Radiation backgrounds from the first sources and the redshifted 21 cm signal

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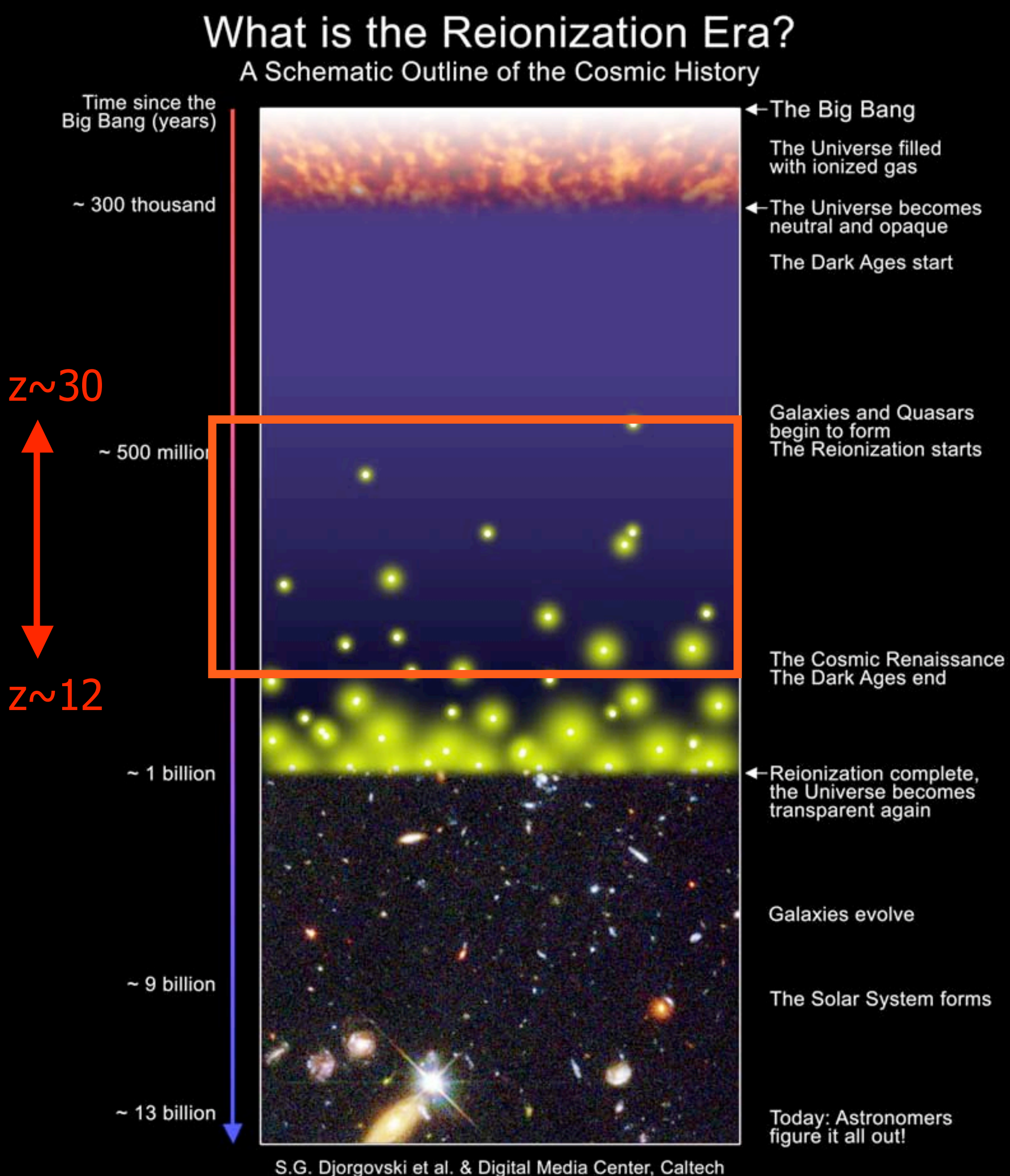
Overview

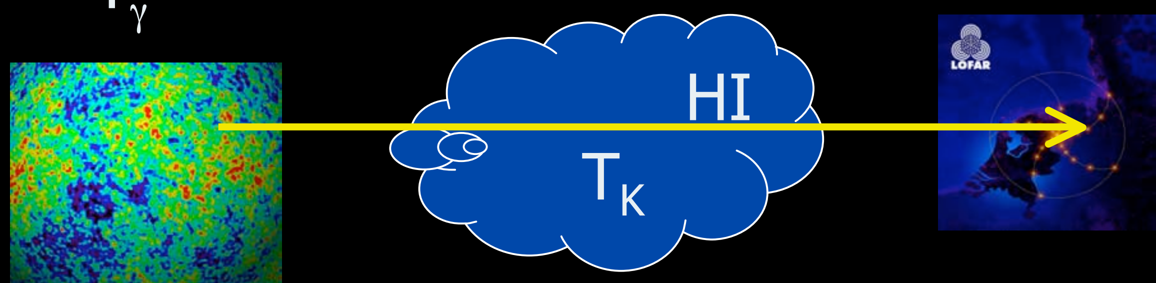


1. 21 cm as probe of high-z radiation backgrounds
2. Fluctuations in Lyα and X-ray backgrounds lead to 21 cm fluctuations
3. What might 21 cm observations tell us about first sources?
4. Experimental prospects (SKA)

