HORIZON PROJECT   LIDAU PROJECT

Simulating the 21 cm signal in absorption during the early EoR

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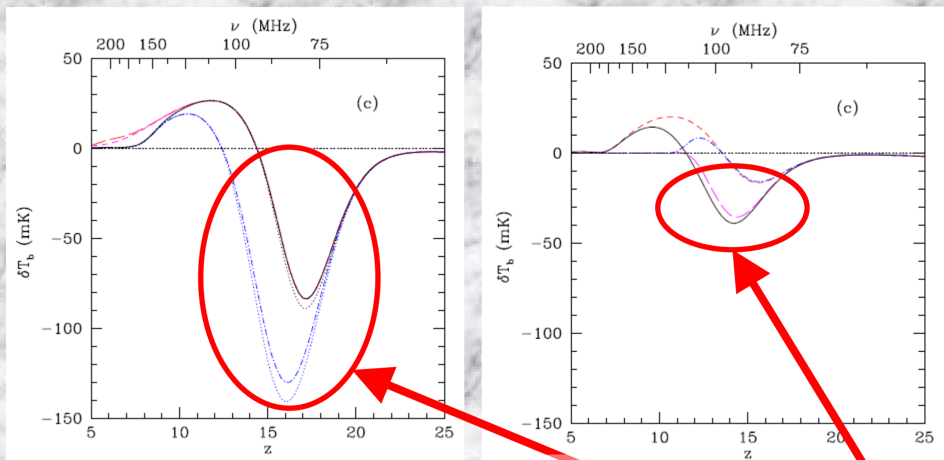
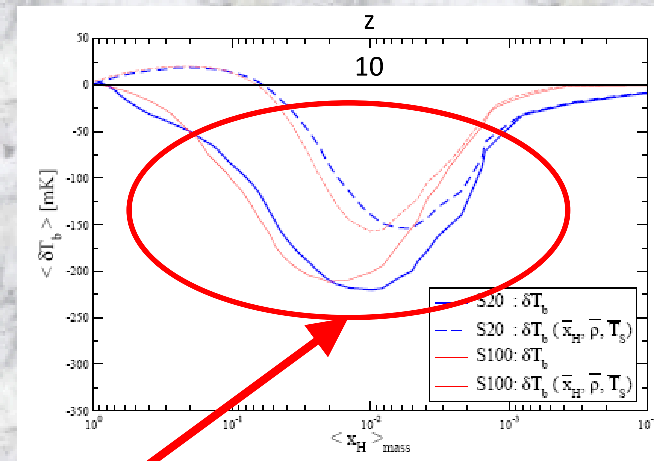
LERMA   Observatoire de Paris

What is this about ?

δT_b



Furlanetto, Oh and Briggs, 2006



Baek et al., 2009

History

A strong absorption signal ! (~100 mK)

-It depends on the source model.

-Modeling the signal involves additional physics.

Simulating the 21 cm emission during the "late" EoR

For a standard cosmology , **assuming $T_{spin} >> T_{CMB}$** :

$$\delta T_B = T_B - T_{CMB} = 28.1\,\mathrm{mK}\,(1+\delta)(1-x_i)\left(\frac{1+z}{10}\right)^{\frac{1}{2}}$$

T_{gas} is not needed !

