High-redshift X-ray sources and their effect on the 21-cm signal

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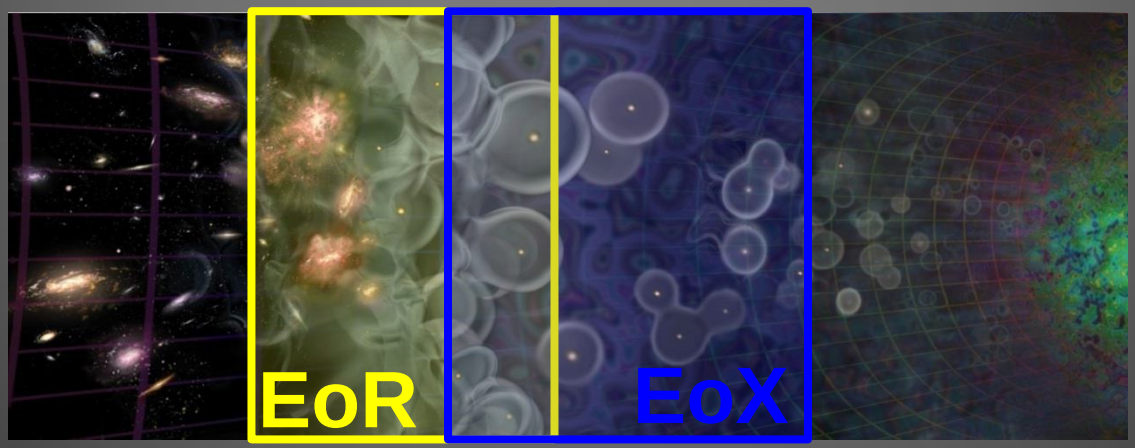
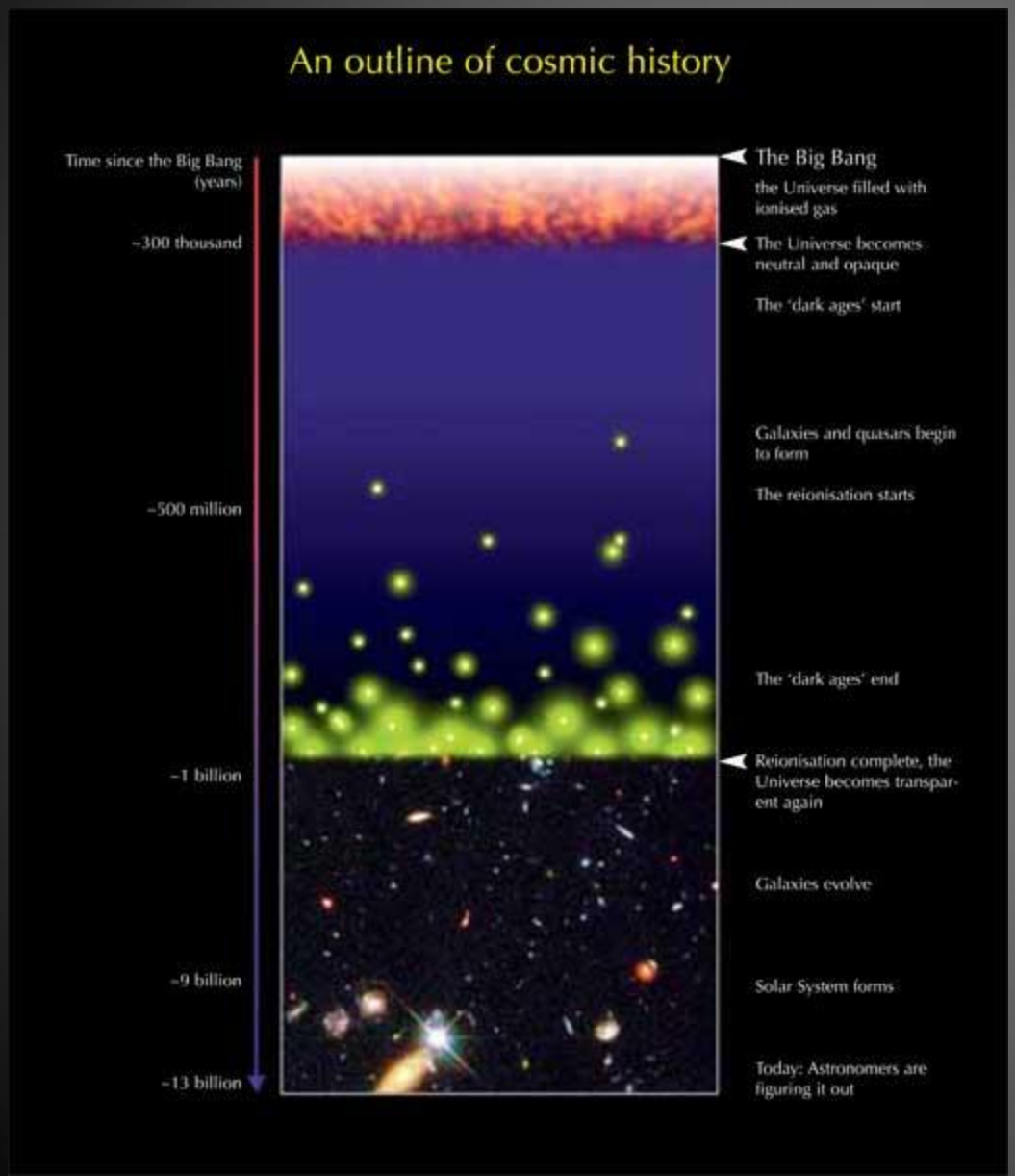


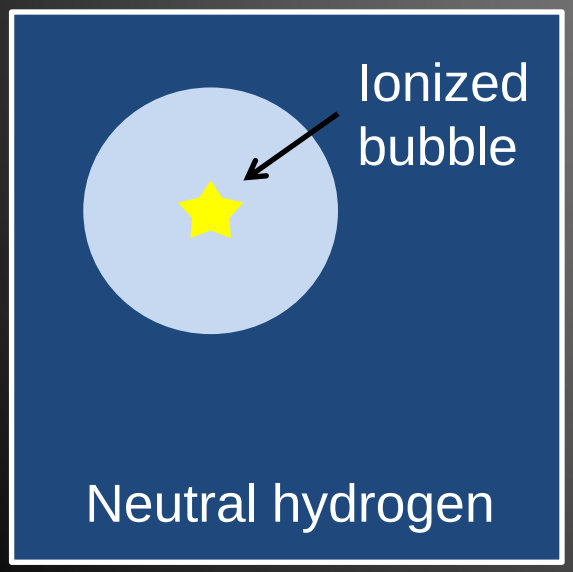
Unobserved Part of The Universe

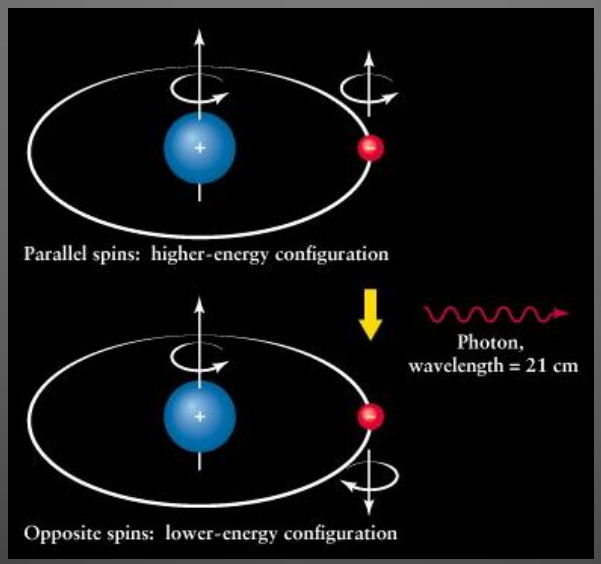


- CMB
- Dark Ages
- Cosmic Dawn
- Reionization
- Post EoR

Answer in Radio: Faint Signal of Neutral Hydrogen

- The “highly forbidden” spin-flip transition ($2.9 \times 10^{-15}\ s^{-1}$) happens often enough in the volume of the Universe.
- The Universe is transparent to these photons, they can be observed today





