

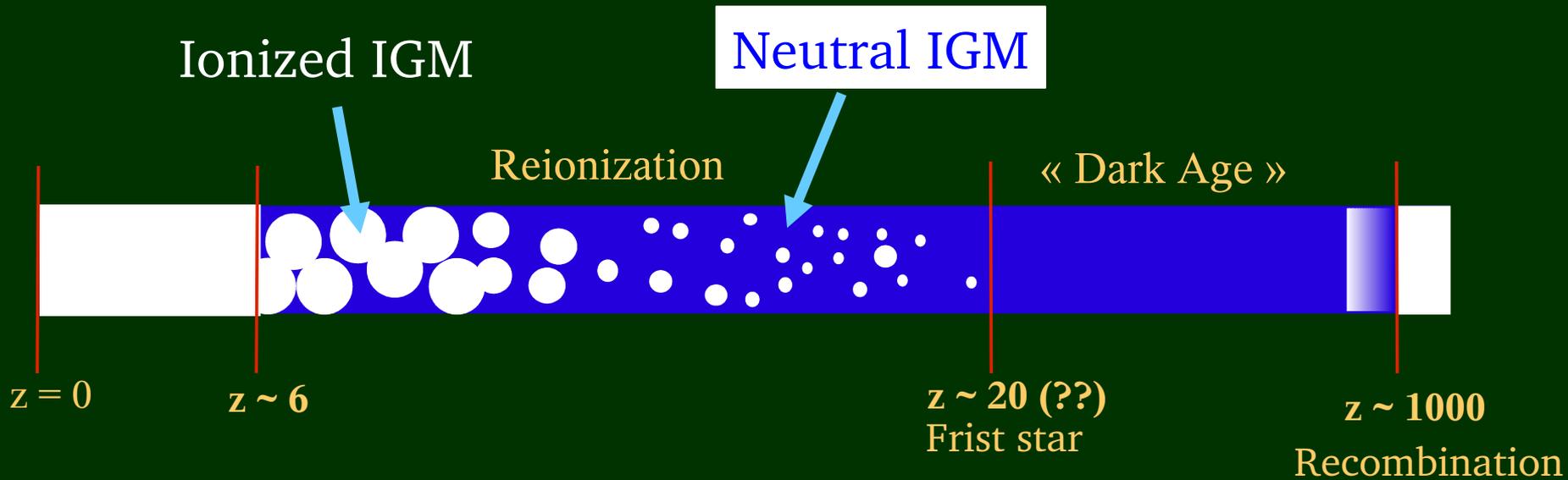
Simulated 21-cm Signal from the EoR Including Full Ly- α Radiative Transfer

Bonn, April 2008

Baek, Di Matteo, Semelin, Combes, Revaz

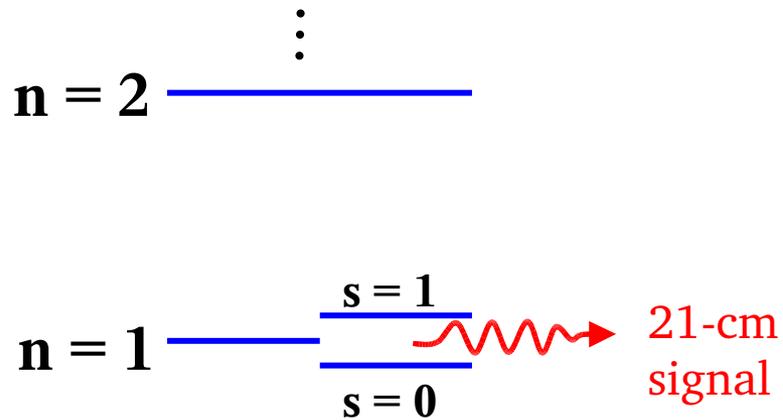
LERMA - Observatoire de Paris

Epoch of Reionization



- 21-cm signal emitted from neutral H atom :
 - Direct probe of neutral IGM during this era
- Detect highly redshifted 21-cm signal : SKA, LOFAR, MWA...
- Numerical simulation to predict the 21-cm signal

21-cm signal



H atom

- Spin Temperature : T_s

$$\frac{n_{s=1}}{n_{s=0}} = 3 \exp(-T_{\text{c}}/T_s)$$

$$T_{\text{c}} \equiv h\nu_{10}/k_B = 0.07 K$$

What we need to predict the 21-cm signal?

