GMRT Observations of Low $z$ Damped Ly$\alpha$ Absorbers

Jayaram N. Chengalur$^1$* and Nissim Kanekar$^1$†

$^1$National Center for Radio Astrophysics (TIFR), University of Pune Campus, P. O. Bag 3, Ganeshkhind, Pune 411007, India.

ABSTRACT

We present Giant Metrewave Radio Telescope (GMRT) observations of redshifted HI 21cm absorption in two low redshift ($z = 0.2212$, $z = 0.0912$) damped Ly$\alpha$ systems seen towards the Gigahertz peaked source OI 363 ($z_{em} = 0.630$). The object at $z = 0.0912$ is the lowest redshift damped Ly$\alpha$ system known to date. Ground based imaging (Rao & Turnshek 1998) shows that at neither redshift is there a large spiral galaxy at low impact parameter to the line of sight to OI 363, in contradiction with the suggestion that damped Ly$\alpha$ systems are large proto-disks. Since OI 363 is a highly compact, core dominated source, the covering factor of the HI gas is likely to be unity. Nonetheless, the spin temperatures derived from the 21cm optical depth (and using the $N_{HI}$ measured from HST spectra (Rao & Turnshek 1998)) are high, viz. $1120 \pm 200$ K and $825 \pm 110$ K for the high and low redshift systems respectively. These values are considerably higher than typical values ($100 - 200$ K) measured in our Galaxy and Andromeda and are, in fact, similar to those obtained in high redshift damped Ly$\alpha$ systems. Our observations hence suggest that evolutionary effects may not be crucial in understanding the difference in derived spin temperature values between local spiral disks and high redshift damped Ly$\alpha$ systems.

Key words: quasars: absorption lines, galaxies: evolution, ISM: general, cosmology: observations

1 INTRODUCTION

Damped Ly$\alpha$ systems are the extremely high HI column density ($N_{HI} > 2 \times 10^{20}$ atoms cm$^{-2}$) systems seen in absorption in the spectra taken towards distant quasars. Although rare, they are the dominant contributors (by mass) to the observed neutral gas at high ($z \sim 3$) redshifts. Principally for this reason, these systems are natural candidates for the precursors of $z = 0$ galaxies. Consistent with this interpretation, the mass density of neutral gas in damped Ly$\alpha$ systems at $z \sim 3$ is comparable to the mass density in stars in luminous galaxies at $z = 0$. Thus, to zeroth order, the evolution with redshift of the neutral gas density matches that expected from gas depletion due to star formation (eg. Lanzetta et al. 1991, Lanzetta, Wolfe & Turnshek 1995, Storrie-Lombardi, McMahon & Irwin 1996). Further, the evolution of metallicity with redshift also roughly matches what one would expect from models of galactic evolution (Ferrini, Mollá & Diaz 1997, Fall 1997).

On the other hand, the morphology of damped Ly$\alpha$ systems remains poorly understood. Based on the edge-leading asymmetries seen in the absorption profiles of low ionization metals associated with these systems, Prochaska & Wolfe (1997) suggest that they are rapidly rotating large disks with significant vertical scale heights. However, such profiles can also be explained by models in which damped systems are much smaller objects that are undergoing infall and merger (Haehnelt, Steinmetz & Rauch 1997). It has also been claimed that the metal abundance of damped Ly$\alpha$ systems depends on the total HI column density in a way as would be expected from large disks with central HI holes (Wolfe & Prochaska 1998), although the number of systems involved in this study is small.

For damped Ly$\alpha$ systems that lie in front of radio loud quasars, it is possible to augment the optical/UV spectra with HI 21cm absorption spectra. Such a comparison, yields, among other things (and under suitable assumptions), the spin temperature, $T_s$, of the HI gas. Derived spin tempera-
tures of damped Lyα systems have, in general, been much larger than those observed in the disk of the Galaxy or in nearby galaxies (Braun & Walterbos 1992, Braun 1996), implying that either damped Lyo systems are not disks, or that the ISM in the damped Lyo proto-disks is considerably different from that in the local z = 0 disks, presumably due to evolutionary effects.

