APM $z \gtrsim 4$ QSO Survey:  
Spectra and Intervening Absorption Systems

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arch-ive/9604021 — to appear in ApJ Supplements, 1 September 1996

ABSTRACT

The APM multicolor survey for bright $z > 4$ objects, covering 2500 deg$^2$ of sky to $m_r \sim 19$, resulted in the discovery of thirty-one quasars with $z \gtrsim 4$. High signal-to-noise optical spectrophotometry at 5Å resolution has been obtained for the twenty-eight quasars easily accessible from the northern hemisphere. These spectra have been surveyed to create new samples of high redshift Lyman-limit systems, damped Lyman-α absorbers, and metal absorption systems (e.g. CIV and MgII). In this paper we present the spectra, together with line lists of the detected absorption systems. The QSOs display a wide variety of emission and absorption line characteristics, with 5 exhibiting broad absorption lines and one with extremely strong emission lines (BR2248−1242). Eleven candidate damped Lyα absorption systems have been identified covering the redshift range $2.8 \leq z \leq 4.4$ (8 with $z > 3.5$). An analysis of the measured redshifts of the high ionization emission lines with the low ionization lines shows them to be blueshifted by $430 \pm 60$ km s$^{-1}$. In a previous paper (Storrie-Lombardi et al. 1994) we discussed the redshift evolution of the Lyman limit systems catalogued here. In subsequent papers we will discuss the properties of the Lyα forest absorbers and the redshift and column density evolution of the damped Lyα absorbers.

Subject headings: quasars: general — quasars: absorption lines — quasars: emission lines

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1. Introduction

Many QSOs have now been discovered beyond redshifts of 4 and they provide powerful probes for exploring these early epochs. They are the youngest objects known in the Universe and it is likely that they flag regions where galaxy formation is very active. Their host galaxies are probably still forming and they may occur in the exceptional ‘5 σ’ peaks in the matter distribution of the early Universe (Efstathiou & Rees 1988). Observational information from this epoch yields constraints on galaxy formation theories and clues for better understanding of the astrophysics of galaxy formation and evolution.

In addition to being of intrinsic interest themselves, bright high redshift QSOs are particularly valuable as probes of the intervening gas clouds and galaxies superimposed on their spectra in absorption. The study of these absorption systems provides information about the formation and evolution of galaxies over most of the age of the Universe. Neutral hydrogen (HI) absorption can be detected over a staggering 10 orders of magnitude from the Lyα forest region with the weakest detectable lines having a column density \( N_{\text{HI}} \sim 10^{12} \) atoms cm\(^{-2}\), up to the damped Lyα absorbers with \( N_{\text{HI}} \sim 10^{21} \). The rich zoo of these absorbers, in addition to those produced by heavier elements such as carbon, silicon, oxygen, and magnesium, are illuminated along a QSO line-of-sight, leaving their imprint as absorption in the QSO continuum. Study of the Lyα forest (\( 12 < \log N_{\text{HI}} < 17 \)) yields important information about the intergalactic medium and the background ionizing flux at high redshifts (e.g. Hunstead et al. 1986; Carswell et al. 1987; Bajtlik, Duncan, & Ostriker 1988; Williger et al. 1994). Lyman-limit systems (\( \log N_{\text{HI}} \gtrsim 17 \)) provide a means of directly studying the evolution of galaxies over the redshift range \( 0.1 < z < 5 \) (e.g. Sargent, Steidel, & Boksenberg 1989; Lanzetta et al. 1991; Storrie-Lombardi et al. 1994; Stengler-Larrea et al. 1995). The absorbers detected via the damped Lyα lines they produce (\( \log N_{\text{HI}} \gtrsim 20 \)) show features consistent with an early phase of galactic evolution and are widely believed to be the progenitors of spiral galaxies like our own (e.g. Wolfe et al. 1986; Wolfe 1987; Fall, Pei, & McMahon 1989; Pettini, Boksenberg, & Hunstead 1990; Rauch et al. 1990; Lanzetta et al. 1991; Lanzetta, Wolfe, & Turnshek 1995; Wolfe et al. 1995).

The APM Color Survey for \( z > 4 \) QSOs was under-taken to find bright (\( m_R < 19 \)) quasars with redshifts \( 4 < z < 5 \) (Irwin, McMahon, & Hazard 1991). The aim of the program was to find a large sample of QSOs for both intrinsic and absorption line studies. The survey covers approximately 2500 square degrees of sky from the equatorial region of the UK Schmidt Telescope (UKST) B, R, I Survey with \( |b| > 30^\circ \) and declination range +3 to −17.5. High signal-to-noise optical spectrophotometry at 5Å resolution covering the wavelength region 3500–9000Å were obtained for all the QSOs discovered in the APM Color Survey that are accessible using the William Herschel Telescope (WHT) (28 of 31 objects). In addition, spectra were obtained at 5Å resolution of three high redshift radio-selected QSOs (Hook et al. 1995; McMahon et al. in preparation). The spectra have been utilized to discover Lyman-limit, damped Lyα, and metal absorption systems (e.g. CIV and MgII).

The results and analyses from these studies are presented in a series of papers. In this paper we present the spectra, together with a list of accurate redshift determinations of the intrinsic QSO emission lines, a study of the velocity differences between high and low ionization emission lines, and the results of surveys for intervening absorption systems. Line lists for damped Lyα candidates, Lyman limit systems, and metal absorption systems are provided. The analysis of the redshift evolution of the Lyman limit systems was previously presented in Storrie-Lombardi et al. (1994). We will present a detailed analysis of the damped Lyα systems and the redshift evolution of their number density and column density distribution (Storrie-Lombardi, Irwin, & McMahon 1996), and describe the implications derived from the damped Lyα survey for the evolution of the mass density of neutral gas with redshift and the implications for galaxy formation (Storrie-Lombardi, McMahon, & Irwin 1996).

Other papers will cover studies of the Lyα forest at high redshift and the intrinsic properties of the QSOs. High resolution studies of the Lyα forest region at \( z > 4 \) have been completed by Williger et al. (1994) and Wampler et al. (1996).

2. Observations

High signal-to-noise optical spectrophotometry at 5Å resolution covering the wavelength range 3500–8800Å was obtained with the 4.2m William Herschel telescope of the Isaac Newton Group of telescopes in the Canary Islands. We used the ISIS double-spectrograph...
with typical integration times of 2700-3600 seconds. The spectrophotometry is accurate to within 5-10 percent. ISIS is a double beam spectrograph with arms optimized for blue and red light, mounted at the f/11 Cassegrain focus of the WHT. For this project the lowest dispersion was required, and gratings with 158 lines/mm and a dichroic to split the light at ~5400Å were used. This gives 2.71Å/pixel in the red arm and 2.89Å/pixel in the blue. The gratings were arranged so that the blue part of the spectrum was centered on 4600Å and covered a range of 2950Å while the red was centered on 7000Å and covered a range of 3380Å. The red and blue arm observations were carried out simultaneously. On the red arm an English Electric Valve (EEV) 1242 × 1152 CCD with 22.5μm pixels was used as detector. On the blue arm a thinned Tektronix 1024 × 1024 CCD with 24μm pixels was used. All the narrow slit observations were taken with a slit width of 1.5” except for BR 2237 – 0607 (1”) and all were taken with the slit perpendicular to the horizon (at the parallactic angle). This slit orientation is used to minimize the effects of atmospheric differential refraction (Filippenko 1982).

Though the QSOs from the APM Color Survey are bright for high redshift objects (mR < 19), they were barely visible on the acquisition TV, so nearby offset stars (mR ~ 15 – 17) were acquired first. Blind-offsetting was then used to position the target object in the slit and as a check the TV integration time was increased until the periphery of the QSO was visible in the slit. All observations were made with a long slit and the CCDs were windowed in the spatial direction to reduce the overhead due to readout time. The observations are summarized in table 1.

3. Data Reduction

The data were reduced using standard software from the IRAF\(^2\) package. After the data were overscan, bias, and flat-field corrected they were extracted using the variance-weighted extraction in APALL. Typically the ISIS spectra curved by less than a pixel from one end of the chip to the other. APALL outputs the sky spectrum which was used for quick wavelength calibration at the telescope. A sample dark sky spectrum taken with ISIS is shown in figure 4. CuNe+CuAr arcs were taken at intervals throughout the night to provide an accurate wavelength calibration. Emission lines were identified and a pixel-to-wavelength calibration curve was found by fitting a 3rd order chebyshev polynomial to the calibration points in IDENTIFY. Typical \(\sigma\) residuals from the fit were 0.2Å. The dispersion solution was applied to the extracted spectra and they were put on a linear wavelength scale using DISPCOR.

The individual spectra were then extinction corrected and coadded. Spectrophotometric standards taken from Oke (1974) and Oke & Gunn (1983) were used to flux calibrate the spectra. The goal was absolute spectrophotometry correct to within 10 percent and relative flux levels from the blue and red arms accurate enough to allow determination of the spectral indices. The flux calibration procedure was checked by flux-calibrating the standards and overlaying calibration points. It was found that calibration was reliable over the wavelength range 5500Å-8600Å (ISIS red) and 3500Å-5500Å (ISIS blue). Observations with a 5” slit were obtained for all but three of the QSOs. These were reduced in the same way as the narrow slit observations and used to correct the absolute flux levels for slit losses. The slit losses ranged from 0–50%.

‘Featureless’ B-stars were selected from the Bright Star Catalogue (Hoffleit & Jaschek 1982) or Sky Catalogue 2000.0 (Hirshfeld, Simott, & Ochsenbien 1991) for use in removing the effects of atmospheric absorption in the red spectra, (e.g. O₂ A-band at 7600Å). Observations of B-stars were taken at different air masses to provide a range of absorption so that as many objects as possible could be corrected. The spectrum of HR4468 taken at an airmass of 1.48 is shown in figure 2 and HD13679 taken at an airmass of 1.06 is shown in figure 3(a). The atmospheric absorption features seen in the B-star spectrum were removed by interpolating between values on either side of the feature, resulting in the spectrum shown in figure 3(b). The original B-star spectrum was then divided by this featureless spectrum with the result shown in figure 3(c). The object spectra taken at comparable air masses were then divided by the result. The technique was successful in almost all cases though it remains an art form to do it properly.