21 cm basics

- Use CMB backlight to probe 21cm transition

T_γ T_S T_b



z=13
f_{21cm}=1.4 GHz

z=0
f_{obs}=100 MHz

- 3D mapping of HI possible - angles + frequency
- 21 cm brightness temperature

$$T_b = 27 x_{\rm HI}(1+\delta_b)\left(\frac{T_S - T_\gamma}{T_S}\right)\left(\frac{1+z}{10}\right)^{1/2}\ {\rm mK}$$

- 21 cm spin temperature

$$T_S^{-1} = \frac{T_\gamma^{-1} + x_\alpha T_\alpha^{-1} + x_c T_K^{-1}}{1 + x_\alpha + x_c}$$

- Coupling mechanisms:
  - Radiative transitions (CMB)
  - Collisions
  - Wouthuysen-Field

Wouthuysen-Field effect

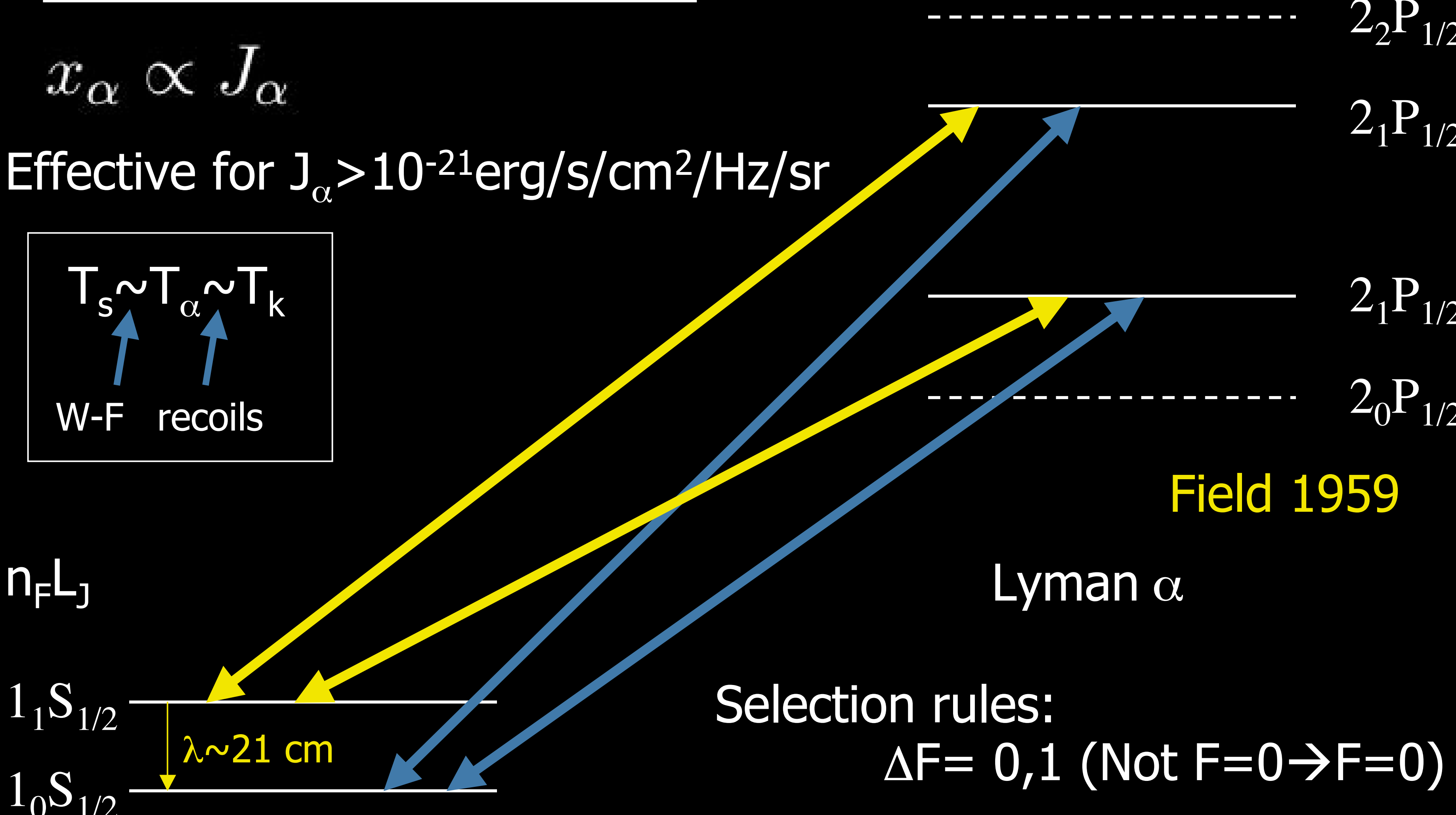
Hyperfine structure of HI

$$x_\alpha \propto J_\alpha$$

Effective for $J_\alpha > 10^{-21}$ erg/s/cm^2/Hz/sr

$T_s \sim T_\alpha \sim T_k$

W-F recoils



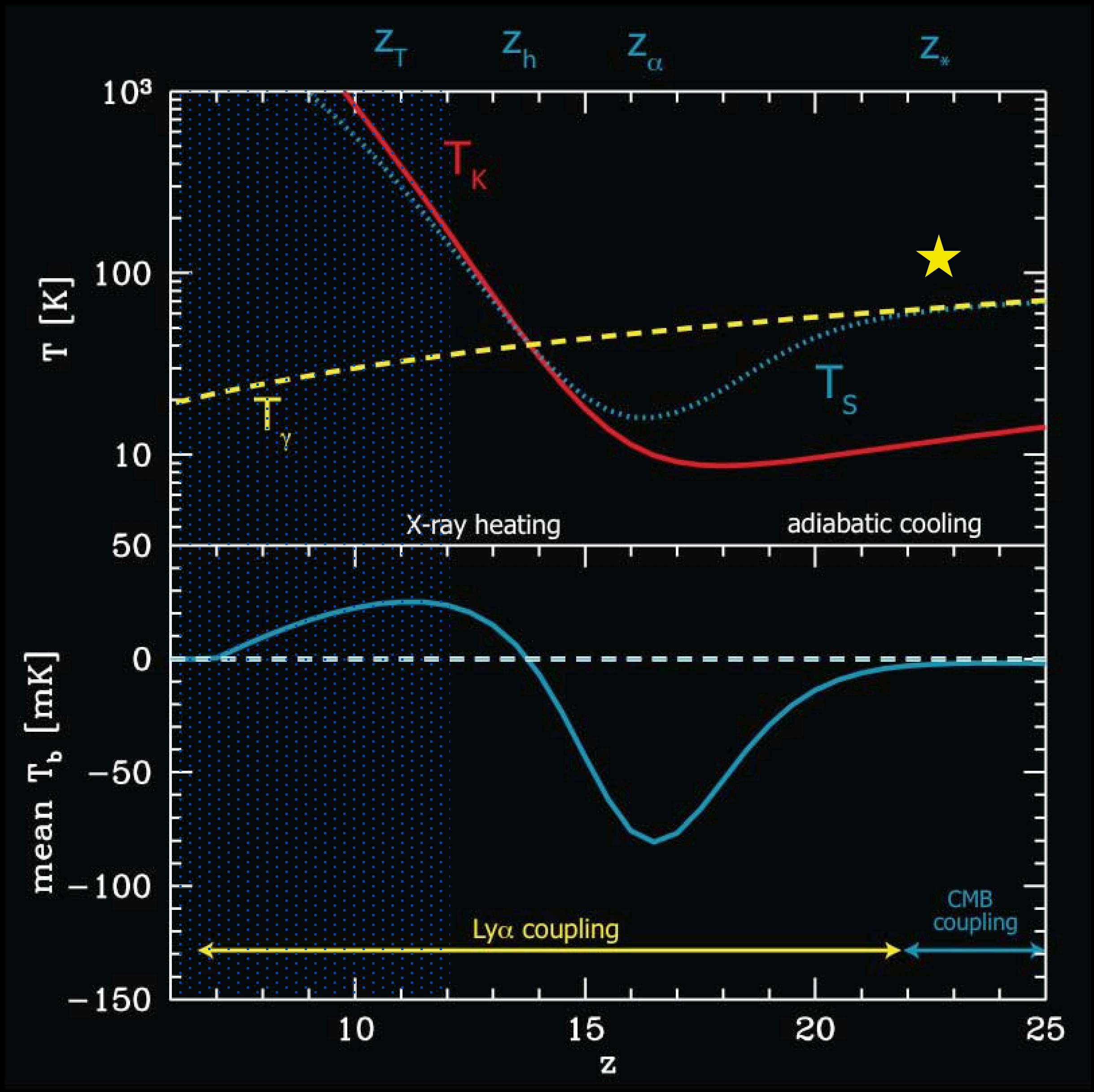
Field 1959

Lyman α

Selection rules:

$\Delta F = 0,1$ (Not $F=0 \rightarrow F=0$)