λ = 21 cm

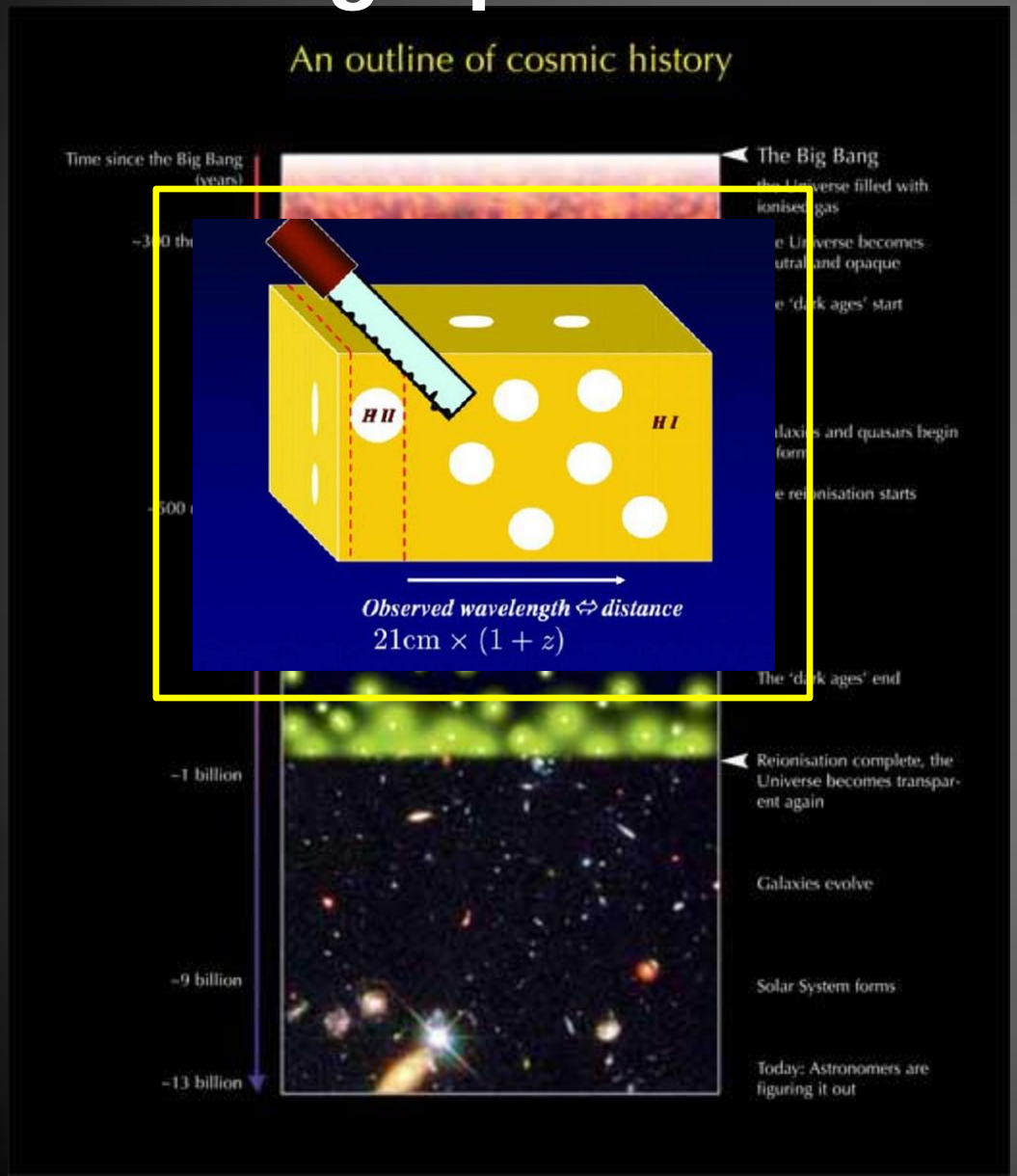
ν = 1420 MHz

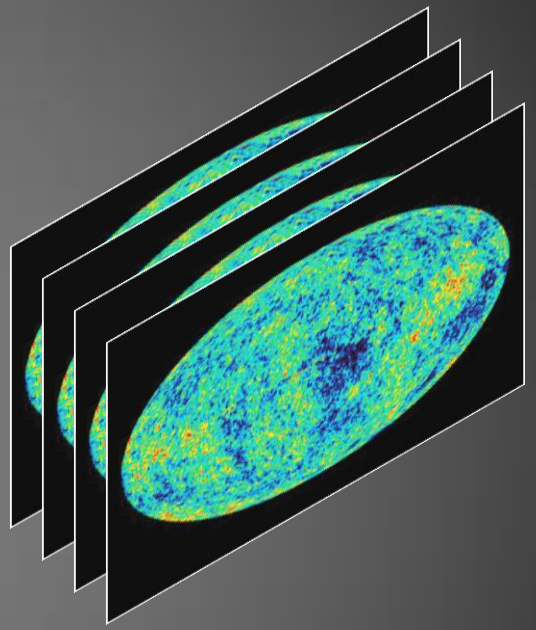
Spin Temperature

$n_1/n_0 \equiv 3\exp(-T_*/T_S)$,

$T_* = 0.068$ K

21-cm Signal: Tomographic Scan of the Universe



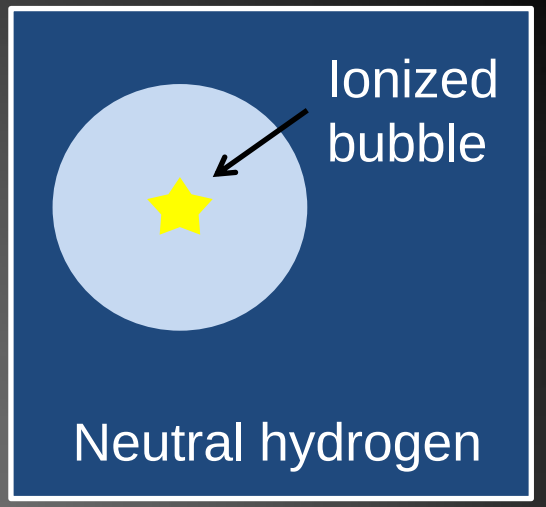


Probe of

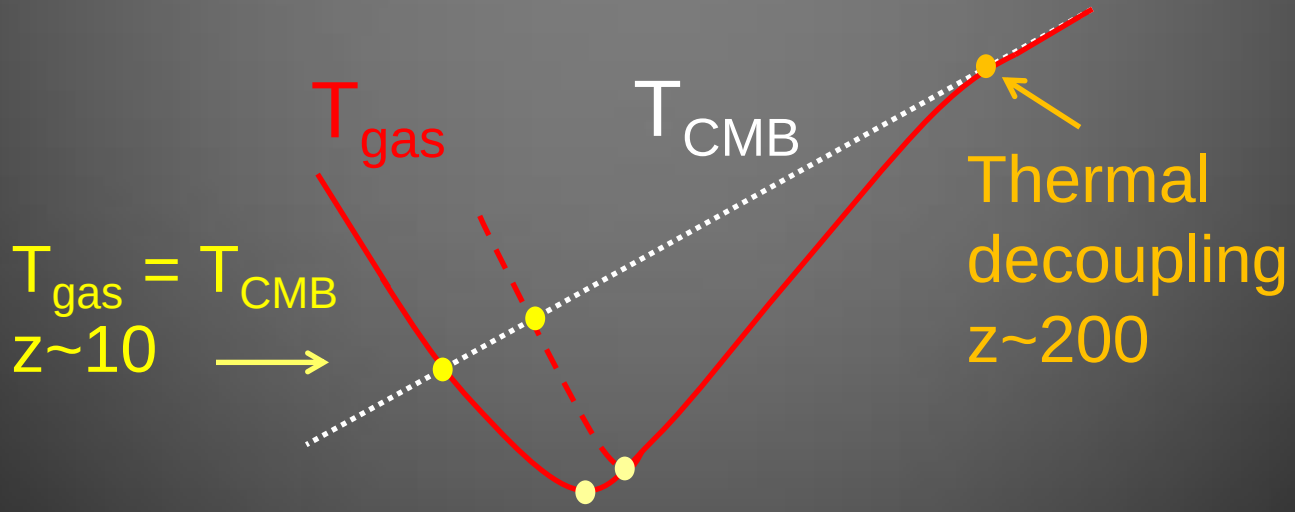
- Dark Ages
- First Stars and Galaxies
- Reionization

