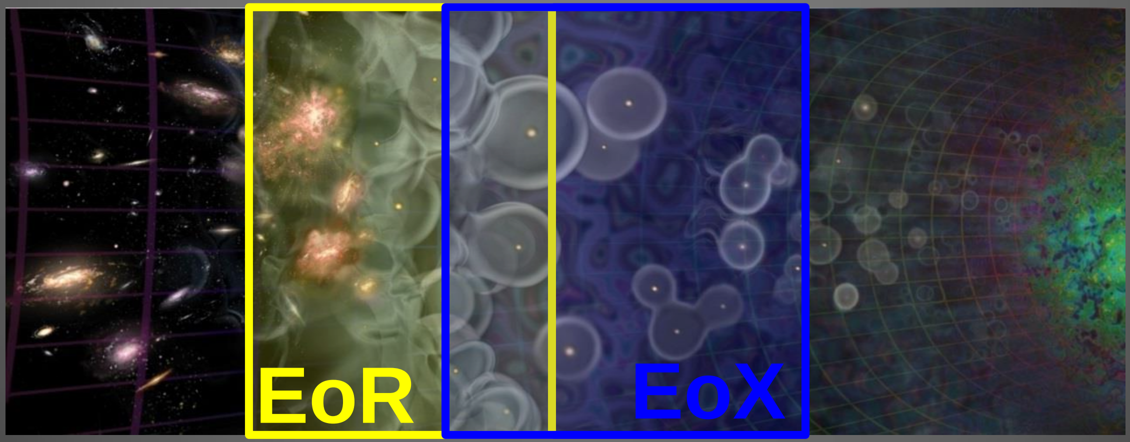
The Effect of First X-ray Sources on Reionization and the 21-cm Signal

Anastasia Fialkov,

ITC Fellow, Harvard

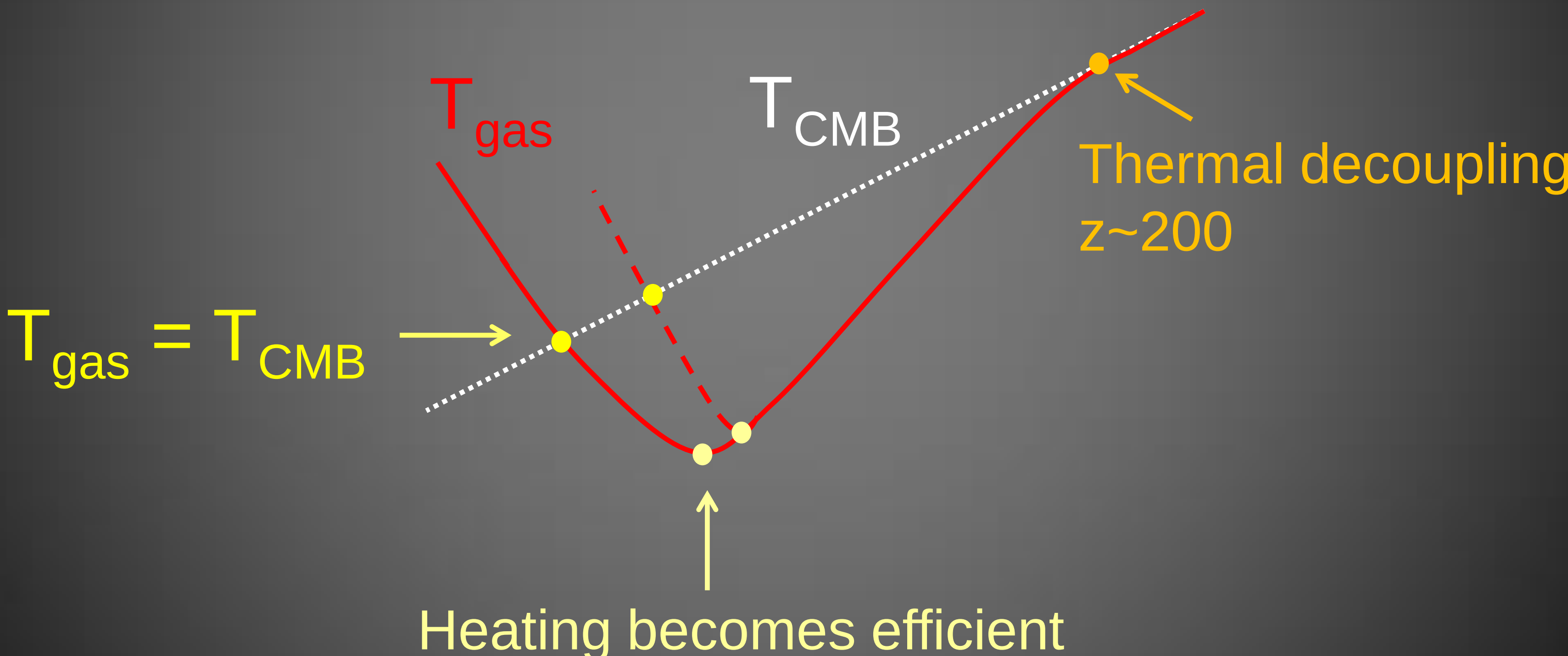


In collaboration with:

R. Barkana, A. Cohen, A. Loeb, J. Silk, E. Visbal

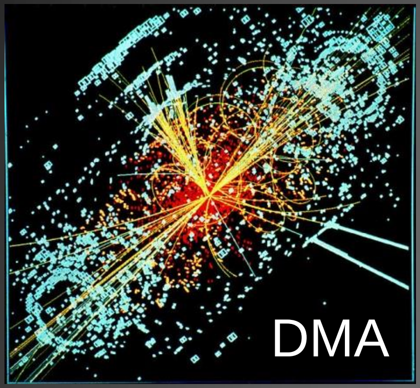
03.09.2016, Aspen

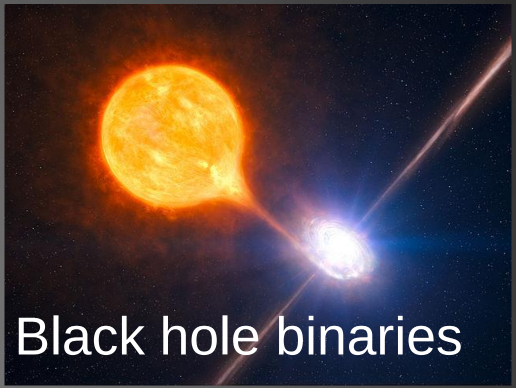
Role of X-ray Sources in Cosmic History



Heat and partially ionize the IGM far from the source

What Heated Up the IGM?





Open Questions:

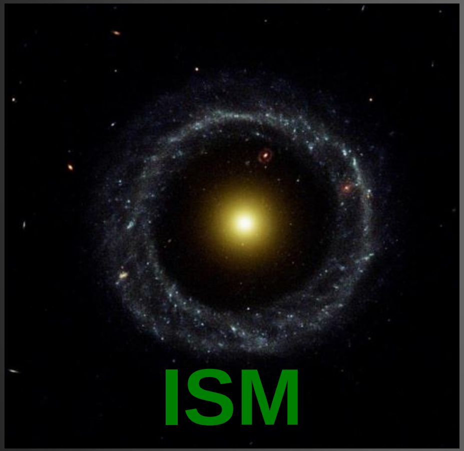
- Nature of heating sources
- Spectral energy distribution (SED)
- Efficiency
- Time dependence
- X-ray absorption
- Effects of metallicity

