CONSTRAINING REIONIZATION PARAMETERS

Cosmology From Home conference

Margaret Ikape

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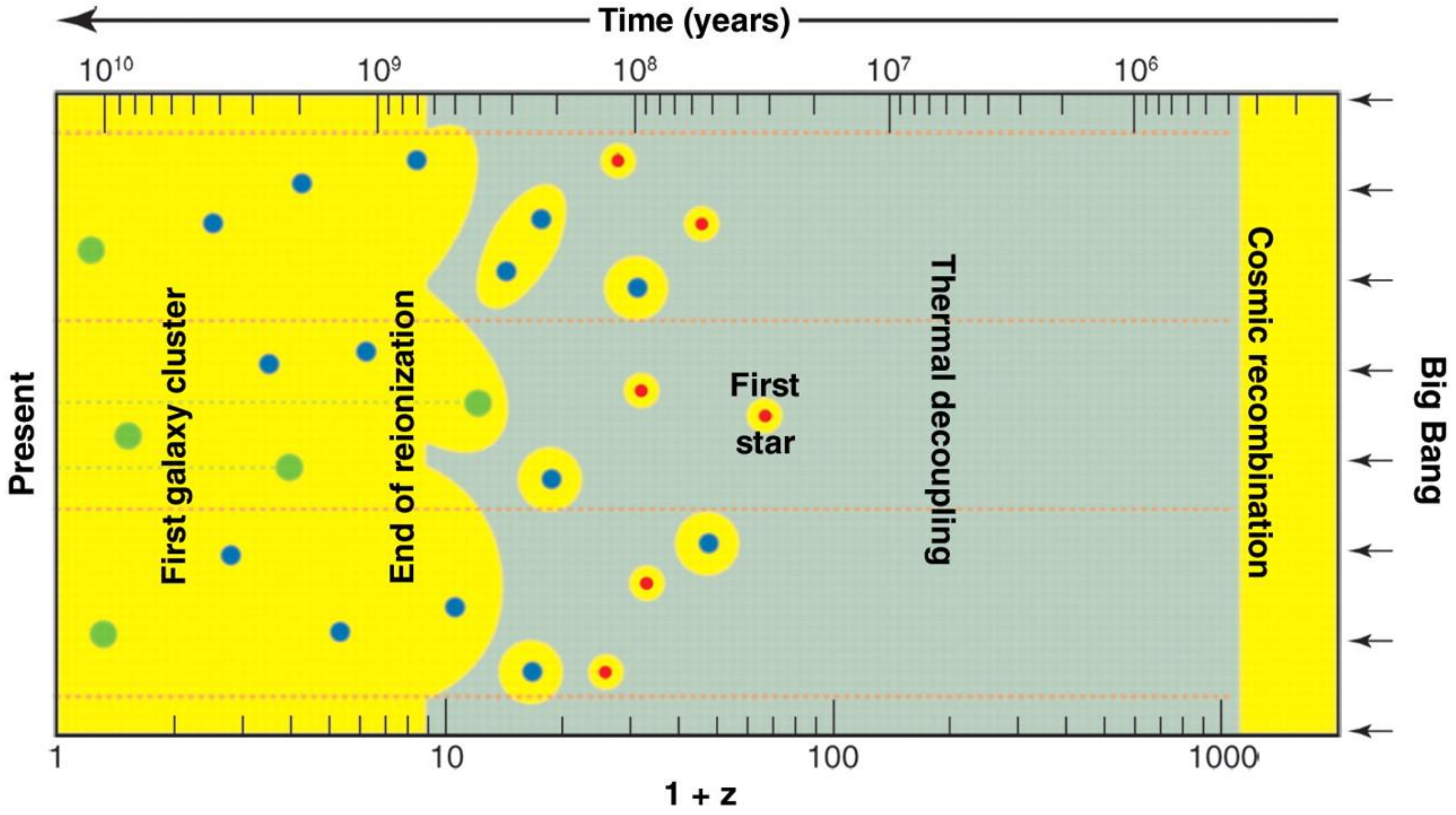
Constraining reionization parameters



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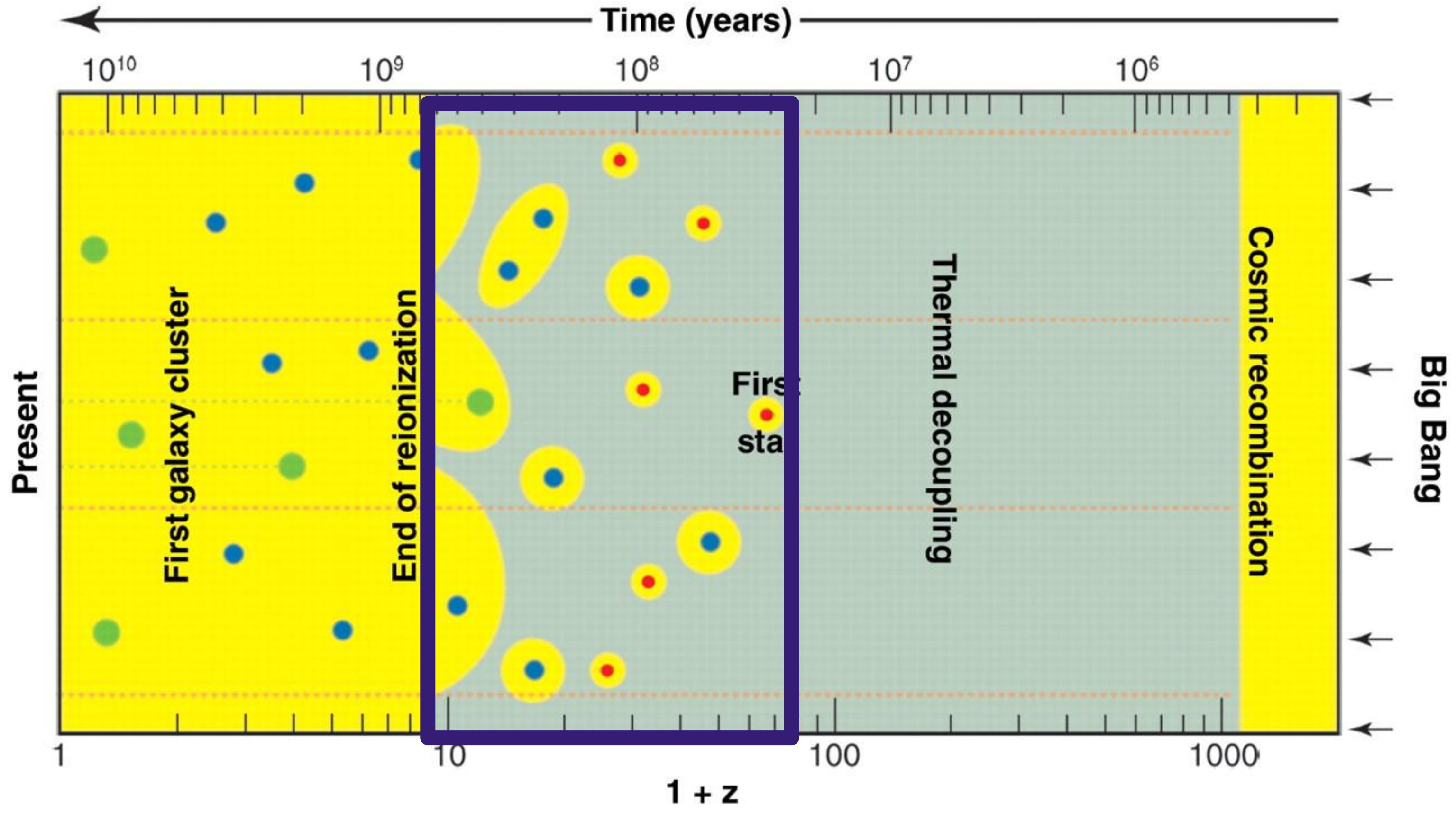
Constraining reionization parameters



