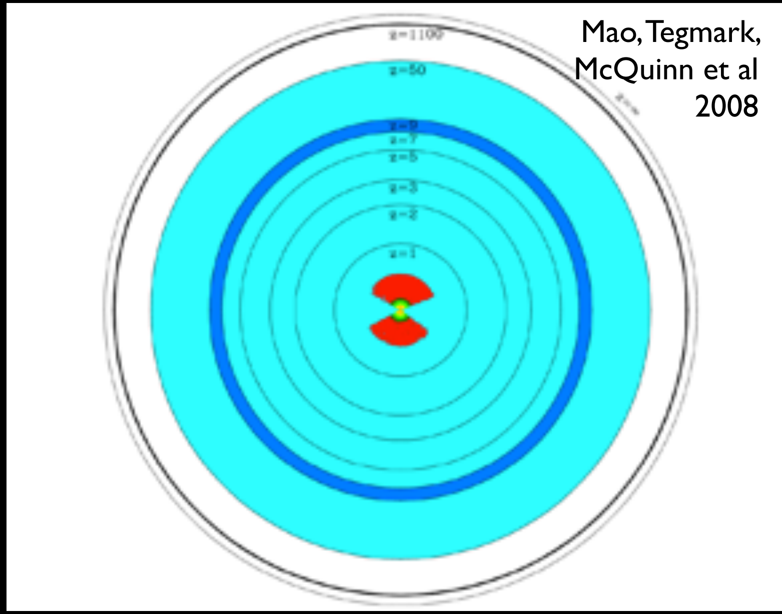
high-redshift 21cm tomography

Matthew McQuinn (Berkeley)

with Gianni Bernardi, Lars Hernquist, Lincoln Greenhill, Adam Lidz, Aaron Parsons, Eric Switzer, Matias Zaldarriaga

The Basics



Mao, Tegmark, McQuinn et al 2008

- the Universe is primarily hydrogen and helium.
- hyperfine transition of neutral hydrogen only viable line. $T_{ex} \sim 0.07$ K, $T_b = 30\text{mK}\,(1+\delta)\,x_{HI}\,(z/10)^{1/2}$
- 21cm signal can be observed at $0<z<\sim 200$, Hydrogen highly ionized at $z<6$ so signal is strongest at $z>6$

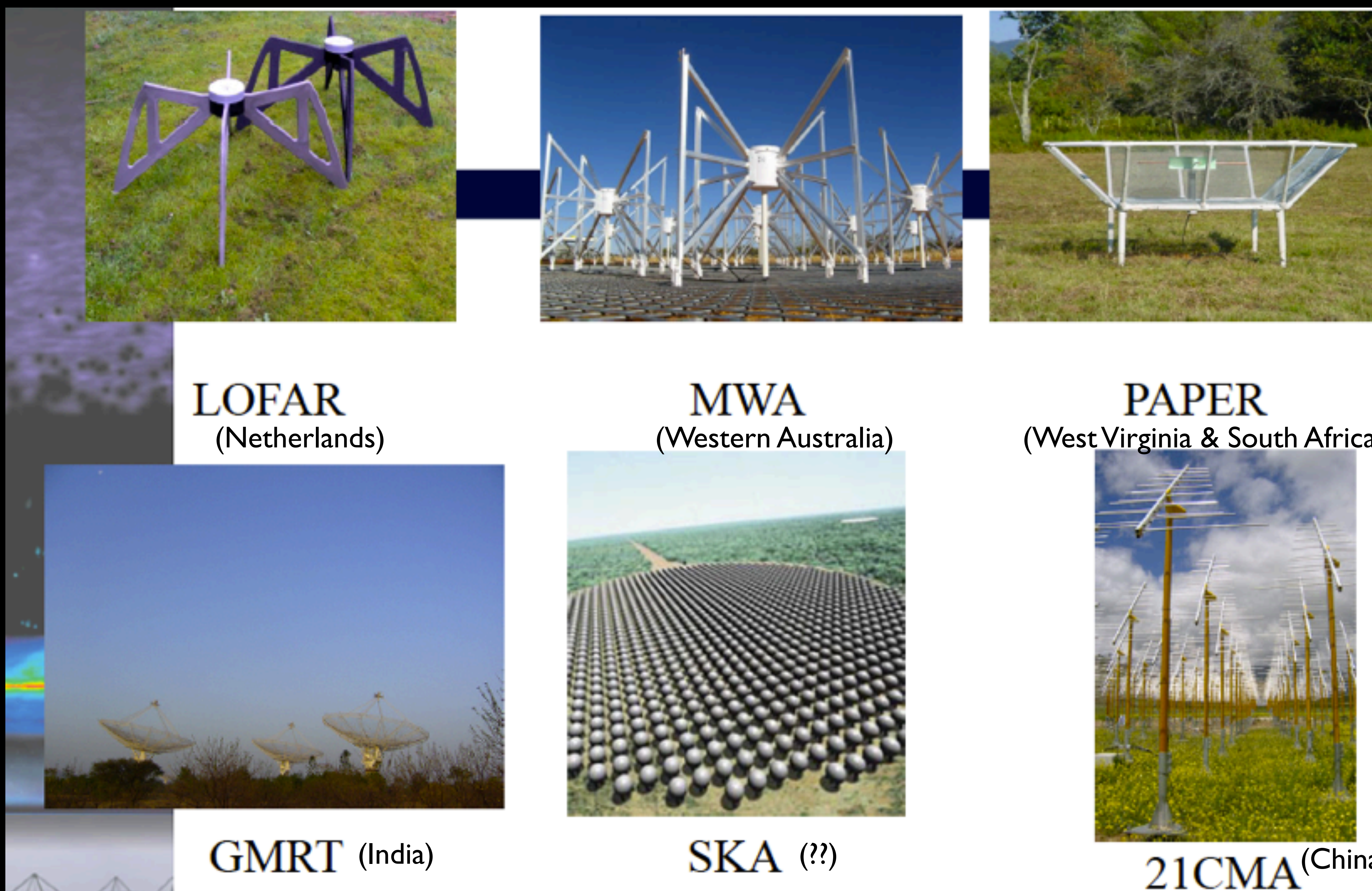
Field 1958, Madau, Meiksin, & Rees 1997; Furlanetto, Oh & Briggs 2006 for recent review

The Science

(in order of increasing difficulty)

- <u>hydrogen reionization</u> (6 <~ z <~ 15), 1% SKA
- cosmological parameters (z=0.5-3), 10% SKA
- <u>the first stars</u> (15 <~ z <~ 30), 100% SKA
- the dark ages (30 <~ z <~200), 100x SKA

Efforts to Detect the Spatially Fluctuating 21cm Signal from Reionization



I involved with PAPER.

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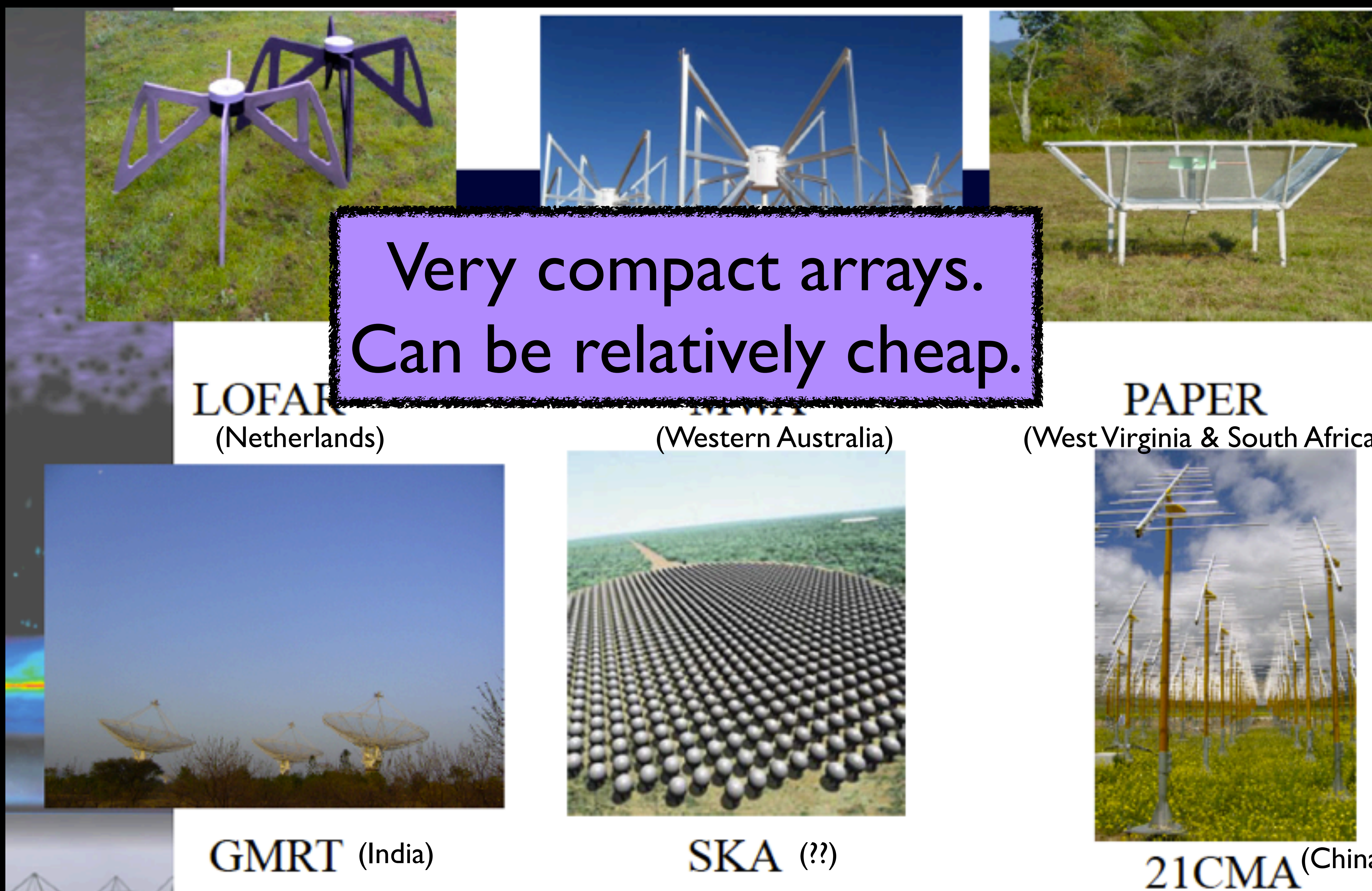