The red and blue arm spectra were joined using SCOMBINE. The final reduced spectra are shown in figure 4 and the individual QSOs are described in

\(^2\)IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under cooperative agreement with the National Science Foundation.
section 5. The AB magnitude measured at $\lambda_{\text{rest}} = 1450\text{Å}$ and $\lambda_{\text{observed}} = 7000\text{Å}$, along with the APM $R$ magnitudes measured from the plate scans are listed in table 2. Using the absolute flux calibration for Vega taken from Hayes & Latham (1975) and defining the zero-point of the AB magnitude system at $\lambda = 5556\text{Å}$ leads to the following magnitude zero-point differences: AB measures at $\lambda = 7000\text{Å}$ are 0.25 magnitudes fainter than on a Vega-based system; for $\lambda = 1450 \times (1 + z)$ the difference ranges between 0.3 and 0.5 magnitudes for a $4 \leq z \leq 5$ sample; the effective wavelength of the photographic R-band is $\lambda = 6500\text{Å}$ and the difference between the systems here is 0.2 magnitudes. The $1\sigma$ errors are $\pm 0.1$. For those objects with no long slit observations or non-photometric conditions, only the APM $R$ magnitude is quoted.

4. Redshift Measurements

4.1. Measuring the Emission Line Redshifts

At redshifts greater than 4, Ly$\alpha$+NV (rest wavelengths 1215.67Å and 1240.13Å) and CIV (1549.1Å) are usually the only strong emission lines visible. Ly$\alpha$ is almost 50% absorbed by the Ly$\alpha$ forest, making it difficult to use for redshift determination. Emission lines from Ly$\beta$ (1025.72Å), OVI (1034.0Å), SiII (1263.0Å), OI (1304.46Å), CII (1335.0Å), SiIV+OIV (1400.0Å), NV (1486.0Å), HeII (1640.4Å), and OIII (1663.0Å) may also be detected. Single Gaussians were fit to the emission lines in each QSO, and the redshifts for each line were determined from the zero-point of the AB magnitude system at Vega taken from Hayes & Latham (1975) and defined as

$$\Delta v = \frac{z_{\text{ion}} - z_{\text{civ}}}{(1 + z_{\text{civ}})}.$$

The same trend is exhibited in the APM sample, with a median difference of $430\pm 60\text{ km s}^{-1}$ between OI and CIV, with the high ionization line CIV blue-shifted with respect to the OI. The velocity difference relative to CIV has been calculated for all the measured emission lines and the results are summarized in table 4. The BAL QSOs have been excluded from this analysis. Histograms of the velocity differences are shown in figure 3. Some of the very large differences of several thousand kilometers per second are due to the difficulty in accurately measuring some of the heavily absorbed emission lines, e.g. Ly$\alpha$. These shifts are important in estimating the metagalactic ultraviolet background flux based on the proximity effect (e.g. Williger et al. 1994) since an error in the redshift of the QSO of $\sim 1000\text{ km s}^{-1}$ can lead to a factor of 2–3 error in the derived ionizing flux.

5. Emission and Absorption Features

The character of the emission lines and the HI and metal absorption systems detected are described below for each QSO. Additional analysis of the intrinsic properties of the QSOs are described in a separate paper. The metal absorption systems in the non-BAL QSOs were selected with an automated algorithm that detected absorption features redward of Ly$\alpha$ emission with an equivalent width $W \geq 3\sigma$ in 2.5 resolution elements. In the cases where the feature detected included more than one line, Gaussians were fit to the lines individually to measure the redshifts and equivalent widths. The results, with $1\sigma$ errors, are listed in table 5, along with the identification of ion and redshift where possible. The selection of the damped Ly$\alpha$ candidates is discussed in section 6 and the Lyman limit systems previously published in Storrie-Lombardi et al. (1994) are summarized in table 6.

- a) BR0019−1522, ($z_{\text{em}} = 4.528$)
  The Ly$\alpha$+NV and CIV emission lines are strong and sharp. There is a Lyman-limit system at $z=4.27$ and a damped Ly$\alpha$ candidate system at $z=3.98$. SiII, CIV, and FeII absorption are observed at $z=3.4$.

- b) BRI0103+0032, ($z_{\text{em}} = 4.437$)
  Strong and sharp Ly$\alpha$ and CIV, with weaker OI,
CII, and SiIV+OIV] can be seen. There is weak MgII at \(z=1.818\) with 2 corresponding FeII lines and MgII at \(z=1.366\). There are absorption edges visible just shortward of the emission lines that correspond to OI+SiII at \(z=4.41\) and SiIV and CIV at \(z=4.37\). There are two Lyman-limit systems at \(z=4.31\) and 4.15.

c) BRI0151−0025, \((z_{em} = 4.194)\)

The Lyα and CIV emission lines are strong and sharp with weaker OI and SiIV+OIV] emission. There is a Lyman-limit system at \(z=4.05\) and CIV at \(z=3.876\). At \(z=4.17\) there is a strong Lyα absorption line, a NV doublet, and a single line that could be CIV. There is MgII with at least one FeII line at \(z=1.91\).

d) BRI0241−0146, \((z_{em} = 4.053)\)

The Lyα+NV, OI, CII, SiIV+OIV], and CIV emission lines are broad and rounded. There is a strong Lyman-limit system at \(z=4.10\). There are numerous absorption lines redward of the Lyα emission but they are not easily identifiable. MgII and FeII are identifiable at \(z=1.435\). Shallow absorption troughs are also visible.

e) BR0245−0608, \((z_{em} = 4.238)\)

The Lyα+NV, OI, SiIV+OIV], and CIV emission lines are weak. There is strong Lyα absorption on the blue side of the Lyα emission corresponding to the Lyman-limit system at \(z=4.23\). An MgII doublet with 4 corresponding FeII lines is observed at \(z=1.711\). There are strong, narrow Lyα absorption lines (though not damped candidates) at \(z=3.36\) and 4.14, with corresponding SiIV and CIV at \(z=4.14\). CIV is also detected at \(z=3.184\).

f) BR0351−1034, \((z_{em} = 4.351)\)

This is one of the most unusual objects in the survey with saturated CIV absorption in the middle of the CIV emission. There are a large number of absorption lines including SiIV at \(z=4.098\) and 4.352, CIV at \(z=3.633, 4.098, 4.351\), and 4.351, MgII at \(z=1.340\) and 1.931, and NV at \(z=4.353\). Due to the difficulty in measuring redshifts from the heavily absorbed emission lines, the redshift for this object was calculated from the CIV absorption at \(z=4.351\).

g) BR0401−1711, \((z_{em} = 4.236)\)

The Lyα+NV, OI, and CIV emission lines are strong and sharp, while the SiIV+OIV] is broader and weaker. The OI is unusually prominent. There is strong absorption in the CIV emission line at \(z=4.229\). There is Lyman limit system at the QSO redshift. The absorption feature at \(\sim 7600\AA\) is a residual from the removal of the atmospheric absorption line. The spectrum is very noisy at the red end of the blue arm portion \((\sim 5600\AA)\) and does not join together smoothly with the red arm spectrum.

h) BR0945−0411, \((z_{em} = 4.145, BAL)\)

This is the first of the five QSOs in the APM Color Survey that exhibits broad absorption lines. OVI, NV, SiIV, and CIV are observed at \(z=4.01\).

i) BR0951−0450, \((z_{em} = 4.369)\)

The Lyα+NV, OI, CII, SiIV+OIV], and CIV emission lines are weak. There are damped Lyα candidates at \(z=3.84\) and 4.20. CIV doublets are identified at \(z=3.703, 3.855, 4.196\), and 4.364 and SiIV at \(z=3.703\) and 3.858. There is a Lyman-limit system at \(z=4.22\).

j) BR0952−0115, \((z_{em} = 4.426)\)

This QSO is gravitationally lensed (McMahon, Irwin, & Hazard 1992). The Lyα+NV, SiIV+OIV], and CIV emission are weak and heavily absorbed. There is a strong damped Lyα candidate systems at \(z=4.01\). CIV doublets are identified at \(z=3.294, 3.475, 3.719\) and 4.023 and MgII at \(z=1.993\). There is a Lyman-limit system at \(z=4.25\).

k) BR1013+0035, \((z_{em} = 4.405)\)

The Lyα+NV, OI, CII, SiIV+OIV], and CIV emission lines are weak. There is a damped Lyα candidate at \(z=3.10\) with corresponding FeII detected. There is an MgII doublet at \(z=2.054\) with 6 corresponding FeII lines at \(z=2.058\). There is a Lyman-limit system at \(z=3.78\).

l) BR1033−0327, \((z_{em} = 4.509)\)

The Lyα+NV, OI, CII, SiIV+OIV], and CIV emission lines fall at the strong end of the weaker-lined objects. There is a Lyman-limit system at \(z=4.19\) and CII tentatively identified at \(z=4.148\). See Williger et al. (1994) for a detailed analysis of the Lyα forest region in this object.

m) BR1050−0000, \((z_{em} = 4.286)\)

The Lyα and CIV emission lines are strong and sharp with weaker OVI, OI, and SiIV+OIV] emission. There is CII, SiIV, and CIV detected at \(z=3.862\) and a Lyman-limit system at \(z=4.08\).

n) BR1108−0747, \((z_{em} = 3.922)\)
The Lyα and CIV emission are strong and this is one of the few objects where Lyβ, OVI, and NV are easily distinguished, along with OI, CII, SiIV+OIV, and NIV. CIV doublets are observed at z=3.575, and 3.607.

o) BRI1110+0106, (zem = 3.918)

The Lyα+NV, OI, CII, SiIV+OIV, and CIV emission are weak. The O2 A-band atmospheric absorption has been removed from the CIV emission line and a residual spike was cut-off, resulting in the unreal flat top to the emission line. MgII and 2 FeII lines are observed at z=1.479 and MgII at z=1.800.

p) BRI1114–0822, (zem = 4.495)

The Lyα+NV, SiIV+OIV, and CIV emission lines are weak though the Lyβ+OVI is fairly prominent. There is a damped Lyα candidate at z=4.25 and a Lyman-limit system at z=4.51. There is absorption in the blue wing of the Lyα emission line that corresponds to MgII at z=1.395 but no confirming FeII can be observed due to the Lyα forest. Single absorption lines are observed that could correspond to SiIV and CIV at z=3.91 and CIV at 4.25. CIV doublets are seen at z=3.422, 3.571, and 3.589. There is an MgII doublet at z=1.794.

q) BRI1117–1329, (zem = 3.958, BAL)

This QSO exhibits broad absorption lines for OVI, NV, SiIV, and CIV at z=3.62 and 3.89.

r) BRI1144–0723, (zem = 4.147, BAL)

This object exhibits broad absorption lines but also has detectable intervening absorption. There is a strong broad absorption trough corresponding to CIV and a weak trough for SiIV at z=4.00. The emission lines are weak. There is a damped Lyα candidate system at z=3.26 but this is probably confused with broad OVI absorption at z=4.0. There is MgII absorption at z=1.905 and 5 corresponding FeII lines.