The 21-cm brightness temperature(T_B) depends on :

- δ : Baryon Overdensity \leftarrow Dynamics
- $1-x_i$: Neutral Fraction \leftarrow Dynamics+SF+RT(UV)
- T_s : Spin Temperature \leftarrow Dynamics+SF+RT(UV+Ly-)

< What we need >

<Numerical Simulation>

$$\delta T_B = T_B - T_{CMB} \propto (1 + \delta) (1 - x_i) \left(\frac{T_s - T_{CMB}}{T_s} \right)$$

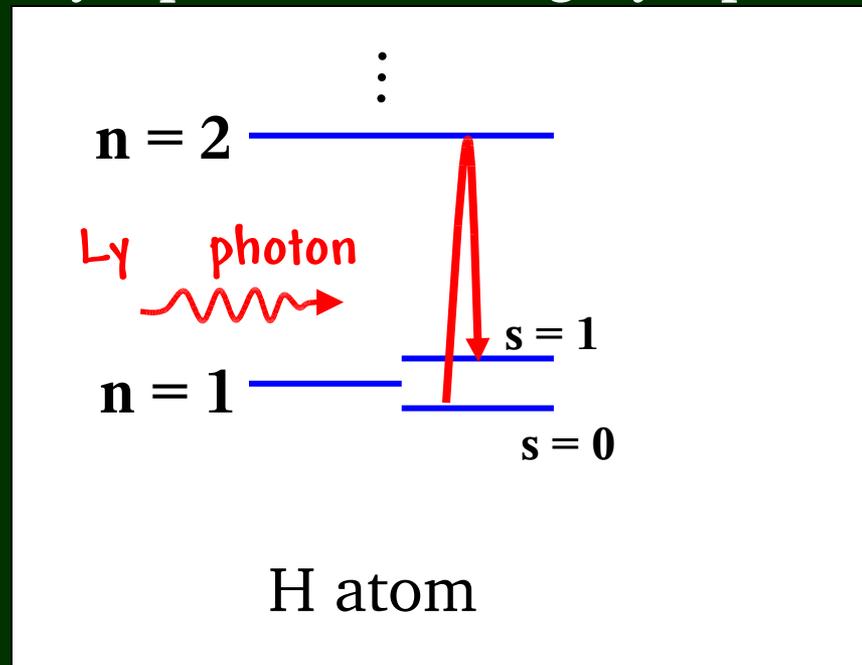
\Rightarrow If $T_s < T_{CMB}$, signal seen in absorption against the CMB

If $T_s > T_{CMB}$ signal seen in emission.

If $T_s = T_{CMB}$ no signal.

Spin Temperature : T_s

- Coupling of T_s to T_{CMB} ($T_s = T_{\text{CMB}}$) \rightarrow Signal undetectable!
- Two process $T_s \sim T_K \neq T_{\text{CMB}}$
 - Collision (in overdense region)
 - Pumping by Ly- photon (strong Ly- photon flux)



Spin Temperature : T_s

- Coupling of T_s to T_K - High density (Collision)
 - Sufficient Ly- α photon flux
- $T_s \sim T_K \gg T_{\text{CMB}}$ is always valid?
 - False - When Ly- α flux is weak.
 - If gas is not heated in the voids by quasars.

→ No absorption regime

- Motivation
 - Full modelization of the Ly- α radiative transfer
 - Compare the resulting 21-cm signal
 - “Homogeneous Ly- α flux” vs. “Local Ly- α flux”

The code LICORICE

Dynamic Part

- Treecode + SPH + Star Formation
- GADGET or LICORICE

UV Continuum Part

- Monte Carlo on adaptative grid
- Source model : Salpeter IMF cut off 1-120 M_{\odot}

