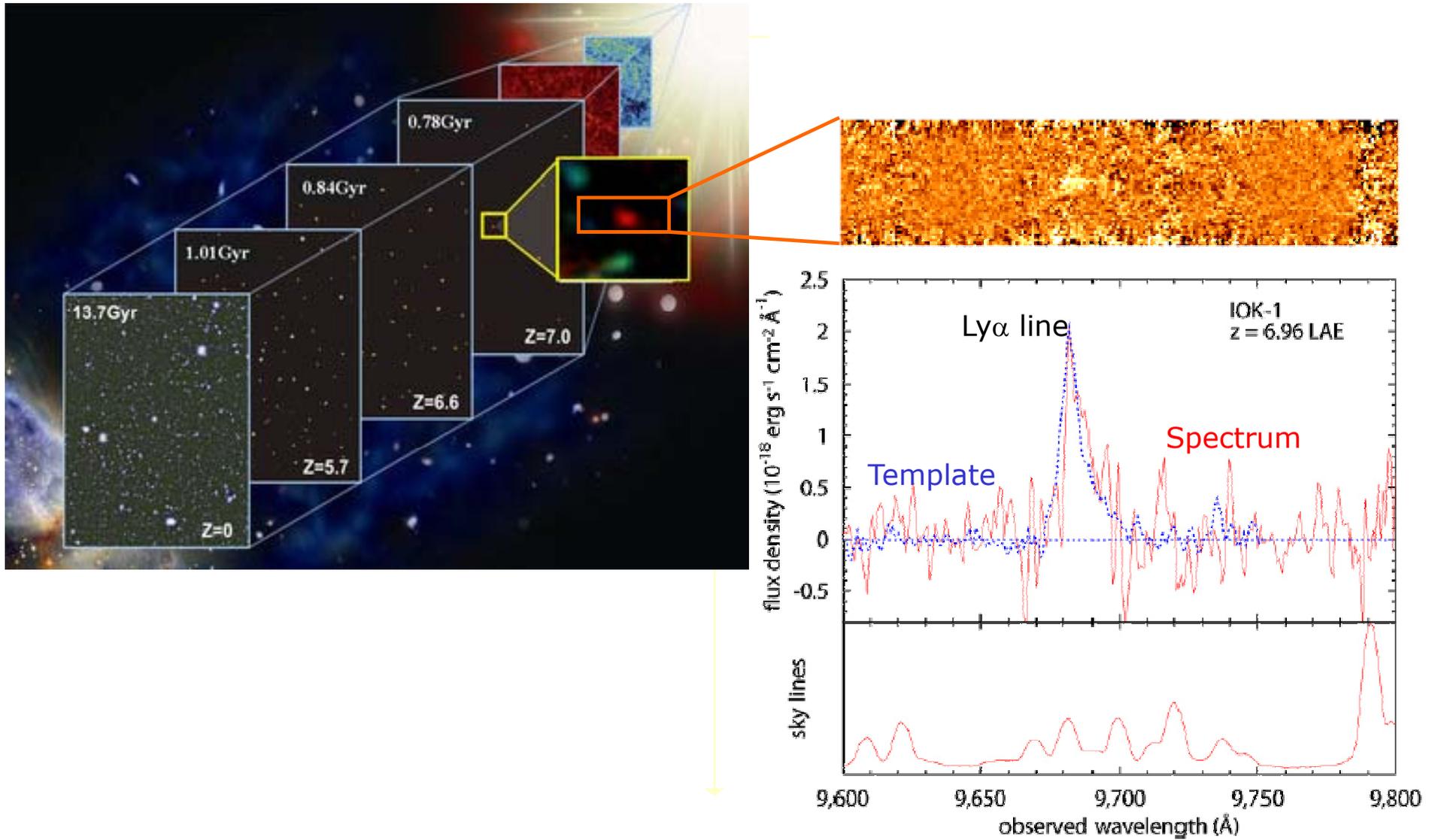
COSMIC STAR FORMATION HISTORY



# FIRST STARS HOST GALAXIES

*Iye+ 2006; Kashikawa+ 2006; Nagao+ 2007*

## LYMAN ALPHA EMITTERS

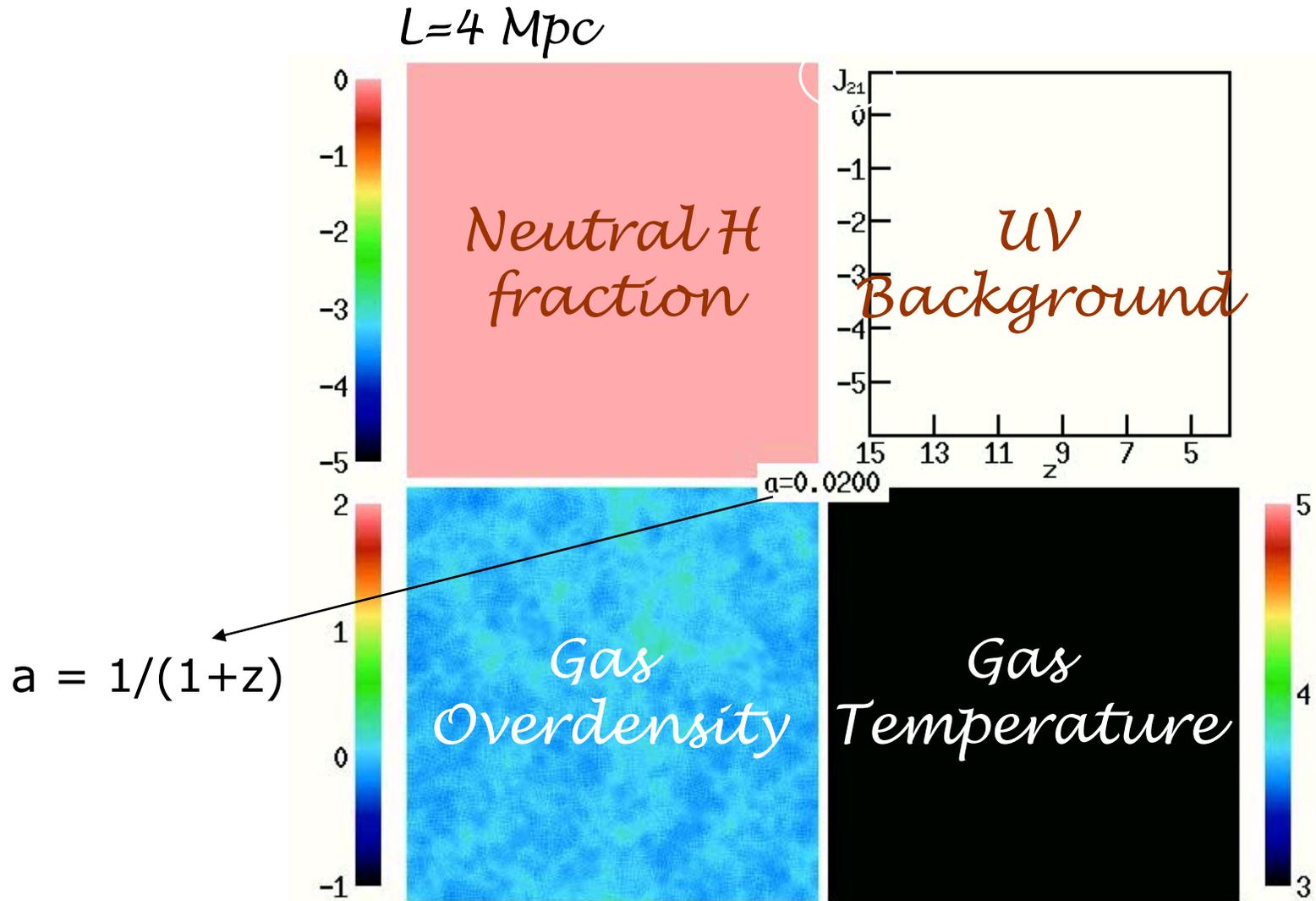


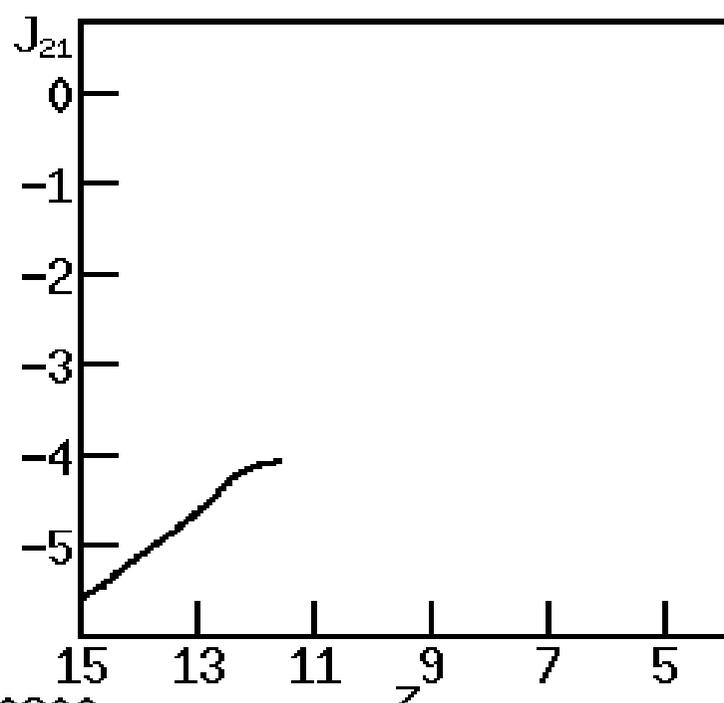
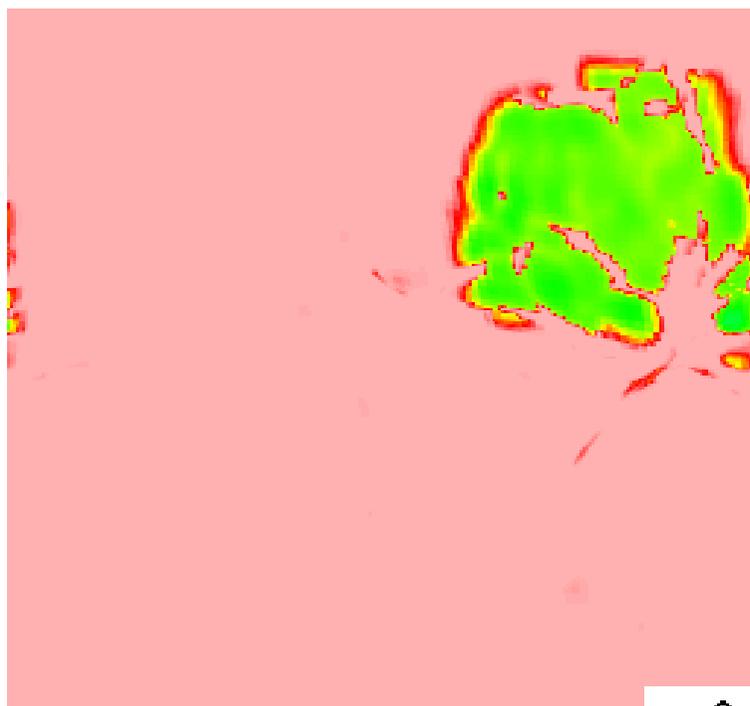
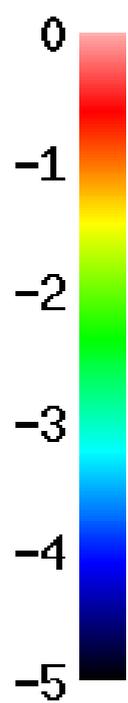
# Cosmic Reionization