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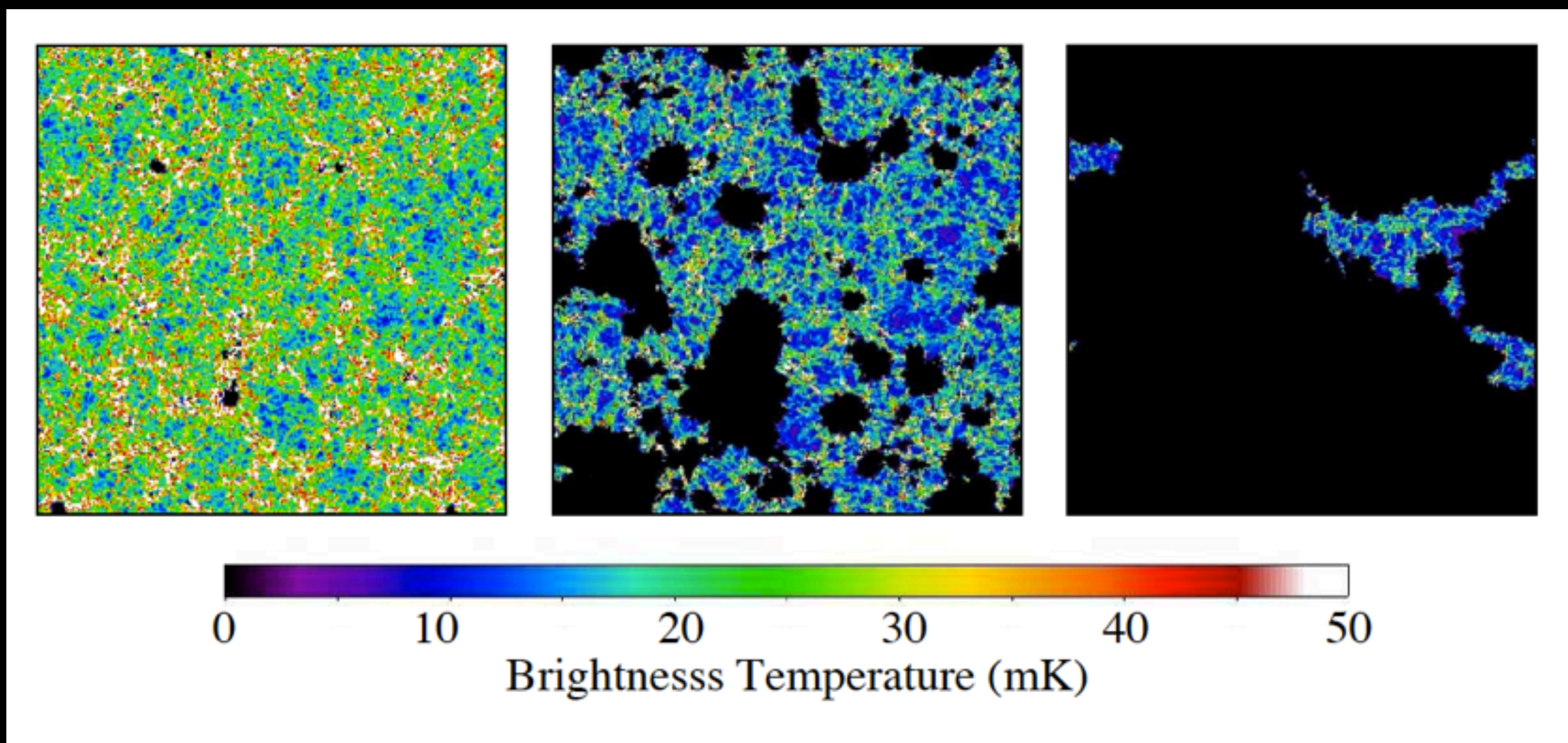
21 (1+z) cm Emission

Field 1958; Madau, Meiksin & Rees 1997; images from simulation in McQuinn et al ’07

z = 15 z = 10 z=8

0.5 degree

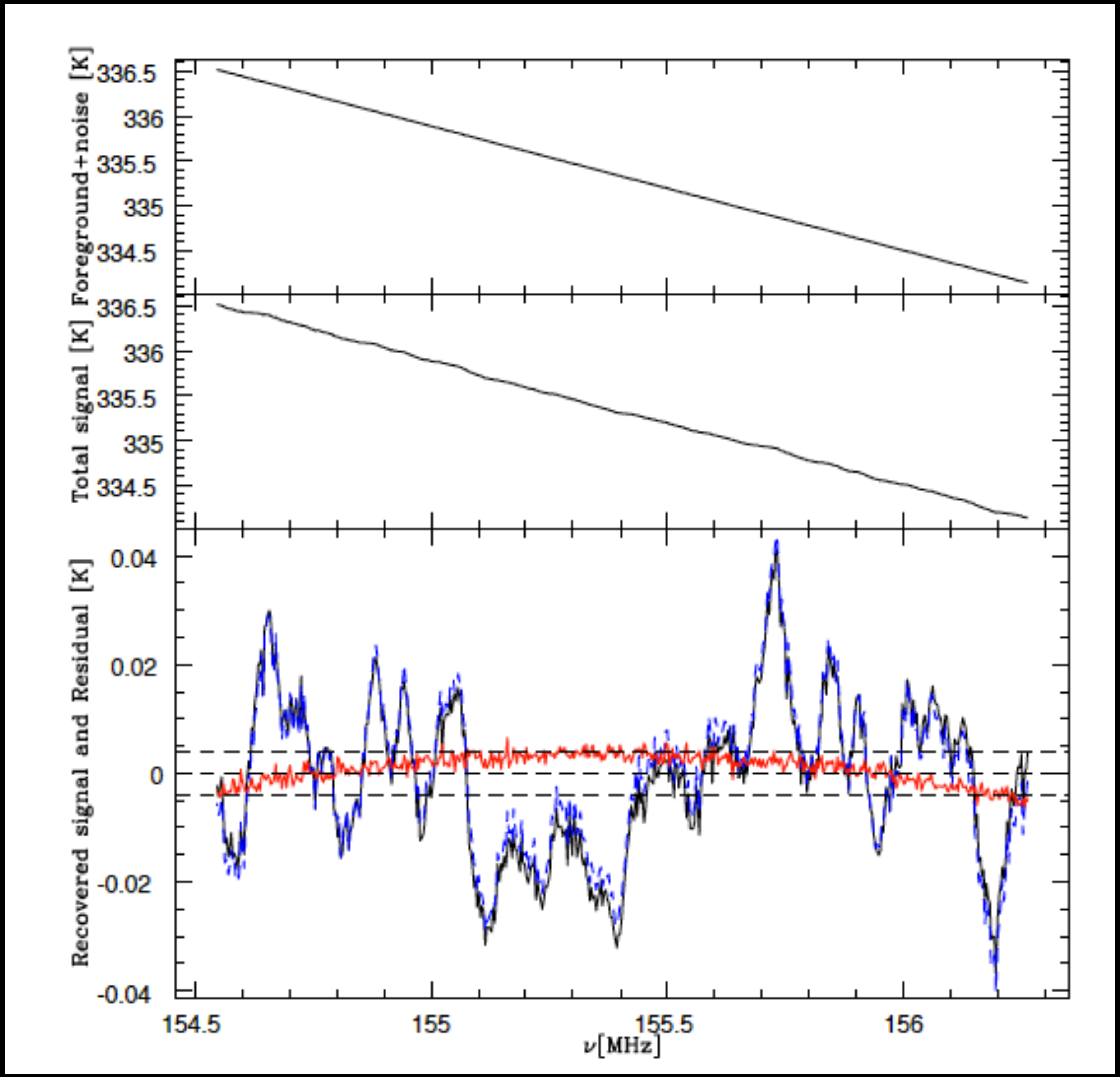


100 comoving Mpc

The sky is the limit: $T_{\rm sky} = 400 \left(\frac{1+z}{9}\right)^{2.7}$ K

whereas the signal strength is $T_{\rm 21cm} = 26\, x_H \left(\frac{T_{\rm S} - T_{\rm CMB}}{T_{\rm S}}\right)$ mK