Ly- Line Transfer

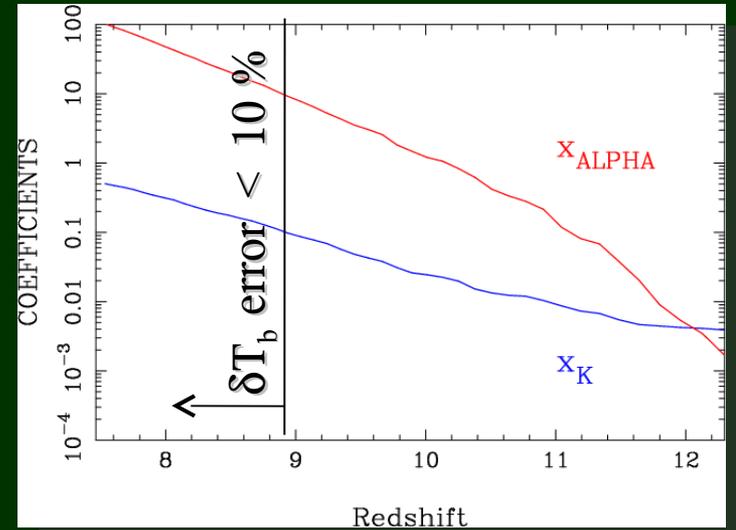
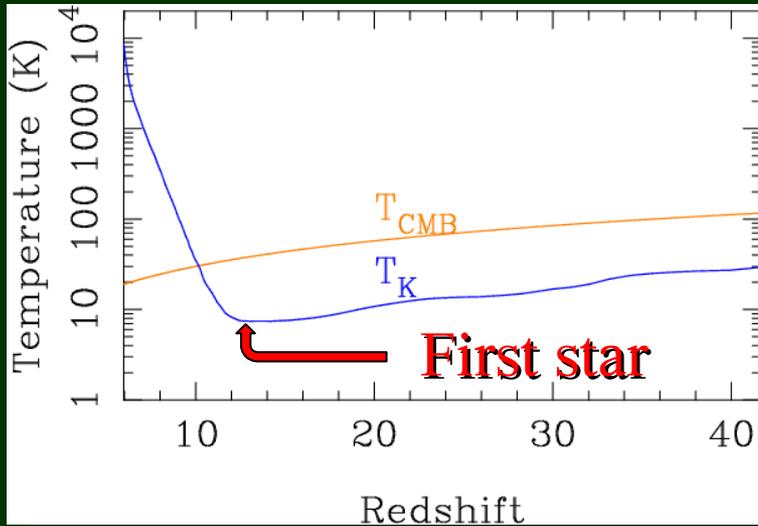
- Monte Carlo on adaptative grid
- Full comoving line transfer $\rightarrow x$
- Validity and relevance tested in Semelin et al. 2007

$$x_{\alpha} = \frac{4P_{\alpha} T_{i}}{27 A_{10} T_{CMB}}$$

If $x \rightarrow \infty$,

$T_S \sim T_K$ by Ly- pumping

The $T_S = T_K$ assumption : $x = \infty$



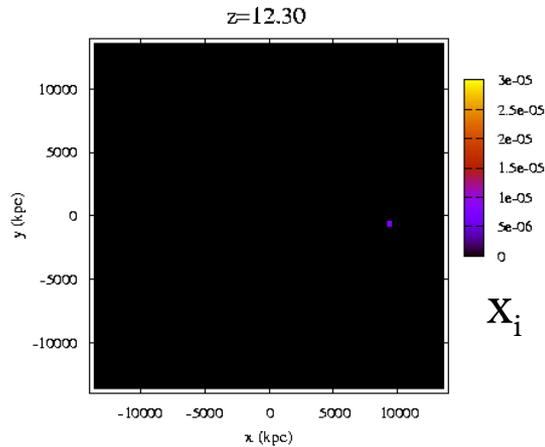
This is a **lower limit** on the T_B error :

- Larger box \rightarrow larger x fluctuations
 \rightarrow Larger T_B error
- Harder source spectrum \rightarrow Delayed x saturation
 \rightarrow Larger T_B error

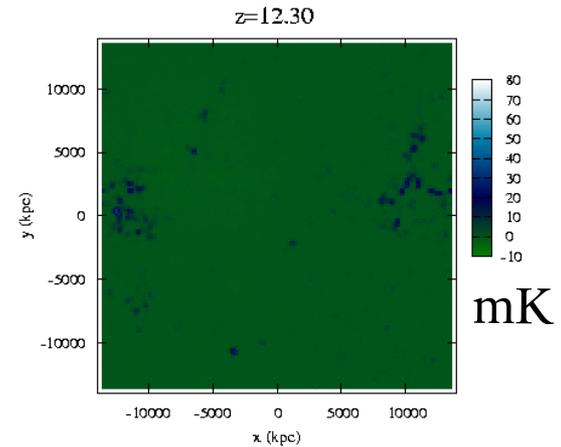
$T_S = T_K$ assumption is **incorrect** during the absorption phase (and early emission).

