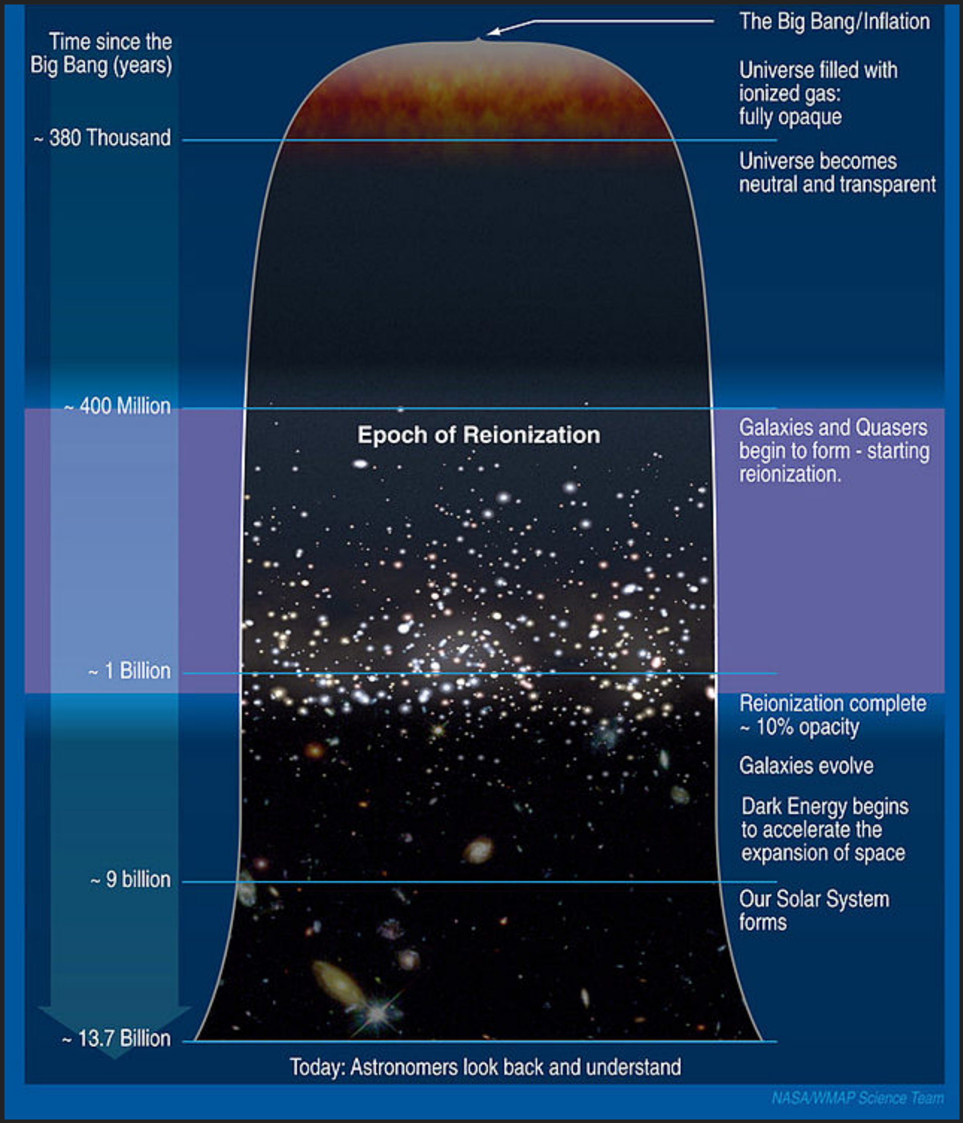
SUVODIP MUKHERJEE

PATCHY REIONIZATION AND CMB B-MODE POLARIZATION

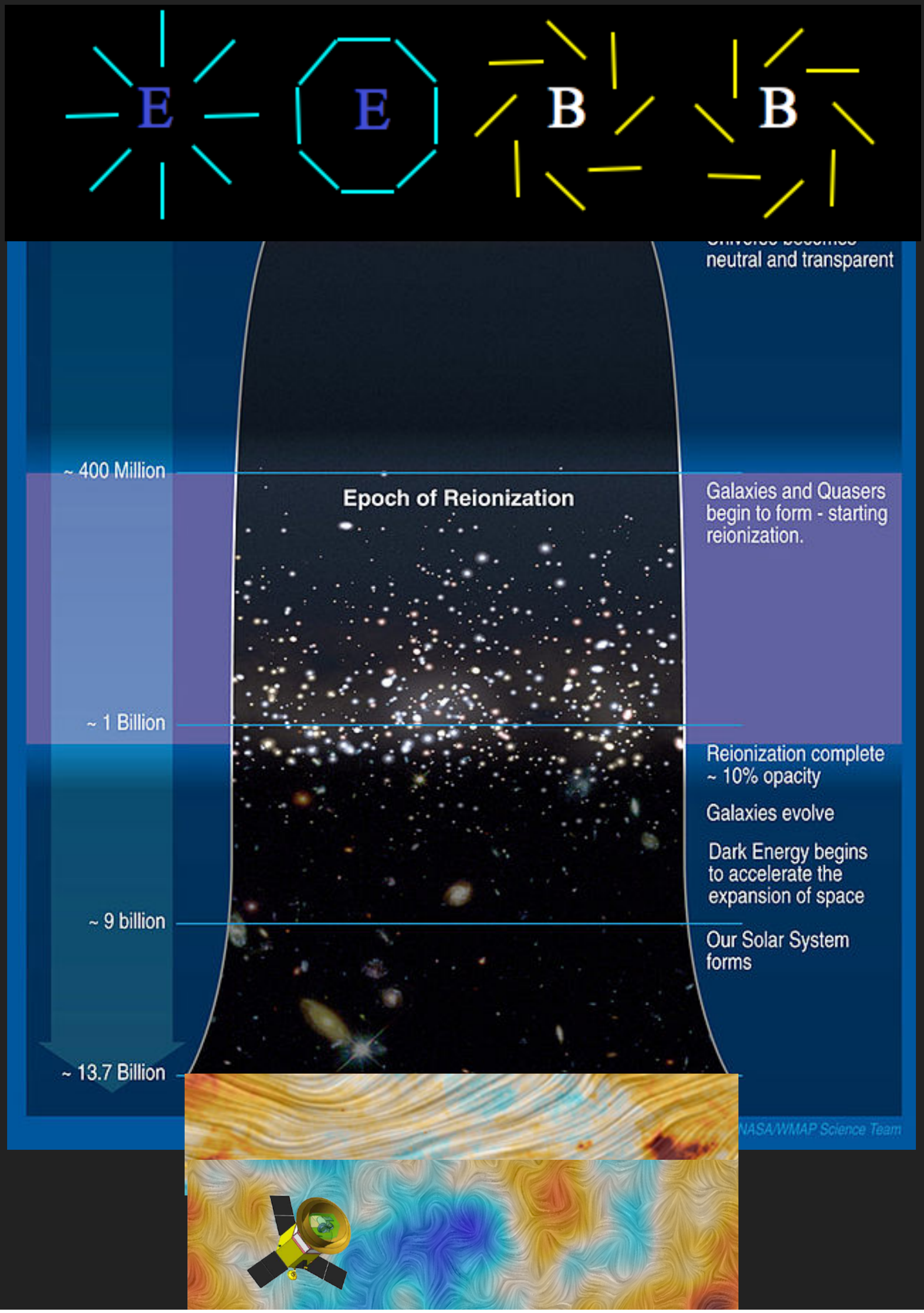
B-mode from Space-2019, MPA, Garching

COSMIC HISTORY-101

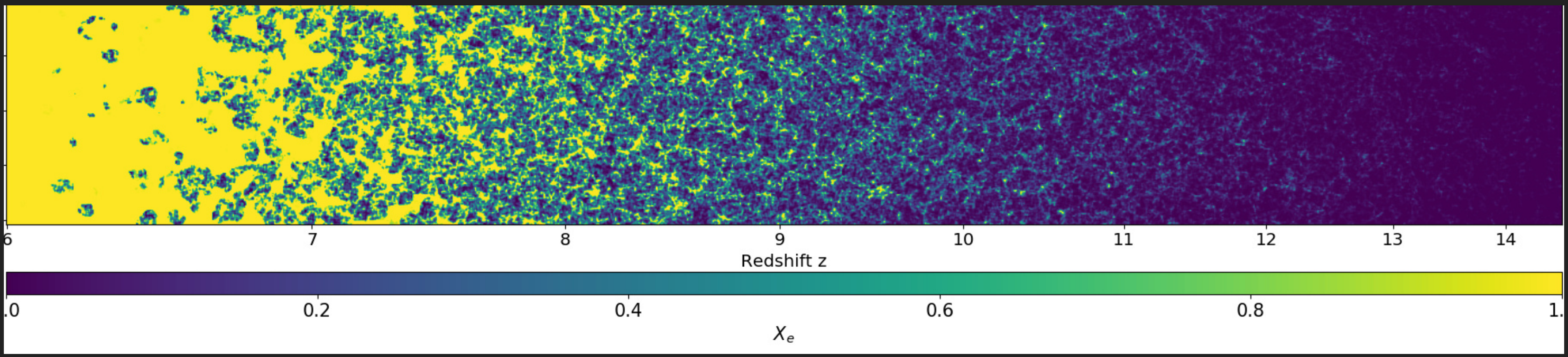


HURDLES TO THE PRIMORDIAL B-MODES

- Instrument noise
- Systematic effects
- Galactic foregrounds
- Extragalactic foregrounds
  - Weak Lensing of CMB polarization
  - Epoch of cosmic reionization