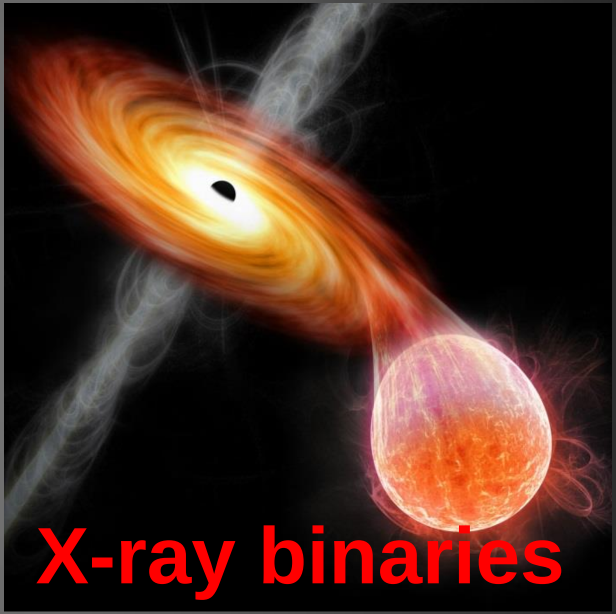
Possible Sources:

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

In this talk:

Sources with hard and soft SED

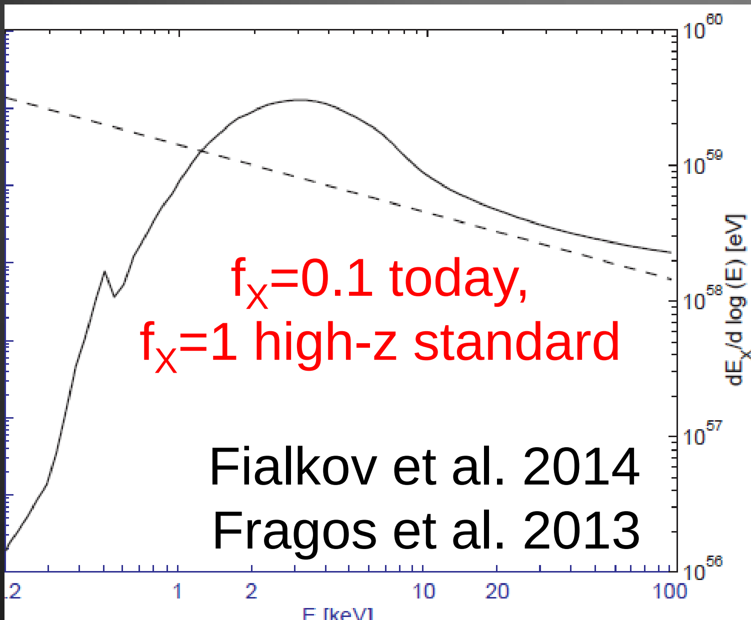




X-ray SED and Luminosity of Sources

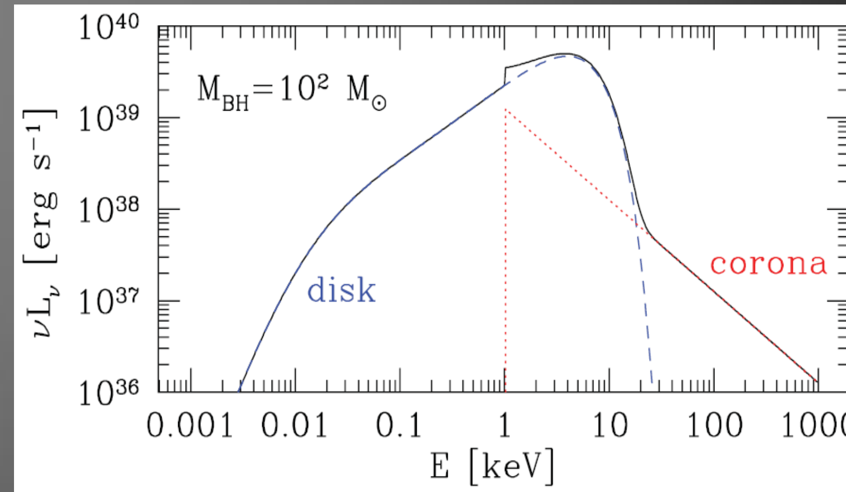
- Soft (ISM): power law with slope α and low-freq. cutoff ν_{min}
- Hard (X-ray binaries Fragos et al. 2013)
- Luminosity scales with SFR

$$\frac{L_X}{\mathrm{SFR}} = 3\times10^{40} f_X \ \mathrm{erg\ s^{-1}} M_\odot^{-1}\ \mathrm{yr}$$



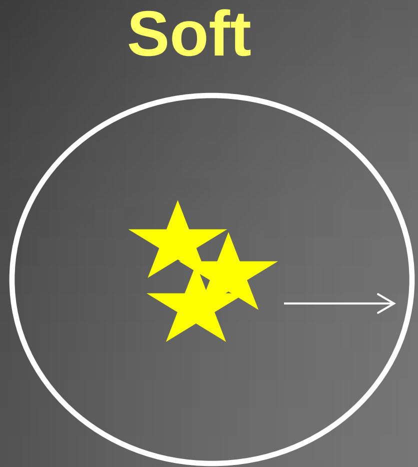
- Mini-quasars:
- High-z black holes 10^2-10^4 M_{sun}
- Internal feedback model (Wyithe & Loeb 2003) $M_{halo} \rightarrow M_{BH}$
- Luminosity weighted by mass

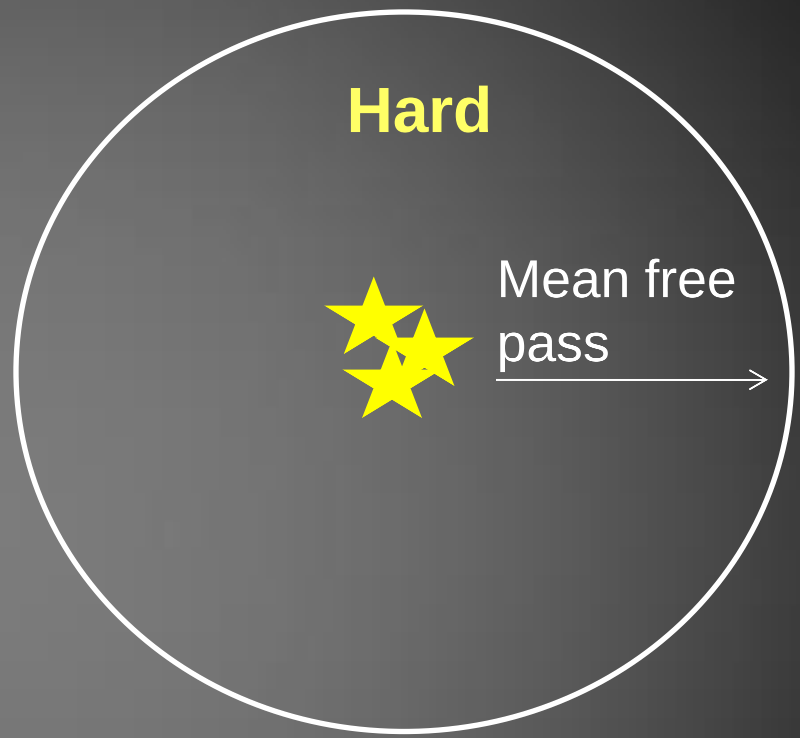
$$\frac{L_{MQ}}{L_{XRB}} \sim 0.1 \left(\frac{0.05 f_X^{MQ}}{f_X f_\star}\right)\left(\frac{M_h}{10^8\ M_\odot}\right)^{2/3} \frac{1+z}{10}$$



Shakura & Sunyaev (1973)
Tanaka et al. (2012)

Were First X-ray Sources Soft or Hard?