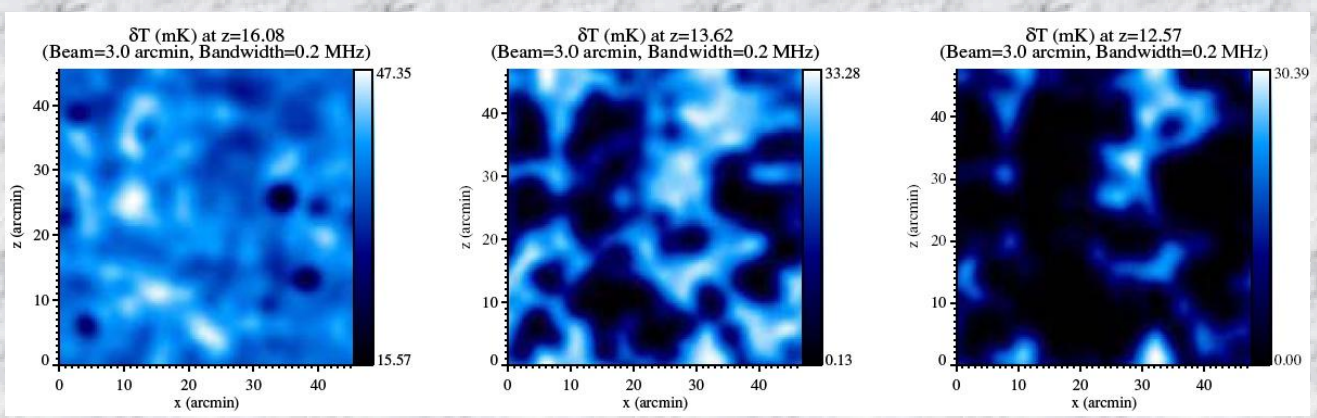
δ : Baryon overdensity

$1-x_i$: Neutral fraction

E.g. : Mellema et al. 2006:

- DM simulation
- cst bias $\Rightarrow$ **gas distribution**
- 3D RT simulation $\Rightarrow$ **x_i**
- 21 cm computation.

Signal in emission !



The 21 cm emission during the early EoR

δ : Baryon overdensity

1-x_i : Neutral fraction

$$\delta T_B = T_B - T_{CMB} = 28.1\,\mathrm{mK}\ (1+\delta)(1-x_i)\left(\frac{1+z}{10}\right)^{\frac{1}{2}}\left(\frac{T_S - T_{CMB}}{T_S}\right)\left(1+\frac{1+z}{H(z)}\frac{dv_{||}}{dr_{||}}\right)$$

Spin Temperature : $T_S^{-1} = \dfrac{T_{CMB}^{-1} + x_\alpha T_c^{-1} + x_{col} T_K^{-1}}{1 + x_\alpha + x_{col}}$

Coupling to T_{CMB} :

via CMB photon scattering,

time scale ~ 300 000 years

Coupling to $T_c \approx T_K$:

via Ly-α photon pumping,

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

Coupling to T_K :

via collisions

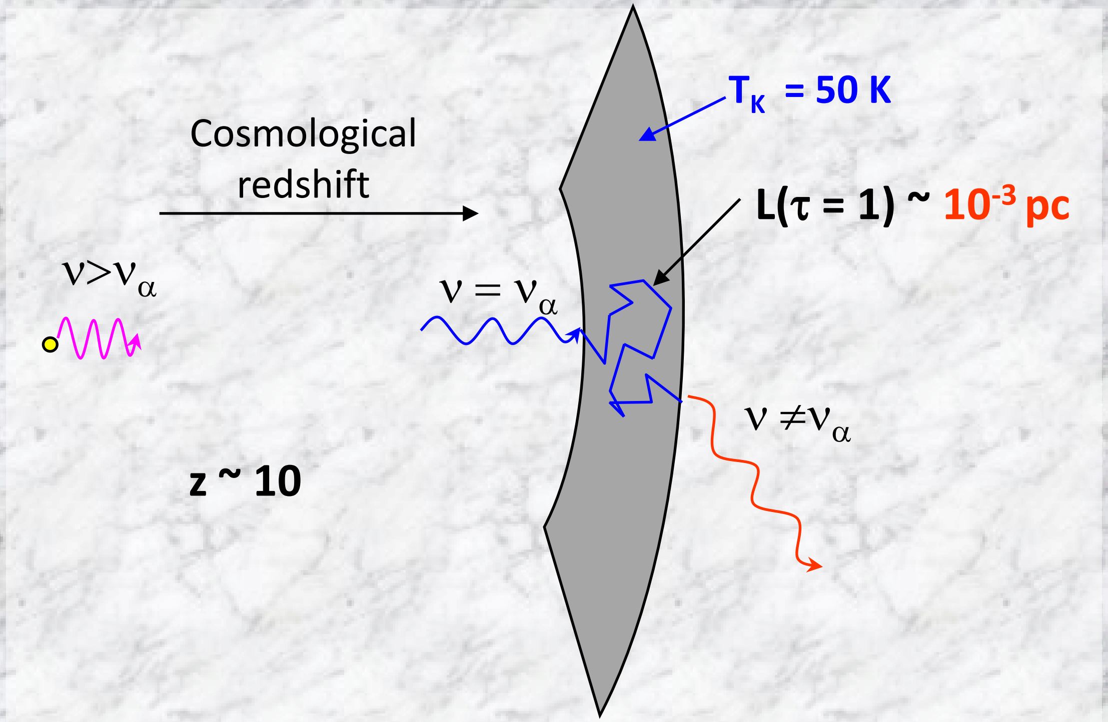
where δρ/ρ >> 1

Computing P_α: is 3D Lyman-α line transfer necessary?

