Constraining the Astrophysics of the Cosmic Dawn and the Epoch of Reionization with SKA (Mesinger et al., arXiv:1501.04106)

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21cm intensity mapping with CMB backlight

Transition between two hyperfine (n=1) states of atomic hydrogen $\nu_{21} = 1.42GHz$: $h\nu_{21}/k = 0.068K \ll T_{CMB}$

$$f(ra, dec, \nu) = f_{CMB}(\nu) + f_{HI}(z + 1 = 1420MHz/\nu)$$

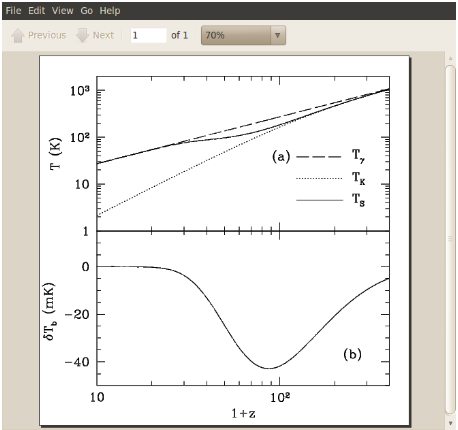
$$+f(Galactic\ sychrotron) + f(extragalactic\ sources)$$

HI can contribute positive or negative flux according to whether spin temperature greater or less than CMB temperature

$$\delta T(\nu) \propto x_{HI} \left(1 - \frac{T_\gamma}{T_S}\right)(1 + \delta_{nl}) \left(\frac{H(z)}{dv/dr + H(z)}\right)$$

Fluctuation of δT along line-of-sight come from fluctuations in x_{HI} (e.g. from ionizing radiation), T_S, δ_{nl}, velocity gradiants. Fluctations perpendicular to line-of-sight come from foregrounds.

Three temperatures after recombination



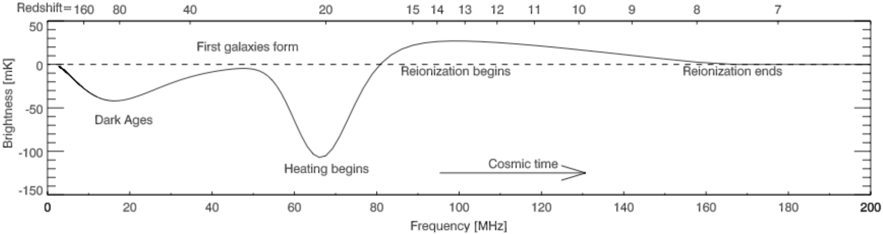
(gas kinetic energy, spin, CMB)

$200 < z < 1100$: $T_K = T_\gamma$
(residual Compton scattering)
$T_K = T_S$ (collisional coupling)

$40 < z < 200$: $T_S = T_K < T_\gamma$
($T_K \sim 1/a^2$, $T_\gamma \sim 1/a$)
and collisional coupling)

$30 < z < 40$: $T_K < T_S \rightarrow T_\gamma$
(end of collisions, radiative coupling)

$\delta T_b \sim T_S - T_\gamma$ vs. time

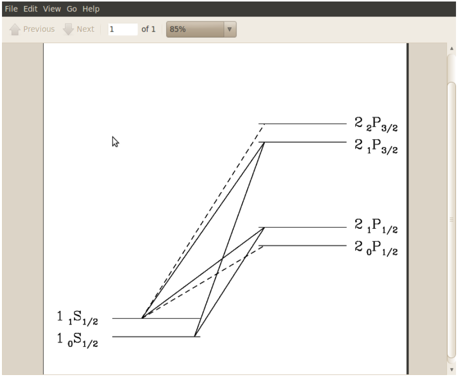


Simplicity ends at $z \sim 30$

- $z \sim 30$ Cosmic Dawn: spin cooling by Wouthuysen-Field effect
- $z \sim 20$ Heating by x-rays (black holes?)
- $z \sim 15$ reionization begins
- $z \sim 7$ reionization complete eliminating intergalactic signal

δT_b is in principle measureable but not by interferometers

Wouthuysen-Field spin cooling

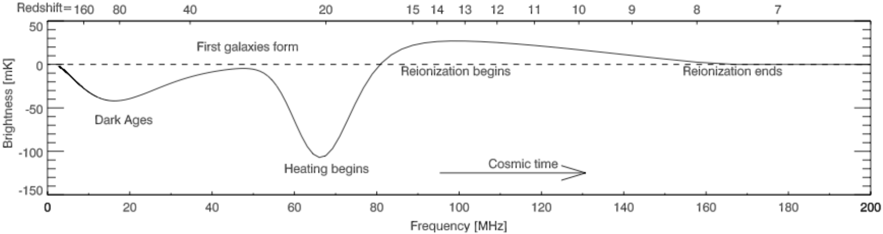


$z \sim 40$: $T_S > T_K$
(excess in upper spin state)

UV photons from first stars induce spin transitions.

