

The Physical Characteristics of Quasar Absorption Systems

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1 Introduction

Quasars (originally short for “quasi-stellar radio sources”) were first discovered in the 1950s as randomly distributed radio sources in the Cambridge radio surveys, with the first identification of an optical counterpart in 1963 (e.g. Hazard et al. 1963; Oke 1963; Schmidt 1963). Although first discovered as radio sources, the majority of quasars are not radio-loud (i.e. their radio flux is $< 5 \text{ mJy}^1$), with only about 10% having significant radio emissions. Optically, quasars are point sources even at the highest resolution available to current telescopes, both ground- and space-based. The discovery of absorption lines in quasar spectra followed shortly after the discovery of quasars themselves (e.g. Bahcall et al. 1966 for the detection of absorption at $z = 1.949$ in a QSO with a redshift of $z = 2.118$). By the 1980s, the absorption lines were shown to be the result of intervening gas, thus also demonstrating that the redshifts of the quasars themselves were cosmological (e.g. Young et al. 1982). See Figure 1 for an example of a quasar spectrum, including absorption lines.

Quasar absorption systems are classified based both on their method of discovery, and on their neutral hydrogen column density ($N(\text{H I})$). Classifications based on $N(\text{H I})$ (using the Lyman- α ($\text{Ly}\alpha$) $\lambda 1215.67 \text{ \AA}$ transition of H I) include $\text{Ly}\alpha$ forest absorbers ($N(\text{H I}) < 10^{17} \text{ cm}^{-2}$), Lyman limit systems ($10^{17} < N(\text{H I}) < 2 \times 10^{20} \text{ cm}^{-2}$), and finally damped $\text{Ly}\alpha$ systems (DLAs) ($N(\text{H I}) > 2 \times 10^{20} \text{ cm}^{-2}$). Methods of detection include the presence of the $\text{C IV } \lambda\lambda 1548.1, 1550.7 \text{ \AA}$ doublet (systems detected primarily through C IV are generally $\text{Ly}\alpha$ forest systems) and the $\text{Mg II } \lambda\lambda 2796.3, 2803.5 \text{ \AA}$ doublet (depending on the rest equivalent width of the Mg II line (W_r^{2796}), these may be $\text{Ly}\alpha$ forest systems, Lyman limit systems, or even DLAs, although the Mg II doublet saturates quickly enough that a high W_r^{2796} does not necessarily indicate that the system is a DLA).

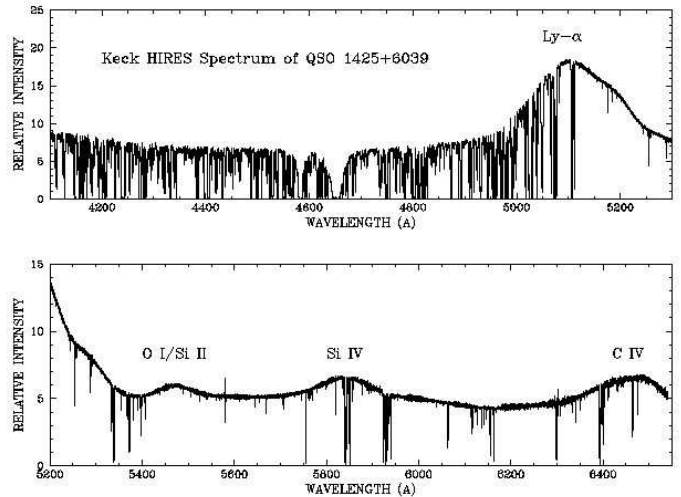


Figure 1: The spectrum of quasar Q1425+6039 (emission redshift $z_{em} = 3.18$), taken with the Keck High Resolution Echelle Spectrograph (HIRES). Note the absorption lines to the blue of the $\text{Ly}\alpha$ emission line (the “Lyman α forest”), including the large absorber at 4650 \AA (a Damped Lyman- α system). Metal lines associated with the absorbers are seen redwards of the quasar’s $\text{Ly}\alpha$ emission peak. Figure from Wallace Sargent, <http://www.astro.caltech.edu/~wvs/qsoabs.html>.

The existence of absorption systems was initially a clue as to the origin of quasars, but quickly became its own area of study. High column-density absorbers (such as DLAs) offer an insight into the interstellar medium (ISM) at high redshift, as well as into the metallicity evolution of galaxies (Wolfe et al., 2005). Absorbers with lower $N(\text{H I})$ offer an opportunity to investigate the power spectrum of the cosmic microwave background (CMB), as well as insight into the relative importance of outflows and Population III stars in producing metal enrichment in the low-density voids (Rauch, 1998).

¹1 Jy $\equiv 10^{-26} \text{ W m}^{-2} \text{ Hz}^{-1}$

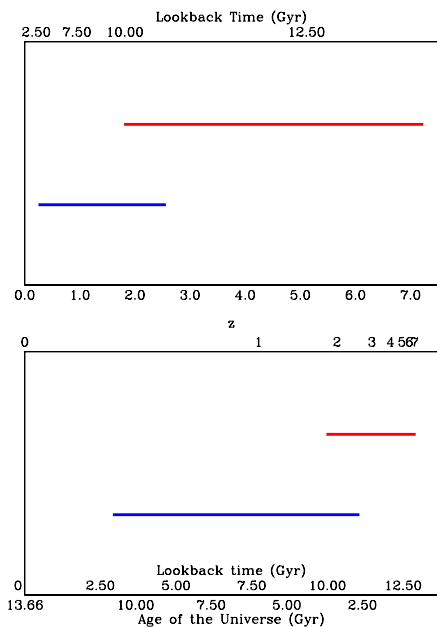


Figure 2: The redshifts and lookback times during which Mg II systems (blue, bottom line in both panels) and the Ly α transition (red, top line in both panels) can be detected in the optical ($3500 \text{ \AA} < \lambda < 10000 \text{ \AA}$).