Foreground Removal



Wang et al 2006

What this signal looks like

100 Mpc, 0.6 deg

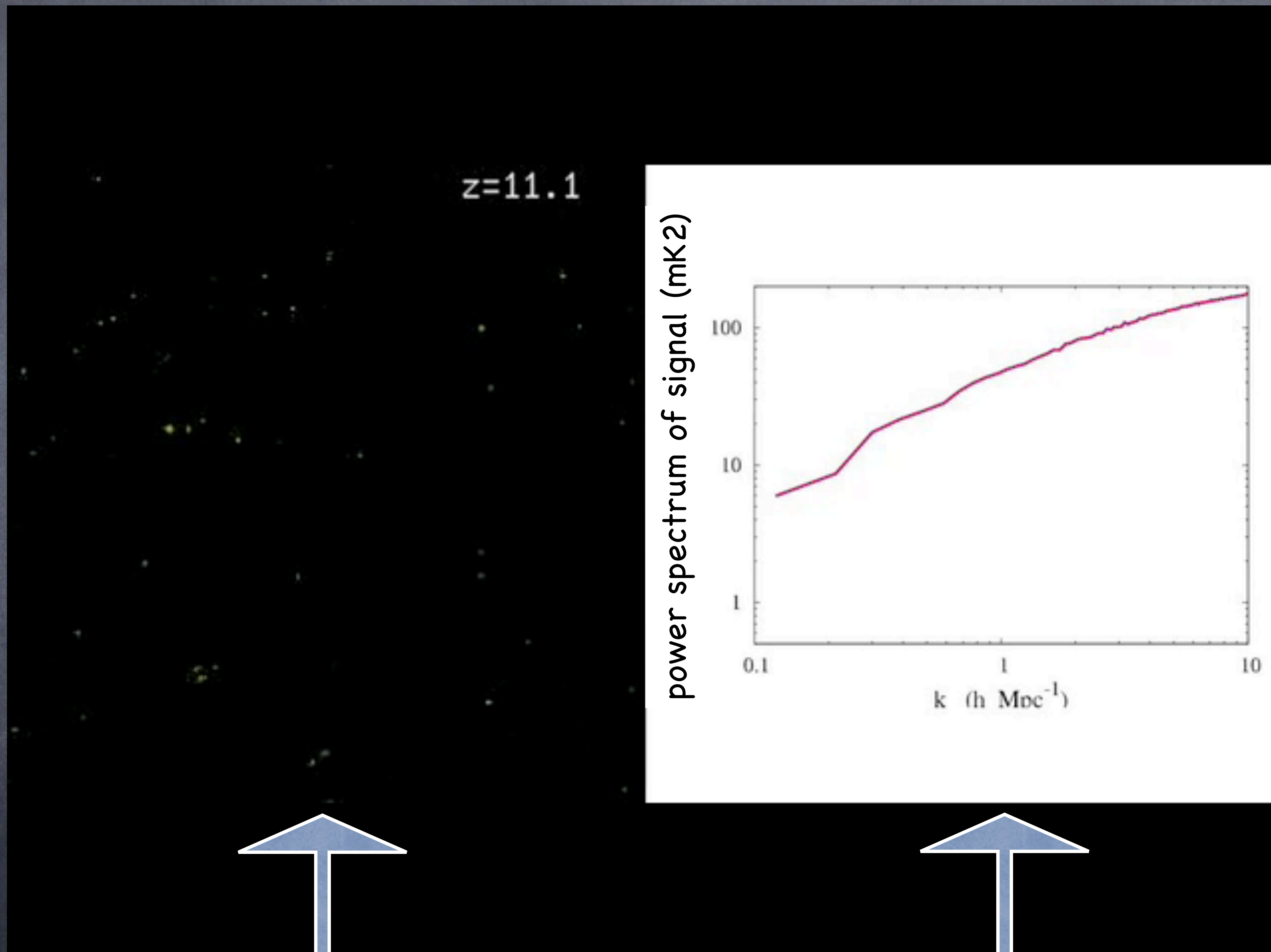
power spectrum of signal (mK2)

Will not be able to see this (initially).