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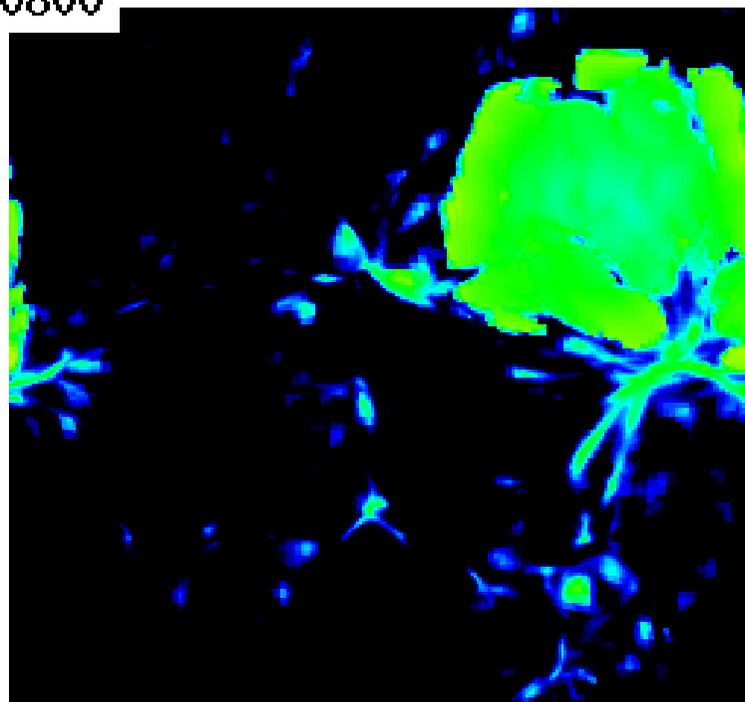
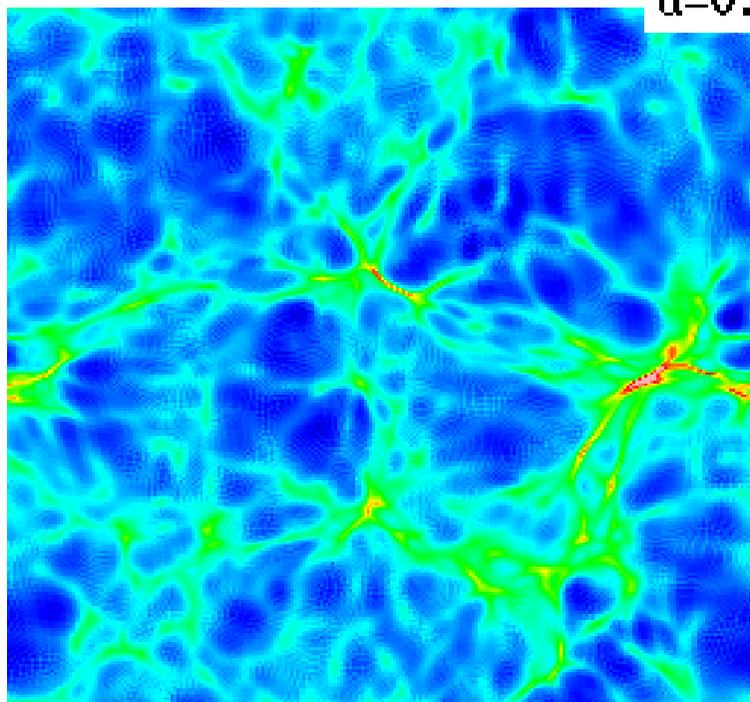
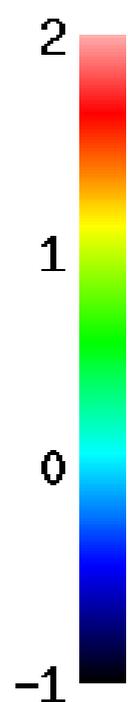
# COSMIC REIONIZATION

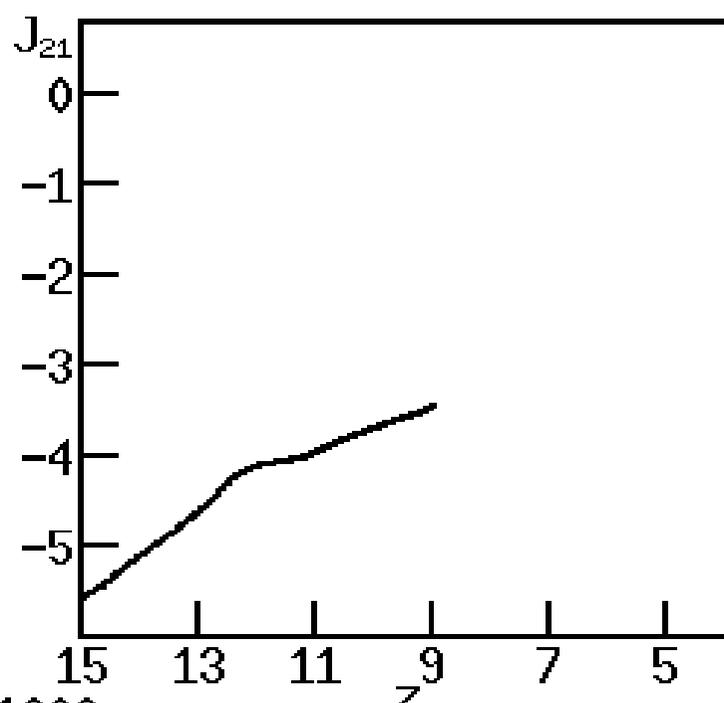
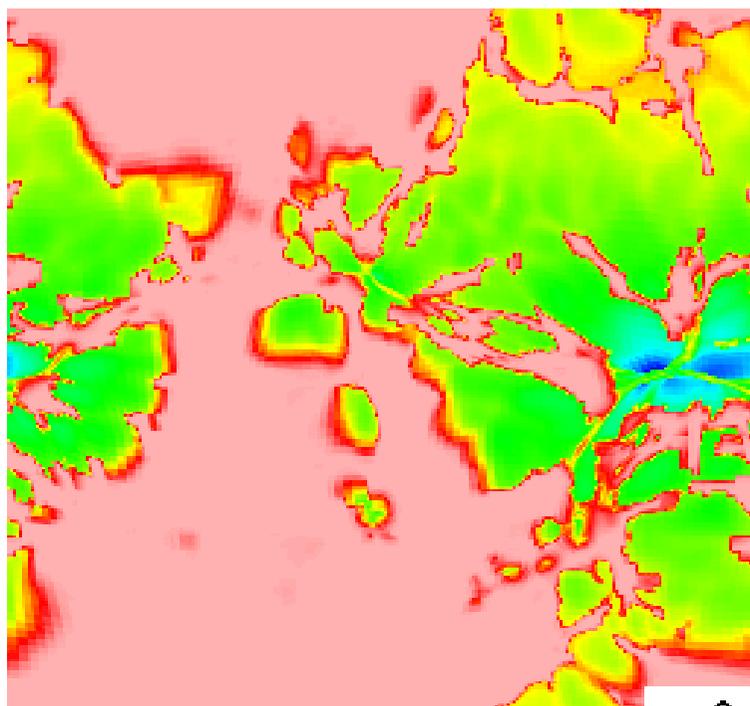
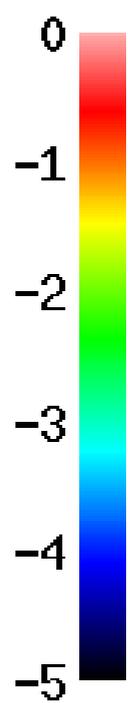
*Gnedin 2000; Gnedin, AF, Zweibel 2000; Ciardi, AF, White+03; Alvarez+2007*



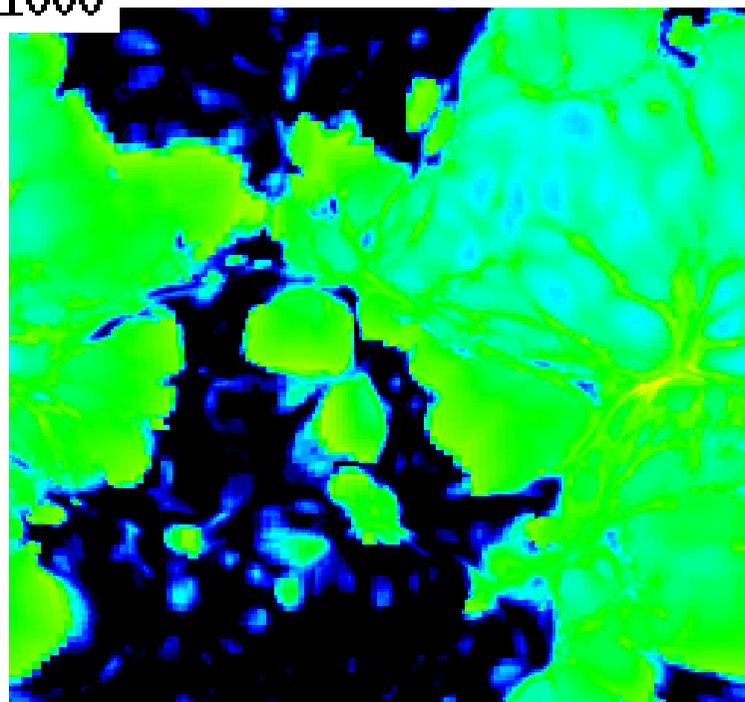
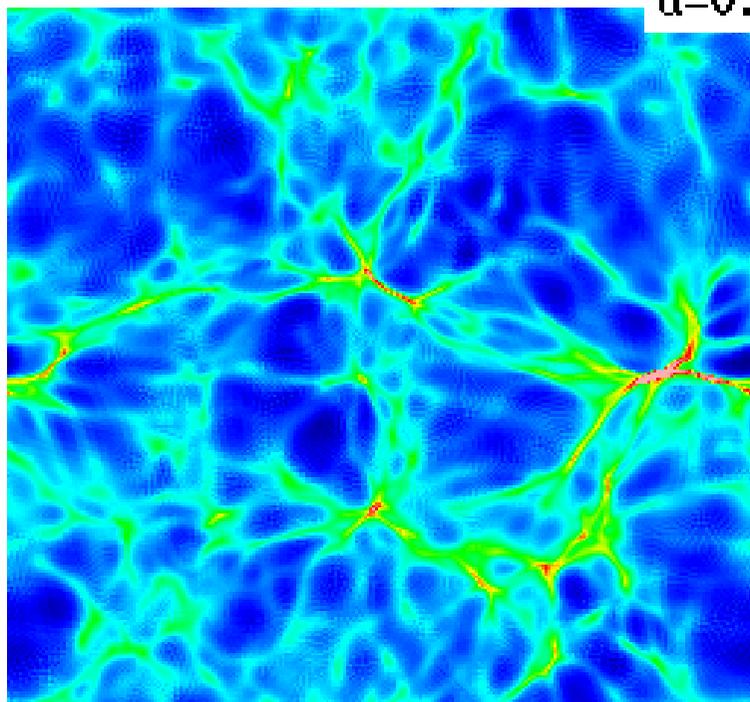
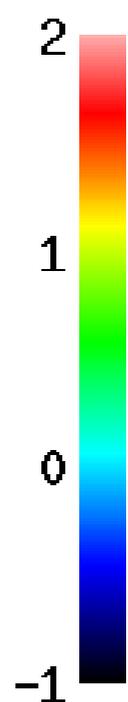