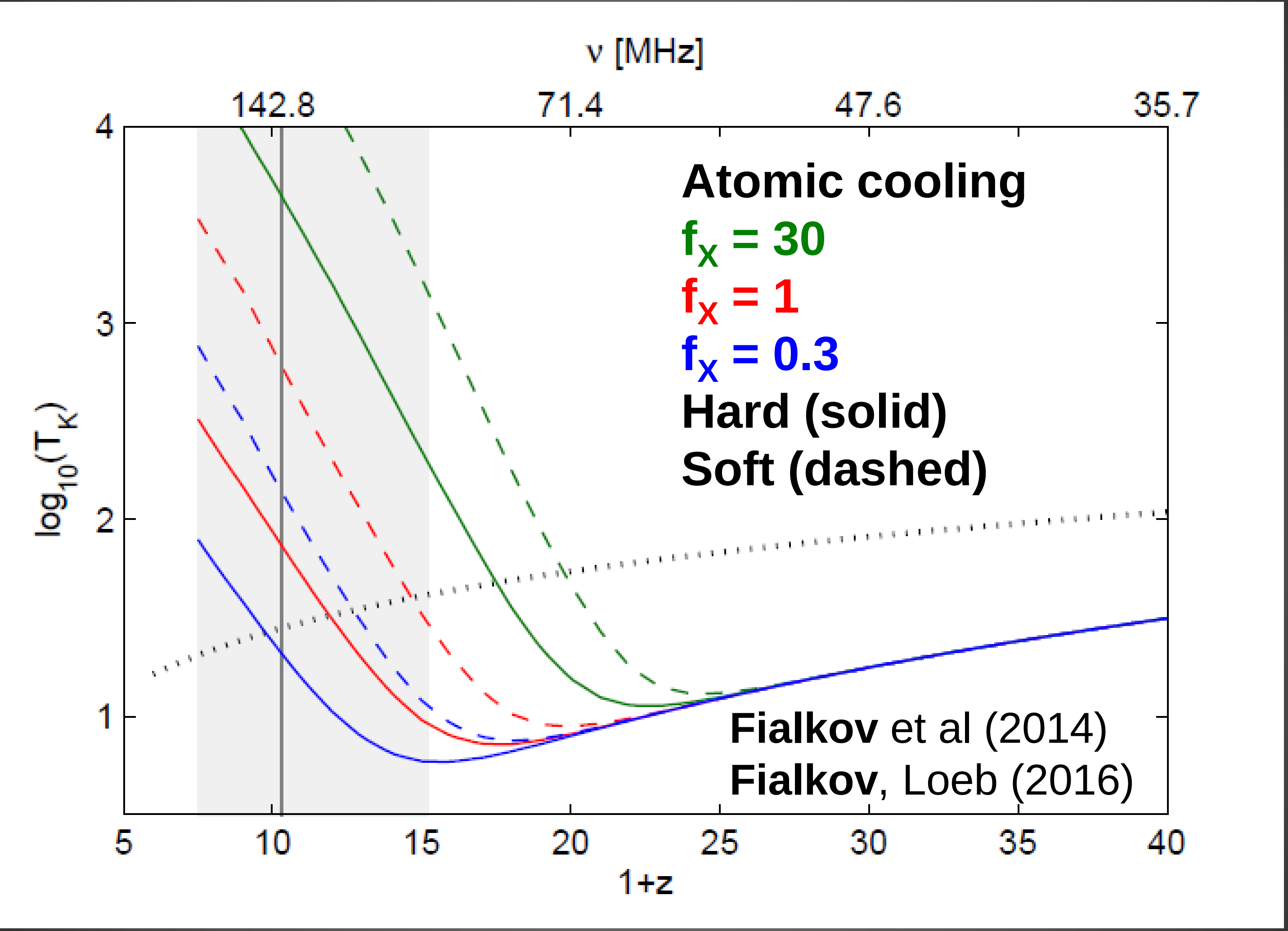


Details of SED are crucial!

If hard X-rays

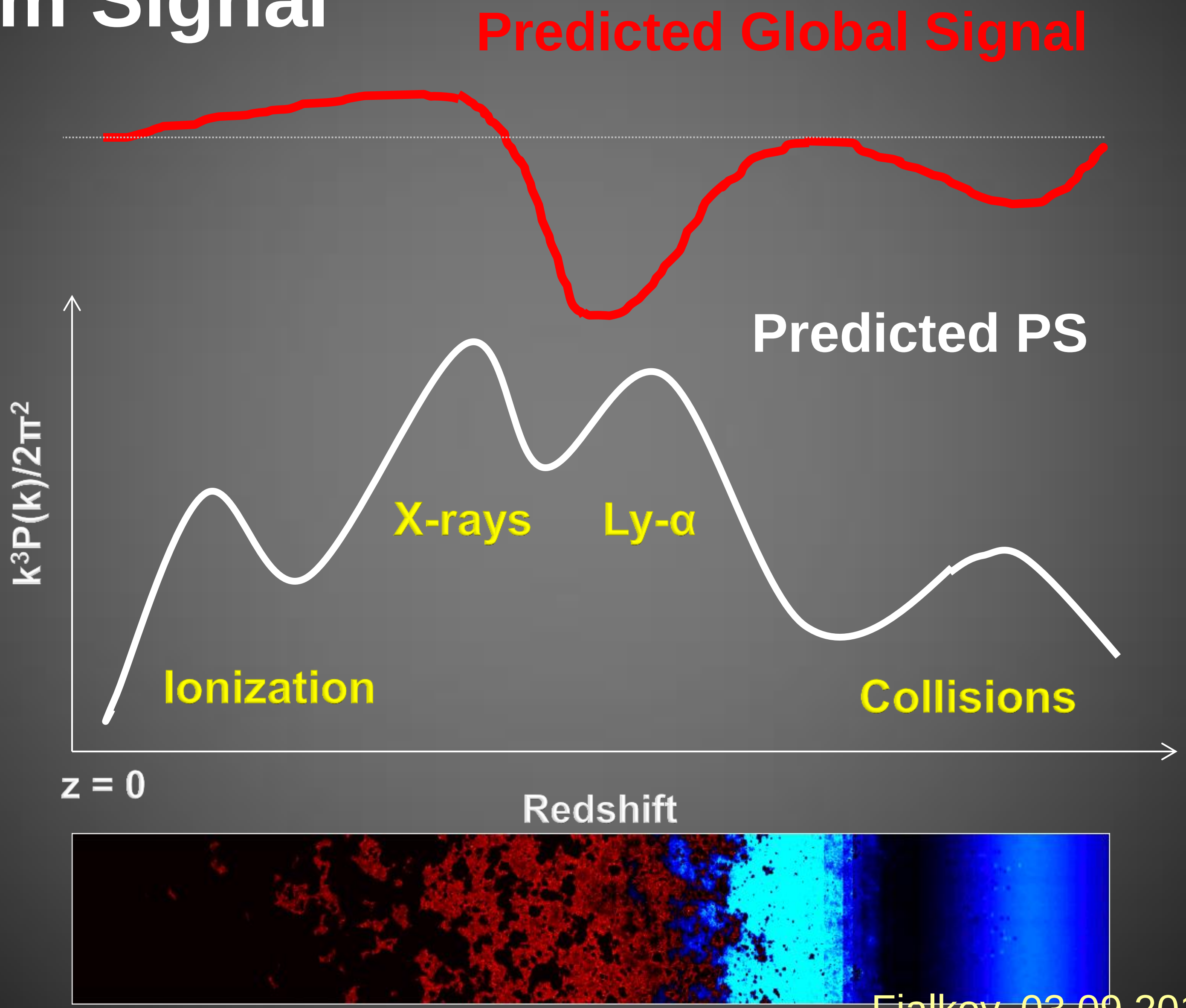
- Mean free pass is longer
- Heat and ionize the gas far from the source
- Fluctuations in gas temperature are washed out at scales below the mfp
- Delayed heating (energy redshifts away)