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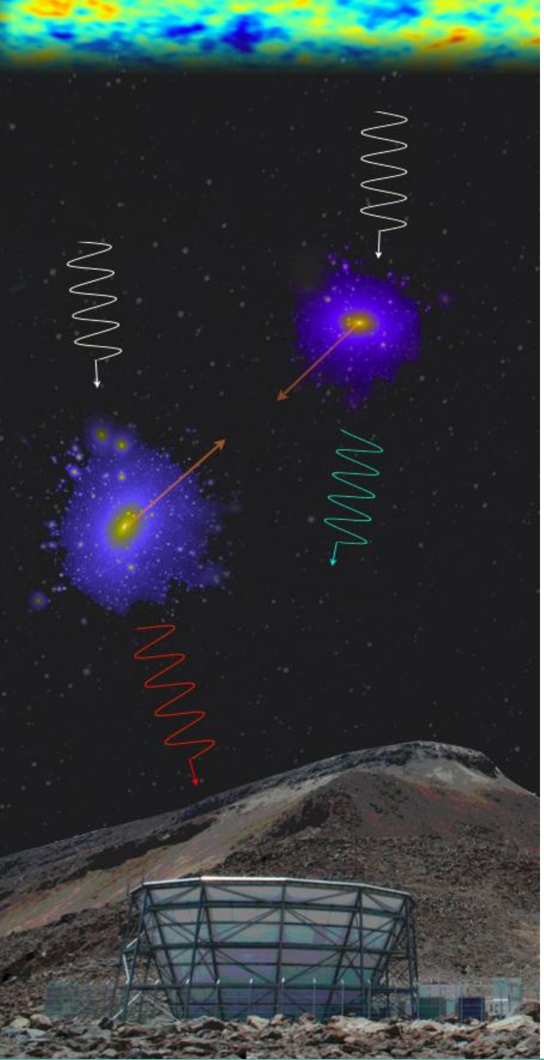
Questions ???

- When did reionization start?
- How long did it take the universe to go from completely neutral to completely ionized?
- What triggered it?
- How were the first stars formed?
- How big were they?
- What was the quantity of ionizing photons they gave off?
- What regions ionized first (high density regions or low density regions)
- ….. etc

Using the CMB as a probe of the Epoch of Reionization

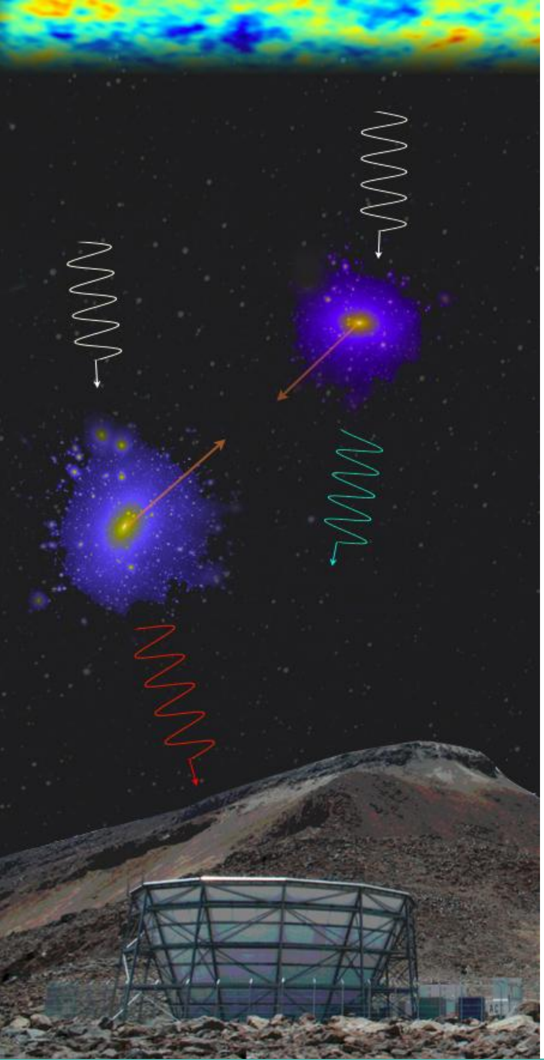
Using the CMB as a probe of the Epoch of Reionization

Mitigating the optical depth degeneracy using the kinematic Sunyaev-Zel'dovich (kSZ) effect with CMB-S4



Using the **kinetic Sunyaev Zel'dovich (kSZ)** to provide constraints on reionization through the analysis of the angular power spectrum of the CMB.

Image: sdss3.org



Using the kSZ to provide constraints on reionization through the analysis of the angular power spectrum of the CMB.

$$\frac{\Delta T}{\bar{T}}|_{kSZ}(\hat{n}) = -\frac{\sigma_T}{c}\int \frac{d\chi}{1+z} e^{-\tau(\chi)} n_e(\chi\hat{n}, \chi)\vec{v}_e.\hat{n}$$