Studies of low redshift damped Lyα systems are particularly interesting in this regard, since evolutionary effects are expected to be negligible. Further, much more detailed information is obtainable, in particular from HST and/or ground based imaging, which makes identification of the absorber possible (eg. Le Brun et al. 1997, Lanzetta et al. 1997). Of course, it remains a possibility that the population that gives rise to damped Lyα absorption at low redshift is distinct from that at high redshift.

In this paper, we report the detection of redshifted 21cm absorption in two low redshift (z = 0.2212, z = 0.0912) damped Lyα systems seen towards the quasar OI 363 (0738+313, z_em = 0.630) [Lane et al. (1998)]. Observations of the higher redshift system confirm, at considerably improved spectral resolution and sensitivity, earlier results from the Westerbork Synthesis Radio Telescope (WSRT) (Lane et al. 1998), while the lower redshift (z = 0.0912) system is the lowest redshift damped Lyα system known to date.

2 OBSERVATIONS AND DATA REDUCTION

The observations were carried out using the GMRT (Swarup et al. 1991, Swarup et al. 1997). The backend used was the proto-type eight station FX correlator, which gives a fixed number (128) of spectral channels over a total bandwidth that can be varied from 64 kHz to 16 MHz. Due to various ongoing maintenance and installation activities, the actual number of antennas that were available during our observing runs varied between six and eight.

For the observations of the z = 0.0912 system the bandwidth was set to 1.0 MHz. No spectral taper was applied, giving a channel spacing of ∼ 1.8 km s⁻¹. Two observing runs were made, one on 27 June 1998 and the other on 5 July 1998. The on source time for each run was about six hours. Two observing runs were also taken for the z = 0.2212 system (on 26 June 1998 and 4 July 1998), the first with a total bandwidth of 1.0 MHz (i.e. a channel spacing of ∼ 2.0 km s⁻¹) and the other with a total bandwidth of 0.5 MHz (i.e. a channel spacing of ∼ 1.0 km s⁻¹). Each of these observing runs had an on source time of ∼ 4 hours. Bandpass calibration at both redshifts was done using 3C 295, which was observed at least once during each observing run.

The data was converted from the raw telescope format to FITS and then reduced in AIPS in the standard way. Maps were produced after subtracting out the continuum emission of the background quasar using UVLIN, and spectra extracted from the resulting three dimensional cube. The GMRT does not do online doppler tracking; this is, however, unimportant since the doppler shift within any one of our observing runs was a small fraction of a channel. For the lower redshift system, data from the observations on different days were corrected to the heliocentric frame and then combined.

The final spectrum for the z = 0.0912 system is shown in Figure 1. There appear to be two components, one considerably deeper than the other. The fainter component, although weak, was detected in both our observing runs, and its magnitude is also considerably higher than the noise level. It is, of course, possible that the spectrum consists of two components, one of which is broad and weak and the other, much deeper but narrow. The redshift of the narrow component is consistent with the redshift quoted in Rao & Turnshek (1998). The peak optical depth is ∼ 0.18 (i.e. a depth of 390 mJy with the continuum flux of OI363 being 2.0 Jy), and occurs at a redshift of z = 0.09118 ± 0.00001. The FWHM of the line is small, ∼ 5 km s⁻¹.

Lane et al. (1998) report a redshift of z = 0.2212 for the higher redshift system, based on WSRT observations. The 2.0 km s⁻¹ GMRT spectrum (which has a considerably better velocity resolution and sensitivity than the WSRT spectrum) is shown in Figure 2. The redshift measured from this spectrum is 0.2212 ± 0.00001. This is consistent with the redshift measured from the 1.0 km s⁻¹ resolution spectrum (which is not shown here). The peak optical depth (∼ 0.07) is somewhat less than that of the lower redshift system, but the velocity width is comparable, ∼ 5.5 km s⁻¹ (FWHM).
The total HI column density of a damped system can be determined from its Lyα optical depth, to which the HI 21cm optical depth has been measured. The case of OI 363, which the HI column density has been derived from UV absorbers appears to be associated with galaxies spanning a wide range of morphological types (Le Brun et al. 1997). In contrast, at intermediate redshifts, the absorbers appear to be associated with galaxies spanning a wide range of morphological types (Le Brun et al. 1997), and not directly with the disks of large spirals.