Gas Temperature



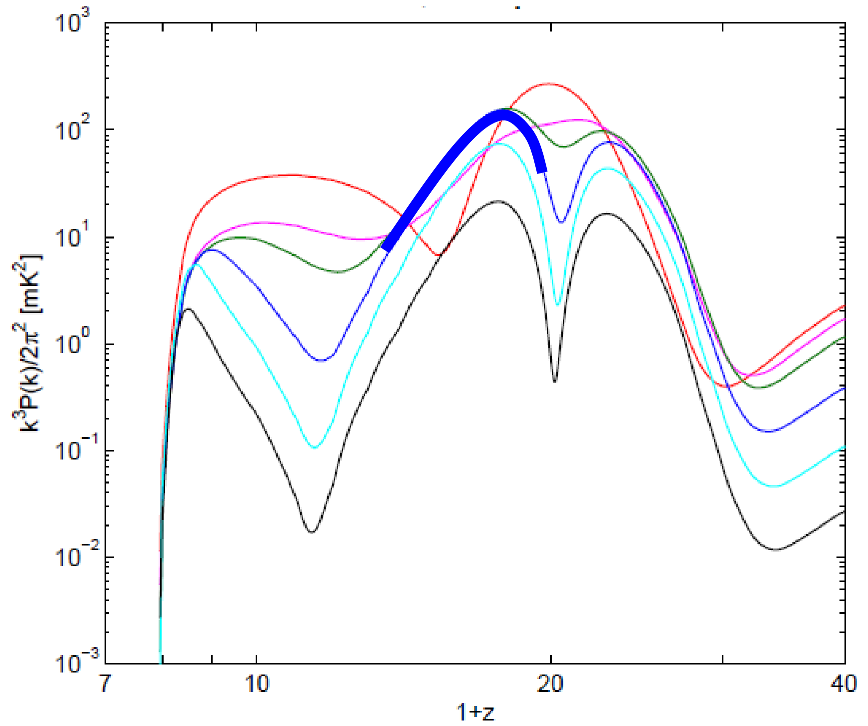
Gas can be rather cold during EoR!

Nature of X-rays Sources from the 21-cm Signal



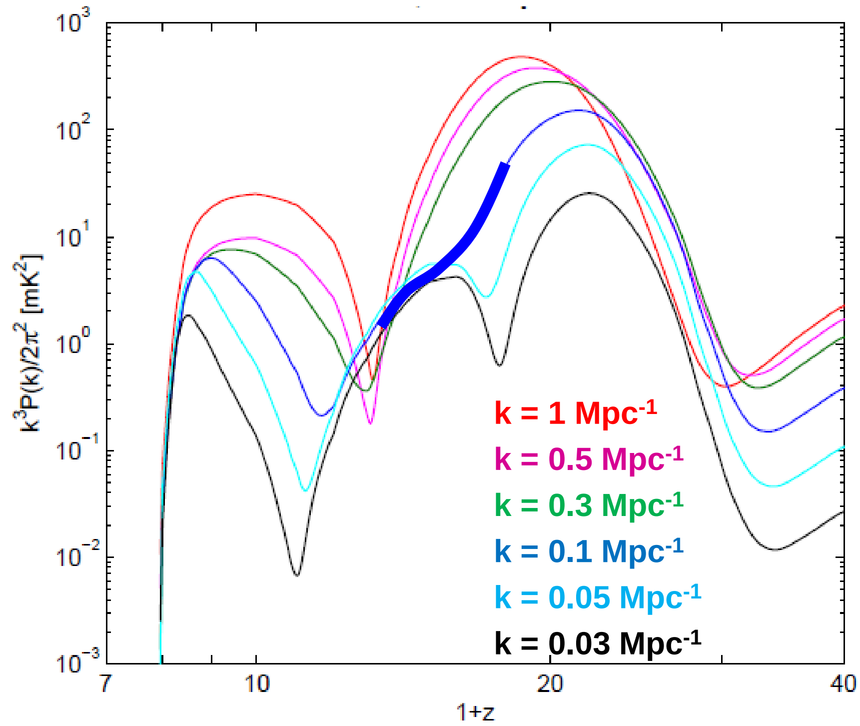
Hard vs Soft X-rays: Heating Peak

Soft X-rays



Hard X-rays

Almost uniform heating



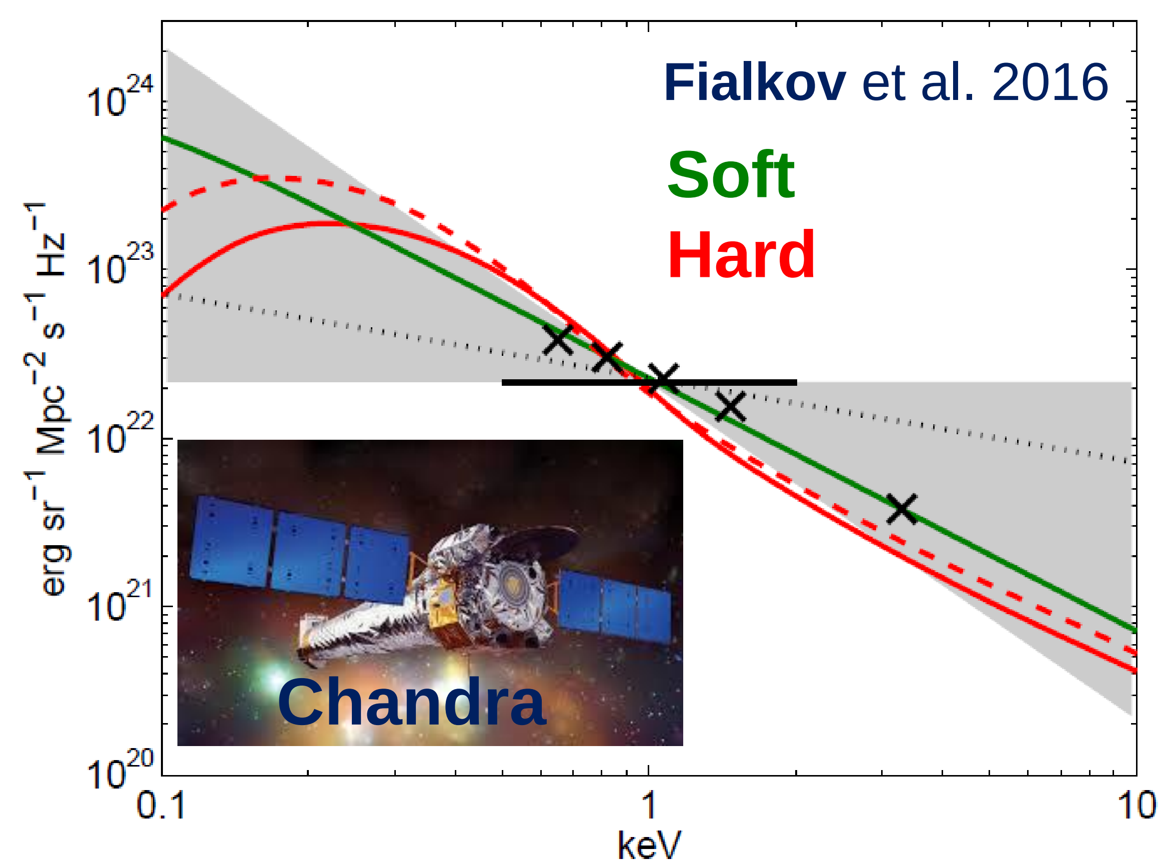
Fialkov & Barkana (2014)

