Towards complete understanding of 21-cm signal from high redshifts

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Stellenbosch, 18 February 2014

The main idea

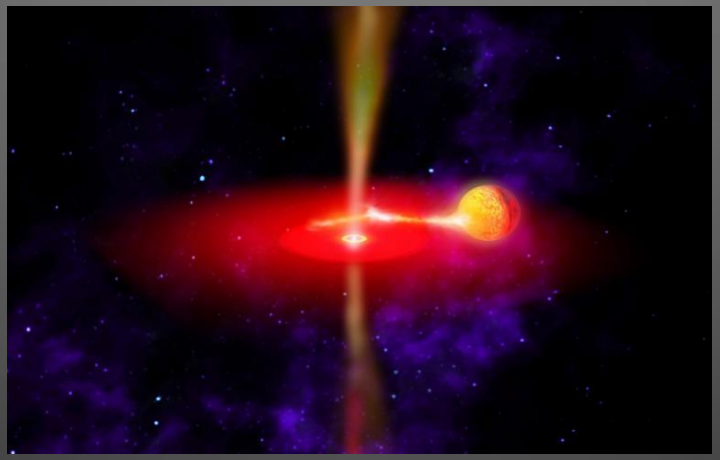
Realistic heating model qualitatively changes our expectations for the 21-cm signal from reionization ($x_i < 0.5$)

LETTER

doi:10.1038/nature12999

The observable signature of late heating of the Universe during cosmic reionization

A. Fialkov, R. Barkana & E. Visbal, **Nature, February 2014**

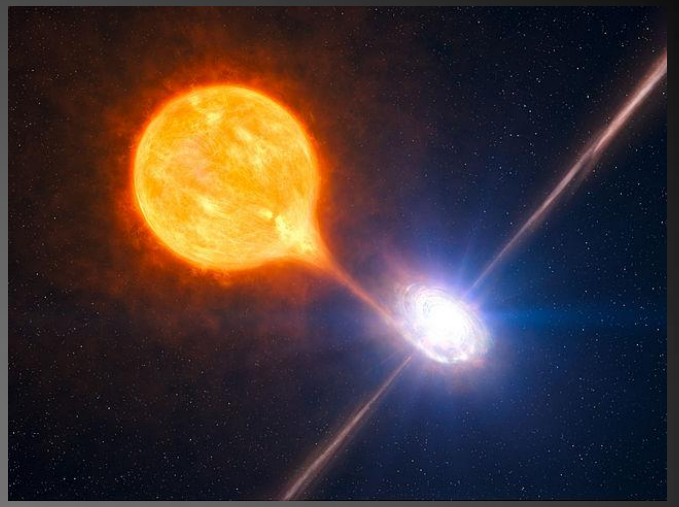


First heating sources

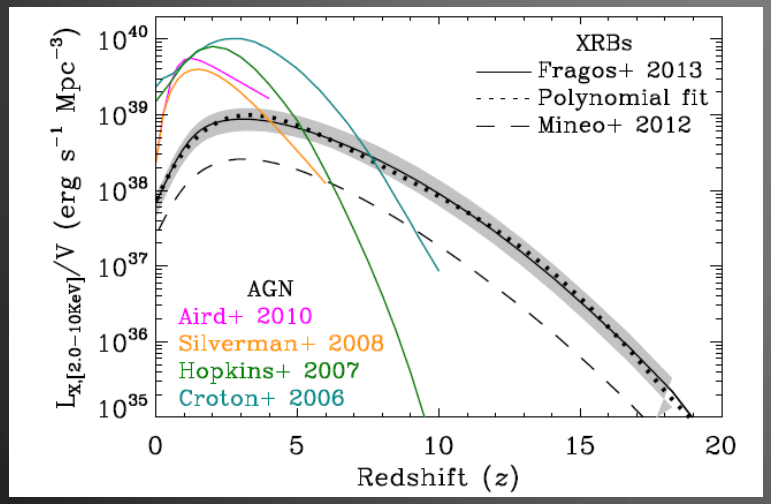
The most natural heating source at high redshifts:

