

Cosmology in the Cosmic Dark Ages

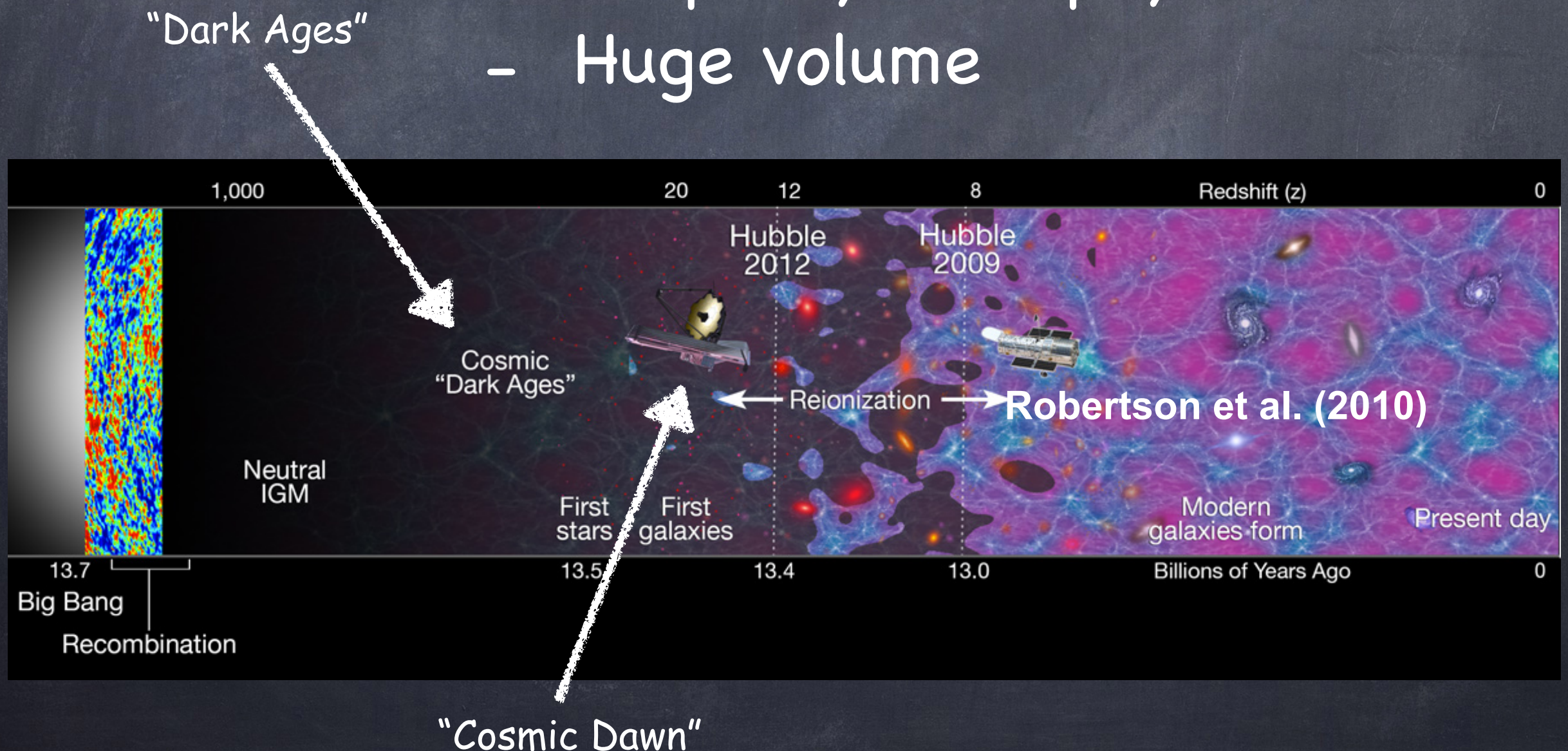
Steve Furlanetto

(on behalf of Nick Kern and the MegaWave Radio Surveyor)

September 2, 2026

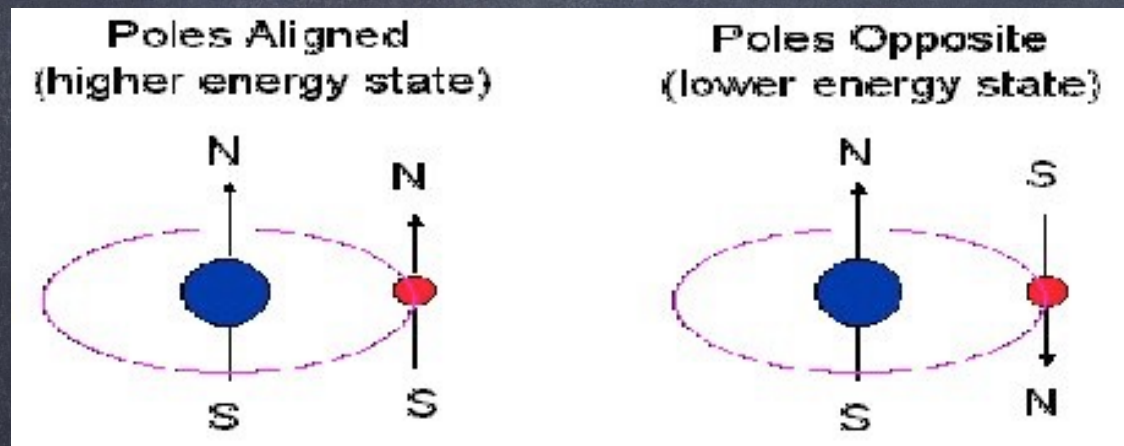
The Cosmic Dawn and the Dark Ages

- No pesky astrophysics!
- Huge volume



The 21-cm/Spin-Flip Transition

- Hyperfine transition of neutral hydrogen



- Rest wavelength = 21-cm BUT redshifted by $\sim 10\times$!
- Rest frequency = 1420 MHz BUT observed frequencies 20-200 MHz

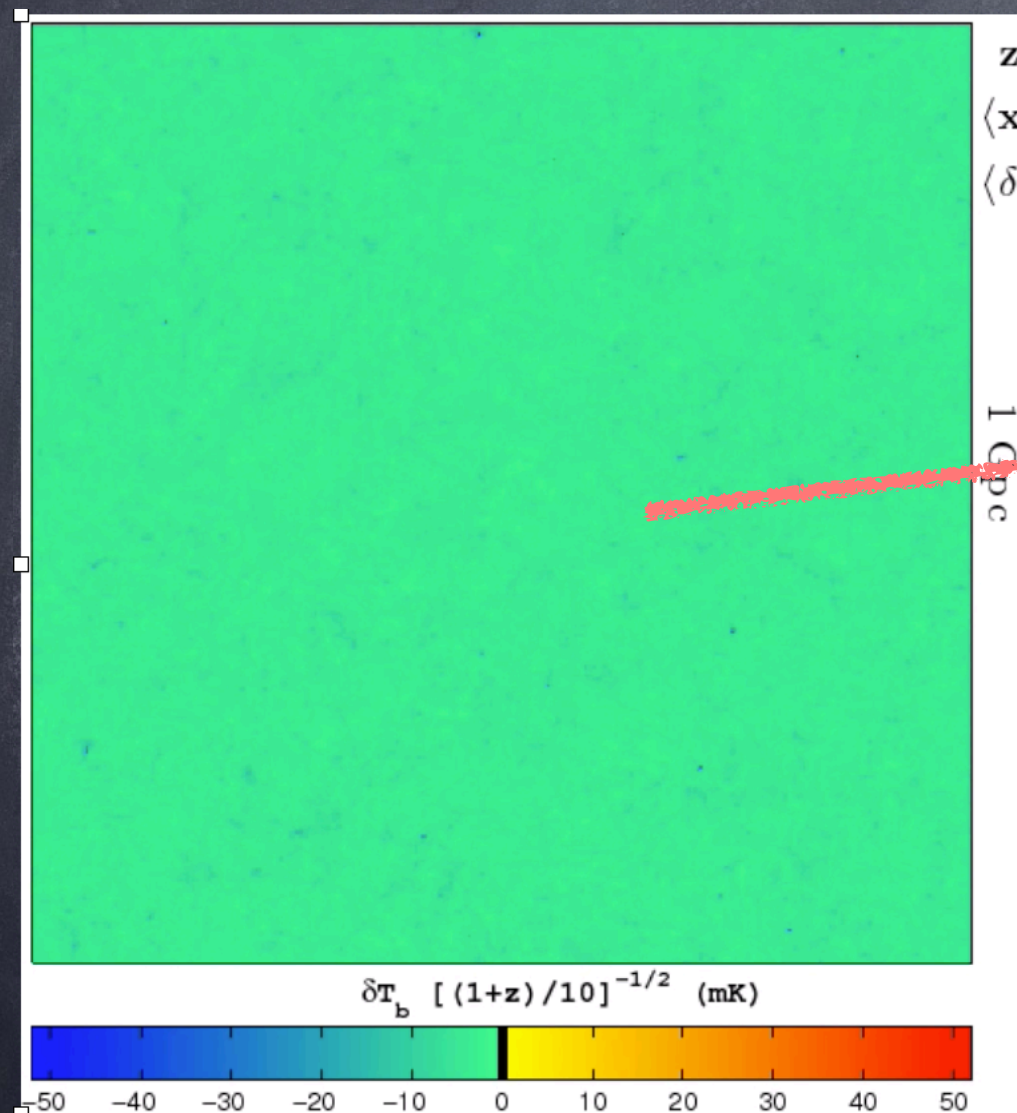
The 21-cm Signal From The Dark Ages

The 21-cm signal depends on:

