Revealing High-Redshift Galaxies: Results from a New Damped Lyman-α System Survey

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1. Probing High-Redshift Galaxies with Quasar Absorption Lines

Using quasar absorption lines as a tool to probe matter in the line of sight towards high-redshift quasars has proved to be a powerful technique for studying both galaxies and the intergalactic medium (IGM) alike. High-resolution echelle spectrographs such as UVES on the VLT can now deliver exquisite data which probe the structure and chemical enrichment of the high-redshift universe with unparalleled accuracy. At somewhat lower resolution, instruments such as FORS can provide an efficient means with which to identify the high column density systems that are associated with distant galaxies. Within the menagerie of systems that make up the quasar absorption line 'zoo', Damped Lyman Alpha systems (DLAs) have the highest column densities and are traditionally defined as systems with neutral hydrogen column densities N(H I) ≥ 2 × 10^{20} atoms cm^{-2}. Although DLAs are thought to be the progenitors of present-day galaxies, the precise nature of these absorbers at high redshift is still unclear. At low redshift, however, there is mounting evidence that DLAs are likely to represent a mixed morphological bag (Le Brun et al 1997), including a significant population of LSBs (Bowen et al. 2000).

The power law distribution of H I column densities that extends from the low N(H I) Lyα forest clouds that constitute the IGM up to DLAs implies that these high *z* galaxies seen in absorption are relatively rare. Indeed, it has taken a considerable investment over many years to establish the current database of known DLAs (e.g. Wolfe et al. 1986; Lanzetta et al. 1991; Lanzetta, Wolfe and Turnshek 1995). However, one of the important consequences of this power law distribution, $f(N) \sim N^{-1.5}$, is that although Lyα forest clouds are far more numerous, DLAs contain the bulk of the H I gas by mass. A measure often used to quantify the amount of neutral gas in DLAs is Ω_{DLA}, basically defined as the mass of HI expressed as a fraction of the closure density of the universe. Since this quantity does not depend on the geometry or covering factor of the absorbers, it represents an unbiased census of the neutral gas in the universe. Many of the early DLA surveys have measured the redshift evolution of Ω_{DLA} and found that it decreases steadily from $z \sim 3$ to $z < 1$ (Lanzetta et al. 1991; Lanzetta, Wolfe and Turnshek 1995; Wolfe et al. 1995). Extending this work to higher redshifts, Storrie-Lombardi, McMahon and Irwin (1996) found evidence for a turnover in Ω_{DLA} beyond a $z \sim 3$ and also noted that there is an agreement between the lowest Ω_{DLA} point and the measurement by Rao and Briggs (1993) of the local HI mass density inferred from 21-cm measurements (which is dominated by spirals). In addition, it has been pointed out (e.g. Lanzetta et al. 1999) that the mass of H I in DLAs at $z \sim 3$ is approximately equal to that of luminous matter observed at the present time, i.e. Ω_{DLA} ($z \sim 3$) ~ Ω_{stars} ($z = 0$). Together, these lines of evidence led to the interpretation that DLAs were the basic galactic building blocks assembling the major gas reservoirs for star formation at high redshift.

This rather simple picture has been queried recently by work which has extended the search for DLAs to lower redshifts. Using the HST, Rao and Turnshek (2000) have found evidence that Ω_{DLA} remains approximately constant from $0.5 < z_{abs} < 3.5$, evidence that the situation is probably more complex than once thought. However, it is important to realise that the interpretation of this work is pivotal upon the assumption that DLA surveys afford a fair representation of HI absorption systems over a range of redshifts. Our view of the universe could be severely blinkered if previous samples were shown to be biased due to a selection effect that preferentially identifies a particular breed of absorber.

One factor that could cause such a bias is the presence of dust in the intervening galaxy population, which would cause dimming of the background QSOs. Since almost all known DLAs at this time have been identified from optically-selected samples of quasars, they are susceptible to such a dust bias. It has been shown by Fall and Pei (1993) that, based on the dust-to-gas ratios inferred by reddening of background QSOs, up to 70% of bright quasars at $z \sim 3$ could be missing from current samples. Moreover, Pei and Fall (1995) have shown that dust is *required* in order for the models to reproduce many of the observed properties of DLAs, such as their mean metallicity. The presence of dust in metal-rich systems could also explain the paucity of DLAs with high Zn abundances (Pettini et al. 1999) and the apparent anti-correlation between metallicity and N(H I) (Prantzos and Boissier 2000).