High mass X-ray binaries

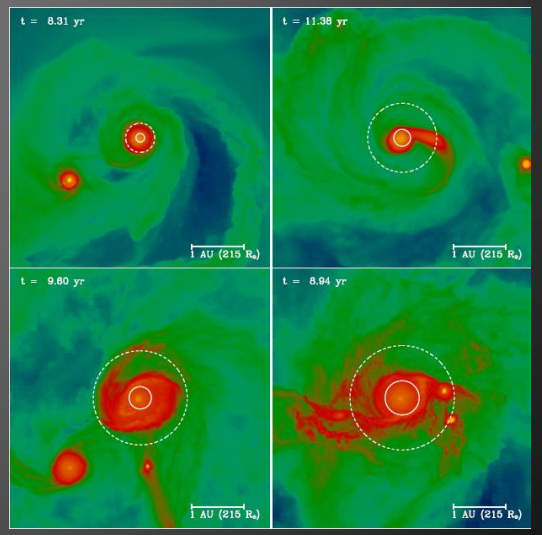
- Direct consequence of SF at high z
- Other sources are expected to be subdominant at high z



Formation of ~ 30 M_{sun} PopIII stars
(Stacy et al 2013)

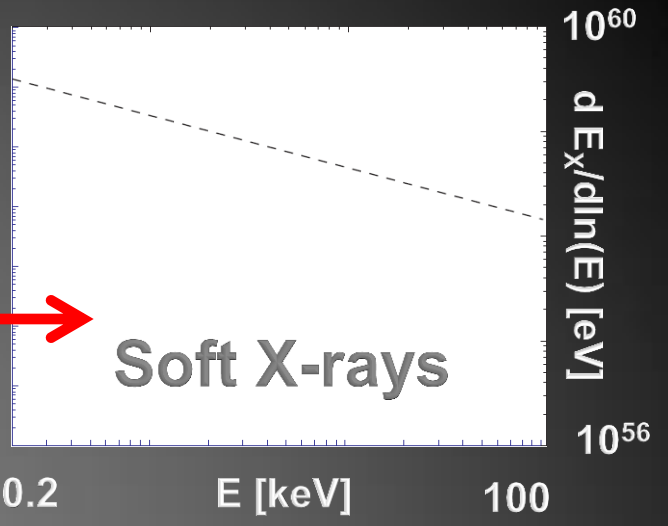


Xray luminocity:
Xray binaries win over AGNs at high z
(Fragos et al 2013)