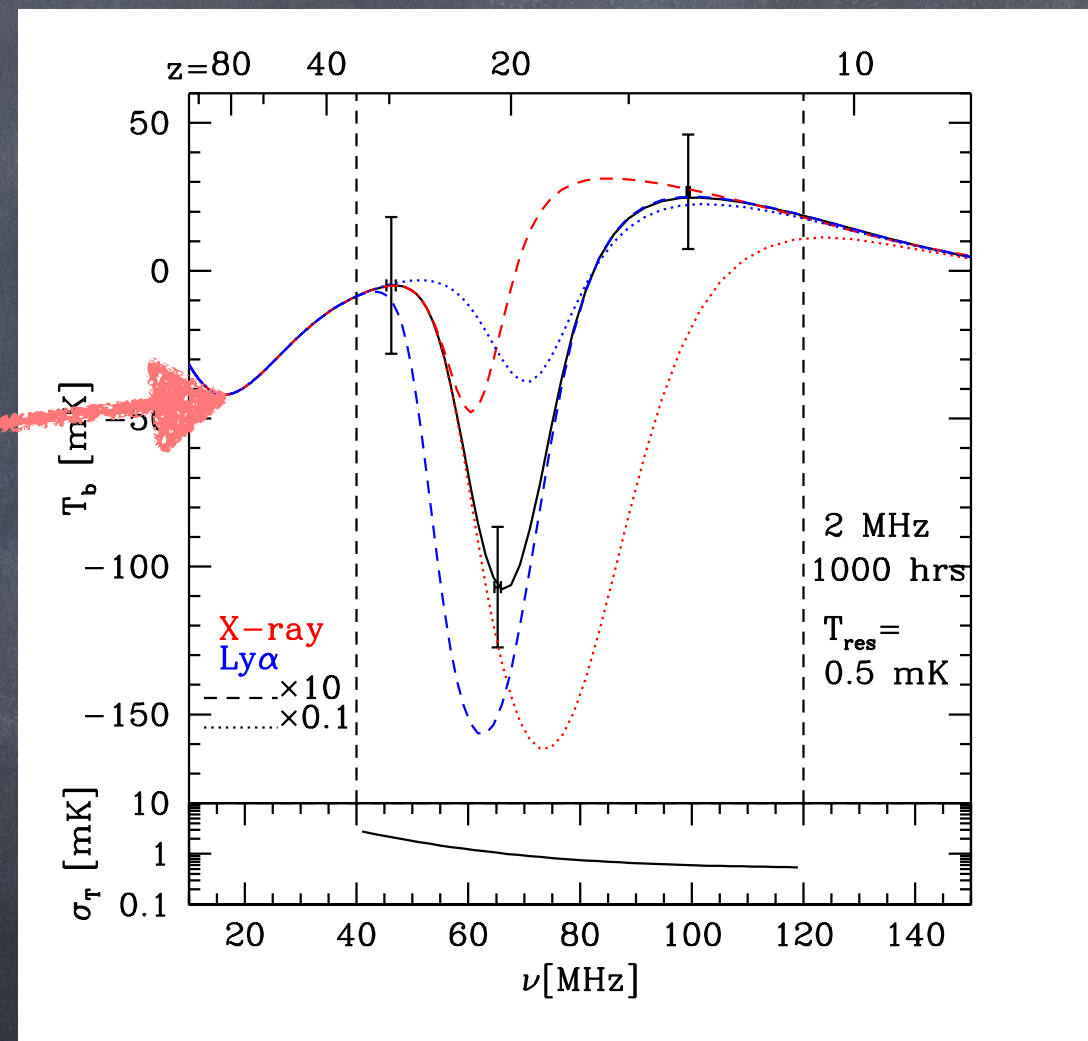
- The ionization field
- The density field
- The gas temperature
- Coupling with the CMB

$$\delta T_b \approx 23 x_{\text{HI}} (1 + \delta) \left(\frac{1+z}{10} \right)^{1/2} \left(\frac{T_S - T_{\text{bkgd}}}{T_S} \right) \left(\frac{H(z)/(1+z)}{\partial v_r / \partial r} \right) \text{ mK}$$

The 21-cm Signal

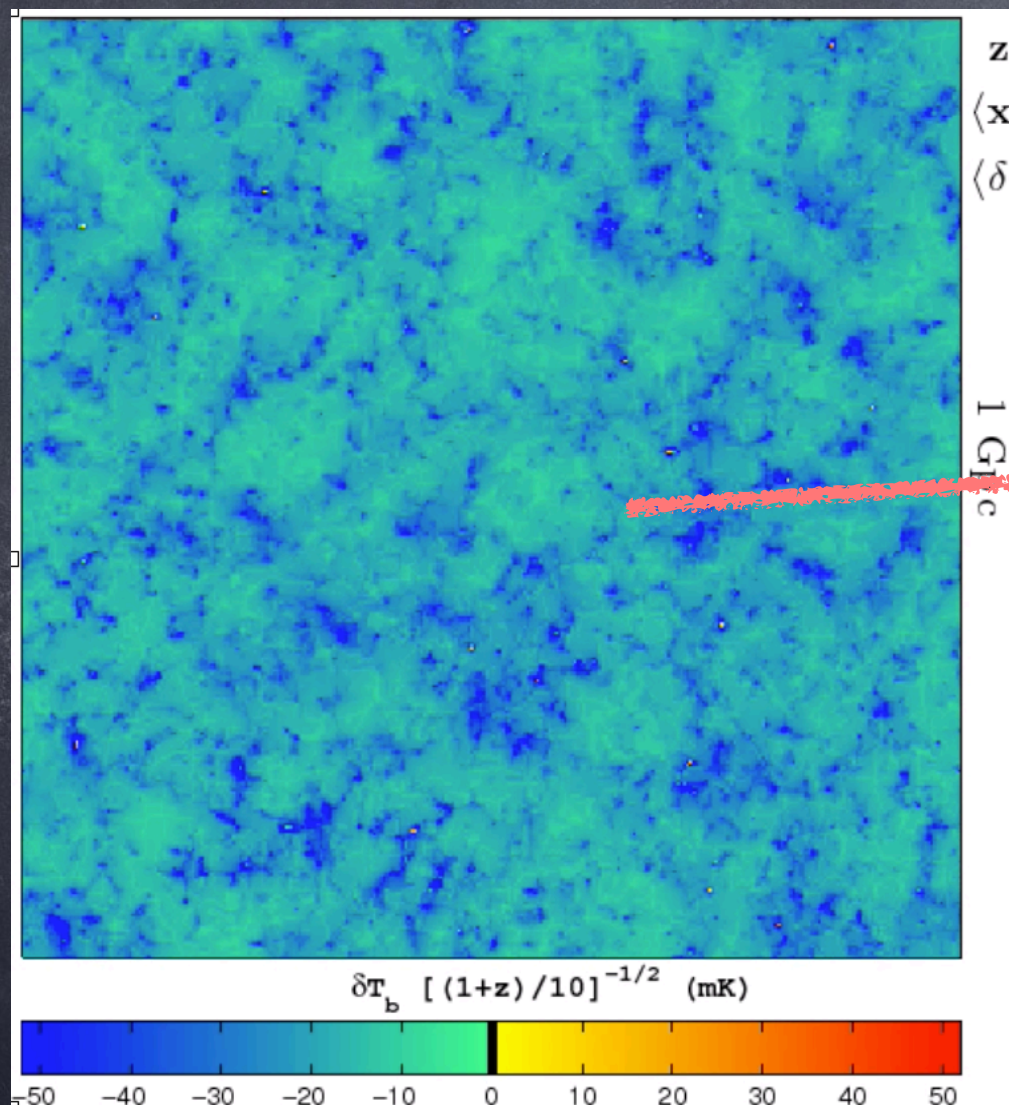


Mesinger, Furlanetto, & Cen (2011)