International Effort in Radio

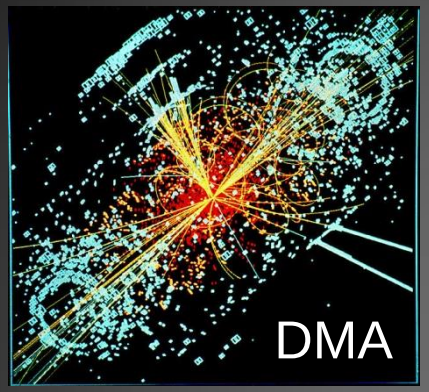
Role of X-ray Sources in Cosmic History

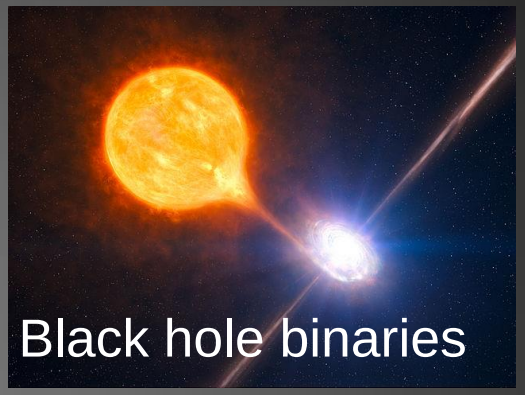


Heat and partially ionize the IGM far from the source affecting the 21-cm signal



What Heated Up the IGM?





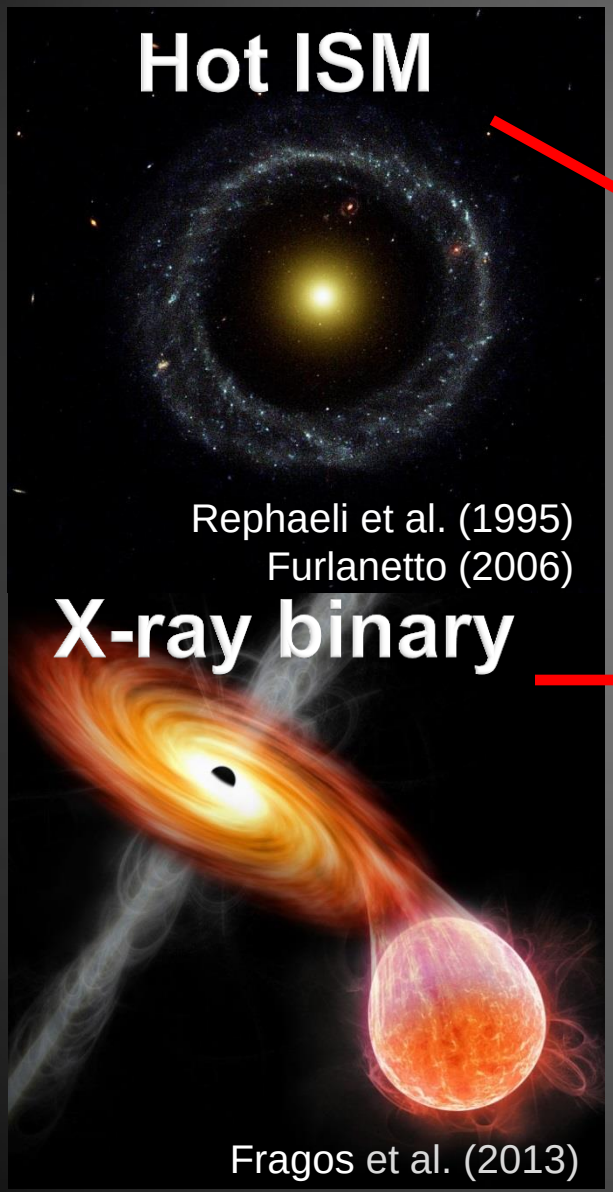
Open Questions:

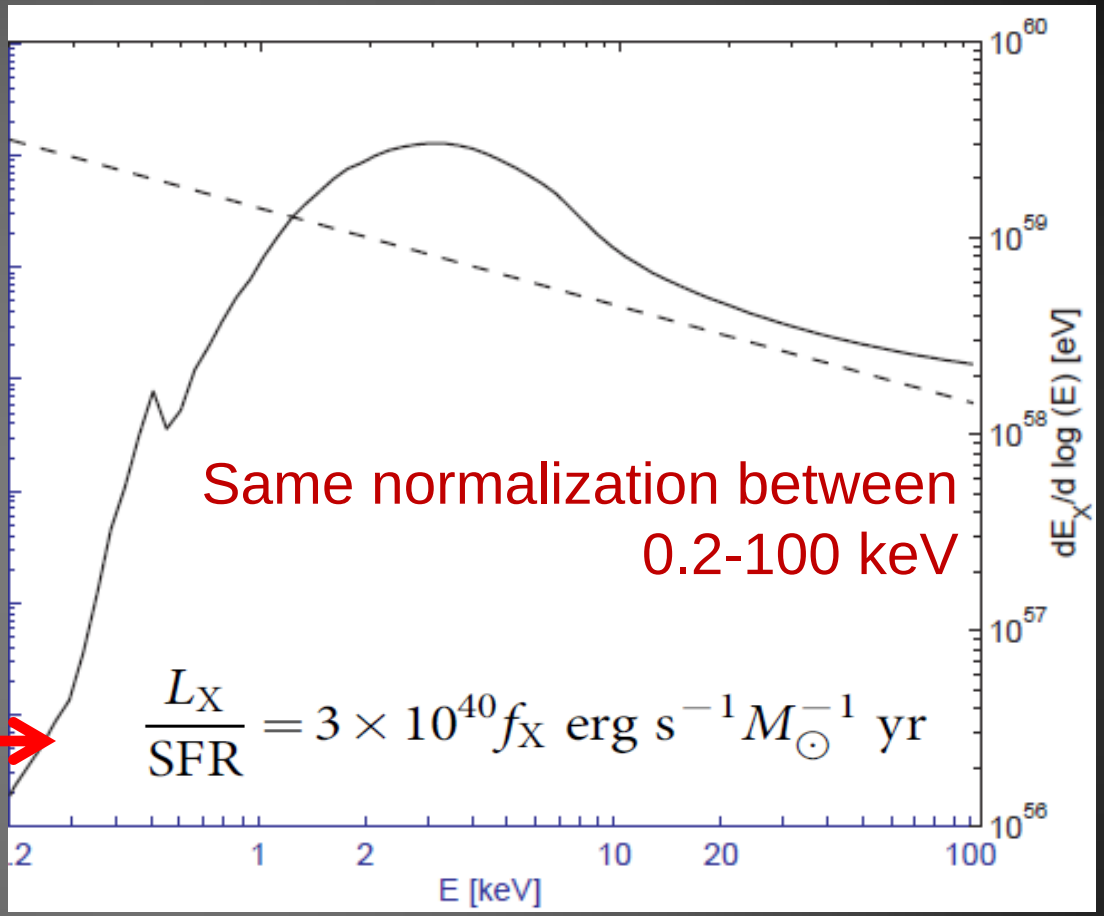
- Nature of heating sources
- Spectral energy distribution (SED)
- Efficiency
- Time dependence
- X-ray absorption
- Effects of metallicity

Possible Sources:

- X-ray binaries
- Mini-quasars
- Thermal emission from galaxies
- Shocks
- Dark matter annihilation
- Etc.

