1. Introduction

The rare damped-Ly$-\alpha$ systems seen in absorption against the UV continuum of high redshift QSOs nonetheless dominate the observed neutral gas at high redshift. HI 21cm absorption studies of these systems are challenging and only a handful have been detected hitherto (Carilli 1994). HI 21cm observations are however of great value because they potentially yield physical information (velocity dispersion, spin temperature, size), that cannot be obtained by other means.

If some damped-Ly$-\alpha$ systems contain a significant amount of dust, then QSOs behind such systems will be considerably extincted. Further, since high resolution optical spectroscopy is only practical for bright QSOs, such extincted QSOs will be excluded from observing samples, leading to an underestimate of the number count of damped-Ly$-\alpha$ systems, and hence also of the gas content of the early universe. If the dust obscuration is sufficient, the number counts of QSOs themselves could be strongly biased, and if the damped-Ly$-\alpha$ population is sharply divided into two halves, one with little or no dust and another with substantial dust, (if for example systems above a certain redshift are much dustier than those at lower redshifts) this bias could in fact be completely undetectable in purely optical studies (Heisler & Ostriker 1988). Such a bias however would be apparent when trying to find optical counterparts to radio sources, and the fact that optical identification was possible for a complete sample of radio sources (Shaver, 1994) makes this unlikely.

Although the effect of obscuration by dust may not be as substantial as envisaged by Heisler & Ostriker, it could nonetheless be important. Two independent observations in fact provide complementary evidence for the
presence of dust in high redshift damped-Ly-α systems, (i) QSOs with damped-Ly-α systems along the line of sight have redder UV continuum than those without, (Pei et al. 1991) (ii) The gas phase Cr abundance in these systems is much lower than that of Zn, (Steidel et al. 1995). In the galaxy Cr is depleted onto dust grains while Zn is not. Thus the count of both damped-Ly-α systems and that of QSOs is biased, however since the spectral properties of the dust are poorly constrained, the severity of the bias is correspondingly uncertain. Fall & Pei (1995) estimate that up to 70% of high redshift quasars could be missed.

Blind radio searches (against the lobes of radio galaxies which are often well removed from the central core, however note that since one requires to detect the Ly-α line to determine the redshift, the line of sight to the central object itself must be relatively dust free), are less subject to the bias introduced by dust extinction and are hence of particular value in resolving this controversy. Such searches have traditionally been difficult because of the challenging instrumental requirements and the hostile radio interference environment at low frequencies. In this paper we describe a pilot radio search for damped-Ly-α systems made using a novel observing mode at the WSRT and present preliminary results.

2. Observations and Data Reduction

2.1. OBSERVATIONS

An absorber with column density \( N_H > 2 \times 10^{20} \text{ cm}^{-2} \) is encountered on the average 0.25 times along a line of sight a unit redshift long and centered at \( z \sim 2.5 \) (Lanzetta et al. 1991). For a column density \( N_H > 1.0 \times 10^{21} \) the corresponding probability is 0.09. Note that this probability estimate includes only those absorbers seen against optically bright QSOs and is hence a lower limit if dusty systems do indeed exist. Further, the estimate is based largely on QSOs with redshift \( < 3 \), and there is some evidence that the probability of encountering a high column density absorption system increases (by a factor of 2 - 3) at a redshift of \( \sim 3 \). (White, Kinney & Becker 1993). However, even in the most optimistic scenario, the number count is low enough to make it essential to search a large redshift path interval before the probability of detecting a damped-Ly-α system becomes meaningful. The velocity width of the HI 21cm absorption signal is probably small, \( 10 - 100 \text{ km s}^{-1} \) (however, any object which large enough to cover the entire radio emitting region is unlikely to have very small velocity width). This combination of high spectral resolution and simultaneously high instantaneous bandwidth is quite challenging to achieve. Further the interference environment at these frequencies (200 – 300 MHz) is often hostile. The new Compound Interferometry (CI) observing mode...
at the WSRT, along with the newly commissioned broadband 92cm system (Carilli et. al.1995) however does make such observations feasible.

