Abstract

Observations of the redshifted 21-cm signal from neutral hydrogen (H I) are a very promising probe of the Epoch of Reionization (EoR), and there is a considerable observational effort underway to detect the EoR 21-cm power spectrum. A significant amount of effort has gone into making quantitative predictions of both the expected EoR 21-cm power spectrum and the sensitivity of the different instruments to measure the expected signal.

The EoR 21-cm signal is expected to become increasingly non-Gaussian as reionization proceeds. This severely affects the error predictions of the EoR 21-cm power spectrum. Most of the earlier works have assumed that the EoR 21-cm signal is a Gaussian random field where the error depends only on the power spectrum $P(\boldsymbol{k})$ and the number of Fourier modes $N_{\rm k}$ in the particular k bin. We have used semi-numerical simulations to study how this non-Gaussianity affects the error predictions for the EoR 21-cm power spectrum. We expect signal-to-noise ratio SNR $\propto \sqrt{N_{\rm k}}$ for a Gaussian random field. We find that non-Gaussianity is important at high SNR where it imposes an upper limit $[{\rm SNR}]_l$. For a fixed volume V, it is not possible to achieve SNR $>$ $[{\rm SNR}]_l$ even if $N_{\rm k}$ is increased. At a fixed redshift $z = 8$, we have considered different values of mass averaged neutral fraction $\bar{x}_{\rm H\,I}$ and have shown that the value of $[{\rm SNR}]_l$ falls as reionization proceeds. We have also shown that it is possible to interpret $[{\rm SNR}]_l$ in terms of the trispectrum, and we expect $[{\rm SNR}]_l \propto \sqrt{V}$ if the volume is increased.

The error estimates, in general, is quantified through the error covariance matrix. We develop a general theoretical framework for interpreting the binned power spectrum error covariance matrix C_{ij} in terms of the power spectrum and trispectrum. We use semi-numerical simulations to generate large statistical ensembles of the expected EoR 21-cm signal and use these to estimate C_{ij} and study its evolution through different stages of reionization. We present a novel statistical technique which allows us to decompose the simulated C_{ij} into a Gaussian and non-Gaussian contribution respectively. The non-Gaussian contribution to C_{ij} is quantified through the trispectrum. We find that its relative contribution is comparable to or larger than that of the Gaussian term for the k range $0.3 \leq k \leq 1.0\,{\rm Mpc}^{-1}$, and can be even ~ 200 times larger at $k \sim 5\,{\rm Mpc}^{-1}$ at $\bar{x}_{\rm H\,I} = 0.5$.

We establish that the off-diagonal terms of C_{ij} have statistically significant non-zero values which arise purely from the trispectrum. For $\bar{x}_{\rm H\,I} = 0.5$ at $z = 8$, we find significant correlations between the errors at the small length-scales ($\geq 0.5\,{\rm Mpc}^{-1}$) and between the small and the large length-scale. Considering the later stages of reionization, we find that the errors in the different k bins are highly correlated, barring the two smallest k bins that are anti-correlated with the other bins.

Our results are relevant for predicting the sensitivity of different instruments to measure the EoR 21-cm power spectrum and model parameter forecasts, which till date have been largely based on the Gaussian assumption.

Keywords: cosmology: theory, large-scale structure of Universe, dark ages, epoch of reionization, methods: statistical, first stars, diffuse radiation.