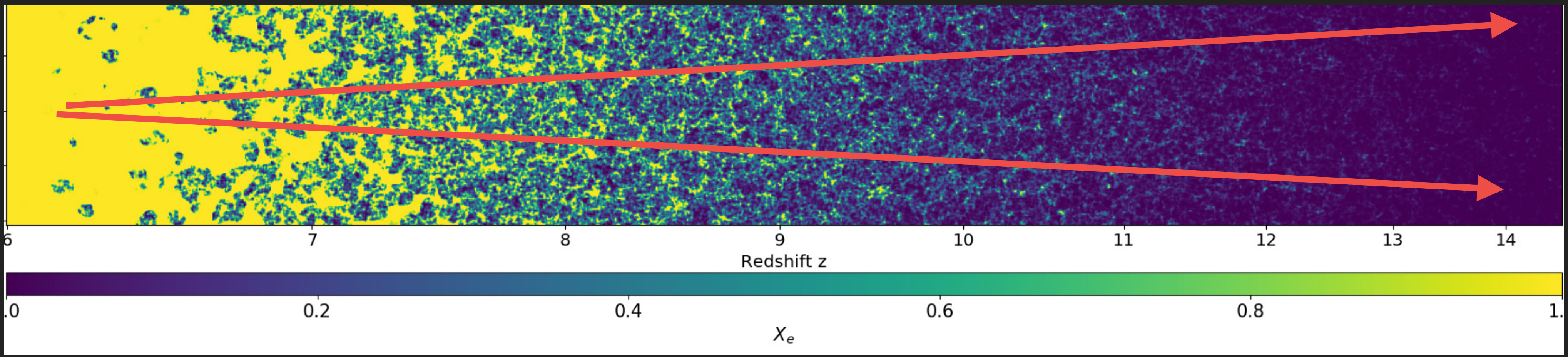


COSMIC REIONIZATION



- When reionization started ?
- When reionization ended ?
- Is it a fast process or a slow process?
- Are they driven by lighter halos or massive halos?
- How much inhomogeneous is the reionization process?

COSMIC REIONIZATION



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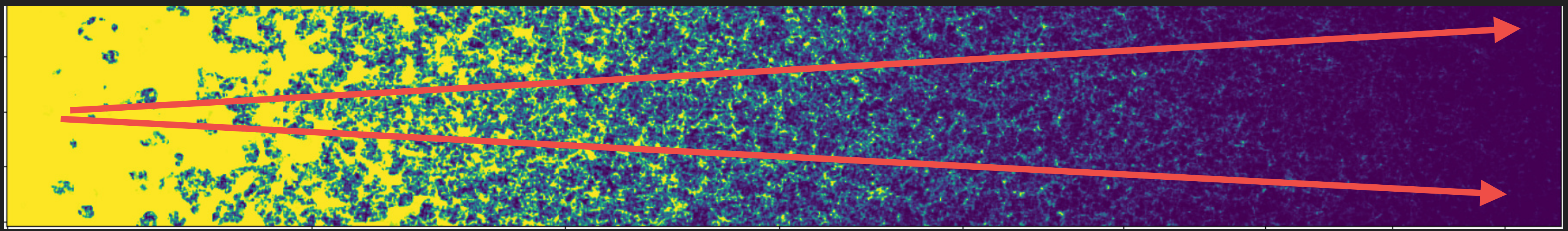
FROM INHOMOGENEOUS DISTRIBUTION OF FREE ELECTRONS TO B-MODE POLARIZATION SIGNAL



Screening: Important at small angular scales

Scattering: Important at large angular scales

Hu (2000), Dvorkin and Smith (2009),

Mortonson and Hu (2010)

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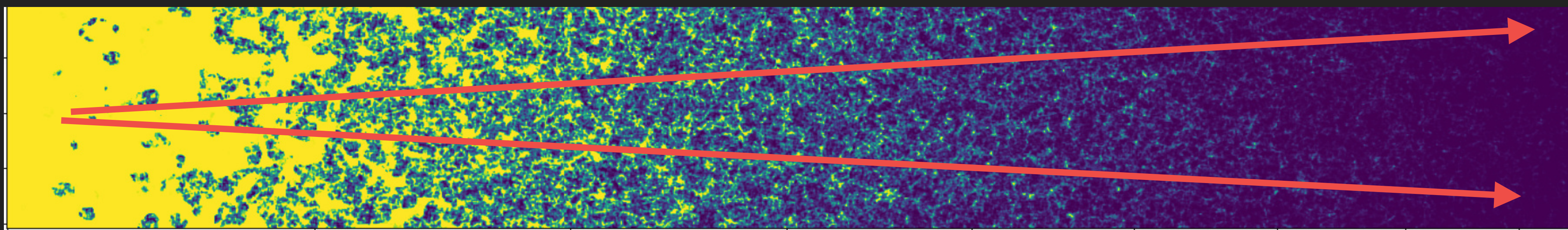
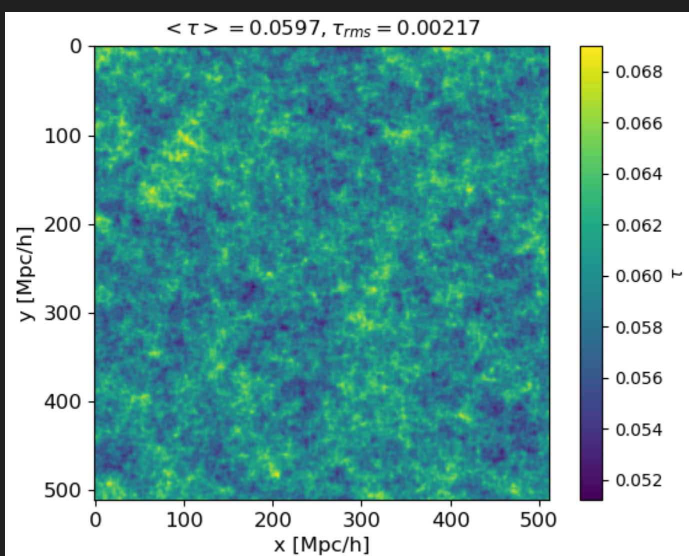
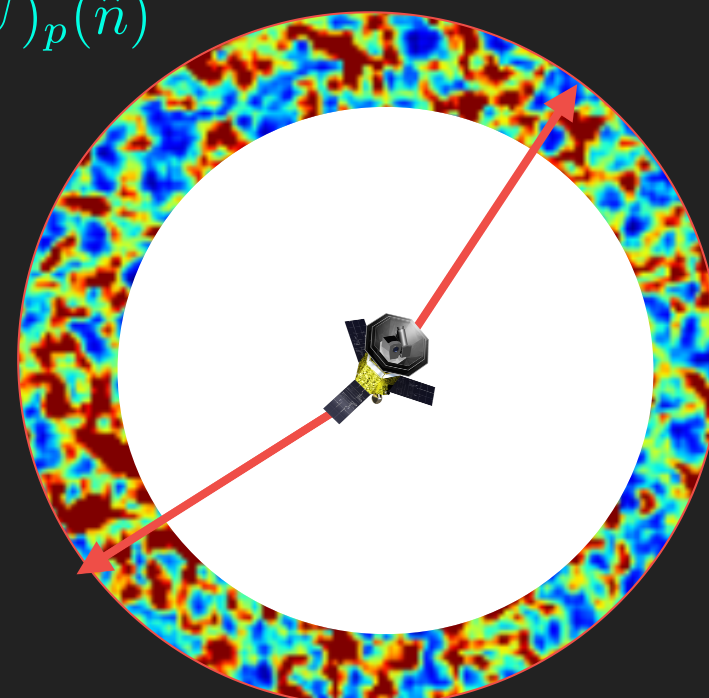


Screening: Important at small angular scales

$$(Q \pm iU)(\hat{n}) = e^{-\tau(\hat{n})}(Q \pm iU)_p(\hat{n})$$





$$C_l^{BB} = e^{-2\bar{\tau}} \int \frac{d^2 l'}{(2\pi)^2} C_{l'}^{EE,p} C_{|l-l'|}^{\tau\tau} \sin^2(2\phi'_l)$$

Dvorkin, Hu and Smith 2009

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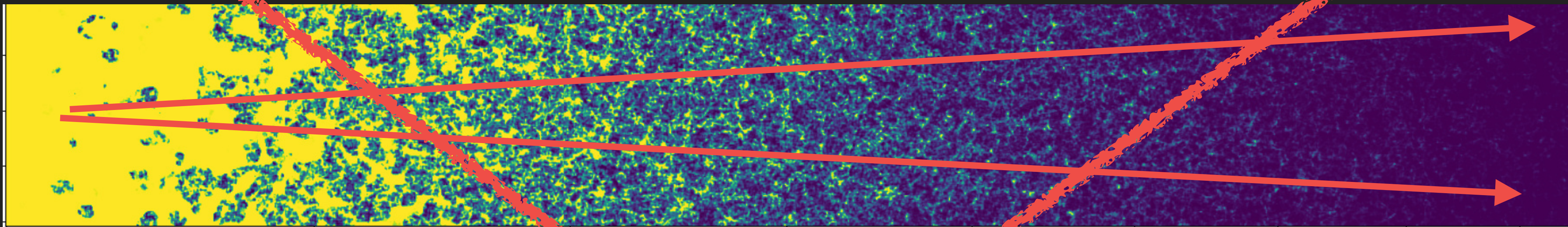

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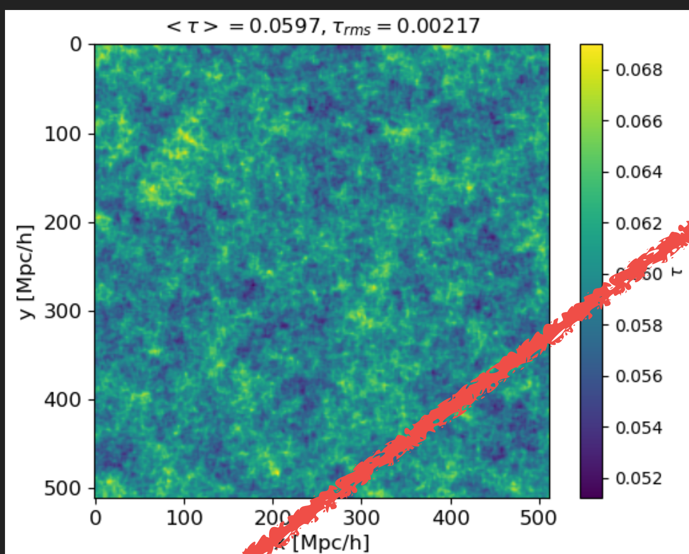