While the low number density of damped Lyman-α systems at z < 1 makes it a priori extremely unlikely that two such systems might be found along the same line of sight, the VLB1 map of OI 363 appears to rule out the possibility of this line of sight being biased due to gravitational lensing. The current observations (and the absence of detectable gravitational lensing) do not however place strong constraints on the spin temperatures of the two damped systems, are $1.82 \pm 0.02 \times 10^{18} T_1$ atoms cm$^{-2}$ and $0.71 \pm 0.04 \times 10^{18} T_1$ atoms cm$^{-2}$, for the lower and higher redshift systems, respectively. The column densities measured by Rao & Turnshek (1998), from the damped Lyman-α lines, are $7.9 \pm 1 \times 10^{20}$ atoms cm$^{-2}$ and $1.5 \pm 0.2 \times 10^{21}$ atoms cm$^{-2}$, again in order of decreasing redshift. The spin temperatures obtained are hence $825 \pm 110$ K (for the $z = 0.0912$ absorber) and $1120 \pm 200$ K for the $z = 0.2212$ system. For the higher redshift system, our measurement agrees within the errors with that of Lane et al. (1998). The overwhelming source of the (formal) uncertainty is in the determination of the HI column density from the UV measurements. Thus, even at redshifts where no evolution is expected, the derived spin temperature is significantly higher than that typically seen in the Galaxy. If one assumes that the HI 21cm spectral width is entirely due to thermal motions, the required kinetic temperatures are $\sim 625$ K and $\sim 750$ K for the lower and higher redshifted system respectively, i.e. comparable to the derived spin temperatures. Note however, that in the ISM of the Galaxy, there is no stable neutral phase with temperature $\sim 1000$ K. On the other hand, such high spin temperatures appear common at both high and intermediate redshifts (see eg. de Bruyn, O'Dea & Baum 1996, Carilli et al. 1996, Lane et al. 1996, Kanekar & Chengalur 1997, Boissé et al. 1998).

Ground based imaging of the OI 363 field (Rao & Turnshek 1998) shows that there are no spiral galaxies at small impact parameters to the line of sight, contrary to the canonical model where damped systems arise in extended disks. Similarly, the next lowest redshift damped Lyα absorber (0850+4400, Lanzetta et al. 1997) appears to be associated with an S0 galaxy, while, at intermediate redshifts, the absorbers appear to be associated with galaxies spanning a wide range of morphological types (Le Brun et al. 1997). Interestingly, at lower redshifts still, where imaging of HI 21cm emission is possible, 21cm absorption from quasar galaxy pairs appears to be associated more with tidal tails or other extended features of gas rich galaxies (Carilli & van Gorkom 1992), and not directly with the disks of large spirals.
constraints on the surface density or mass of the absorbing systems.

In summary, it appears that even at the lowest redshifts, gas outside the disks of spiral galaxies and with apparent physical parameters considerably different from the ISM of nearby galaxies has a non-trivial contribution to the total absorption cross-section. This is consistent with observations that, even for intermediate redshift damped Lyα absorbers, the metallicity is considerably lower than typical solar values [Boissé et al. 1998]. Finally, the present GMRT observations also suggest that evolutionary effects may not play an important role in understanding why the derived spin temperature for damped Lyα systems are in general higher than those measured in nearby spiral galaxy disks.

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Figure 1. GMRT redshifted 21cm absorption spectrum of the lower redshift system towards OI363. The channel spacing is $\sim 1.8$ km s$^{-1}$. The deepest optical depth ($\sim 0.18$) is at a heliocentric redshift of 0.09118. The width (FWHM) of the line is $\sim 5$ km s$^{-1}$.

Figure 2. GMRT redshifted 21cm absorption spectrum of the higher redshift system towards OI363. The channel spacing is $\sim 2.0$ km s$^{-1}$. The peak optical depth ($\sim 0.07$) occurs at a heliocentric redshift of 0.2212. The width (FWHM) of the line is $\sim 5.5$ km s$^{-1}$.

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