Because of their high column density, DLAs have sufficient hydrogen self-shielding to produce a *predominantly* neutral medium. Indeed, on the redshift interval $z = [0, 5]$, DLAs dominate the neutral gas content of the universe, and may thus be seen as the reservoir for star formation at high redshifts. Unlike galaxies, which are seen through their emitted light, and which thus tend to provide information on their stellar populations and ionized gas, DLAs are able to trace the gaseous medium directly, including gas-phase molecules and physical properties of the interstellar medium (e.g. metallicity, temperature, dust-to-gas ratio). Finally, because they are seen in absorption and are selected solely because they are located between us and a background quasar, DLAs offer what is in principle an unbiased view of the high-redshift universe, whereas galaxy surveys, because they rely on the light emitted by the galaxies themselves, tend

2 Research Goals

In order to amass as large as possible a sample of low-redshift DLAs, some method other than UV spectroscopy must be devised to determine the N(H I) of an absorption system where the Ly α line is in the UV. The diffuse interstellar bands (DIBs) offer one possible proxy for N(H I). First discovered in the early 1920s (Heger, 1922), the DIBs are a family of several hundred broad

to be inherently biased towards the more luminous objects (Wolfe et al., 2005).

While DLAs offer a valuable insight into the high-redshift universe, Mg II systems, *some* of which are DLAs, have been detected in much greater abundance. Their key advantage of Mg II systems (when it comes to detection) is the range of redshifts over which they can be detected by optical telescopes. Although both the Ly α and the Mg II transitions have rest wavelengths in the ultraviolet (which does not penetrate the Earth's atmosphere below $\sim 3000 \text{ \AA}$), the Ly α transition does not redshift into the optical until $z = 1.8$ (assuming that the Ly α transition can be detected at 3400 \AA), whereas the Mg II transition redshifts into the optical at $z = 0.25$ (assuming that the Mg II transition can be detected at 3500 \AA). Figure 2 shows the redshift range and the lookback times over which both transitions are detectable in the optical². As the figures show, the Mg II transition is easily detectable with optical telescopes over the majority of the age of the universe, while the Ly α transition does not shift into the optical for more than 70% of the age of the universe. UV spectrographs mounted on space telescopes (such as the Space Telescope Imaging Spectrometer (STIS) on the Hubble Space Telescope) were able to detect the Ly α transition in low- z DLAs, but the failure of STIS in 2004 leaves no remaining UV spectrograph in operation.

Rao et al. (2006) determined that the success rate for discovering low-redshift DLAs by selecting Mg II systems with $W_r^{2796} > 0.3 \text{ \AA}$ and the Fe II $W_r^{2600} \geq 0.5 \text{ \AA}$ is $(36 \pm 6)\%$ and that, when the Mg II systems are further selected to so that $W_r^{2796}/W_r^{2600} < 2$ and Mg I $W_r^{2862} > 0.1 \text{ \AA}$, the success rate increases to $(42 \pm 7)\%$. Rao et al. have thus provided a method of selecting *likely* DLAs for later follow-up with UV spectroscopy (when available, and if the exact N(H I) is important). They have also determined the average N(H I) as a function of W_r^{2796} , which allows for a statistical treatment of low- z Mg II-selected systems.

absorption bands arising from gas-phase molecules in interstellar space (see Figure 3). No specific DIB has yet been conclusively linked to a particular molecule, although polycyclic aromatic hydrocarbons (PAHs), long carbon chains, and fullerenes have all been suggested as possible candidates (Sarre, 2006). In addition to their detection along numerous sight-lines in the Milky

²All cosmological calculations assume $\Omega_M = 0.27$, $\Omega_\Lambda = 0.73$, and $H_0 = 100h \text{ km s}^{-1}$, with $h = 0.71$.

Way, DIBs have also been detected towards the Large and Small Magellanic Clouds (e.g. Welty et al. 2006), and towards a number of local starburst galaxies (e.g. Heckman & Lehnert 2000). Given these detections, the stronger DIBs should be detectable in DLAs given spectra with sufficiently high signal-to-noise ratios.

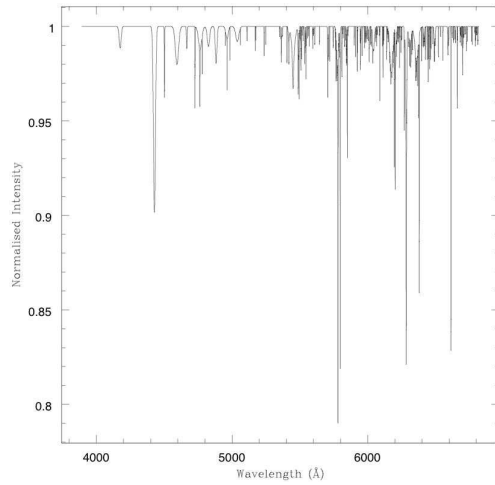


Figure 3: The 226 DIBs observed towards BD+63°1964. Figure from Tuirisg et al. (2000).