Will detect this

What this signal looks like

100 Mpc, 0.6 deg

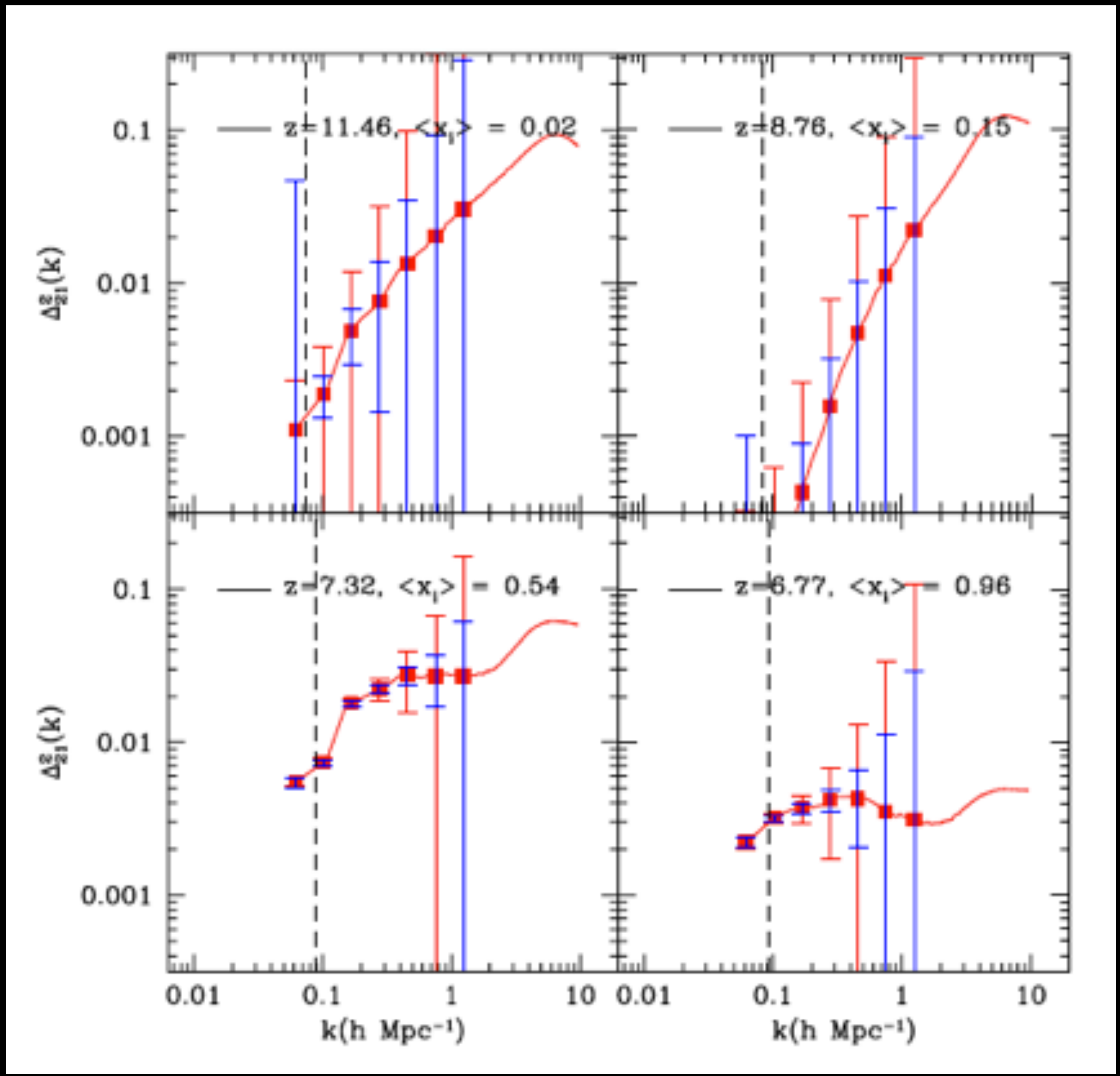


Will not be able to see this (initially). Will detect this

Sensitivity to 21cm Signal

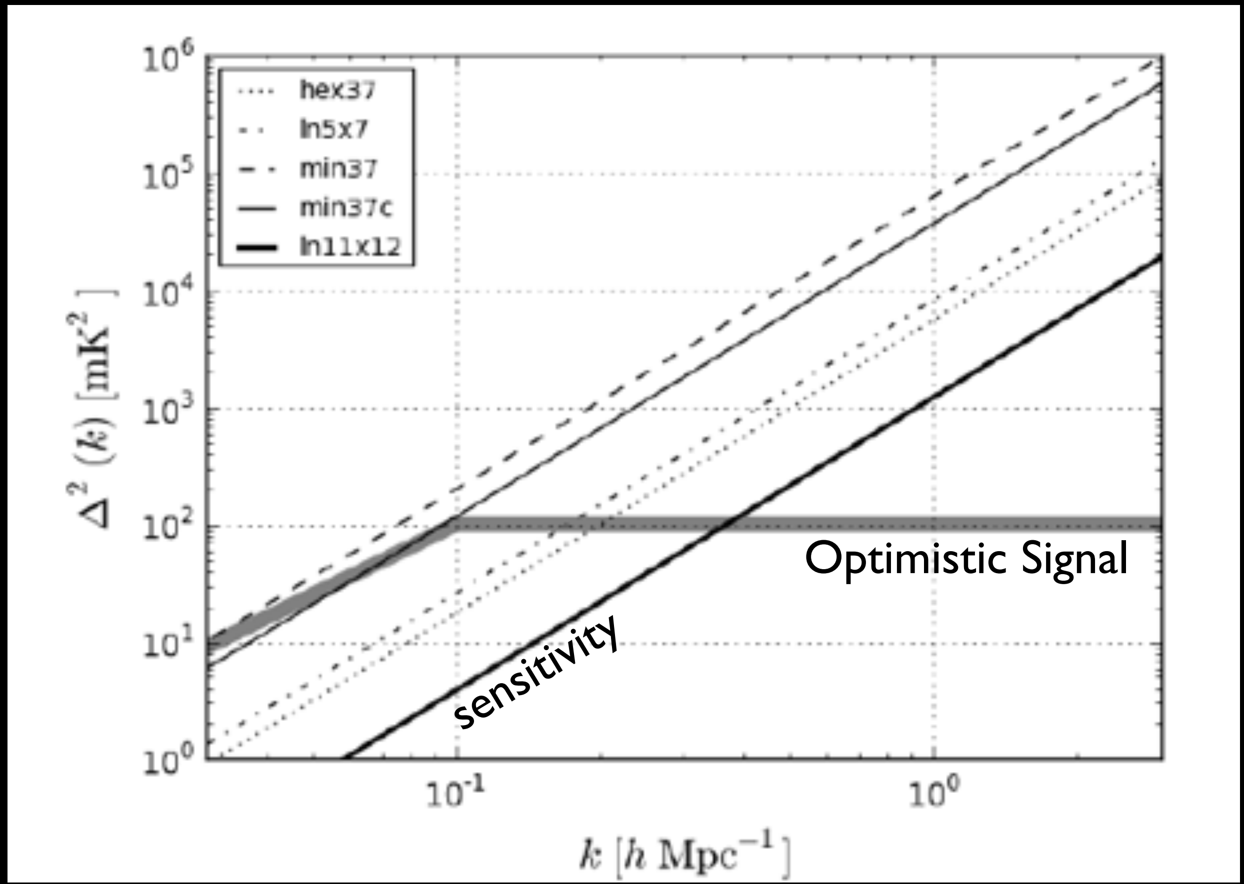
MWA: Projections for 500 Antennae (1000hr observation)

Power Spectrum of 21cm signal



red = current MWA design

PAPER: Projections 132 Antennae (1000 hr)

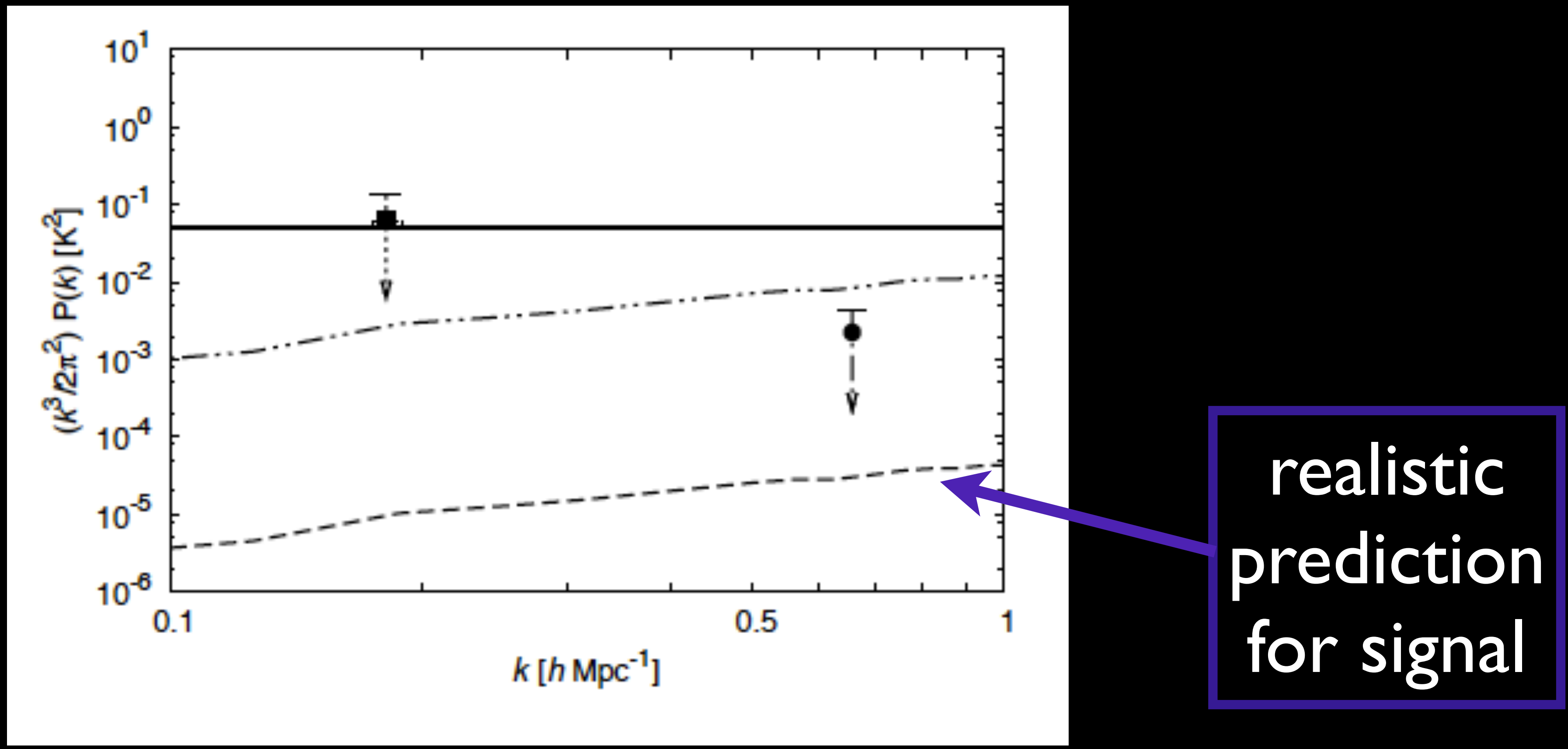


LOFAR/GMRT sensitivity similar to 500 Antennae MWA

MM et al. (2006), Lidz, Zahn, MM et al (2009)
Parsons, MM et al (2011)

Present state of high-z 21cm observations

GMRT: Paciga et al (2010), <6 days of integration



- MWA = 32 tiles in field, money for 128
- PAPER = 32 dipoles down in West VA and South Africa, 128 in ~year
- LOFAR = started EOR observing campaign, 1st results mid 2012

