21cm fluctuations from inhomogeneous X-ray heating before reionization

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Aims and motivation

- X-rays may not heat the pre-reionization IGM uniformly.
  - X-rays deposit more energy close to sources.
  - Sources are clustered.
- Fluctuations may be detected directly by the SKA.
- Fluctuations may persist to the period probed by LOFAR.

Aims and motivation

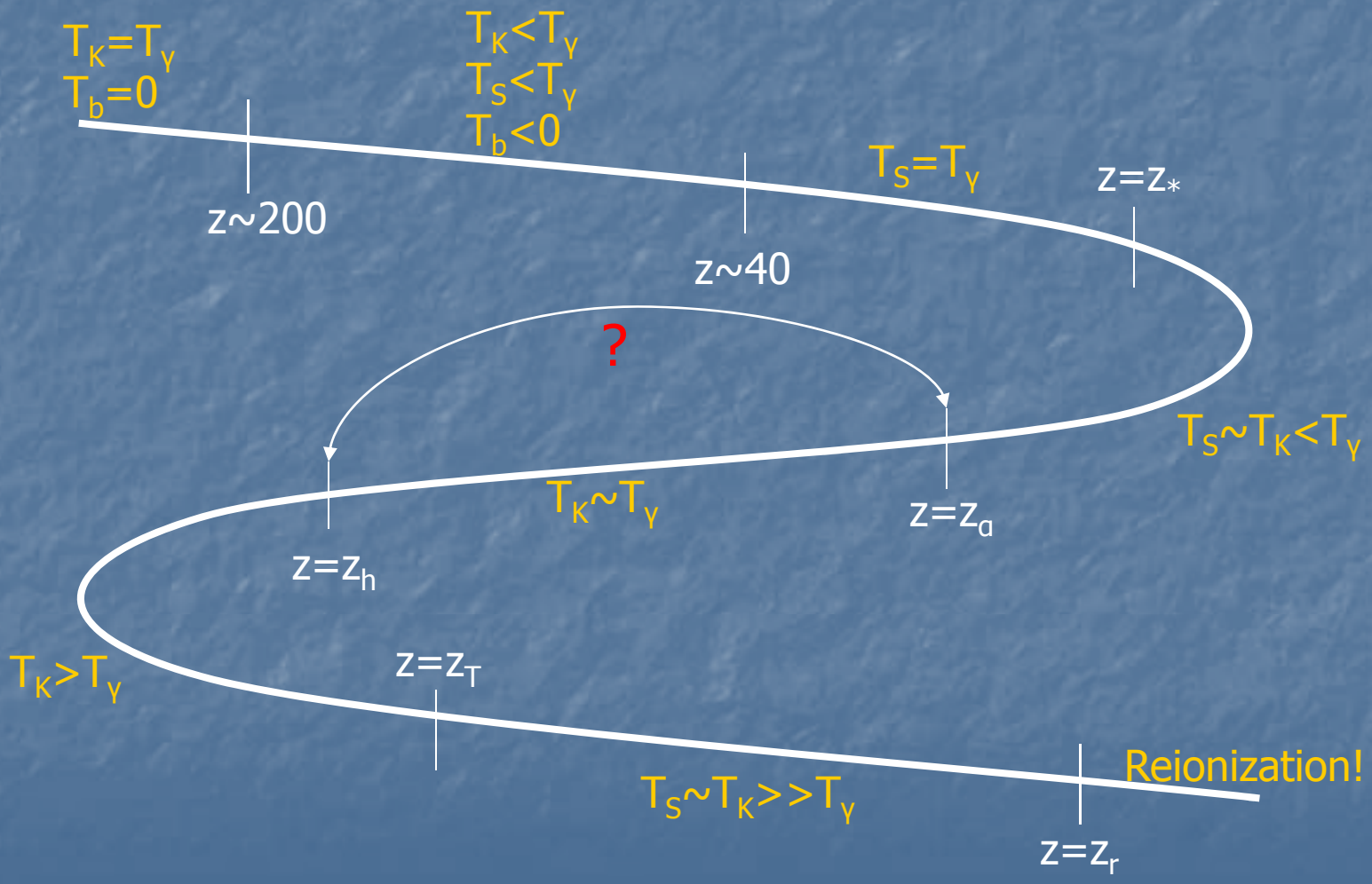
- Aim to predict:

$$\delta T_b = \beta\delta + \beta_x\delta_x + \beta_\alpha\delta_\alpha + \beta_T\delta_T - \delta_{\partial v}$$

$$P_{T_b}(k,\mu) = P_{\mu^0}(k) + \mu^2 P_{\mu^2}(k) + \mu^4 P_{\mu^4}(k)$$

- Can in principle disentangle fluctuations due to cosmology and due to source properties (formation time, spectral index, etc.).