In order to provide a proxy for $N(\text{H I})$, there must be some relationship between the DIBs and the neutral hydrogen column density. While most DIBs are not directly correlated with $N(\text{H I})$, the 5780 Å DIB is strongly correlated with $N(\text{H I})$, at least in the Milky Way (Herbig, 1993). Figure 4 shows this relationship. If the relationship were to hold in DLAs, then the minimum W_r^{5780} encountered would be $\sim 14 \text{ mÅ}$ (corresponding to $N(\text{H I}) = 2.0 \times 10^{20} \text{ cm}^{-2}$), and most DLAs would have an even greater W_r^{5780} . Because the 5780 Å DIB remains in the optical ($\lambda < 1 \mu\text{m}$) until a redshift of $z = 0.7$, the 5780 Å DIB would be able to serve as a useful proxy for almost half of the redshift range over which the Ly α transition is too far into the UV to be detectable with optical telescopes. For higher redshifts ($0.7 < z < 1.8$), the 5780 Å transition remains within the J and H infrared bands, and thus would still be detectable by near infrared spectroscopy.

In addition to the relationship between the 5780 Å DIB and the H I column density, there are other correlations between DIBs which have been observed in the Milky Way (e.g. Sarre 2006). Correlated DIBs are known as “families”, and it is thought that at least some families are sets of lines caused by the same carrier. For example, the weak DIB at 5795 Å is well-correlated with the 5780 Å DIB (Wszolek & Godlowski, 2003), and the strong 5797 Å DIB is correlated with another strong

DIB at 6613 Å (Cami et al., 1997). Determining which correlations actually indicate DIBs with the same carrier (“spectroscopic families”) is a difficult task, and one which observations of DLAs could address. Any correlation observed in Galactic sight-lines but not in DLAs is likely a chance product of the Milky Way’s composition and environment, while a correlation which is found on every sight-line is far more likely to indicate that the DIBs involved arise from the same carrier.

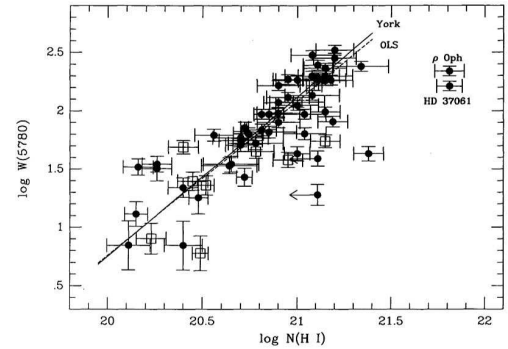


Figure 4: The dependence of W_r^{5780} upon $N(\text{H I})$. Horizontal error bars are those given by the H I observers, and vertical error bars correspond to a recipe defined in Herbig (1993) Figure from Herbig (1993).

The Diffuse Interstellar Bands may also provide information about physical conditions within the DLA’s ISM, particularly since there is evidence that DIB carriers are ionized (Cami et al., 1997). Cami et al. (1997) show that in Galactic sight-lines, the relative strength of the DIBs at 5780 and 5797 Å depends on the UV background. While the 5780 Å DIB reaches its maximum strength only for strong UV radiation, the 5797 Å DIB reaches its maximum much earlier, with its strength declining slowly thereafter, even while the strength of the 5780 Å DIB continues to grow (Cami et al., 1997). This behaviour implies that the two DIBs have carriers with different ionization potentials, with the 5797 Å DIB carrier having the lower potential. If multiple DIBs are detectable in DLAs, their relative strengths might allow a similar determination to be made about the physical conditions inside the DLA.

Another important physical characteristic of DLA absorbers is the temperature of the ISM. The ISM of local galaxies (and low- z DLAs, e.g. Lane et al. 2000) exists in two stable phases, a cold, dense phase (the cold neutral medium or CNM, $T \sim 100 \text{ K}$) and a warm extended phase (the warm neutral medium or WNM, $T \sim 8000 \text{ K}$). H I, in addition to its Ly α absorption, also absorbs at 21 cm (the hyperfine spin-flip transition), with the CNM absorbing considerably more efficiently

³The spin-flip transition arises from the slight energy difference between the spin parallel and spin antiparallel states for the proton and electron in the H I atom.

than the WNM³. Thus, if the $N(\text{H I})$ of a DLA is known from the Ly α transition, and the background quasar is radio-loud (true for less than 10% of QSOs), measuring the 21-cm “spin temperature” (T_s) can determine what fraction of the H I is in the CNM vs. the WNM. For the optically thin case

$$N_{\text{H I}} = \frac{1.823 \times 10^{18} T_s}{f} \int \tau dV, \quad (1)$$

where f is the “covering fraction” (the fraction of the background radio source actually covered by the absorber), τ the optical depth, integrated over the velocity width of the absorption, and T_s the column-density-weighted harmonic mean of the spin temperatures of the individual clouds along the line of sight. If the cloud is optically cold and collisionally-dominated, T_s is equal to the kinetic temperature, T_k . In the local universe, spiral galaxies tend to have an ISM mean temperature of 100-300 K (e.g. Braun 1997), while local dwarf galaxies have much higher mean temperatures, often exceeding 1000 K (e.g. Young & Low 1997). Metallicity likely has some influence on this difference, as the cooling of gas-phase H I is made considerably more efficient by the presence of dust and metals (e.g. Norman & Spaans 1997). In DLAs, the same effect is observed – low-temperature DLAs are associated with spiral galaxies while, at low redshift, DLAs associated with dwarf or LSB galaxies have high spin temperatures, giving an empirical relationship, at least at low redshift, between spin temperature and galaxy morphology (Kanekar & Chengalur, 2003).