s) BRI1202–0725, (zem = 4.694)

This is the highest redshift and brightest object in the APM sample. It has very weak emission lines with Lyα and CIV almost completely absorbed away. The spectrum is very similar to that of BRI1335–0417, described below. The redshift is determined from the edge of the Lyα emission line since the metal lines are so heavily absorbed. (The redshift determined from OI and CIV is 4.679.) There is a damped Lyα system at z=4.38 and a Lyman-limit system at z=4.52. MgII doublets, some with associated FeII, are observed at z=1.463, 1.754, 2.238, 2.339, and 2.444. CIV is detected at z=3.525, 3.565, 4.474, and 4.679. See Wampler et al. (1996) for a detailed analysis of the Lyα forest in this object.

t) BR1302–1404, (zem = 3.996, BAL)

This QSO exhibits a complex series of broad absorption lines for OVI, NV, SiIV, and CIV at z≈ 3.65, 3.72, and 3.92. There are two MgII doublets at z=2.044 and 2.058 with 4 and 3 associated FeII lines, respectively.

u) BRI1328–0433, (zem = 4.217)

The OVI, Lyα, NV, SiIV+OIV, and CIV emission lines are strong with weaker OI present. This is one of the few objects in the sample with well defined NV emission. There is strong MgII absorption at z=1.628 with 2 FeII lines. Lyman-limit systems are seen at z=3.31 and 4.25.

v) BRI1335–0417, (zem = 4.396)

The Lyα+NV and CIV emission lines are very weak, with the Lyα almost completely absorbed away. This QSO is looks very similar to BR1202–0725. MgII with 4 associated FeII lines is seen at z=1.822. There is a Lyman-limit system at z=4.45 and SiIV and CII at z=4.40. There is strong Lyα absorption at the QSO redshift.

w) BRI1346–0322, (zem = 3.992)

The Lyα and CIV emission lines are very strong and sharp. There is NV absorption at z=3.974. There are CIV doublets at z=3.359 and 3.994, and a single line that is most likely CIV at z=3.974. MgII with FeII is seen at z=1.944. There is a damped Lyα candidate at z=3.73 and a corresponding Lyman-limit absorption edge at z=3.75.

x) BRI1500+0824, (zem = 3.943)

The Lyα+NV, OI, SiIV+OIV, and CIV emission lines are weak but sharp. There is a damped Lyα candidate at z=2.80, MgII with 6 FeII lines at z=1.908, and CIV absorption in the emission line at z=3.940. This object shows one of the most successful removals of the O2 A-band absorption at 7600Å, in the middle of the CIV emission.

y) GB1508+5714, zem = 4.283

This is a radio-selected object from Hook et al. (1995). The Lyα and CIV emission lines are strong and sharp. There is a Lyman-limit system at z=3.9.
z) MG1557+0313, $z_{\text{em}} = 3.891$

This is a radio-selected object from McMahon et al. (in preparation). The Ly$\alpha$ and CIV emission are strong and sharp. There is CIV absorption at $z=3.898$.

aa) GB1745+6227, $z_{\text{em}} = 3.901$

This is a radio-selected object from Hook et al. (1995), also discovered independently by Becker, Helfand, & White (1992) on the basis of its X-ray emission. The Ly$\alpha$ and CIV emission are strong and sharp. It has MgII absorption at $z=1.471$. There are 6 FeII lines at $z=2.322$, but the corresponding MgII doublet is not seen as it should occur at 9296Å, redward of the end of this spectrum.

bb) BR2212−1626, $(z_{\text{em}} = 3.990)$

The Ly$\alpha$+NV and CIV emission lines are strong and sharp with weaker OI, SiIV+OIV], and NIV].

c) BRI2235−0301, $(z_{\text{em}} = 4.249, \text{BAL})$

This QSO is the highest redshift BAL in the sample and has very broad absorption troughs. The emission lines are almost completely absorbed, making it difficult to determine an accurate redshift. It exhibits broad absorption lines of OVI $(z= 4.08)$, NV $(z=3.74)$, SiIV $(z=3.83)$, and CIV $(z=3.65, 3.82, 4.03)$. There is a possible MgII doublet at $z=1.873$.

dd) BR2237−0607, $(z_{\text{em}} = 4.558)$

The Ly$\alpha$+NV, OI, SiIV+OIV], and CIV emission are strong with the Ly$\alpha$ line being particularly sharp. There is a damped Ly$\alpha$ candidate at $z=4.08$ and a Lyman-limit system at $z=4.28$. There is a NV doublet at $z=4.545$, SiIV at $z=4.079$, CII at $z=4.078$, CIV at $z=4.482$, FeII at $z=2.155$, and MgII at $z=1.672$.

e) BR2248−1242, $(z_{\text{em}} = 4.161)$

This QSO has pathologically strong emission lines for OVI+Ly$\beta$, Ly$\alpha$, NV, OI, CII, SiIV+OIV], NIV], CIV, HeII, and OIII]. It is the only object with obvious NIV].

6. Survey for Damped Lyman-α Absorption Systems

6.1. Background

While the baryonic content of spiral galaxies that are observed in the present epoch is concentrated in stars, in the past this must have been in the form of gas. The principal gaseous component in spirals is neutral hydrogen which has led to surveys for absorption systems detected by the damped Ly$\alpha$ (DLA) lines they produce (Wolfe et al. 1986; Lanzetta et al. 1991; Lanzetta et al. 1995; Wolfe et al. 1995). Damped Ly$\alpha$ absorption systems comprise the high column density tail of neutral hydrogen absorbers with column densities of $N_{\text{HI}} \geq 2 \times 10^{20}$ cm$^{-2}$. They are identified by the presence of broad (FWHM>5Å) absorption lines shortward of Lyman-α (1216Å) in the QSO rest frame. These lines are broadened by radiation damping and at $z>4$ have observed equivalent widths of W > 25Å. The visibility of the damping wings in the absorption profile is due to the large HI column density and the low velocity dispersion ($\sim 10$ km s$^{-1}$), two features that damped systems have in common with spiral galaxies observed at the present. The column density along a typical line-of-sight in the Milky Way is $N_{\text{HI}} \sim 10^{21}$ atoms cm$^{-2}$. Other features that resemble HI disk galaxies are the presence of metals in mainly low ionization states such as C+, Si+, and Fe+ and the detection of 21 cm absorption associated with damped systems shows that the gas is cold and has a low level of turbulence (c.f. Wolfe et al. 1986; Wolfe 1987; Turnshek et al. 1989).

6.2. Selection of Damped Ly$\alpha$ Candidates

The Ly$\alpha$ forest region in QSO spectra at redshift 4 is very crowded. Many lines are blended at 5Å resolution and may appear broader than they actually are. However, real damped absorbers at high redshift result in very broad lines. They have observed equivalent widths W > 25Å and are relatively easy to see in the spectra. Two techniques were used to select the candidate absorbers. We first selected the candidates interactively and then independently used the standard equivalent width selection criteria with an automated algorithm. There was good agreement between the two selection methods though we only report the candidates selected with the automated algorithm. This is described below.

The technique used for selecting candidates and measuring the sensitivity of the survey with redshift follows the methods described in Lanzetta et al. (1991) and is described below. A local continuum was fit to each spectrum using straight lines between the peaks of the forest regions. An equivalent width spectrum and variance spectrum were created for each
QSO defined as

$$W_i = \Delta \lambda \sum_{n=i-m}^{i+m} (1 - F_n/C_n),$$

and

$$\sigma_{E_i}^2 = (\Delta \lambda)^2 \sum_{n=i-m}^{i+m} (\sigma_{F_n}/C_n)^2,$$

where $C_i$ and $F_i$ are the continuum and flux levels at pixel $i$, $\Delta \lambda$ is the Å/pixel of the spectrum, and $2m + 1$ is the passband over which the total equivalent width is measured. A passband of 15 pixels was used, equivalent to 37.5Å.

The spectra were analyzed using the above algorithm starting 3000 km s$^{-1}$ blueward of the emission redshift to avoid lines possibly associated with the quasar. The analysis was stopped when the signal-to-noise ratio became too low to detect a Ly$\alpha$ line with $W(\text{rest}) \geq 5$Å at the 5σ level. This point was typically caused by the incidence of a Lyman limit system. This selected wavelength range is used to construct the sensitivity function, $g(z)$. It gives the number of lines of sight at a given redshift over which damped systems can be detected at a $> 5\sigma$ level (see Lanzetta et al. 1991 or Lanzetta et al. 1995). Figure 3 shows the sensitivity function of the APM survey compared with three previous damped Ly$\alpha$ surveys (Wolfe et al. 1986; Lanzetta et al. 1991; Lanzetta et al. 1995). The APM survey adds substantial redshift path for damped Ly$\alpha$ absorption system surveys, more than trebling the path surveyed for $z > 3$. The redshift path over which damped systems could be detected is crucial in estimating the cosmological mass density in neutral gas from the damped systems (Storrie-Lombardi, McMahon, & Irwin 1996). Preliminary results from 1.5Å resolution spectra taken with LRIS on the Keck telescope indicate that the rest of the candidates selected are representative of the true distribution of HI column densities at high redshift (Storrie-Lombardi & Wolfe, in preparation). When the follow-up spectroscopy is complete, this will result in a complete sample of damped absorbers for $z > 3.5$, increasing the confirmed numbers of these absorbers by $\approx 20$ percent and covering an epoch crucial to understanding the formation of galaxies.

7. Conclusions

Intermediate resolution (5Å) spectrophotometry are presented for 31 QSOs with redshifts $3.9 \leq z \leq 4.7$, 28 from the APM Color Survey and 3 radio-selected objects. The spectra were surveyed to create new data sets of intervening absorption lines systems. The QSOs display a wide variety of emission and absorption line characteristics, with 5 exhibiting broad absorption lines and one with extremely strong emission lines (BR2248–1242).

This high redshift data set more than triples the $> 3$ redshift path available for damped Ly$\alpha$ absorption system surveys. Eleven candidate damped systems have been identified covering the redshift range $2.8 \leq z \leq 4.4$ (8 with $z > 3.5$). The redshift evolution, column density distribution func-
tion, and contribution to the cosmological mass den-
sity from these systems is discussed in other papers
(Storrie-Lombardi, Irwin, & McMahon 1996; Storrie-
Lombardi, McMahon, & Irwin 1996).