Thermal History



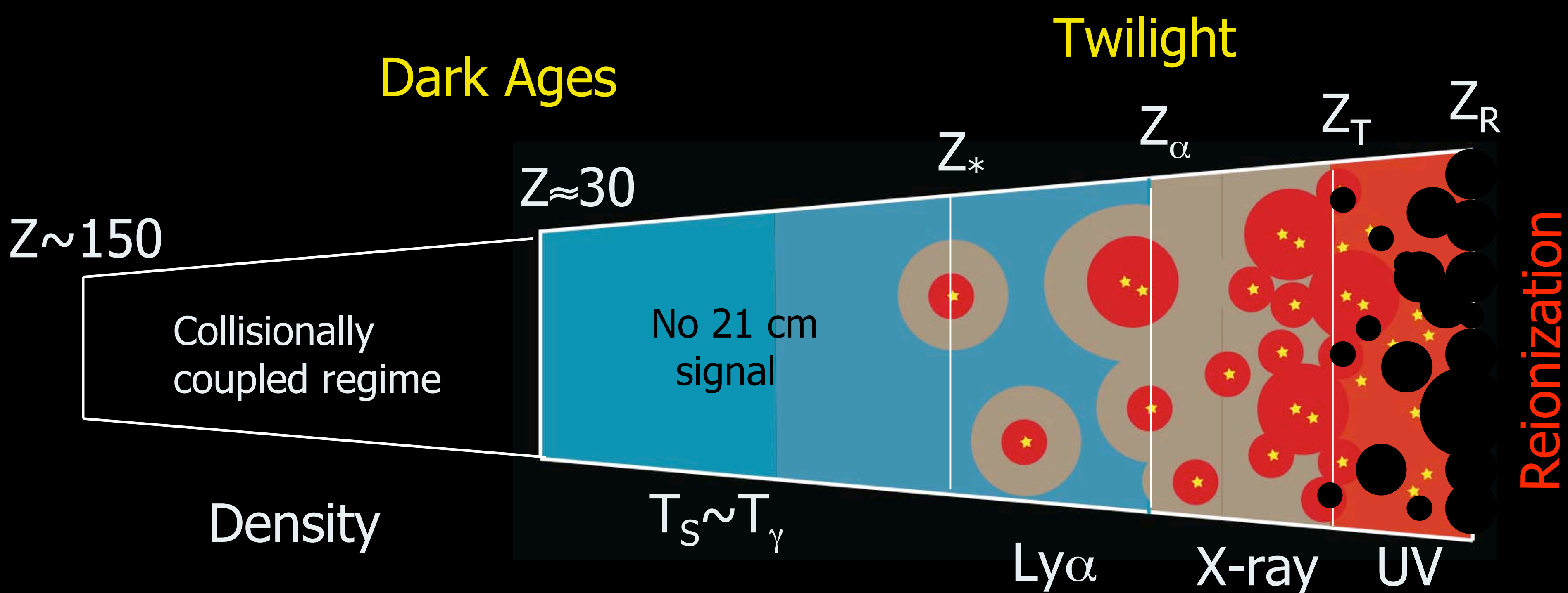
e.g. Furlanetto 2006

21 cm fluctuations

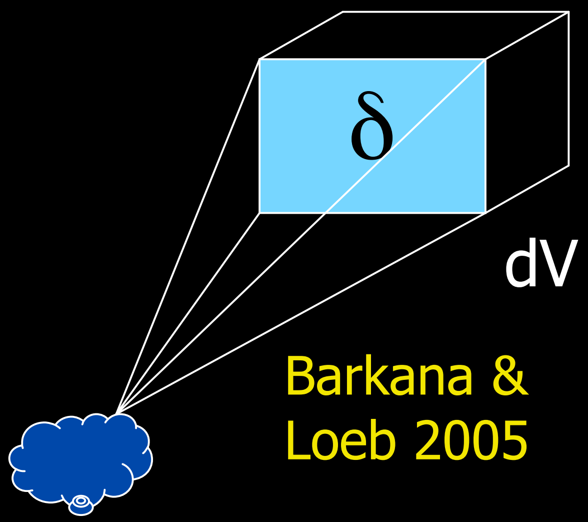
Baryon Density	Neutral fraction	Gas Temperature	W-F Coupling	Velocity gradient

$$\delta_{T_b} = \beta\delta + \beta_x \delta_{x_{HI}} + \beta_T \delta_{T_k} + \beta_\alpha \delta_\alpha - \delta_{\partial v}$$

Cosmology	Reionization	X-ray sources	Lyα sources	Cosmology



Fluctuations from the first stars



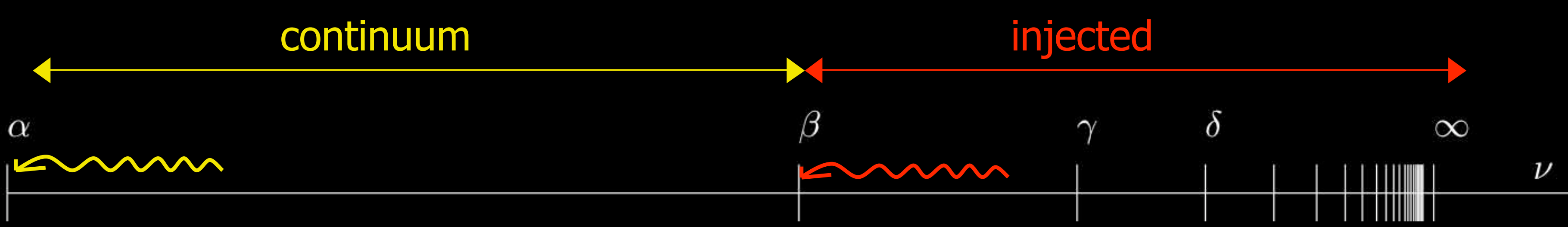
Barkana & Loeb 2005

- Fluctuations in flux from source clustering, $1/r^2$ law, optical depth,…
- Relate fluctuations in Lyα and X-ray fluxes to overdensities

$$\delta_{x_\alpha}(\mathbf{k}) = W(k)\delta(\mathbf{k})$$

- Start with Lyα…

- Three contributions to Lyα flux: continuum & injected from stars + x-ray



Chen & Miralde-Escude 2006, Chuzhoy & Shapiro 2006, Pritchard & Furlanetto 2005,2006