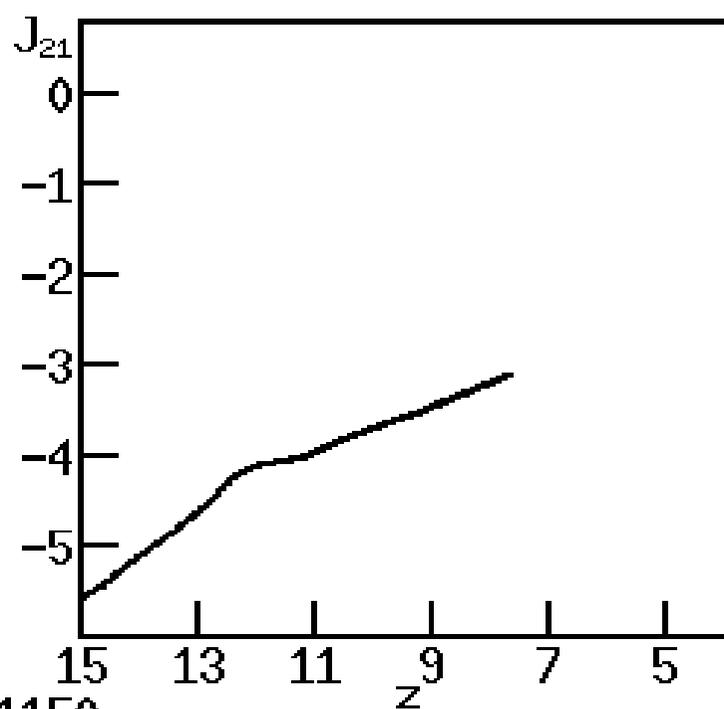
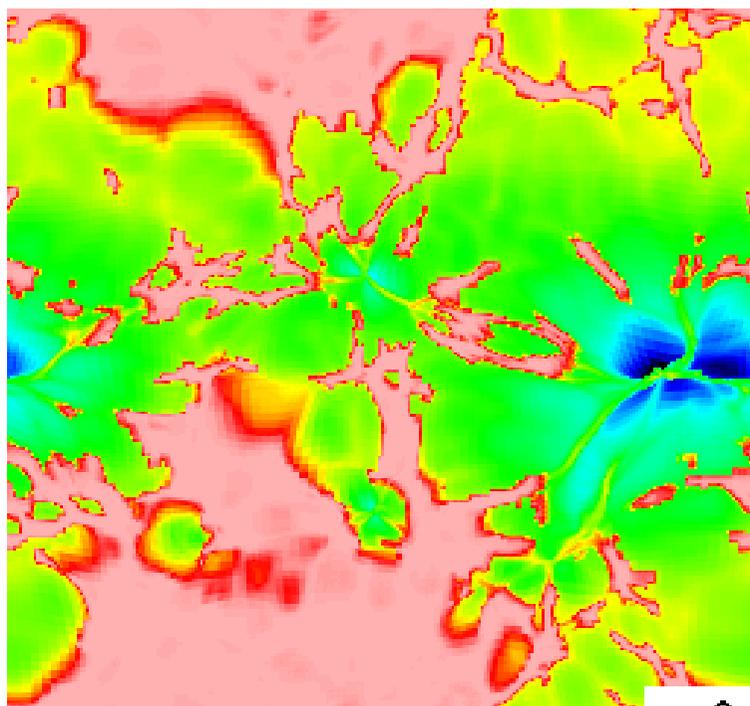
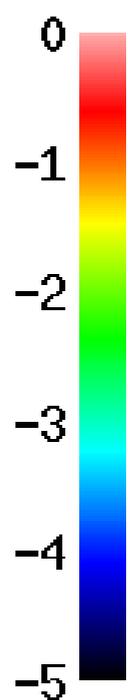
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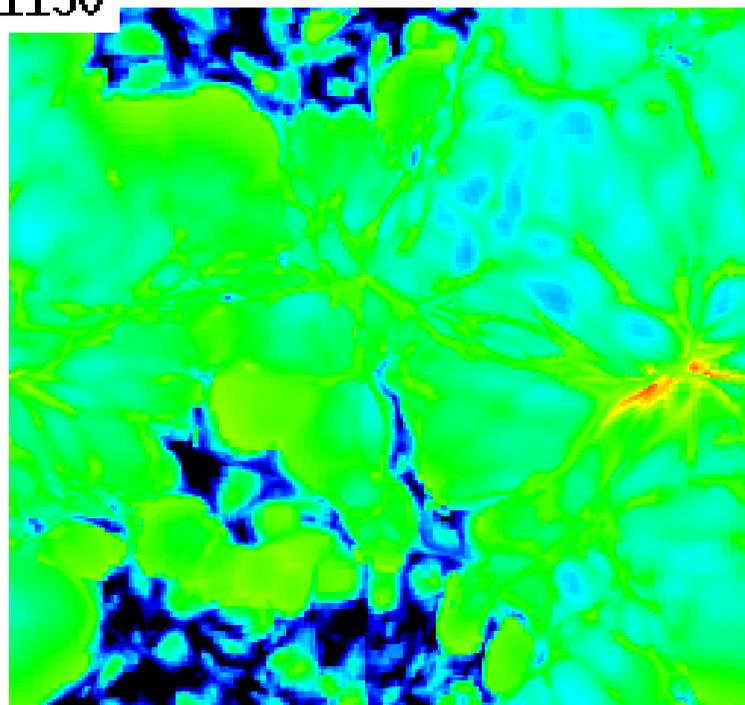
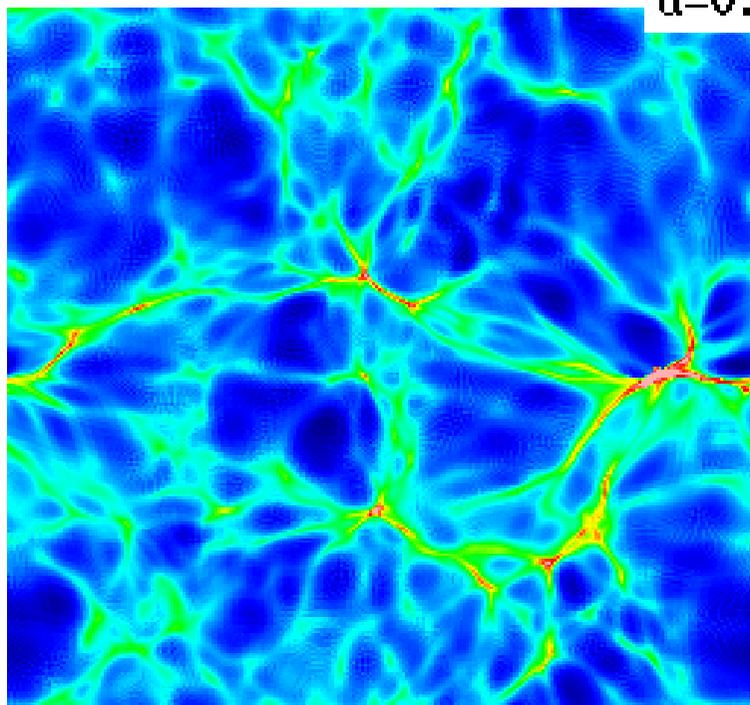
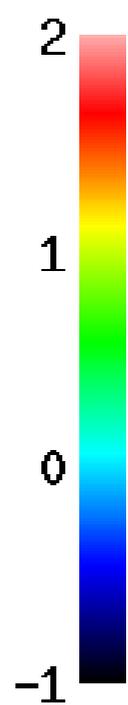