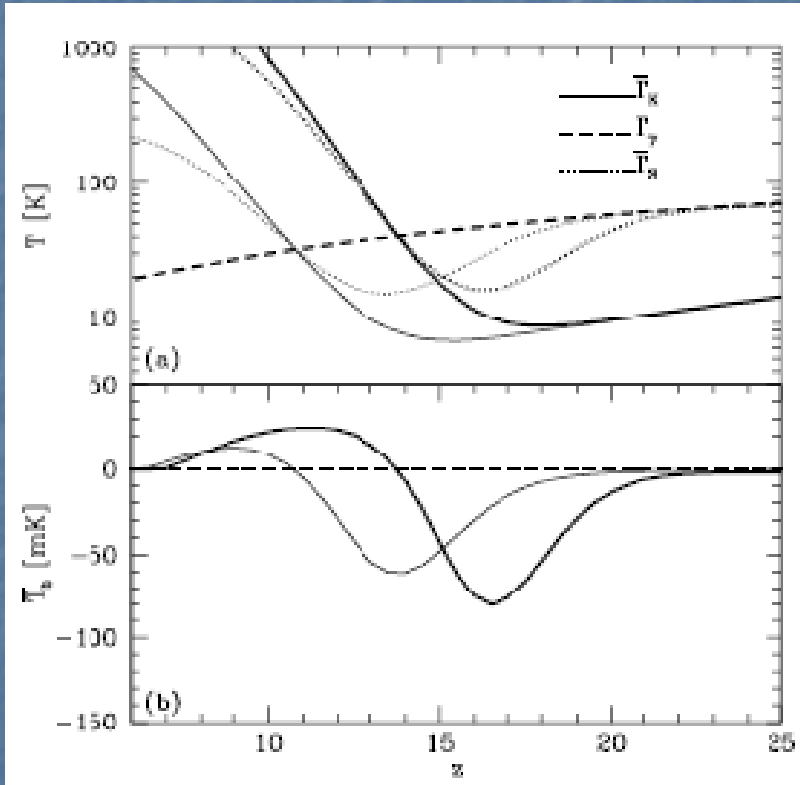
Timeline

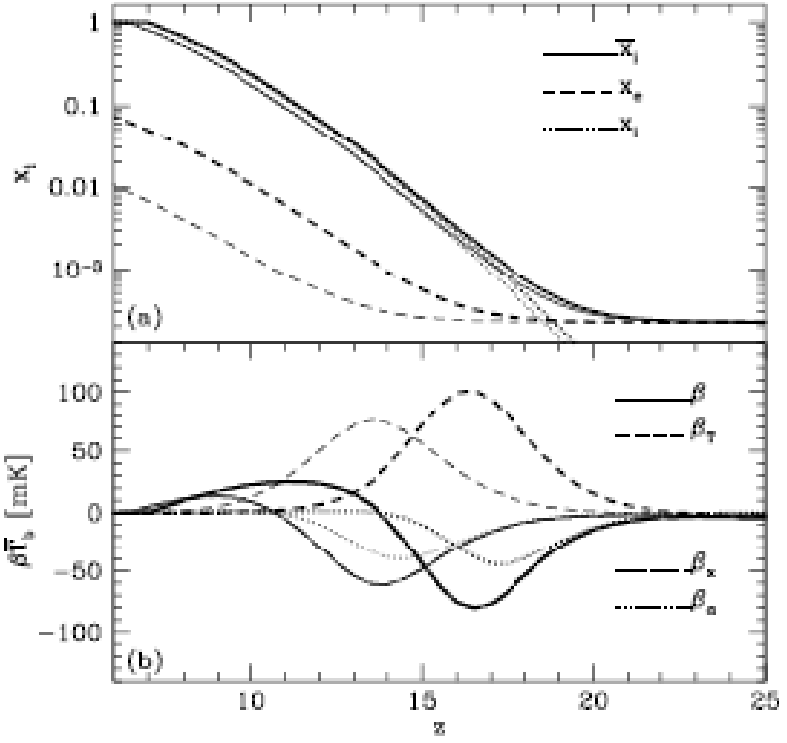

$T_K=T_\gamma$
$T_b=0$
$T_K<T_\gamma$
$T_S<T_\gamma$
$T_b<0$
$T_S=T_\gamma$
$z=z_*$
$z\sim200$
$z\sim40$
?
$T_S\sim T_K<T_\gamma$
$T_K\sim T_\gamma$
$z=z_a$
$z=z_h$
$T_K>T_\gamma$
$z=z_T$
Reionization!
$T_S\sim T_K>>T_\gamma$
$z=z_r$