P_α definition: Nb of scatterings per atom per second.
Depends mainly on local Ly-α flux.

- P_α depends on redshift.
- P_α depends on position $\Rightarrow$ additionnal fluctuations (Barkana & Loeb 2005)

Cosmological Lyman-α radiative transfer:



Difficulties:

From free streaming to full diffusion regime on short scales.

Easy aspects:

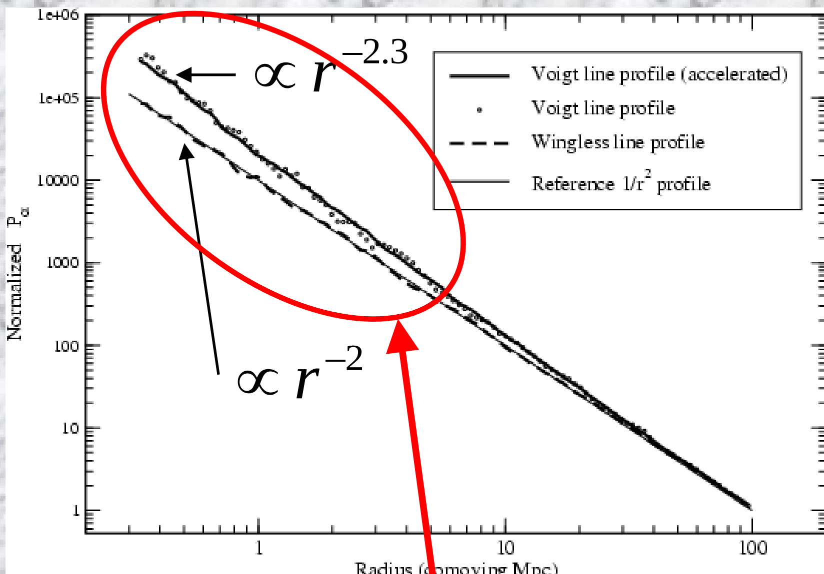
- No feedback on dynamics.
- Very little feeback on ionization.

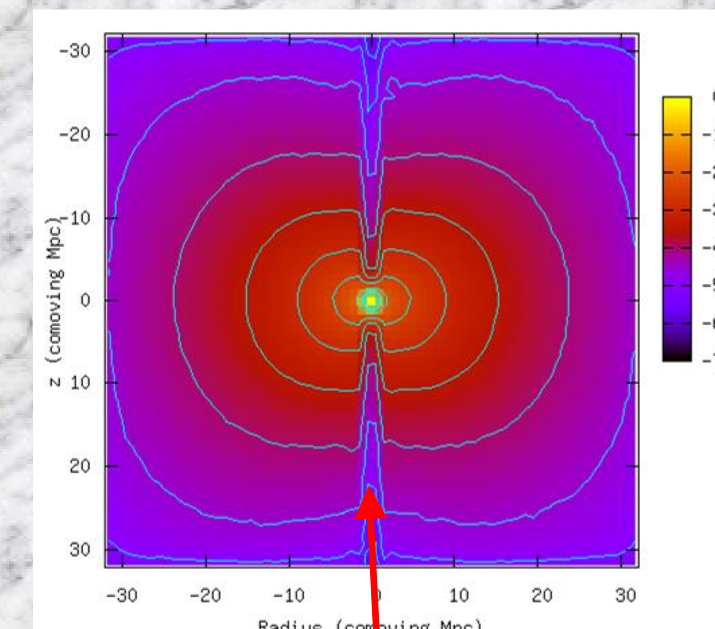
P_α: non trivial RT effects

(Semelin et al. 2007)

- Central source, **flat** spectrum
- Uniform gas medium (T_K=30K, ρ_{gas}= ρ_{crit} , z∼10)

- Central source, **flat** spectrum
- Filament overdensity: $\delta\rho/\rho$=63
- Filament radius: R= 1 Mpc





P_α profile is **not $1/r^2$ at r < 10 Mpc** because of **wing scattering.**

P_α map: strong depletion in the filament (∼ shielding effect).