In CI mode, the WSRT is split into two phased arrays, and the summed signal from these arrays is cross-correlated, i.e. one has a two-element interferometer, with each element being a phased array. The reduction in the number of measured spatial baselines (from 40 to 1) allows one to achieve high spectral resolution, up to 8192 channels across an instantaneous bandwidth of 20 MHz. In practice this 20 MHz bandwidth is obtained by using 4 contiguous 5 MHz bands, and after allowing for overlap between the bands the usable instantaneous bandwidths is 16.4 MHz. There is reduced sensitivity to interference because of the interferometers rejection of terrestrial signals, and further unlike single dish radio spectroscopy there is no need to spend large amounts of time calibrating the total power induced spectral band pass shape. A first round of observations were conducted in March 1995, when a total redshift interval of 3.5 was observed towards 4 objects. The typical integration time per frequency setting was \( \sim 8000 \) seconds. Software limitations prevented us from attaining the highest possible resolution; we were instead restricted to a resolution a factor of two worse (i.e. \( \sim 25 \) km s\(^{-1}\)).

2.2. DATA REDUCTION

The shape of the spectral baseline (or the equivalently the frequency dependence of the visibility) is a function of the distribution of background sources and the hour angle. (For example, a bright source at the 10 dB point of the primary beam would lead to baseline structure on the scales of \( \sim 2 \) MHz). Figure 1[A] shows the observed visibility during a single 80s integration towards the radio source 8C1435, showing the dramatic influence of background sources in determining the shape of spectrum. However, this spectrum can be easily modeled (Figure 1[B]) if one has a map of the sky (as seen by the same telescopes). Modeling is done by special purpose software produced by us, and is in general quite successful although there are occasionally residuals which might be attributable to imperfect knowledge of the shape of the primary beam, and also perhaps to some low level cross-talk in the adding stage.

The data reduction proceeds along the following steps (i) the raw spectra are calibrated to an absolute flux level using observations of calibrator sources interspersed throughout the observation (ii) the spectra are then corrected for the instrumental bandpass using observations of these same calibrator sources (iii) Model background sources (obtained from an independent continuum map of the field, sometimes from the WENSS survey, and sometimes from other projects) are subtracted from the spectrum, (iv)
any residual large scale baseline features are removed by low order polynomial fitting (v) RFI is flagged and the spectra are co-added to yield the final spectrum.

3. Preliminary Results

Figure 2 shows the final spectrum towards 8C1435, which is a radio galaxy at $z \sim 4.25$ (Lacy et al. 1994). It has a flux at 350 MHz of $\sim 2.7$ Jy and a spectral index $\alpha \sim -1.2$. The low frequency flux is presumably dominated by the two hot spots, which have a separation of $\sim 5''$, or $\sim 20$ kpc in a flat $\Omega = 1$ universe. The total redshift range observed is $\Delta z \sim 0.63$, which is about 65% of the available redshift (using the WSRT broadband 92cm system) towards this object. The noise is $\sim 13$ mJy, which is the expected thermal noise limit. The spectral resolution is $\sim 25$ km s$^{-1}$.

We do not detect any narrow linewidth absorption in this redshift interval. At the center of the band the 4$\sigma$ upper limit to the optical depth (assuming that the object covers the entire radio emitting region) is $\tau < 2 \times 10^{-2}$, or

$$N_H \lesssim 8.8 \times 10^{20} \times \frac{\Delta V}{25 \text{ km s}^{-1}} \times \frac{T_s}{1000 \text{ K}}$$  

(1)

The data to the remaining objects is being reduced. A further redshift interval of $\sim 3.5$ will be observed shortly (with a frequency resolution a factor of two better than that for these observations). Continuum mapping observations of the same field with the broadband 92cm should enable us to model the spectra within the thermal noise and thus obviate the necessity to fit low order polynomials and dramatically improve our ability to detect both weak broad lines, (for example from larger scale structure along the line of sight), and also recombination lines from ionized gas associated with the radio galaxy itself.

The WSRT will soon have a UHF(high) system covering the frequency range between 1200 MHz and 700 MHz, with a system temperature $\sim 75$ K at the upper end of the band, which will make it practical to search for HI 21 cm absorption towards complete samples of radio galaxies. Predictions that the maximum effect due to obscuration is at $z \sim 1$, (Fall & Pei 1995) makes such a search specially interesting. Acknowledgments. These observations would not have been possible without the substantial and enthusiastic support of the WSRT staff, in particular A. J. Boonstra, A. Bos, J. Bregman, H. Butcher, H. v. Sommeren Greve and the telescope operators. We are also grateful for software and insightful comments from F. Briggs.
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