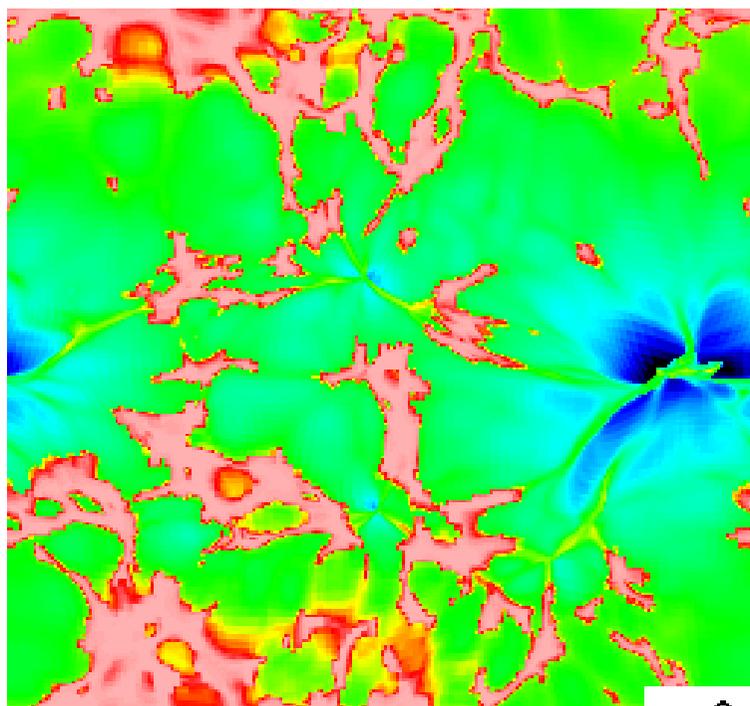
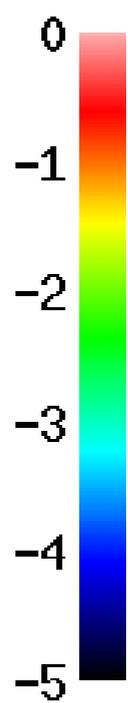
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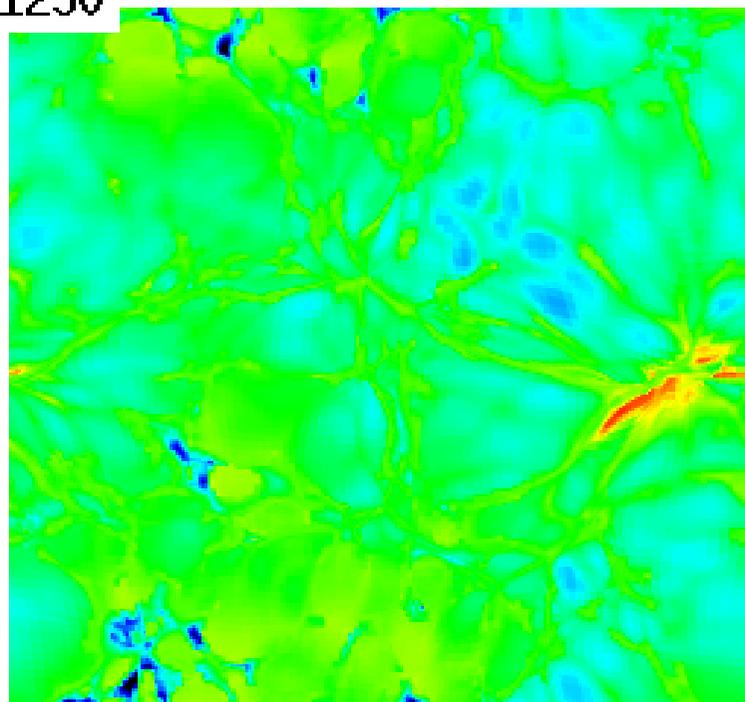
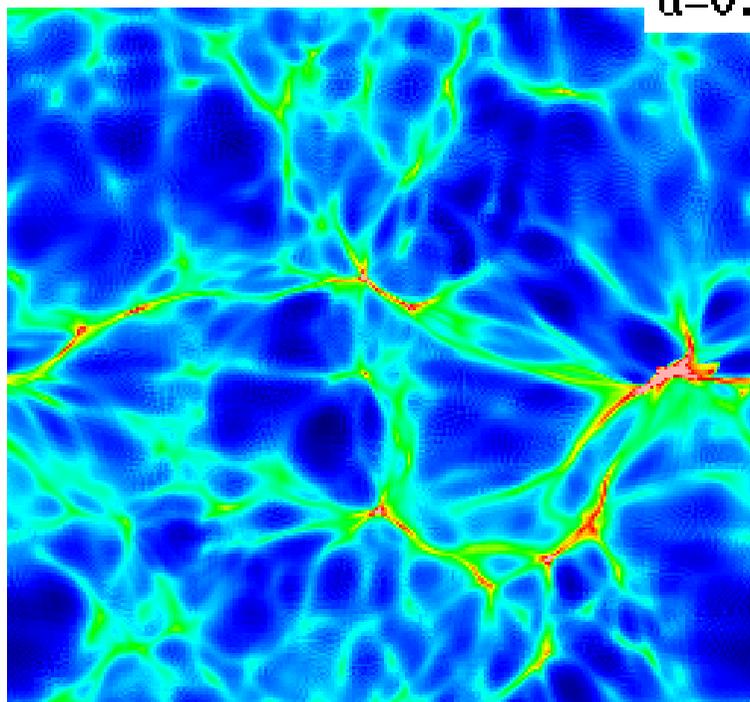
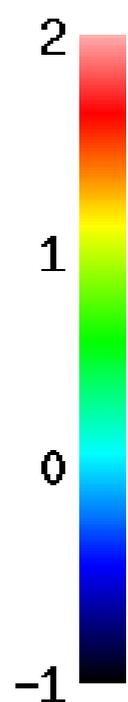
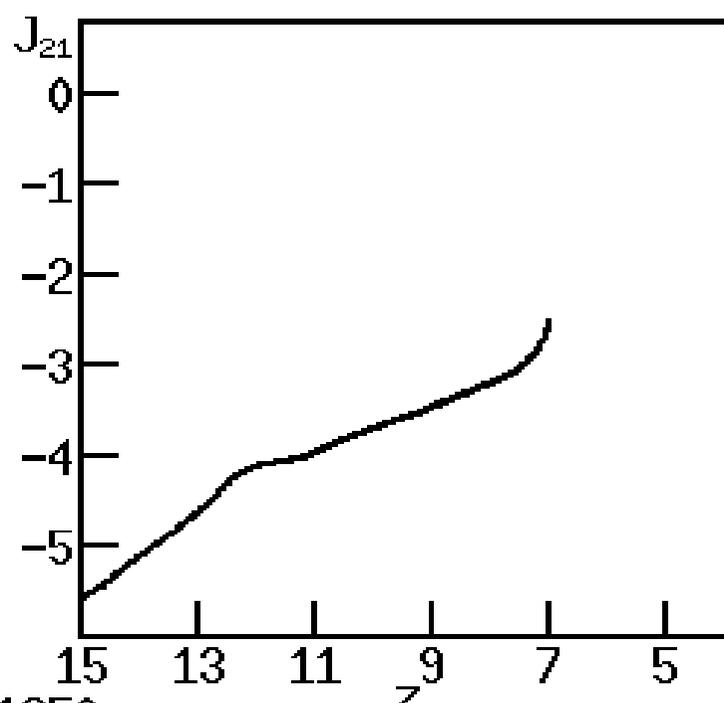


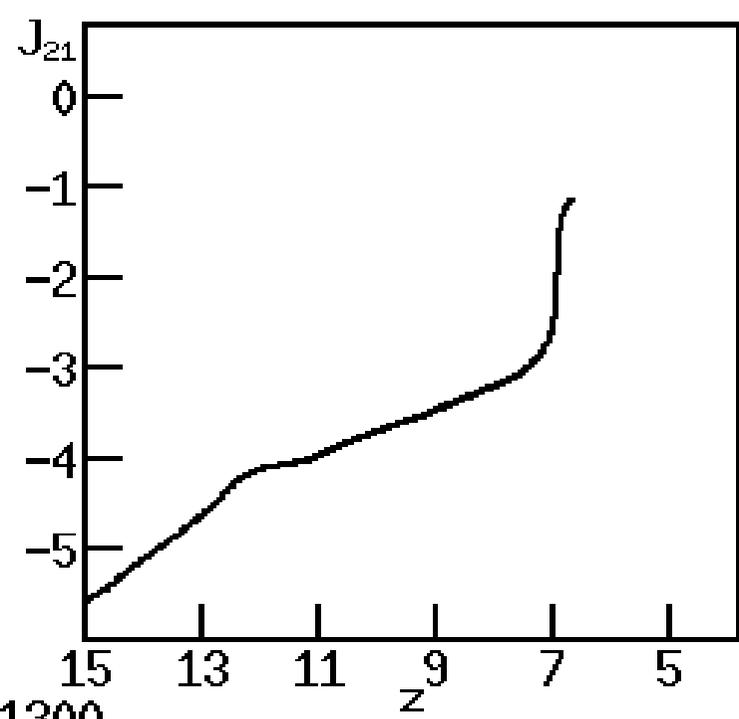
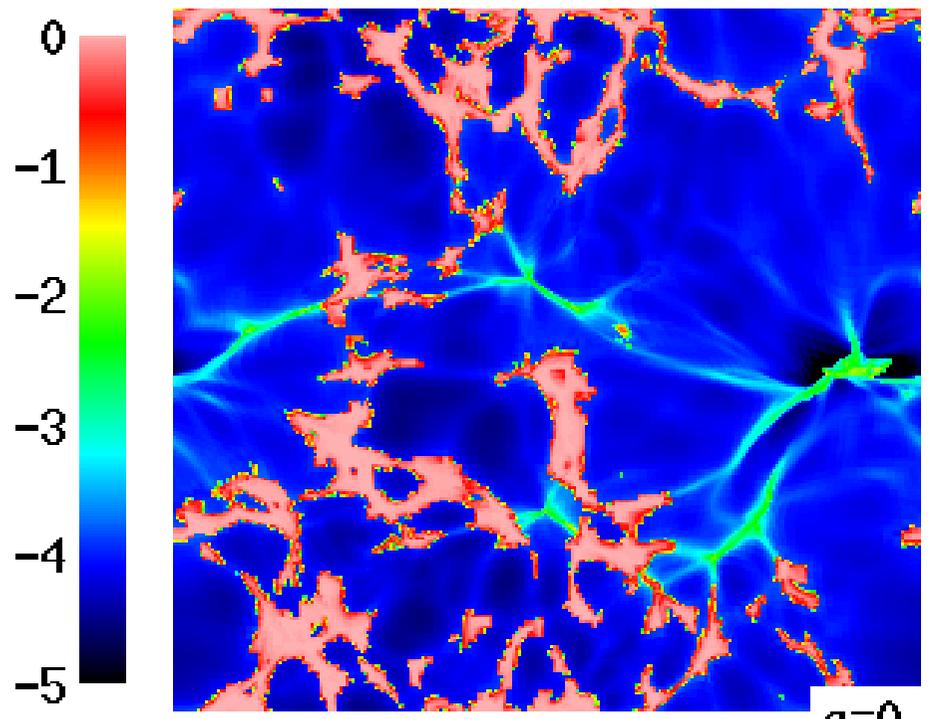
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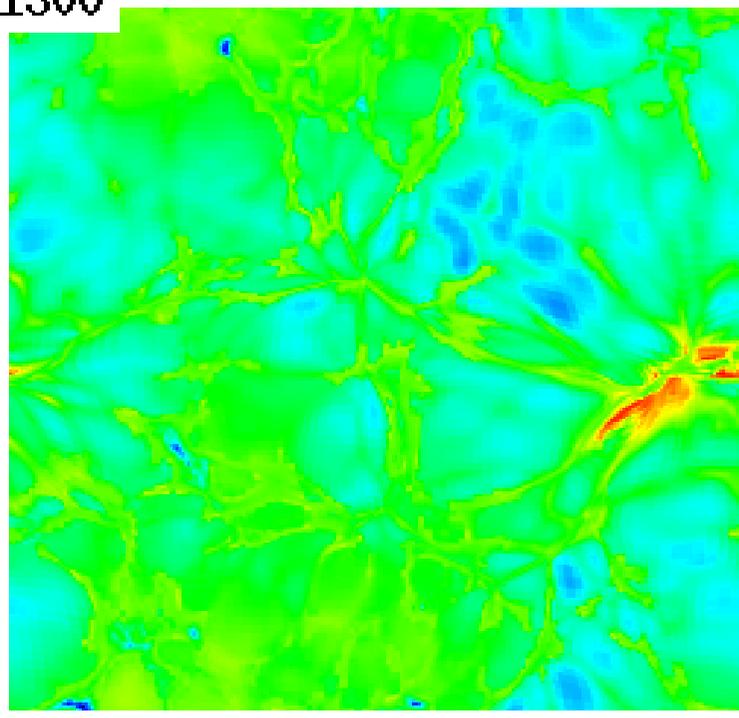
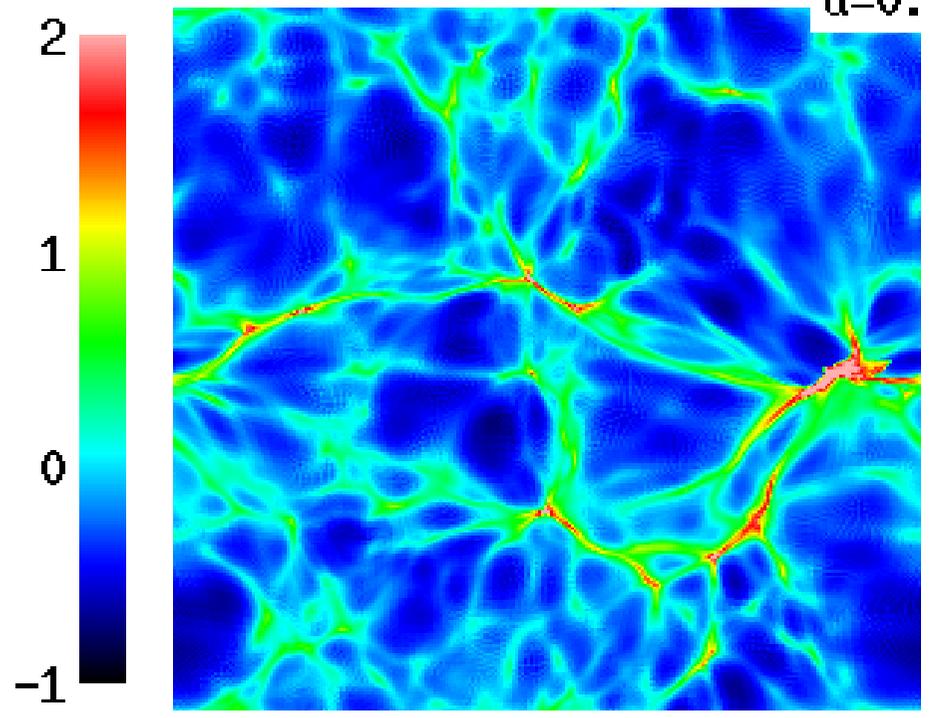