Emission map at different z

2 comoving Mpc slice



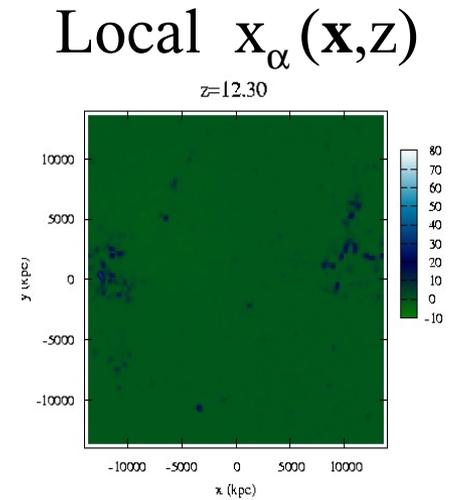
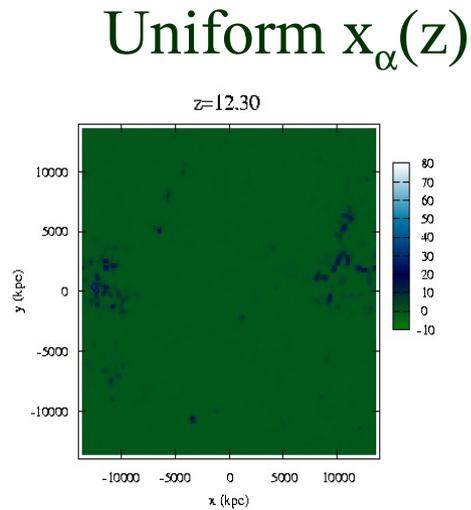
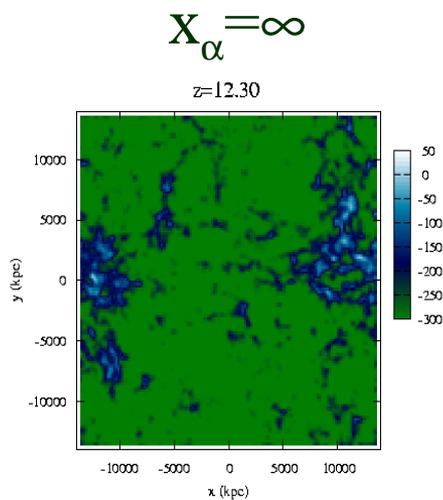
Ionization map



T_B map

Soft source spectrum \Rightarrow no preheating \Rightarrow strong absorption features

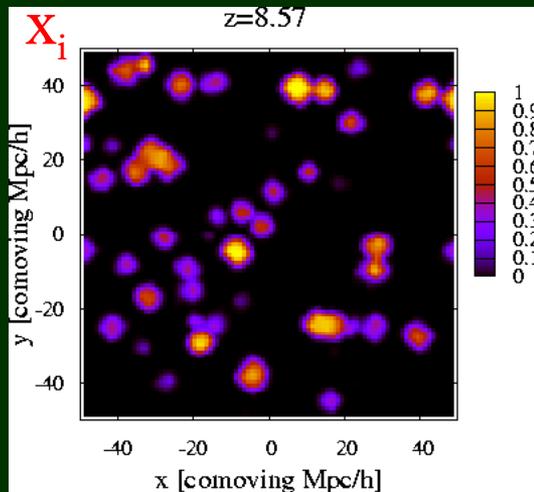
$\delta T_B(z)$: influence of Ly- α treatment



- ✓ Ly- α important mainly in the absorption phase
- ✓ Bigger influence in larger simulation box