The Lyman-limit systems in the QSOs with $z \geq$
4.2 are catalogued and the spectra presented. Their
redshift evolution has been discussed in a previous
paper (Storrie-Lombardi et al. 1994). In addition,
line lists for metal absorption line systems (e.g. CIV
and MgII) are presented. An analysis of the measured
redshifts of the high ionization emission lines with the
low ionization lines shows them to be blueshifted by
430 ± 60 km s$^{-1}$.

We thank an anonymous referee and Mike Fall for
suggestions that improved the paper and Art Wolfe
for the use of his code in the automated damped
candidate selection. We thank the PATT for time
awarded to do the observations with the William Her-
schel Telescope that made this work possible. LSL
acknowledges support from an Isaac Newton Stu-
dentship, the Cambridge Overseas Trust, and a Uni-
versity of California President’s Postdoctoral Fellow-
ship. RGM acknowledges the support of the Royal
Society.
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This 2-column preprint was prepared with the AAS l3TtX macros v4.0.
Fig. 1.— The 5Å resolution flux calibrated sky spectrum from QSO BRI1335−0417 taken with the red and blue arms of the ISIS spectrograph at the WHT.

Fig. 2.— B-star HR4468: [B9.5, m<sub>V</sub> = 4.7, exposure=1 second, 92 Apr 24, airmass=1.48]

Fig. 3.— B-star HD13679: [B8, m<sub>V</sub> = 6.8, exposure=1 second, 93 Aug 21, airmass=1.056] (a) wavelength calibrated counts spectrum, (b) with atmospheric absorption features removed, and (c) the spectrum in ‘a’ divided by the spectrum in ‘b’. The absorption spectrum in ‘c’ is then divided into the QSO spectra taken at a similar airmass to remove the atmospheric absorption features.

Fig. 4.— The final flux calibrated spectra. The z > 4.2 QSOs used in the Lyman limit system evolution analysis show the region blueward of 5500Å magnified in the upper left hand corner. All except BR0351−1034, BR0401−1711 and BR2237−0607 show the flux corrected for slit losses.

Fig. 4 continued.— The flux for BR0351−1034 has not been corrected for slit losses.

Fig. 4 continued.— The flux for BR0401−1711 has not been corrected for slit losses.

Fig. 4 continued.— Fig. 4 continued.— Fig. 4 continued.— Fig. 4 continued.— Fig. 4 continued.— Fig. 4 continued.— The flux for BR2237−0607 has not been corrected for slit losses.

Fig. 4 continued.— The upper panel shows the entire spectrum of BR2248-1242. The lower panel has the Lyα and CIV emission lines cut off to show the additional lines visible in the spectrum.

Fig. 5.— Histograms of the velocity difference relative to CIV for all the measured emission lines are shown. These are tabulated in table 4. Some of the very large differences of several thousand kilometers per second are due to the difficulty in accurately measuring some of the heavily absorbed emission lines, e.g. Lyα.

Fig. 6.— The sensitivity function, g(z), of the damped Lyα absorber surveys. This gives the number of lines of sight along which a damped system at redshift z could be detected. The APM survey adds substantial redshift path for z>3.

Fig. 7.— The Lyα absorbers listed in table 7 are marked with a vertical slash in the spectra in this figure. It shows the Lyα forest region on an expanded scale for the QSOs shown in figure 4 in which an absorber was measured. The damped Lyα candidates with estimated column densities above the threshold of log N<sub>HI</sub> ≥ 20.3 have an asterisk after the column density in table 7 and a circle around the vertical slash in the figure.

Fig. 8.— Two simulated QSOs with absorbers are shown. Panels (a) and (b) show a z = 3.86, log N<sub>HI</sub> = 20.69 damped Lyα absorption system in a z = 4.37 QSO at 1.6Å and 6Å resolution, respectively, with a signal-to-noise ratio of 25. Panels (c) and (d) show a z = 3.73, log N<sub>HI</sub> = 20.15 Lyα absorption system in a z = 4.51 QSO at 1.6Å and 6Å resolution, respectively, with a signal-to-noise ratio of 10.
(a) B-star spectrum -- airmass=1.056

(b) atmospheric absorption features removed

(c) inverted atmospheric absorption spectrum

$O_2$ C-band  $O_2$ B-band  $H_2O$ $\alpha$  + $H_2O$  $O_2$ A-band  $H_2O$ z

Wavelength $\lambda$
(a) B–star spectrum — airmass=1.48
The graph shows the sensitivity function $g(z)$ for different redshifts, specifically for damped Lyman-$\alpha$ absorption. The x-axis represents the damped Lyman-$\alpha$ absorption redshift, ranging from 0 to 5. The y-axis represents the sensitivity function, ranging from 0 to 200.

- The solid line represents APM.
- The dashed line represents WTSC+LWT+MH.
- The dotted line represents LWT.
| QSO          | Date (UT) | EXP (secs) | Arm | Slit ("") | QSO          | Date (UT) | EXP (secs) | Arm | Slit ("") |
|--------------|-----------|------------|-----|-----------|--------------|-----------|------------|-----|-----------|
| BR0019 - 1522 | 92 Oct 04 | 2700       | R/B | 1.5      | BR1117 - 1329 | 92 Apr 24 | 1200       | R/B | 1.5      |
|              | 600       | R/B        | 5   |          |              | 300       | R/B        | 5   |           |
| BRI0103 - 0032 | 93 Aug 21 | 2700       | R   | 1.5      | BR1144 - 0723 | 92 Apr 25 | 1800       | R/B | 1.5      |
| 3000         | B         | 1.5        |     |          |              | 300       | R          | 5   |           |
| 300          | R/B       | 5          |     |          | BR1202 - 0725 | 92 Apr 23 | 2700       | R   | 1.5      |
| BRI0151 - 0025 | 93 Aug 21 | 2700       | R   | 1.5      |              | 2700       | B          | 1.5 |           |
| 3000         | B         | 1.5        |     |          |              | 1200       | R          | 1.5 |           |
| 300          | R/B       | 5          |     |          |              | 300        | R          | 5   |           |
| BRI0241 - 0146 | 93 Aug 21 | 1800       | R/B | 1.5      |              | 93 Apr 17  | 2700       | R   | 1.5      |
| 300          | R/B       | 5          |     |          |              | 3000       | B          | 1.5 |           |
| BRI0245 - 0608 | 93 Aug 21 | 2700       | R   | 1.5      | BR1302 - 1404 | 93 Apr 17 | 1500       | R/B | 1.5      |
| 3000         | B         | 1.5        |     |          | BR1328 - 0433 | 93 Apr 17 | 2700       | R   | 1.5      |
| 300          | R/B       | 5          |     |          |              | 3000       | B          | 1.5 |           |
| BRI0351 - 1034 | 93 Aug 21 | 2700       | R/B | 1.5      | BR1335 - 0417 | 92 Apr 25 | 2700       | R/B | 1.5      |
| 3000         | B         | 1.5        |     |          |              | 300        | R          | 5   |           |
| 2800         | B         | 1.5        |     |          |              |            |            |     |           |
| BRI0401 - 1711 | 95 Feb 02 | 3600       | R/B | 1.5      | BR1346 - 0322 | 92 Apr 24 | 2700       | R/B | 1.5      |
|              | 300       | R          | 5   |           |              | 300        | R          | 5   |           |
| BRI0945 - 0411 | 92 Apr 24 | 2700       | R/B | 1.5      | BR1500 + 0824 | 92 Apr 25 | 2700       | R/B | 1.5      |
| 300          | R         | 5          |     |          |              | 300        | R          | 5   |           |
| BRI0951 - 0450 | 92 Apr 25 | 2700       | R/B | 1.5      | GB1508 + 5714 | 93 Apr 17 | 2700       | R   | 1.5      |
| 300          | R         | 5          |     |          |              | 3000       | B          | 1.5 |           |
| BRI0952 - 0115 | 92 Apr 24 | 900        | R   | 1.5      | MG1557 + 0313 | 92 Apr 25 | 2700       | R/B | 1.5      |
| 1000         | B         | 1.5        |     |          |              | 300        | R          | 5   |           |
| 300          | R         | 5          |     |          |              | 300        | R          | 5   |           |
| BRI1013 + 0035 | 92 Apr 24 | 2700       | R/B | 1.5      | GB1745 + 6227 | 93 Aug 92 | 2700       | R   | 1.5      |
| 3000         | R         | 5          |     |          |              | 3000       | B          | 1.5 |           |
| BRI1033 - 0327 | 93 Apr 17 | 2700       | R/B | 1.5      | BR2122 - 1626 | 93 Aug 21 | 2700       | R   | 1.5      |
| 600          | R/B       | 5          |     |          |              | 600        | R          | 5   |           |
| BRI1050 - 0000 | 92 Apr 25 | 1800       | R/B | 1.5      | BR2215 - 0607 | 92 Oct 03 | 2700       | R/B | 1.5      |
| 300          | R         | 5          |     |          |              | 450        | R/B        | 5   |           |
| BRI1108 - 0747 | 92 Apr 25 | 1800       | R/B | 1.5      | BR2235 - 0301 | 93 Aug 21 | 2700       | R   | 1.5      |
| 300          | R         | 5          |     |          |              | 3000       | B          | 1.5 |           |
| BRI1110 + 0106 | 92 Apr 25 | 1800       | R/B | 1.5      |              | 450        | R/B        | 5   |           |
| 300          | R         | 5          |     |          |              | 300        | R          | 5   |           |
| BRI1114 - 0822 | 93 Apr 11 | 2700       | R   | 1.5      | BR2237 - 0607 | 92 Apr 24 | 2700       | R   | 1.5      |
| 3000         | B         | 1.5        |     |          | BR2248 - 1242 | 93 Aug 21 | 3000       | B   | 1.5      |
| 300          | R         | 5          |     |          |              | 300        | R          | 5   |           |
### Table 2