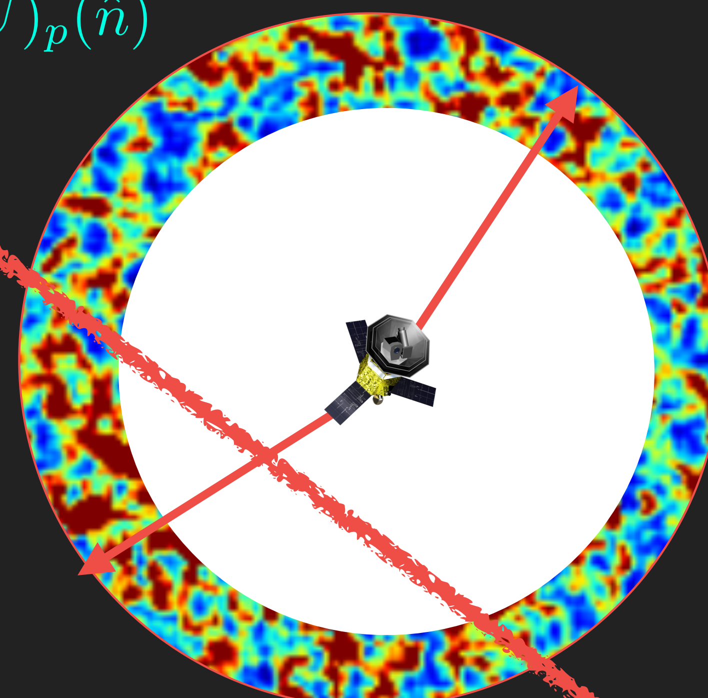

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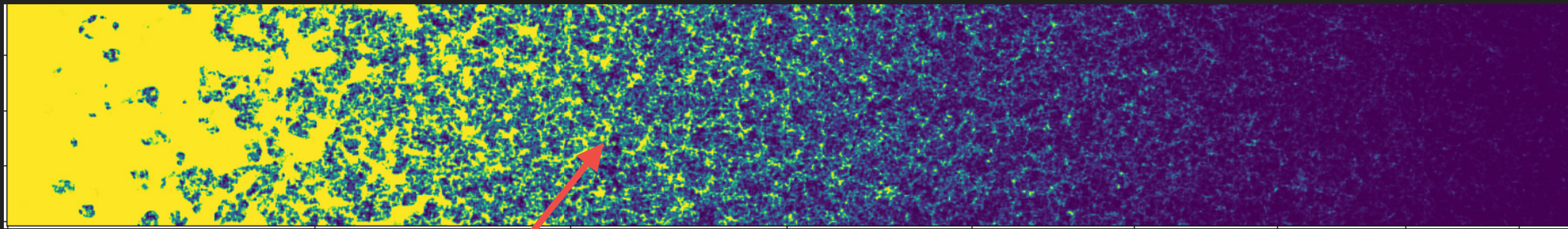

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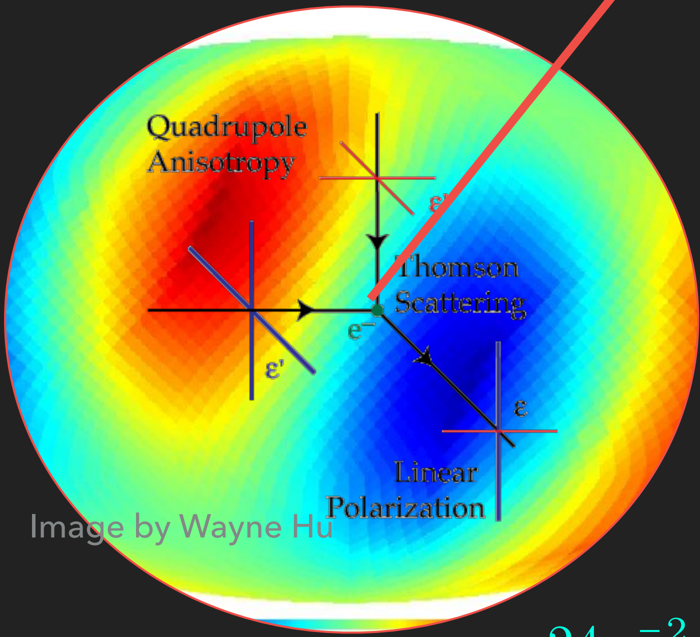
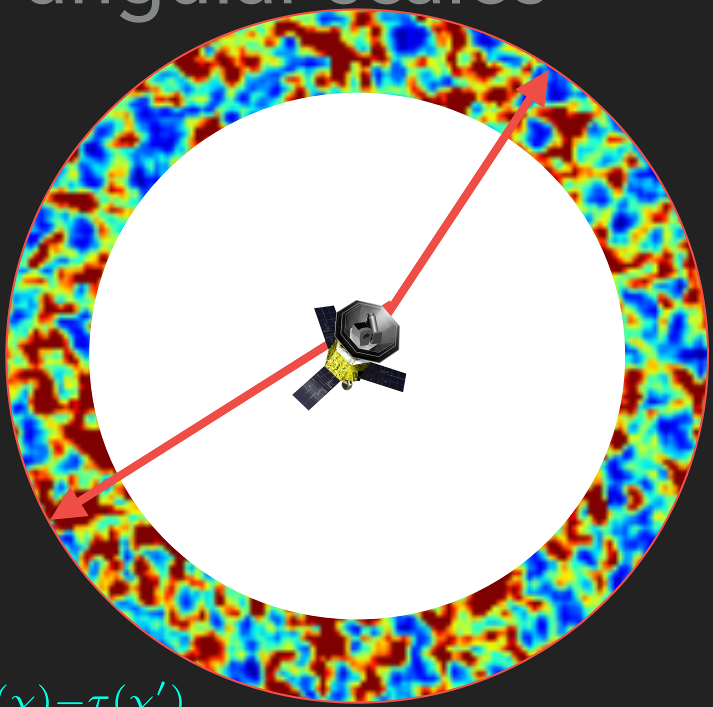


Image by Wayne Hu



$$C_l^{BB} = \frac{24\pi \bar{n}_H^2 \sigma_T^2}{100} \int d\chi \frac{1}{a^2} \int d\chi' \frac{1}{a'^2} e^{-\tau(\chi)-\tau(\chi')}$$

$$\times \int dk \frac{k^2}{2\pi^2} P_{ee}(k,\chi,\chi') j_l(k\chi) j_l(k\chi') \frac{Q_{RMS}^2}{2}$$

Hu (2000), Dvorkin and Smith (2009),

Mortonson and Hu (2010)

COSMIC REIONIZATION HISTORY: NOT KNOWN YET

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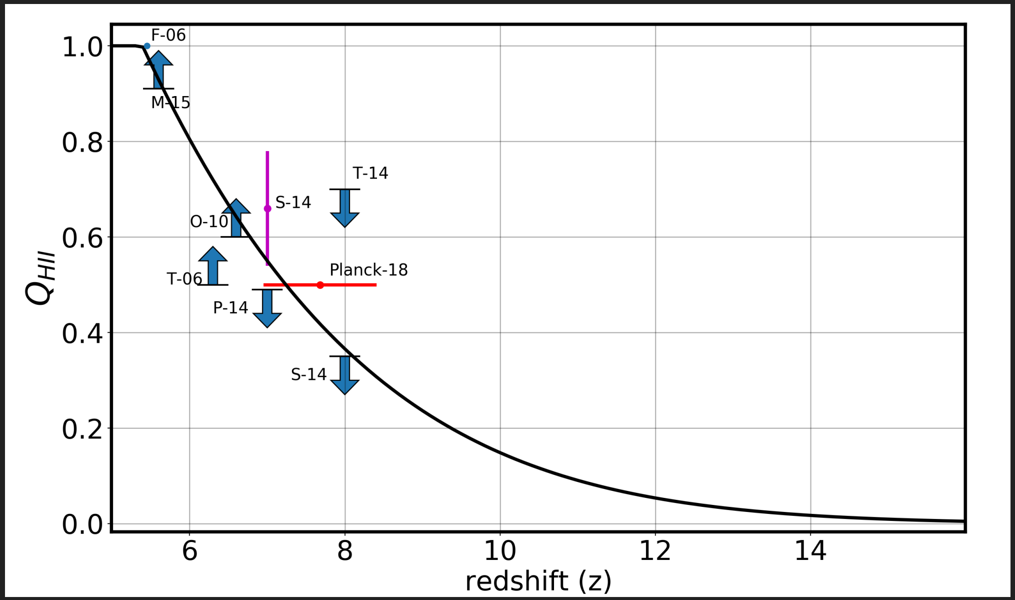
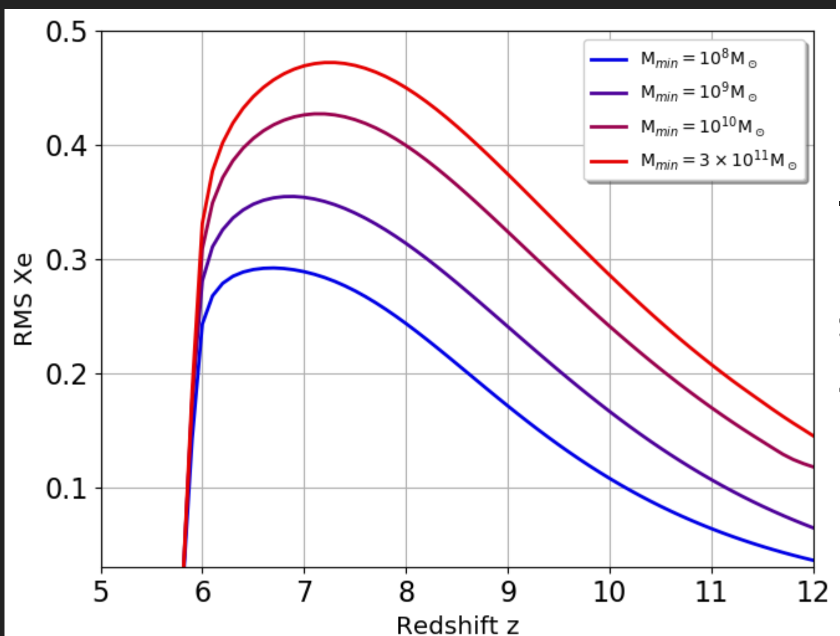
- Quasars probe the reionization history
- CMB constraints from Temperature and E-mode polarization can constrain the optical depth.
- Patchy Kinetic SZ can constrain the width of epoch of reionization