Spectral Energy Distribution of X-rays

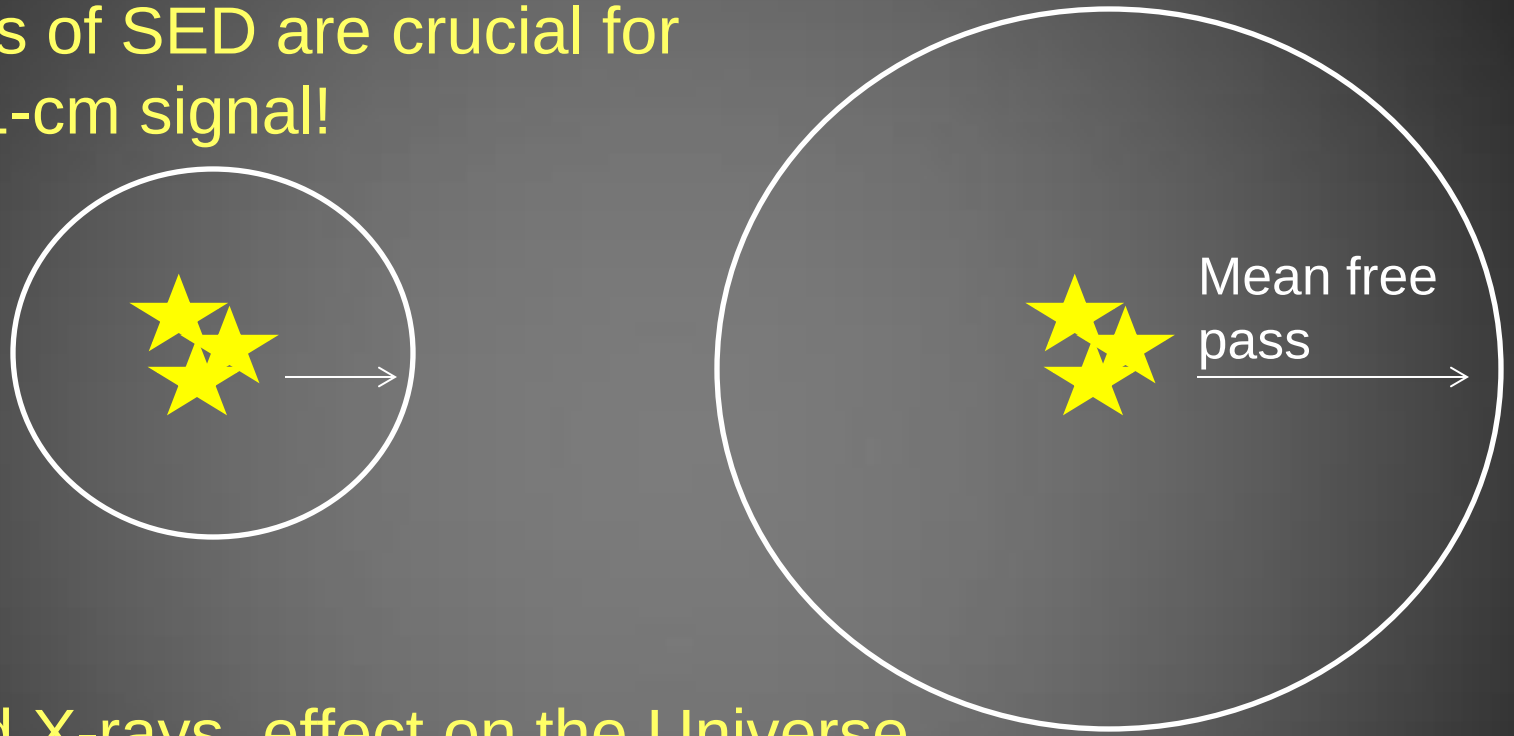




Based on Chandra observations
(Fragos et al. 2013)

Were High-z X-ray Sources Soft or Hard?

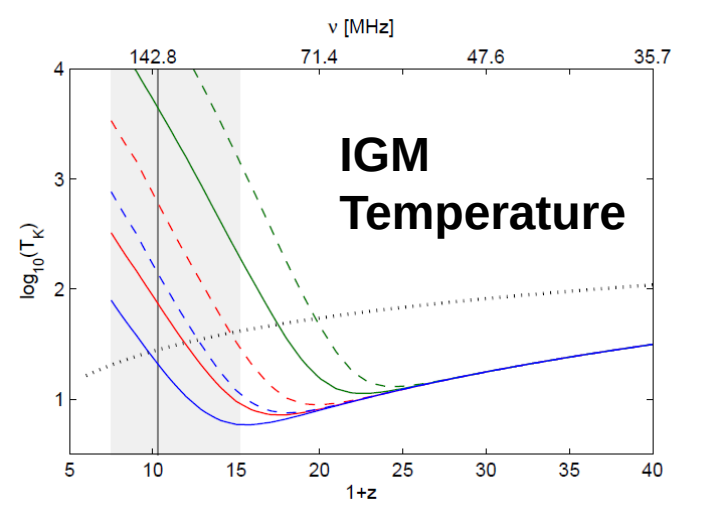
Details of SED are crucial for the 21-cm signal!

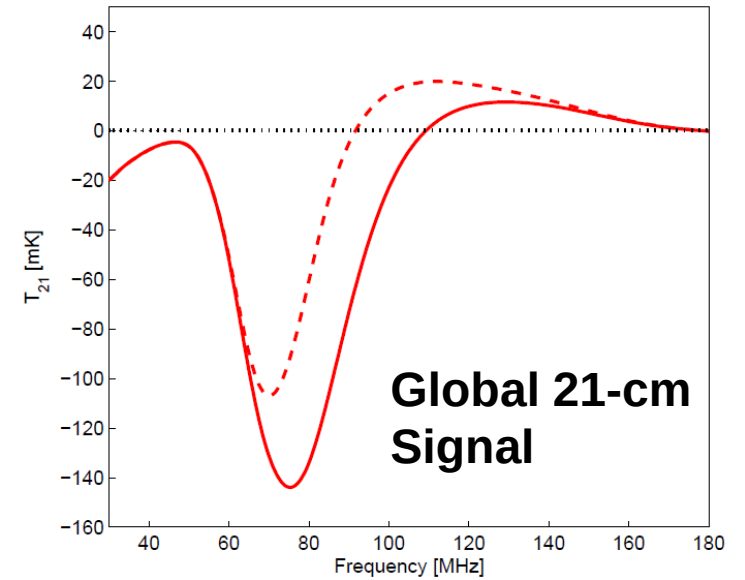


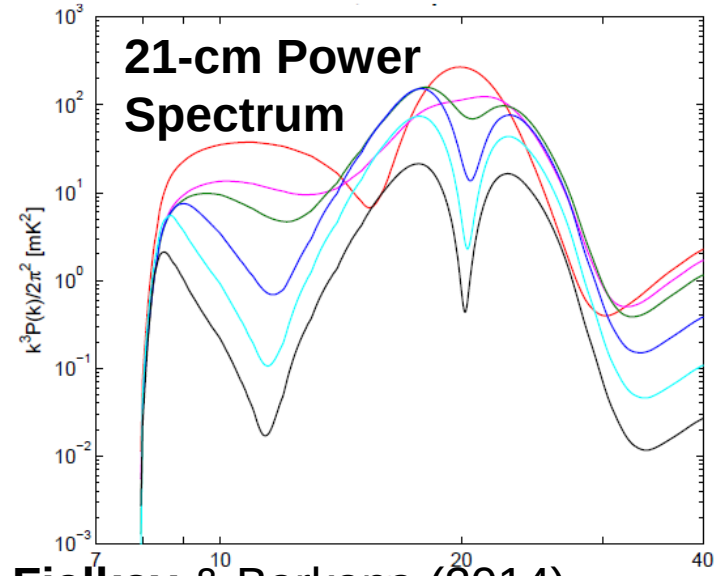
If hard X-rays, effect on the Universe

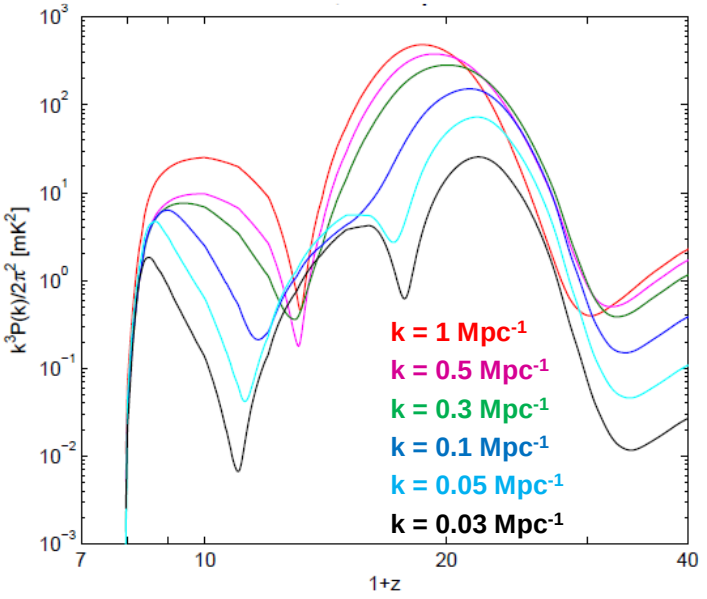
- Mean free pass is longer
- Delayed heating
- Heating fluctuations are washed out at scales below mfp