Determining the first sources

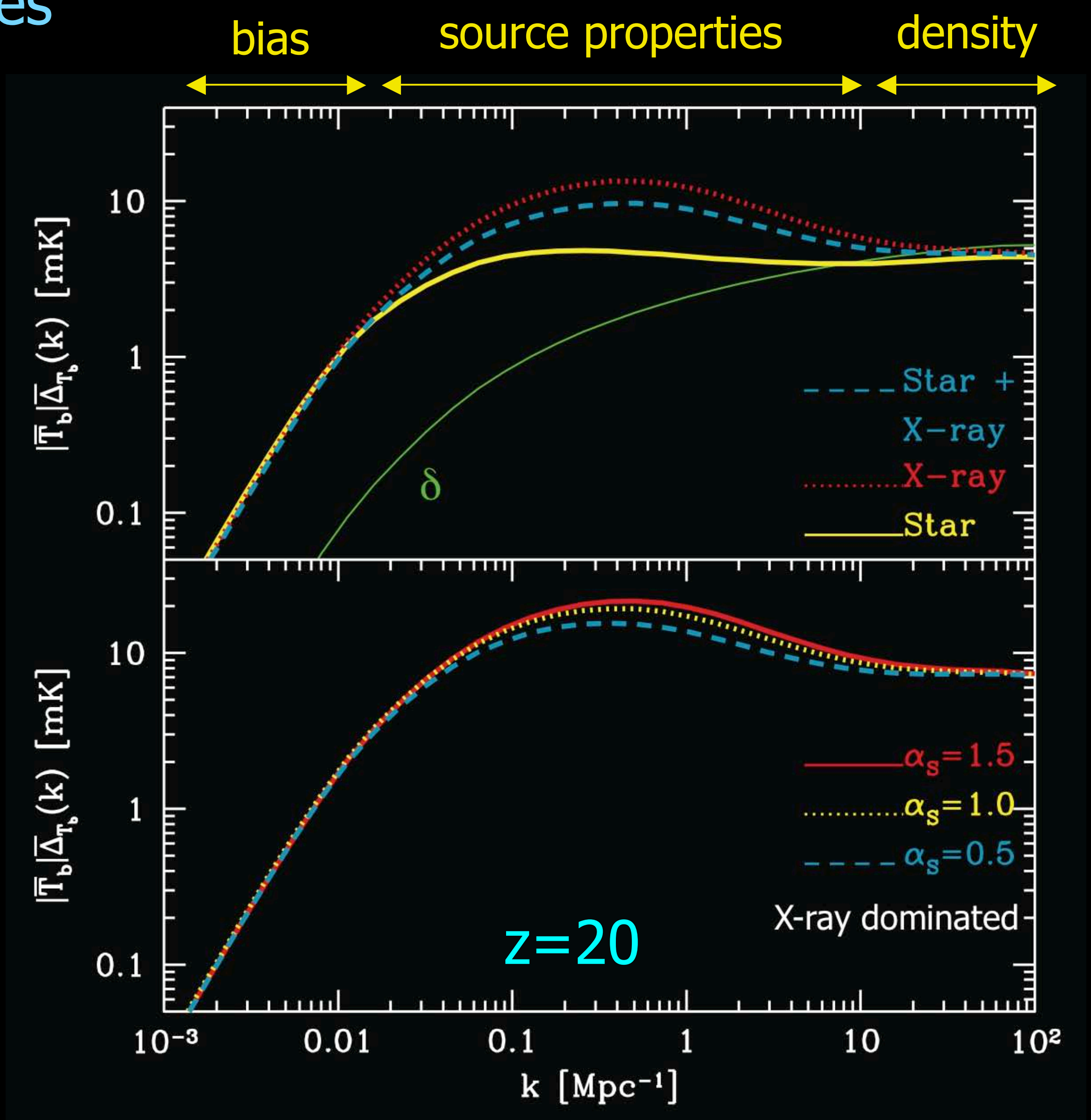
δ_α dominates

Sources

$J_{\alpha,*}$ vs $J_{\alpha,X}$

Spectra

α_S



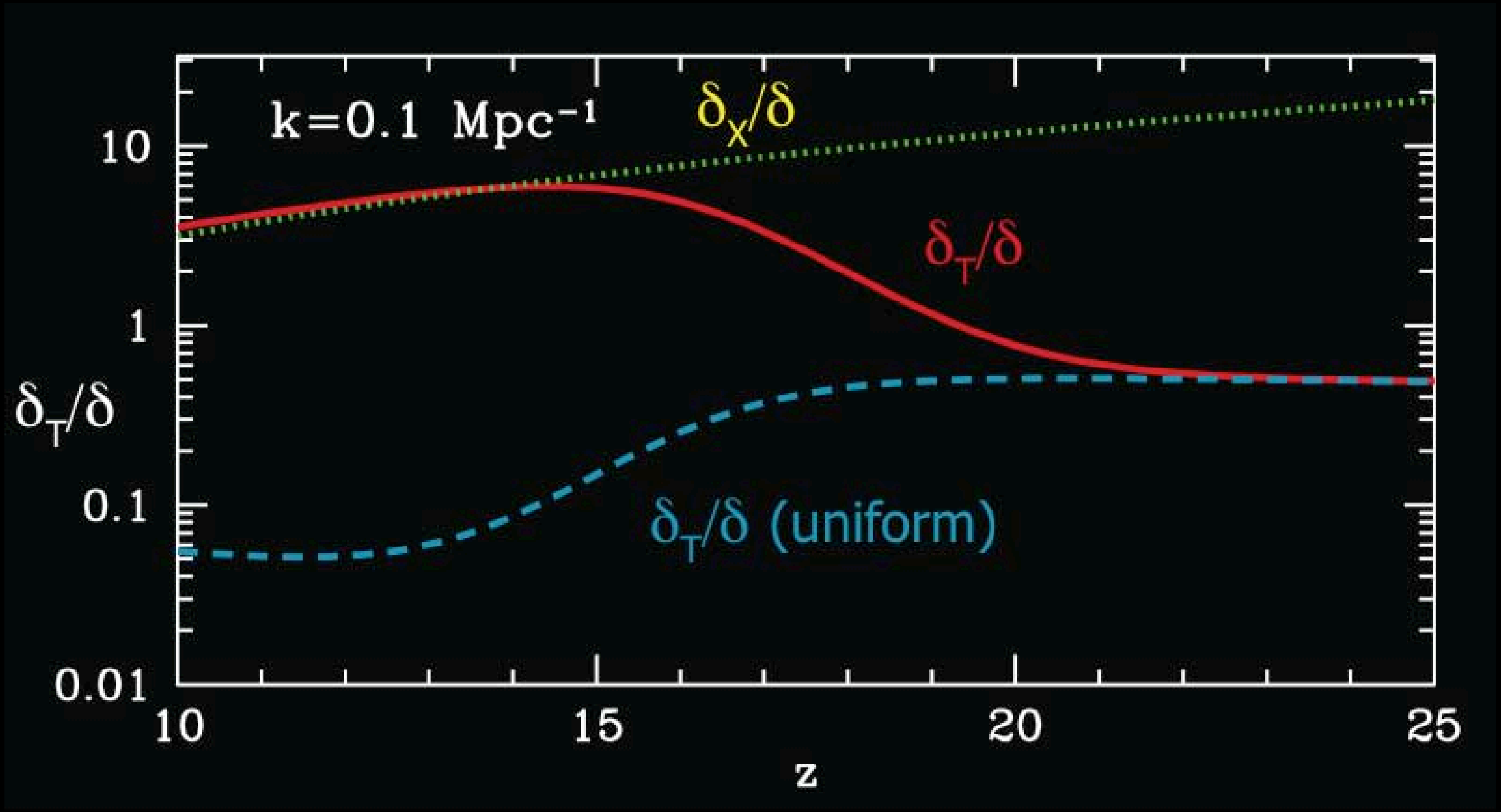
Chuzhoy, Alvarez, & Shapiro 2006 (+poster)

Pritchard & Furlanetto 2006

X-ray heating

- Soft X-rays heat closer to source, hard X-rays have long m.f.p.
- X-ray flux -> heating rate -> temperature evolution
- Integrated effect - so whole SF history contributes