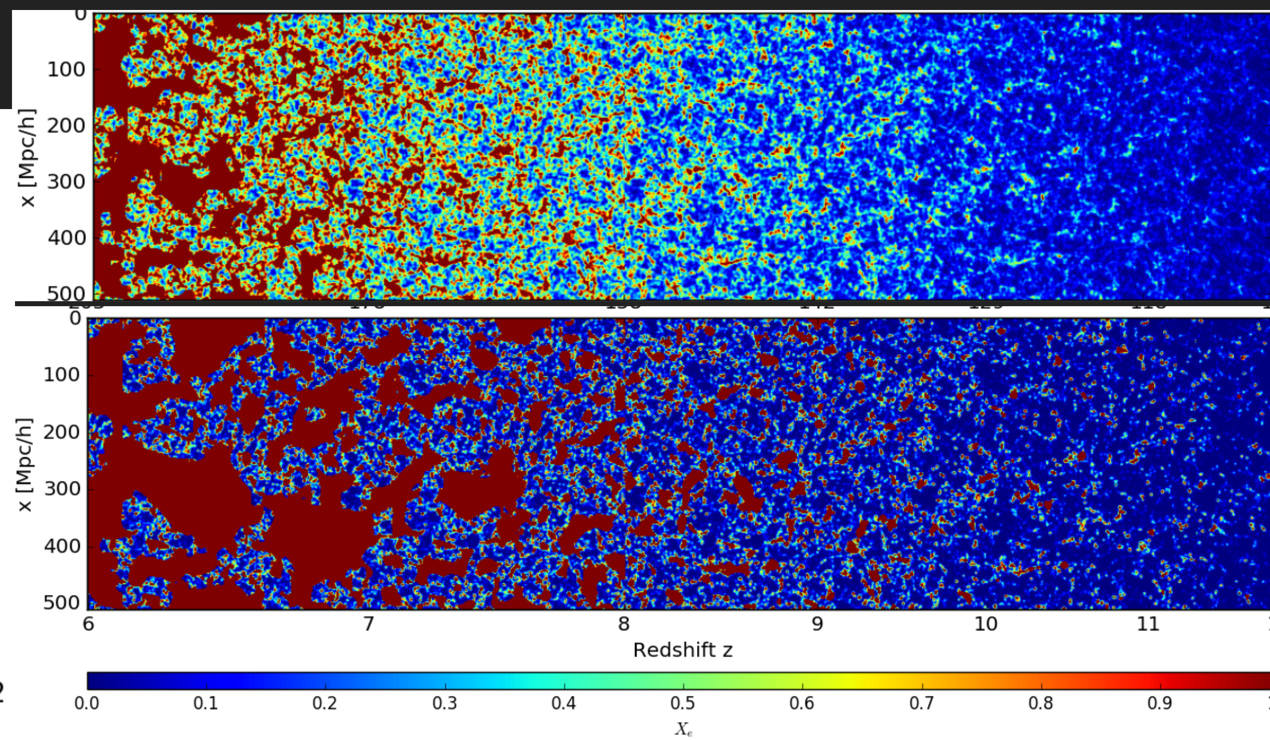


We consider a fixed reionization history and make simulations of cosmic reionization (with MANY assumptions)

FOR A FIXED REIONIZATION HISTORY WITH DIFFERENT HALO MASSES 10^8 TO 10^{11} M_{SUN} DRIVING THE REIONIZATION

For 10^8 M_{sun}





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For 10^{10} M_{sun}

Reionization driven by big halos lead to large bubbles hence large fluctuations

CMB B-MODE POWER SPECTRUM

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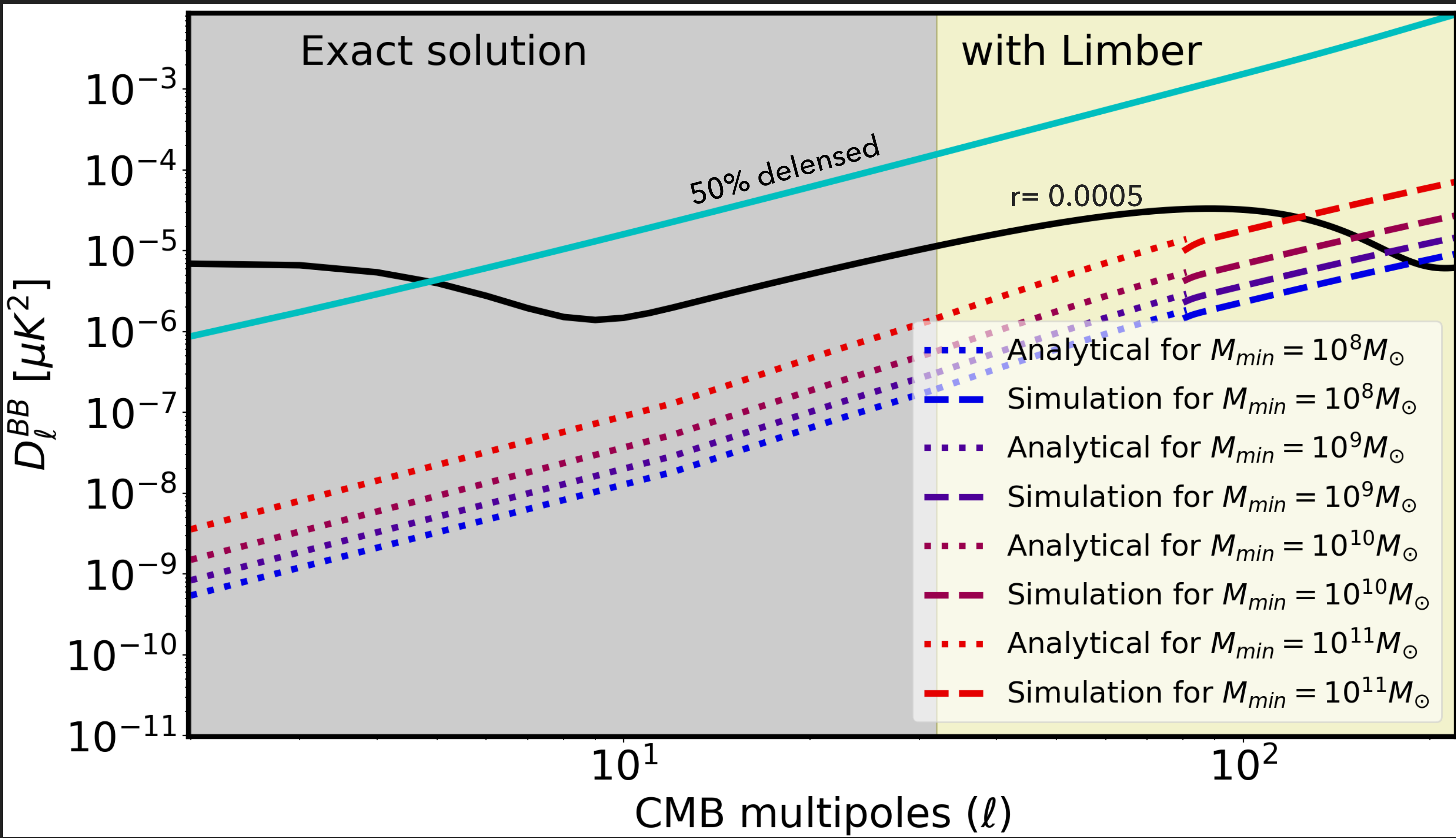
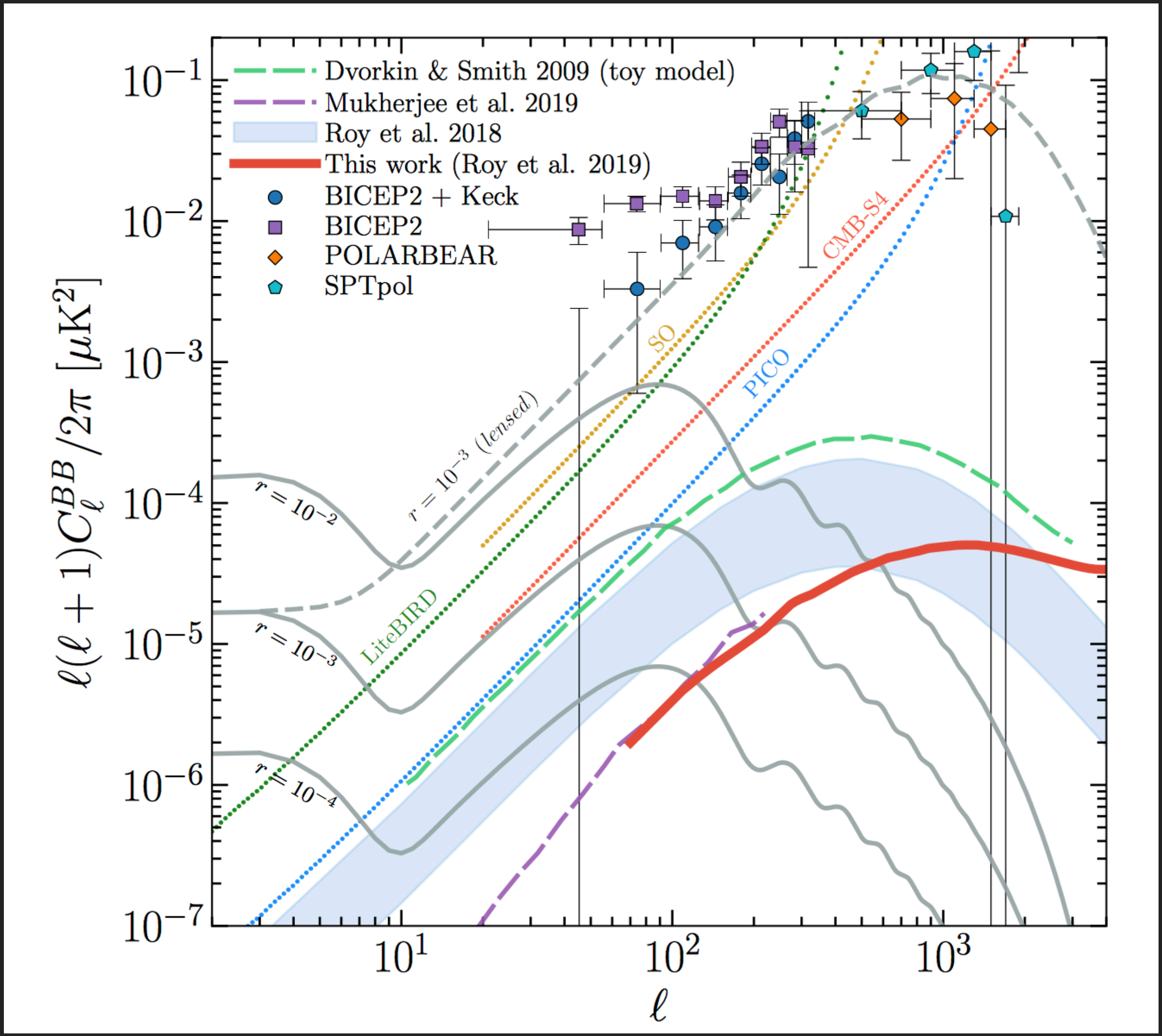
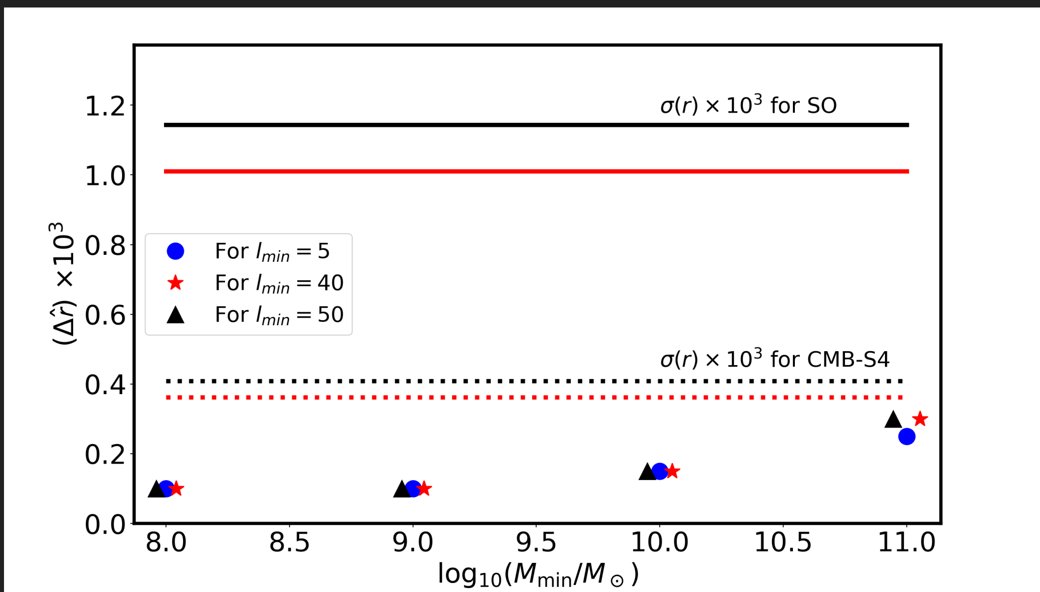