The Global Signal

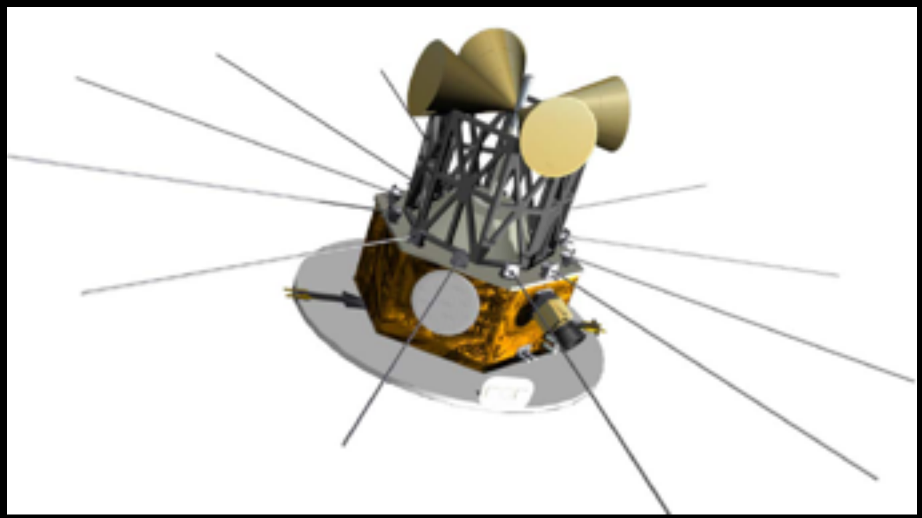
Mean (sky-averaged) signal:

Madau et al '97, Gnedin & Shaver '04

EDGES

LEDA (I'm involved w/)

DARE



A single dipole has the potential to measure the signal from z~6-50

$10\text{mK} \sim T_{sys}/(B\ t_{obs})^{1/2}$

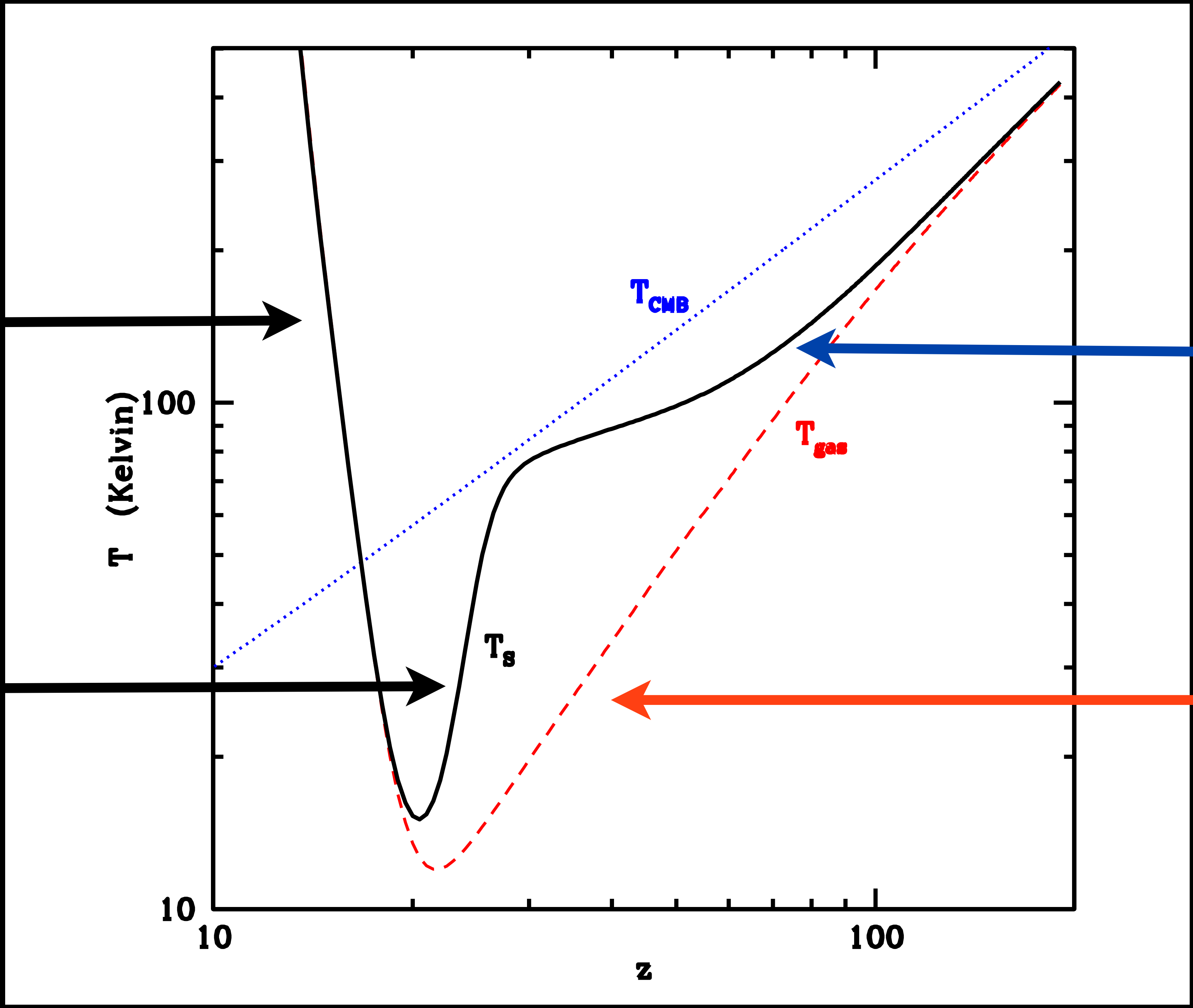
The evolution of the signal

$$\delta T_{21} = 28\, x_H\, \Delta_b \frac{T_S - T_{\rm CMB}}{T_S} \left(\frac{1+z}{10}\right)^{1/2} \ \mathrm{mK}$$

$$T_{\rm S}^{-1} = \frac{T_{\rm CMB}^{-1} + x_c\, T_{\rm gas}^{-1} + x_\alpha\, T_{\rm rad}^{-1}}{1 + x_c + x_\alpha}$$

Heating from X-rays (Tassos Fragos' talk)