Methods

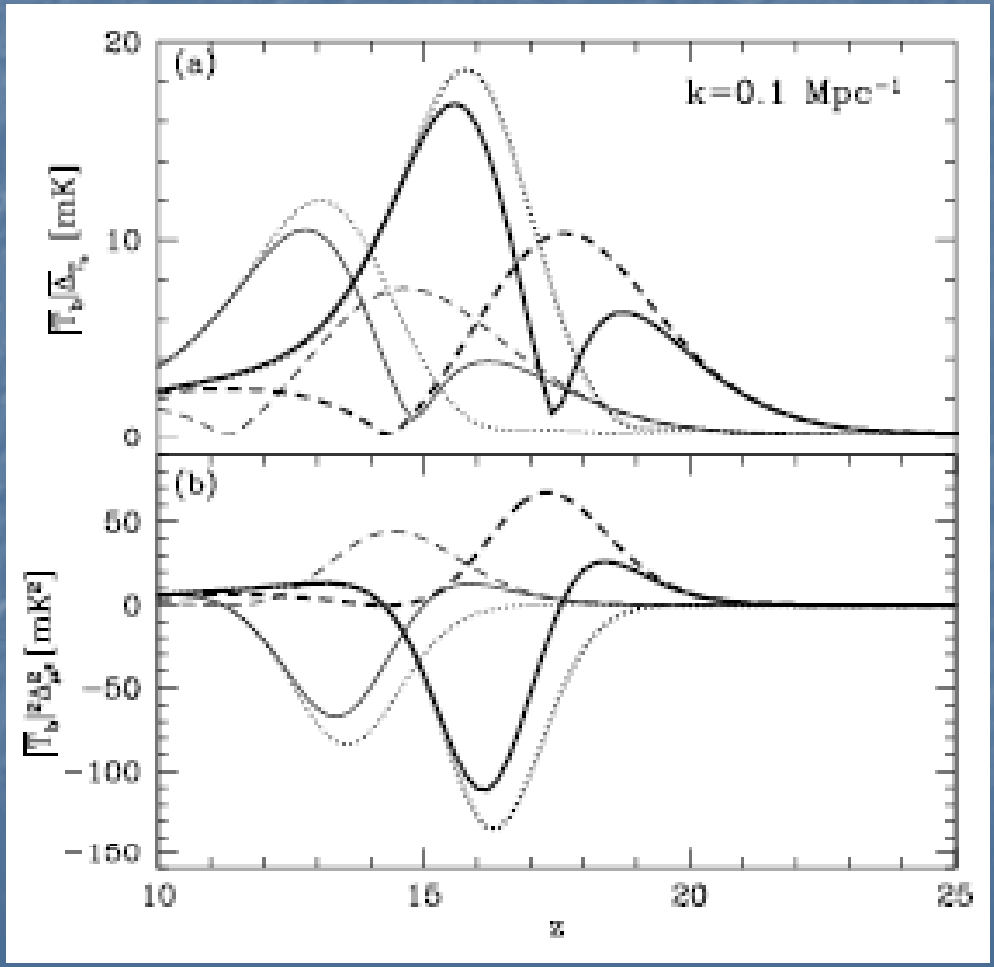
- Assume the ionized fraction is just the volume filling fraction of HII regions.
- Assume sources trace the density field with some bias.
- Formation of sources governed by the fraction of gas in collapsed objects.
- Two models:
  - A: Pop. II + starburst galaxies
  - B: Pop. III + starburst galaxies
- Starbursts have emissivity per unit comoving volume per unit frequency $\sim(\text{frequency})^{-2.5}$.
- Pop. III form with lower efficiency than pop. III but with more ionizing photons per baryon.