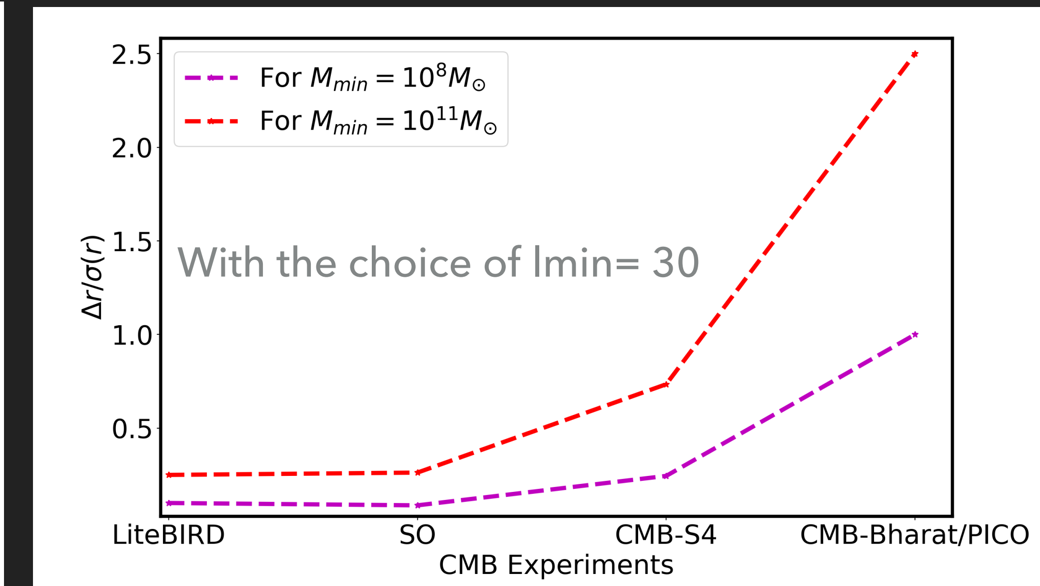
CMB B-MODE POWER SPECTRUM: COMPARISON OF DIFFERENT RESULTS



PhD Thesis, A. Roy (2019)

IMPACT OF THE CONTAMINATION ON TENSOR TO SCALAR RATIO: BIAS





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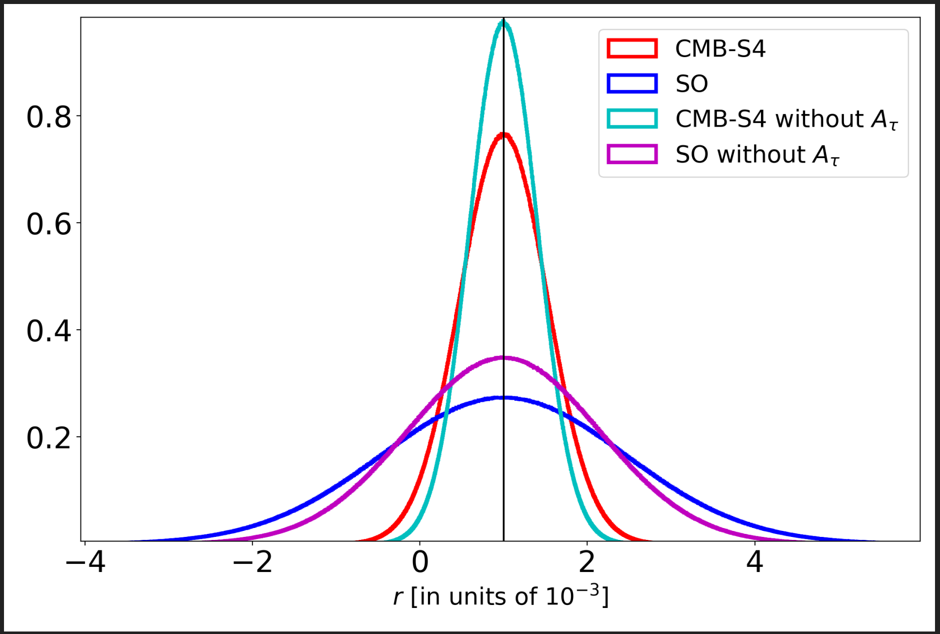
$$-2\mathcal{L} \propto \sum_{l,l'=l_{min}}^{l_{max}} (\tilde{C}_l^{BB} - C_l^{BB})\Sigma_{ll'}^{-1}(\tilde{C}_{l'}^{BB} - C_{l'}^{BB})$$

$$\tilde{C}_l^{BB} = C_l^{BB,prim} + A_\tau C_l^{BB,reion}(M_{min}) + A_{lens} C_l^{BB,lens}$$

$$\Sigma_{ll'} = \frac{2}{f_{sky}(2l+1)} \left(\tilde{C}_l^{BB} + N_l\right)^2 \delta_{ll'}$$

IMPACT OF THE CONTAMINATION ON TENSOR TO SCALAR RATIO: ERROR-BAR

- Reionization driven by larger halos creates more bias in the value of tensor to scalar ratio.
- The shape of the power spectrum of B-mode signal from primordial GW and patchy reionization differs and can be distinguished.