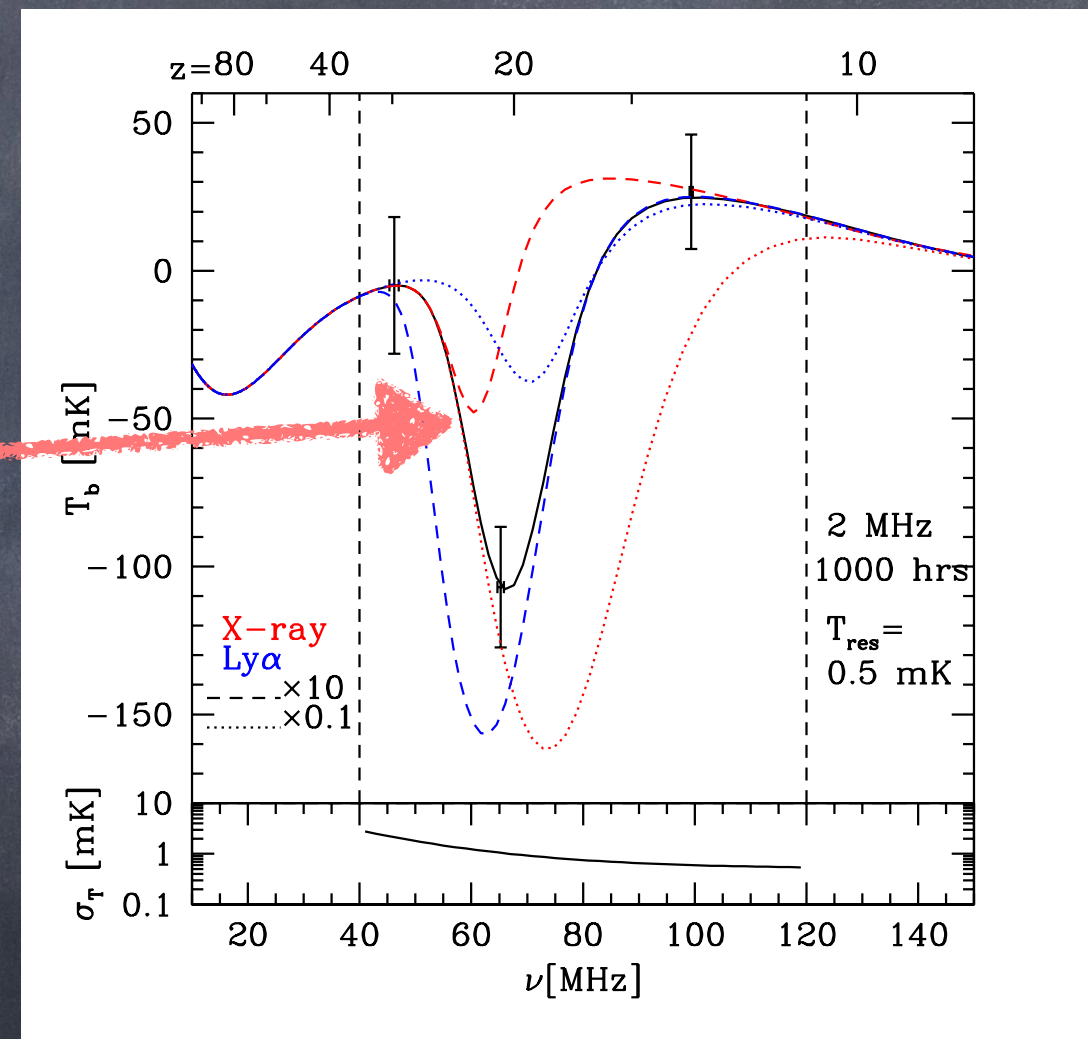


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The 21-cm Signal

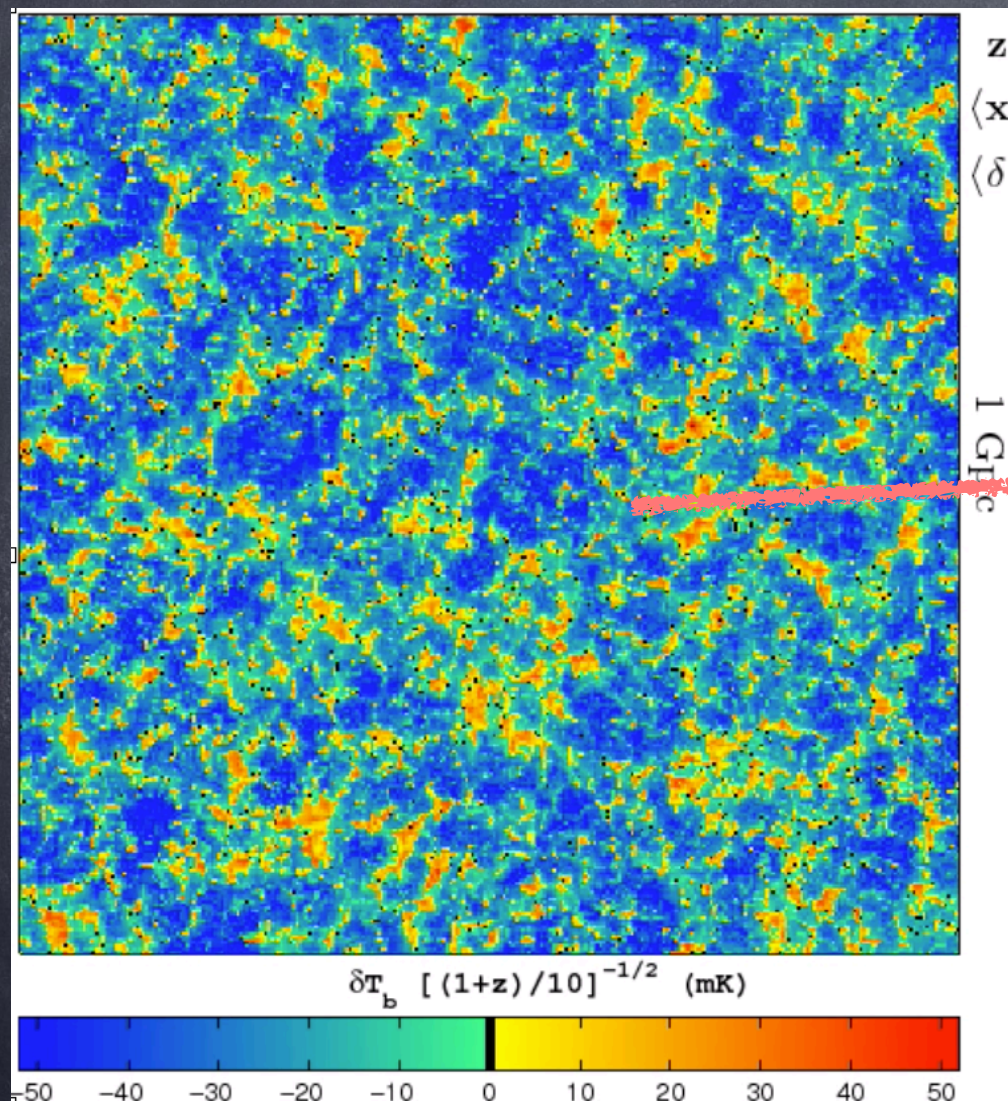


Mesinger, Furlanetto, & Cen (2011)