Global thermal and ionization histories

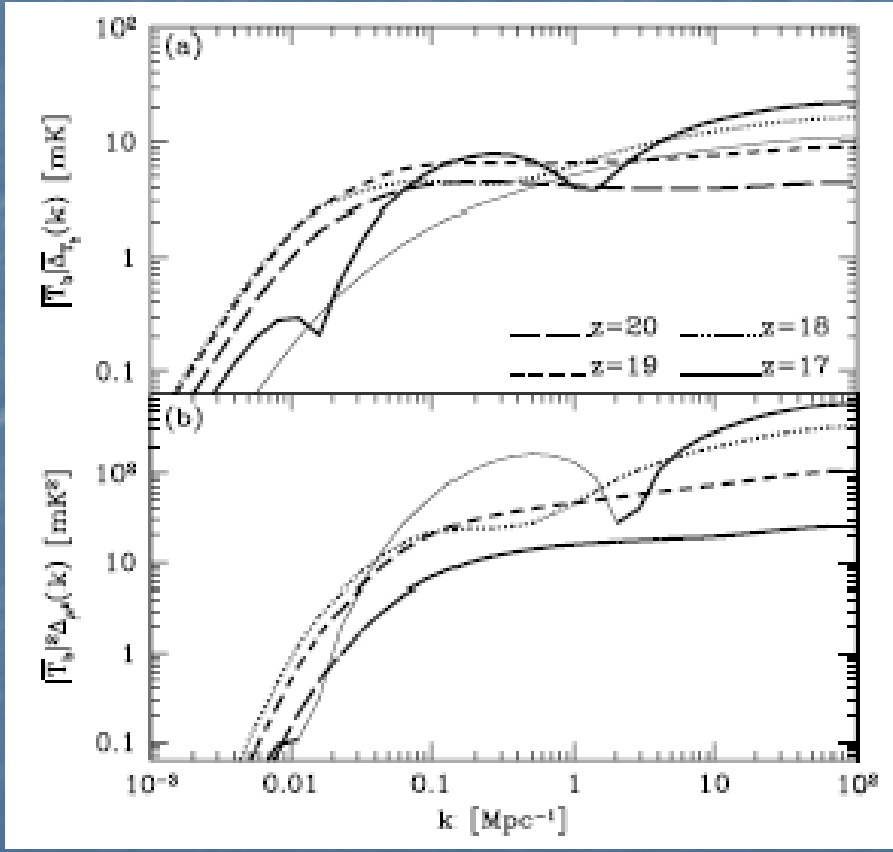


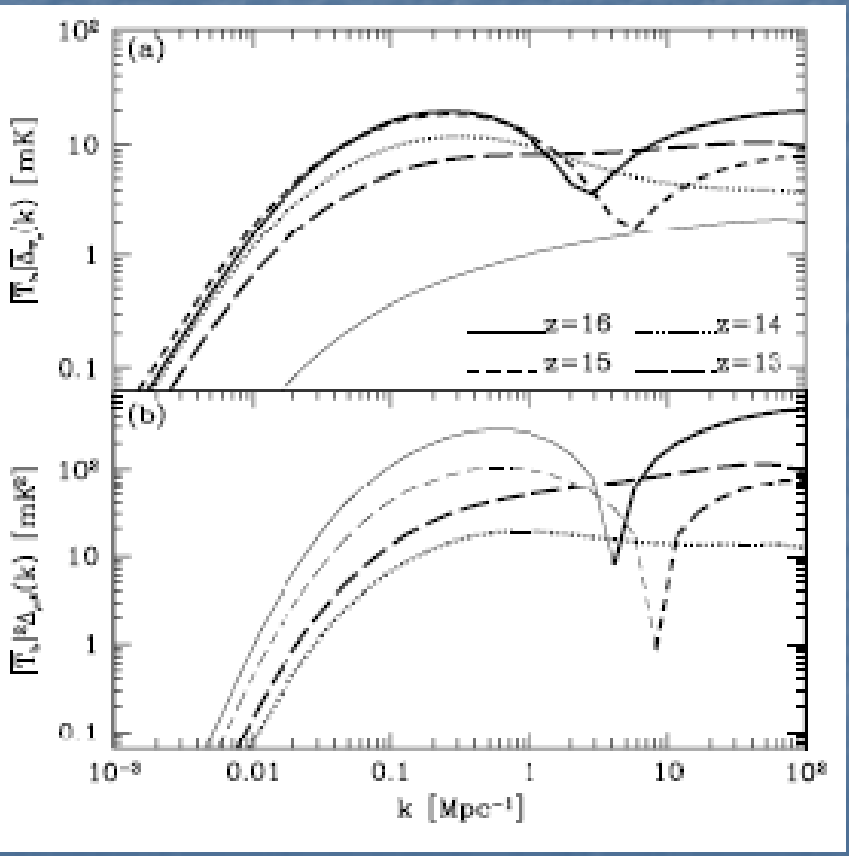


Evolution of brightness temperature