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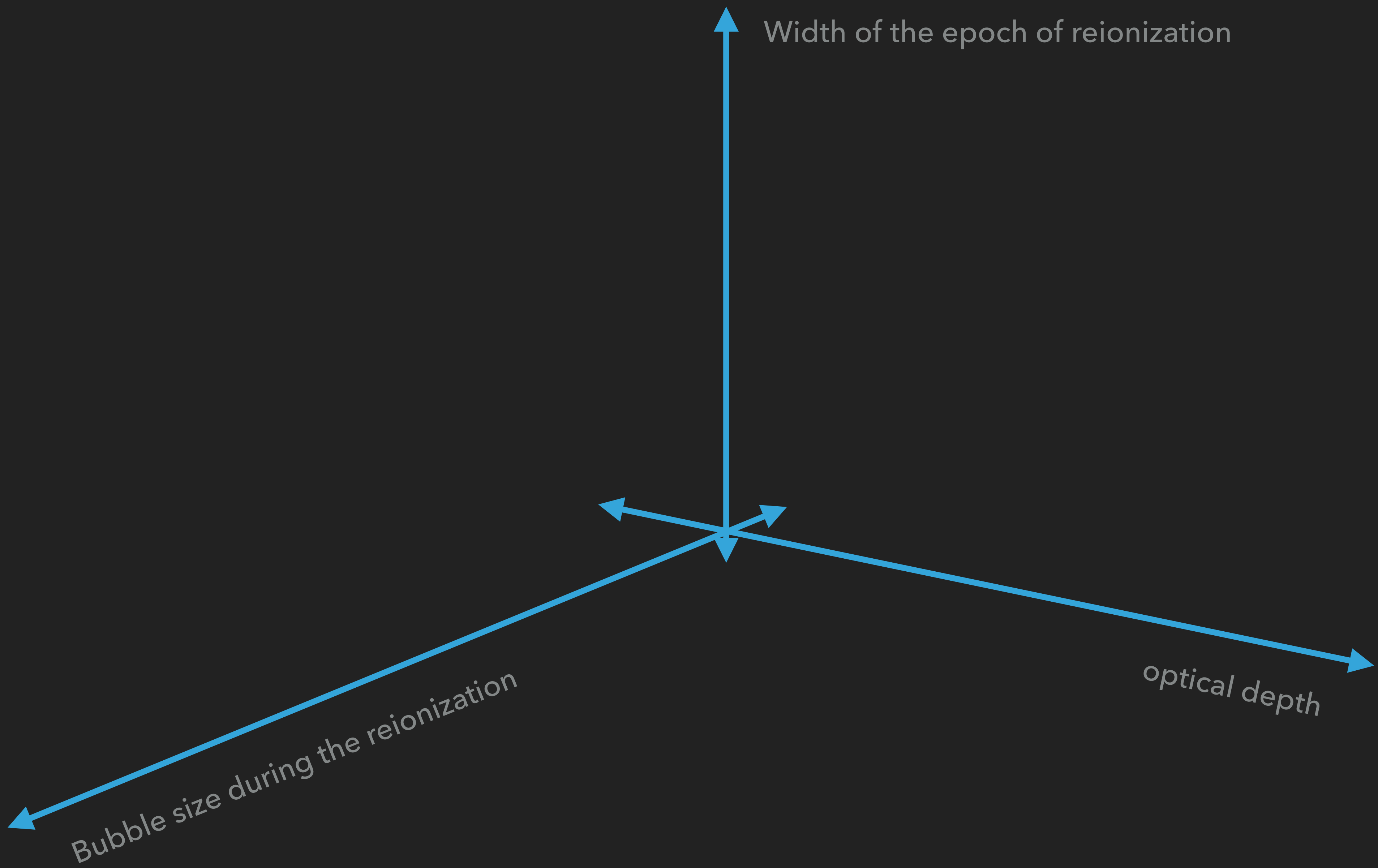
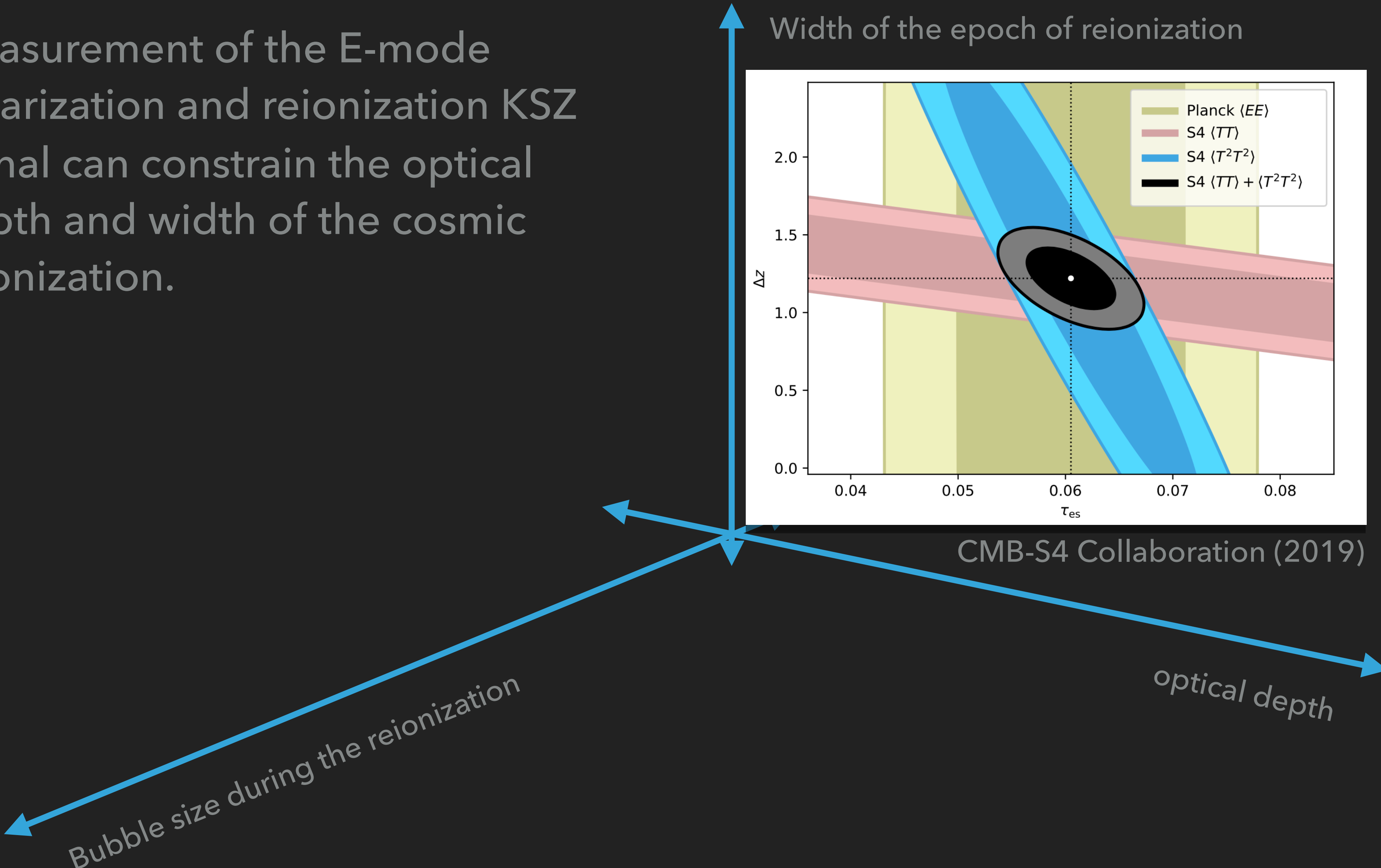
COMBINING DIFFERENT PROBES TO UNDERSTAND COSMIC REIONIZATION



COMBINING DIFFERENT PROBES TO UNDERSTAND COSMIC REIONIZATION

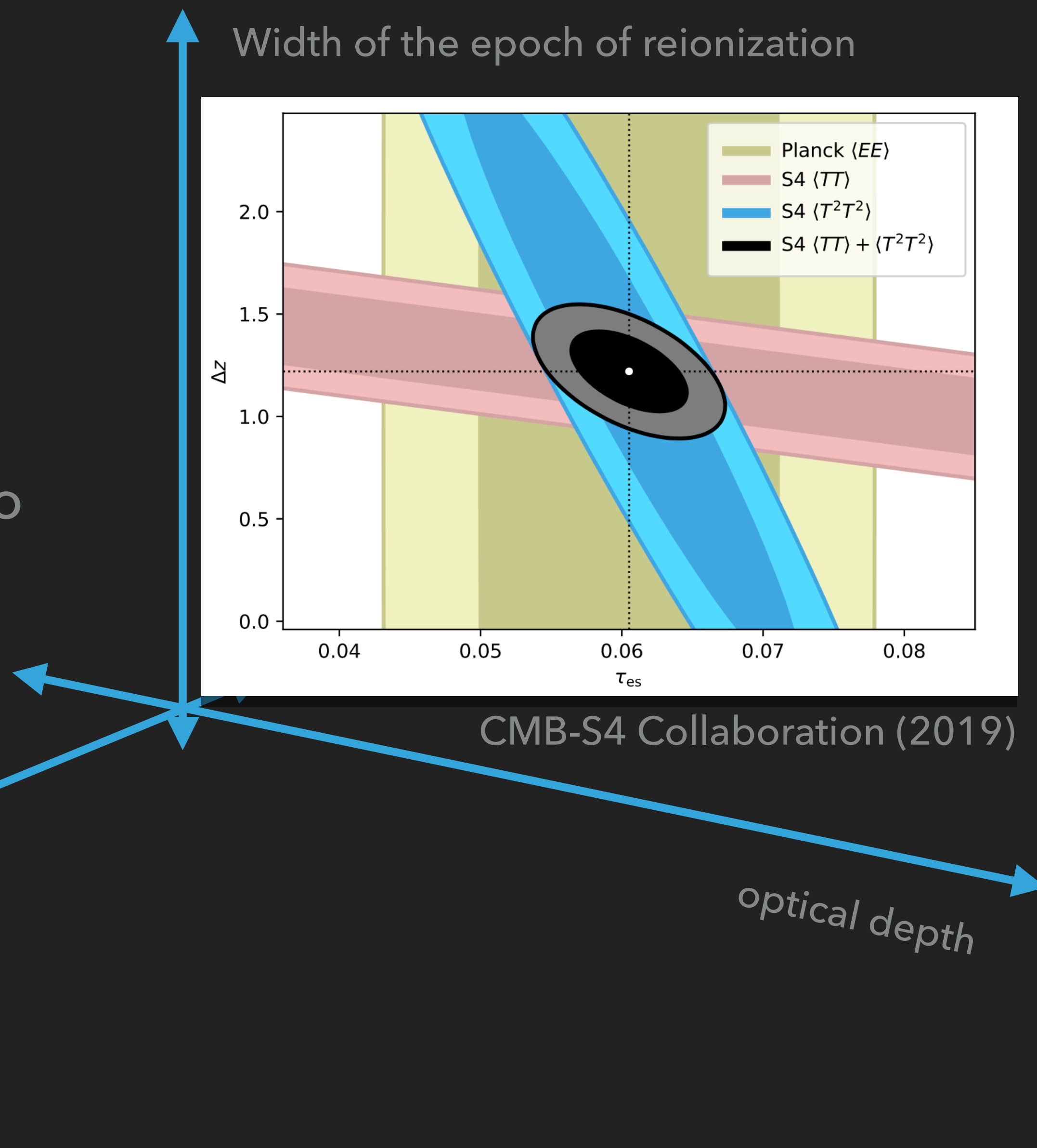
- Measurement of the E-mode polarization and reionization KSZ signal can constrain the optical depth and width of the cosmic reionization.