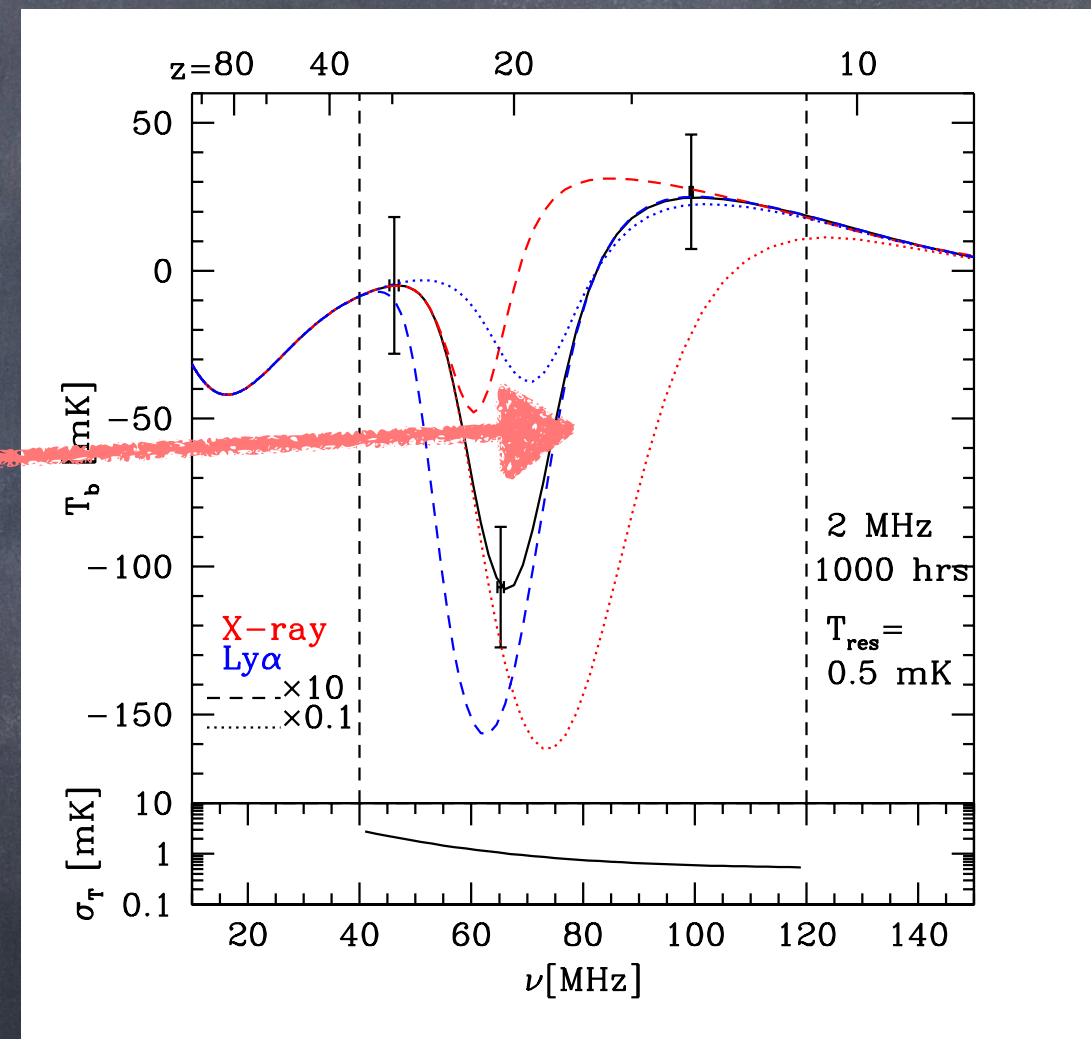


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The 21-cm Signal

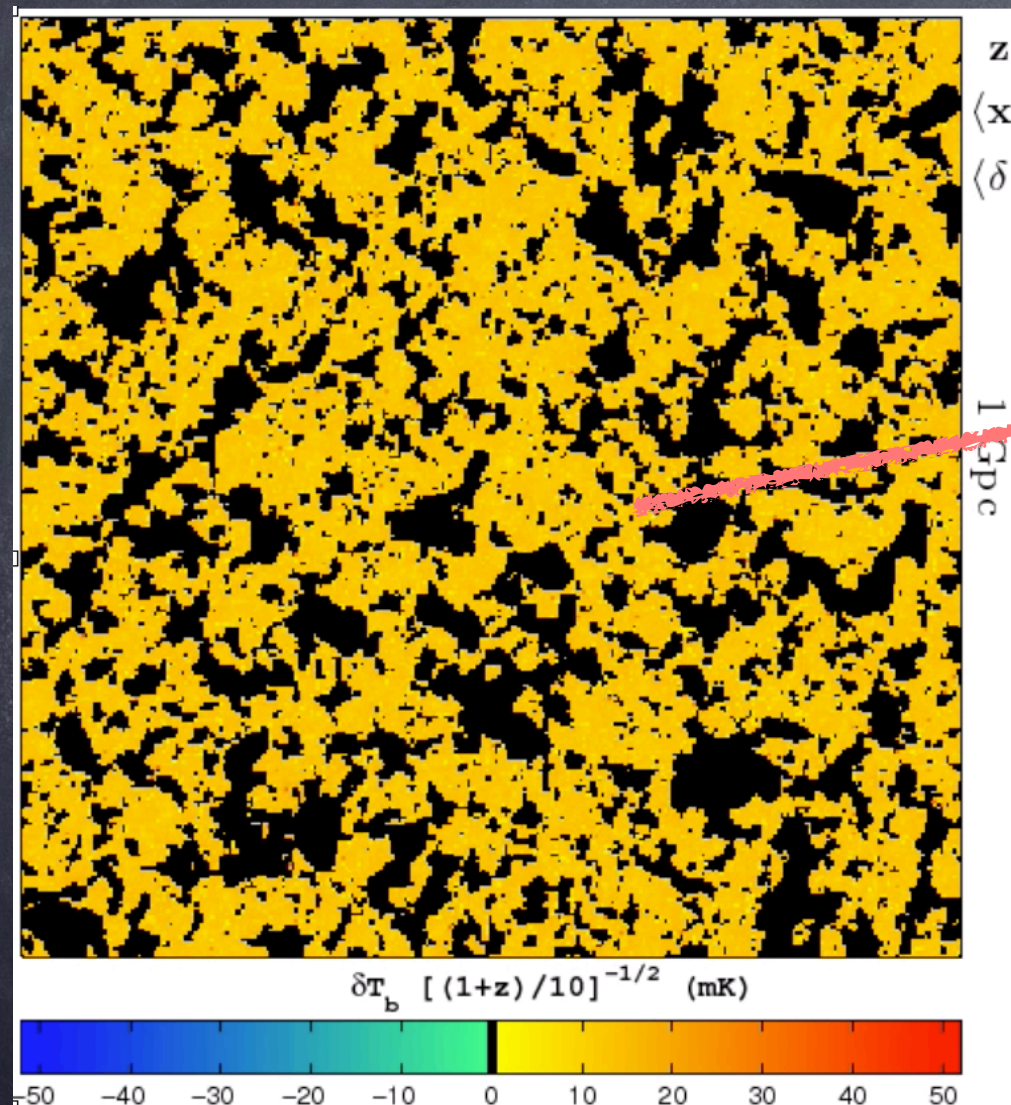


Mesinger, Furlanetto, & Cen (2011)