(Baek et al. 2009)
The simulation pipeline

Dynamical simulations:

- DM + Baryons
- 2x256^3 particles
- 20 and 100 h^{-1}.Mpc

By Y. Revaz: GADGET

Post treatment

3D radiative transfer (RT) :

- Ionizing continuum
- 1000 CPU hours
- 10 Go

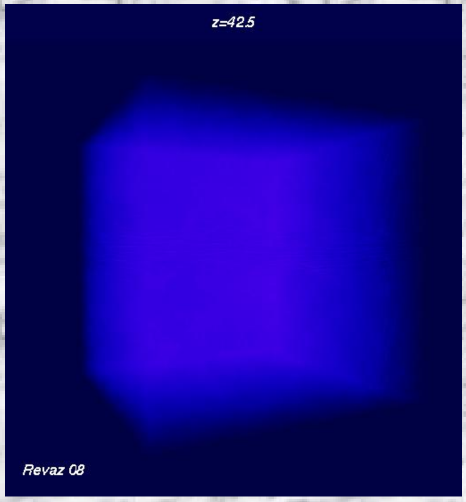
Using **LICORICE**

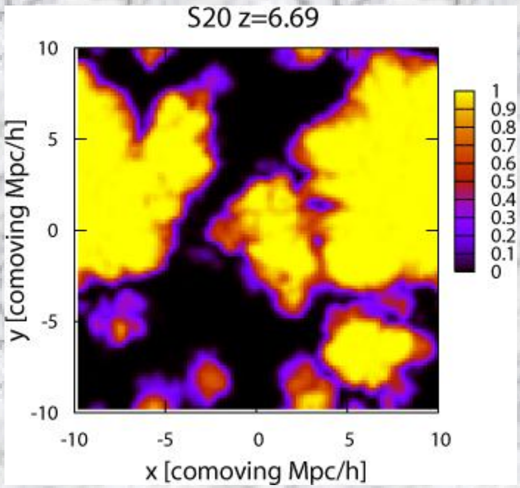
Post treatment

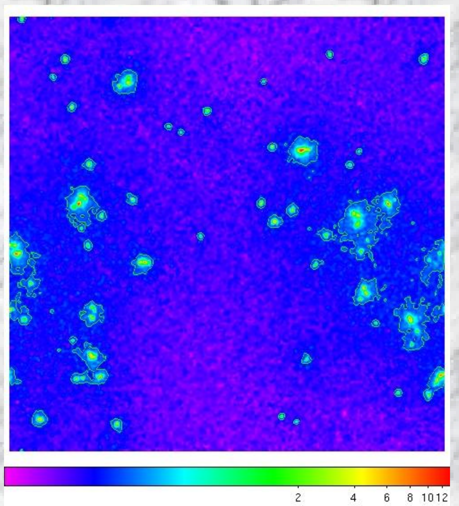
Ly-α line transfer:

- Acceleration scheme
- up to 10^9 photons

Using **LICORICE**





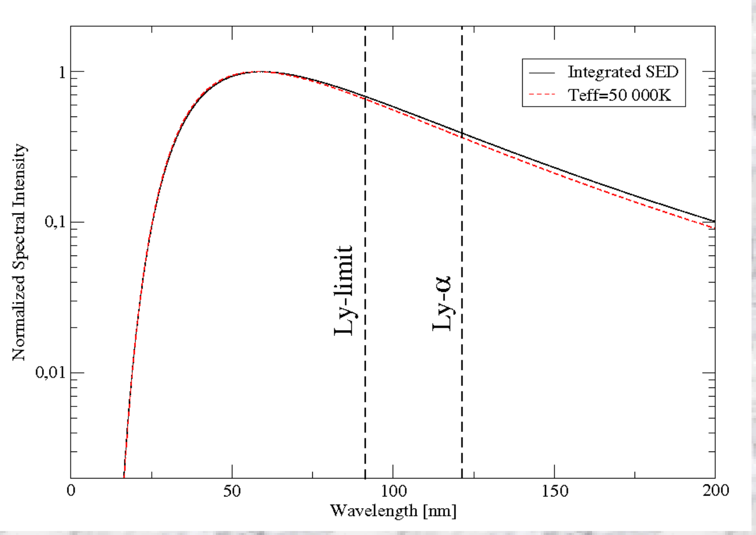


(Baek et al. 2009)
Our first source model

The first sources of light:

- ✓ Pop III stars, M> 100 M_{sol}
- ✓ QSOs
- ✓ X-ray binaries (?)