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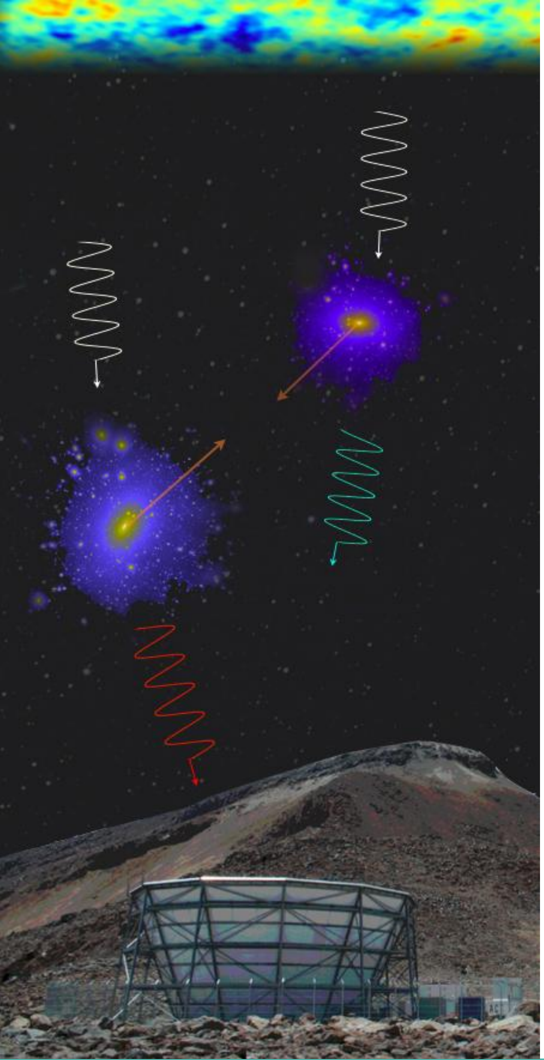

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Mean CMB temperature

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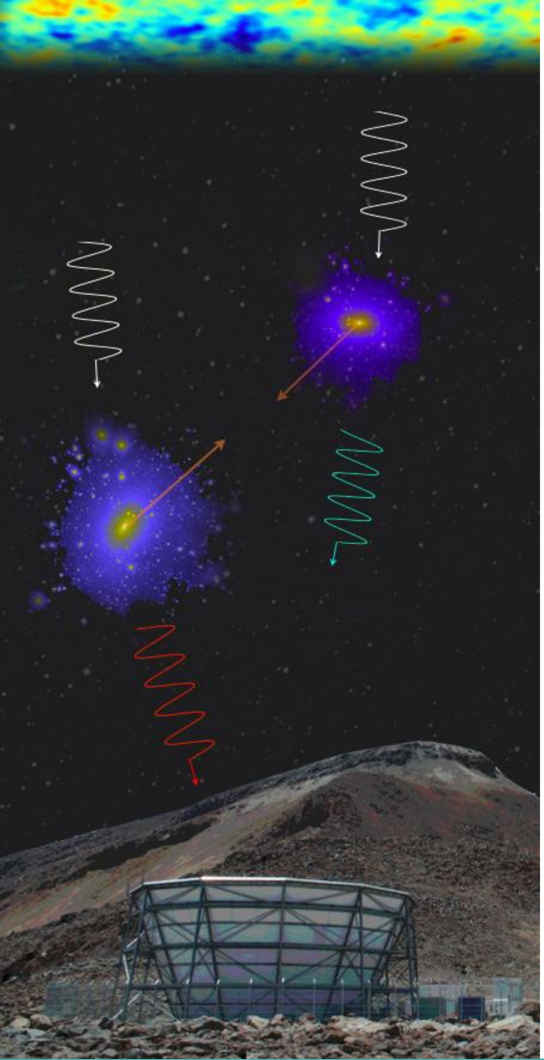

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Thomson scattering cross section

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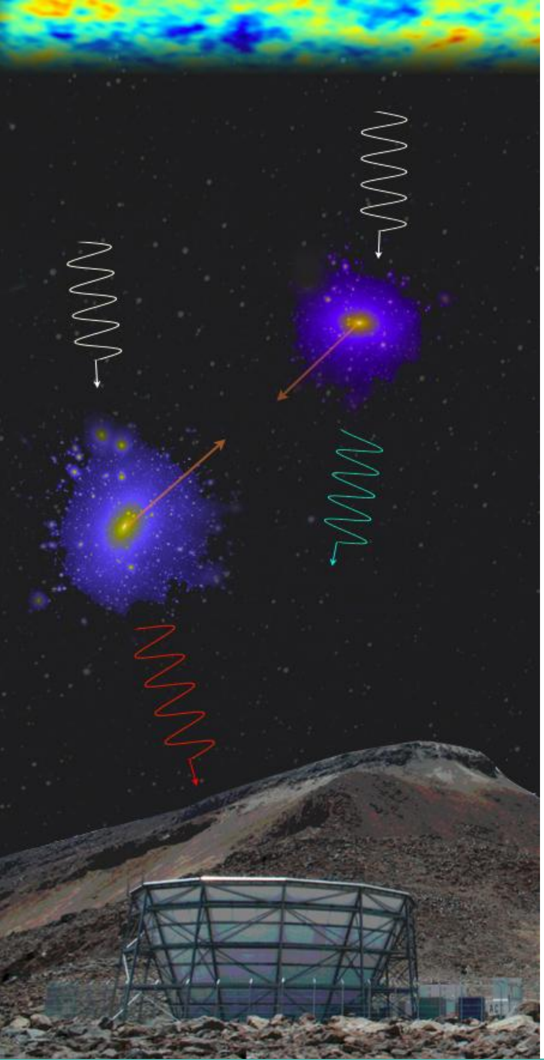

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Mean CMB temperature

Comoving distance

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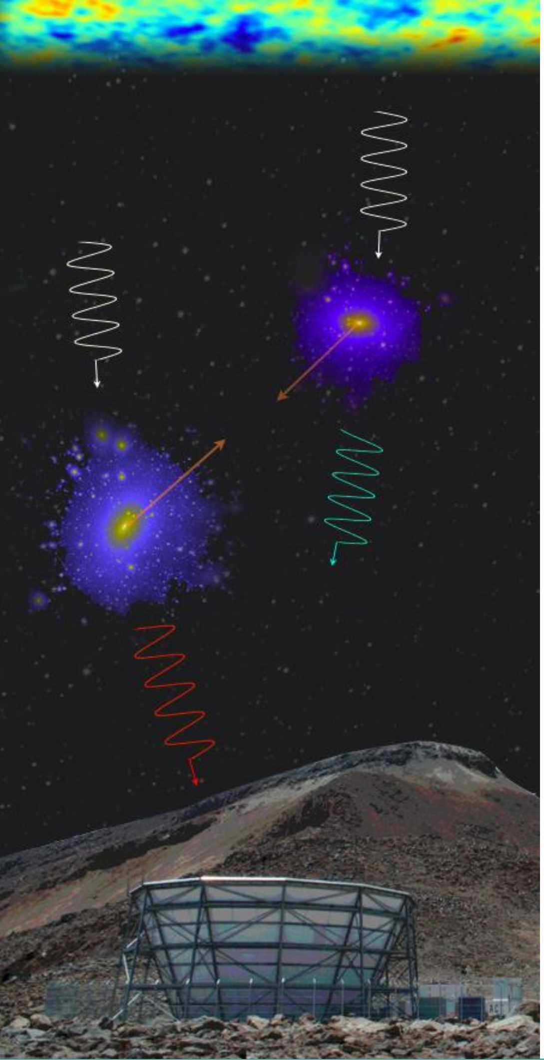