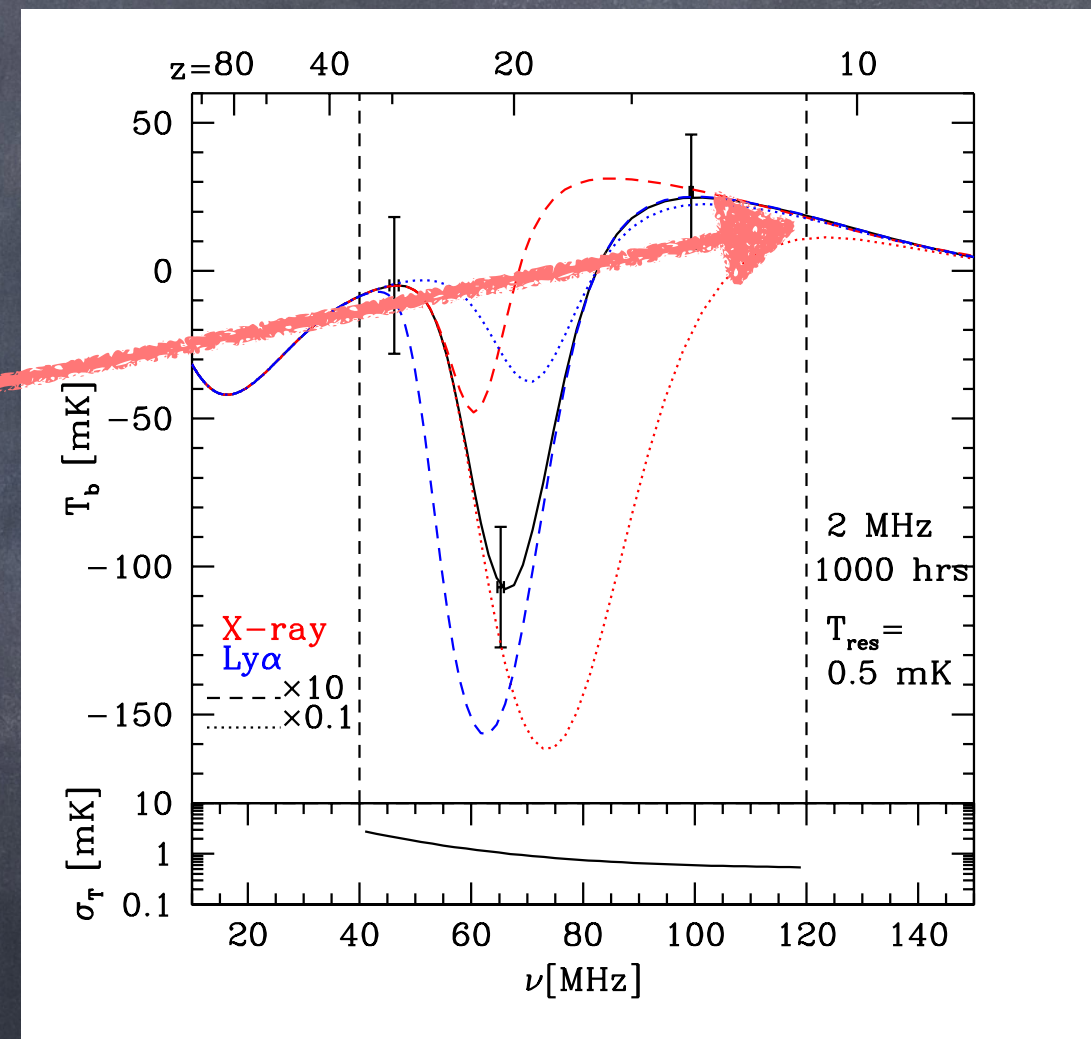


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The 21-cm Signal

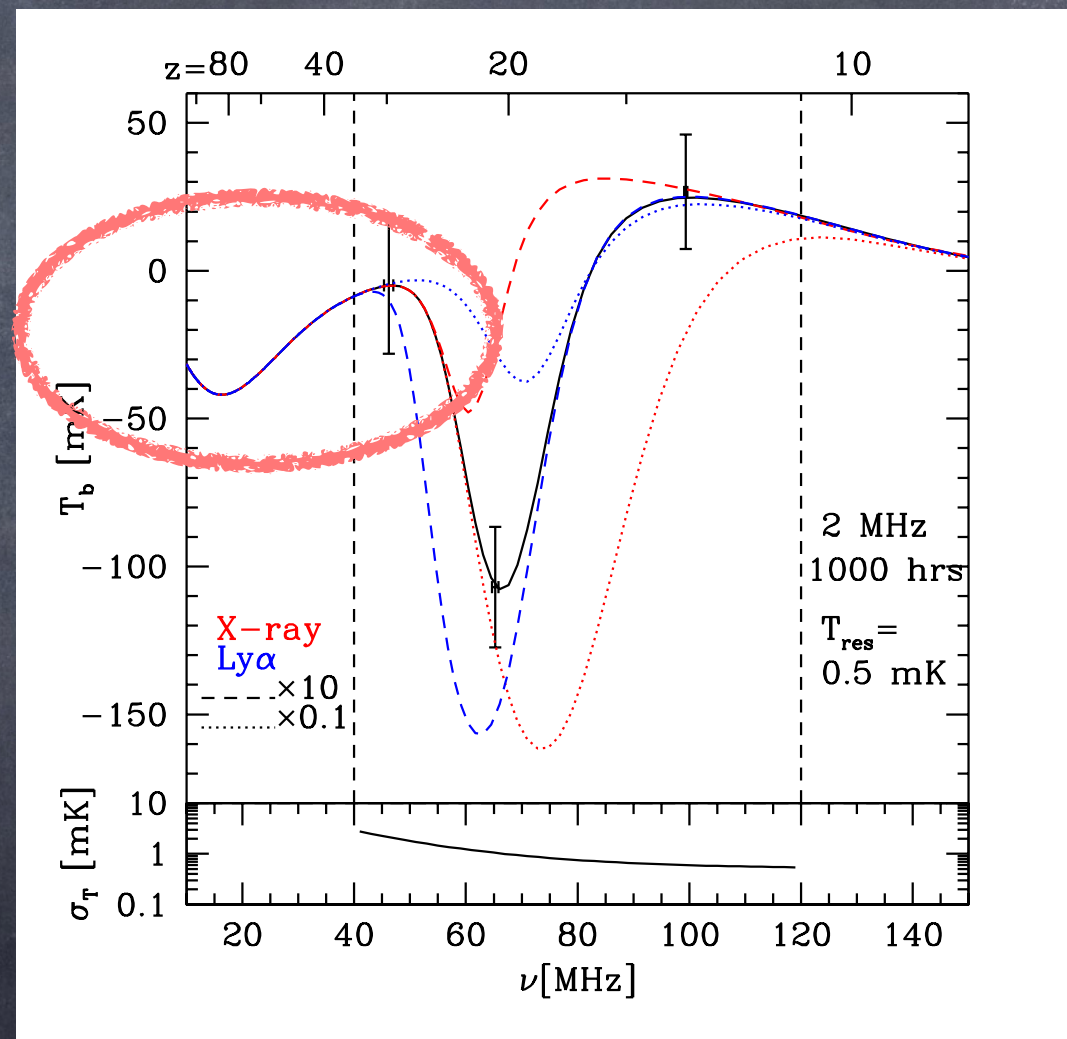


Mesinger, Furlanetto, & Cen (2011)



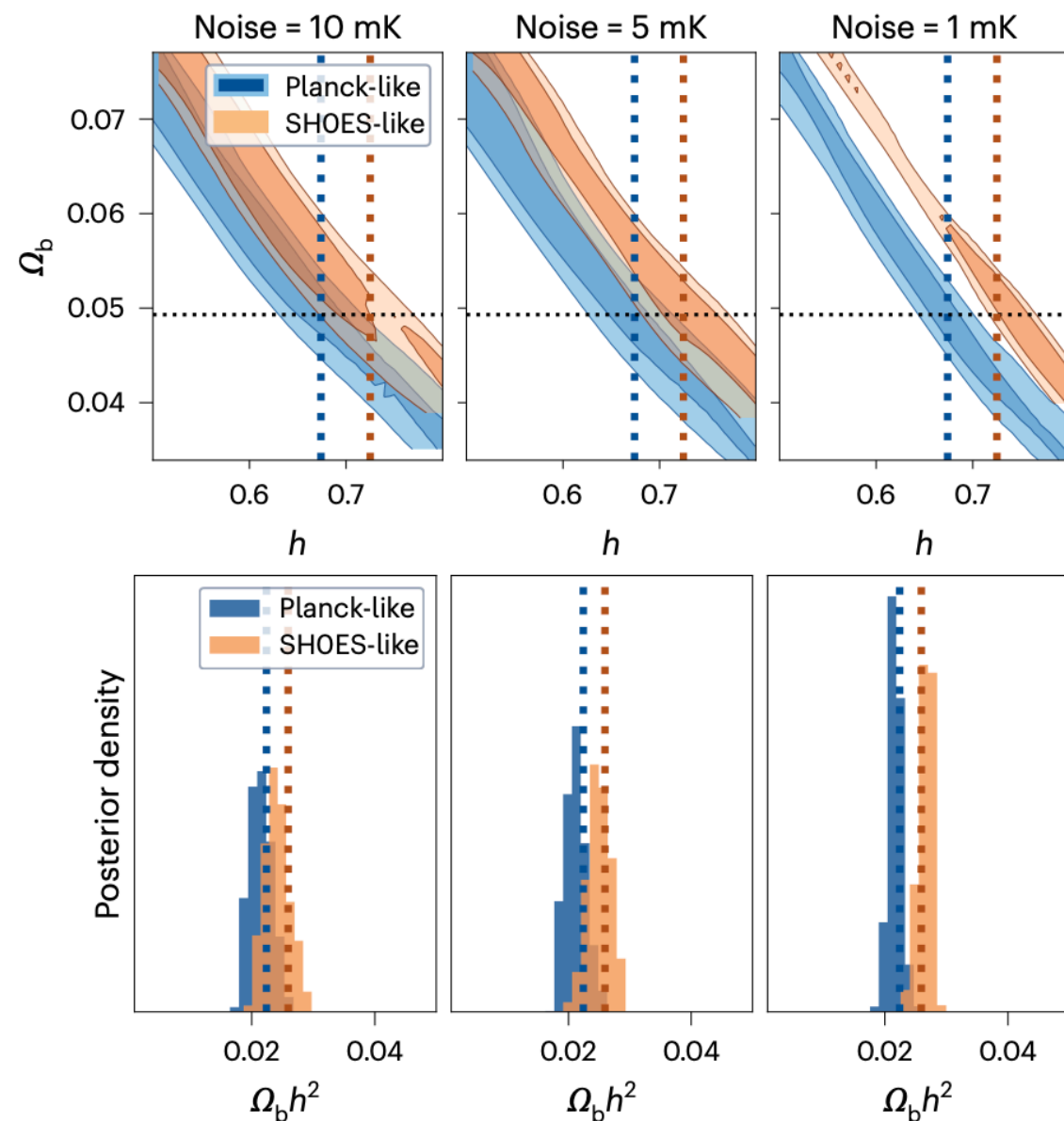
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The Global Signal in the Dark Ages



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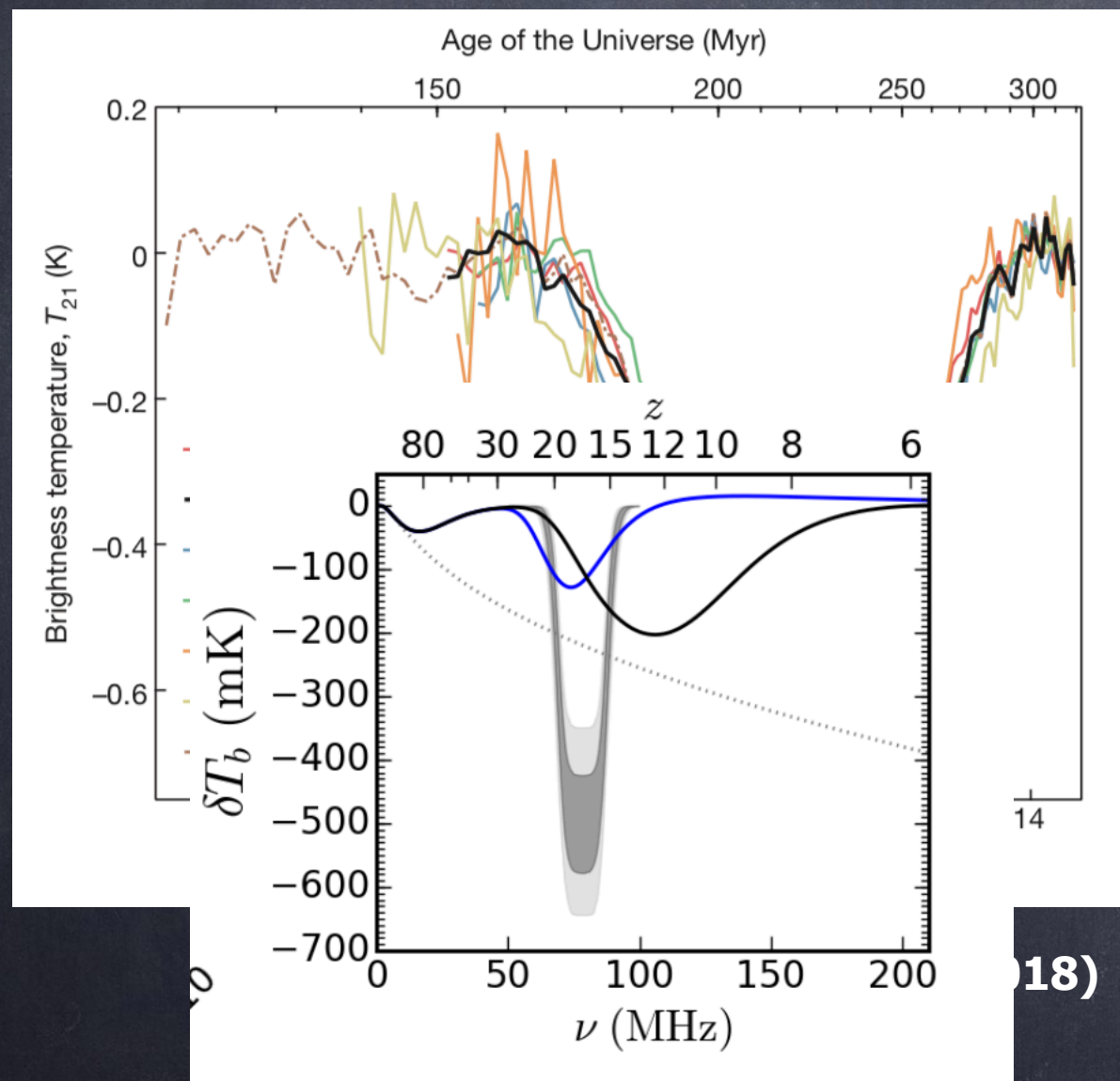
Precision Cosmology from the Global Signal