No observations!



Our first model:

- ✓ **Salpeter IMF with 100 M_{sol} cutoff** (intermediate Pop III / Pop II stars)
- ✓ ~10 Myr lifetime for ionizing sources (degenerate with escape fraction)
- ✓ Star formation history from hydrodynamics (Schmidt law)
- ✓ 10% escape fraction for Ly-alpha, unlimited lifetime.
- ✓ **No X-ray** sources ! (no IGM preheating)

IONIZATION FRONT:

From z~11 to z~6

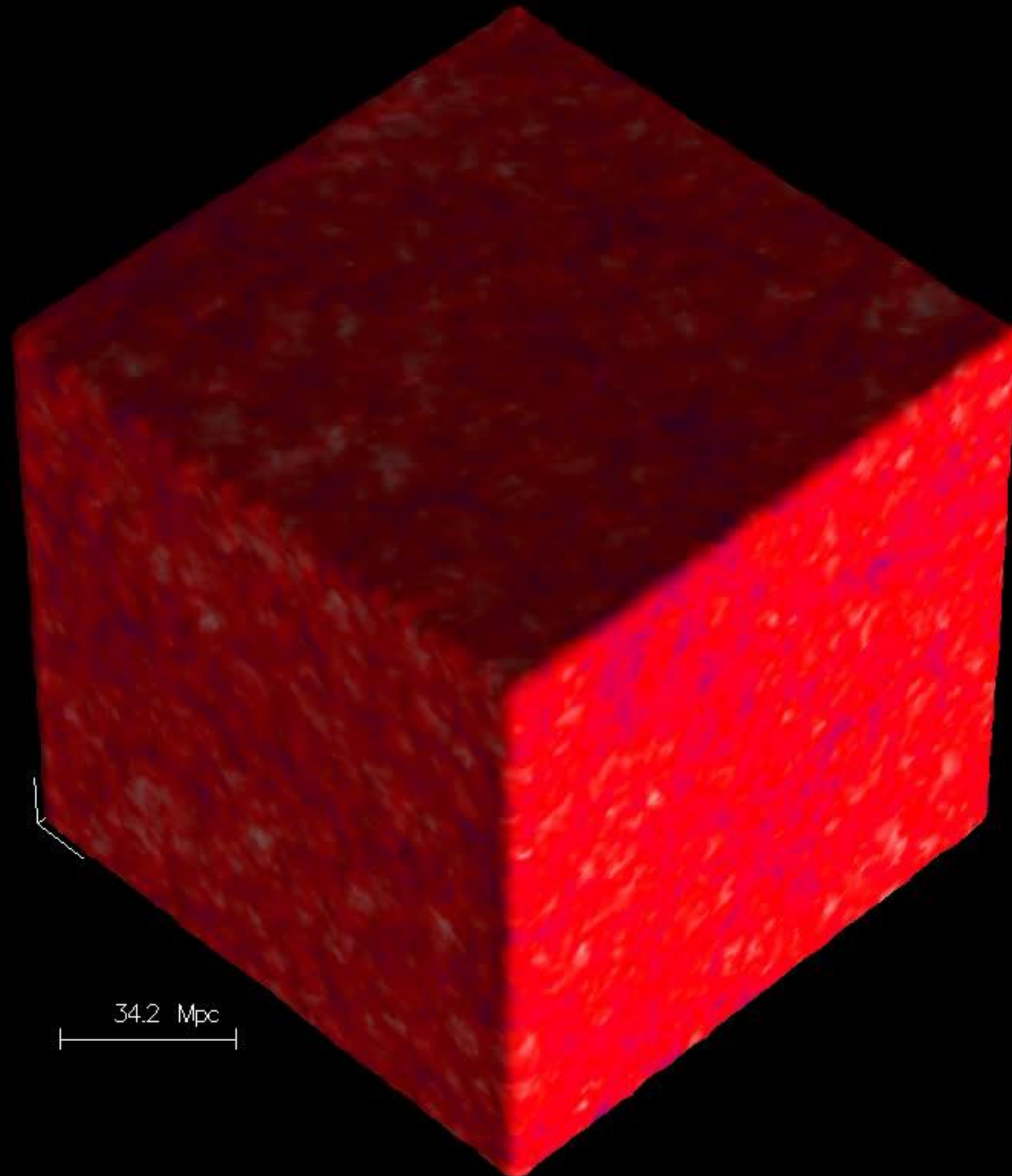
Boxsize: 100 Mpc/h

Enough for 21 cm!