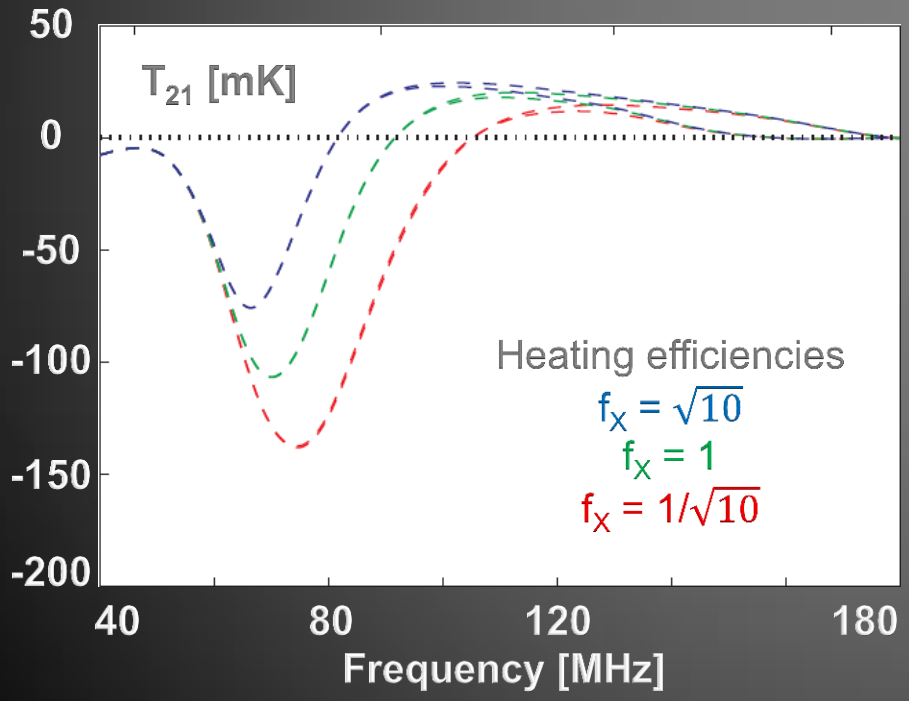


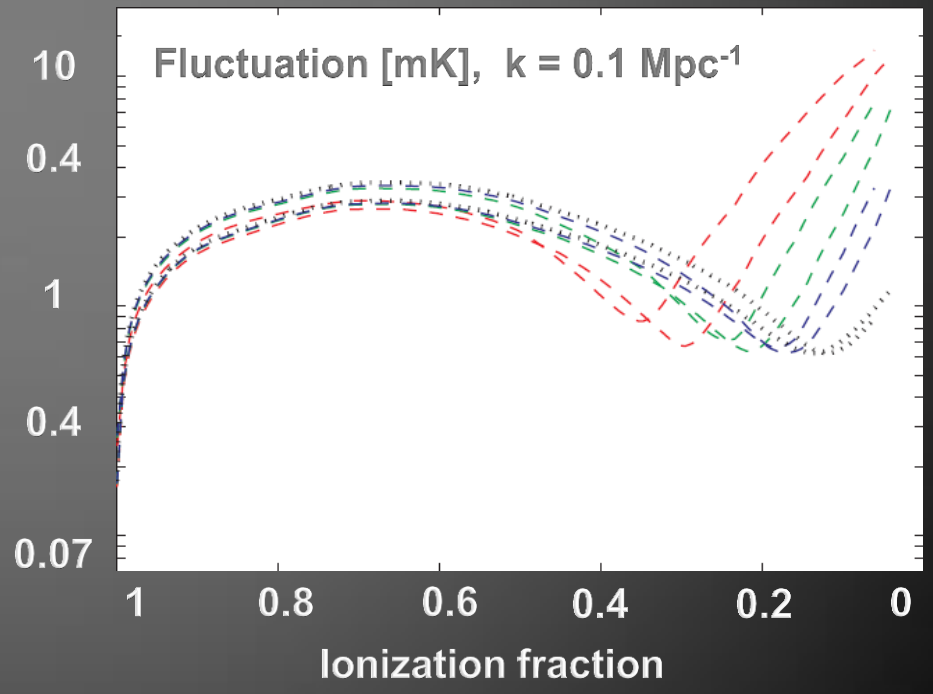
Heating by XRBs, Traditional Pictured.

- Model: power-law X-ray spectrum
- Gas heats and then ionizes ($T_{gas} > T_{CMB}$, EoR)
- Large (well-defined) heating fluctuations



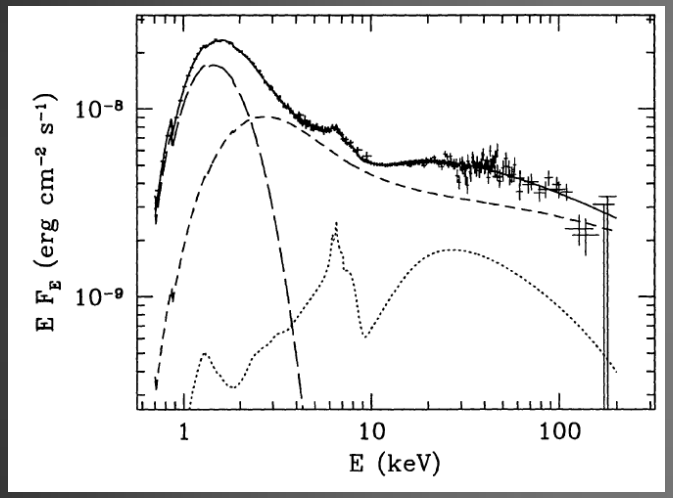
A. Fialkov, R. Barkana & E. Visbal, Nature 2014