radiation from first stars re-couples T_s to T_{gas}

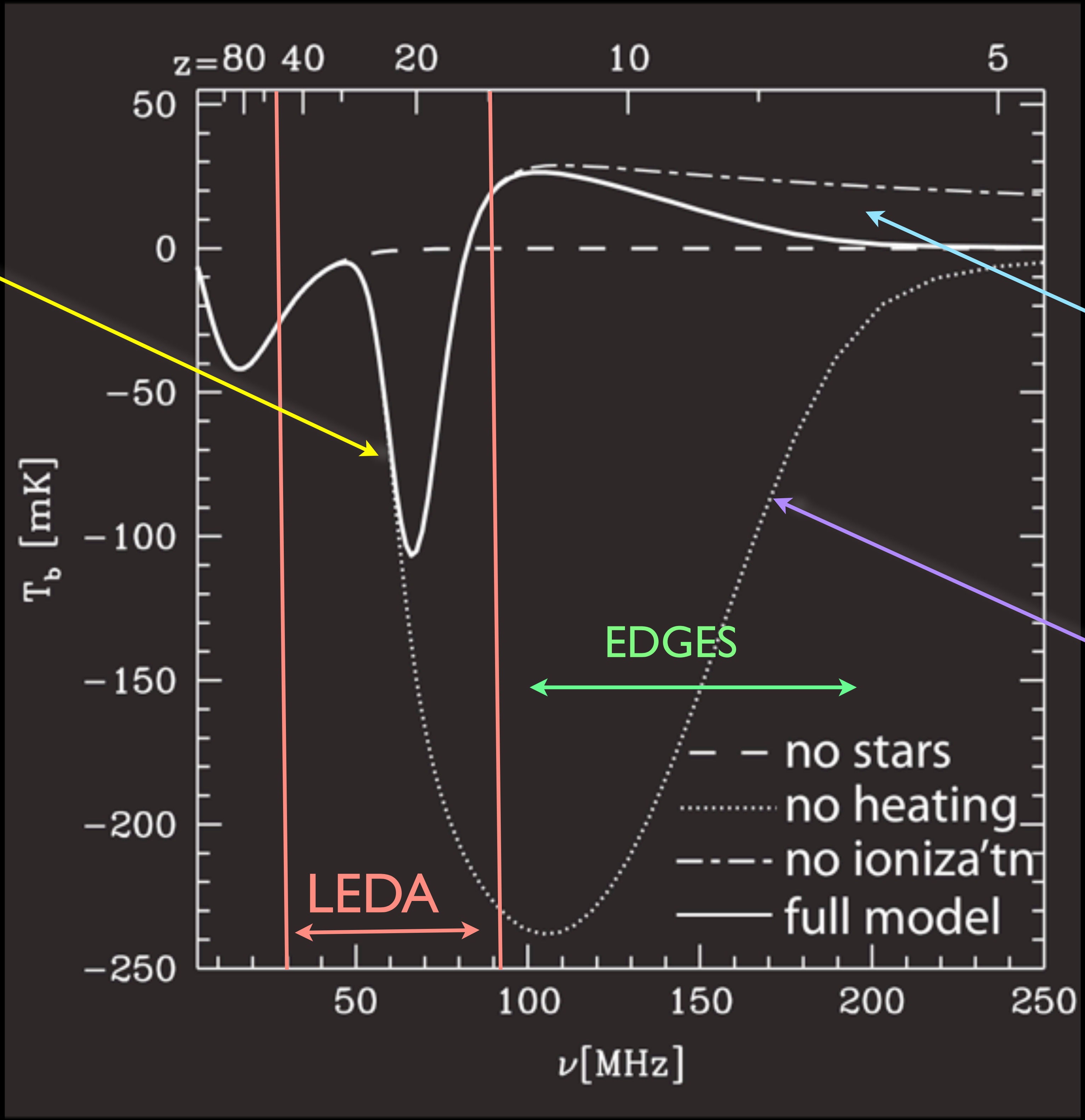


Collisions can no longer keep T_S coupled to T_{gas}

Gas cools adiabatically after recombination

The Global Signal

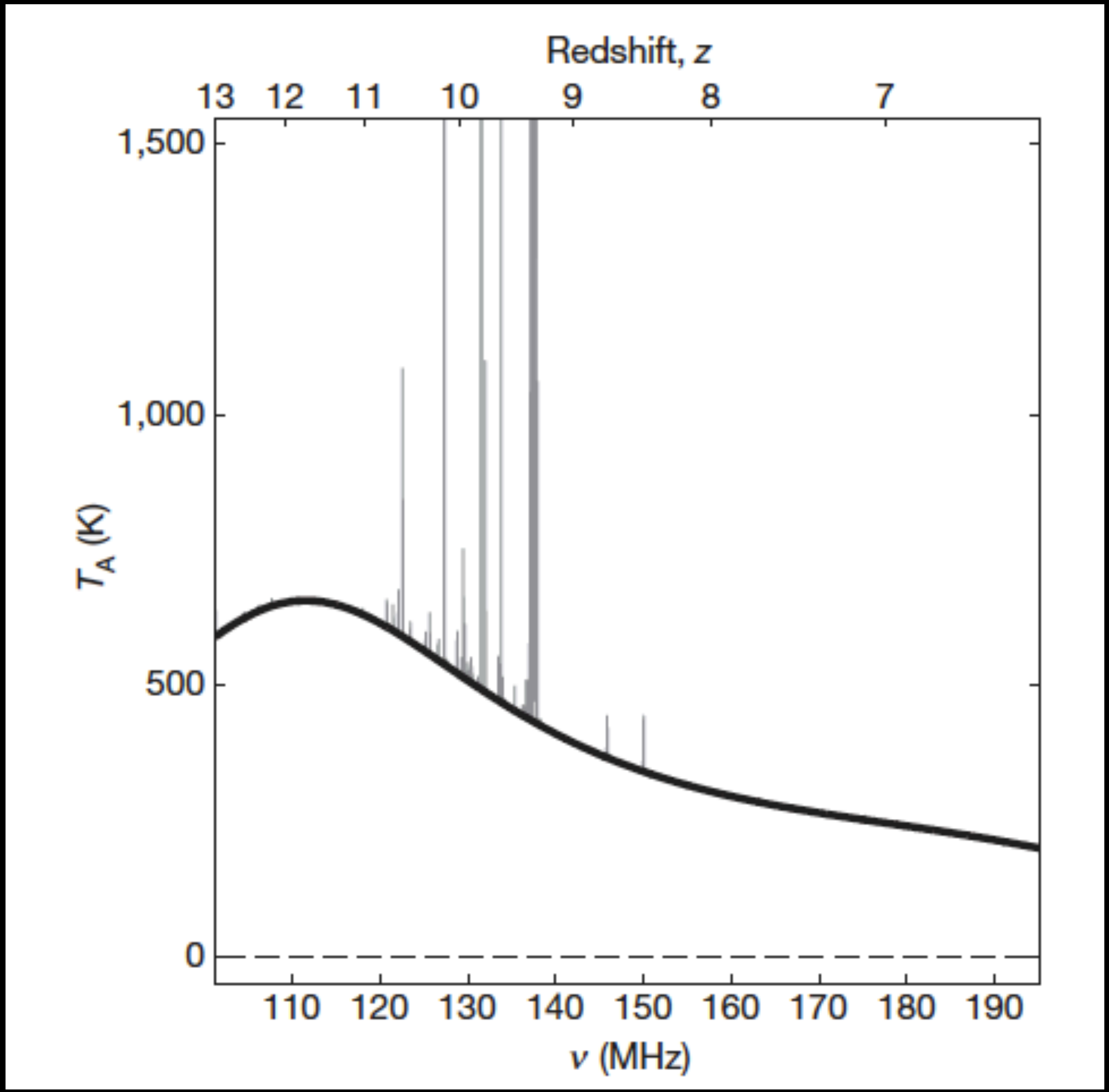
Lyman-α photon production (likely from stars) determines magnitude of decoupling from the dashed curve

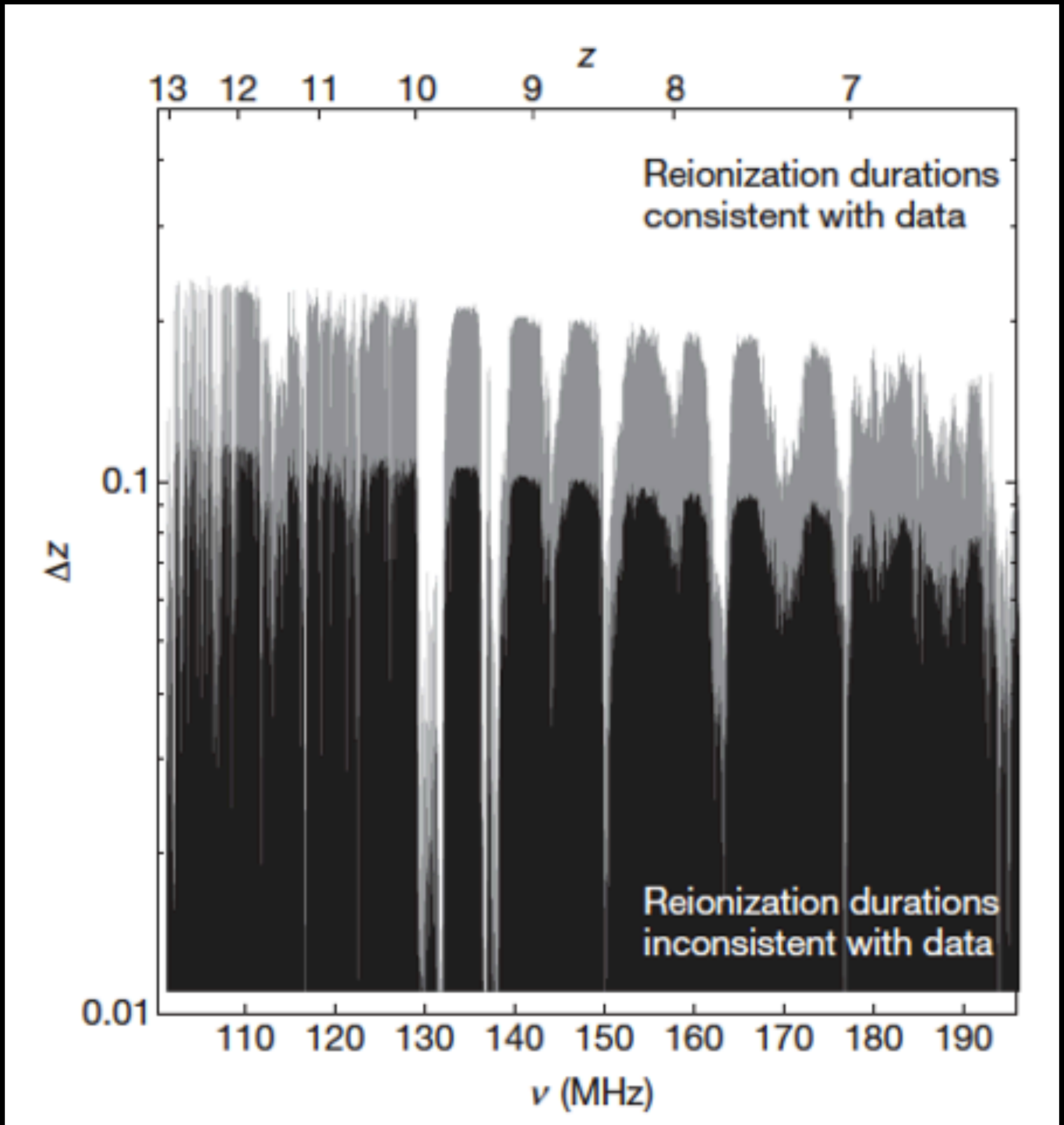


Production of ionizing photons determines the difference between dash-dot and solid curves

Case where IGM not reheated prior to reionization. It takes just 10^{-3} eV per baryon to significantly change this curve.