#### QSO Magnitudes & Positions

| QSO          | APM R | AB 7000Å | AB 1450Åx(1 + z) | RA        | Declination | Ref. |
|--------------|-------|----------|------------------|-----------|-------------|------|
| BR 0019 - 1522 | 19.0  | 18.8     | 18.8             | 00 19 35.9 | -15 22 17   | 1    |
| BR J0103 + 0032 | 18.6  | 18.9     | 18.8             | 01 03 45.2 | +00 32 21   | 1    |
| BR J0151 - 0025 | 18.9  | 19.0     | 18.9             | 01 51 06.0 | -00 25 49   | 1    |
| BR J0241 - 0146 | 18.2  | 18.4     | 18.4             | 02 41 29.3 | -01 46 42   | 1    |
| BR 0245 - 0608 | 18.6  | 18.9     | 18.8             | 02 45 27.4 | -06 08 27   | 1    |
| BR J0351 - 1634\* | 18.6  | -       | -                | 03 51 23.7 | -10 34 08   | 1    |
| BR J0401 - 1711\* | 18.7  | -       | -                | 04 01 40.8 | -17 11 34   | 1    |
| BR 0946 - 0413\* | 18.8  | 18.9     | 18.9             | 09 46 18.6 | -04 11 17   | 1    |
| BR J0951 - 0450 | 18.9  | 19.4     | 19.2             | 09 51 25.0 | -04 50 07   | 1    |
| BR J0952 - 0115 | 18.7  | 18.8     | 18.7             | 09 52 27.2 | -01 15 53   | 1    |
| BR J1013 + 0035 | 18.8  | 19.1     | 19.0             | 10 13 15.0 | +00 35 17   | 1    |
| BR 1033 - 0327 | 18.5  | 18.8     | 18.8             | 10 33 51.5 | -03 27 46   | 1    |
| BR J1050 - 0600 | 18.6  | 19.5     | 19.4             | 10 50 46.7 | -00 00 50   | 1    |
| BR J1108 - 0747 | 18.1  | 18.8     | 18.8             | 11 08 41.9 | -07 47 44   | 1    |
| BR J1110 + 0306 | 18.3  | 19.0     | 18.9             | 11 10 12.3 | +01 06 18   | 1    |
| BR J1114 - 0822 | 19.4  | 20.1     | 19.7             | 11 14 55.2 | -08 22 34   | 1    |
| BR J1117 - 1329\* | 18.0  | 18.1     | 18.1             | 11 17 39.4 | -13 29 59   | 1    |
| BR J1144 - 0723\* | 18.6  | 18.9     | 18.8             | 11 44 02.4 | -07 23 25   | 1    |
| BR J1202 - 0725 | 18.7  | 18.1     | 18.0             | 12 02 49.2 | -07 25 50   | 1    |
| BR J1302 - 1404\* | 18.6  | 18.4     | 18.4             | 13 02 46.8 | -14 04 38   | 1    |
| BR J1328 - 0433 | 19.0  | 19.1     | 19.1             | 13 28 54.9 | -04 33 26   | 1    |
| BR J1335 - 0417 | 19.4  | 19.2     | 19.1             | 13 35 27.5 | -04 17 21   | 1    |
| BR J1346 - 0322 | 18.8  | 19.4     | 19.4             | 13 46 41.1 | -03 22 22   | 1    |
| BR J1500 + 0824 | 19.3  | 19.1     | 19.1             | 15 00 18.6 | +08 24 49   | 1    |
| GB 1508 + 5714 | 18.9  | 20.0     | 19.8             | 15 08 45.2 | +07 14 02   | 2    |
| MG 1557 + 0313 | 19.8  | 20.0     | 20.0             | 15 57 00.5 | +03 13 15   | 3    |
| GB 1745 + 6227 | 18.3  | 19.3     | 19.3             | 17 45 48.0 | +02 27 55   | 2    |
| BR 2212 - 1626 | 18.1  | 18.7     | 18.6             | 22 12 44.8 | -16 26 30   | 1    |
| BR J2335 - 0316 | 18.2  | 18.5     | 18.5             | 23 35 47.4 | -03 01 30   | 1    |
| BR J2337 - 0607\* | 18.3  | -       | -                | 23 37 17.4 | -06 07 59   | 1    |
| BR J2348 - 1245 | 18.5  | 19.5     | 19.4             | 23 48 39.8 | -12 42 59   | 1    |

\*No wide slit observations were obtained.

\*Not photometric conditions.

\*Exhibits broad absorption lines (BAL).

1References for positions: (1) Irwin et al., in preparation, (2) Hook et al. (1995), (3) McMahon et al., in preparation.

Note.—The APM R magnitudes are measured from the APM scans of the UK Schmidt plates. The errors are estimated to be ±0.25. The AB magnitudes at λ=7000Å and λ=1450Åx(1 + z) are calculated from the flux measured in the wide slit observations listed in Table 1 using \( AB = -2.5 \cdot \log(f/\mu ergs/s/cm^2/Hz) \). The errors are estimated to be ±0.1. The AB measures are 0.3 magnitudes fainter at 7000Å and from 0.3 - 0.5 magnitudes fainter at 1450Åx(1 + z) than magnitudes measured with respect to Vega.
### TABLE 3
**Determination of QSO Emission Redshifts**

| QSO     | Redshift         | Lyβ | OVI | Lyα | NV | SiII | OI  | CII | Si/OIV | CIV | HeII | OIII |
|---------|------------------|-----|-----|-----|----|------|-----|-----|--------|-----|------|------|
| BR 0019 | 1522             | 4.528±0.005 | 4.531 | 4.523 | 4.533 | 4.526 |
| BR0103  | 0032             | 4.437±0.012 | 4.444 | 4.435 | 4.447 | 4.447 | 4.422 | 4.420 | 4.185 | 4.199 |
| BR0151  | 0025             | 4.194±0.009 | 4.218 | 4.205 | 4.189 | 4.204 | 4.185 | 4.199 |
| BR0241  | 0146             | 4.018±0.008 | 4.090 | 4.058 | 4.060 | 4.052 | 4.042 | 3.994 |
| BR 0245 | 0608             | 4.238±0.013 | 4.265 | 4.200 | 4.250 | 4.240 | 4.223 |
| BR 0351 | 1034             | 4.351±0.005 | 4.398 | 4.320 | 4.327 |
| BR 0401 | 1711             | 4.236±0.014 | 4.261 | 4.251 | 4.257 | 4.247 | 4.235 | 4.227 |
| BR 0495 | 0115             | 4.436±0.020 | 4.467 | 4.448 | 4.432 | 4.425 | 4.400 |
| BR 0951 | 0450             | 4.406±0.038 | 4.442 | 4.432 | 4.378 |
| BR 1033 | 0327             | 4.509±0.005 | 4.521 | 4.503 | 4.511 | 4.516 | 4.507 | 4.504 |
| BR1108  | 0000             | 4.286±0.005 | 4.310 | 4.294 | 4.291 | 4.281 | 4.285 |
| BR1110  | 0106             | 3.918±0.006 | 3.988 | 3.916 | 3.913 | 3.924 |
| BR1114  | 0822             | 4.495±0.004 | 4.518 | 4.516 | 4.557 | 4.491 | 4.498 | 4.497 |
| BR 1117 | 1329             | 3.965±0.031 | 3.983 | 3.982 | 4.043 | 3.925 | 3.964 | 3.986 |
| BR 1144 | 0723             | 4.147±0.004 | 4.169 | 4.152 | 4.145 | 4.150 |
| BR 1202 | 0725             | 4.694±0.010 | 4.694 | 4.694 | 4.679 |
| BR 1302 | 1404             | 3.996±0.013 | 4.078 | 4.060 | 3.986 | 4.005 |
| BR1328  | 0433             | 4.217±0.011 | 4.224 | 4.181 | 4.222 | 4.223 | 4.205 |
| BR1135  | 0417             | 4.395±0.026 | 4.489 | 4.381 | 4.410 | 4.426 | 4.378 | 4.370 |
| BR1136  | 0322             | 3.992±0.014 | 4.011 | 3.984 | 4.006 | 3.976 | 3.966 | 3.965 | 3.935 | 3.965 |
| BR1150  | 0824             | 3.943±0.013 | 3.991 | 3.950 | 3.951 | 3.928 |
| GJ 1056 | 5714             | 4.283±0.019 | 4.309 | 4.292 | 4.266 | 4.279 | 4.304 |
| MG 1557 | 0313             | 3.891±0.001 | 3.900 | 3.896 | 3.845 | 3.889 | 3.892 | 3.891 |
| GB 1745 | 6227             | 3.901±0.016 | 3.903 | 3.910 | 3.875 | 3.911 | 3.919 | 3.888 | 3.888 |
| BR 2212 | 1626             | 3.990±0.002 | 4.005 | 3.952 | 3.990 | 3.988 | 3.992 |
| BR2235  | 0301             | 4.249±0.018 | 4.322 | 4.269 | 4.245 | 4.234 |
| BR 2237 | 0607             | 4.558±0.003 | 4.569 | 4.559 | 4.562 | 4.555 |
| BR 2248 | 1242             | 4.161±0.002 | 4.168 | 4.164 | 4.111 | 4.160 | 4.163 | 4.159 | 4.159 | 4.160 | 4.168 |

**Note:** The redshifts in **boldface** type were used to calculate the mean QSO emission redshift.

*Redshift calculated from the strong CIV absorption doublet.

*Redshift calculated from the Lyα edge. The redshift quoted for CIV in the table is for an absorption feature.
### Table 4

**Emission Line Velocity Shifts**

| Line Pair     | Median$^a$$^c$ | Mean$^a$ | $\sigma$ | N$^b$ |
|---------------|----------------|----------|----------|-------|
|               | $\Delta v$ (km s$^{-1}$) | $\Delta v$ (km s$^{-1}$) | (km s$^{-1}$) |       |
| Ly$\beta$ – CIV | 850 ± 210 | 850 | 420 | 2 |
| OVI – CIV | 1040 ± 50 | 930 | 330 | 7 |
| Ly$\alpha$ – CIV | 1100 ± 70 | 2050 | 1790 | 25 |
| NV – CIV | −680 ± 130 | −450 | 1930 | 15 |
| SiII – CIV | −170 ± 120 | −170 | 240 | 2 |
| OI – CIV | 430 ± 60 | 550 | 1260 | 22 |
| CII – CIV | 940 ± 100 | 1130 | 1040 | 11 |
| SiIV+OIV| – CIV | 140 ± 40 | 320 | 960 | 24 |
| HeII – CIV | −500 ± 376 | −1270 | 1880 | 5 |
| OIII| – CIV | 470 ± 470 | −240 | 1410 | 3 |