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Thomson scattering cross section

Number density of free electrons

$$\frac{\Delta T}{\bar{T}}\Big|_{kSZ}(\hat{n}) = -\frac{\sigma_T}{c}\int \frac{d\chi}{1+z} e^{-\tau(\chi)} n_e(\chi\hat{n},\chi)\vec{v}_e.\hat{n}$$

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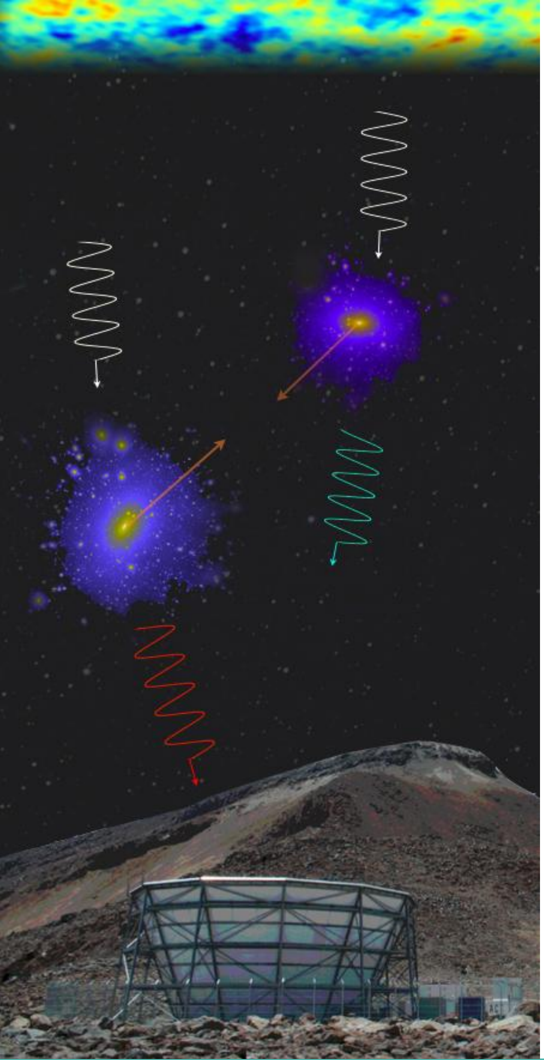

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- Thomson scattering cross section (σ_T)
- Number density of free electrons (n_e)
- Mean CMB temperature ($\bar{T}$)
- Comoving distance (χ)
- optical depth (τ)

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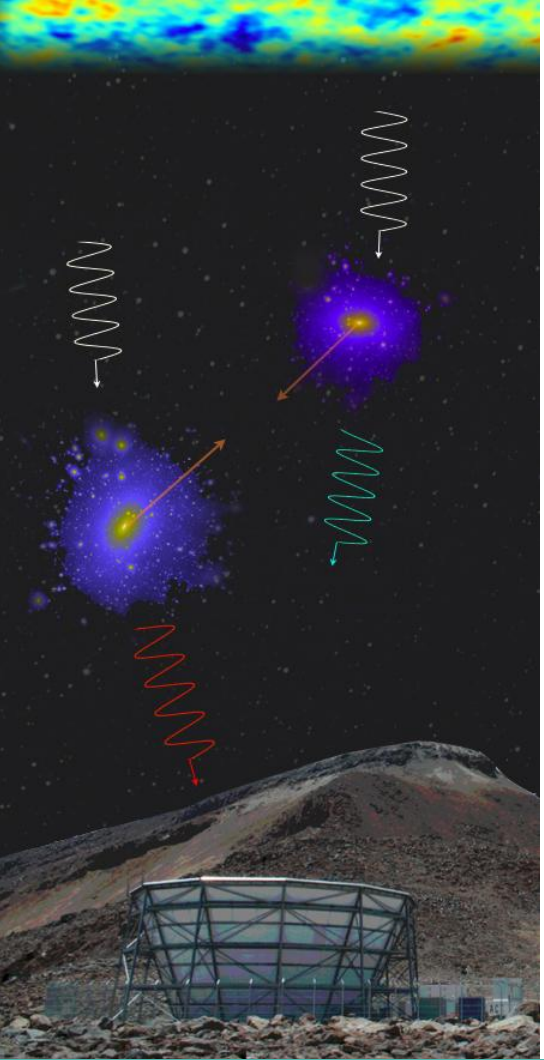

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- Thomson scattering cross section (σ_T)
- Number density of free electrons (n_e)
- Peculiar velocity of free electrons ($\vec{v}_e$)
- Mean CMB temperature ($\bar{T}$)
- Comoving distance (χ)
- optical depth (τ)

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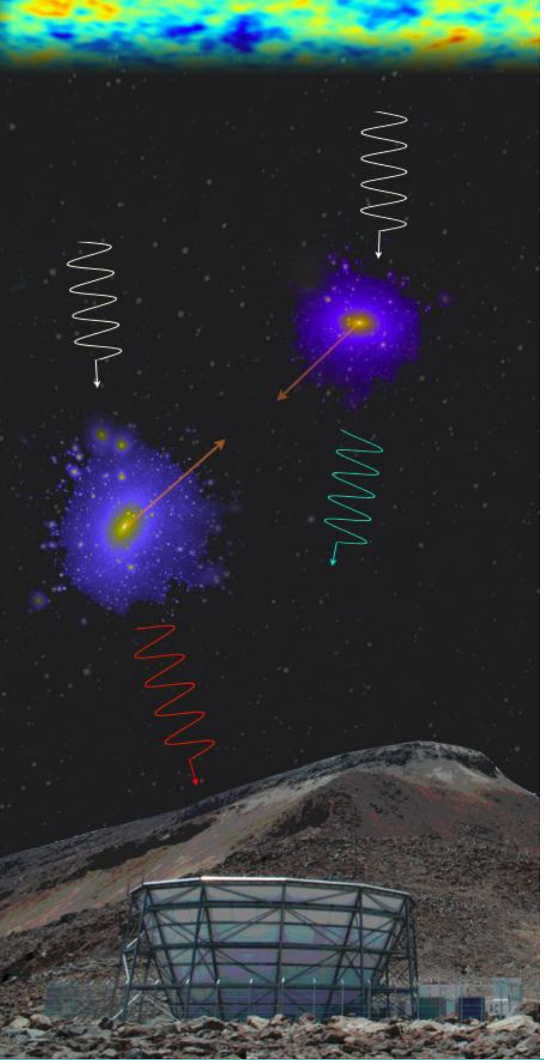