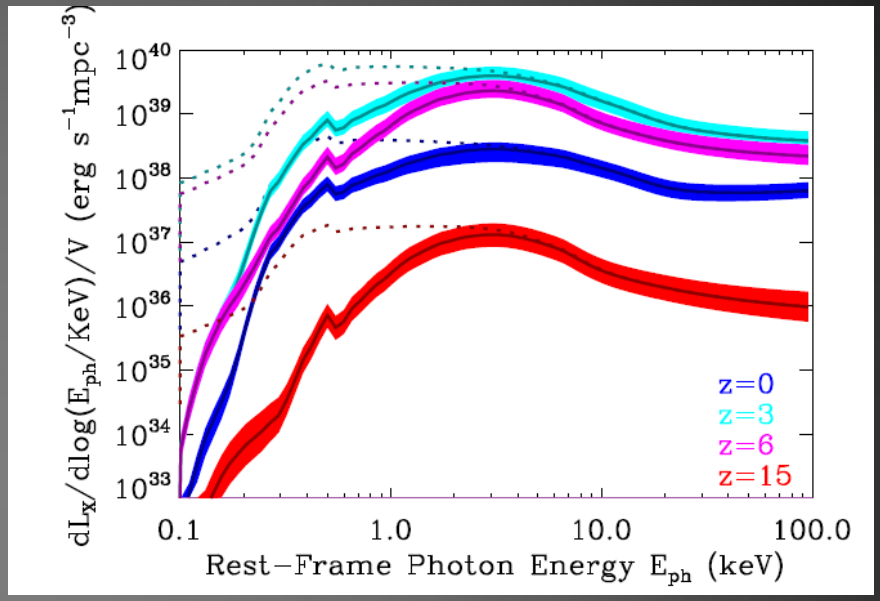
But realistic high mass XRBs spectrum … is hard!

Old news:



Gierlinski 1999

Cyg X-1 a binary with a black hole and a supergiant star.



Fragos et al 2013

Results of a population synthesis simulations calibrated to all available observations of XRBs

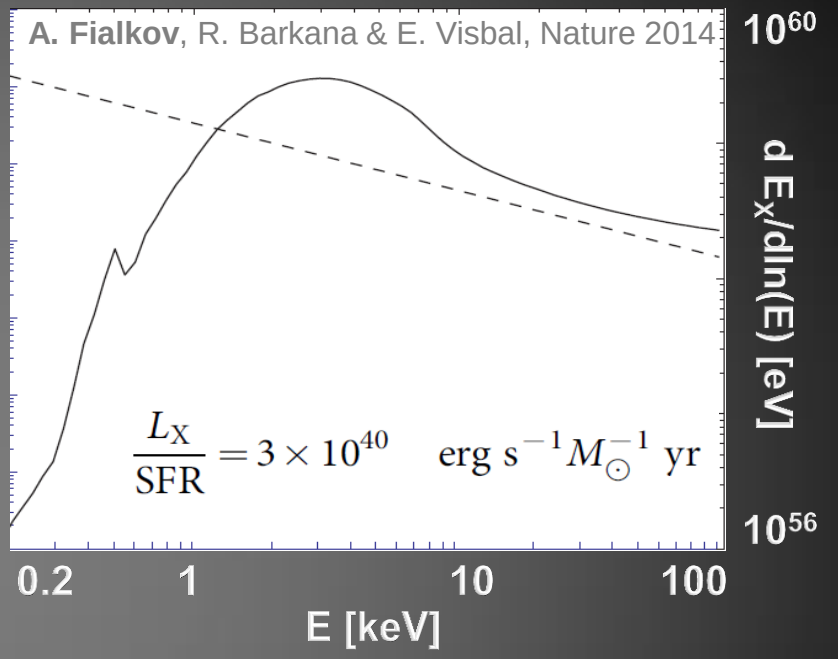
+ many other works

Realistic high mass XRBs spectrum:

- Harder X-rays → longer mean free pass
- The absorbed energy by gas is reduced by ~ 5 (redshift)

Unlike previously expected:

- Now the gas is cold ($T_{gas} < T_{CMB}$) during the first half of EoR ($x_i < 0.5$)
- Heating is much more uniform