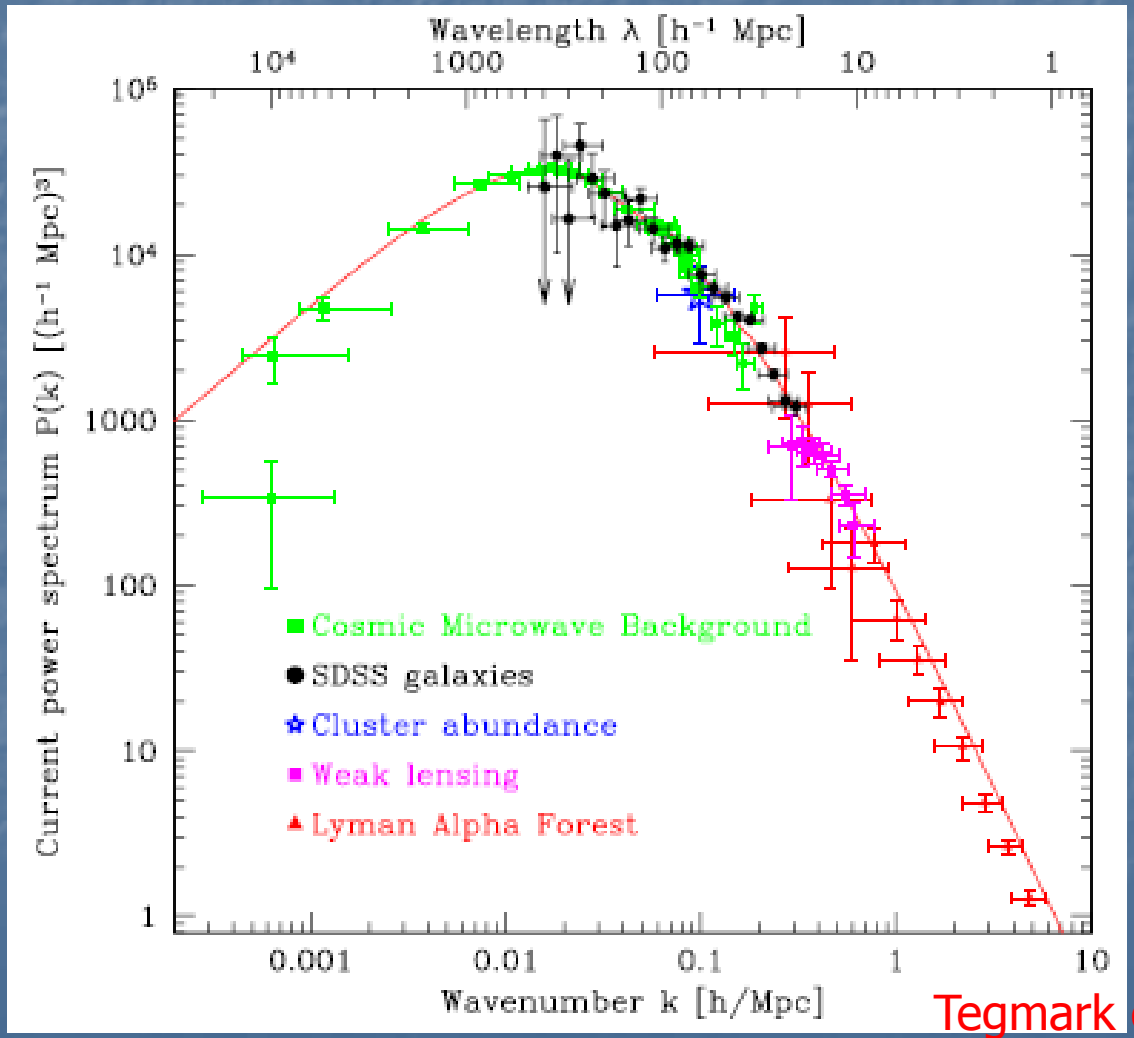


Brightness temperature power spectra





Comparison to cosmological power spectrum



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