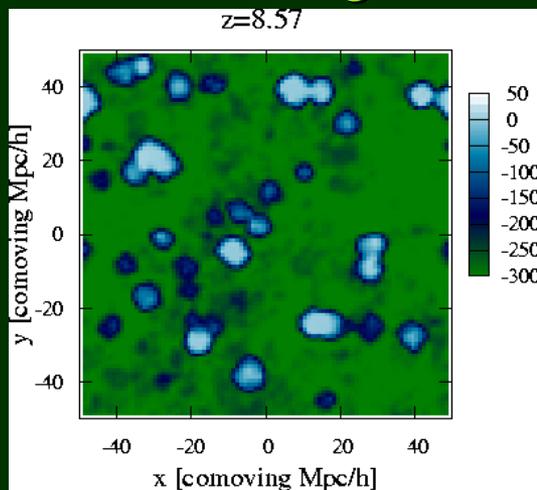
Two interesting redshifts ($z=8.57$)

Ionization map

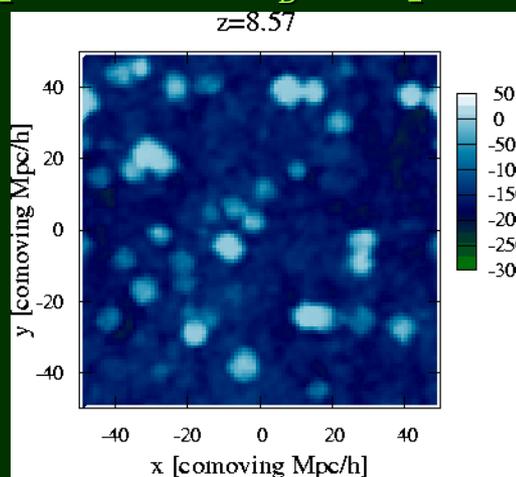


$$\langle X_\alpha \rangle = 1$$
$$\langle X_i \rangle = 0.05$$

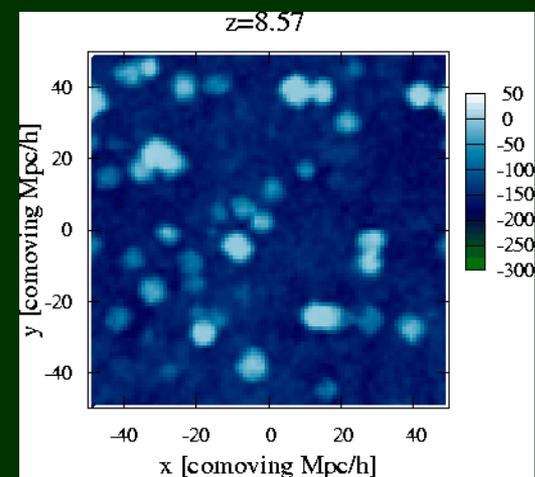
Differential brightness temperature (δT_B) map