2. A New DLA Survey Sample – Seeing Through the Dust

The strategy of this new survey for DLAs, which will indicate whether previous work has suffered from a dust bias, is to search for DLAs in a complete sample of *radio-selected* quasars. All of these targets will be followed up with optical spectroscopy, regardless of their optical magnitudes.

The survey described here is based on a complete sample of flat-spectrum radio sources from the Parkes Catalogue with flux densities at 2.7 GHz (11 cm) ≥ 0.25 Jy (Shaver et al. 1996). The sample consists of all flat-spectrum ($\alpha > -0.4$, measured at 2.7 and 5.0 GHz) sources with declinations between +2.5° and –80°, excluding low galactic latitudes ($|b| < 10°$) and regions around the Magellanic Clouds. Accurate radio source positions for these 878 sources were taken from the Parkes Catalogue where available and a combination of VLA and Australia Telescope measurements otherwise. Source identification and B-band magnitudes were determined by cross-correlation with images obtained from either the COSMOS Southern Sky Catalogue or taken at the ESO 3.6-m telescope at La Silla. Low-resolution spectra (FWHM = 12–14 Å) were obtained for the 442 stellar identifications (QSOs and BL Lacs) with the EFOSC on the ESO 3.6-m to determine redshifts.

For this survey, we have selected the 66 QSOs with emission redshifts $z_{em} \geq 2.2$. Optical spectroscopy is used to identify DLAs with $1.8 \leq z_{abs} \leq z_{em}$ in all of these targets, the faintest of which has a B = 24.0. Our strategy has been to divide the sample into a 4-m sample (B < 20) and an 8-m sample (B > 20). The former have been observed with the ESO 3.6-m on La Silla at a typical resolution of 7 Å FWHM and at the AAT with a typical resolution of 3 Å FWHM (see Ellison 2000 for more details), whilst the latter will be observed with FORS1 on the VLT.

3. Preliminary Results

Observations for the 4-m sample have now been completed and resulted in the identification of 10 DLAs towards 48 QSOs. Figure 1 shows an example of a DLA found towards one of our targets (left panel) and the DSS finding chart for the QSO with overlaid radio contours (right panel). The remaining 18 targets which constitute the 8-m sample will be observed this semester (Period 66) with FORS1 on the VLT. Clearly, these faint targets represent the important sight lines which will determine whether previous magnitude limited surveys suffer from a dust bias.

With the termination of 4-m observations, the survey is currently complete down to B = 20 and therefore does not represent a major improvement over previous samples. In fact, somewhat encouragingly, we determine that Ω_{DLA} for our 4-m sample is consistent with previous estimates from surveys with similar magnitude limits, $\Omega_{DLA} h_{100} = 1.8 \times 10^{-3}$ ($q_0 = 0.5$). In addition, we find that the number of DLAs per unit redshift also agrees with previous work, n(z) = 0.25 for $z_{abs} = 2.32$. However, an interesting departure emerges when the 4-m sample (hereafter S1) is split by magnitude into S2 ($B \geq 19.0$) and S3 ($B < 19.0$). As can be seen in Figure 2, although the error bars are still large due to limited statistics (7 DLAs in S2 and 3 in S3), there appears to be more HI in systems found towards faint QSOs. Since we can discount the possibility that this is merely a colour effect caused by redshift (the S1 sample shows no trend of B magnitude versus z_{em}), we conclude that this result is consistent with the presence of a dust bias. In order to improve the statistics, S3 has been supplemented with DLAs found in the LBQS (Wolfe et al 1995) which also has a limiting magnitude of approximately $B = 19$. The LBQS+S3 point in Figure 2 remains significantly lower than S2.