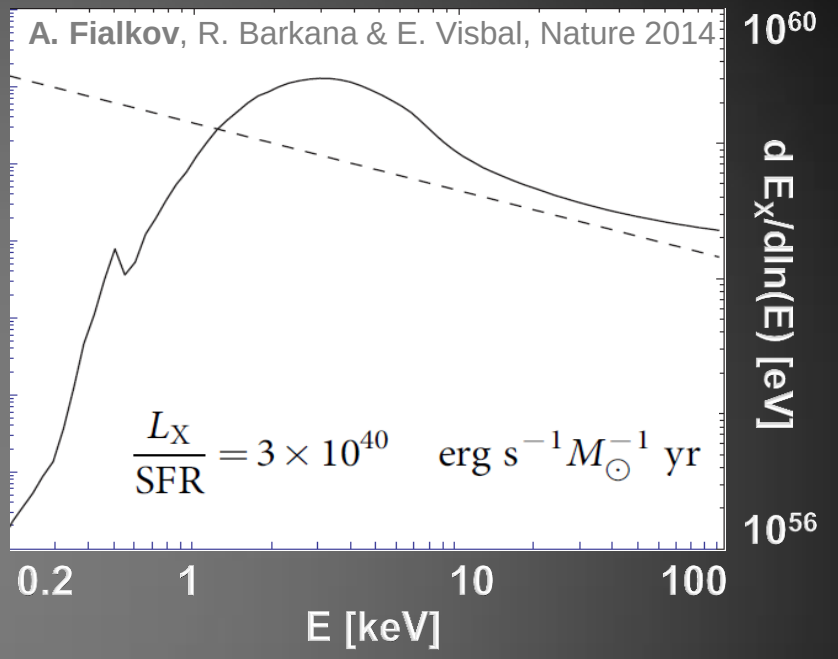
(Based on Fragos et al 2013)

Realistic high mass XRBs spectrum:

- Harder X-rays → longer mean free pass
- The absorbed energy by gas is reduced by ~ 5 (redshift) → heating is delayed

Unlike previously expected:

- Now the gas is cold ($T_{gas} < T_{CMB}$) during the first half of EoR ($x_i < 0.5$)
- Heating is much more uniform



(Based on Fragos et al 2013)

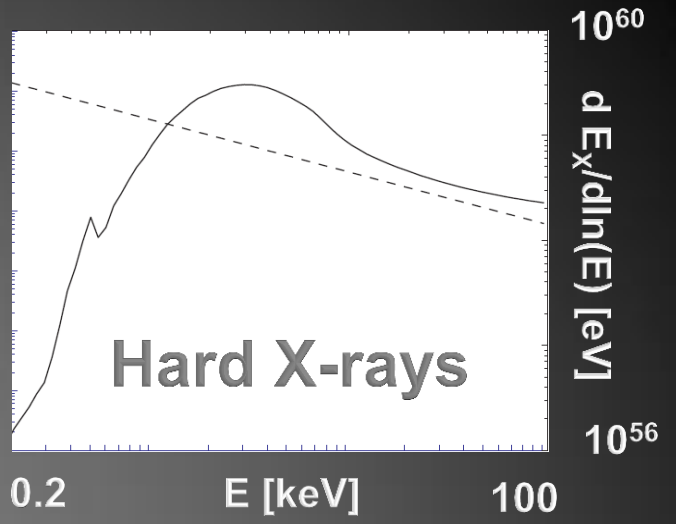
What are the new predictions for the 21-cm signal?