$$X_\alpha = \infty$$

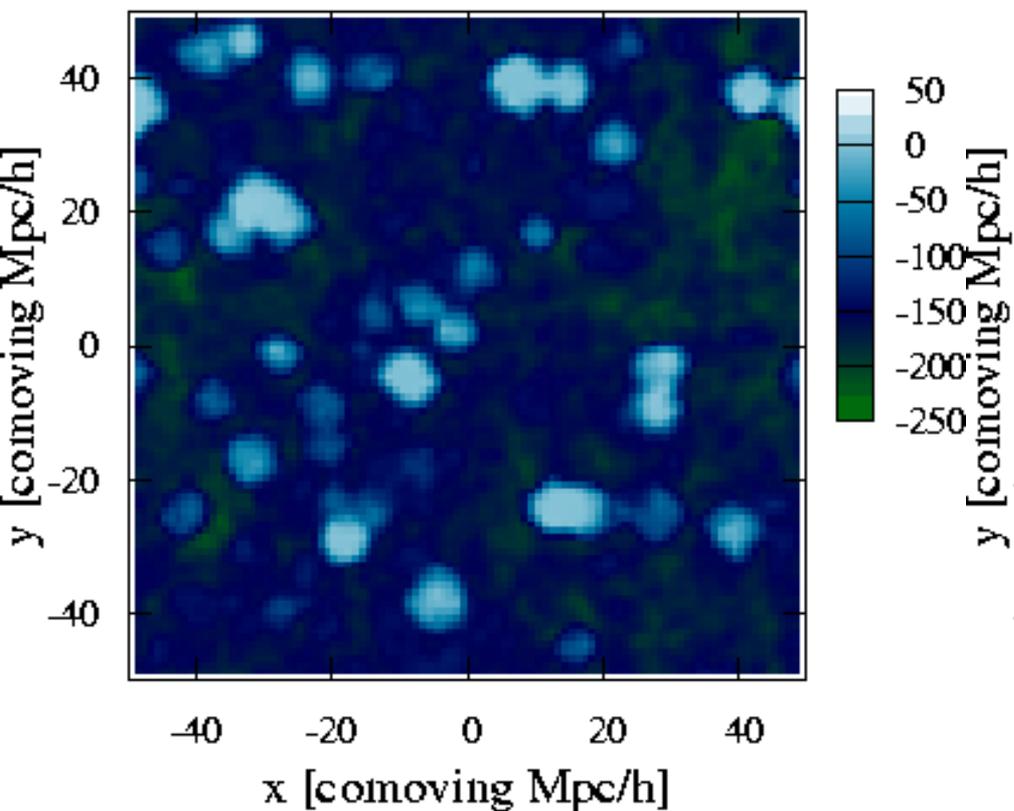


$$X_\alpha(z)$$

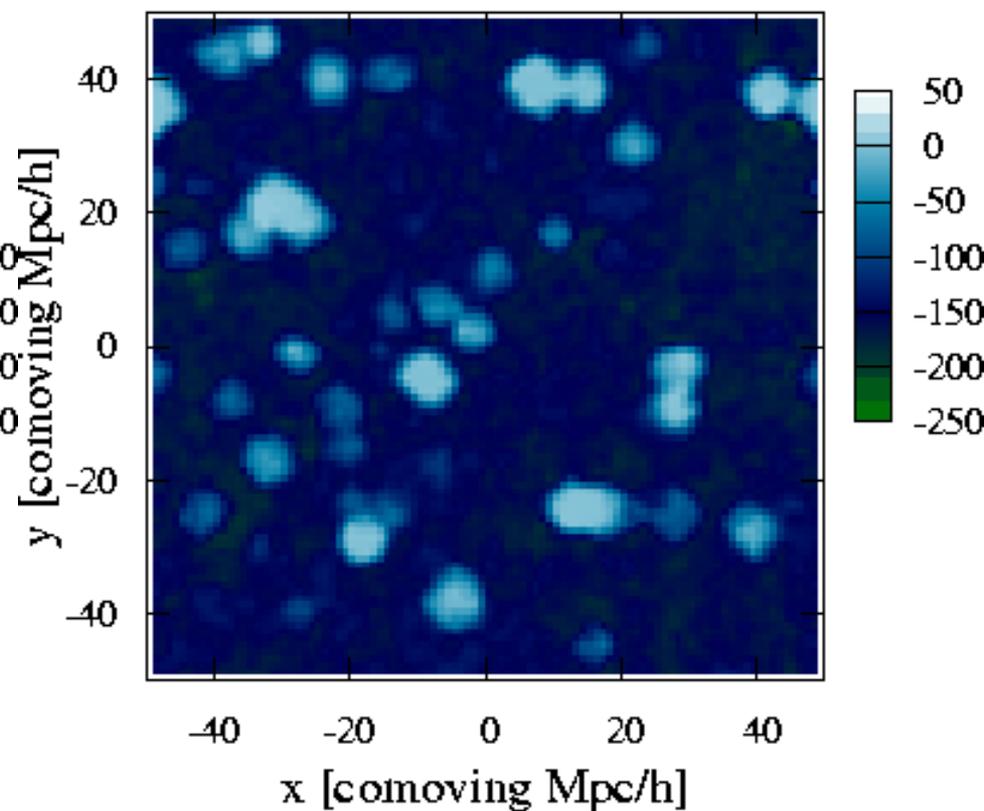


$$X_\alpha(x,z)$$

$z=8.57$

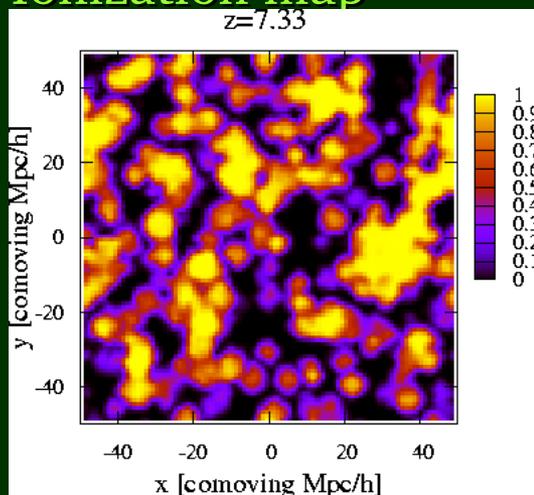


$z=8.57$



Two interesting redshifts ($z=7.33$)