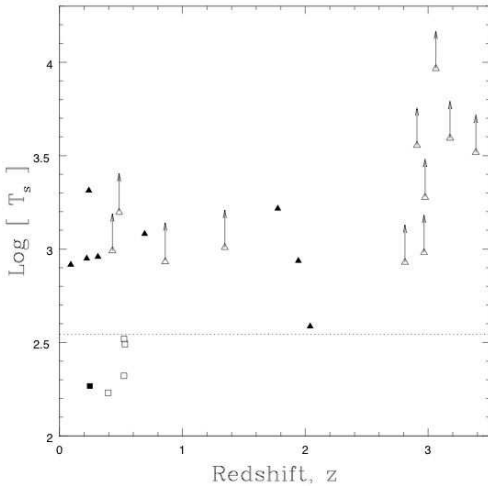


Figure 5: DLA T_s/f vs. redshift. Squares are spiral galaxies, filled triangles are 21-cm detections, and open triangles 21-cm non-detections. Figure from Kanekar & Chengalur (2003).

At higher redshifts, only high spin temperatures have

⁴A non-detection at 21-cm corresponds to a lower limit to T_s

⁵Wolfe, Gawiser & Prochaska used a solution with a 50% WNM and 50% CNM

been observed thus far, with four detections and nine lower limits⁴ at $z > 2$, but no absorbing galaxy identifications have been made amongst the high- z galaxies with spin temperature measurements (see Figure 5). Kanekar & Chengalur (2003) found that, with respect to T_s measurements, low- and high-redshift DLAs were drawn from different populations at the 99% confidence level. Curran et al. (2005), however, argued that this effect was instead due to the covering fraction (which is often unknown, and which would be expected to be lower at higher redshifts because the angular size of a high-redshift absorber would be closer to the angular size of the quasar’s background radio source), and that the difference was not apparent when unknown covering fractions were not assumed to be one (see Figure 6). A DLA with $f < 1$ has a lower T_s than one with the same $N(\text{H I})$ and τ but $f = 1$ (see Equation 1). Covering fractions have long been acknowledged as an issue, and VLBI mapping of the core flux density of the quasars has been able to determine the covering fraction for several previously unknown systems (e.g. Kanekar et al. 2007).

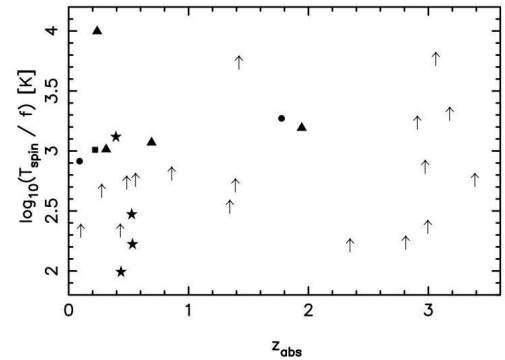


Figure 6: DLA T_s/f vs. redshift. Stars are spiral galaxies, squares dwarf galaxies, triangles LSB galaxies, circles unknown galaxies and arrows 21-cm non-detections. Figure from Curran et al. (2005).

Another argument for the existence of a substantial cold neutral medium in DLAs was made by Wolfe et al. (2003), where the presence of the C II* absorption line was shown to rule out a *pure* warm neutral medium (even in systems with a high measured T_s), but to allow a two-phase ISM⁵. In the case of PKS 0201+113, however, Kanekar et al. (2007) showed that, while a two-phase medium is possible, the fraction of H I in the cold neutral medium could be at most $f_{\text{CNM}} = N_{\text{CNM}} / (N_{\text{CNM}} + N_{\text{WNM}}) \sim 0.17$. Whatever the precise solution, the low number of 21-cm measurements (and, especially, the low number of detections) at $z > 2$ is a key problem.

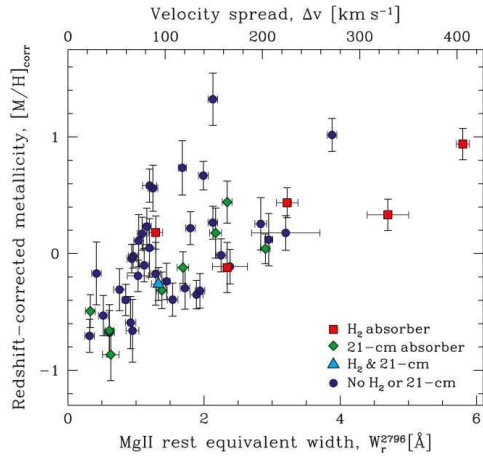


Figure 7: The correlation of W_r^{2795} with absorber metallicity. Figure from Murphy et al. (2007).

The T_s -morphology relationship observed at low redshift is also effectively a T_s -mass relationship, because the metal-rich spirals with low measured spin temperatures are also relatively massive galaxies (there is a known mass-metallicity relationship for galaxies, e.g. Köppen et al. 2007). If the masses of DLAs could be determined, then the mass-metallicity of DLAs (if any) could also be determined, and compared to the galactic mass-metallicity relationship, a comparison which might help to determine how close the association between DLAs and galaxies actually is. One potential way to determine the mass of DLAs involves the equivalent width of the Mg II line (or any other easily-detectable, often saturated line). Because this line is saturated for DLAs (and even for Lyman limit systems), $W_r^{2796} \propto \Delta v_r^{2796}$. If Δv_r^{2796} is related to the velocity dispersion of the absorber as a whole, then W_r^{2796} would be related to the DLA absorber’s mass via an existing empirical relationship between mass and velocity dispersion (e.g. De Rijke et al. 2007).