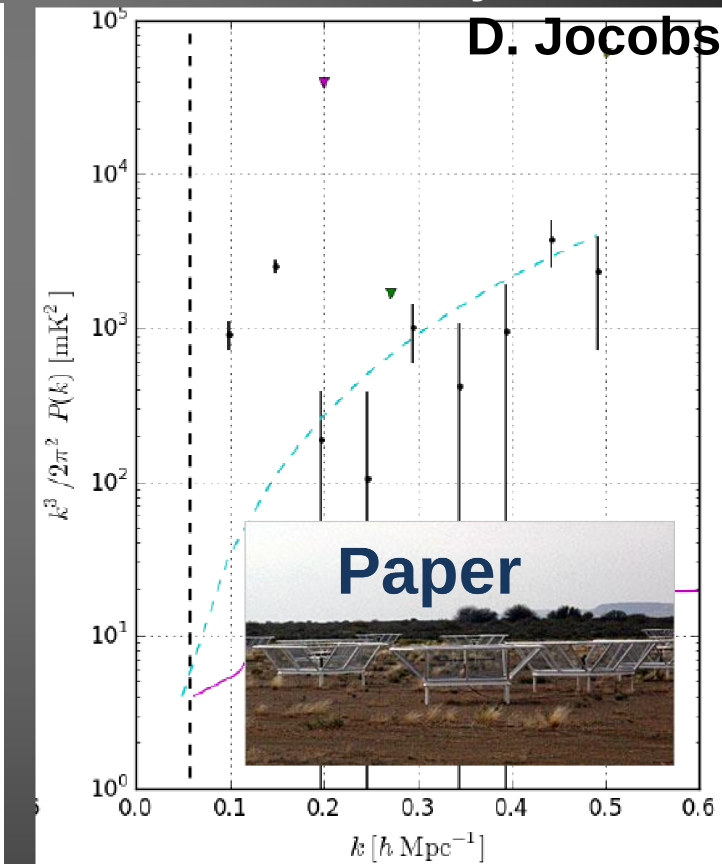
Limits on X-ray Efficiency of Sources, f_X

Upper Limit (f_X ~ 15 – 450) from unresolved X-ray background (~ 12%, Lehmer et al. 2012).

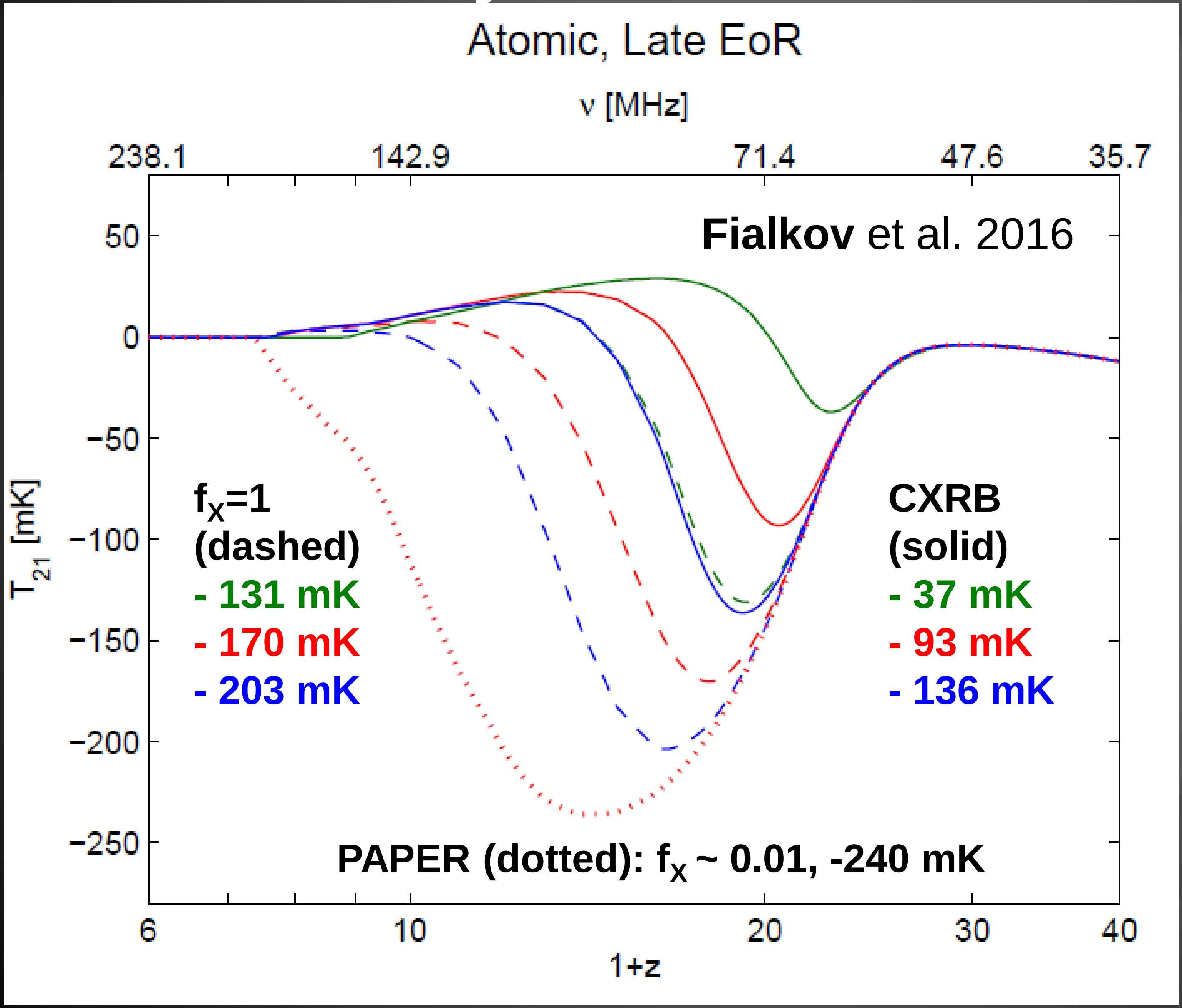
Lower Limit (f_X ~ 0.001-0.01) from 21-cm power (Ali et al. 2015, Pober et al. 2015).

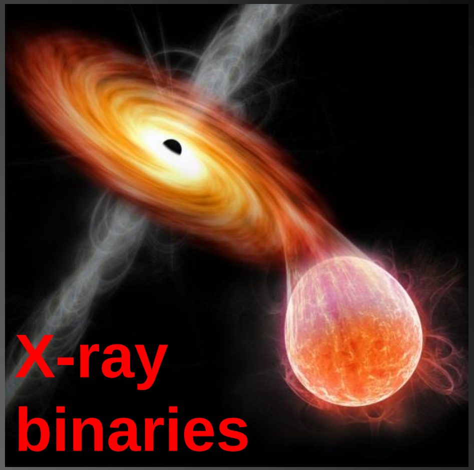
Pober et al. 2016
Talk by J. Dillon
D. Jocobs