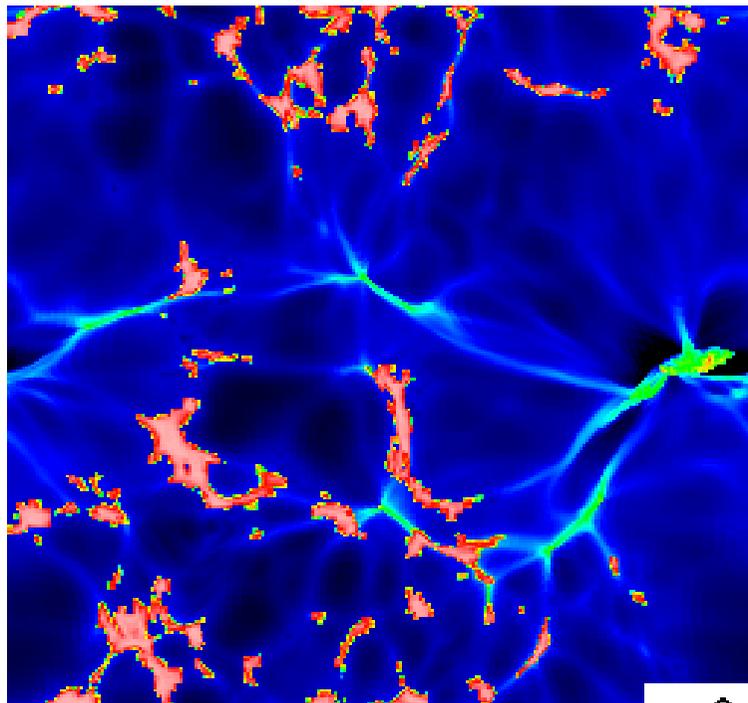
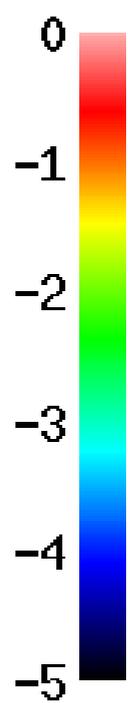
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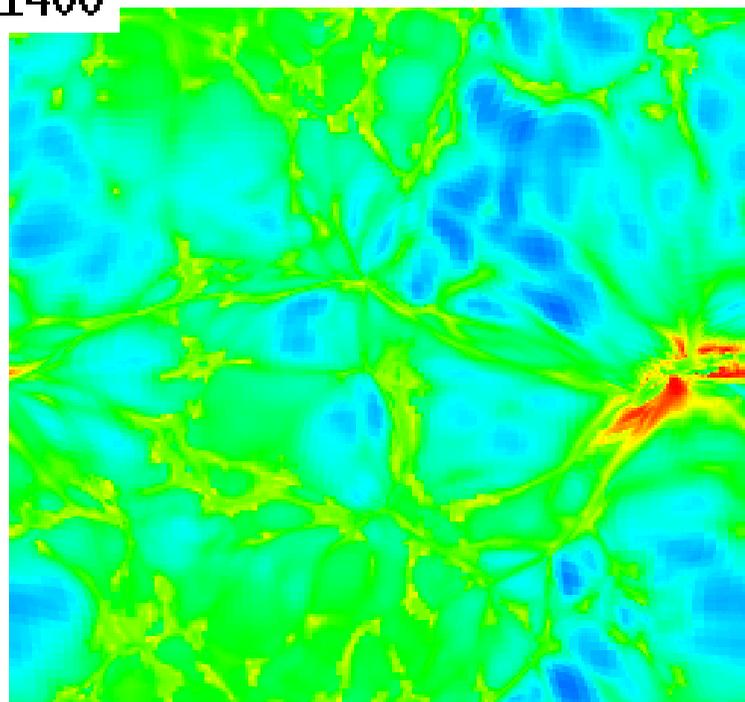
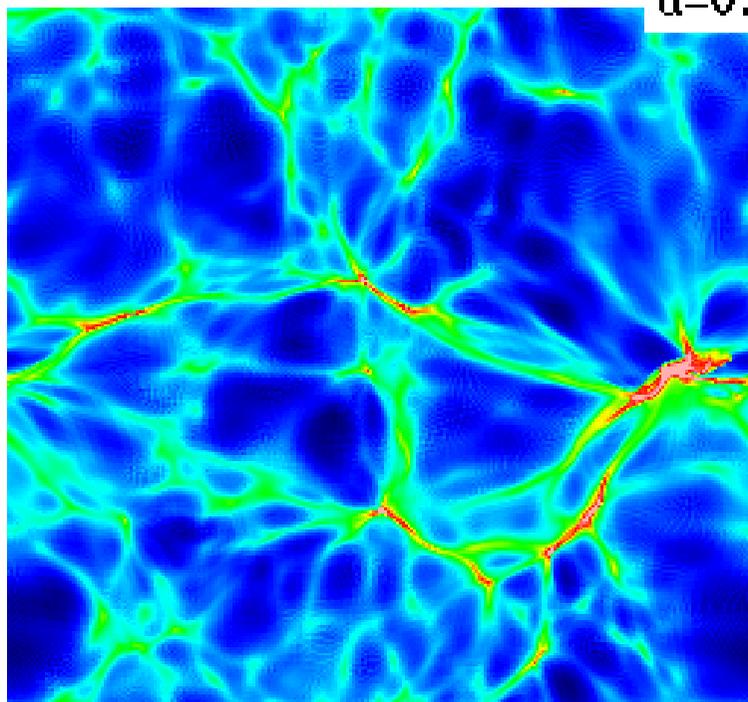
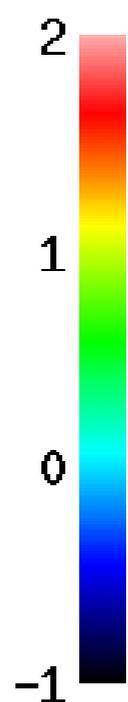
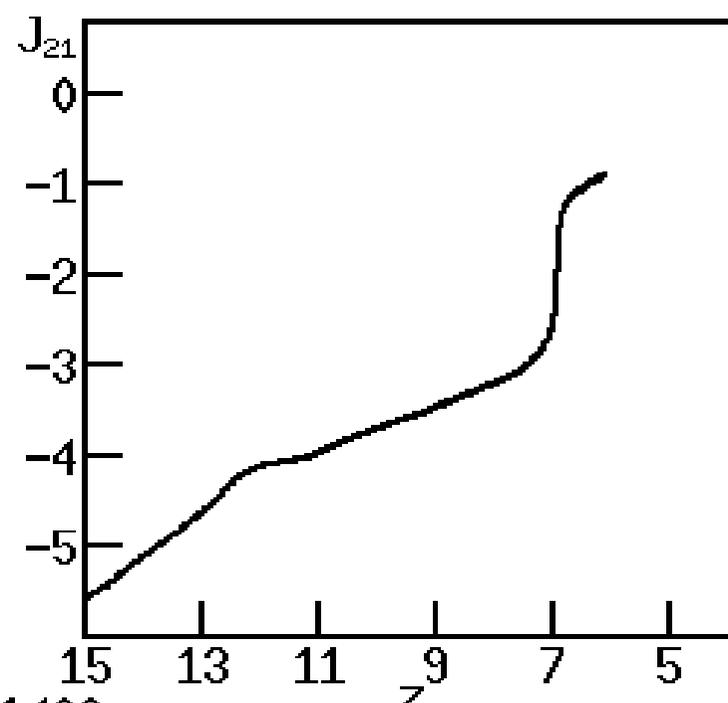