Strong Effect on the IGM and the 21-cm Signal









Fialkov & Barkana (2014)

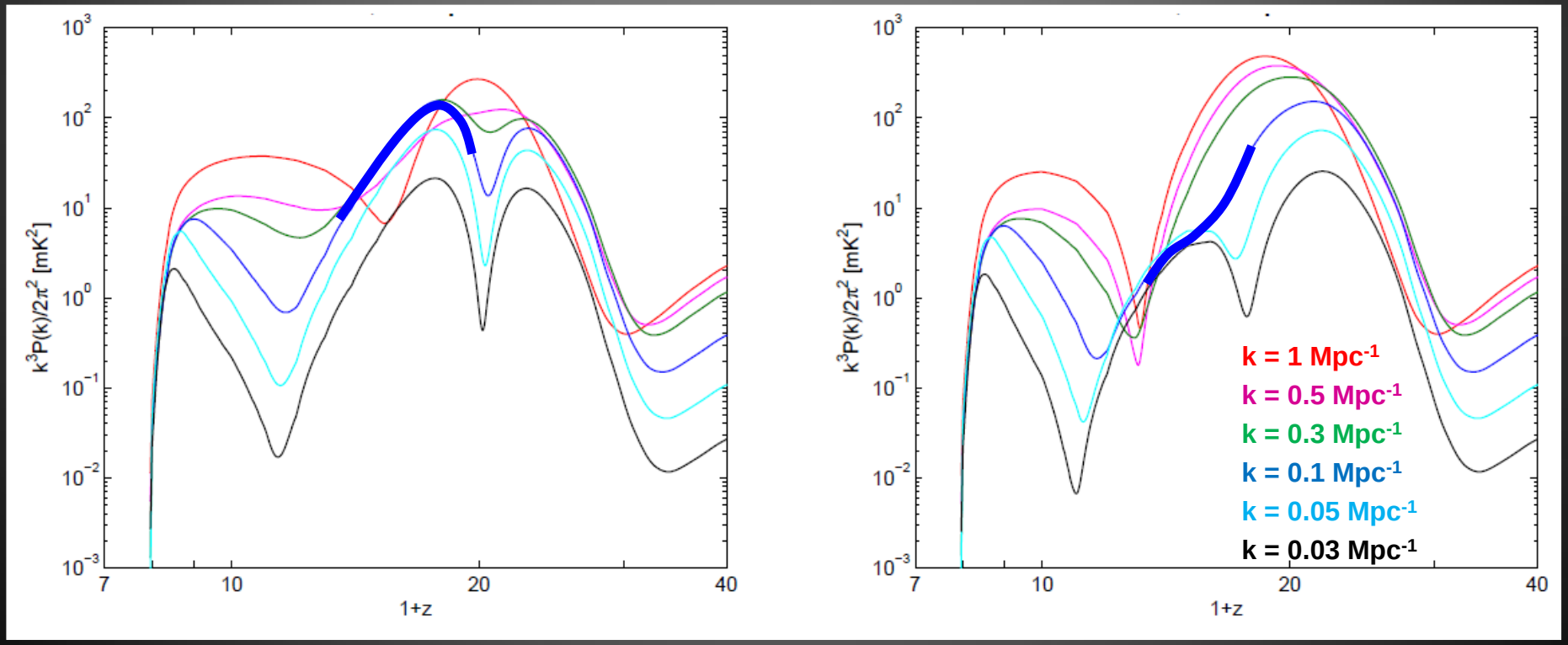
21-cm PS, Hard vs Soft X-rays:

Soft SED: three peaks in PS vs z
Hard SED: heating peak is lost

Soft X-rays

Hard X-rays

Almost uniform heating

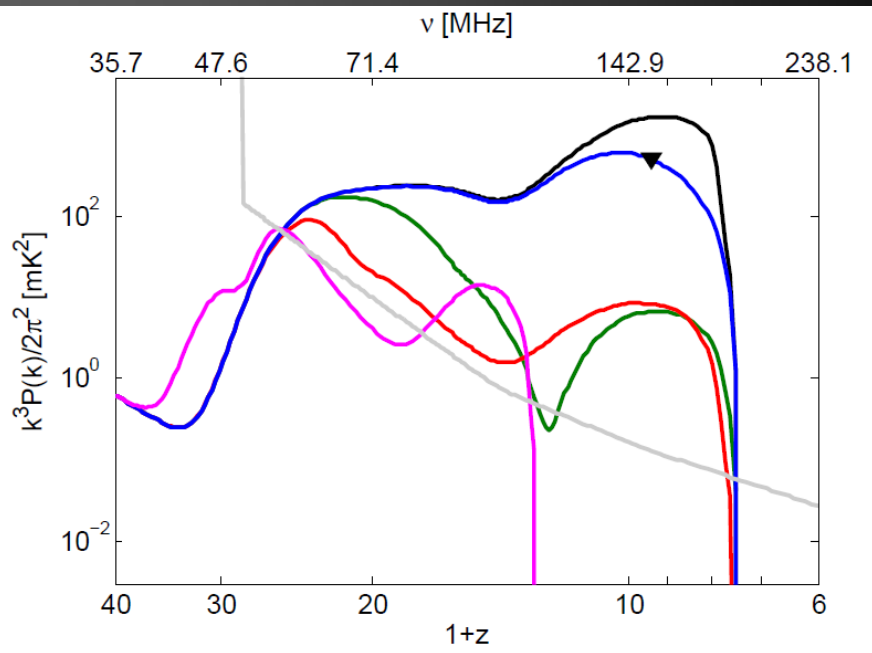


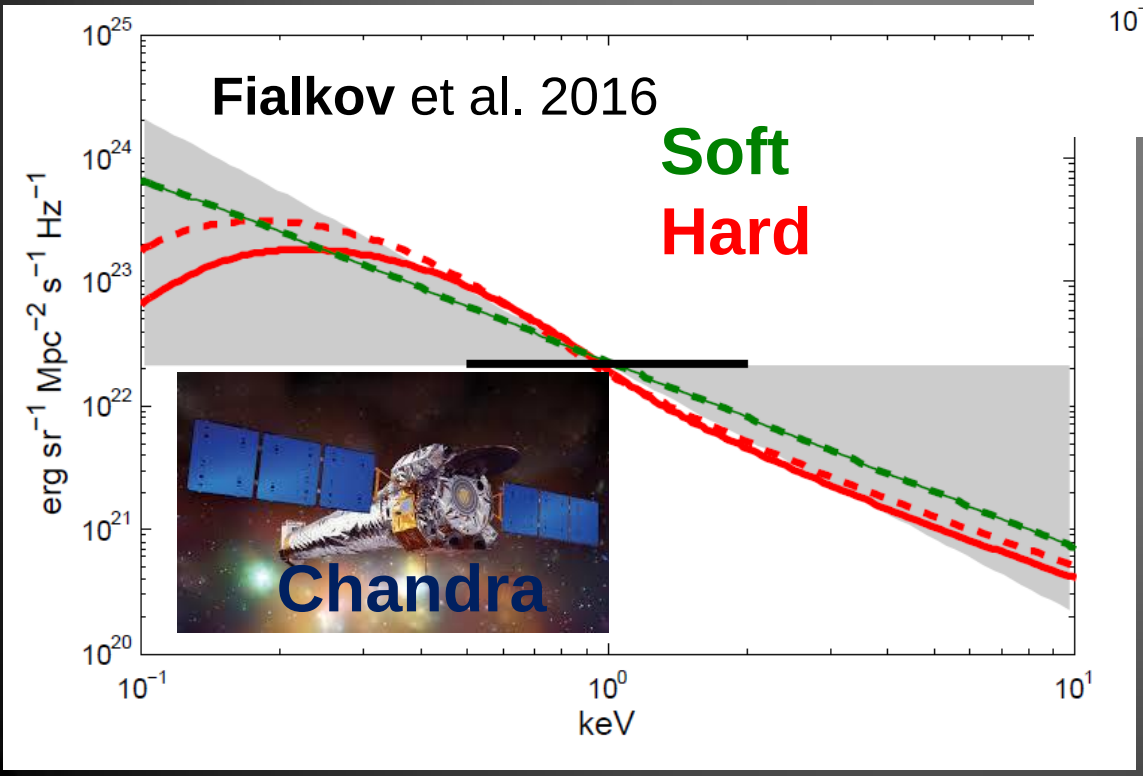
Fialkov & Barkana (2014)

Chandra Observations are Used to Limit f_X

$$\frac{L_X}{\mathrm{SFR}} = 3 \times 10^{40} f_X \ \mathrm{erg\ s^{-1}} M_\odot^{-1}\ \mathrm{yr}$$

Unresolved X-ray background yields upper limit on heating (f_X=10-100).