$$J \propto e^{-\tau}/r^2$$

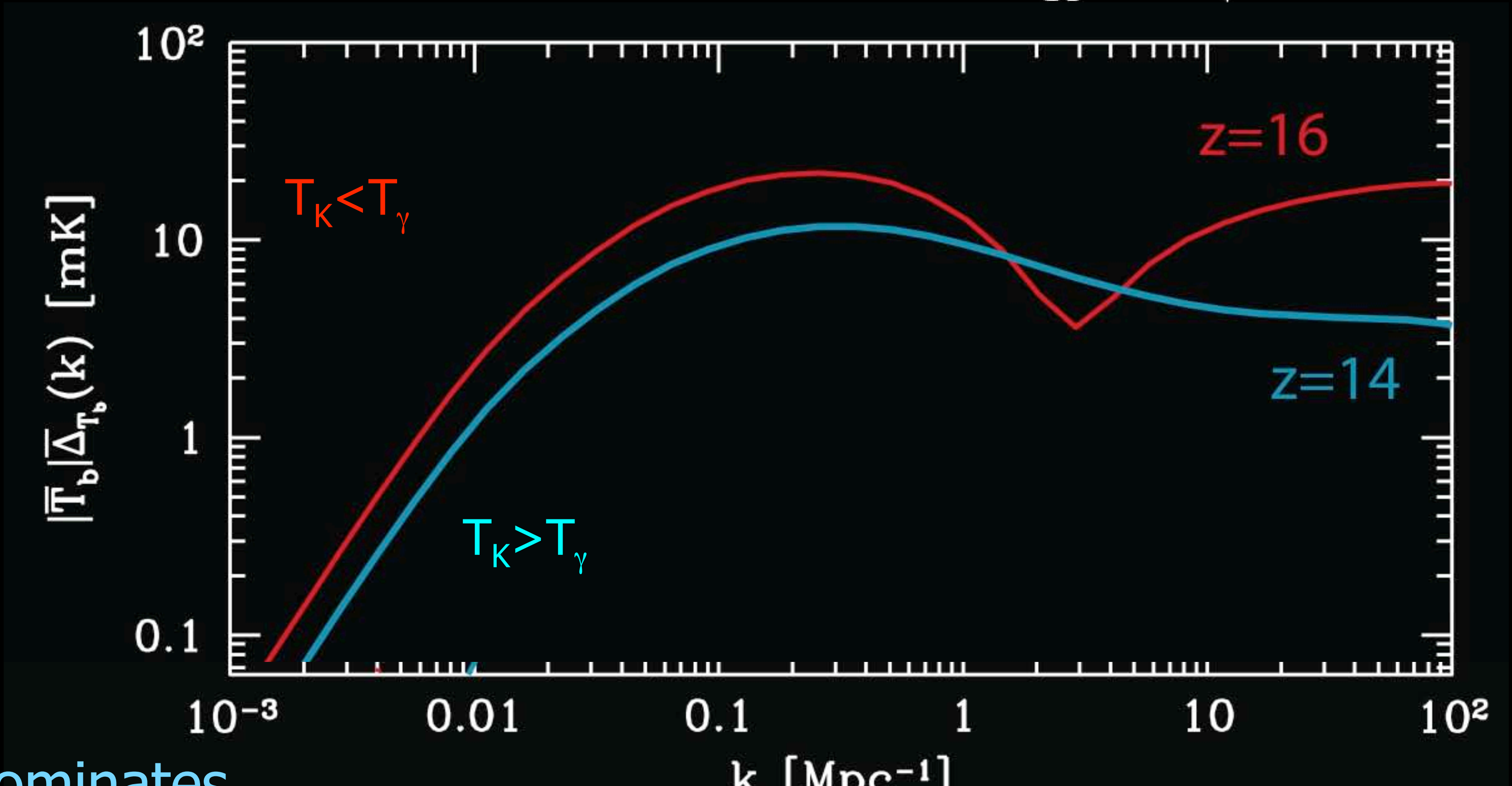


Pritchard & Furlanetto 2006

Indications of T_K

- Learn about source bias and spectrum in same way as Lyα
- Constrain heating transition

$$\delta_{T_b} \approx \delta + \beta_T \delta_{T_k} \qquad \beta_T \approx \frac{T_\gamma}{T_K - T\gamma}$$



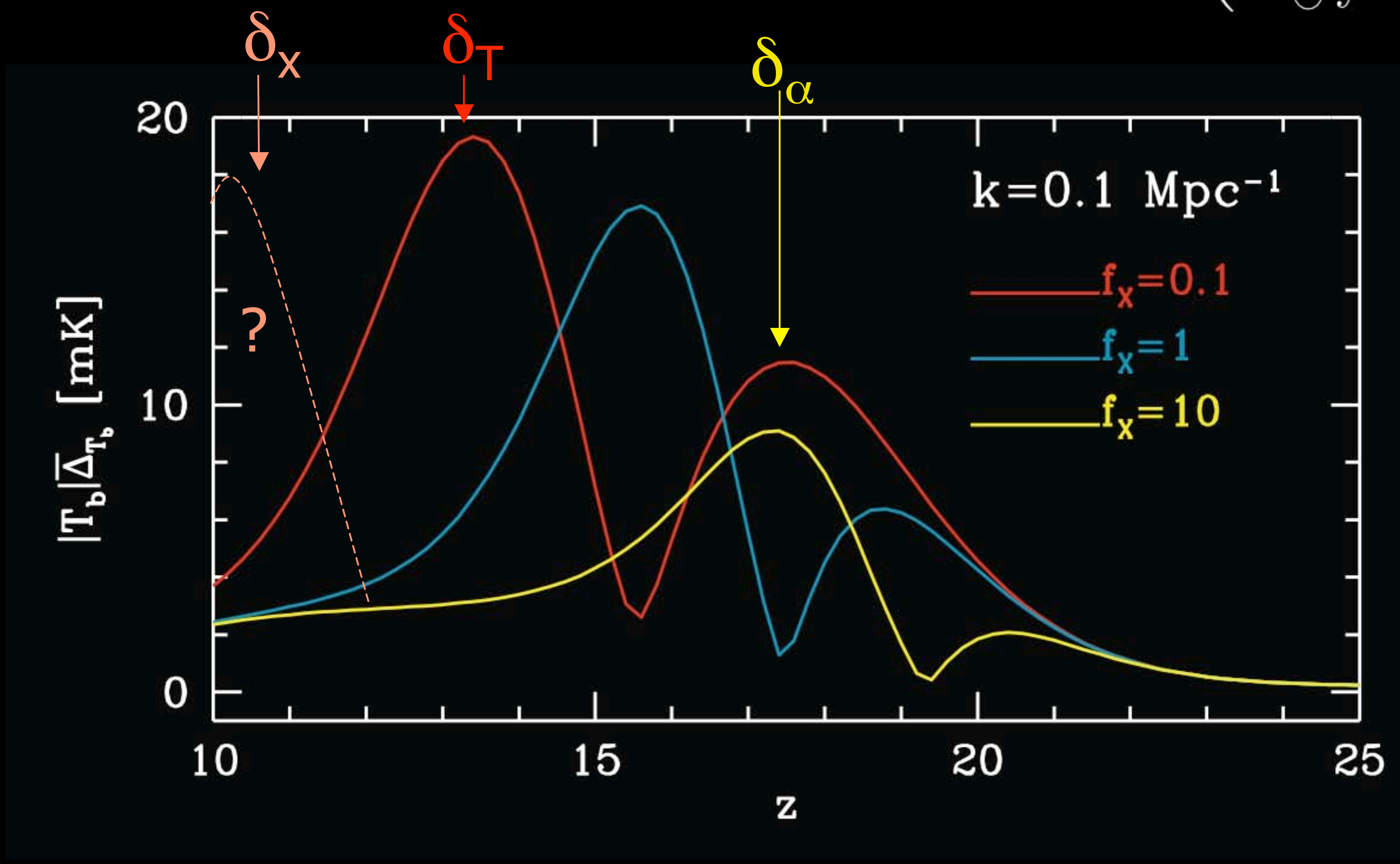
δ_T dominates

X-ray background?