**Note:** The emission line redshifts are listed in Table 3.

$^a$ $\Delta v = c \times (z - z_{\text{civ}})/(1 + z_{\text{civ}})$

$^b$ $N = \text{number of pairs of lines used in the calculation}$

$^c$ The error is $\sigma/N$. 
| QSO           | λ (Å) | W  | σ(W) | Ion  | z     |
|--------------|------|----|------|------|-------|
| BR1500 + 0824 | 6106.8 | 1.4 | 0.3  | FeII | 2.797 |
|              | 6343.9 | 4.0 | 0.5  | AlII | 2.796 |
|              | 6545.6 | 1.7 | 0.5  | -    | -     |
|              | 6819.0 | 4.9 | 0.7  | FeII | 1.909 |
|              | 6907.6 | 4.0 | 0.4  | FeII | 1.910 |
|              | 6931.3 | 7.3 | 0.6  | FeII | 1.909 |
|              | 7524.2 | 3.9 | 0.6  | FeII | 1.908 |
|              | 7563.7 | 7.7 | 0.8  | FeII | 1.909 |
|              | 7648.5 | 2.4 | 0.4  | CIV  | 3.940 |
|              | 7660.8 | 2.8 | 0.4  | CIV  | 3.940 |
|              | 8130.5 | 14.8| 0.7  | MgII | 1.908 |
|              | 8150.1 | 10.6| 0.7  | MgII | 1.908 |
| GB1508 + 5714 | 6518.1 | 2.3 | 0.5  | -    | -     |
|              | 7428.5 | 3.7 | 1.1  | -    | -     |
| MG1557 + 0313 | 5952.6 | 6.4 | 0.3  | -    | -     |
|              | 7583.3 | 2.4 | 0.4  | CIV  | 3.898 |
|              | 7596.1 | 1.5 | 0.4  | CIV  | 3.898 |
| GB1745 + 6227 | 5957.5 | 1.8 | 0.2  | -    | -     |
|              | 6910.1 | 6.2 | 0.7  | MgII | 1.471 |
|              | 6928.8 | 6.3 | 0.7  | MgII | 1.471 |
|              | 7098.1 | 2.0 | 0.6  | -    | -     |
|              | 7512.3 | 1.3 | 0.4  | FeII | 2.323 |
|              | 7785.8 | 3.2 | 0.8  | FeII | 2.322 |
|              | 7887.3 | 2.7 | 0.8  | FeII | 2.322 |
|              | 7914.9 | 6.9 | 1.1  | FeII | 2.321 |
|              | 8590.3 | 4.1 | 1.1  | FeII | 2.321 |
|              | 8637.0 | 6.1 | 1.3  | FeII | 2.322 |
| BR2212 − 1626 | 6167.3 | 2.8 | 0.6  | -    | -     |
|              | 6276.0 | 2.3 | 0.5  | -    | -     |
|              | 6496.3 | 2.1 | 0.6  | -    | -     |
|              | 8236.0 | 2.5 | 0.8  | -    | -     |
| BR2237 − 0607 | 6777.2 | 2.8 | 0.1  | CII  | 4.078 |
|              | 6868.8 | 1.7 | 0.4  | NV   | 4.545 |
|              | 6888.0 | 1.1 | 0.2  | NV   | 4.545 |
|              | 7079.1 | 2.2 | 0.5  | SiIV | 4.079 |
|              | 7126.9 | 1.7 | 0.5  | SiIV | 4.079 |
|              |       |     |      | or FeII | 2.152 |
|              | 7310.2 | 1.6 | 0.6  | -    | -     |
|              | 7385.6 | 1.4 | 0.4  | FeII | 2.151 |
|              | 7412.4 | 3.6 | 0.5  | MgII | 1.672 |
|              | 7491.4 | 1.1 | 0.3  | MgII | 1.672 |
|              |       |     |      | or FeII | 2.156 |
|              | 7519.2 | 1.5 | 0.5  | FeII | 2.155 |
|              | 8164.1 | 1.6 | 0.5  | FeII | 2.156 |
|              | 8487.7 | 1.6 | 0.5  | CIV  | 4.482 |
|              | 8502.3 | 0.6 | 0.2  | CIV  | 4.482 |
| BR2248 − 1242 | 6487.5 | 6.0 | 1.1  | -    | -     |
|              | 7202.4 | 2.2 | 0.6  | -    | -     |
|              | 7939.5 | 2.0 | 0.6  | -    | -     |
| QSO          | λ (Å) | W  | σ(W) | Ion | z  |
|--------------|-------|----|------|-----|----|
| BRI1114 – 0723 continued |       |    |      |     |    |
| 7300.6       | 3.6   | 0.4| –    | –   | –  |
| 7329.1       | 1.7   | 0.4| –    | –   | –  |
| 7812.8       | 2.8   | 0.4| MgII | 1.794 |   |
| 7832.3       | 2.7   | 0.4| MgII | 1.794 |   |
| 8331.5       | 4.2   | 1.3| –    | –   | –  |
| BRI1202 – 0725 |       |    |      |     |    |
| 6888.5       | 5.6   | 0.3| MgII | 1.463 |   |
| 6906.2       | 6.1   | 0.3| MgII | 1.463 |   |
| 7005.0       | 3.8   | 0.3| CIV  | 3.525 |   |
| 7017.2       | 1.3   | 0.3| CIV  | 3.525 |   |
| 7076.4       | 1.4   | 0.3| CIV  | 3.565 |   |
| 7079.9       | 0.8   | 0.2| CIV  | 3.565 |   |
| 7122.3       | 2.8   | 0.3| FeII | 1.753 |   |
| 7161.1       | 3.1   | 0.3| FeII | 1.754 |   |
| 7183.2       | 3.8   | 0.2| CII  | 4.383 |   |
| 7702.6       | 6.4   | 0.5| MgII | 1.754 |   |
| 7722.2       | 4.4   | 0.4| MgII | 1.754 |   |
| 7852.4       | 2.6   | 0.4| CIV  | 4.072 |   |
| 7865.5       | 1.8   | 0.4| CIV  | 4.072 |   |
| 8064.6       | 2.1   | 0.4| FeII | 2.441 |   |
| 8194.9       | 7.6   | 0.6| FeII | 2.439 |   |
| 8212.6       | 3.1   | 0.6| SiII | 4.379 |   |
| 8475.6       | 3.3   | 0.5| CIV  | 4.474 |   |
| 8491.3       | 1.8   | 0.4| CIV  | 4.474 |   |
| 8793.0       | 3.8   | 0.5| CIV  | 4.679 |   |
| 8806.1       | 1.4   | 0.4| CIV  | 4.679 |   |
| 8891.4       | 2.5   | 0.6| FeII | 2.437 |   |
| 8937.7       | 2.7   | 0.7| FeII | 2.438 |   |
| 9053.9       | 3.9   | 0.9| MgII | 2.238 |   |
| 9076.2       | 3.1   | 0.7| MgII | 2.238 |   |
| 9314.7       | 4.6   | 0.6| –    | –   | –  |
| 9337.1       | 8.4   | 0.6| MgII | 2.339 |   |
| 9360.1       | 5.8   | 0.6| MgII | 2.339 |   |
| 9526.4       | 4.5   | 1.3| MgII | 2.339 |   |
| 9630.6       | 13.4  | 1.0| MgII | 2.444 |   |
| 9656.1       | 9.8   | 1.0| MgII | 2.444 |   |
| BRI1328 – 0433 |       |    |      |     |    |
| 6797.6       | 5.4   | 0.5| FeII | 1.628 |   |
| 6832.7       | 8.0   | 0.7| FeII | 1.628 |   |
| 6862.8       | 2.9   | 0.6| –    | –   | –  |
| 7349.4       | 15.0  | 0.6| MgII | 1.628 |   |
| 7367.6       | 13.2  | 0.6| MgII | 1.628 |   |
| BRI1335 – 0417 |       |    |      |     |    |
| 6617.0       | 2.4   | 0.3| FeII | 1.823 |   |
| 6702.4       | 1.3   | 0.4| FeII | 1.823 |   |
| 6725.3       | 3.3   | 0.5| FeII | 1.822 |   |
| 6813.9       | 2.9   | 0.6| SiII | 4.406 |   |
| 7210.6       | 3.3   | 0.8| CII  | 4.403 |   |
| 7339.6       | 2.4   | 0.6| FeII | 1.823 |   |
| 7696.9       | 2.6   | 0.5| –    | –   | –  |
| 7707.6       | 5.2   | 0.5| –    | –   | –  |
| 7892.6       | 5.5   | 0.7| MgII | 1.822 |   |
| 7914.8       | 4.4   | 1.1| MgII | 1.822 |   |
| BRI1346 – 0322 |       |    |      |     |    |
| 6115.7       | 1.6   | 0.2| –    | –   | –  |
| 6160.4       | 6.3   | 0.4| NV   | 3.974 |   |
| 6182.3       | 7.4   | 0.4| NV   | 3.974 |   |
| 6207.1       | 1.1   | 0.3| –    | –   | –  |
| 6428.4       | 1.8   | 0.6| –    | –   | –  |
| 6654.7       | 1.8   | 0.6| FeII | 1.943 |   |
| 6749.8       | 7.5   | 0.8| CIV  | 3.359 |   |
| 6760.2       | 5.0   | 0.7| CIV  | 3.359 |   |
| 6986.5       | 1.2   | 0.3| FeII | 1.943 |   |
| 7002.2       | 1.8   | 0.5| SiIV | 3.992 |   |
| 7705.7       | 9.9   | 0.7| CIV  | 3.974 |   |
| 7737.3       | 4.1   | 0.5| CIV  | 3.994 |   |
| 8116.9       | 3.0   | 0.8| CIV  | 3.994 |   |
| 8222.1       | 1.2   | 0.8| –    | –   | –  |
| 8231.8       | 1.8   | 0.8| MgII | 1.944 |   |
### Table 5—Continued