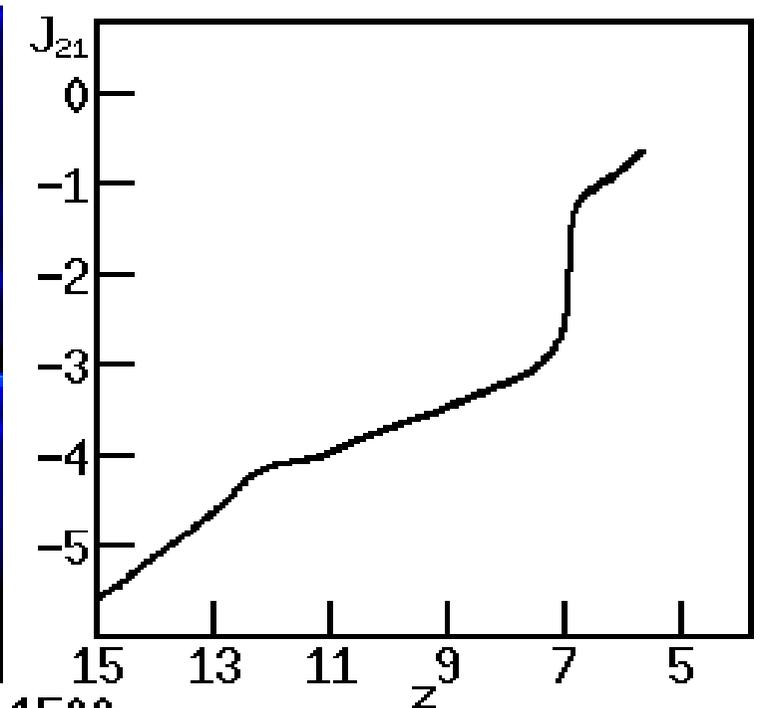
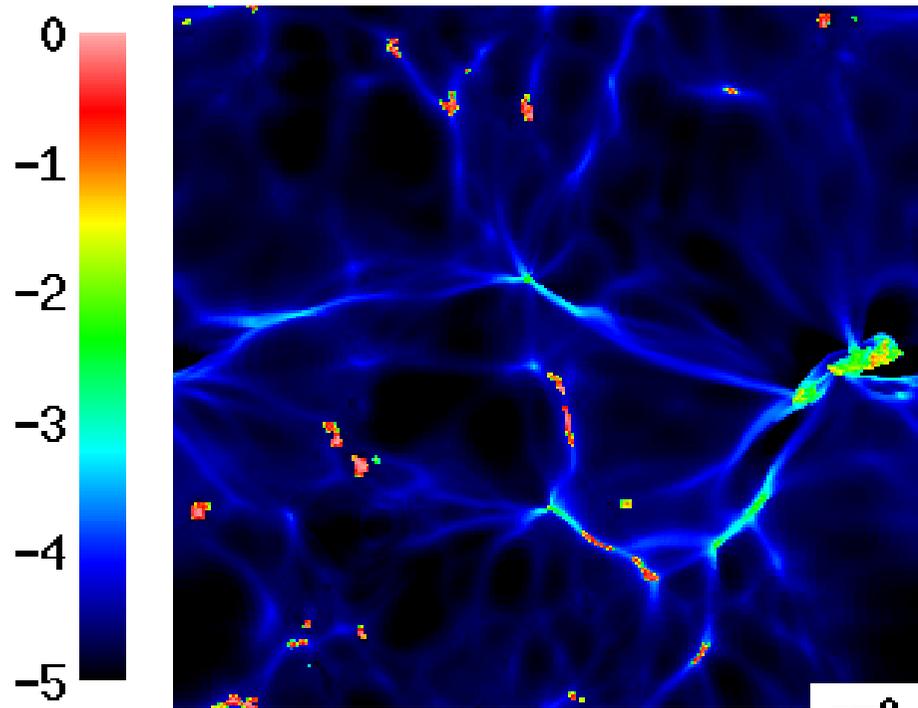
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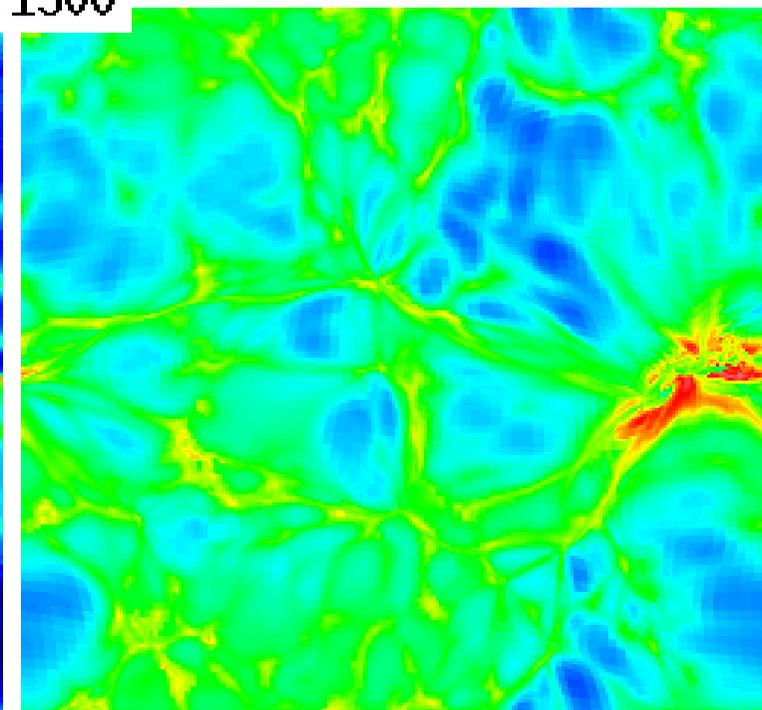
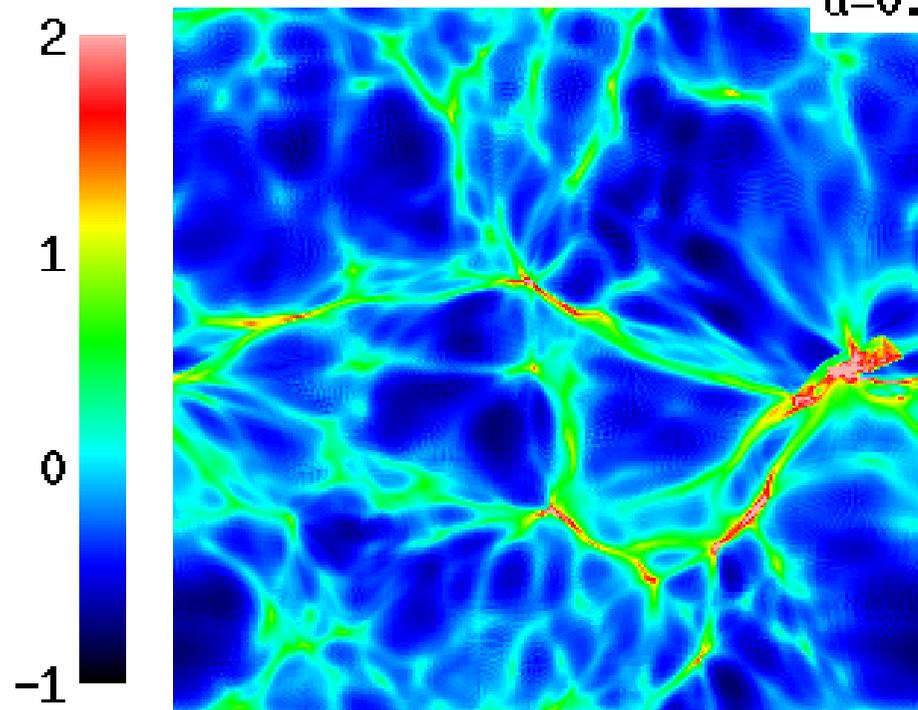


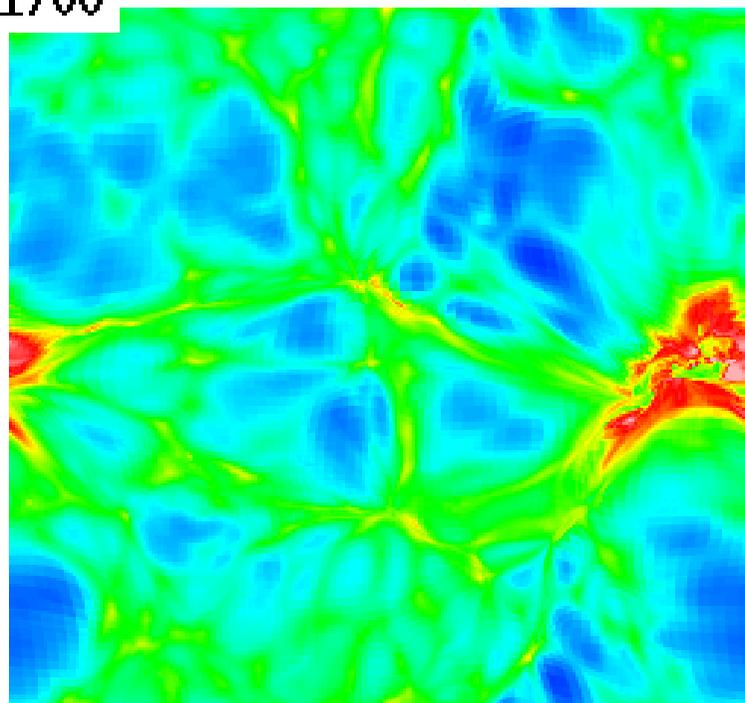
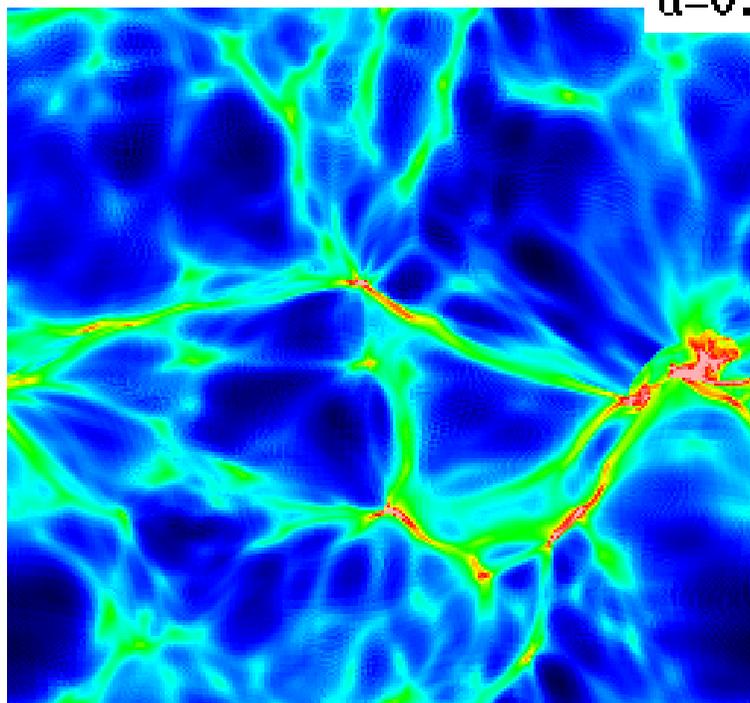
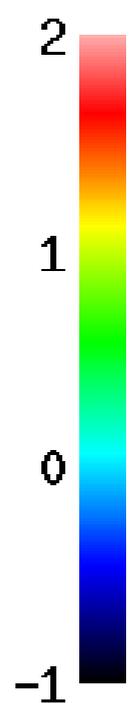