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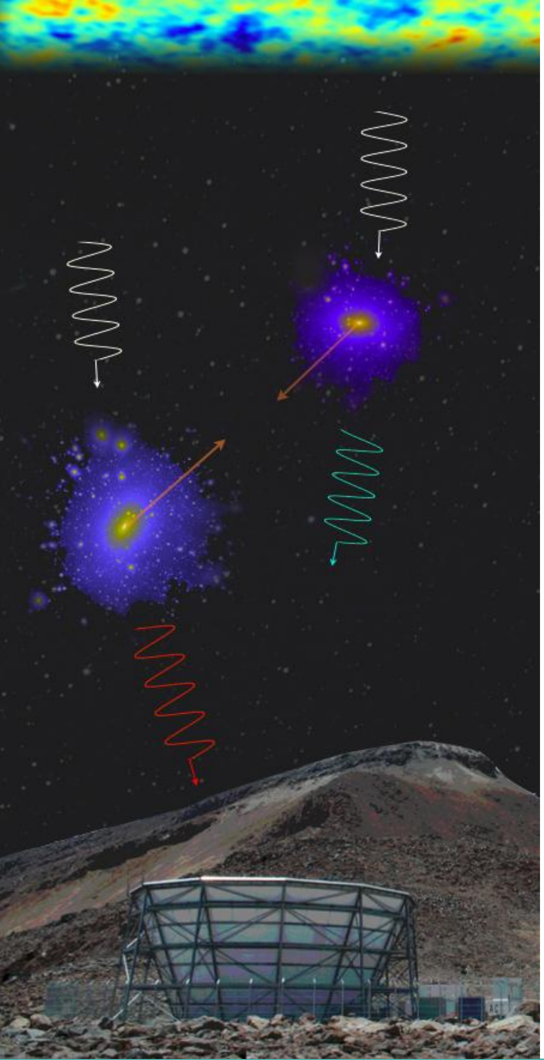
Mean CMB temperature

Comoving distance

optical depth

Direction

Image: sdss3.org

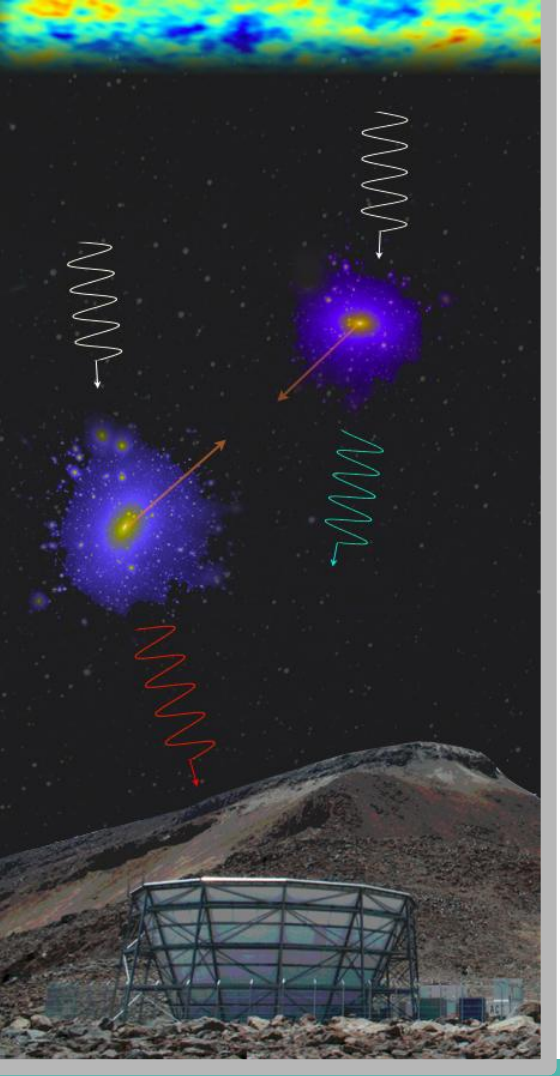


Using the kSZ to provide constraints on reionization through the analysis of the angular power spectrum of the CMB.

Early time kSZ effect at $z \sim 7$

Late time kSZ effect at $z \leq 3$

Image: sdss3.org



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Early time kSZ effect at z ~ 7

Late time kSZ effect at $z \leq 3$

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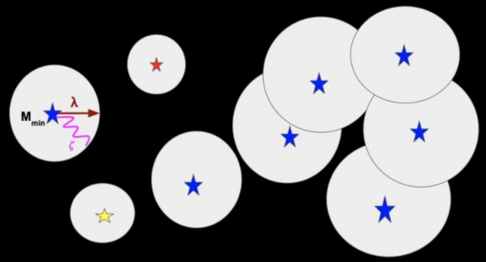
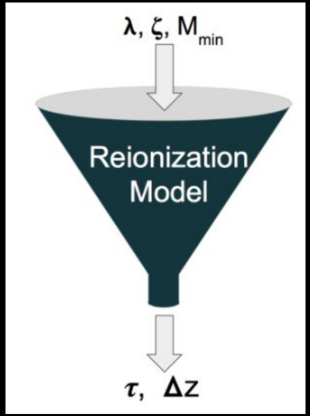
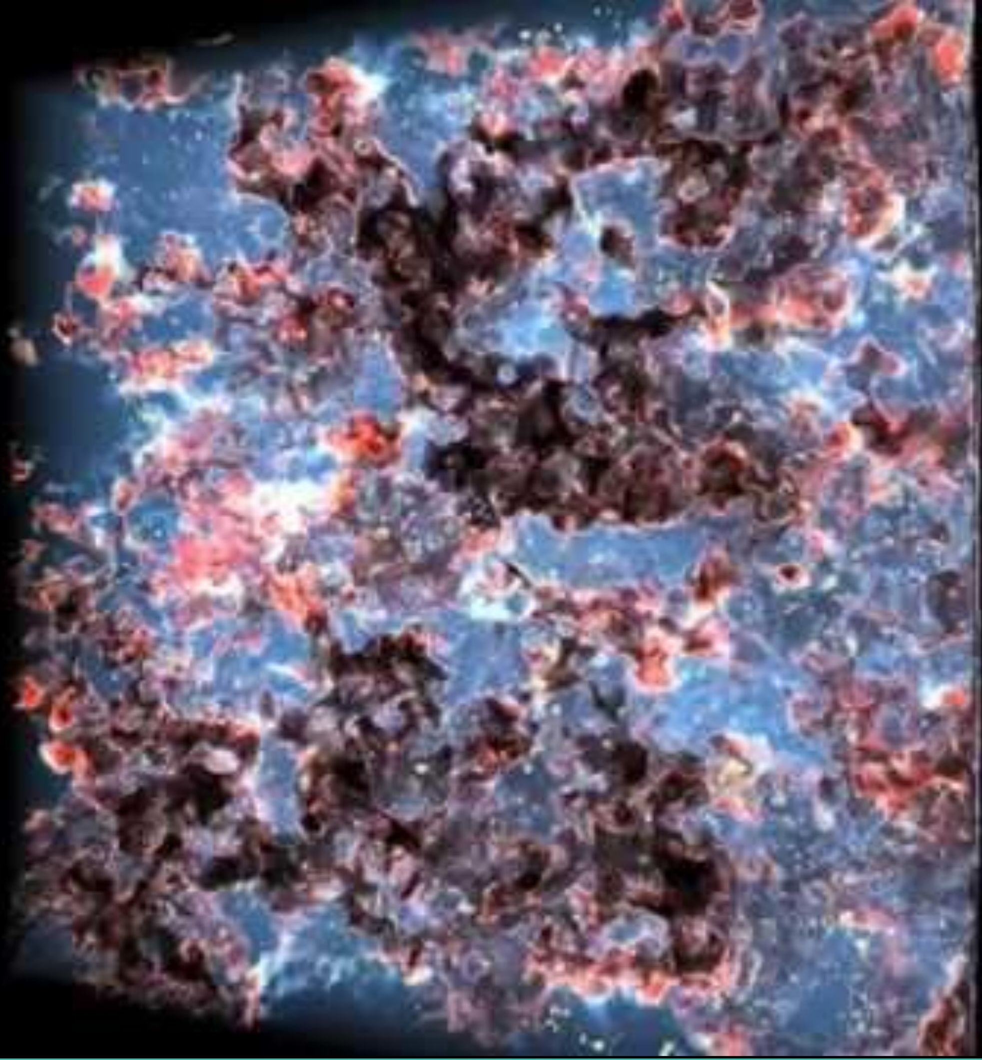
SIMULATION