Question: why doesn't this heat up the gas?

$\delta T_b \sim T_S - T_\gamma$ vs. time



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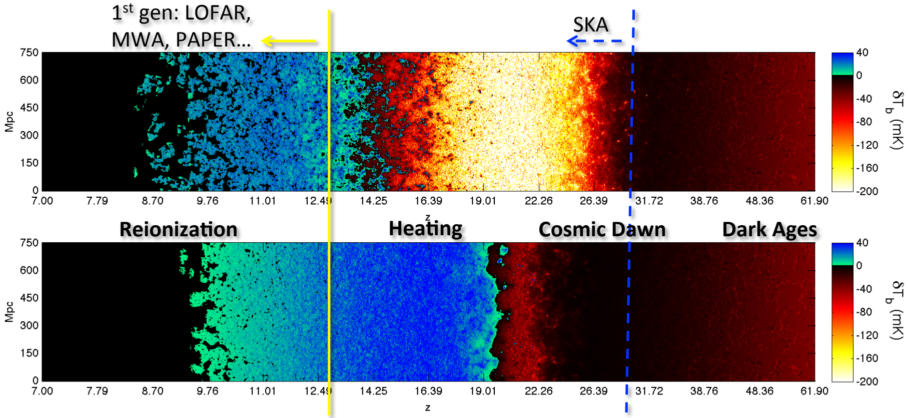
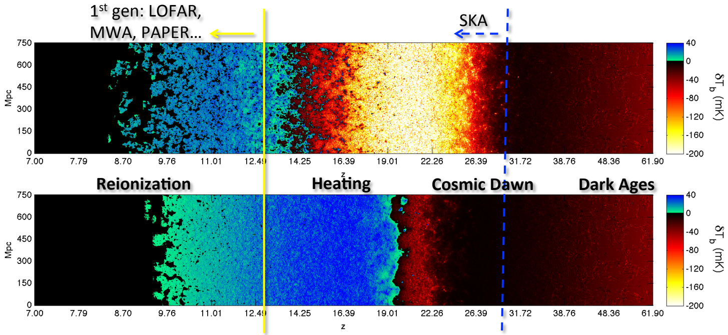
Power spectrum measurements



Slices are 750Mpc wide and 1.5Mpc thick.

- top: "fiducial" x-ray sources for heating
- bottom: "extreme x-ray model": primordial galaxies produce many more hard x-rays than low-redshift galaxies (saturating unresolved x-ray background).

Sources of fluctuations



Fiducial model fluctuations:

$z > 40$ gas-density fluctuations

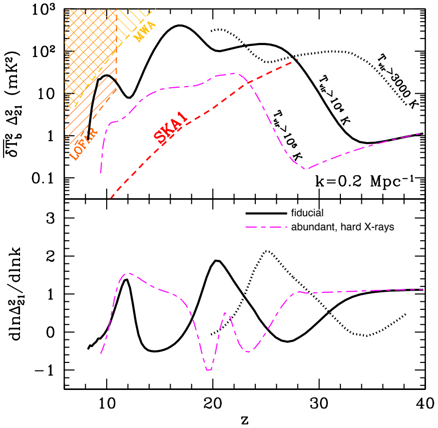
$z \sim 25$ UV photon fluctuations (W-E effect)

$z \sim 15$ Temperature fluctuations (depends of x-ray spectrum)

$z \sim 10$ Ionization-fraction fluctuations (UV flux)

$z \sim< 7$ Density fluctuations (emission by gas in halos (DLA's))

21cm power spectrum evolution

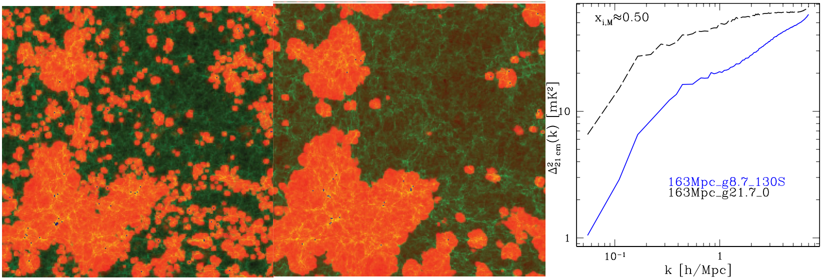


Solid Black: fiducial model: Three peaks: (WE, heating, reionization)

Dotted Black: Enhanced UV production in first galaxies: early WF epoch.

Dashed magenta: Early hard x-ray sources: early uniform heating

EoR morphologies



Slices are 53Mpc on a side, midpoint of reionization.
Left: reionization fueled by UV from light galaxies ($M \sim 10^8 M_\odot$)
Middle: reionization fueled by UV from heavy biased galaxies ($M \sim 10^9 M_\odot$)