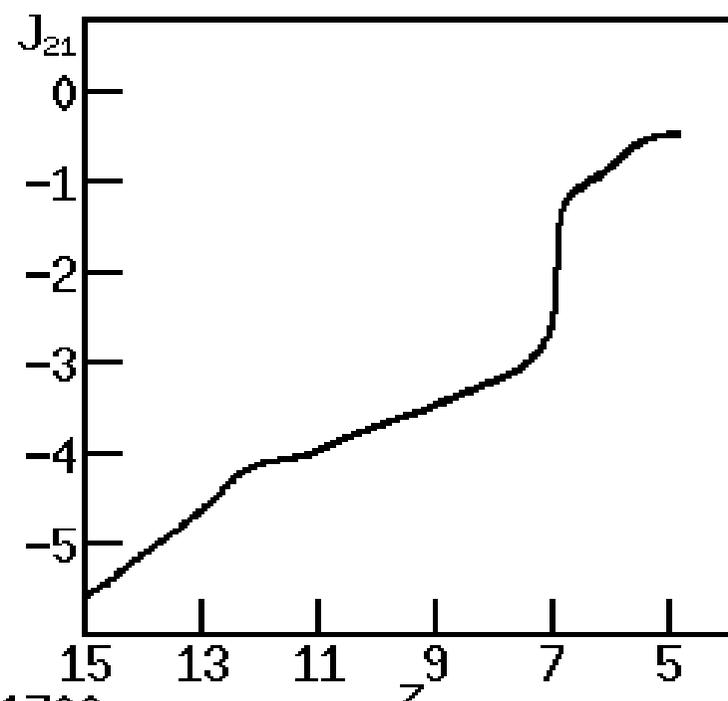
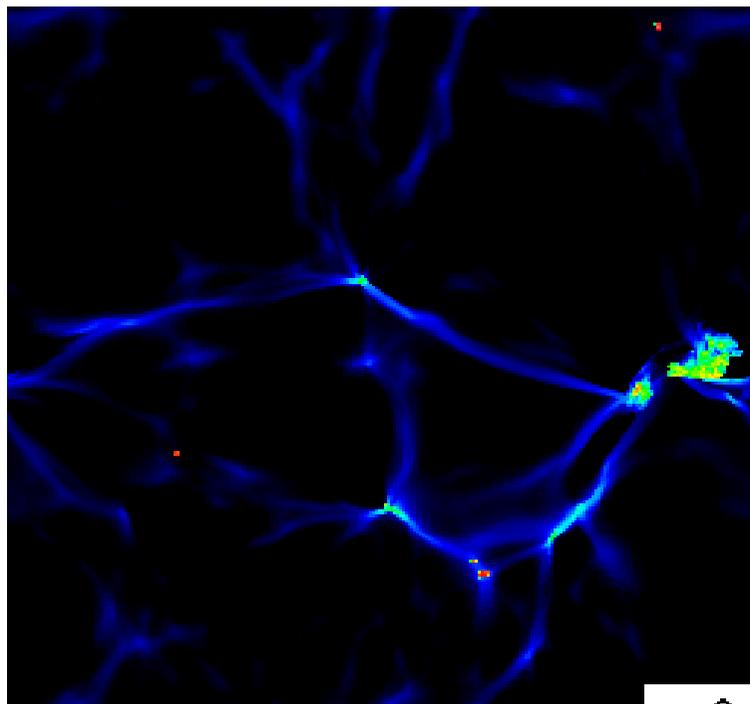
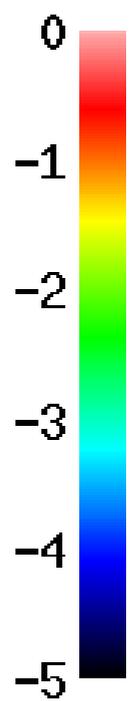
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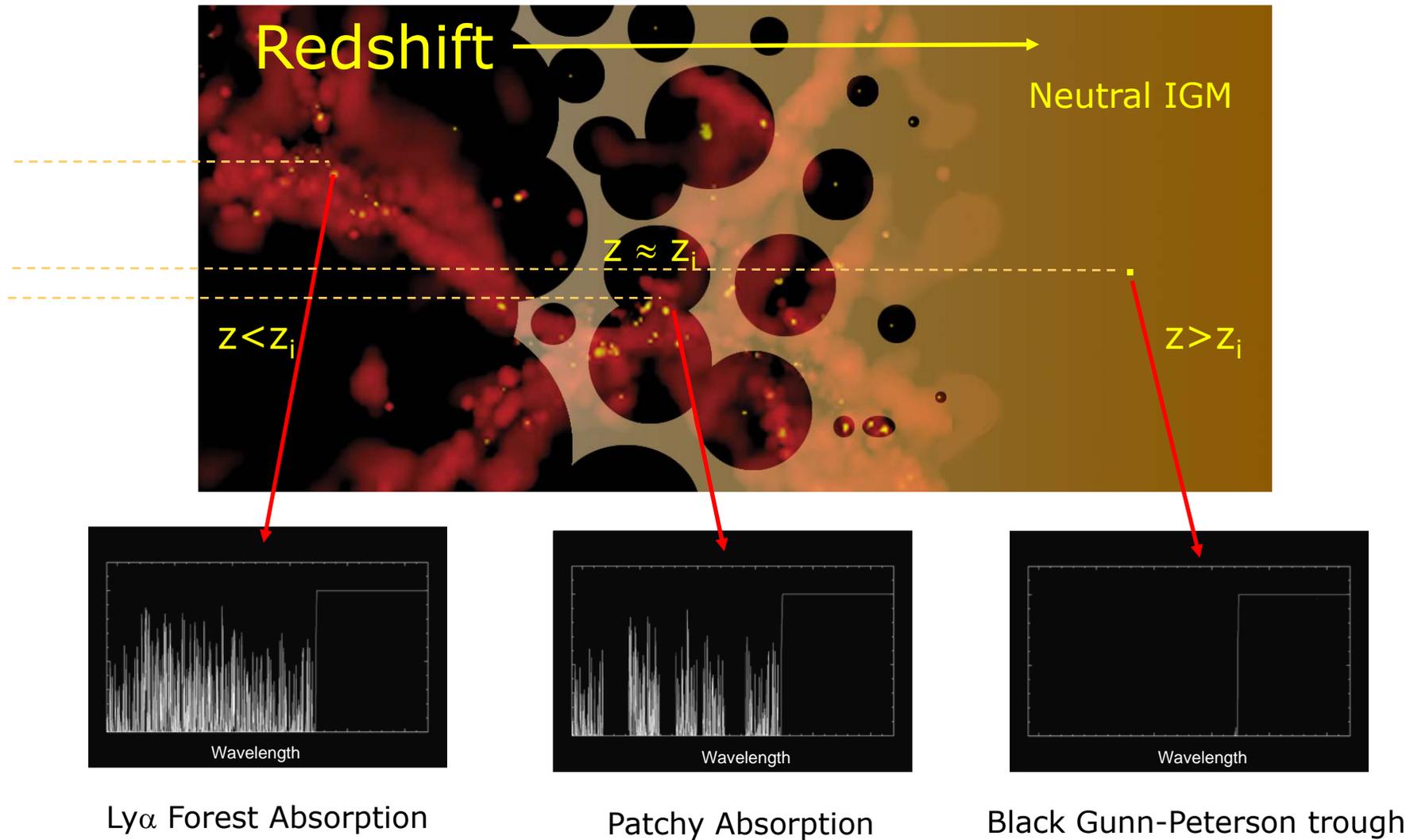
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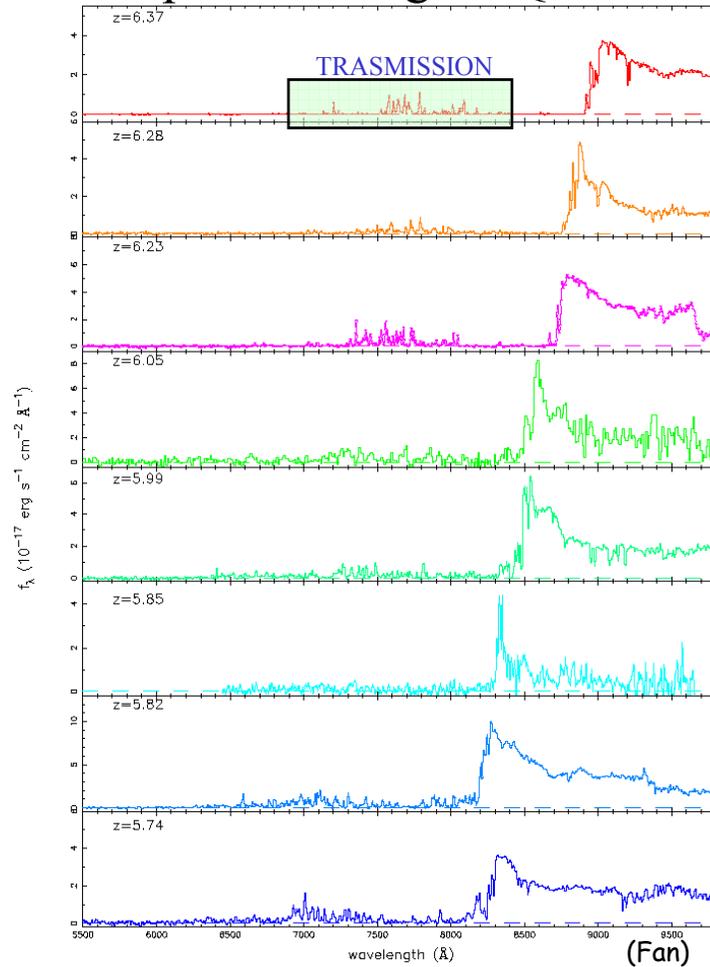
Reionization completed