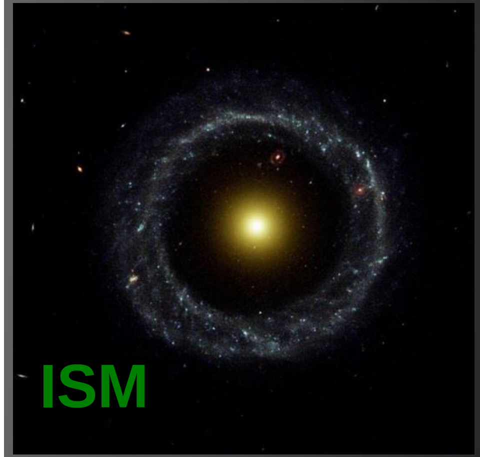




Limits on f_X
Uncertainty in the Global







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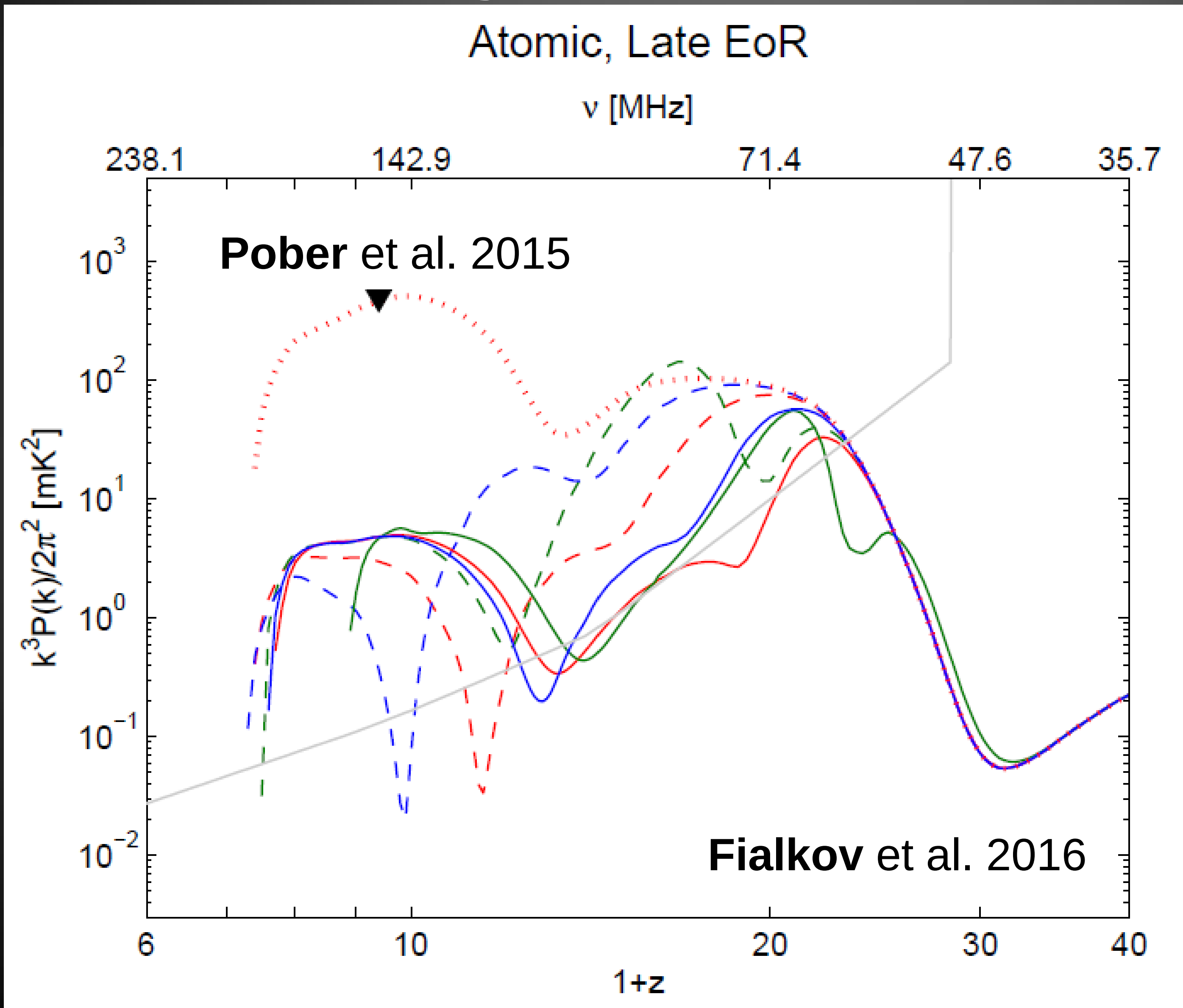
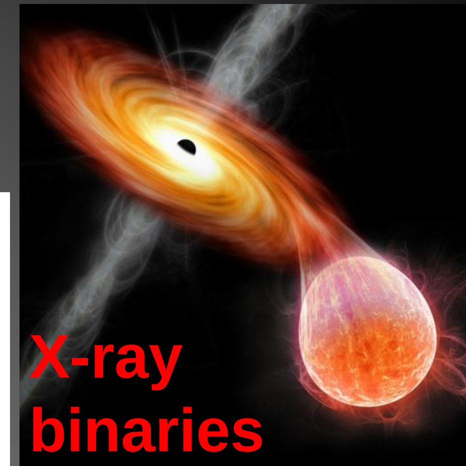
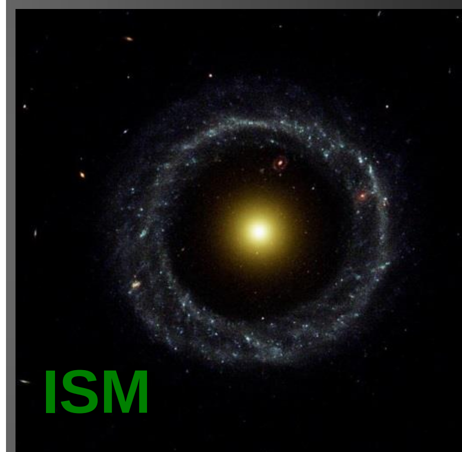
Limits on f_X
Uncertainty in the PS







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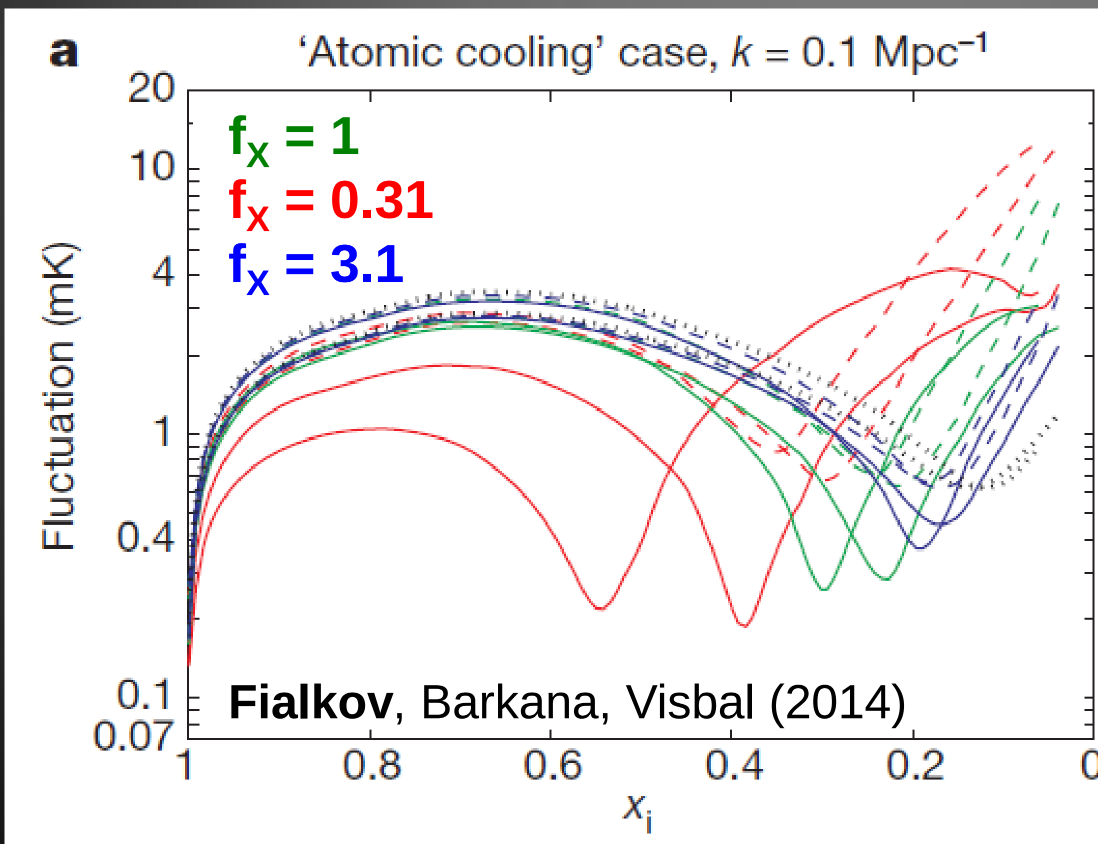
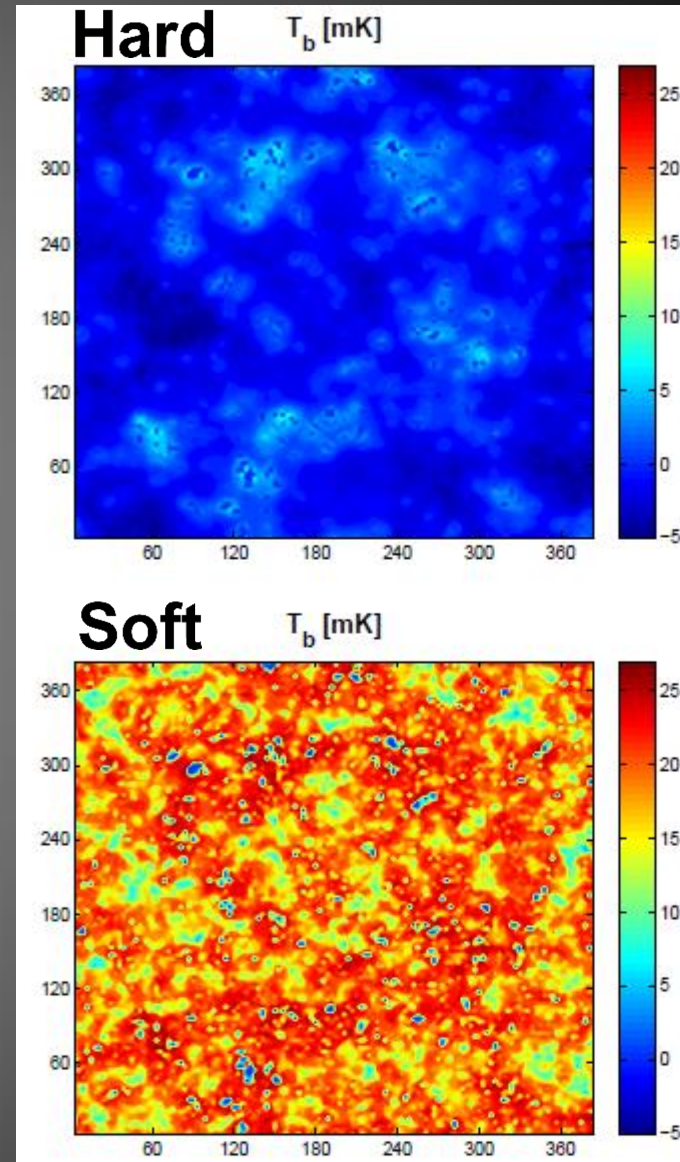
Effect of X-rays on EoR:

Partial ionization by X-rays: Increases τ
Δτ = 14% (soft), Δτ = 2% (XRBs),
Δτ = 1% (MQ)
Reionization is smoother
Fluctuations in the 21-cm are suppressed



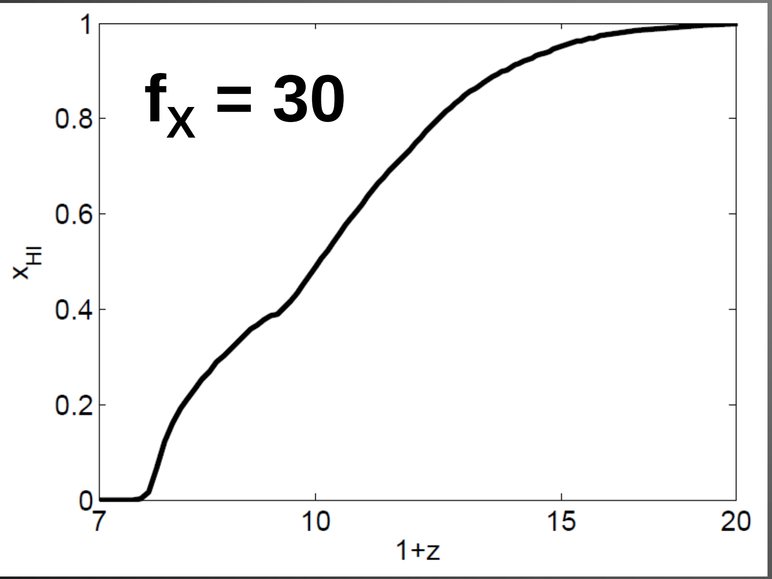
Fialkov & Barkana (2014)



May be Challenging to Reconstruct x_{HI} from 21-cm

$$\delta T_b \approx \delta T_{b,0}(1+z)^{1/2} x_{HI}(1+\delta)\left(1-\frac{T_{CMB}}{T_S}\right), \quad T_S \neq T_K$$

If thermal effects can be ignored, we expect to fully recover x_{HI} from the global 21-cm signal



Fialkov & Loeb 2016

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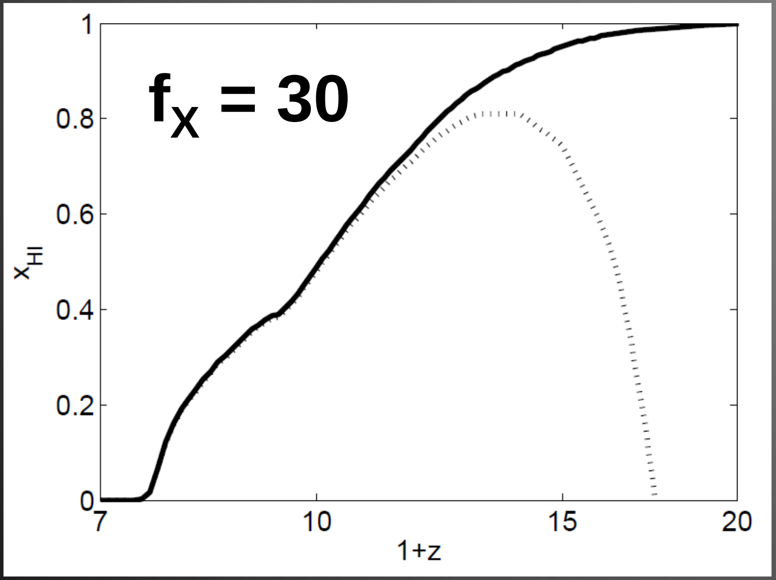
However, in practice the reconstructed x_{HI} deviates from the true one due to the temperature effects



Fialkov & Loeb 2016

May be Challenging to Reconstruct x_{HI} from 21-cm

$$\delta T_b \approx \delta T_{b,0}(1+z)^{1/2} x_{HI}(1+\delta)\left(1-\frac{T_{CMB}}{T_S}\right) \quad , \; T_S \neq T_K$$

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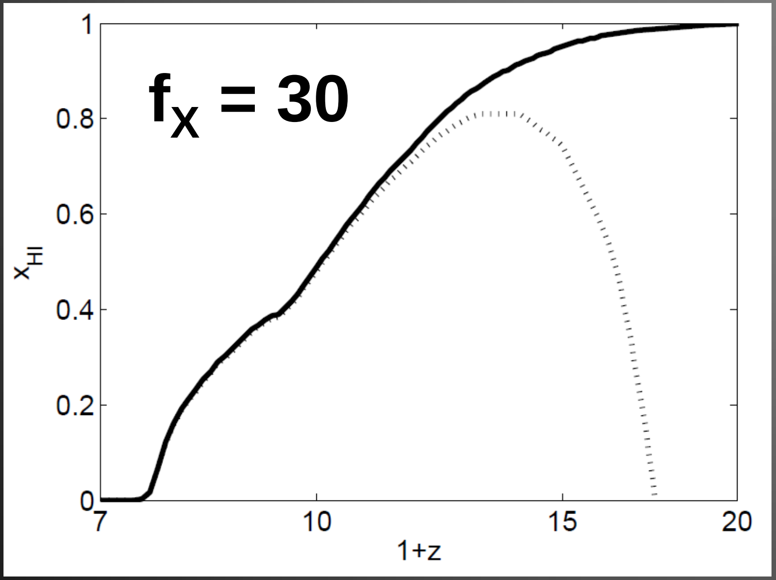