- The Dark Ages signal depends on
- Baryon density
- Temperature
- Expansion history

de Iera Acedo et al. (2026)

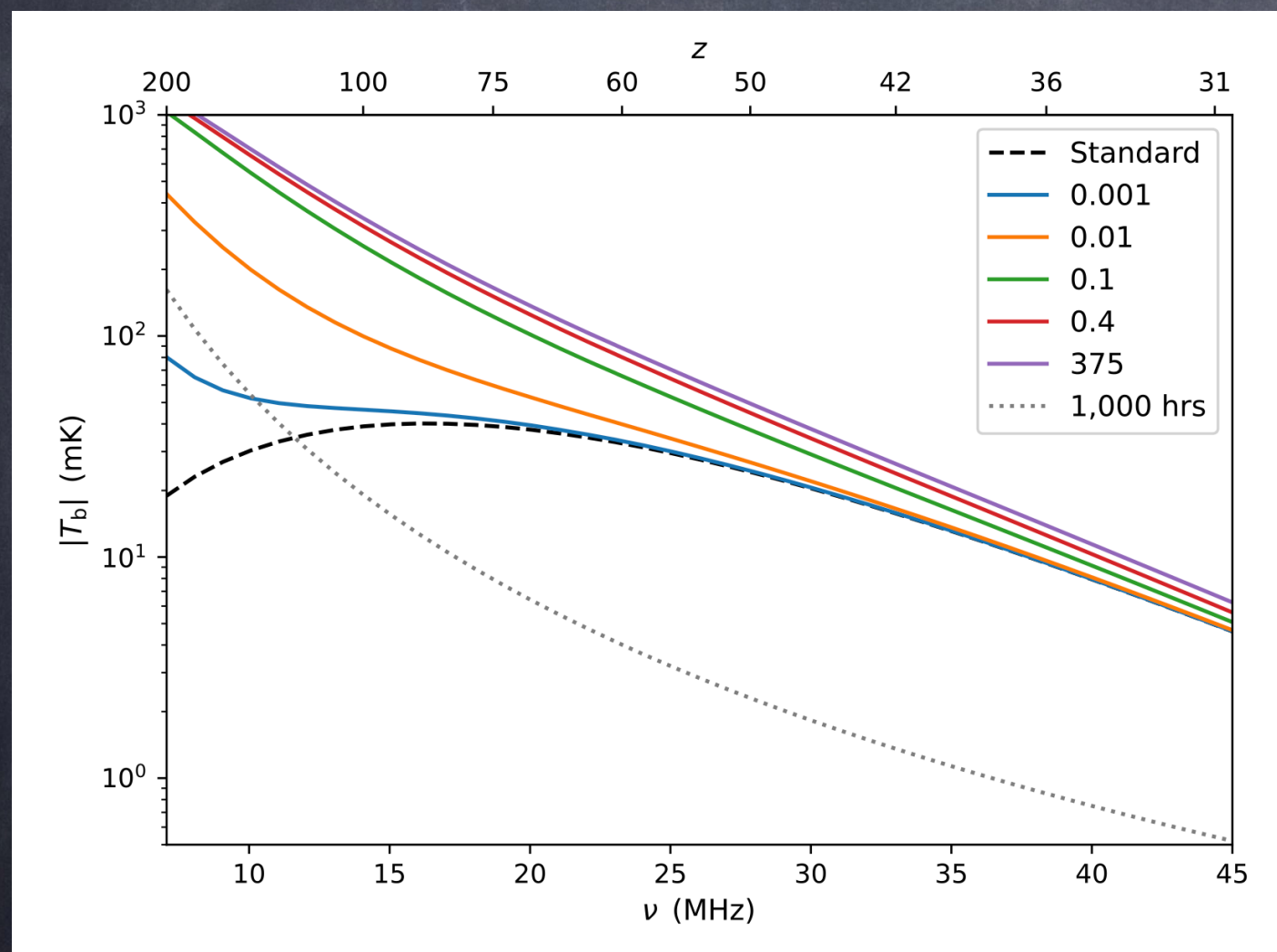
Exotic Cosmology from the Global Signal



Mirocha et al. (2017)

- Bowman et al. (2018) claimed the detection of a deep trough at $z \sim 17$
- MUCH deeper than expected in adiabatically cooling gas viewed against the CMB!
- 1100 references, most proposing complicated explanations....

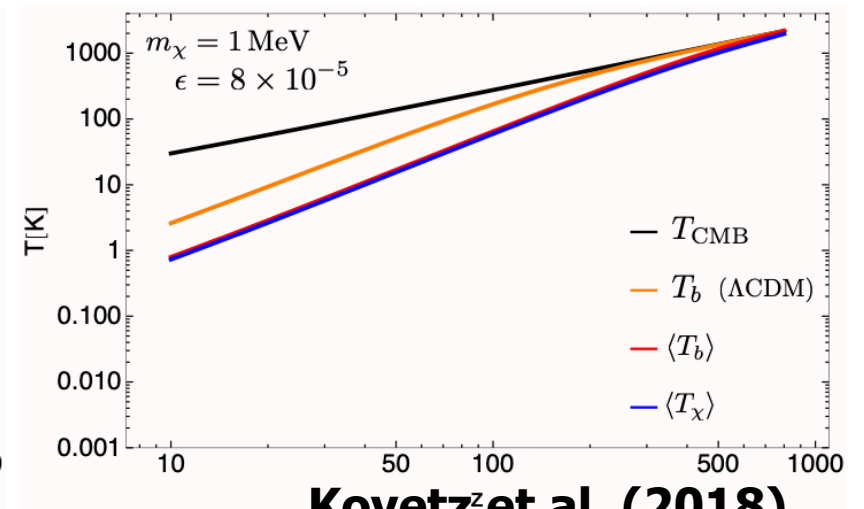
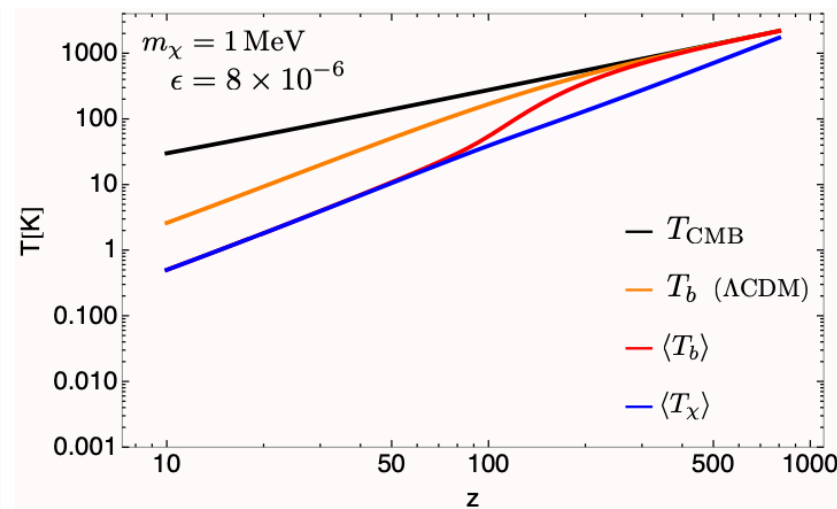
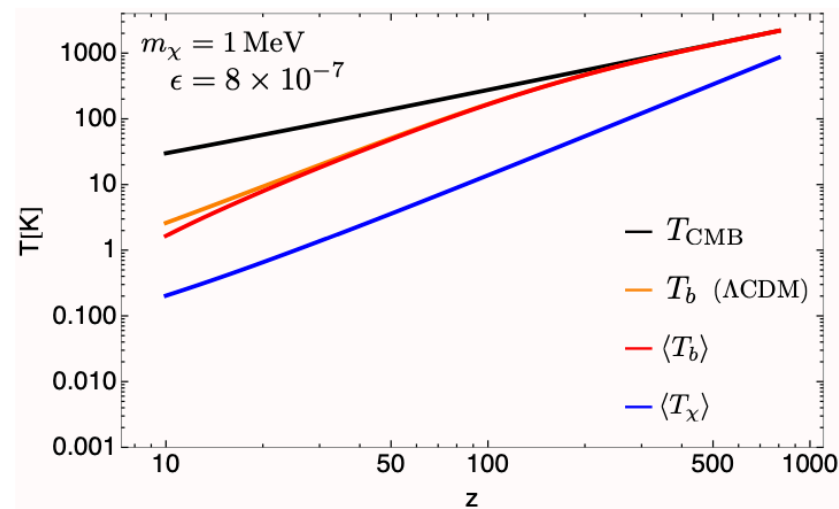
Exotic Cosmology from the Global Signal



Mondal, Fialkov, & Barkana (2024)

- Variety of potential exotic physics explanations with signatures in the Dark Ages...
- Radio background from dark matter decay, primordial black holes, string decay,...