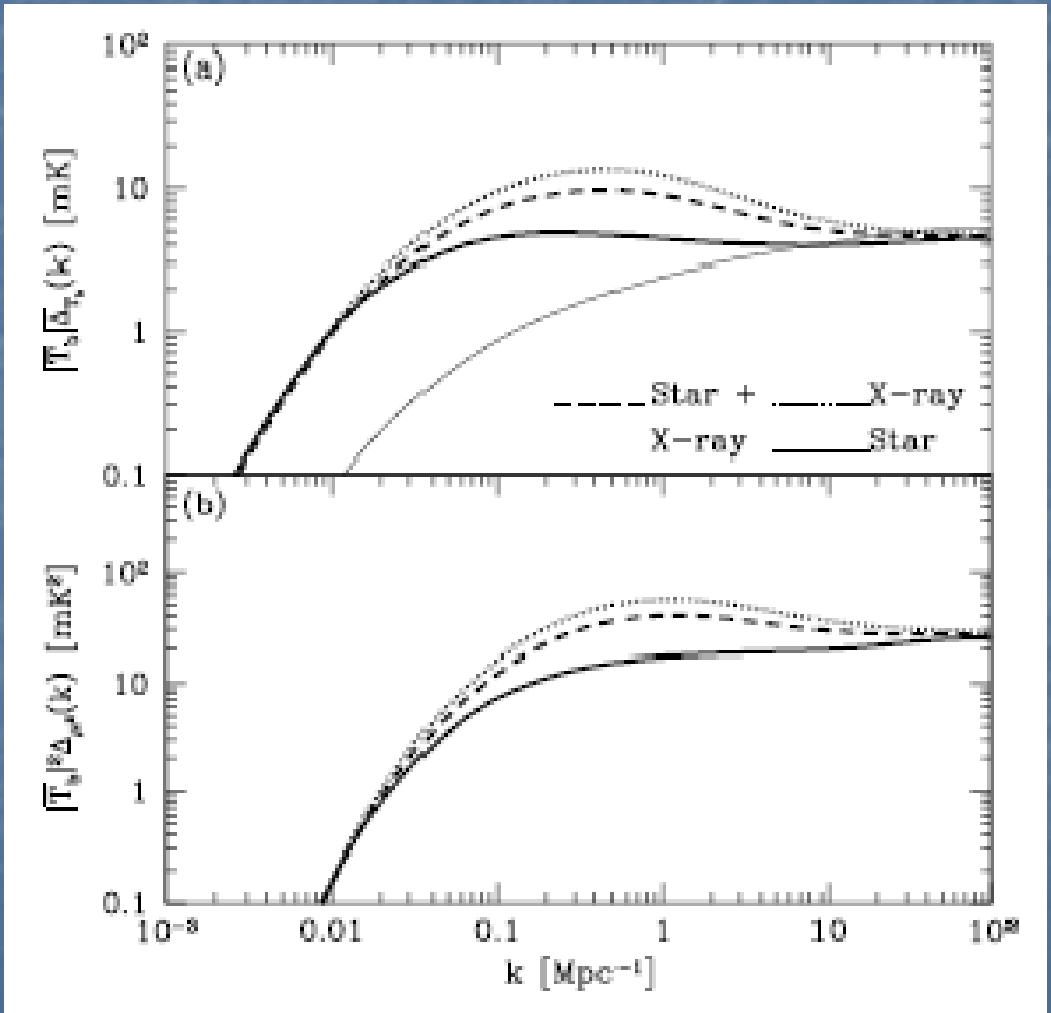
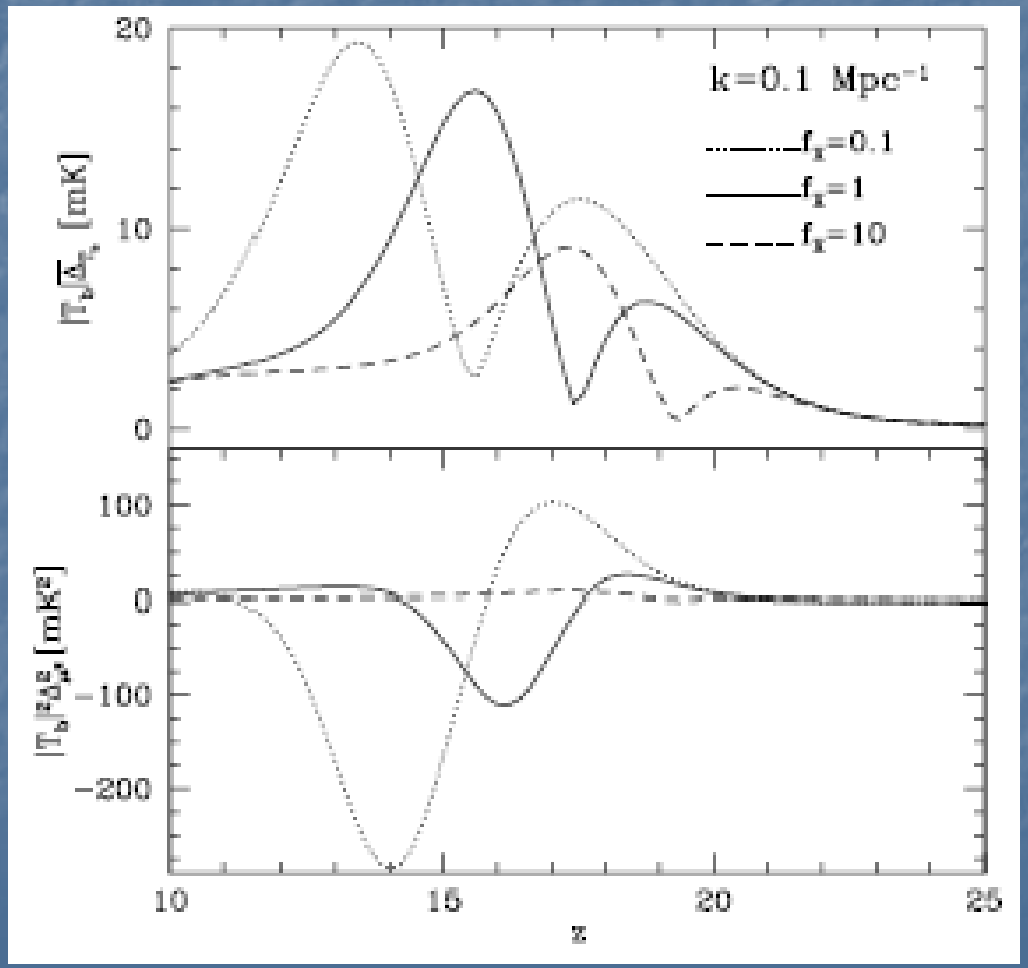
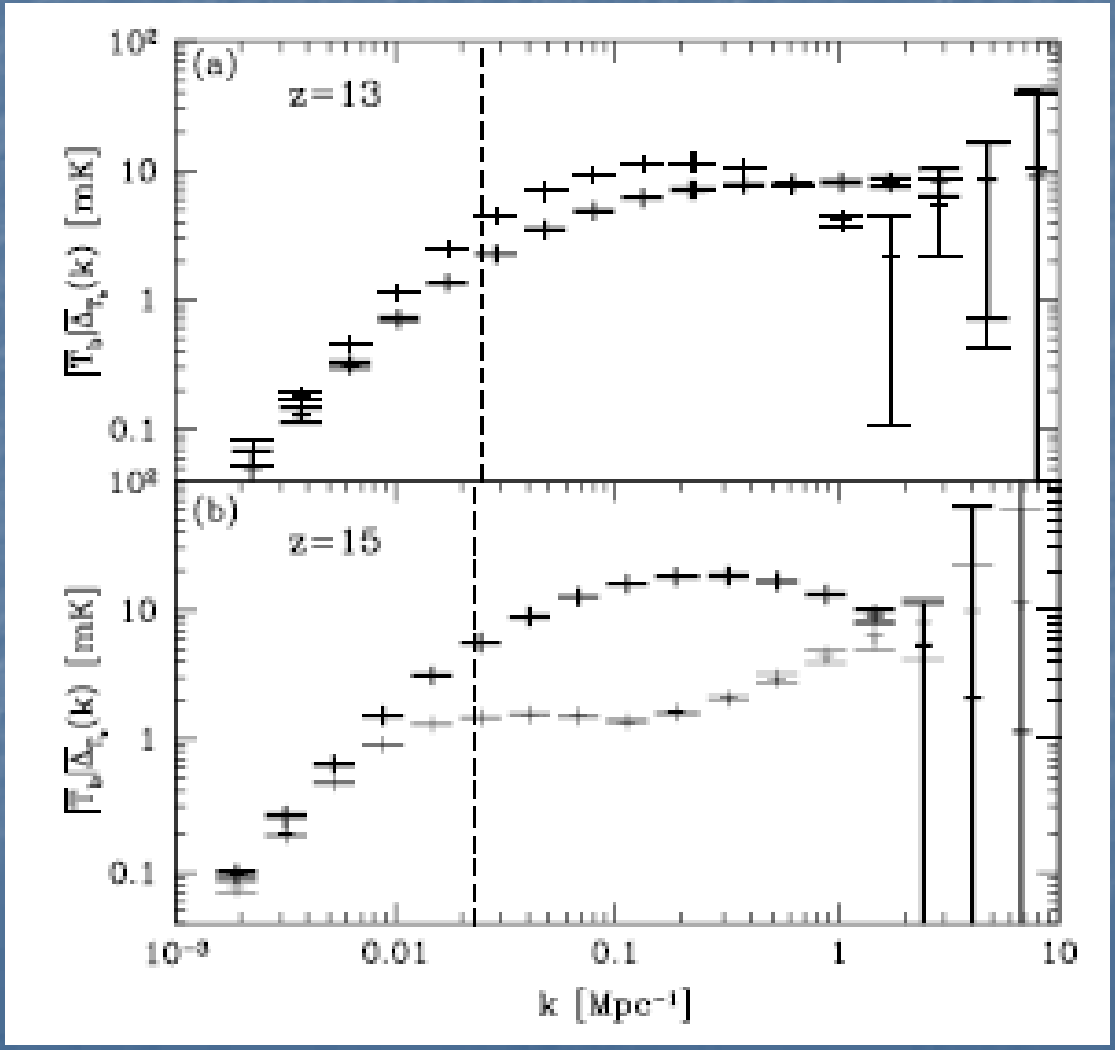
Different Lyman alpha sources