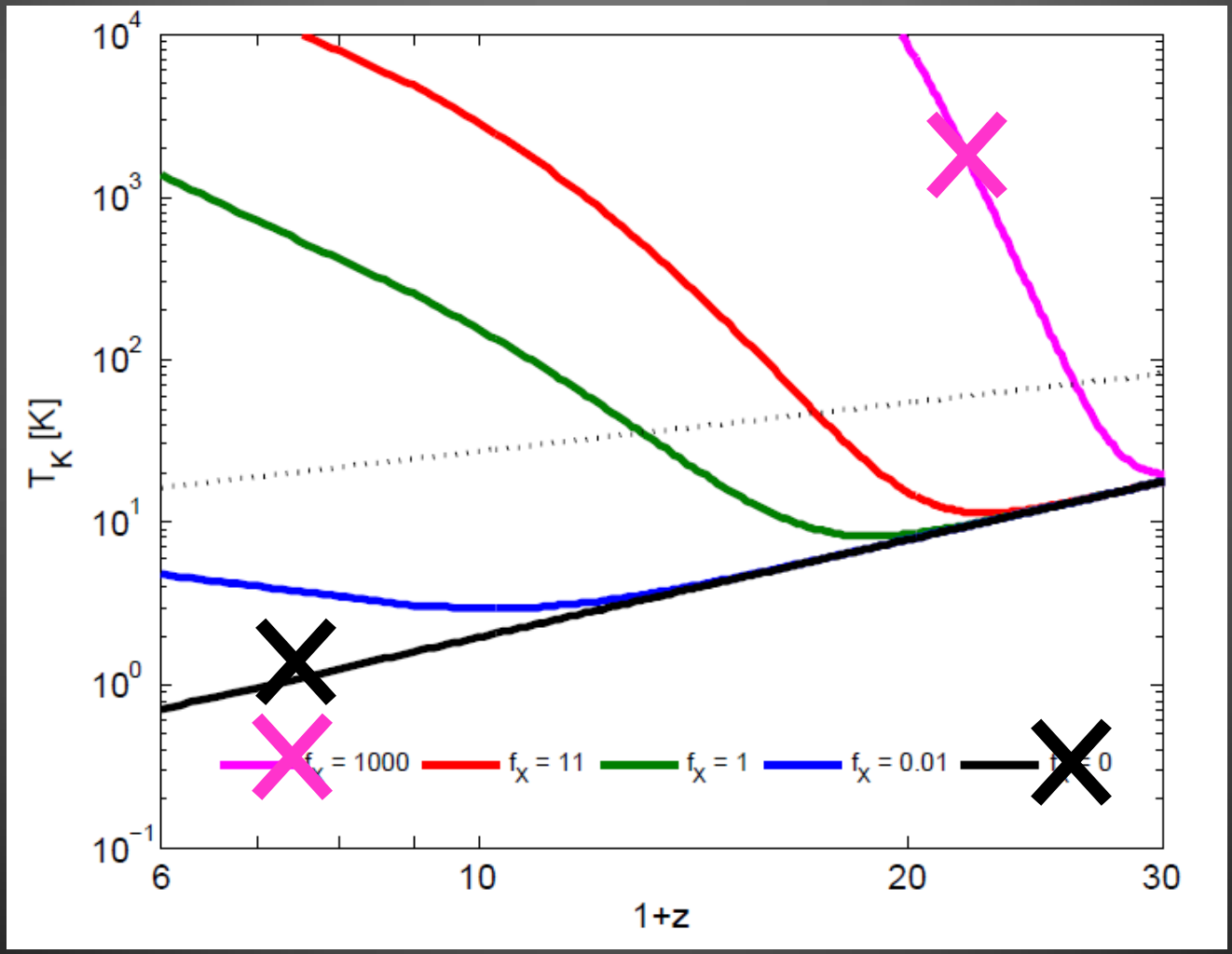
Also: 21-cm power gives lower limit on cosmic heating (f_X=0.001).

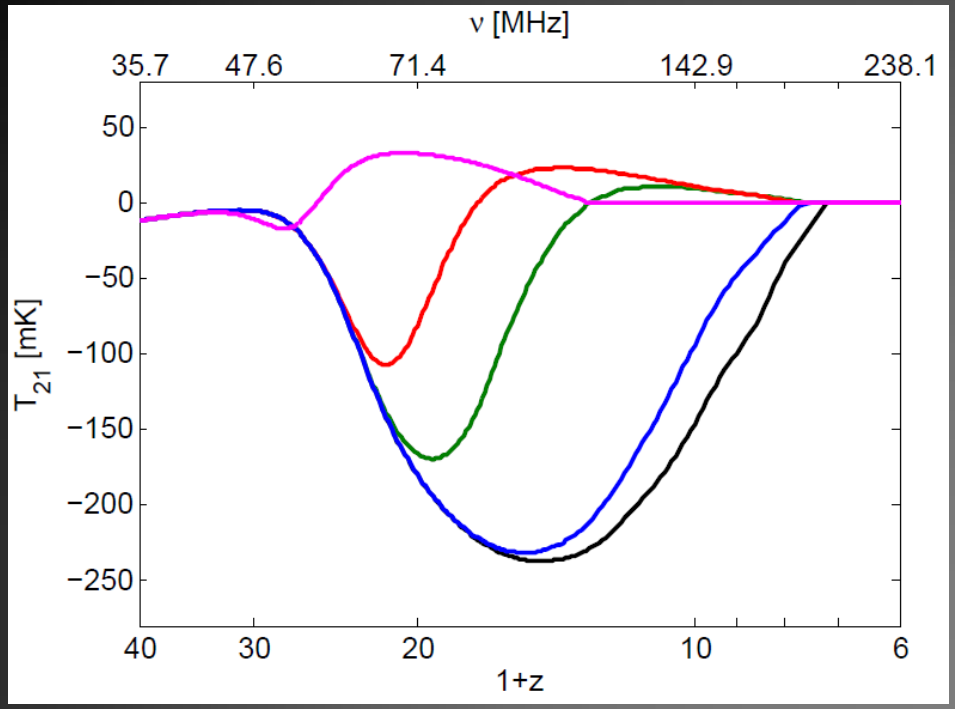
(Ali et al. 2015, Pober et al. 2015)

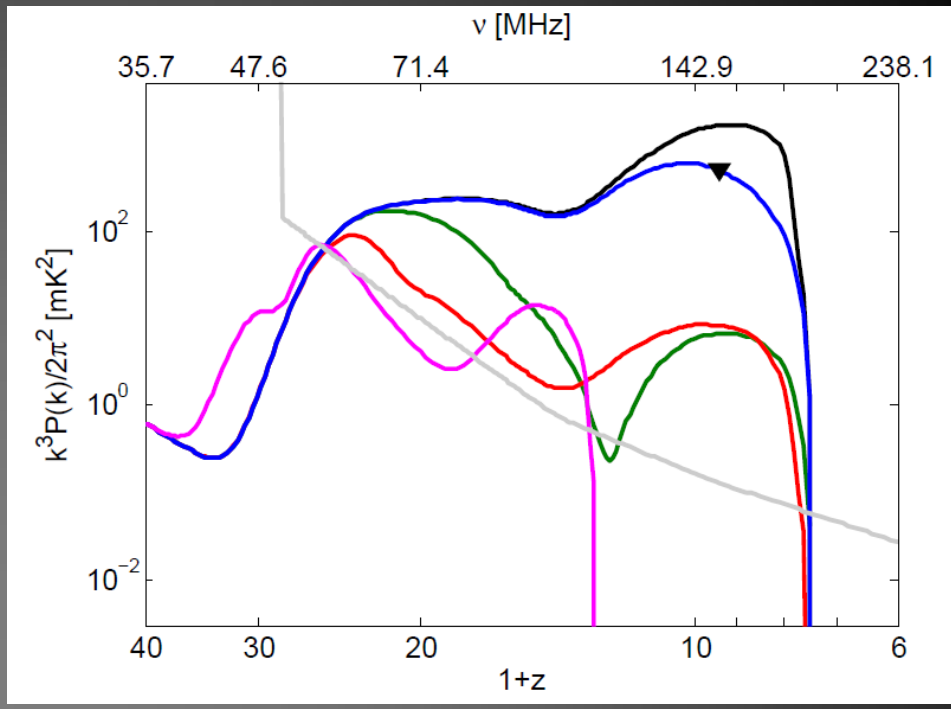
From 21-cm Signal and X-rays Limits on Cosmic Heating