Minimum halo mass:

$\sim 10^{10}\ M_{sol}$

Not really enough!



When and where is Ly-α important for 21cm ?

The usual assumption:

$T_S >> T_{CMB}$ $\Rightarrow$ No signal in aborption, no need for T_K and x_α

(Ciardi & Madau 2003, Mellema et al. 2006, Zahn et al. 2007, Lidz et al. 2007, Iliev et al. 2008, etc…)

- **OK** if Ly-α flux high and sufficient pre-heating in the voids.
- **Fails** early in the EoR or if little pre-heating $\Leftarrow$ Ly-α necessary !

The results from our simulations: (Baek et al. 2009)

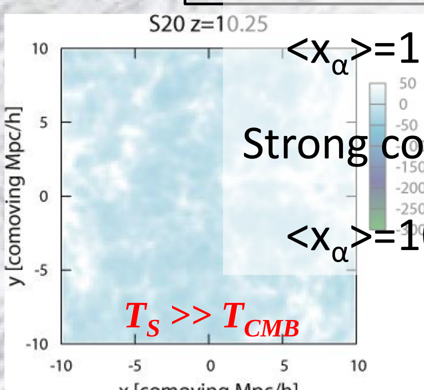
Early (moderate Ly-α)

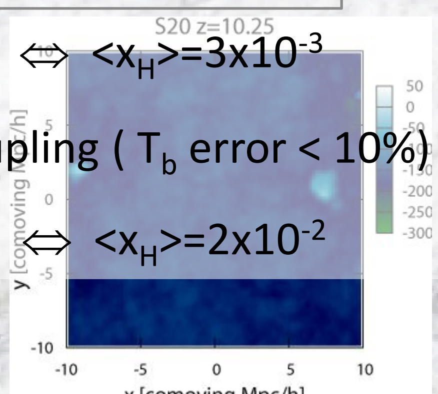
Moderate coupling :

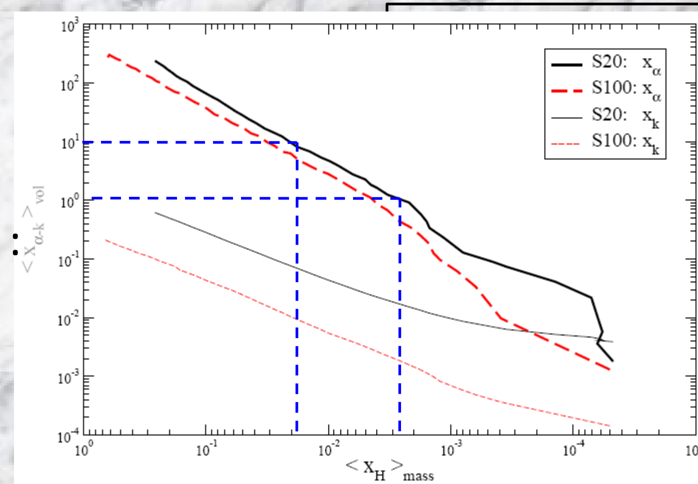
$<x_\alpha>=1 \Leftrightarrow <x_H>=3\times10^{-3}$

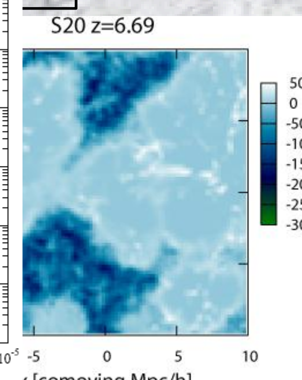
Strong coupling (T_b error < 10%) :