Hard spectrum
Global signal

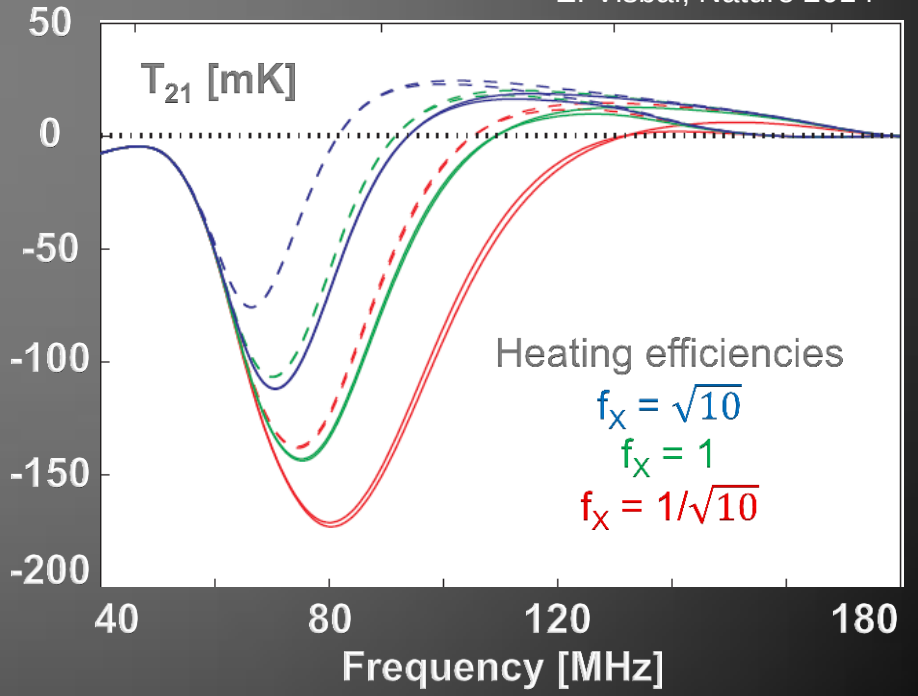
- Gas heats and ionizes at the same time ($T_{gas} < T_{CMB}$, EoR).
  Adiabatic cooling to lower T

- Maximal derivative is moved to higher frequencies.

- Easier to observe!