Previous research has shown two separate clues to the situation. Using Sloan Digital Sky Survey (SDSS) data, Nestor et al. (2003) found that W_r^{2796} and metallicity were correlated for Mg II systems (assuming that the mean $N(\text{H I})$ was not significantly different for

systems with $W_r^{2796} \geq 1.3 \text{ \AA}$ than for systems with $1.0 < W_r^{2796} < 1.3 \text{ \AA}$), while York et al. (2006b) found an anticorrelation based on a constant dust-to-gas ratio (i.e. $N(\text{H I}) \propto E(B - V)$, assuming an SMC extinction curve and using composite SDSS spectra to determine $E(B - V)$). Murphy et al. (2007), using only known DLAs with existing $N(\text{H I})$ measurements, found that W_r^{2796} and metallicity (measured by $[\text{Zn}/\text{H}]^6$ when possible, and either $[\text{Fe}/\text{H}]$ or $[\text{Cr}/\text{H}]$ otherwise) were correlated for DLAs and sub-DLAs (see Figure 7. As a separate result Bouché et al. (2006), by measuring the clustering of luminous red galaxies (LRGs) both with respect to Mg II absorbers and with respect to one another, found an anticorrelation between W_r^{2796} and absorber mass (see Figure 8. While these results seem initially to be contradictory, there are several possible explanations. If DLAs are associated with outflow winds from galaxies rather than the galaxies themselves, then less massive galaxies might be expected to have stronger escaping winds with more metals. Alternately, by requiring candidate Mg II systems to also show absorption from Fe II $\lambda 2600$ or Mg I $\lambda 2852$, Bouché et al. (2006) may be incomplete in their lowest W_r^{2796} bin, and it is this bin which shows the strongest correlation. An independent test of the relationship (if any) between absorber mass and W_r^{2796} could resolve this uncertainty.

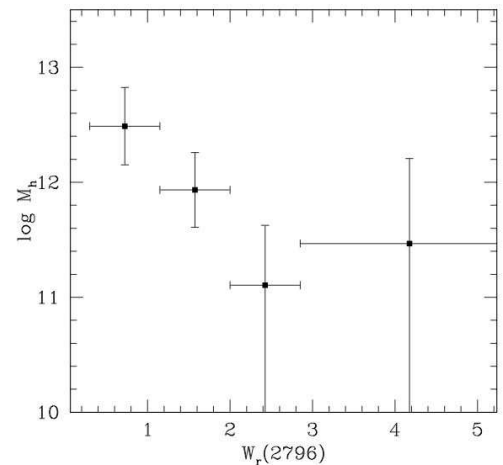


Figure 8: The anticorrelation of W_r^{2795} with absorber halo mass. Figure from Bouché et al. (2006).

3 Plan of Action

In order to address these questions, my thesis will include three related sets of observations. The first group of observations will include high signal-to-noise spectroscopy taken of quasars with known low-redshift DLAs whose $N(\text{H I})$ has already been measured. These

systems will be selected to ensure that, at the redshift of the absorber, any strong DIB features will not be superimposed on either skylines or telluric absorption. The goal of these observations will be to detect at least any strong DIBs (e.g. 5780, 5797, 6284, and 6613 \AA) and,

⁶For metallicities here, $[\text{X}/\text{H}] \equiv \log(N(\text{X})/N(\text{H})) - \log(N(\text{X})/N(\text{H}))_{\odot}$

in particular, the 5780 Å DIB, in order to test the relationship between DIB strength and $N(\text{H I})$.

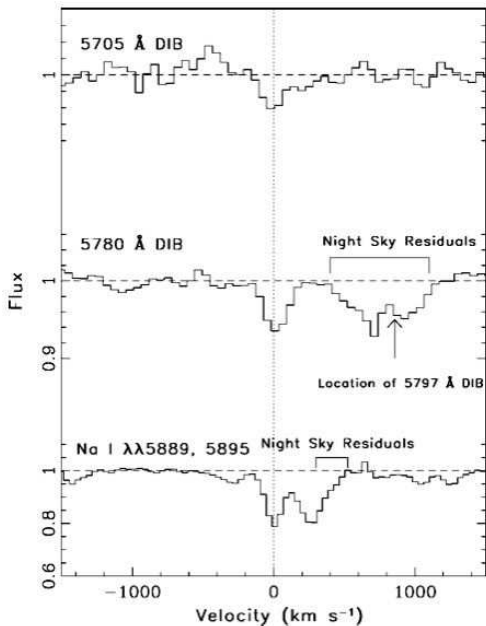


Figure 9: The 5705 and 5780 Å DIBs, and the $\text{Na I } \lambda\lambda 5891, 5897$ doublet from the DLA towards AO 0235+164. Velocity scale is relative to $z_{\text{abs}} = 0.5238$. Figure from York et al. (2006a).

The next set of observations is designed to obtain a larger sample of 21-cm measurements for high-redshift DLAs. While an existing set of observations (such as SDSS, which is linked with the FIRST 21-cm radio survey) might seem like an ideal choice, optically-selected QSO surveys are extremely inefficient at selecting targets for 21-cm follow-up. Only one in ten quasars is radio-loud (defined as having a flux of 5 mJy) and, of those, many are not radio-loud at the low frequencies (below 1.4 GHz) where redshifted 21-cm absorption would be found. Thus the SDSS DR2, despite having more than 2,500 quasars at $z > 2.5$, had only three DLAs which *might* have been suitable for 21-cm follow-up (none of these candidates had a known low-frequency flux). The proper survey method, then, is to begin with a *radio*-selected survey. In particular, the Texas low-frequency survey (Cotton, 1976) is ideal as QSOs detected by that survey are known to be radio-loud at

4 Observations and Results

Thus far, we have observed four DLAs (towards AO 0235+164, Q0952+179, Q1127-145, and Q1229-020) in a search for DIBs in the optical. Of these, we detected two DIBs (at 5705 and 5780 Å) in one DLA at $z = 0.524$ towards AO 0235+164 (York et al., 2006a,

proper frequencies for 21-cm follow-up. While not every QSO will have a DLA absorber at a detectable redshift, the odds are still better using this method than they would be for an optically-selected survey.