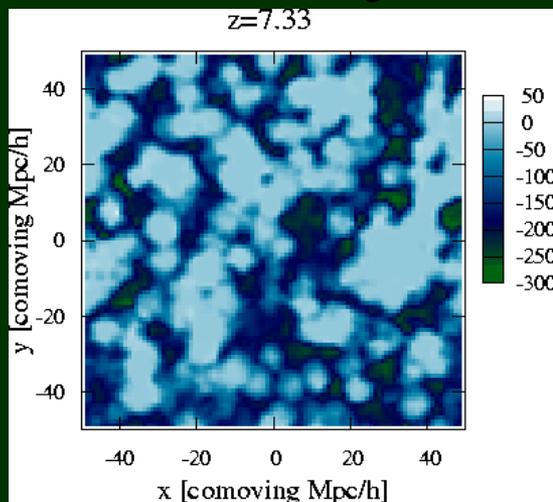
Ionization map



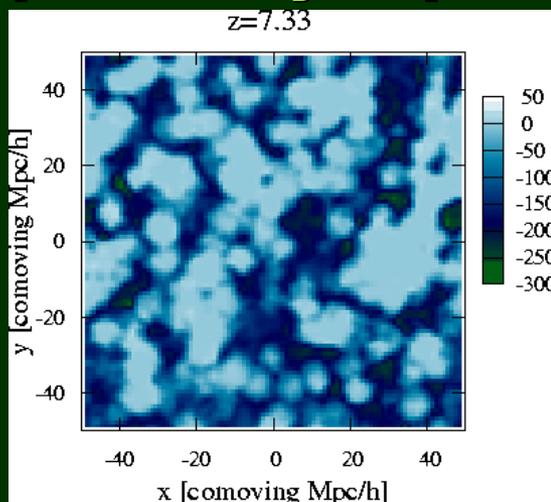
$$\langle x_\alpha \rangle = 11.9$$

$$\langle x_i \rangle = 0.37$$

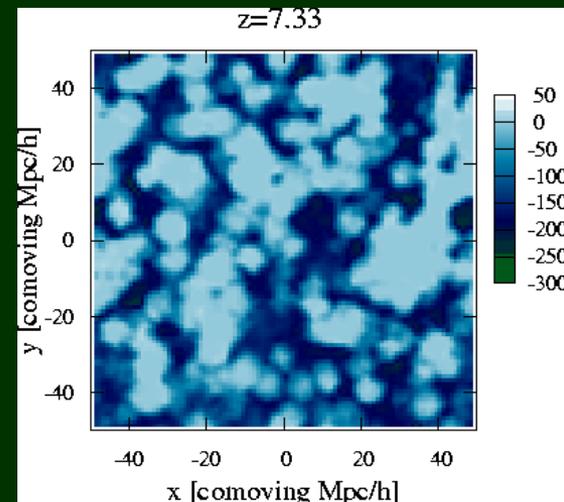
Differential brightness temperature (δT_B) map



$$X_\alpha = \infty$$



$$X_\alpha(z)$$



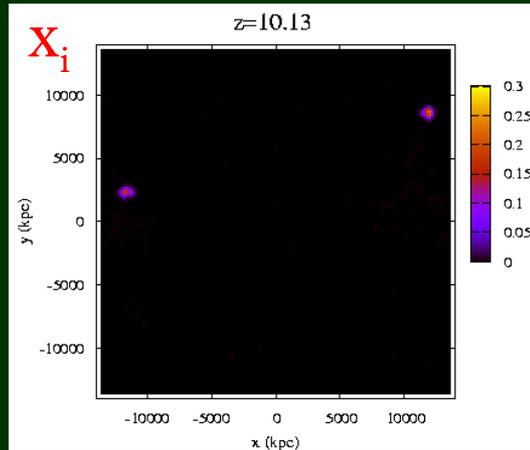
$$X_\alpha(x, z)$$

Final Words

- 21-cm map available for $20 h^{-1}$ Mpc and $100 h^{-1}$ Mpc (256^3 DM + 256^3 baryon)
- Future work
 - Different type of source models including the quasars
 - 512^3 DM + 512^3 baryon for $100 h^{-1}$ Mpc
 - Helium reionization

