Abstract

Observations of the cosmological redshifted neutral hydrogen (H I) 21-cm (1420 MHz) signal, which arises from the ground state hyperfine transition of the H I, holds the potential of probing the large scale structures of the Universe. The Ooty Radio Telescope (ORT) is currently being upgraded to a linear radio-interferometric array, the Ooty Wide Field Array (OWFA). The OWFA operates at a nominal frequency of $\nu_c = 326.5\,\mathrm{MHz}$ which corresponds to the 21-cm signal from $z = 3.35$. The upgrade will result in two concurrent modes namely OWFA PI and PII respectively. Measuring the redshifted H I 21-cm power spectrum is one of the major science goals of OWFA.

We present two different prescriptions to simulate this signal and calculate the visibilities expected in radio-interferometric observations with OWFA. In the first method we use an input model for the expected 21-cm power spectrum to directly simulate different random realizations of the brightness temperature fluctuations and calculate the visibilities. This method, which models the H I signal entirely as a diffuse radiation, is completely oblivious to the discrete nature of the astrophysical sources which host the H I . While each discrete source subtends an angle that is much smaller than the angular resolution of OWFA, the velocity structure of the H I inside the individual sources is well within reach of OWFA's frequency resolution and this is expected to have an impact on the observed H I signal. The second prescription is based on cosmological N-body simulations. Here we identify each simulation particle with a source that hosts the HI, and we have the freedom to implement any desired line profile for the H I emission from the individual sources. Implementing a simple model for the line profile, we have generated several random realizations of the complex visibilities. Correlations between the visibilities measured at different baselines and channels provide an unique method to quantify the statistical properties of the H I signal. We have used this to quantify the results of our simulations, and explore the relation between the expected visibility correlations and the underlying H I power spectrum.

Considering redshifted 21-cm intensity mapping with the upcoming OWFA, whose field of view subtends $\sim 57^\circ$ in the N-S direction, we present a formalism which relates the measured visibilities to the spherical harmonic coefficients of the sky signal. We use this to calculate window functions which relate the two visibility correlations to different multipoles of the multi-frequency angular power spectrum $C_\ell(\nu_1, \nu_2)$. The formalism here is validated using simulations. We also present approximate closed form analytical expressions which can be used to calculate the window functions. We show comparison of our spherical harmonic formalism with the widely adopted flat sky approximation.

Galactic and extragalactic foregrounds which are 4−5 orders of magnitude larger than the signal itself, pose a severe challenge to the H I 21-cm signal detection. Considering the foreground contributions from the diffuse galactic synchrotron emission (DGSE) and the extragalactic point sources (EPS), we run all-sky simulations to predict the foreground contribution to the cylindrical power spectrum $P(k_\perp, k_\parallel)$. We find that the foreground contribution is largely restricted to a wedge (the foreground wedge) in the $(k_\perp, k_\parallel)$ plane. One expects to use the $(k_\perp, k_\parallel)$ region outside this wedge for H I signal detection, a foreground isolation technique widely referred to as "Foreground Avoidance". We find that foreground leakage outside the wedge poses a severe problem for detecting the H I signal. This problem can however be mitigated by applying appropriate filtering to the visibilities along the frequency band. We use different frequency filters to suppress the foreground leakage and identify the best suited frequency filter for the OWFA which can improve the scenario significantly.

Keywords: Cosmology, large scale structure of the Universe, intergalactic medium, diffuse radiation, neutral hydrogen, statistics, cross-correlation, power spectrum.