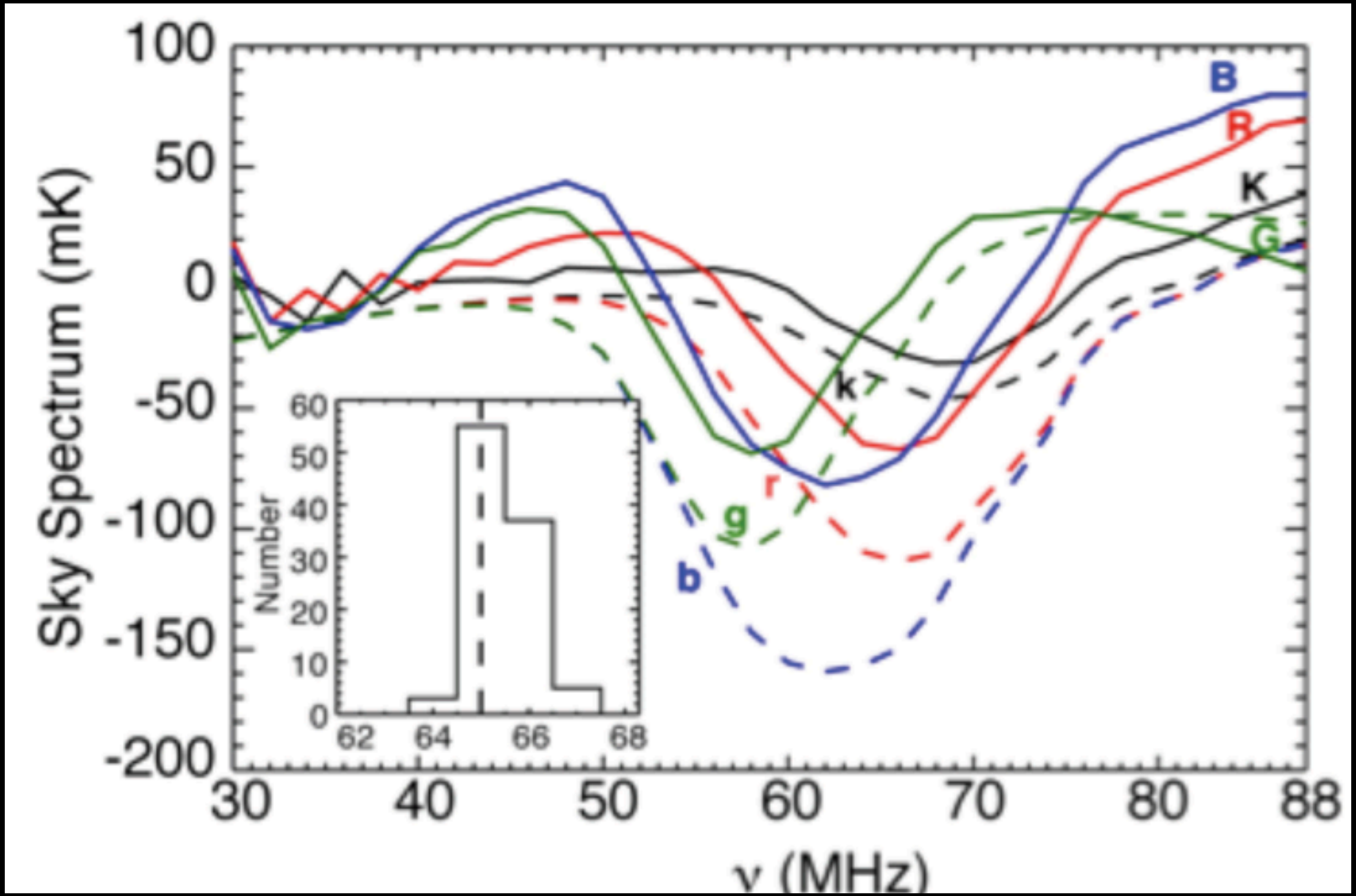
Edges: constraint on duration of reionization (reaching RMS noise of 10 mK!)





Bowman & Rodgers 2011

Forecasts for LEDA



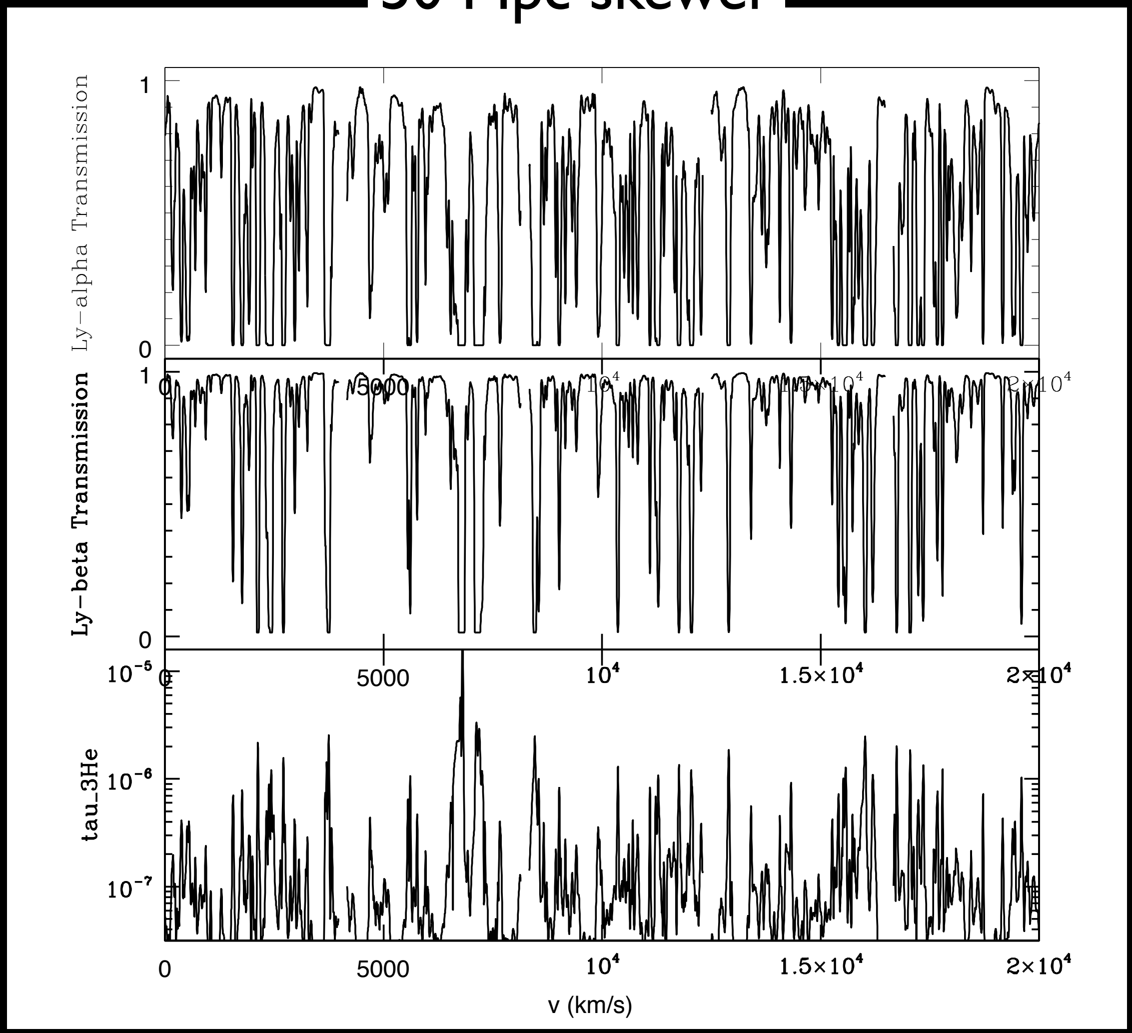
b,r,k,g are four potential signals and B,R,K,G is the recovered signal after an 80 hr observation with LEDA, fitting out a 3rd order polynomial. Note that the bias can be corrected.

$^3He^+$ 8.7 GHz Hyperfine Forest (MM & Switzer `09)

- helium reionization likely ending at z=3
- $T_s = T_{cmb}$, which maximizes absorption ($\tau \propto T_s^{-1}$)
- In principle, detectable in 10 hr observation with Arecibo towards brightest z=4 source at 2GHz. Should be easily detected with the SKA.