| QSO            | λ(A)   | W   | σ(W) | Ion | z   |
|----------------|--------|-----|------|-----|-----|
| BRI0922 - 0115 | 7776.9 | 7.9 | 0.6  | CIV | 4.023 |
| continued      | 7788.5 | 3.2 | 0.6  | CIV | 4.023 |
|                | 7987.2 | 3.3 | 0.8  | -   | -    |
|                | 8082.3 | 1.9 | 0.5  | FeII| 4.025 |
|                | 8234.5 | 1.8 | 0.4  | -   | -    |
|                | 8344.7 | 5.6 | 0.6  | -   | -    |
|                | 8383.8 | 4.7 | 0.5  | MgII| 1.993 |
|                | 8403.9 | 2.5 | 0.4  | MgII| 1.993 |
|                | 8418.9 | 2.4 | 0.6  | -   | -    |
|                | 8482.8 | 2.3 | 0.5  | -   | -    |
|                | 8663.2 | 2.7 | 0.9  | -   | -    |
| BRI1013 + 0035 | 6599.4 | 4.4 | 0.4  | FeII| 3.103 |
|                | 6855.6 | 6.3 | 0.5  | -   | -    |
|                | 6911.3 | 2.5 | 0.5  | FeII| 2.057 |
|                | 7169.2 | 5.2 | 0.5  | FeII| 2.059 |
|                | 7269.8 | 3.3 | 0.6  | FeII| 2.058 |
|                | 7287.1 | 6.9 | 0.5  | FeII| 2.058 |
|                | 7303.2 | 0.8 | 0.2  | -   | -    |
|                | 7324.8 | 3.0 | 0.7  | -   | -    |
|                | 7907.7 | 5.2 | 0.9  | FeII| 2.057 |
|                | 7948.5 | 6.8 | 0.7  | FeII| 2.057 |
|                | 8539.9 | 8.4 | 0.6  | MgII| 2.054 |
|                | 8561.2 | 9.1 | 0.6  | MgII| 2.054 |
| BRI1033 - 0327 | 6680.2 | 2.9 | 0.2  | -   | -    |
|                | 6869.4 | 1.9 | 0.3  | CII | 4.148 |
| BRI1050 - 0000 | 6487.3 | 1.7 | 0.3  | CII | 3.861 |
|                | 6776.0 | 2.1 | 0.5  | SiIV| 3.862 |
|                | 6818.6 | 1.7 | 0.5  | SiIV| 3.862 |
|                | 7528.0 | 3.7 | 0.6  | CIV  | 3.862 |
|                | 7538.1 | 4.3 | 0.6  | CIV  | 3.862 |
|                | 8117.7 | 1.6 | 0.3  | -   | -    |
|                | 8141.8 | 0.6 | 0.2  | -   | -    |
| BRI1108 - 0747 | 5977.9 | 6.1 | 0.3  | -   | -    |
|                | 6630.1 | 2.6 | 0.5  | -   | -    |
|                | 6791.7 | 3.1 | 0.4  | -   | -    |
|                | 6804.1 | 0.7 | 0.2  | -   | -    |
|                | 7083.9 | 1.4 | 0.4  | CIV | 3.575 |
|                | 7094.0 | 1.1 | 0.3  | CIV | 3.575 |
|                | 7132.3 | 2.5 | 0.4  | CIV | 3.607 |
|                | 7143.8 | 1.2 | 0.4  | CIV | 3.607 |
|                | 8310.5 | 4.24 | 0.9 | -  | -    |
| BRI1110 + 0106 | 6413.0 | 2.7 | 0.5  | FeII| 1.479 |
|                | 6464.4 | 1.9 | 0.5  | FeII| 1.479 |
|                | 6634.7 | 1.4 | 0.4  | -   | -    |
|                | 6932.2 | 1.6 | 0.4  | MgII| 1.479 |
|                | 6950.7 | 1.5 | 0.4  | MgII| 1.479 |
|                | 7158.6 | 1.7 | 0.5  | -   | -    |
|                | 7299.6 | 1.6 | 0.5  | -   | -    |
|                | 7323.0 | 2.4 | 0.6  | -   | -    |
|                | 7829.7 | 2.2 | 0.7  | MgII| 1.800 |
|                | 7852.1 | 2.5 | 0.8  | MgII| 1.800 |
|                | 8574.3 | 4.5 | 1.1  | -   | -    |
| BRI1114 - 0723 | 6697.5 | 3.0 | 0.3  | MgII| 1.395 |
|                | 6713.7 | 3.1 | 0.3  | MgII| 1.395 |
|                | 6846.4 | 1.6 | 0.3  | CIV | 3.422 |
|                | 6858.7 | 1.2 | 0.3  | CIV | 3.422 |
|                | 6877.1 | 4.8 | 0.6  | -   | -    |
|                | 7016.4 | 2.5 | 0.6  | -   | -    |
|                | 7076.9 | 3.6 | 0.4  | CIV | 3.571 |
|                | 7088.1 | 1.9 | 0.4  | CIV | 3.571 |
|                | 7105.2 | 2.0 | 0.4  | CIV | 3.589 |
|                | 7116.3 | 1.4 | 0.3  | CIV | 3.589 |
|                | 7280.2 | 4.3 | 0.5  | -   | -    |
| QSO       | $\lambda$ (Å) | W  | $\sigma(W)$ | Ion | $z$ |
|-----------|---------------|----|-------------|-----|-----|
| BR0351 – 1034 continued | 7173.5 | 2.0 | 0.6 | CIV | 3.633 |
|           | 7185.2 | 1.2 | 0.5 | CIV | 3.633 |
|           | 7196.0 | 0.7 | 0.2 | -   | -   |
|           | 7431.7 | 1.5 | 0.4 | -   | -   |
|           | 7458.8 | 6.6 | 0.5 | SiIV | 4.352 |
|           | 7507.5 | 5.2 | 0.4 | SiIV | 4.352 |
|           | 7550.7 | 5.0 | 0.6 | -   | -   |
|           | 7822.5 | 3.3 | 0.5 | -   | -   |
|           | 7834.6 | 2.4 | 0.5 | -   | -   |
|           | 7843.6 | 2.0 | 0.5 | -   | -   |
|           | 7895.7 | 12.6 | 0.7 | CIV | 4.098 |
|           | 7906.9 | 11.4 | 0.7 | CIV | 4.098 |
|           | 7916.4 | 8.5 | 0.5 | -   | -   |
|           | 7940.0 | 11.1 | 0.7 | -   | -   |
|           | 7952.2 | 8.4 | 0.5 | -   | -   |
|           | 8159.8 | 6.0 | 0.5 | -   | -   |
|           | 8173.1 | 4.7 | 0.5 | -   | -   |
|           | 8188.0 | 3.7 | 0.5 | -   | -   |
|           | 8197.0 | 3.4 | 0.5 | MgII | 1.931 |
|           | 8218.2 | 2.0 | 0.4 | MgII | 1.931 |
|           | 8228.1 | 2.4 | 0.4 | CIV | 4.315 |
|           | 8241.9 | 2.2 | 0.4 | CIV | 4.315 |
|           | 8286.8 | 21.5 | 1.0 | CIV | 4.351 |
|           | 8297.7 | 15.1 | 1.0 | CIV | 4.351 |
| BR0401 – 1711 | 6382.5 | 2.7 | 0.1 | -   | -   |
|           | 6972.7 | 1.6 | 0.3 | -   | -   |
|           | 7198.9 | 3.1 | 0.3 | -   | -   |
|           | 7297.7 | 2.4 | 0.3 | -   | -   |
|           | 7307.9 | 2.2 | 0.3 | -   | -   |
|           | 7344.4 | 1.6 | 0.3 | -   | -   |
|           | 8095.0 | 2.7 | 0.1 | CIV | 4.229 |
|           | 8109.5 | 2.0 | 0.1 | CIV | 4.229 |
|           | 8396.9 | 4.9 | 0.8 | -   | -   |
| BR0951 – 0450 | 6553.5 | 5.7 | 0.4 | SiIV | 3.703 |
|           | 6598.8 | 2.0 | 0.4 | SiIV | 3.703 |
|           | 6614.1 | 3.1 | 0.4 | -   | -   |
|           | 6712.6 | 4.2 | 0.6 | -   | -   |
|           | 6769.5 | 3.5 | 0.6 | SiIV | 3.858 |
|           | 6815.9 | 2.0 | 0.4 | SiIV | 3.858 |
|           | 7282.7 | 5.5 | 0.7 | CIV | 3.703 |
|           | 7293.3 | 4.2 | 0.7 | CIV | 3.703 |
|           | 7359.6 | 5.0 | 1.1 | -   | -   |
|           | 7416.0 | 3.3 | 0.6 | SiII | 3.858 |
|           | 7456.7 | 2.4 | 0.7 | -   | -   |
|           | 7517.4 | 2.1 | 0.6 | CIV | 3.855 |
|           | 7528.4 | 2.8 | 0.6 | CIV | 3.855 |
|           | 8108.8 | 7.1 | 1.1 | -   | -   |
|           | 8306.1 | 1.8 | 0.5 | CIV | 4.364 |
|           | 8317.3 | 1.1 | 0.3 | CIV | 4.364 |
| BR0952 – 0115 | 6648.4 | 2.0 | 0.2 | CIV | 3.294 |
|           | 6660.2 | 1.3 | 0.2 | CIV | 3.294 |
|           | 6704.9 | 6.3 | 0.4 | CII | 4.024 |
|           | 6719.7 | 8.1 | 0.3 | -   | -   |
|           | 6749.6 | 1.2 | 0.3 | -   | -   |
|           | 6826.4 | 1.8 | 0.4 | -   | -   |
|           | 6875.6 | 2.7 | 0.3 | -   | -   |
|           | 6928.4 | 2.8 | 0.5 | CIV | 3.475 |
|           | 6941.3 | 1.7 | 0.5 | CIV | 3.475 |
|           | 7002.6 | 2.8 | 0.4 | SiIV | 4.024 |
|           | 7047.6 | 2.2 | 0.4 | SiIV | 4.024 |
|           | 7132.2 | 1.2 | 0.3 | FeII | 1.993 |
|           | 7208.8 | 2.4 | 0.5 | -   | -   |
|           | 7306.4 | 4.6 | 0.5 | CIV | 3.719 |
|           | 7317.6 | 3.6 | 0.5 | CIV | 3.719 |
|           | 7345.5 | 1.6 | 0.5 | -   | -   |
|           | 7478.4 | 1.6 | 0.5 | -   | -   |
|           | 7659.4 | 3.9 | 0.5 | SiII | 4.024 |
| QSO          | λ (Å) | W  | σ(W) | Log | z  |
|-------------|-------|-----|------|-----|----|
| BR0019 − 1522 | 6777.7 | 4.4 | 0.3  | SiII | 3.439 |
|             | 6805.5 | 5.0 | 0.4  | CIV  | 3.396 |
|             | 6819.3 | 1.7 | 0.4  | CIV  | 3.396 |
|             | 7141.0 | 2.0 | 0.5  | FeII | 3.440 |
|             | 7153.9 | 1.9 | 0.4  |      | -    |
|             | 7417.2 | 3.4 | 0.5  |      | -    |
| BR0103 + 0032 | 6616.6 | 3.4 | 0.1  | MgII | 1.366 |
|             | 6634.2 | 5.4 | 0.2  | MgII | 1.366 |
|             | 6664.6 | 1.0 | 0.2  | FeII | 1.810 |
|             | 6695.1 | 9.7 | 0.4  | FeII | 1.810 |
|             | 7326.0 | 8.3 | 0.7  | MgII | 1.818 |
|             | 7880.5 | 2.2 | 0.6  | MgII | 1.818 |
|             | 7898.5 | 4.2 | 0.7  | MgII | 1.818 |
| BR0151 − 0025 | 6405.0 | 5.9 | 0.4  | NV   | 4.170 |
|             | 6425.0 | 4.3 | 0.3  | NV   | 4.170 |
|             | 7549.7 | 1.1 | 0.3  | CIV  | 3.876 |
|             | 7562.7 | 1.0 | 0.3  | CIV  | 3.876 |
|             |        |     |      |      |      |
| BR0241 − 0146 | 6317.8 | 1.1 | 0.4  | FeII | 1.437 |
|             | 6336.9 | 1.7 | 0.5  | FeII | 1.437 |
|             | 6382.3 | 1.4 | 0.4  |      | -    |
|             | 6467.4 | 1.5 | 0.5  |      | -    |
|             | 6809.0 | 0.6 | 0.2  | MgII | 1.435 |
|             | 6827.8 | 0.7 | 0.2  | MgII | 1.435 |
|             | 6882.3 | 2.1 | 0.5  |      | -    |
|             | 6923.6 | 2.5 | 0.5  |      | -    |
|             | 6966.7 | 2.2 | 0.6  |      | -    |
|             | 7691.1 | 4.8 | 0.6  |      | -    |
|             | 8060.4 | 3.3 | 0.9  |      | -    |
| BR0245 − 0608 | 6312.4 | 11.2 | 0.5  | FeII | 1.712 |
|             | 6356.4 | 17.0 | 0.5  | FeII | 1.712 |
|             | 6380.5 | 4.9 | 0.4  |      | -    |
|             | 6438.0 | 4.6 | 0.4  | FeII | 1.708 |
|             | 6453.2 | 4.2 | 0.4  | FeII | 1.712 |
|             | 6477.5 | 0.9 | 0.2  | CIV  | 3.184 |
|             | 6488.0 | 3.2 | 0.4  | CIV  | 3.184 |
|             | 6861.5 | 2.8 | 0.6  |      | -    |
|             | 7047.2 | 1.9 | 0.5  | FeII | 1.710 |
|             | 7093.1 | 4.1 | 0.5  |      | -    |
|             | 7104.8 | 1.9 | 0.4  |      | -    |
|             | 7160.7 | 2.1 | 0.4  | SiIV | 4.139 |
|             | 7208.3 | 3.0 | 0.5  | SiIV | 4.139 |
|             | 7580.5 | 3.0 | 0.5  | MgII | 1.711 |
|             | 7600.9 | 3.5 | 0.6  | MgII | 1.711 |
|             | 7957.1 | 5.9 | 0.7  | CIV  | 4.140 |
|             | 7971.9 | 1.8 | 0.5  | CIV  | 4.140 |
| BR0351 − 1034 | 6545.9 | 9.2 | 0.4  | MgII | 1.340 |
|             | 6559.5 | 7.9 | 0.4  | MgII | 1.340 |
|             | 6576.0 | 3.6 | 0.4  |      | -    |
|             | 6631.7 | 4.9 | 0.3  | NV   | 4.353 |
|             | 6653.0 | 4.4 | 0.4  | NV   | 4.353 |
|             | 6744.9 | 1.3 | 0.3  | SiIII| 4.351 |
|             | 6967.2 | 2.6 | 0.5  |      | -    |
|             | 6873.9 | 2.3 | 0.5  |      | -    |
|             | 6989.2 | 5.8 | 0.5  | FeII | 1.933 |
|             | 7000.7 | 3.5 | 0.4  |      | -    |
|             | 7105.2 | 1.4 | 0.4  | SiIV | 4.098 |
|             | 7148.3 | 1.4 | 0.4  | SiIV | 4.098 |
| QSO*   | z_em | z_min | z_lls | τ_lls |
|--------|------|-------|-------|-------|
| BR 0019 – 1522 | 4.52 | 2.51  | 4.27  | >5.8  |
| BR1013 + 0032  | 4.44 | 2.51  | 4.31  | 1.6   |
| BR1015 – 0025  | 4.20 | 2.51  | 4.05  | >3.7  |
| BR 0245 – 0608  | 4.24 | 2.51  | 4.23  | >3.9  |
| BR 0951 – 0450  | 4.37 | 2.84  | 4.22  | >3.1  |
| BR10952 – 0115  | 4.43 | 2.84  | 4.25  | >2.1  |
| BR11013 + 0035  | 4.41 | 2.84  | 3.78  | >2.3  |
| BR 1033 – 0327  | 4.51 | 2.84  | 4.19  | >3.5  |
| BR11050 – 0000  | 4.29 | 2.84  | 4.08  | >2.5  |
| BR11114 – 0822b | 4.51 | 2.84  | 4.50  | >3.7  |
| BR 1202 – 0725  | 4.69 | 2.84  | 4.52  | >3.0  |
| BR1328 – 0433  | 4.22 | 2.84  | 4.25  | 0.6   |
| BR1335 – 0417b  | 4.40 | 2.84  | 4.45  | >3.1  |
| GB 1508 + 5714  | 4.30 | 2.84  | 3.88  | >4.6  |
| BR 2237 – 0607  | 4.56 | 2.51  | 4.28  | >2.6  |