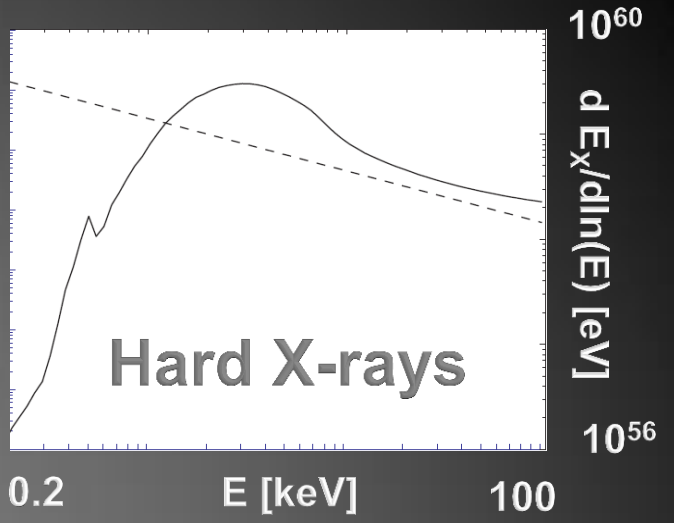


A. Fialkov, R. Barkana & E. Visbal, Nature 2014

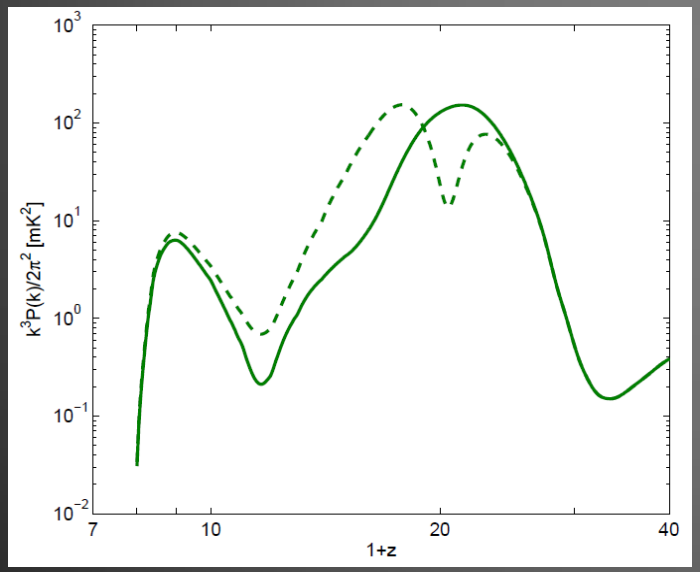


Hard spectrum Fluctuations

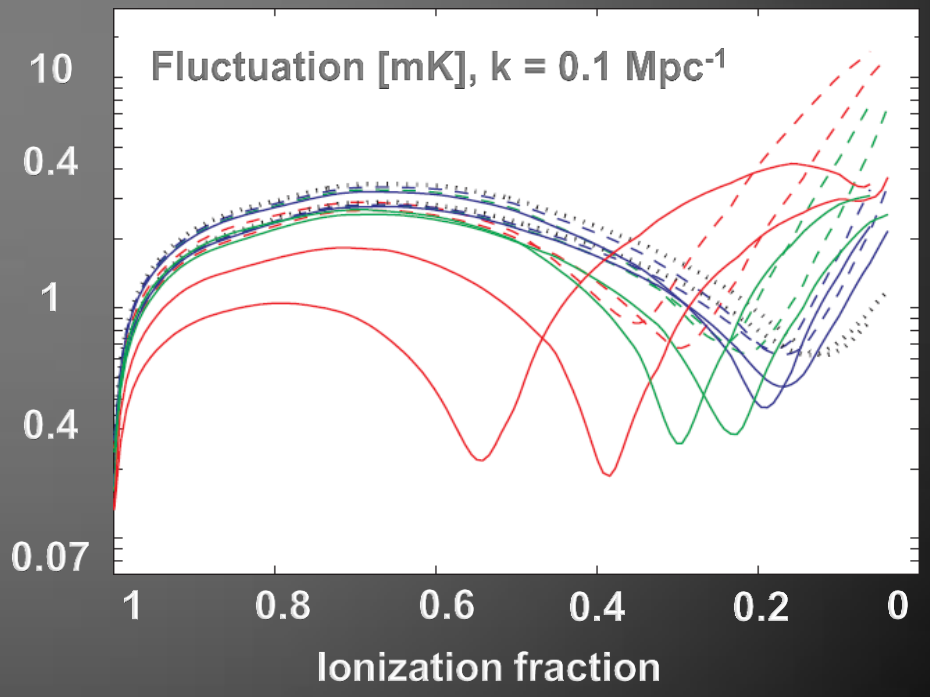
- A deep minimum during EoR, no peak.
- Small impact on Lyα domain z > 20 and later stages of EoR ($x_i > 0.5$)
- Complex signature, depends on the parameters, wavelength



A. Fialkov, R. Barkana & E. Visbal, Nature 2014



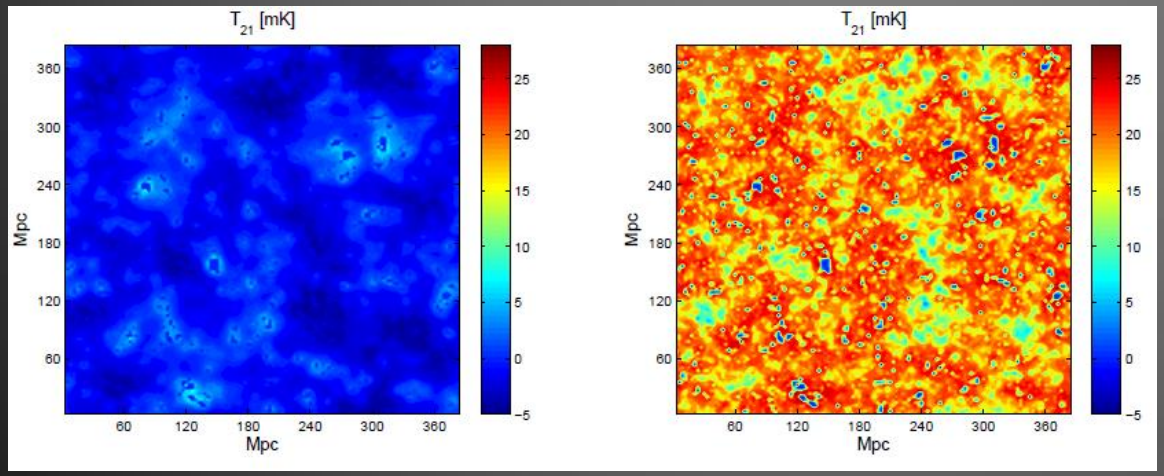
A. Fialkov & R. Barkana in preparation



Summary: realistic X-ray heating

- Cold reionization
- More complex signal from EoR than expected
- Detecting a low minimum in the 21-cm power spectrum during reionization - a clear signature of late heating by hard X-rays

Hard X-rays **Soft X-rays**



A. Fialkov & R.Barkana, in preparation