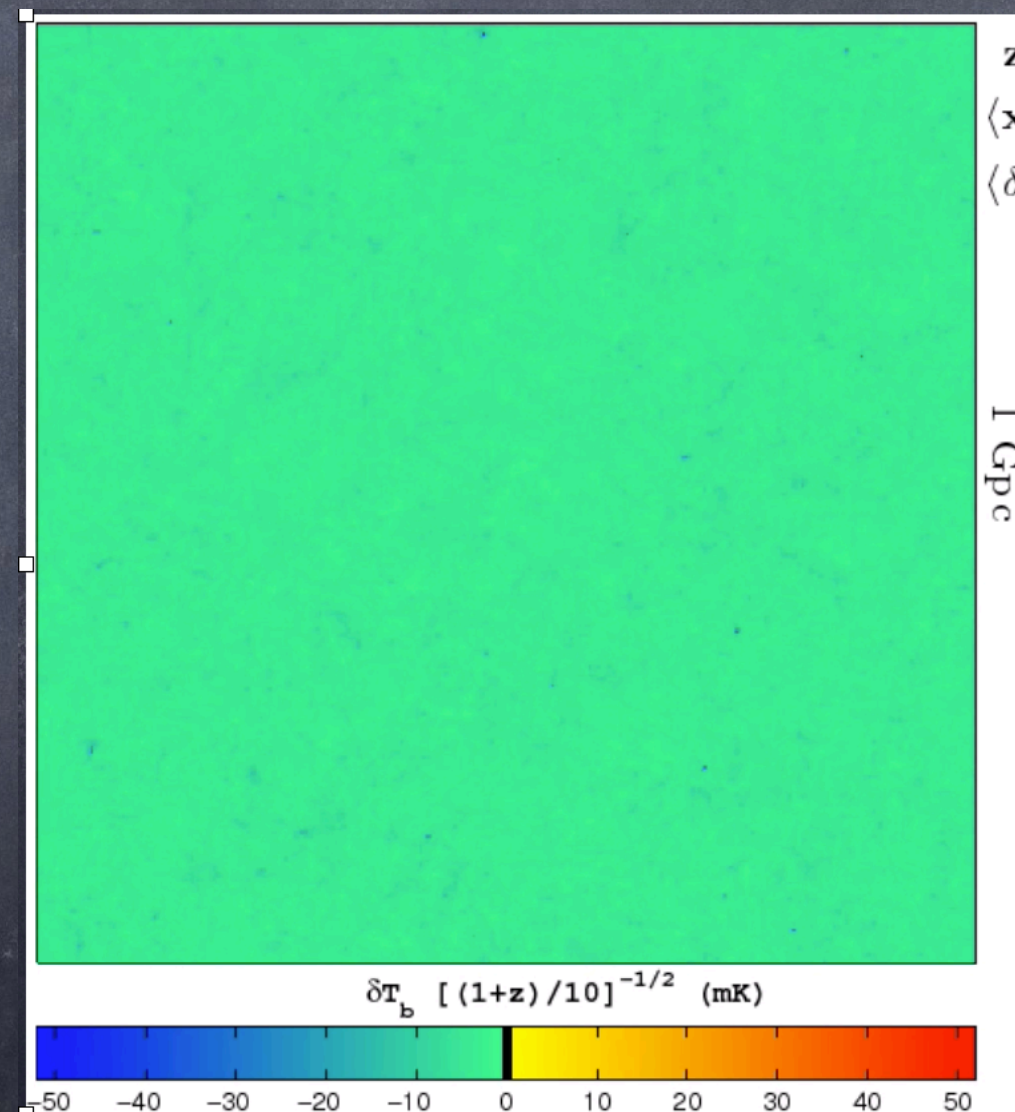
Exotic Cosmology from the Global Signal



Kovetz et al. (2018)

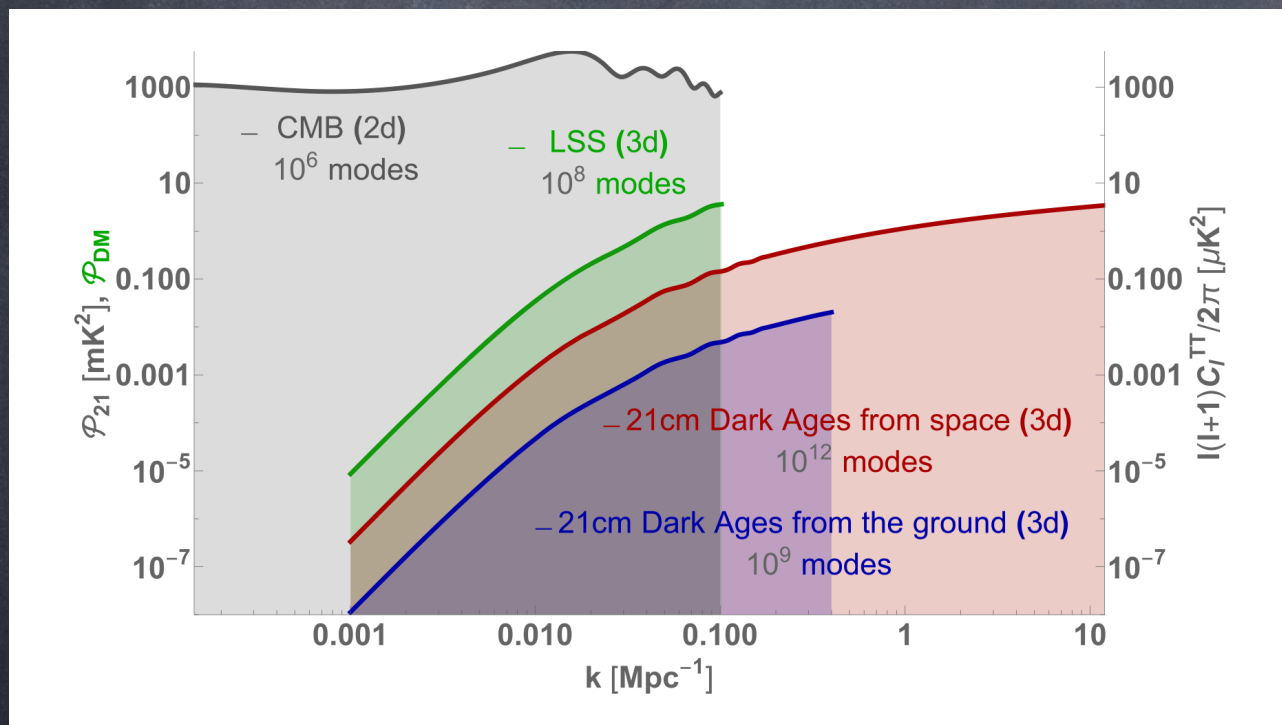
- Variety of potential exotic physics explanations with signatures in the Dark Ages...
 - Radio background from primordial black holes, string decay, ...
 - Dark matter-baryon interactions

21-cm Fluctuations in the Dark Ages



Mesinger, Furlanetto, & Cen (2011)