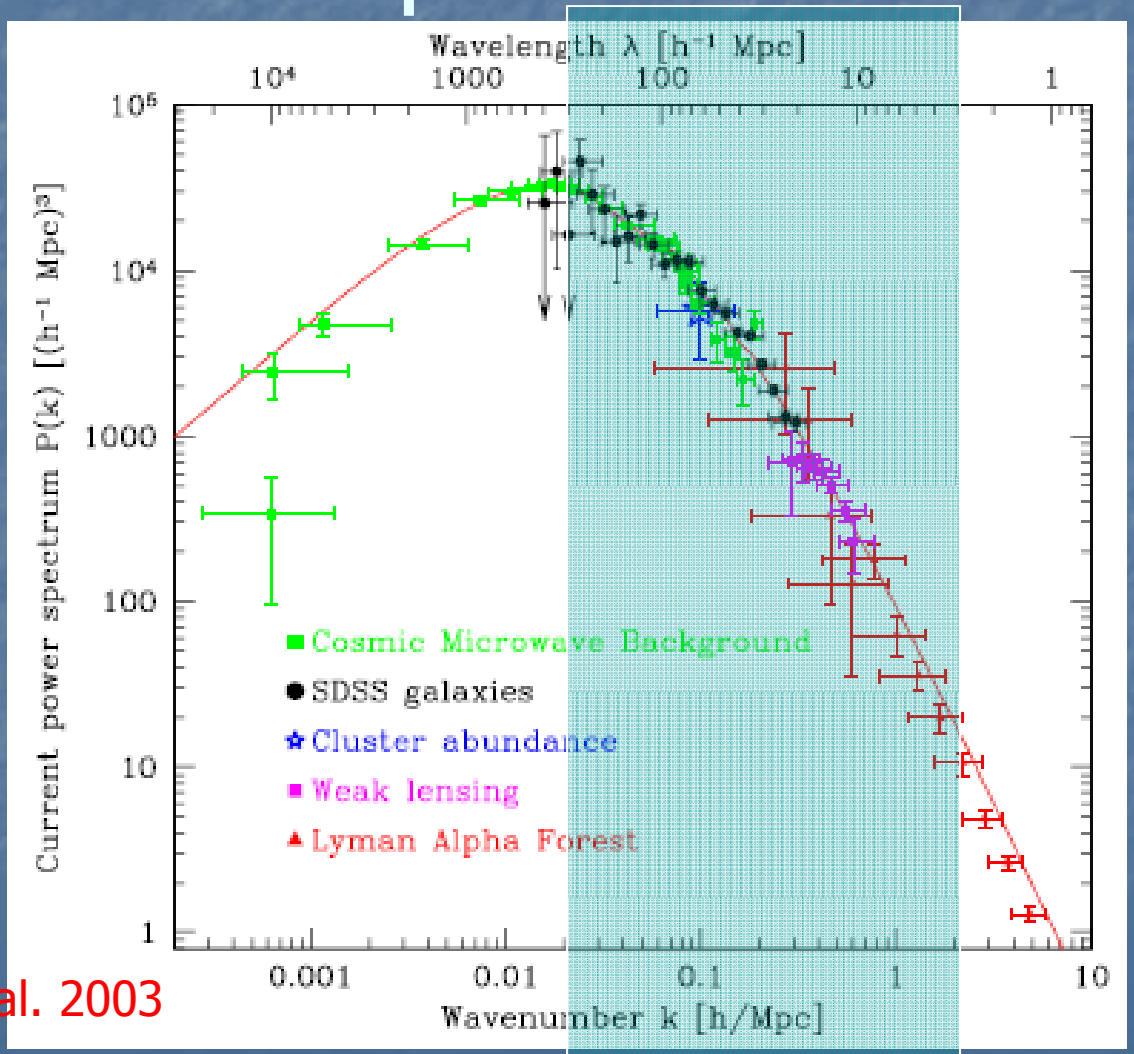
Different X-ray luminosities (late or early heating)