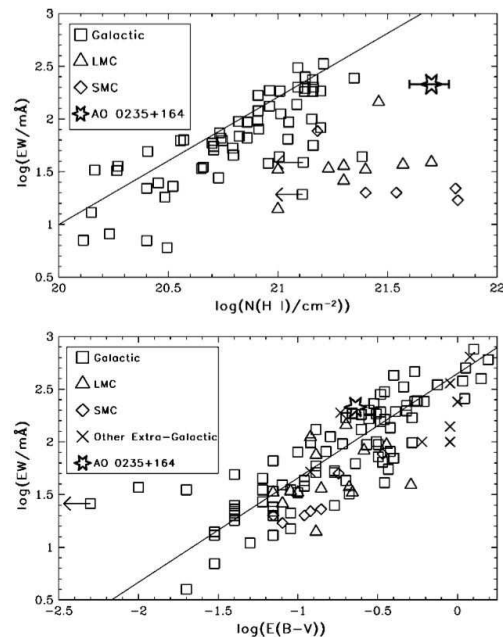


Figure 10: The 5780 Å DIB- $N(\text{H I})$ relationship, and the 5780 Å DIB- $E(B - V)$ relationship. Figure from York et al. (2006a).

Finally, in order to obtain candidate Mg II systems to test the relationship between mass and W_r^{2796} , the SDSS does prove to be an appropriate solution. J. Willis, P. Hewett and R. LASTNAME have already amassed a catalogue of systems which have both a background quasar and a foreground galaxy in the same 3'' fibre aperture (and which thus have their SDSS spectra superimposed on one another). Currently they have obtained high-resolution imaging data for 32 of these systems, and they will be using gravitational lensing to determine the system mass. In cases where the foreground galaxy is at a sufficiently high redshift, the Mg II absorption, if any, may be directly obtained from the SDSS spectrum. For the remaining systems, if the Mg II lines are redshifted into the optical, follow-up spectroscopy with either a 4- or 8-m class telescope should prove sufficient to determine W_r^{2796} .

and see Figure 9), and we have derived upper limits for the remaining systems. In all cases, W_r^{5780} is less than the Galactic relation from Herbig (1993) would suggest (see Figure 10), and the 6284 Å DIB, which is at least twice as strong as the 5780 Å DIB in every Galactic

sightline, has an upper limit of less than twice W_r^{5780} (a characteristic it shares with one extra-galactic sightline towards Sk 143 in the Small Magellanic Cloud e.g. Welty et al. 2006). The two Galactic relationships that hold in the DLA towards AO 0235+164 are the $W_r^{5780}-E(B-V)$ relationship, and the $W_r^{5705}-W_r^{5780}$ relationship (e.g. Thorburn et al. 2003, and see Figure 11).

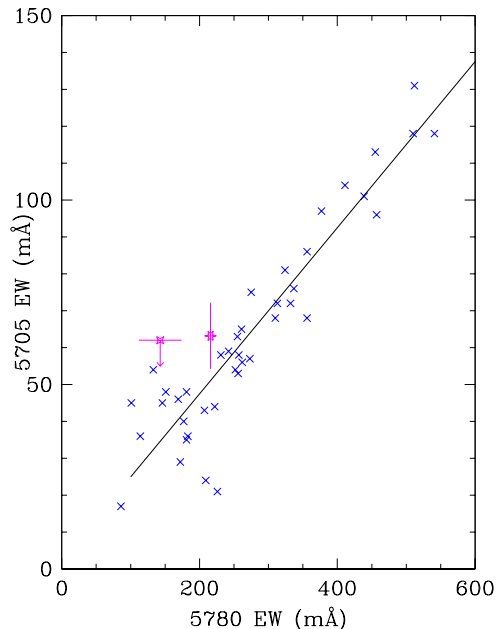


Figure 11: The 5705–5780 DIB relationship. The purple stars are AO 0235+164 (detection) and J0013-0024 (upper limit).

If the DIBs are not a useful proxy for $N(\text{H I})$ or ISM conditions in most DLAs, they still might serve as such in some subset of the population. Alternately, if a subset of DLAs could be found in which DIBs were easy to detect, DLAs might serve as a laboratory for investigating the correlations between various DIBs. The Ca II DLAs are a set of absorbers found in the SDSS which, while they do not have direct Ly α measurements, are almost certainly DLAs and, moreover, DLAs with unusually high dust content (Wild & Hewett, 2005). We examined nine Ca II absorption systems, and we were able to detect the 5780 Å DIB in one system: J0013-0024 (see Figure 12). Our limit for W_r^{6284} is less than W_r^{5780} (once again inconsistent with Galactic sight-lines), although the upper limit we derive for W_r^{5705} is consistent with the existing relationship. Since no $N(\text{H I})$ measurement exists for J0013-0024, we are unable to determine whether or not w_{5780} is consistent with $N(\text{H I})$ in this system. Overall, given our rate of success so far, we must conclude that the 5780 Å DIB is not a useful proxy for $N(\text{H I})$, and that, given our inability to detect even the majority of the strong DIBs, the relative strengths of the

DIBs offer a limited amount of useful information.