CMB-S4 Collaboration (2019)

COMBINING DIFFERENT PROBES TO UNDERSTAND COSMIC REIONIZATION

- Measurement of the E-mode polarization and reionization KSZ signal can constrain the optical depth and width of the cosmic reionization.
- Use KSZ-21 cm cross-correlation to probe the bubble size during the epoch of cosmic reionization.



CMB-S4 Collaboration (2019)

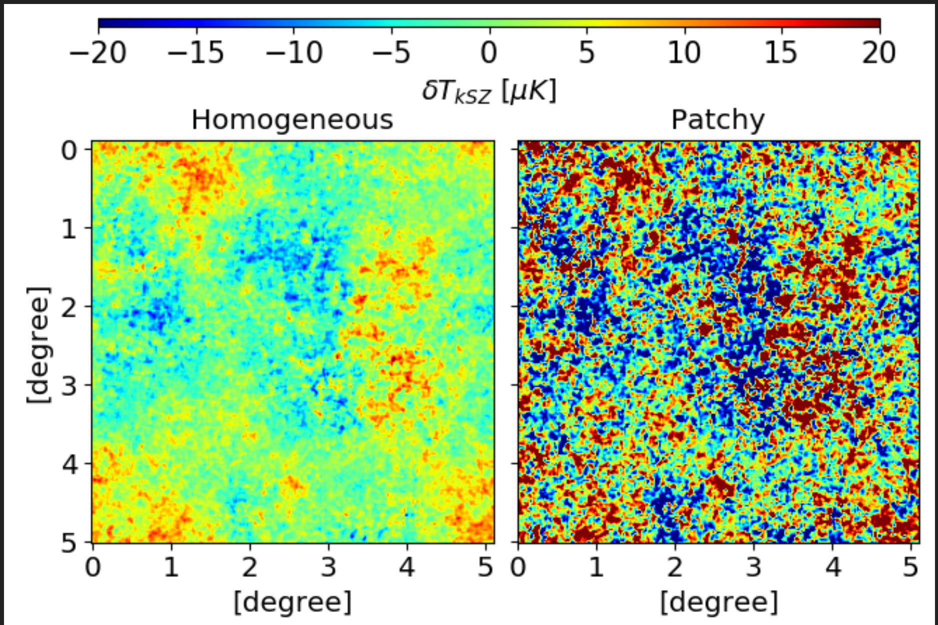
KSZ X 21 CM : PROBE TO THE BUBBLE SIZE

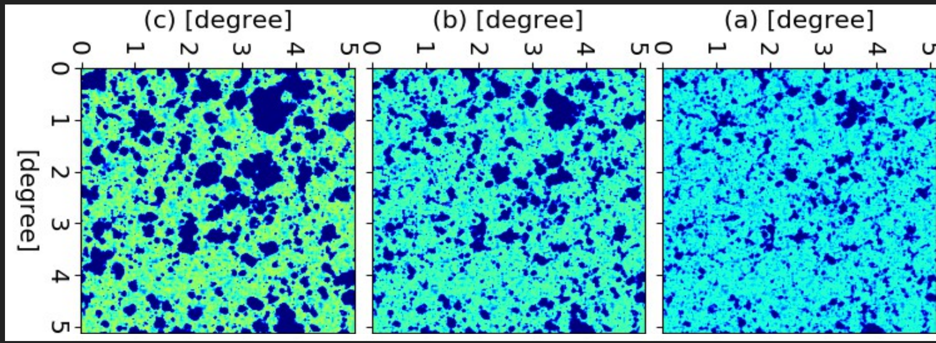
$$\frac{\Delta T(\hat{n})}{T_0} = -\frac{\sigma_T \bar{n}_{e,0}}{c} \int \frac{d\chi}{a^2} e^{-\tau} \mathbf{q}\cdot\hat{n}$$

$$\mathbf{q} = x_e(1+\delta)\mathbf{v}$$

$$\delta T_b(\mathbf{x}, z) = 27\, x_{\rm HI}(\mathbf{x}, z)[1+\delta(\mathbf{x}, z)] \left(\frac{\Omega_B h^2}{0.023}\right) \times \left(\frac{0.15}{\Omega_m h^2}\frac{1+z}{10}\right)^{1/2} \left(1 - \frac{T_\gamma}{T_S}\right) \mathrm{mK}$$

Realizations from the same initial conditions

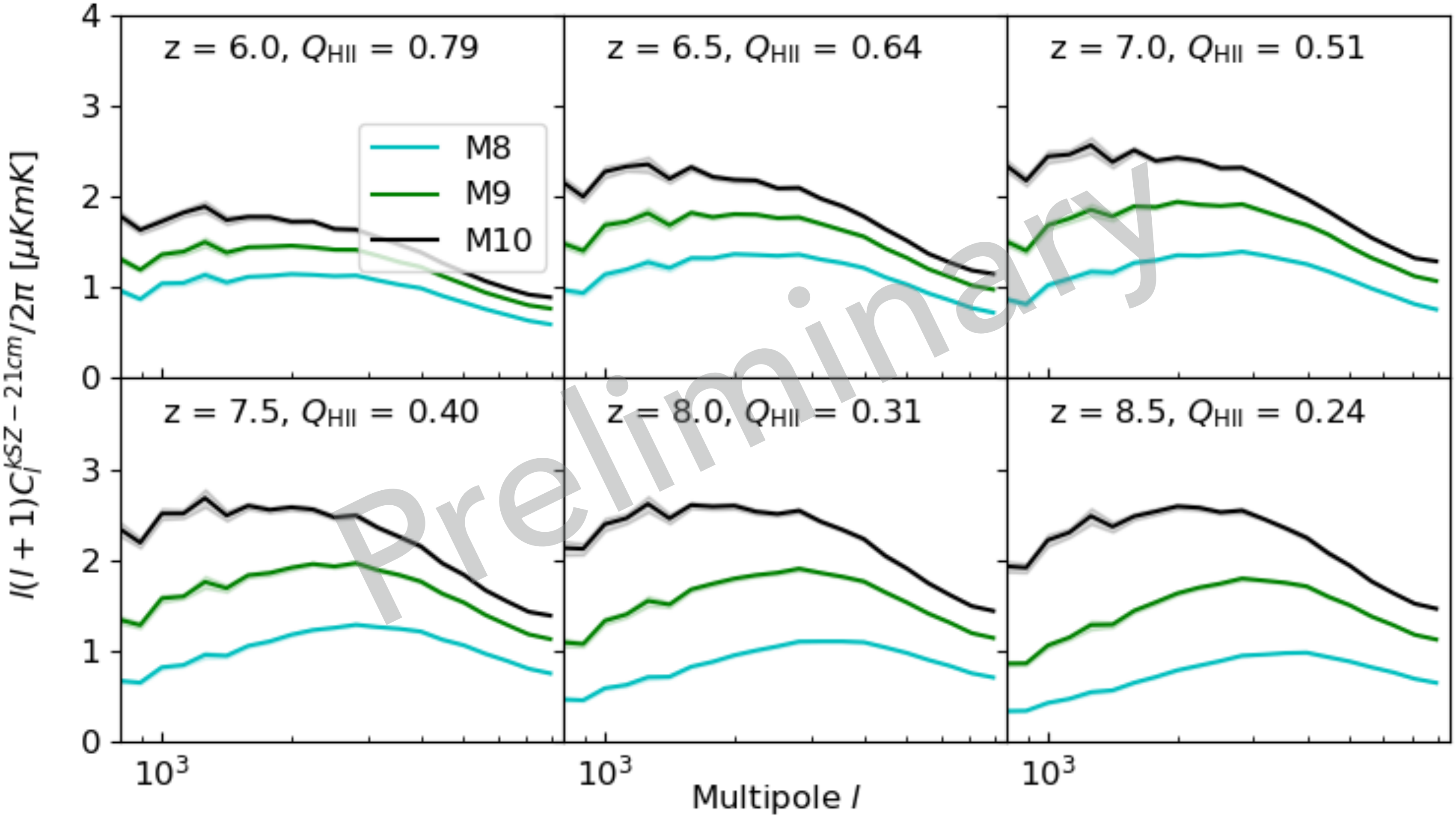




10^{10} M_{sun} 10^{9} M_{sun} 10^{8} M_{sun}

(Under Preparation)