50 Mpc skewer

3He Forest ->



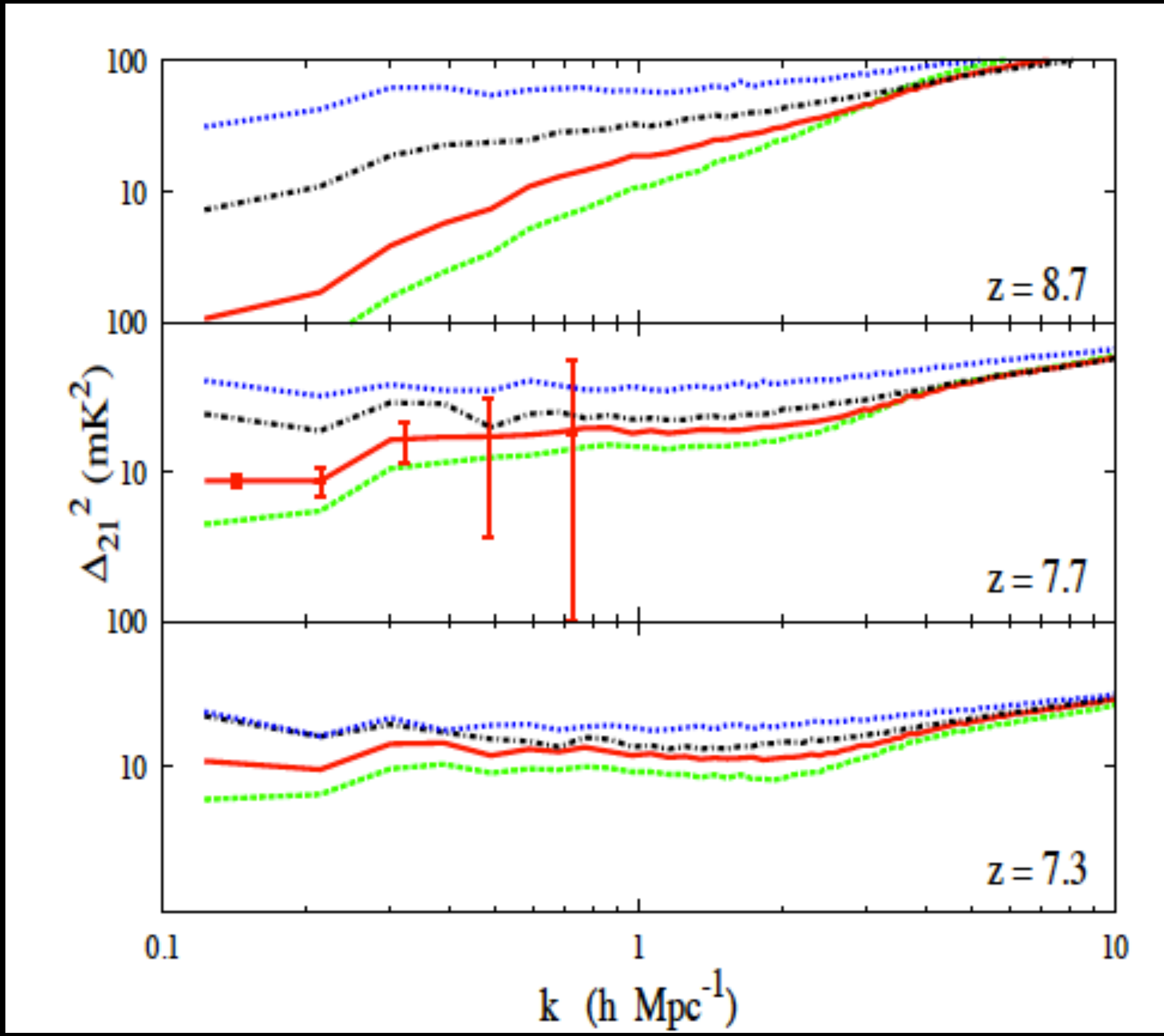
Looking for $\sim 1(1+\delta)$ μ Jy absorption from a 1 Jy source.

Can do matched filter using HI Lyman forest absorption.

Conclusions

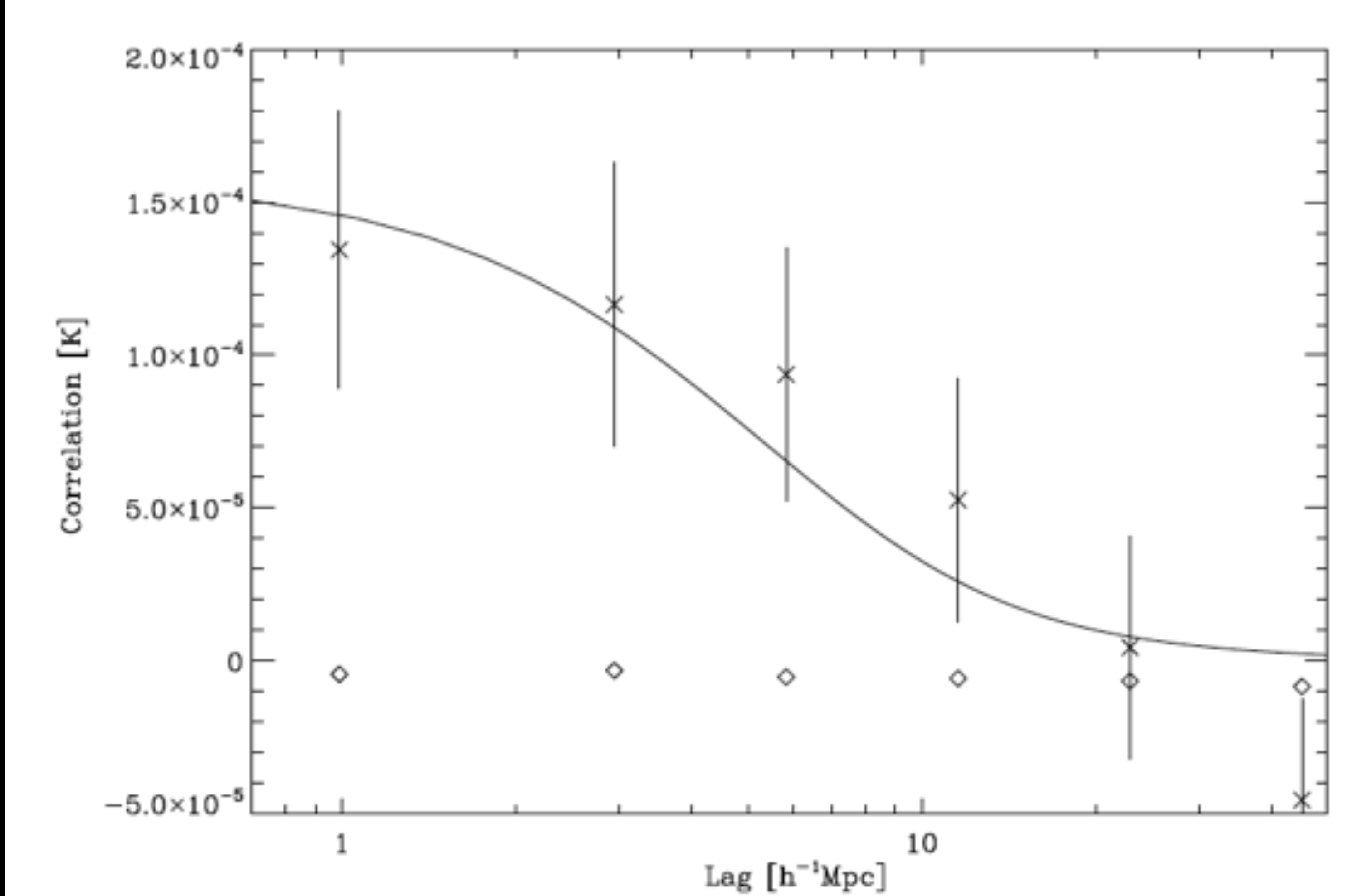
- Many instruments coming/presently online that aim to detect high-z 21cm radiation from reionization
- has potential to provide detailed maps of the reionization history
- Unclear when 21cm instruments will achieve projected sensitivities, but starting to publish first constraints
- Global signal another avenue with different challenges

More power = rarer sources ionize Universe



Successes at lower z

GBT 800MHz-DEEP2 cross correlation, z = 0.8



Chang et al '10

- Foregrounds much smaller at low-z, but so is amount of neutral hydrogen -> Tsig/Tfor is about the same
- Chang et al '10 detect in cross-correlation with GBT & DEEP2
- rumored to have a detection in auto-power