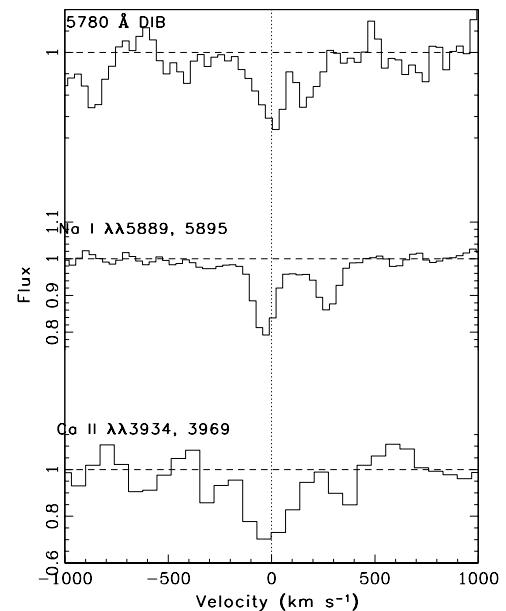


Figure 12: The 5780 Å DIB in J0013-0024, along with Na I and Ca II doublets.

In order to increase the sample size of 21-cm observations, we have completed a new optical survey for high-redshift DLAs. Because our primary goal was to detect DLAs suitable for 21-cm follow-up, we chose QSOs with strong low-frequency radio emission from the Texas 365–380 MHz survey (Cotton, 1976). We observed 48 quasars over a wavelength range from $\sim 3000 - \sim 6000$ Å, and found a total of 10 DLAs (and one Mg II system) in absorption in front of 8 quasars, of which seven are suitable for 21-cm follow-up at the Green Bank Telescope (GBT), one may be observed with the Giant Metrewave Radio Telescope (GMRT), and two are unobservable currently due to the required frequency or the presence of RFI at GBT. We have observed four of these systems (including one with unacceptable RFI, and the Mg II system), and reduced our observations of TXS 0311+430 (see Figure 13). This system has a DLA at $z = 2.289$ with strong 21-cm absorption corresponding to a spin temperature $T_s = 142 \pm 39$ K, amongst the lowest seen at any redshift and certainly the first low- T_s system seen at high redshift (see Figure 14). If the T_s -morphology relationship holds, we expect this system to be a large, metal-rich spiral galaxy. We currently have a metallicity limit of $[\text{Si}/\text{H}] \geq -0.48$ based on the saturated Si II $\lambda 1808$ Å line.

Finally, I have become aware of a project currently being undertaken by J. Willis, R. LASTNAME and collaborators to determine the masses of a set of galaxies through gravitational lensing. In particular, they have

selected a number of systems from the SDSS in which both a galaxy and a quasar are within the $3''0$ fibre aperture of an SDSS spectrum, determined the redshifts and impact parameters of both systems (and that the quasar has not been gravitationally lensed by the galaxy), and they are using this information to determine an upper

limit to the mass of the galaxy. In some of these cases, the SDSS spectra directly cover the Mg II $\lambda\lambda 2796, 2803$ doublet, from which W_r^{2796} may be extracted. In other cases, follow-up spectroscopy with another optical telescope should be able to detect the doublet.

5 Planned Observations & Other Work

With respect to the Diffuse Interstellar Bands work, there is little left to do. In addition to the ApJ letter (already published), a paper describing the entire first search is currently in preparation (by B. Lawton and C. Churchill). The Ca II system DIB search has not yet been published, but the data reduction and analysis has essentially been completed. The remaining work involves an analysis of the absorbing galaxy associated with the DLA to determine its properties, and whether the W_r^{5780} - $E(B-V)$ relation also holds in this system, and potentially a further analysis involving the Ca II absorbers as a whole and the W_r^{5780} upper limits, to determine whether the DLA sight-lines are drawn from the same population as Galactic or local extra-galactic sight-lines.

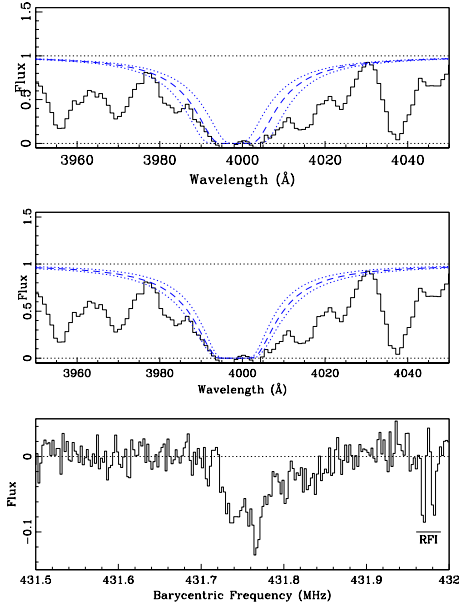


Figure 13: TXS 0311+430, including optical (top two panels) and 21-cm (bottom panel) absorption.

For the 21-cm project, the 21-cm observations and data reduction must be completed, and the results published (including a paper on the optical survey and another, currently in progress, on the detection of TXS 0311+430). If there are any other QSOs which may be profitably added to the optical survey set, they

must also be observed, both in the optical and, if necessary, in the radio. Finally, once the 21-cm observations and data reduction have been finished, the full data set must be analysed to determine what insight it provides on the nature of high-redshift absorbers and their spin temperature. We have also been granted time on Gemini North to observe TXS 0311+430 in order to determine its metallicity from the Zn II $\lambda 2026$ absorption line, and we will be applying for imaging time in an attempt to detect the host galaxy, and determine if it is a large, bright spiral.

