Constraints on the Epoch of Reionization from the Cosmic Microwave Background using the CROC suite of simulations

Nishant Mishra, Nickolay Gnedin

Epoch of Reionization and the CMB

The Epoch of Reionization (EoR) is a critical period in the thermal history of our universe. This period is when radiation from the first light sources reionized the neutral hydrogen. Because CMB photons must pass through this epoch, we can measure how Reionization effects the CMB anisotropies:

- Optical Depth: Quantifies the Compton scattering of CMB photons by free electrons in the intergalactic medium (IGM), a semi-transparent screen between us and the CMB. Compton scattering is proportional to free electron density, and therefore integrated neutral gas fraction along line-of-sight

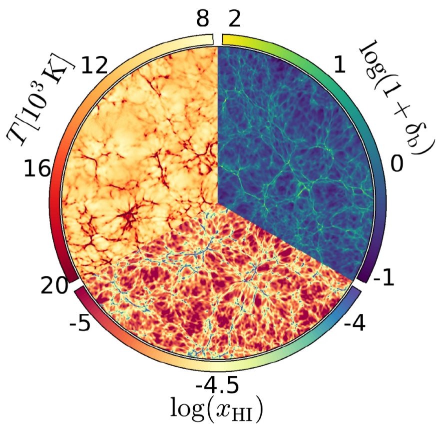
$$\tau = c\sigma_T \int (x_e n_b) dx$$

$$\delta\tau = c\sigma_T \int (x_e n_b - \bar{x}_e \bar{n}_b) dx$$

$$x_e n_b - \bar{x}_e \bar{n}_b = (x_e - \bar{x}_e) n_b + \bar{x}_e (n_b - \bar{n}_b)$$

- Kinetic Sunyaev-Zeldovich Effect (kSZ): The SZ effect is caused by the inverse Compton scattering of low energy CMB photons by high energy electrons. kSZ is caused by the bulk motion of high energy electrons, and is therefore a tracer of ionized bubbles.

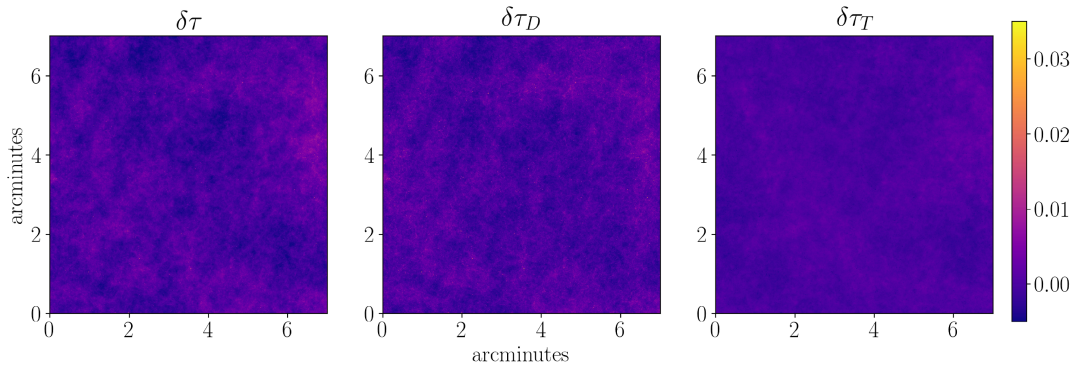
$$\Delta T_{kin} = -T_{CMB} \frac{V_p}{c} \tau$$



Garaldi et al. (2019)

Cosmic Reionization on Computers

The latest suite of hydrodynamic cosmological simulations. With volumes large enough that we can explore a large range of scales. They also provide a reasonable match to the observed galaxy luminosity functions for the redshift ranges we are exploring. Secondly, they agree with observations on the location of the Gunn-Peterson trough. For these reasons, we infer that the CROC simulations provide a reasonable model for the reionization of the IGM.

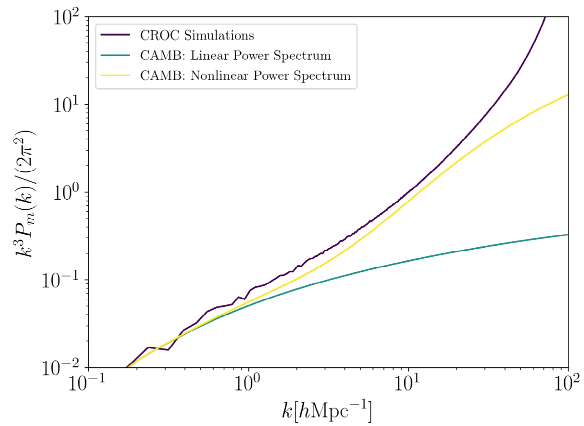


Optical Depth Maps

We construct light cones and optical depth maps using the simulation boxes. We then calculate the difference from mean optical depth (left panel). This quantity is then further broken into two components, fluctuations from density, and fluctuations from temperature. We find that those two components are anti-correlated.

Power Spectrum Comparison

We first calculate the matter power spectrum of the CROC simulations and compare to the outputs for the nonlinear and linear power spectrum from CAMB (Code for Anisotropies of the Microwave Background). We find that the analytic codes under predict structure formation when compared against the simulations on small scales.



Conclusion and Next Steps

Our next job is the quantify this anti-correlation in temperature driven optical depth fluctuations vs. density driven optical depth fluctuations. We then consider these quantities in cross-correlation with kSZ maps that we will generate. Future work will utilize these measurements to put constraints on the phase-space of ionized bubbles during the Epoch of Reionization.

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