Two interesting redshifts ($z=10.13$)

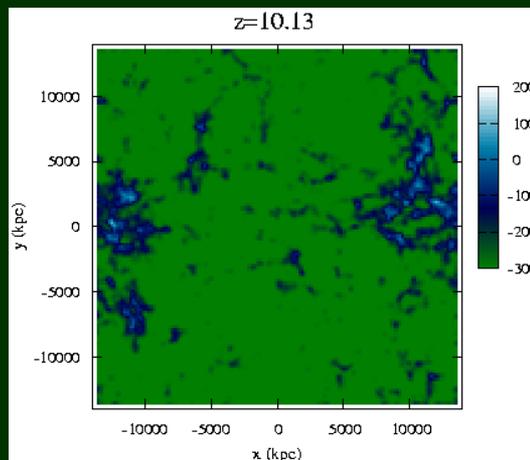
Ionization map



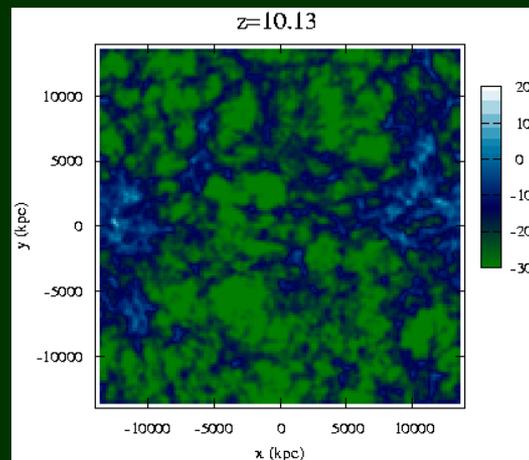
$$\langle X_\alpha \rangle = 1$$

$$\langle X_i \rangle = 0.004$$

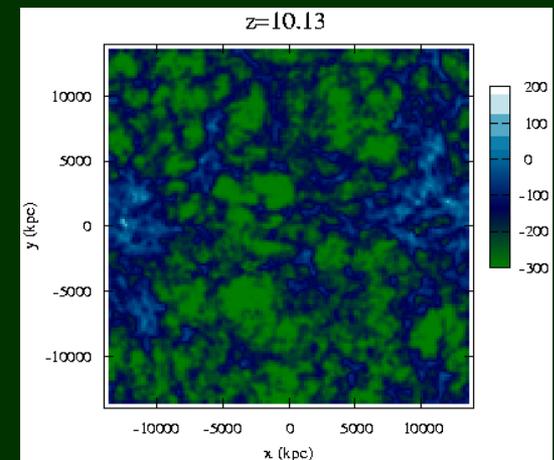
Differential brightness temperature (δT_B) map



$$X_\alpha = \infty$$



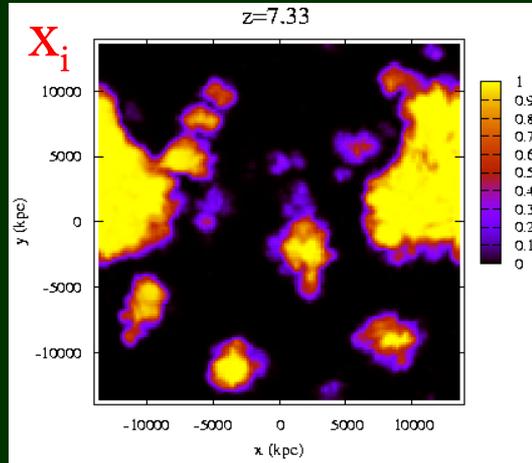
$$X_\alpha(z)$$



$$X_\alpha(x, z)$$

Two interesting redshifts ($z=7.33$)

Ionization map



Saturated x_α
 $\langle x_i \rangle = 0.3$

Differential brightness temperature (δT_B) map