- To avoid giving the idea of certainty…

Extrapolating low-z X-ray:IR correlation gives: Glover & Brand 2003

$$L_X = 3.4 \times 10^{40} f_X \left(\frac{\mathrm{SFR}}{\mathrm{M}_\odot\,\mathrm{yr}^{-1}} \right) \mathrm{erg\,s^{-1}}$$



Experimental efforts

LOFAR: Netherlands
Freq: 120-240 MHz
Baselines: 100m-100km

MWA: Australia
Freq: 80-300 MHz
Baselines: 10m-1.5km

PAST: China
Freq: 70-200 MHz

SKA: S. Africa/Australia ???
Freq: 60 MHz-35 GHz
Baselines: 20m-3000km

Foregrounds are the big problem!

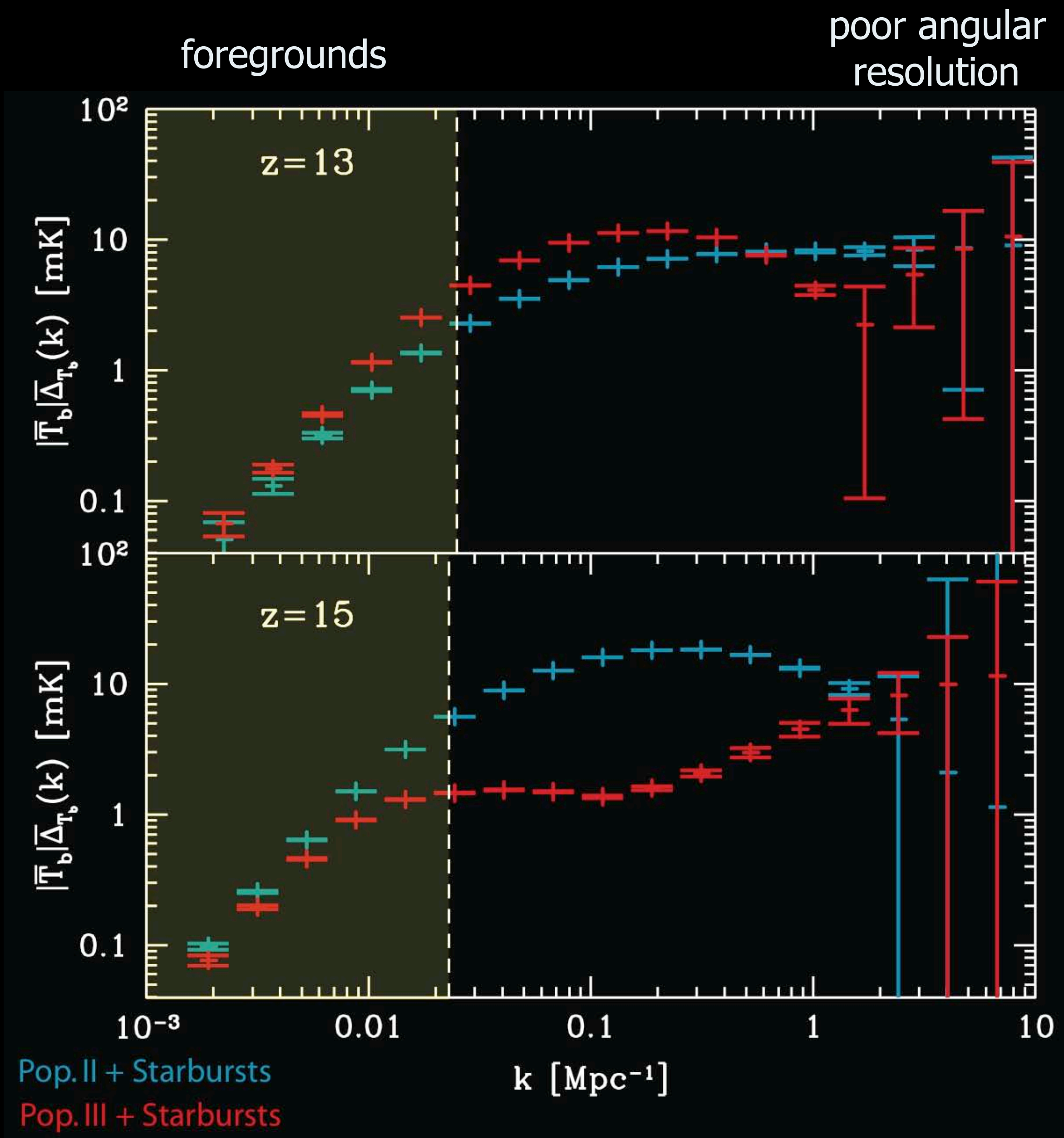
See Bowman poster
+ Hewitt talk tomorrow

Observations

- Need SKA to probe these brightness fluctuations

- Observe scales k=0.025-3 Mpc^{-1}

- Can distinguish different models



Conclusions

- Today told a simple story - lots of uncertainty in all attempts at modeling this period
- Can use 21 cm to learn about the first luminous sources via the Lyα background
- Temperature fluctuations should give insight into thermal evolution of IGM
- If X-ray heating important, then can learn about early X-ray sources
- Measurements discussed will require SKA and luck
- Early days for 21 cm and still unclear what will and will not be possible - foregrounds will be determining factor
- For more details: astro-ph/0607234 + astro-ph/0508381