Predictions for SKA



Comparison to cosmological power spectrum



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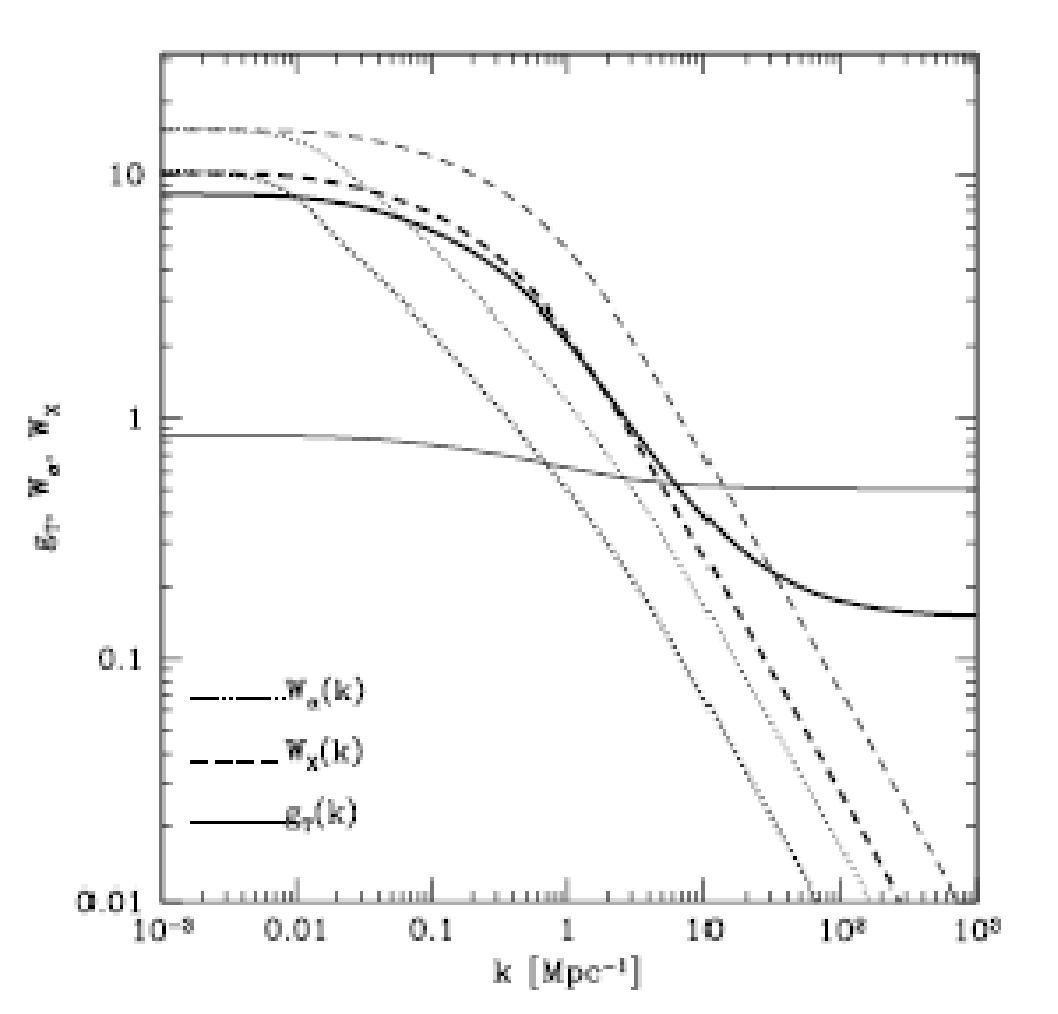
Conclusions

- Examined a redshift range round z_h and showed there is a regime where some pockets of gas are seen in emission and others in absorption.
- Large difference between uniform and inhomogeneous heating.
- Extra constraints from an angular separation of the power spectrum.
- Measuring the time evolution could constrain total X-ray luminosity (late heating could affect measurements during the epoch of reionization).
- Fluctuations observable by SKA at intermediate scales.

Window functions



Fluctuations in T_K and their evolution with redshift