$<x_\alpha>=10 \Leftrightarrow <x_H>=2\times10^{-2}$





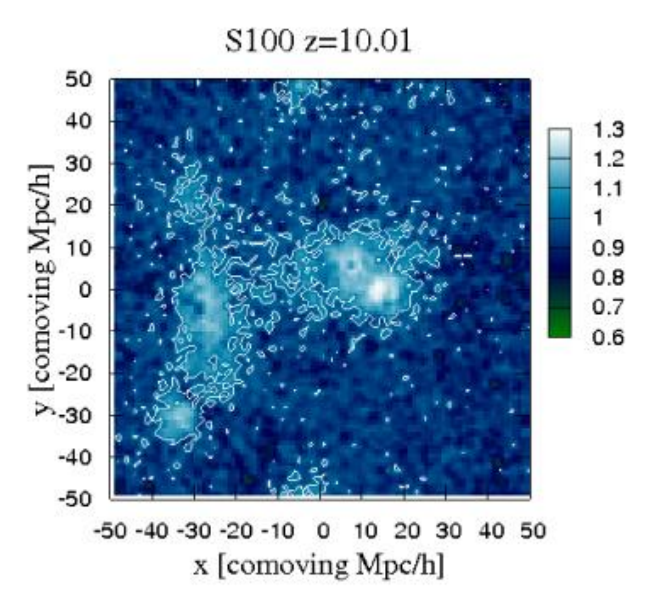




3D Line transfer?... Really ??
No shortcut ???

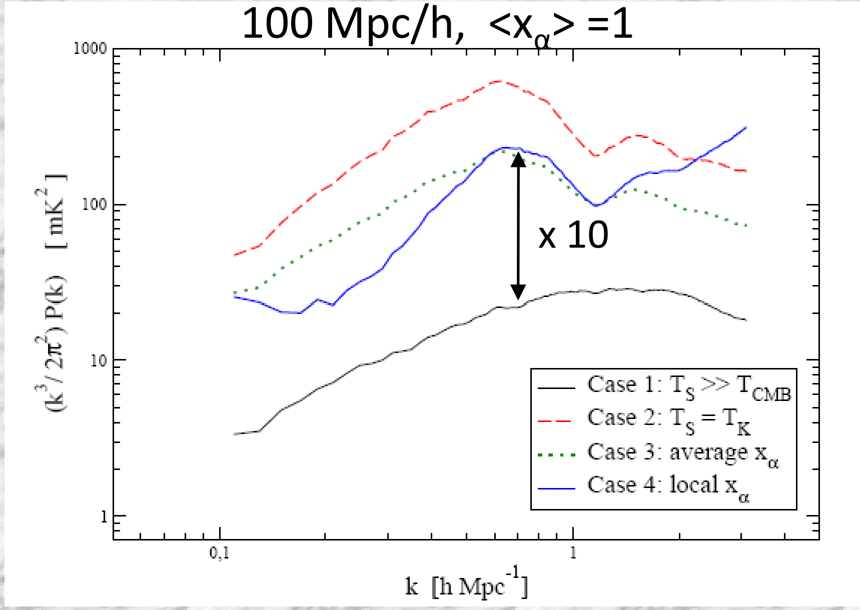
Full RT vs homogenous flux ($x_\alpha(z)$)

Up to 50 % difference in T_b locally



Visible effect in the 3D powerspectrum

(Directly observable by interferometers)



New source model (Baek et al., in prep)

New model:

- ✓ **Salpeter IMF**
- ✓ Lifetime weighted SED

mass $[M_\odot]$	$\log(L/L_{M_\odot})$	$\log(T_{eff})$	$t_{life}[Myr]$
120	6.3	4.7	3
60	5.8	4.6	4.5
40	5.6	4.5	6
30	5.2	4.5	7
20	4.8	4.45	10
15	4.65	4.4	14
12	4.2	4.37	20
9	3.8	4.3	34
5.9	2.92	4.18	120
2.9	1.73	3.97	700
1.6	0.81	3.85	3000

Derived from Meynet & Maeder (2005)

Integration with Salpeter IMF

Energy band	$10.24\,\mathrm{eV} \leqslant \mathrm{E} < 13.6\,\mathrm{eV}$	$E \geqslant 13.6\,\mathrm{eV}$
Luminosity[erg/s]	6.32×10^{44}	2.14×10^{45}
Life time[Myr]	20.36	8.03

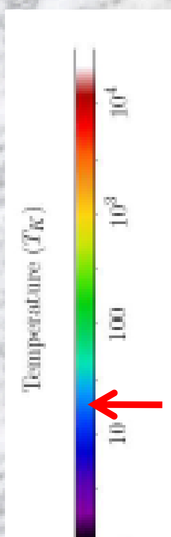
✓Sources with a constant **X-ray** fraction !