- arXiv.1511.02846 - **THE KINETIC SUNYAEV-ZEL'DOVICH EFFECT FROM REIONIZATION: SIMULATED FULL SKY MAPS AT ARCMINUTE RESOLUTION**
- Parameters include.
  - Ionization efficiency, ζ.
  - Photon mean free path, $\boldsymbol{\lambda}$.
  - Minimum halo mass of galaxies.





- Outputs kSZ Cls and the reionization history.
  - Determine the Thomson scattering optical depth, $\boldsymbol{\tau}$ and the duration of reionization, Δz.



kSZ from the two-point function

$$F_{\mathrm{AB}} = -\left\langle \frac{\partial^2 \ln \mathscr{L}}{\partial \theta_{\mathrm{A}} \partial \theta_{\mathrm{B}}} \right\rangle \longrightarrow \frac{\partial C_\ell}{\partial \tau} = \frac{\partial \zeta}{\partial \tau} \frac{\partial C_\ell}{\partial d\zeta} + \frac{\partial M_{\mathrm{min}}}{\partial \tau} \frac{\partial C_\ell}{\partial M_{\mathrm{min}}}$$

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kSZ from the four-point function

$$\left(\frac{dC_\ell}{dz}\right)_{\mathrm{rei}} (z, l, \tau, \Delta z) = C_{\ell,\mathrm{rei}}(\tau, \Delta z) \frac{e^{-(z-\bar{z})^2/2\sigma_z^2}}{\sqrt{2\pi\sigma_z^2}}$$

Ferraro & Smith (2018), arxiv:1803.07036

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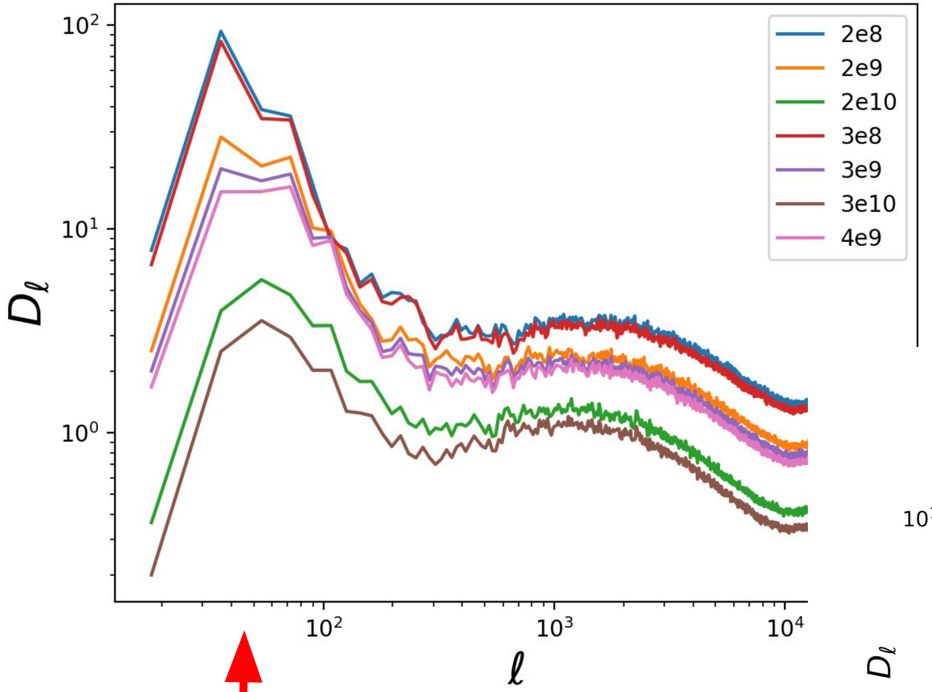
$M_{\mathrm{min},0} = 3 \times 10^9 M_\odot, \zeta_0 = 70$, and $\lambda_{\mathrm{mfp},0} = 300$ Mpc/h

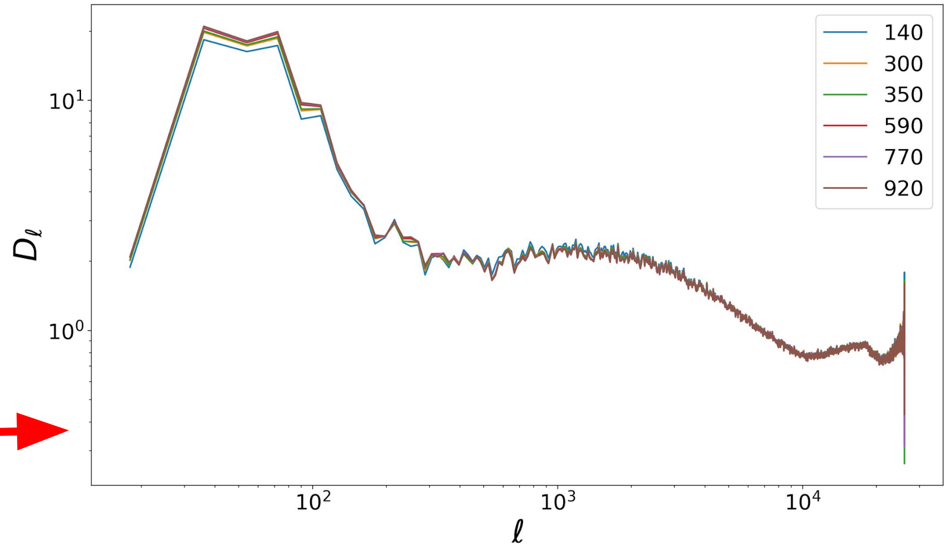
$\tau_0 \simeq 0.06$ and $\Delta z_0 \simeq 1.2$

Amplitude and shape of the kSZ power spectrum are affected by a change in the reionization parameters.

