

Abstract

The first luminous objects appeared in the universe at a redshift of around 15 and started to reionize the universe. The reionization is known to have been completed by a redshift of 6 (Saleem Zaroubi (2012)). Afterwards, smaller structures formed first and then accumulated to form larger structures like galaxies and clusters of galaxies. This era after the reionization epoch, the epoch of galaxy formation and assembly, is when the structures in the universe took shape of their present phase. Nature of the sources, the evolution of ISM and star formation, the evolution of galaxy, circum-galactic and intergalactic medium properties all gradually evolved in the post reionization epoch. Tracing the evolution of baryonic density, in this epoch holds the clue to the astrophysics of these processes. Hydrogen being the most abundant element, the 21 cm line from it provides a nice tool to probe the reionization and post reionization physics (Bharadwaj and Ali (2005)). In the post reionization era, atomic hydrogen is mostly found in the shielded regions inside the galaxies and in circum-galactic medium. However, the expected 21 cm signal from the structures in the post reionization era is rather weak and much weaker than the other signals in the same frequency of observation. Later, collectively known as the foreground signal, adds to the challenges to observe the H I structures from the post reionization era.

Galaxy clusters locate the over-densities of the dark matter. The gravitating matter bends light and the flux from the sources in the backgrounds are redistributed, their images are magnified, distorted and multiple images formation takes place. This is the well-known phenomenon of strong gravitational lensing. Using spectroscopic observations, the multiple images can be traced back to the source plane, reconstructing the source intensity distribution as well as the lensing potential responsible for the image distortion. Strong gravitational lensing of background galaxies by strong galaxy clusters is hence being used

to probe the spatially resolve properties of high redshift galaxies (Johnson et al (2014), Cerny et al (2018), Richard et al (2021)). In process of these studies, the models for the gravitational lenses are also being enhanced with increasingly better observations.

(Saini et al (2001)) explored the possibility of lensing by galaxies to probe H I distribution in background galaxies. In this work, we investigate the possibility of using the known cluster lens models to measure the enhanced signal of H I distribution in the background. We first investigate the possibility of probing the statistical measures of the post reionization H I distribution, like the power spectrum from post reionization universe. Assuming four simple models of gravitational lenses and fiducial models of H I power spectrum at different post reionization redshifts we demonstrate that the power spectrum is selectively enhanced at certain baseline ranges of observations. Since the major foreground emissions in these cases are from our Galaxy, the lensing enhancement only applies to the H I signal and hence the signal to foreground ratio increases. We show analytically that the effect of strong lensing manifests as a modified sampling function for the radio interferometric observation, which if used effectively holds the promise for this technique. A major drawback of this method has been that the magnification by strong lensing gives rise to only small regions in the baseline plane where the signal is enhanced and hence increase the sample variance of the detection.

To address the issue with sample variance as discussed above we approached using a combination of lensing by multipole cluster lenses together to detect the post reionization H I power spectrum. We developed an estimator, the combined lens estimator, uses the weighted average of the visibility correlations. The weights are chosen so that the estimator unbiasedly estimate the H I power spectrum from the post reionization era suppresses the measurement noise and foreground signal and combines the visibility correlations from many different lenses choosing a suitable threshold. Considering lensing models of 16 lenses from (Smith et al. (2005), Richard et al. (2007), Richard et al. (2010), Johnson et al.

(2014), Jauzac et al. (2015), Bina et al. (2016)), we find that with 400 hours of observations with uGMRT, it would be possible to detect post reionization H I power spectrum from redshifts of 1.25, 1.5 and 3.0 with 5σ significance. The foreground suppression is at the order of 1000 of the original foreground.

We also investigate the possibility of detecting individual galaxies in H I at the known position of the background galaxies from optical studies. Richard et al(2021) give a catalogue of galaxy cluster models with about 400 background galaxies at redshifts between 1 and 5. Using fiducial models of the H I distribution at these galaxy positions in the source plane, we plan to find the parameters from matched filtering techniques in the visibility plane. The method is designed such that we would have rough estimates of the total H I content and tangential rotation velocity of these galaxies. An initial estimate shows that the H I of these galaxies can be detected in two spatially separated beams with 100 hours of observation along with each cluster with SKA low and SKA mid.

In a nutshell, this thesis explores the possibilities of using the upcoming radio telescopes to detect statistical properties of the H I distribution and H I in individual galaxies in the post reionization era. The results are promising for the upcoming radio telescopes and hence will be important to follow up with future observations.