Specific behaviour: long mean free path in the IGM

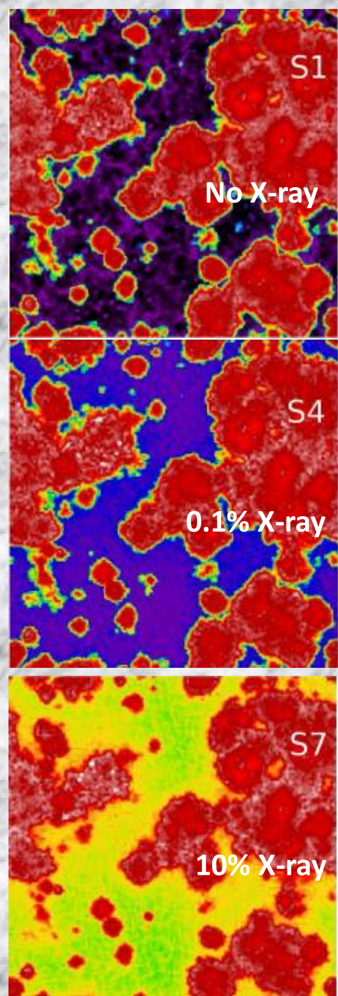
$$\lambda_X \approx 4.9 \left(\frac{E}{300\,\mathrm{eV}}\right)^3 \mathrm{Mpc} \;\; \text{(comoving)}$$

preheat IGM $\Rightarrow$ turn 21 cm absorption to emission

Maps for 3 models

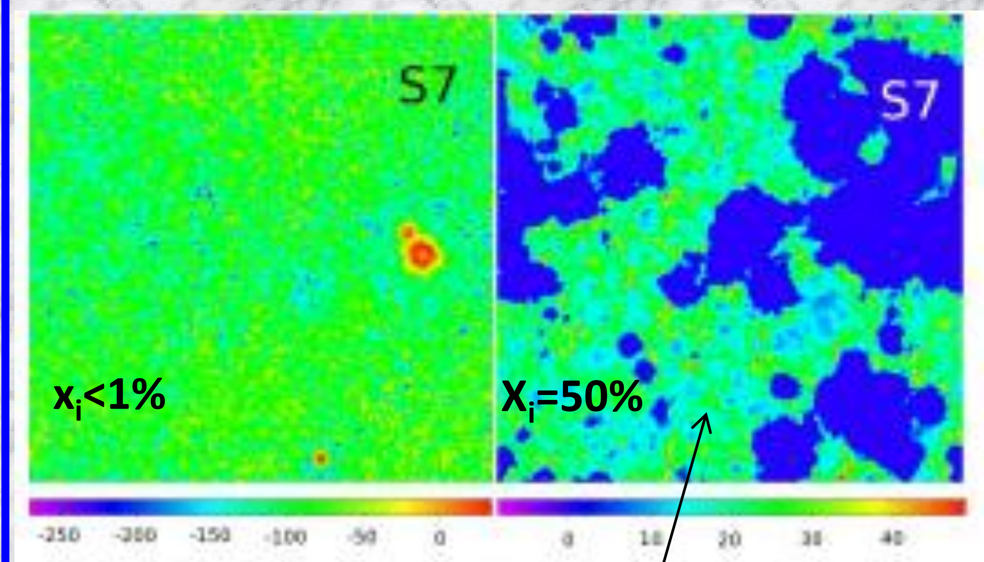


T_{CMB}



Kinetic temperature

Brightness temperature



X-ray heating

Conclusions and Prospects

Conclusion from recent work:

- Heating the IGM takes time!
- Absorption is probably not suppressed

Conclusion for SKA (and pathfinders):

- Observing strategy: **don't neglect the early EoR** ($z\sim 11$-15)

Next steps:

- Include higher Lyman lines.
- Go to larger boxsize/ particle number / photon number:

LIDAU Project with D. Aubert, **512^3 to 1024^3** in 100 to 250 Mpc/h
$\Rightarrow$ compute non-gaussian statistics.

Opening 2 post-doc positions in 2009/2010 ! (See AAS Jobregister)