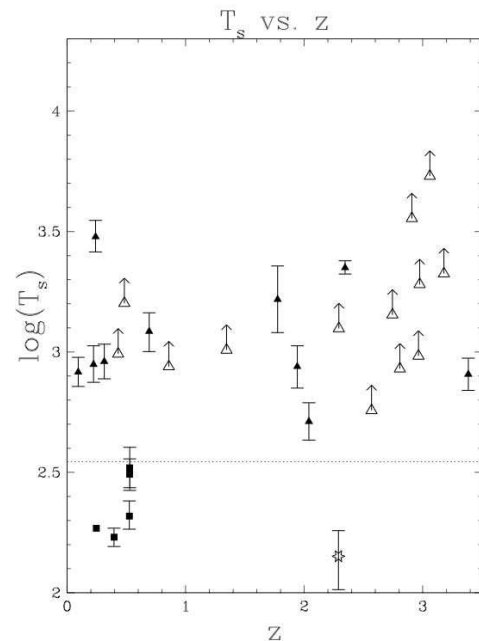


Figure 14: Spin Temperature vs. redshift. Labels are as in Figure 5, except the open star represents TXS 0311+430.

Finally, the Mg II systems which form part of the lensing project must be re-observed (if necessary) and analysed. An analysis of the nine systems with SDSS spectra that include the Mg II doublet may determine whether the project is viable (and, indeed, even the mass determination of the lensing component may prove unworkable), and additional systems must be examined as soon as they are added to the list of systems to be examined by the lensing group.

References

- Bahcall, J. N., Peterson, B. A., & Schmidt, M., 1966, *ApJ*, 145, 369
- Bouché, N., Murphy, M. T., Péroux, C., Csabai, I., & Wild, V., 2006, *MNRAS*, 371, 495
- Braun, R., 1997, *ApJ*, 484, 637
- Cami, J., Sonnentrucker, P., Ehrenfreund, P., & Foing, B. H., 1997, *A&A*, 326, 822
- Cotton, W. D., 1976, *ApJS*, 32, 467
- Curran, S. J., Murphy, M. T., Pihlström, Y. M., Webb, J. K., & Purcell, C. R., 2005, *MNRAS*, 356, 1509
- De Rijke, S., Zeilinger, W. W., Hau, G. K. T., Prugniel, P., & Dejonghe, H., 2007, *ApJ*, 659, 1172
- Hazard, C., Mackey, M. B., & Shimmins, A. J., 1963, *Nature*, 197, 1037
- Heckman, T. M. & Lehnert, M. D., 2000, *ApJ*, 537, 690
- Heger, M. L., 1922, *Lick. Obs. Bull.*, 10, 146
- Herbig, G. H., 1993, *ApJ*, 407, 142
- Herbig, G. H., 1995, *ARA&A*, 33, 19
- Kanekar, N. & Chengalur, J. N., 2003, *A&A*, 399, 857
- Kanekar, N., Chengalur, J. N., & Lane, W. M., 2007, *MNRAS*, 375, 1528
- Köppen, J., Weidner, C. & Kroupa, P., 2007, *MNRAS*, 375, 673
- Lane, W., Briggs, F. H., & Smette, A., 2000, *ApJ*, 532, 146
- Murphy, M. T., Curran, S. J., Webb, J. K., Ménager, H., & Zych, B. J., 2007, *MNRAS*, 376, 673
- Nestor, D. B., Rao, S. M., Turnshek, D. A., Vanden Berk, D., 2003, *ApJ*, 595, L5
- Norman, C. A. & Spaans, M., 1997, *ApJ*, 480, 145
- Oke, J. B., 1963, *Nature*, 197, 1040
- Rao, S. M., Turnshek, D. A., & Nestor, D. B., 2006, *ApJ*, 636, 610
- Rauch, M., 1998, *ARA&A*, 36, 267
- Sarre, P. J., 2006, *JMoSp*, 238, 1
- Schmidt, M., 1963, *Nature*, 197, 1040
- Thorburn, J. A. et al., 2003, *ApJ*, 584, 339
- Tuairisg, S. Ó., Cami, J., Foing, B. H., Sonnentrucker, P., & Ehrenfreund, P., 2000, *A&AS*, 142, 225
- Welty, D. E., Federman, S. R., Gredel, R., Thorburn, J. A., & Lambert, D. L., 2006, *ApJS*, 165, 138
- Wild, V. & Hewett, P. C., 2005, *MNRAS*, 361, L30
- Wolfe, A. M., Gawiser, E., & Prochaska, J. X., 2005, *ARA&A*, 43, 861
- Wolfe, A. M., Gawiser, E., & Prochaska, J. X., 2003, *ApJ*, 593, 215
- Wszolek, B., & Godlowski, W., 2003, *MNRAS*, 338, 990

Young, L. M. & Lo, K. Y., 1997, ApJ, 490, 710

York, B. A., Ellison, S. L., Lawton, B., Churchill, C. W., Snow, T. P., Johnson, R. A., & Ryan, S. G., 2006, ApJ, 647, L29

York, D. G. et al., 2006, MNRAS, 367, 945

Young, P., Sargent, W. L. W., & Boksenberg, A., 1982, ApJS, 48, 455