This is still just a tantalising hint that a dust bias may be affecting the selection of high redshift DLAs, but one which has far-reaching possibilities. DLAs play a key role in our understanding of chemical evolution and structure formation at high redshifts, work which assumes that we can sample high-z galaxies in an unbiased way. For example, Pettini et al. (1997, 1999) have used the Zn abundance to trace the chemical enrichment of DLAs as a function of redshift but have failed to find a significant increase in metallicity with time. This surprising result may be an indication that metal-rich, and therefore dusty, DLAs are under-represented in current DLA samples, which would then give only a partial view of metal enrichment in high-redshift galaxies. As tracers of large matter overdensities, the space density of DLAs reflects the fraction of matter that has collapsed into bound structures at a given redshift. This fact has been used by Peacock et al. (1998) to constrain the initial spectrum of density fluctuations on small scales (< 1 Mpc) and has been shown to be a sensitive test of current theories of structure formation (Gardner et al. 1997).

However, proof will come with the execution of the 8-m VLT sample due to be completed with FORS1 in March 2001. Only with an 8-m-class telescope can intermediate resolution spectroscopy of such faint targets be realised. The VLT/FORS is poised to resolve this crucial issue and determine once and for all the extent to which our view of high-redshift DLAs is biased by dust.

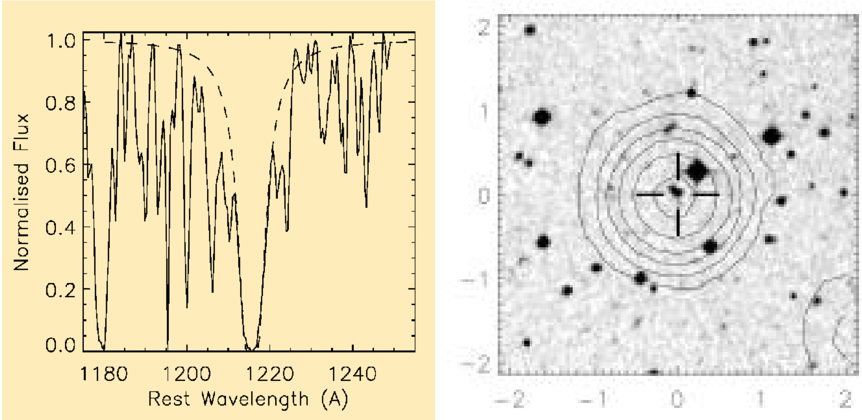

Figure 1: An example of one of the survey targets, B1354-107. In the left panel, a section of the AAT spectrum is shown, the broad absorption trough that is the signature of a DLA is clearly visible. The dashed line shows a fit to the DLA profile, with log N(H I) = 20.4. In the right panel is a DSS image of the QSO overlaid with NVSS radio contours.

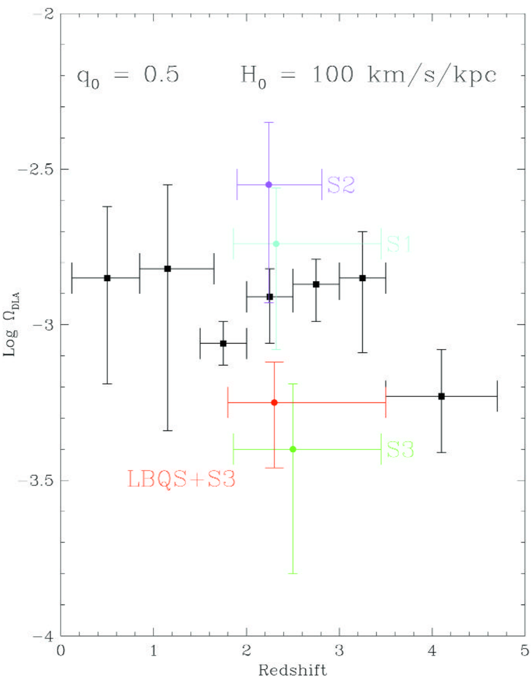

Figure 2: Possible evidence for a dust bias in DLA surveys. Coloured circles show the value of Ω_{DLA} for the 3 sub-samples defined for the new survey described here. The cyan point represents the results for our full 4-m sample (S1), complete down to B = 20 and is consistent with previous determinations from magnitude limited samples (black squares, Rao and Turnshek 2000). Comparison of sub-samples S2 and S3 (supplemented with the LBQS to improve statistics) is consistent with a dust bias and indicative of more HI towards fainter QSOs.

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