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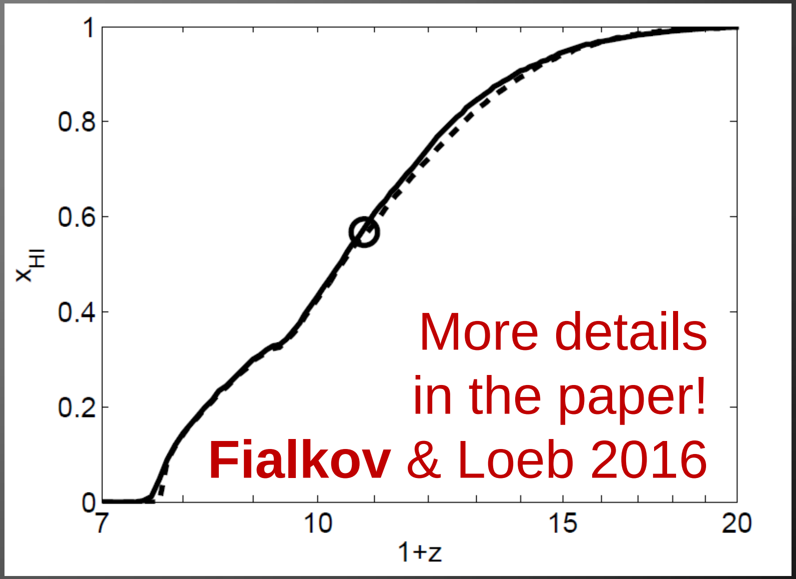
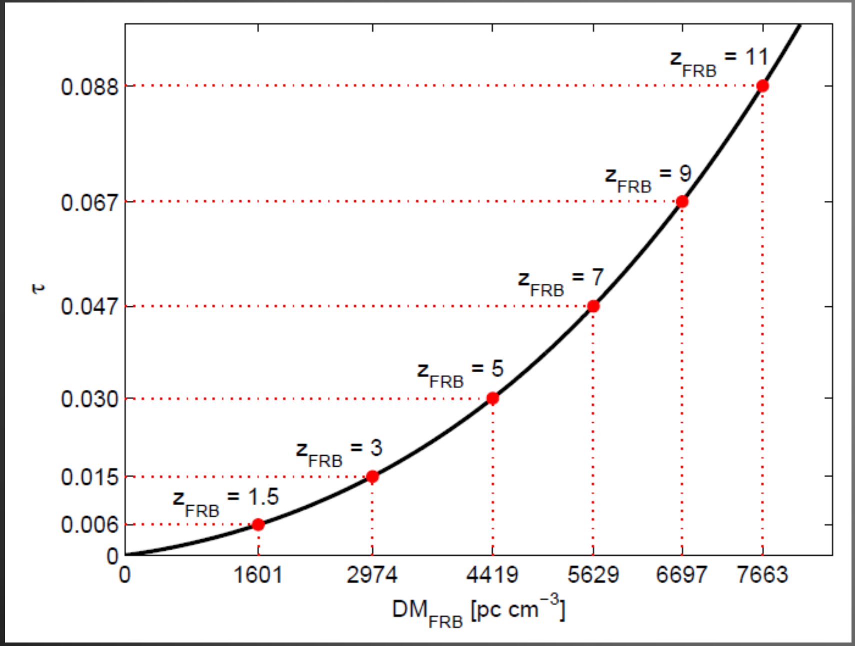
Adding thermal info and fitting allows us to reconstruct x_{HI} and find tau (talk by A. Liu).



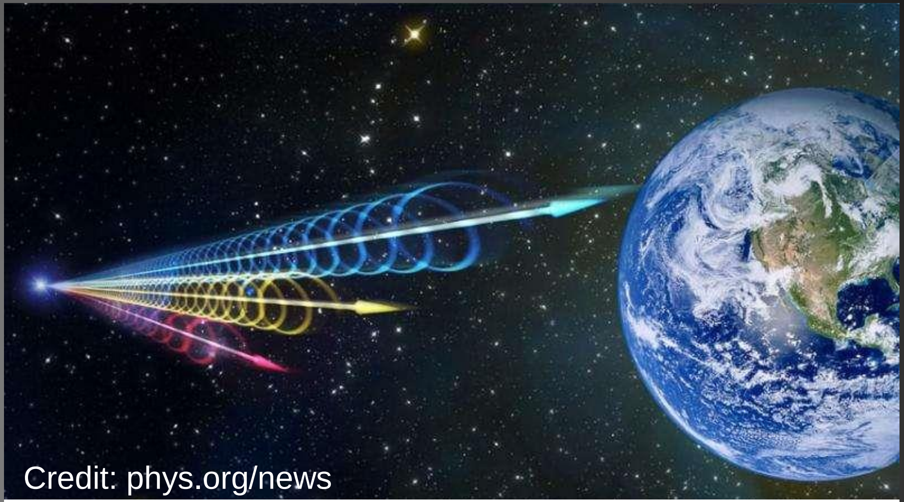
Alternative Probe of EoR

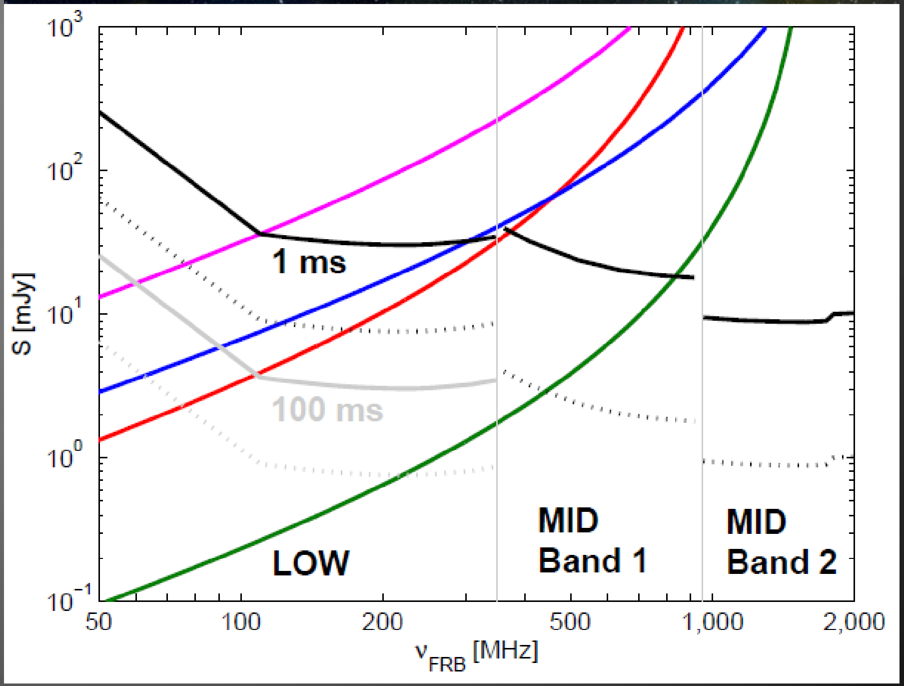
Total optical depth can be probed through the DM of fast cosmological transients

Fialkov & Loeb, 2016b



$$\tau(z) = \left[\frac{\mathrm{DM}(z)}{\mathrm{cm}^{-2}}(1+z) - \int_0^z \frac{\mathrm{DM}(z')}{\mathrm{cm}^{-2}}dz'\right] \times \sigma_T$$





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Conclusions

- High-z X-ray sources are unconstrained (likely X-ray binaries and mini-quasars)
- X-rays may have a strong impact on EoR
- 21-cm is a sensitive probe of the nature of X-ray sources.
- If cosmological, FRB offer an alternative way to probe EoR
- Looking forward for observations!