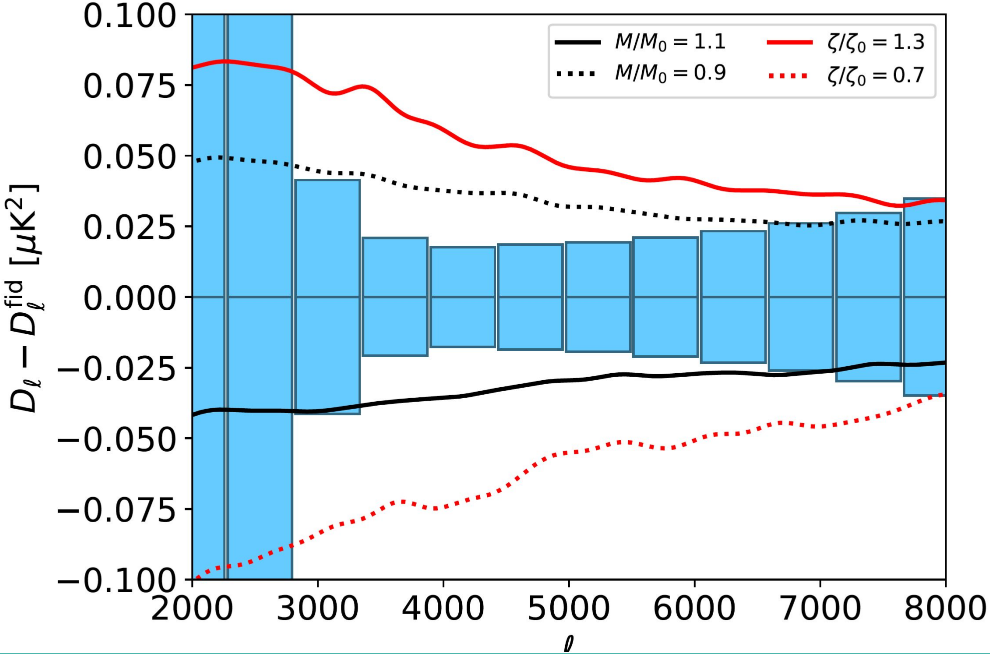


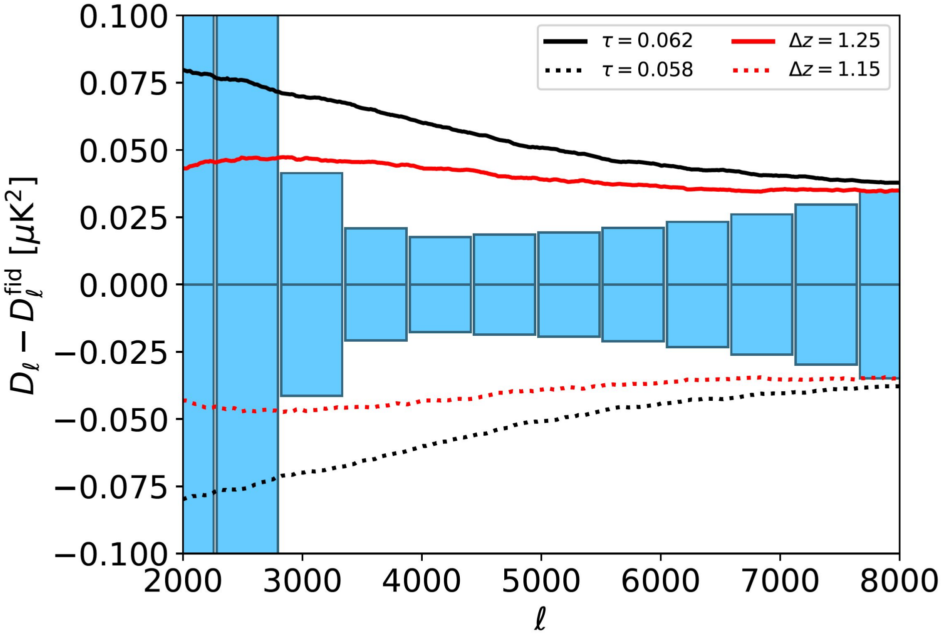
Lambda = 300
Zeta = 70
Mass varying

Mass = 3e9
Zeta = 70
Lambda varying



Dependence of kSZ power spectrum on reionization model parameters.