## REIONIZATION TESTS

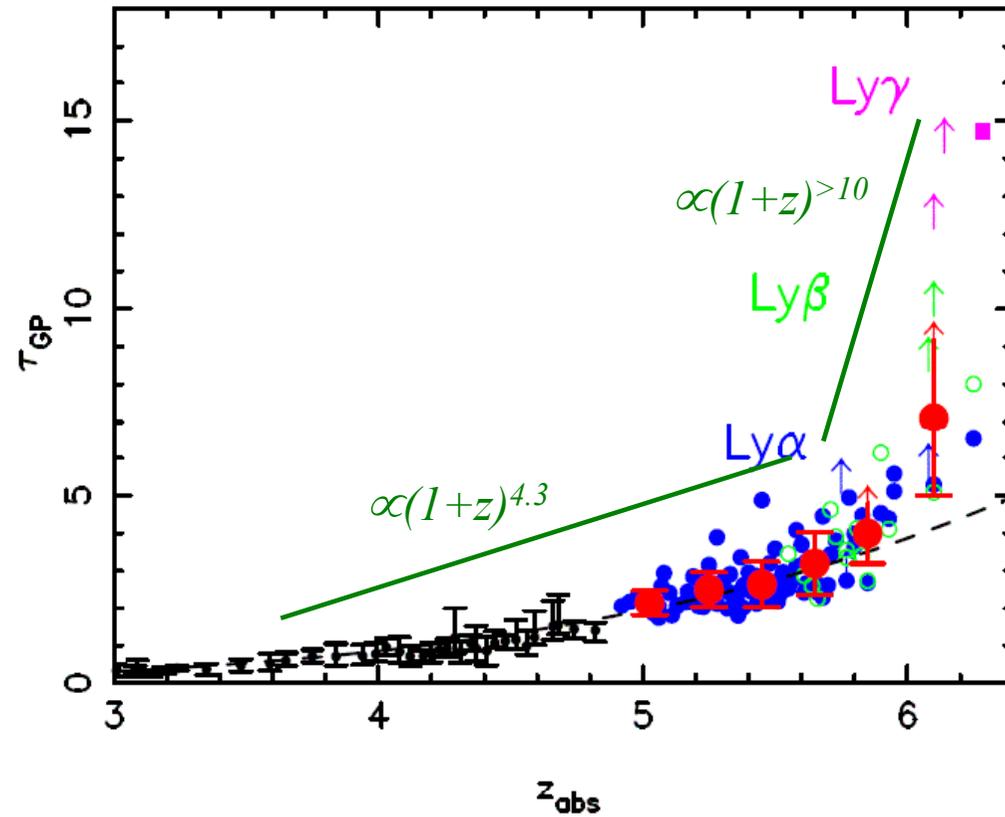


GUNN-PETERSON EFFECT

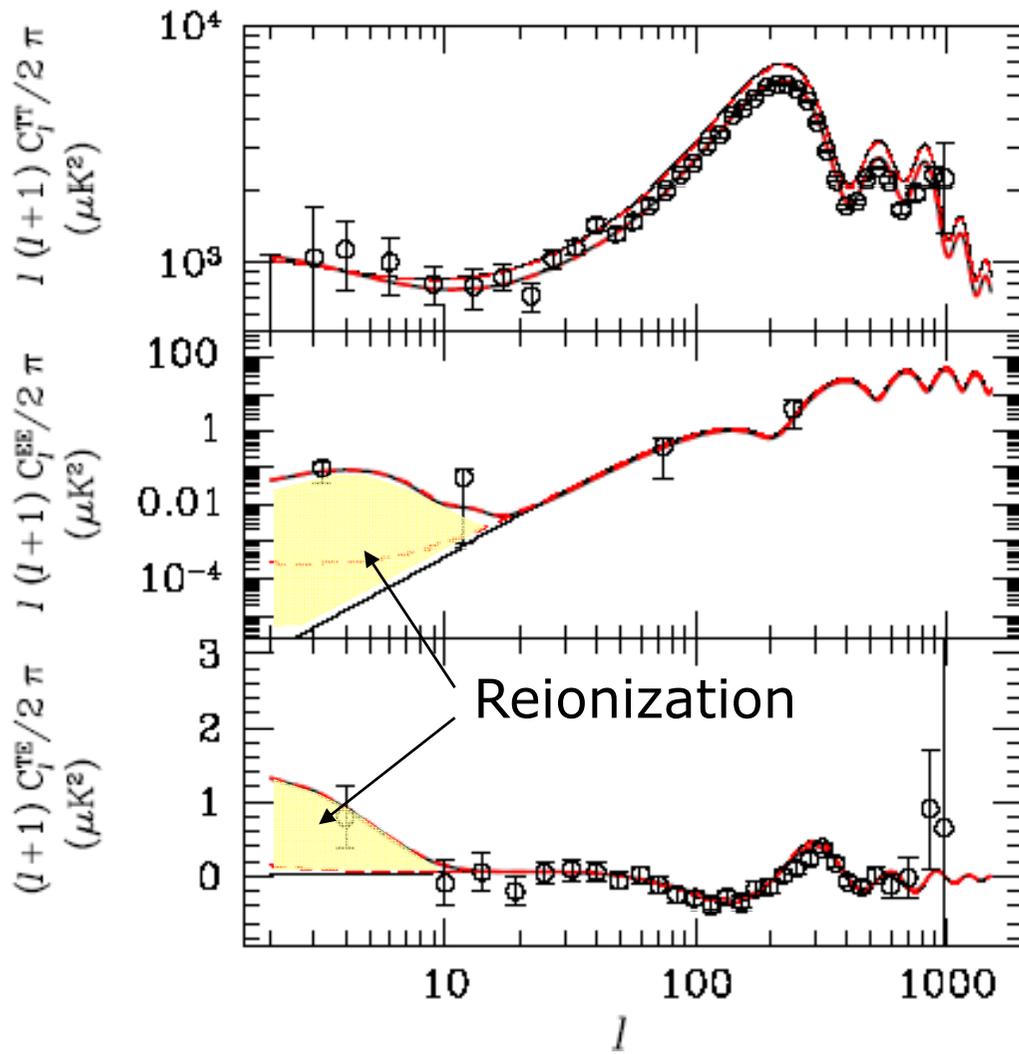
Spectra of high- $z$  QSOs



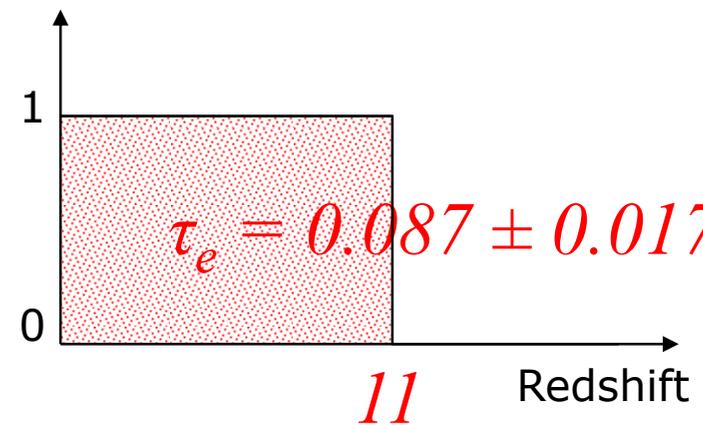
Ly $\alpha$  optical depth



WMAP RESULTS



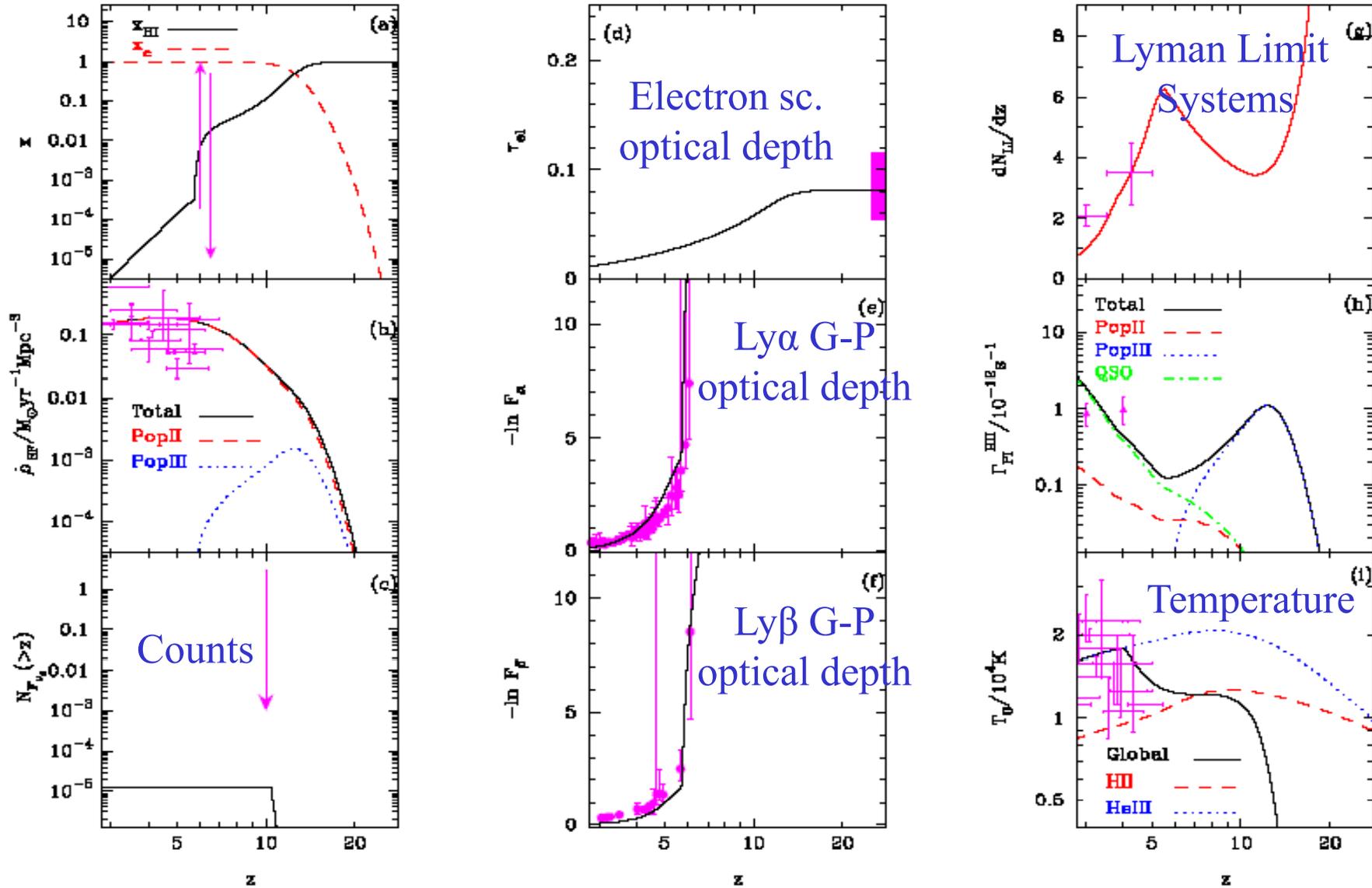
Electron fraction



# GLOBAL REIONIZATION MODELS

## REIONIZATION HISTORY

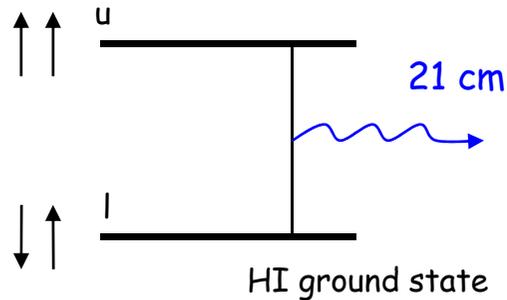
*Choudhury & AF 2005, 2006*



# The Future

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## HI 21 CM LINE EMISSION



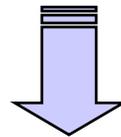
$$n_u/n_l = 3\exp(-0.07\text{K}/T_s)$$

Ideal probe of neutral H at high- $z$   
 different observed frqs.  $\rightarrow$  different  $z$   
 ( $\nu \sim 150, 120, 80$  MHz  $\rightarrow z \sim 8, 11, 18$ )

CMB photons are absorbed  $\rightarrow$  thermal equilibrium

$$T_s \longleftrightarrow T_{\text{CMB}}$$

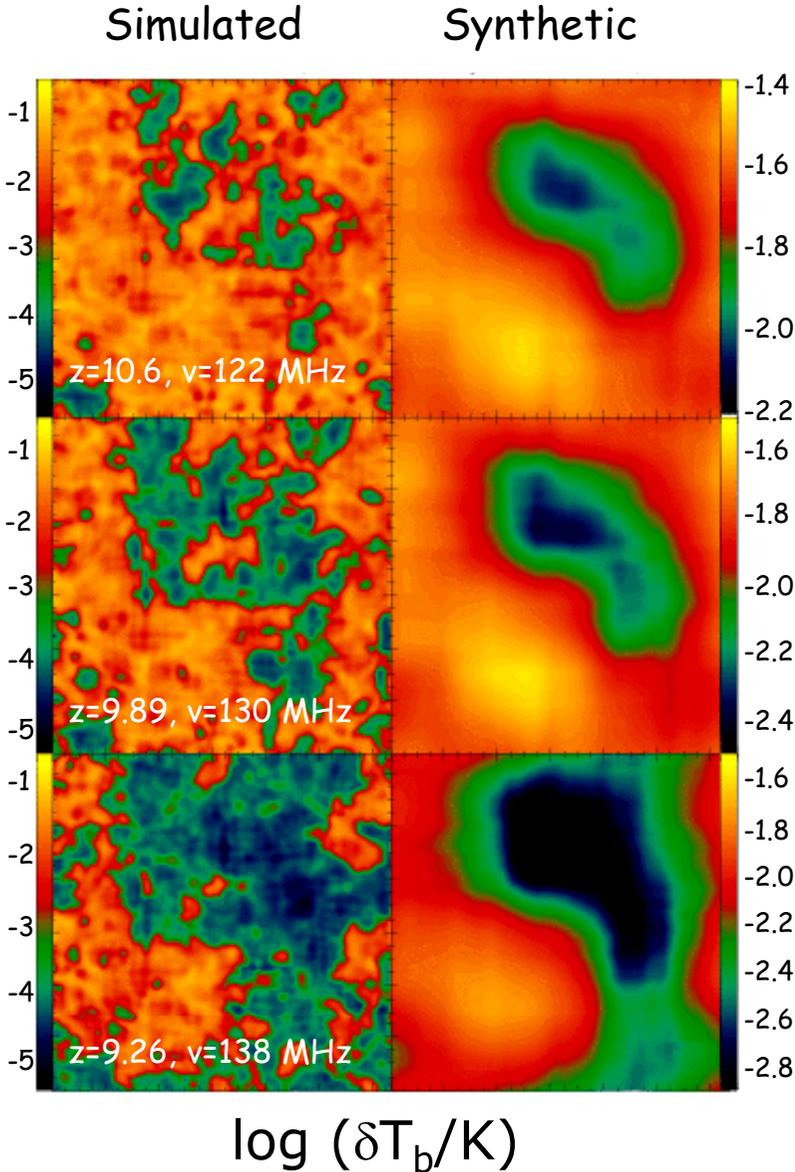
Scattering with Ly $\alpha$  photons



DECOUPLING

LOFAR DETECTION OF REIONIZATION

Valdes+ 2006



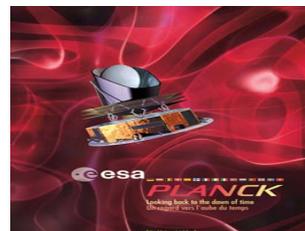
Synthetic LOFAR observation of a simulated reionization history

Brightness temperature

$$T_b = I_\nu \frac{c^2}{2k \nu^2}$$

## FUTURE OUTLOOK

- HI 21cm line detection from Dark Ages/EoR
- Constrain reionization history
- Detecting reionization sources/first stars
- Detecting high-z molecules/dust
- CMB secondary anisotropies: patchy reionization
- Search for high-z Gamma Ray Bursts



The End

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