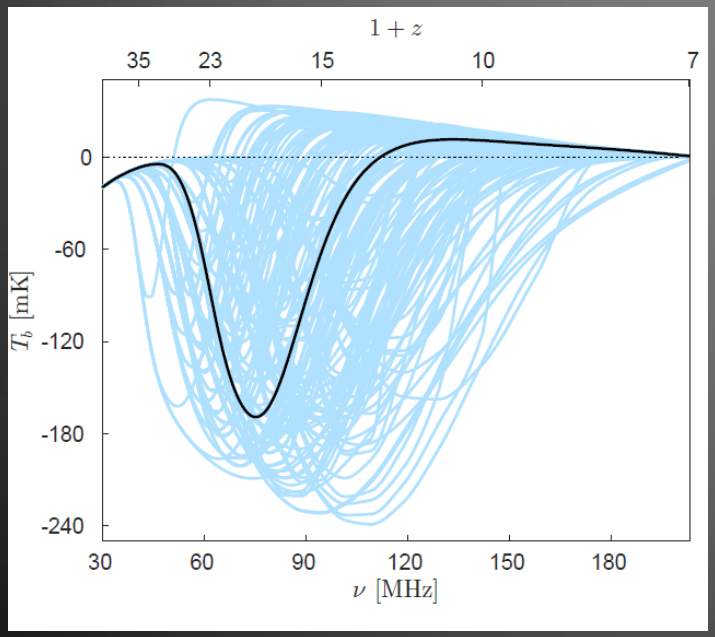
For atomic cooling, hard SED and $z_{re} = 6.2$

f_X <0.01 and f_X >11 are ruled out!