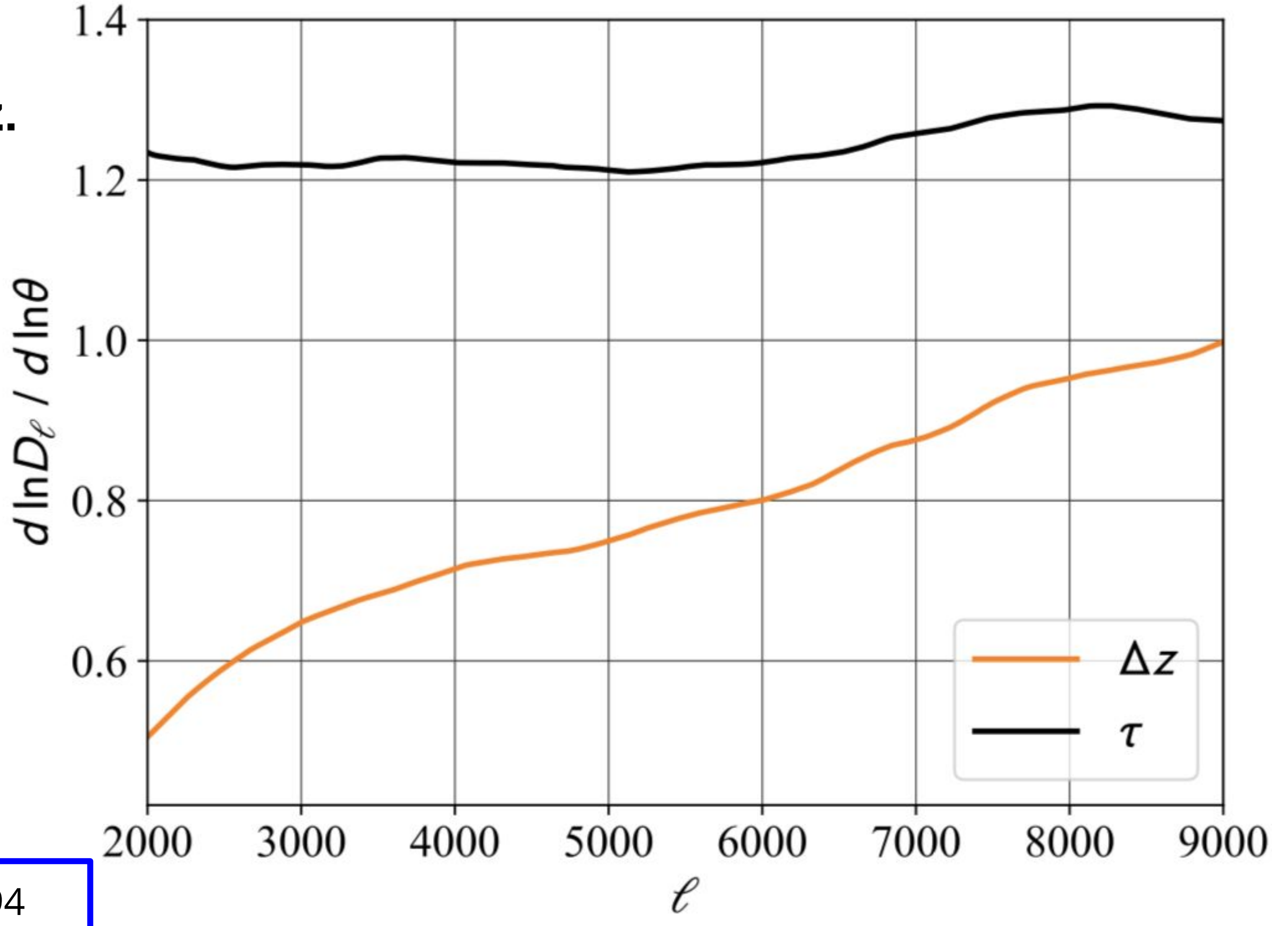


Shaded bars show 1-sigma uncertainties on the Power Spectrum, including instrumental noise and residual foregrounds for a combination of CMB-S4 and Planck data.

Alvarez et al, arxiv: 2006.06594

Response of kSZ power spectrum to variations in τ and Δz.

- Increase in either τ or Δz results in more power at l > 1000.
- The differing scale-dependence of the power spectrum response between the two parameters partially breaks the degeneracy.



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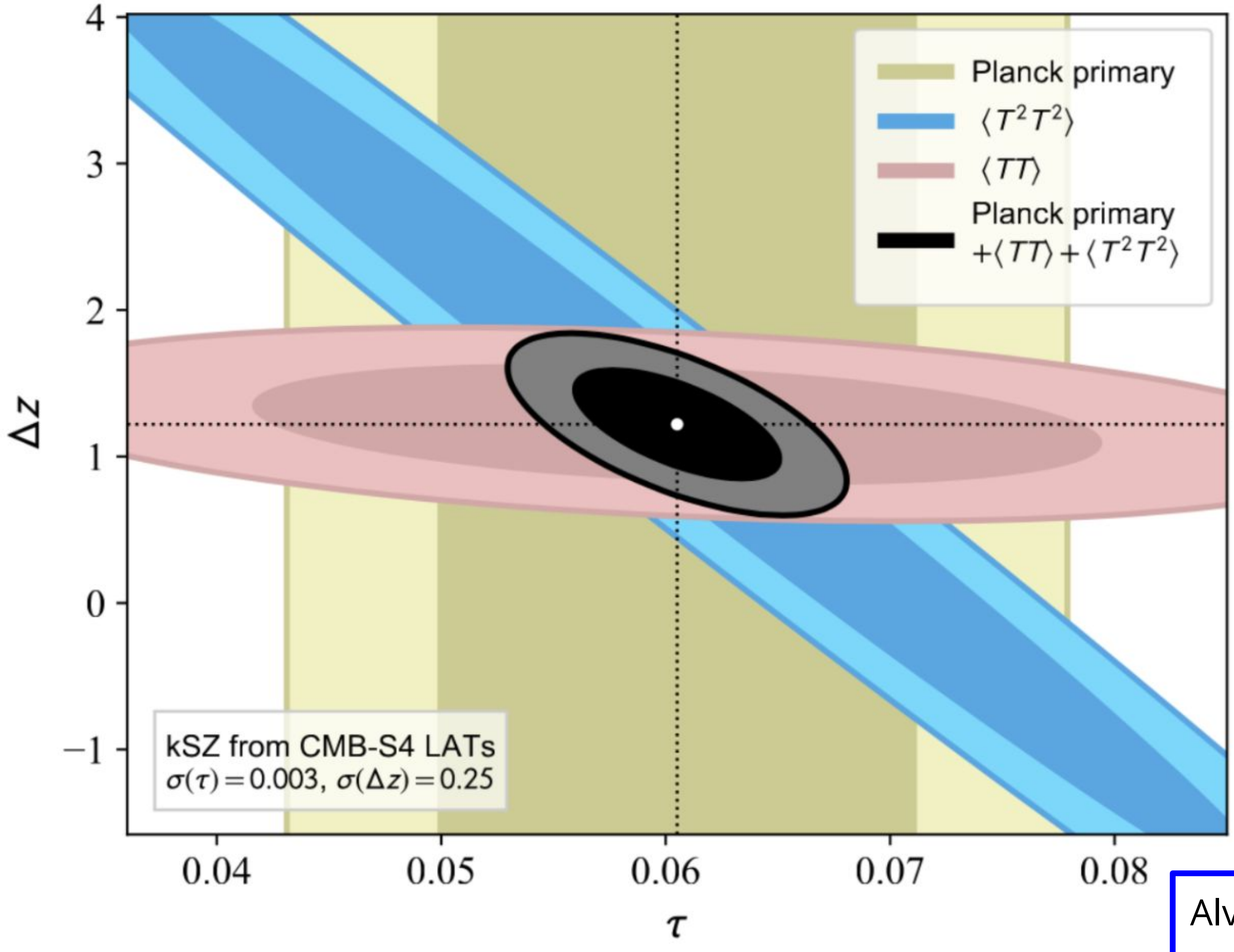

Constraints on the duration of reionization and optical depth.

Forecast reionization constraints from the kSZ power spectrum (pink) and the kSZ four-point function (blue), as derived from CMB-S4 and Planck data.

The black contours show forecast constraints from the combination of all three probes.

The complementary degeneracy directions of the two-point and four-point functions effectively break the degeneracy between the reionization parameters.

Alvarez et al, arxiv: 2006.06594

Conclusion

- We illustrate the power of combining the four-point and two-point constraints due to their complementary degeneracy directions in the reionization parameter space.
- We forecast $\sigma(\tau) = 0.003$ and $\sigma(\Delta z) = 0.25$ for a combination of CMB-S4 and Planck data.
- This constraint on τ is nearly as tight as a CV-limited constraint from the primary CMB ($\sigma(\tau) = 2 \times 10^{-3}$), as targeted by next-generation satellite missions.