Fluctuations in the 21-cm Signal: The Power Spectrum

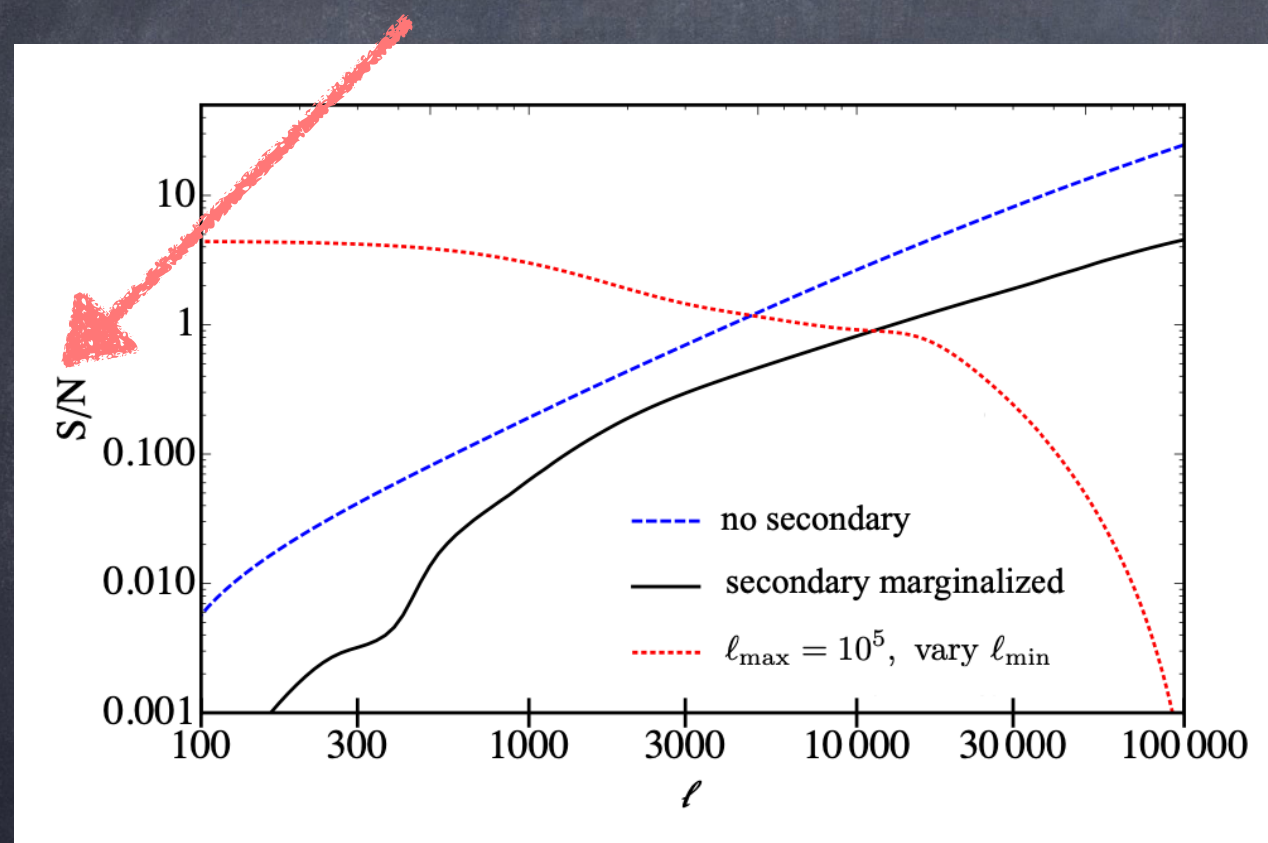


Cole & Silk (2021)

- Two key advantages:
 - Large cosmic volume
 - "Clean" probe of linear physics across many scales
- Allows all the same info as the global signal (but better!)

The Power Spectrum: Non-gaussianity

S/N for $f_{NL}=1$ in single redshift slice



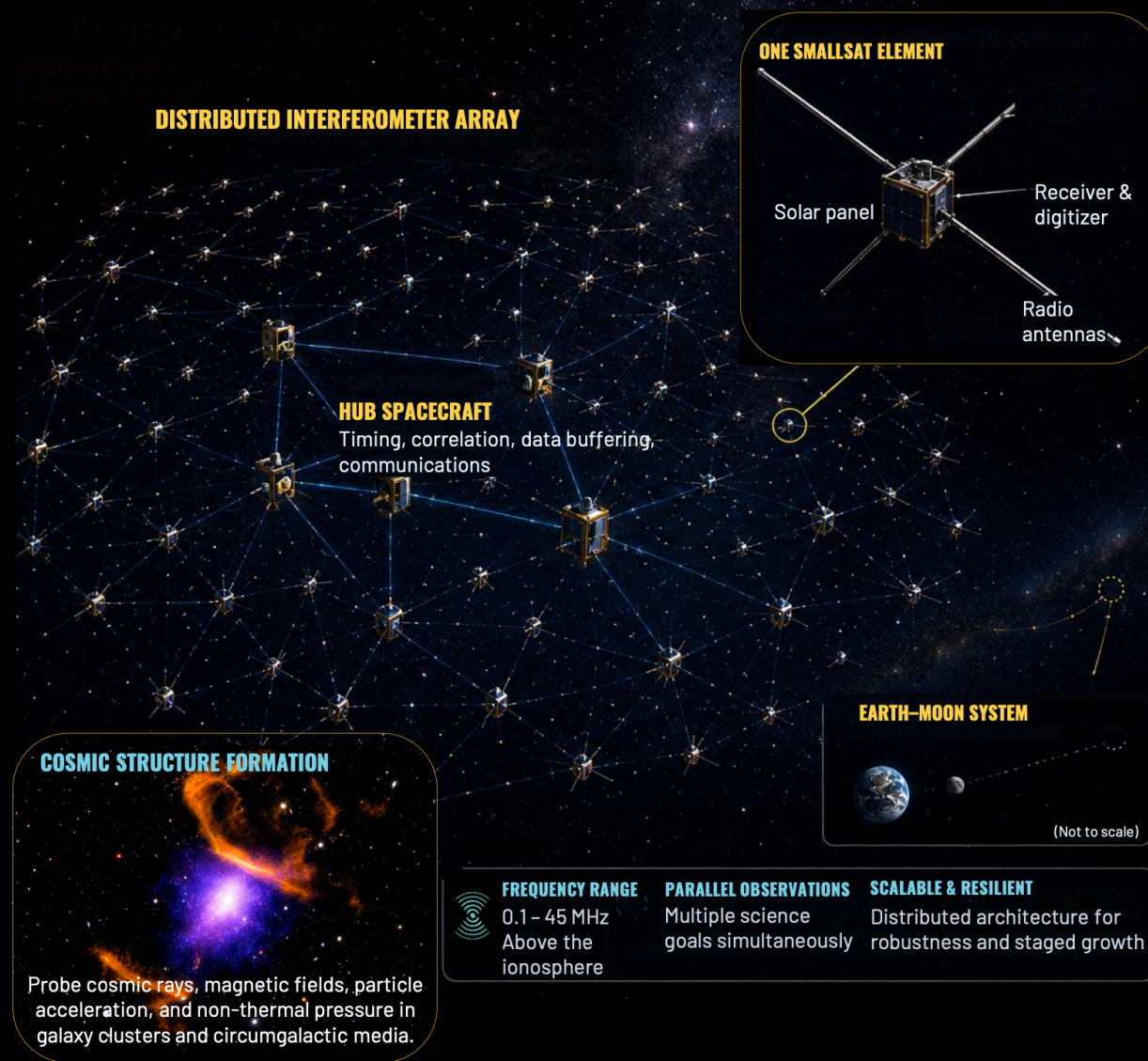
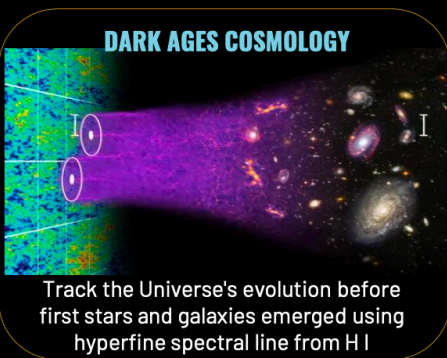
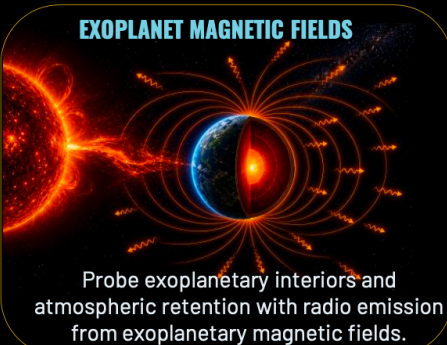
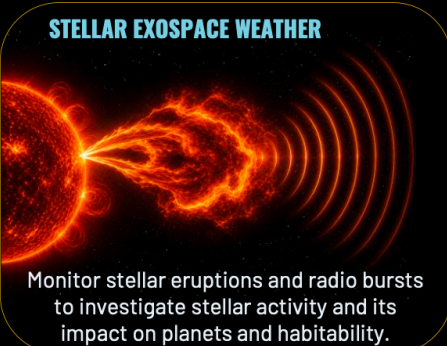
Munoz, Ali-Haimoud, & Kamionkowski (2015)

- Best known probe of primordial non-gaussianity, key test of inflation!
- Typically parameterized by f_{NL} (relative amplitude of three-point function of curvature perturbation)
- In principle, 21-cm Dark Ages can improve CMB by two orders of magnitude and test even most basic inflation models

The MegaWave Radio Surveyor

MEGAWAVE RADIO SURVEYOR

LARGE SATELLITE CONSTELLATION FORMING A SPACE INTERFEROMETER FOR STELLAR AND EXTRAGALACTIC ASTROPHYSICS, EXOPLANETARY SCIENCE, AND COSMOLOGY



see talks by Lazio, Byrne, Jacobs tomorrow!

Summary

- The spin-flip signal is a powerful probe of galaxies (during the Cosmic Dawn) and cosmology (during the Dark Ages)
- The global signal and fluctuations offer unique perspectives on
 - Exotic dark matter
 - The physics of inflation
 - Precision cosmology