Prospects for detecting neutral hydrogen using 21cm radiation from large scale structure at high redshifts

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Abstract. We estimate the signal from large scale structure at high redshifts in redshifted 21cm line. We focus on $z \sim 3$ and the ΛCDM cosmology. We assume that neutral hydrogen is to be found only in galaxies, and normalise the total content to the density parameter of neutral hydrogen in damped Lyman-α absorption systems (DLAS). We find that the rms fluctuations due to the large scale distribution of galaxies is very small and cannot be observed at angular scales probed by present day telescopes. We have used the sensitivity of the Giant meter-wave Radio Telescope (GMRT) for comparison. We find that observations stretching over $10^3$ hours will be required for a $3\sigma$ detection of such objects.

1. Introduction

Observations of galaxies and absorption systems at high redshifts have shown that the assembly of present day galaxies started around $6 \geq z \geq 1$. At higher redshifts, the fraction of matter that had collapsed to form stars was small. By the end of the redshift range mentioned here, the rate of star formation was starting to decline and assembly of larger structures like the clusters of galaxies is the dominant process. In order to understand the process of galaxy formation completely, it is important to study galaxies in this redshift range in as many wavelengths as possible.

In this paper we present results for the large scale distribution of HI at $z \sim 3$. More detailed results for the entire range of redshifts will be presented elsewhere. References for earlier theoretical work as well as related observations can be found in Bagla (1999a) and Bharadwaj (2001).

Observations of galaxies and quasars at high redshifts provide convincing proof that the inter-galactic medium is ionised out to $z \sim 6.2$ (Pentericci et al. 2002). Thus most of the neutral hydrogen at $z \sim 3$ is to be found in galaxies. We have an estimate of the total neutral hydrogen content from observations of DLAS (Storrie-Lombardi, McMahon and Irwin, 1996). There is no observational evidence to support the hypothesis that DLAS and Lyman break galaxies (LBG) have different properties (Fynbo et al. 2002). Thus we can safely assume that
neutral hydrogen is distributed uniformly amongst galaxies at $z \simeq 3$, and that the total amount of neutral hydrogen adds up to give us the density parameter contributed by neutral hydrogen in DLAS.

2. From Haloes to Radio Maps

In this section we outline the method used for estimating the signal from neutral hydrogen at high redshifts.

We ran N-Body simulations of the $\Lambda$CDM model. The size of the simulation box in physical units is $50h^{-1} \text{Mpc}$ (comoving) and the number of particles used in this gravity only simulation was $256^3$. We used the TreePM method (Bagla, 1999b) for these simulations.

The density around each particle was estimated by measuring the distance to the $n$th neighbour, where neighbours were sorted by distance. The results presented here used $n = 16$ but the numbers do not change much for $n = 32$ or for a different choice of estimator for density.

Particles in regions with over-density higher than a threshold were then selected from the simulation. Each of these particles was assigned an equal amount of neutral hydrogen such that the density parameter of neutral hydrogen was 0.002. Results can be scaled trivially if one prefers a different value of $\Omega_{HI}$.

The dependence of emission on the local spin temperature is weak enough to be ignored in physical situations of interest. The optical depth in 21cm is sufficiently small for us to ignore any absorption. Thus the problem of making radio maps essentially reduces to that of assigning frequency and angular position to each particle in high density regions and adding up the signal in relevant frequency channel and pixel. The conversion from neutral hydrogen mass to signal is

$$S_\nu = 309 \mu Jy \left( \frac{M_{HI}}{10^{13} M_\odot} \right) \left( \frac{1 \text{MHz}}{\Delta \nu} \right). \quad (1)$$

The simulated radio maps can then be used to look for optimum frequency window and angular scales at which a search for signal should be carried out. In such an exercise, parameters of present day telescopes need to be considered and we have used sensitivity levels of the GMRT (Swarup et al. 1991) for this. Figure 1 shows the expected signal from the largest objects for a frequency channel of 1MHz as a function of angular scale. We scanned the radio maps with a very fine resolution in order to locate the maximum signal. The expected signal is compared with the sensitivity of the GMRT at 327MHz for a 10$^3$-hour observation. This figure suggests that a 3$\sigma$ detection of the largest structures is possible at angular scales $3' - 6'$ in such an observation. Signal expected from typical structures is much smaller.

The expected observation time is very large and hence it is important to ask whether such extreme structures are likely to be there in the volume sampled by the GMRT beam or not. The volume sampled by a GMRT beam at 327MHz is much larger than the volume of the simulation used here. It is also much larger than the volume of the fields in which spikes in the redshift distribution of LBGs have been observed (Steidel et al. 1998). As the rate at which spikes occur in the redshift distribution of LBGs is close to one per field, we expect that the GMRT beam will contain at least one extreme object.
Figure 1. The expected signal (dots) from largest structures at $z \simeq 3$ as a function of angular scale and frequency width of 1MHz. Estimated noise level (line) for the GMRT is shown as a function of scale for the same bandwidth and $10^3$ hours of integration. We used the sensitivity of GMRT at 327MHz, which corresponds to a redshift slightly higher than 3. A 3σ detection is possible at angular scales around 5′.
3. Discussion

We have used N-Body simulations to estimate the signal in redshifted 21cm line from large scale structure at \( z \approx 3 \). We find that the present day telescopes can detect extreme objects in the large scale structure at these redshifts.

In our estimation, we made use of gravity only simulations and ignored any effects coming from gas physics. These effects play a very important role in the distribution and state of gases at small scales. However, we are interested only in gross properties and that too at large scales and there is no reason to suspect that we will get these wrong in the method that we have used as long as we restrain our estimates to scales larger than 1Mpc (comoving). The weakest point in our method is that we assumed that the amount of neutral hydrogen assigned to an N-Body particle did not depend on the mass of the collapsed structure that contained this particle. We expect larger structures \((M > 10^{13}\text{M}_{\odot})\) to be like groups of galaxies and have less neutral hydrogen by fraction. Also, we expect smaller structures \((M < 10^{10}\text{M}_{\odot})\) to have less neutral fraction as these will be influenced strongly by the photo-ionising background. However, the fraction of mass in haloes at these extremes is negligible and hence we do not expect these effects to invalidate our results at these redshifts. Such effects will be very important at lower redshifts where very massive haloes are more common, or at high redshifts where the low mass haloes contain most of the mass in collapsed structures.

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