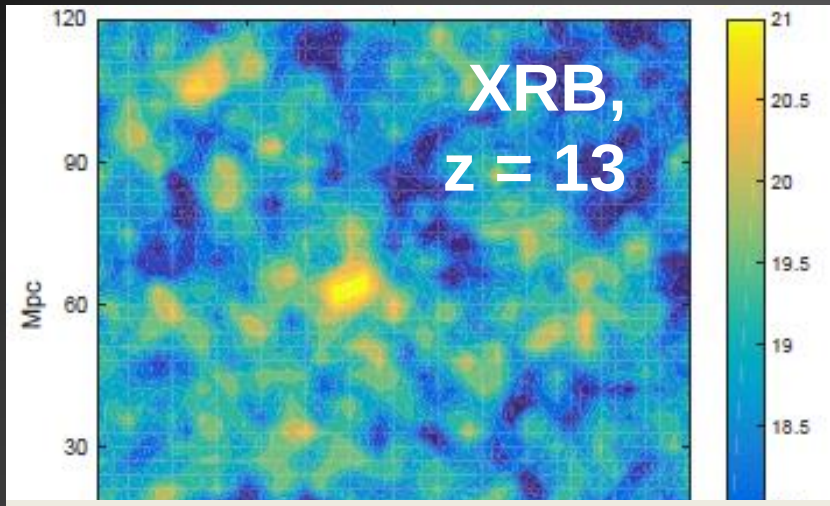


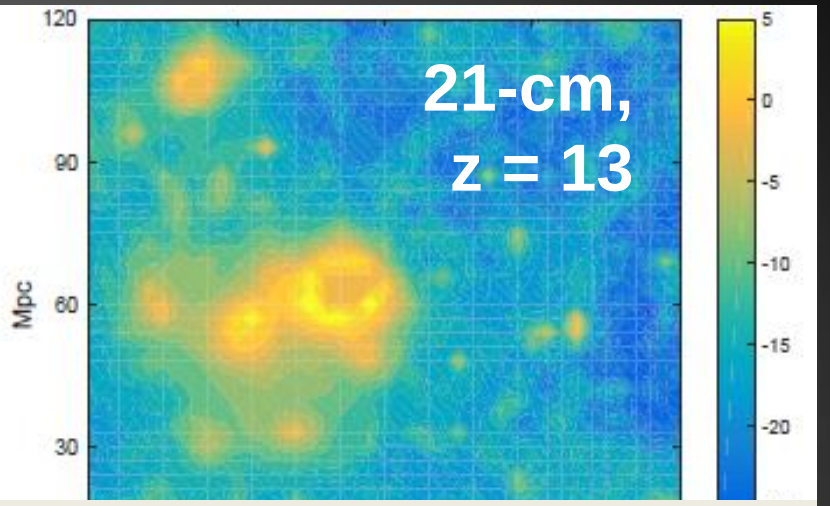




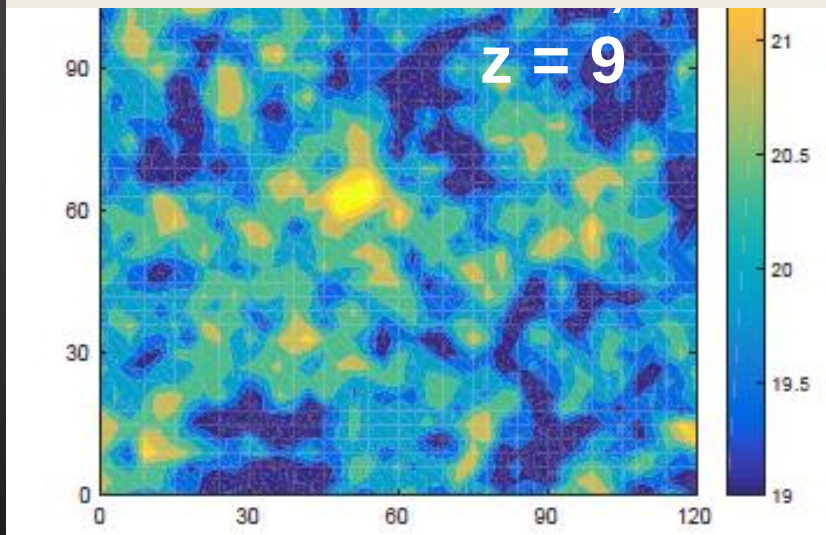


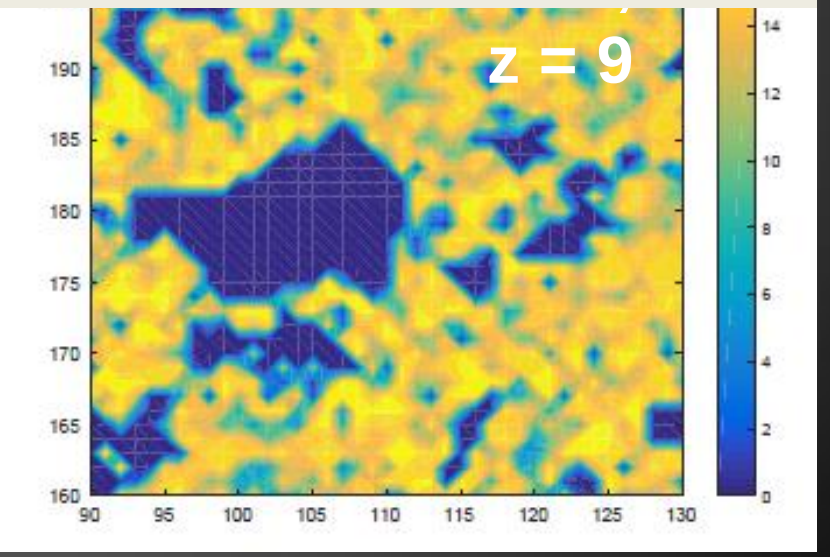
Still a wide space to constrain



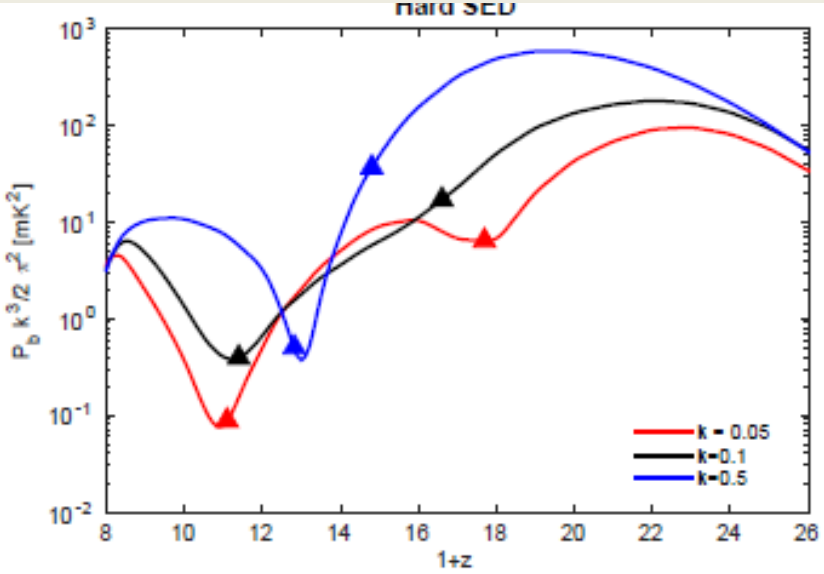


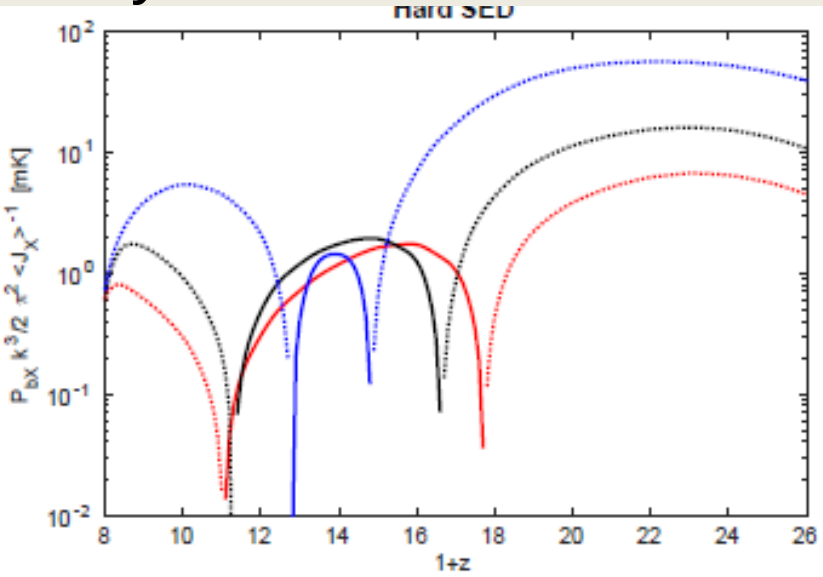
Cross-correlation with large-scale X-ray background can improve understanding of large-scale effect of X-rays

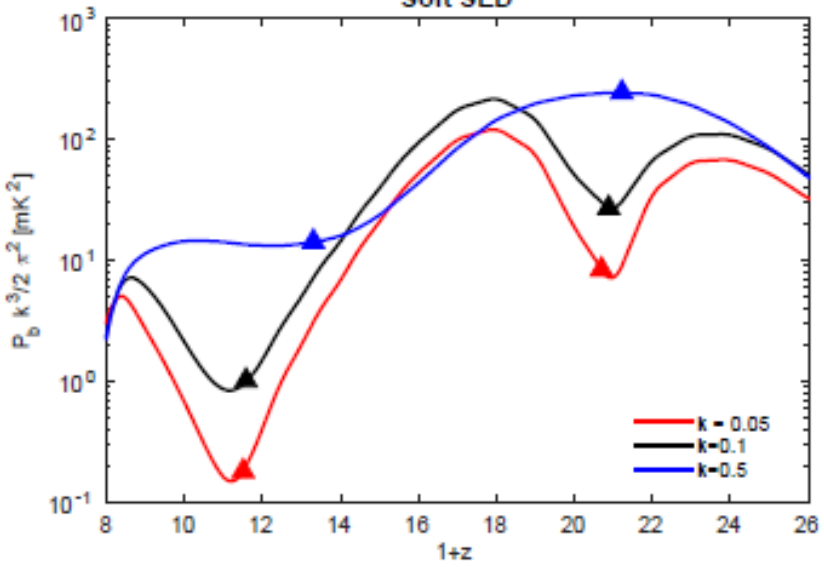


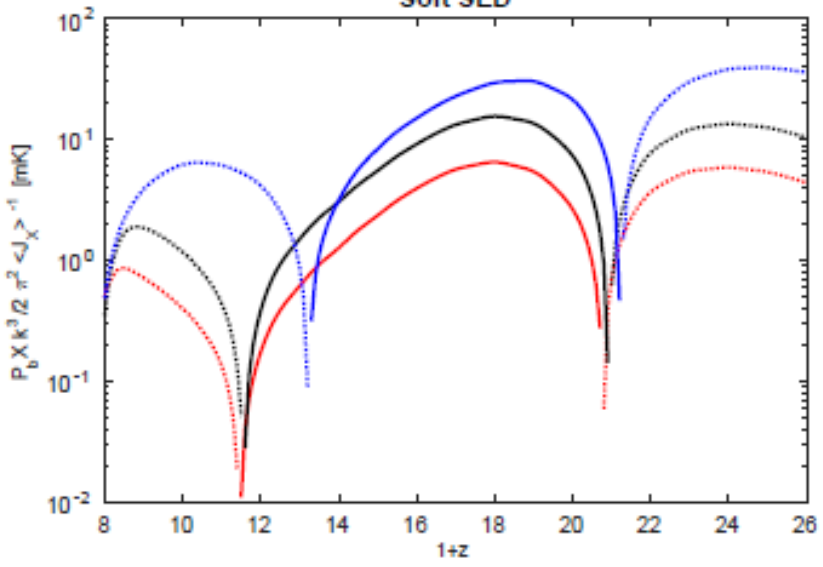


Even in cases when the X-ray peak is not evident in 21-cm, cross-correlating with X-rays background can highlight the effect of X-rays









More on cross-correlation is coming out soon!

Group in Munich: B. Ciardi, N. Cappelluti, et al.

- Hydro simulations & post-process with UV+X-rays (Khandai+ 2015)
- Box size ~ 100 Mpc/h
- Star and BH formation is followed from z = 20 to z = 6
- Preliminary results by the end of the year

Kakiichi et al., 2016

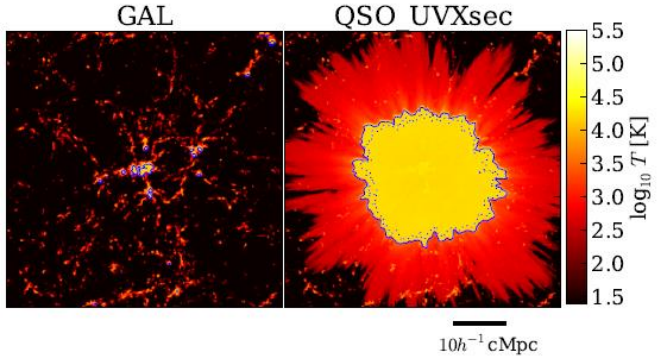


Figure 12. Maps of temperature for models GAL (left) and QSO_UVXsec (right). In both models the sources are turned on in a fully neutral medium at $z = 10$ and shine for 10^7 yr. The maps have a side length of $50h^{-1}$cMpc and the width of the slice is $195h^{-1}$ckpc. The H II (He III) I-front is shown as blue solid (dotted) contour.

Conclusions:

High redshift X-ray study is curtail for understanding the 21-cm signal & the role and nature of the first heating sources

1. Wide surveys: cross-correlation of backgrounds
2. Ultradeep observations: properties of point X-ray sources have strong impact on the large scale 21-cm signal