KSZ X 21 CM : PROBE TO THE BUBBLE SIZE



(Under Preparation)

COMBINING DIFFERENT PROBES TO UNDERSTAND COSMIC REIONIZATION

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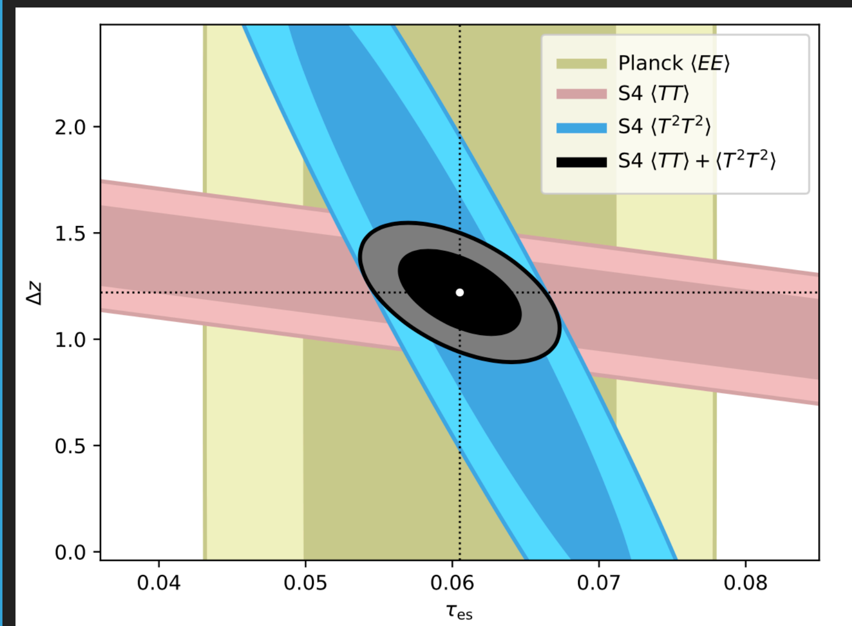
Width of reionization



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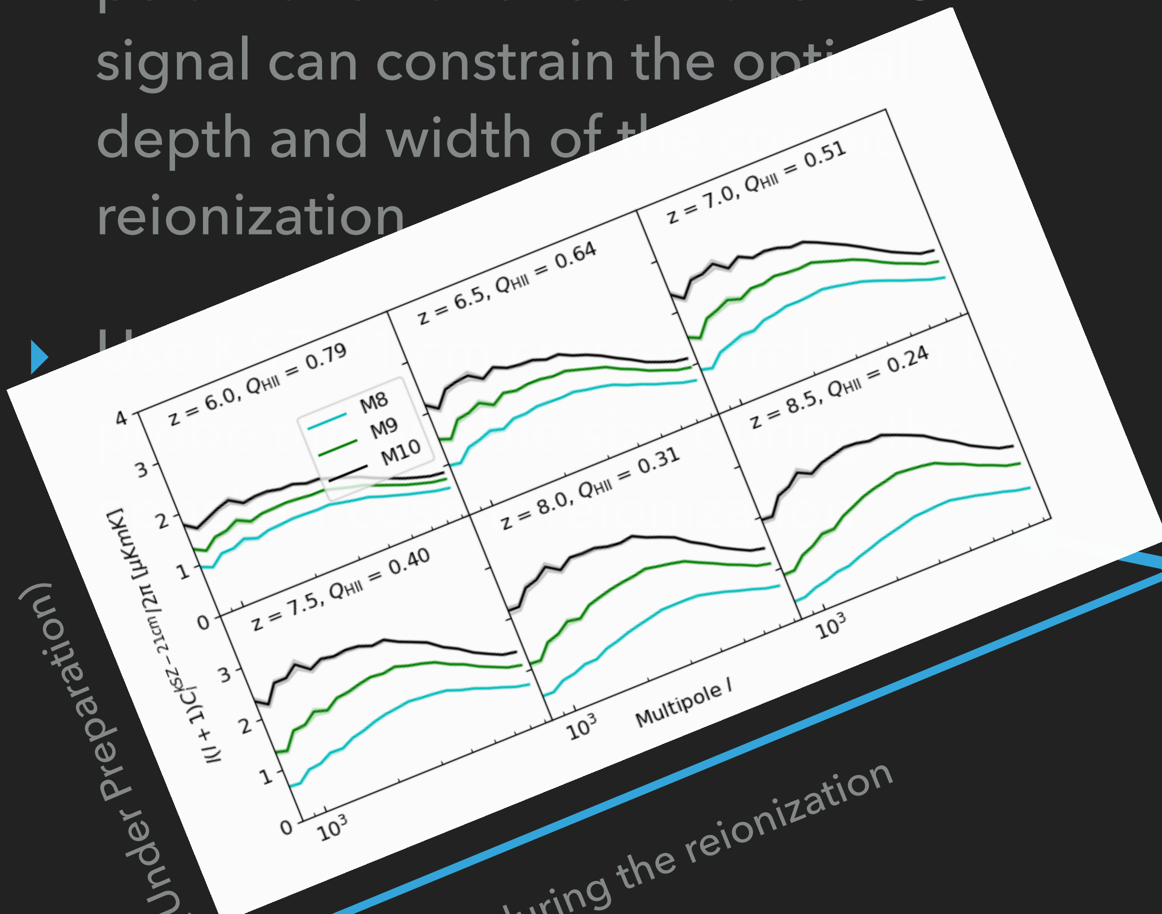
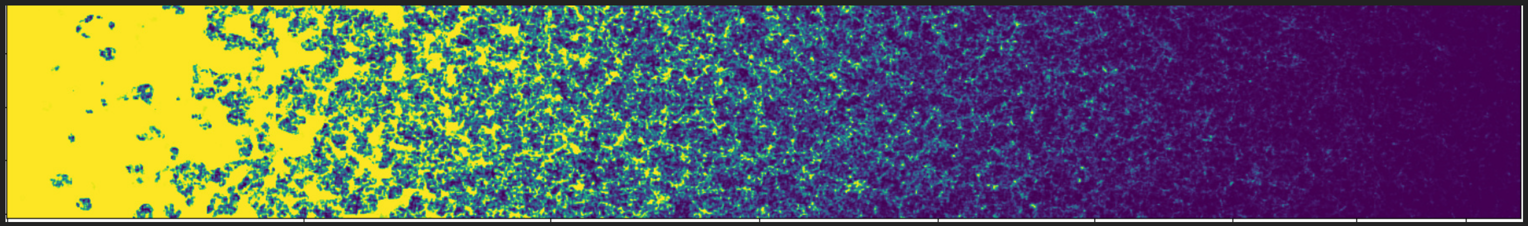


(Under Preparation)

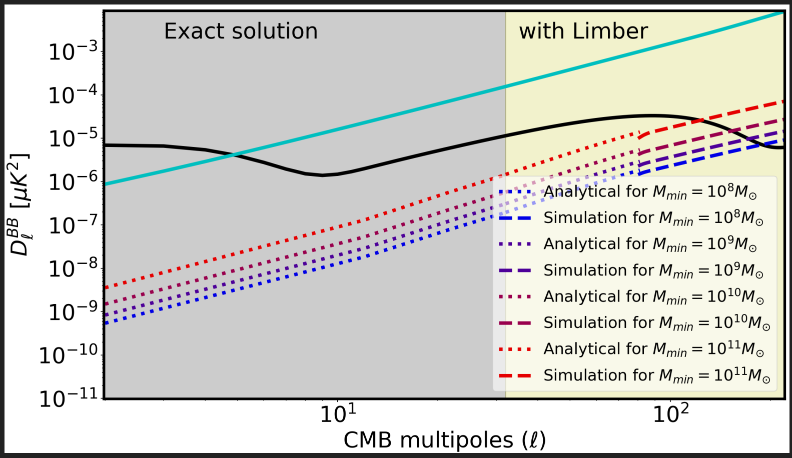
optical depth

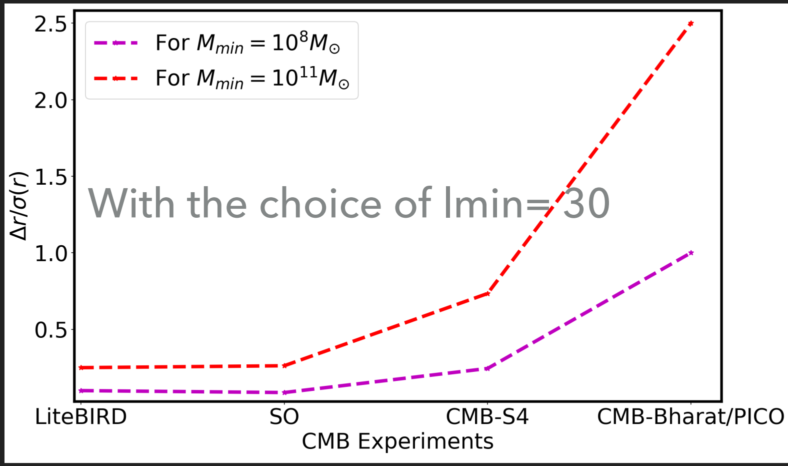
Bubble size during the reionization



CONCLUSIONS

- Reionization driven by massive halos causes larger fluctuations in the electron density.
- Larger fluctuations in the electron density leads to secondary B-mode polarization.
- B-mode signal from reionization differs from the PGW in the spatial domain and can be separated.





PATCHY REIONIZATION IS NOT A SHOW-STOPPER TO DISCOVER PGW SIGNAL WHICH ARE ACCESSIBLE FROM THE UPCOMING CMB MISSIONS

MORE SLIDES FOR ENTHUSIASTIC AUDIENCE

CHARACTERISTIC BUBBLE SIZE AT Z=8

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