- *z_em* = QSO emission redshift
- *z_min* = minimum z at which a LLS could be observed
- *z_lls* = Lyman-limit system redshift
- *τ_lls* = optical depth at the Lyman-limit

*Zem ≥ 4.2, used in Storrie-Lombardi, et al. (1994)*

b*(z_em − z_lls)/(1 + z_em)* < 4000 km s⁻¹


| QSO            | $z_{\text{min}}$ | $z_{\text{max}}$ | $z_{\text{em}}$ | Metals            | $z_{\text{abs}}$ | $W_{\text{rest}}$ [Å] | $\log N_{\text{HI}}$ estimated |
|---------------|-----------------|-----------------|-----------------|------------------|-----------------|------------------------|---------------------------------|
| BR 0019 − 1522 | 2.97            | 4.473           | 4.528           | SiII 1526, FeII1608 CIV1549 | 3.42            | 7.6                     | 20.0                           |
|               |                 |                 |                 |                  | 3.98            |                        | 20.5*                          |
|               |                 |                 |                 |                  | 4.28            |                        | 20.1                           |
| BR10103 + 0032 | 2.87            | 4.383           | 4.437           |                  | 4.23            | 5.8                     | 19.8                           |
| BR10105 − 0025 | 2.74            | 4.142           | 4.194           |                  | 3.41            | 5.7                     | 19.8                           |
| BR10241 − 0146 | 3.86            | 4.002           | 4.053           |                  | 3.61            | 6.6                     | 19.9                           |
| BR 0245 − 0060 | 2.96            | 4.186           | 4.238           |                  | 4.14            | 6.3                     | 19.9                           |
| BR 0351 − 1034 | 3.09            | 4.297           | 4.351           | CIV1549          |                |                        |                                |
| BR 0401 − 1711 | 2.82            | 4.184           | 4.236           |                  | 3.84            | 24.0                    | 21.0*                          |
| BR 0951 − 0450 | 2.93            | 4.315           | 4.369           | SiIV1400, CIV1549 SiII 1526 | 4.20            | 10.6                    | 20.3*                          |
|               |                 |                 |                 |                  | 4.01            |                        | 18.0*                          |
| BR10952 − 0115 | 2.99            | 4.372           | 4.426           | CII1334, CIV1549 SiIV1400, SiII 1526 | 3.10            | 17.5                    | 20.8*                          |
|               |                 |                 |                 |                  | 3.73            |                        | 20.2                           |
|               |                 |                 |                 |                  | 4.15            |                        | 20.0                           |
| BR 1033 − 0327 | 2.91            | 4.454           | 4.509           | CII1334          | 4.15            | 9.6                     | 20.2                           |
| BR11050 − 0000 | 2.83            | 4.233           | 4.286           |                  | 3.79            | 8.3                     | 20.1                           |
| BR11080 − 0747 | 3.64            | 3.873           | 3.922           |                  | 3.61            | 9.0                     | 20.2                           |
| BR11100 + 0100 | 2.58            | 3.869           | 3.918           |                  | 3.25            | 5.2                     | 19.7                           |
| BR11110 − 0822 | 3.19            | 4.440           | 4.495           |                  | 3.91            | 6.7                     | 19.9                           |
| BR 1114 − 0723b| 2.89            | 4.096           | 4.147           |                  | 4.25            | 11.7                    | 20.4*                          |
| BR 1202 − 0725 | 3.16            | 4.637           | 4.694           |                  | 4.45            | 5.3                     | 19.7                           |
|               |                 |                 |                 |                  | 3.26            | 17.8                    | 20.8*                          |
|               |                 |                 |                 |                  | 3.20            | 5.4                     | 19.7                           |
|               |                 |                 |                 |                  | 3.38            | 7.1                     | 20.0                           |
|               |                 |                 |                 |                  | 4.13            | 7.8                     | 20.1                           |
| BR11328 − 0433 | 2.24            | 4.165           | 4.217           |                  | 3.08            | 8.3                     | 20.1                           |
| BR11335 − 0417 | 3.08            | 4.342           | 4.396           |                  | 3.36            | 6.8                     | 19.9                           |
| BR11346 − 0322 | 2.65            | 3.942           | 3.992           |                  | 3.73            | 10.0                    | 20.3*                          |
| BR11500 + 0824 | 2.39            | 3.894           | 3.943           |                  | 3.73            | 10.0                    | 20.3*                          |
| GB 1508 + 5714 | 2.73            | 4.230           | 4.283           |                  | 2.80            | 11.3                    | 20.4*                          |
| MB 1557 + 0313 | 2.66            | 3.842           | 3.891           |                  | 3.90            | 11.5                    | 20.4*                          |
| GB 1745 + 0227 | 2.47            | 3.852           | 3.901           |                  | 4.08            | 11.5                    | 20.4*                          |
| BR 2212 − 1626 | 2.69            | 3.940           | 3.990           |                  | 4.08            | 11.5                    | 20.4*                          |
| BR 2237 − 0607 | 2.96            | 4.502           | 4.518           | CII1334, SiIV1400 | 4.08            |                        | 20.4*                          |
| BR 2248 − 1242 | 2.94            | 4.169           | 4.161           |                  | 3.73            | 10.0                    | 20.3*                          |

* These candidates are above the statistical sample threshold of $N_{\text{HI}} \geq 2 \times 10^{20}$ atoms cm$^{-2}$.

$z_{\text{min}}$ = minimum redshift at which a DLA could be observed

$z_{\text{em}}$ = emission redshift of the QSO

$z_{\text{max}}$ = 3000 km s$^{-1}$ blueward of $z_{\text{em}}$

$z_{\text{abs}}$ = redshift at which a DLA candidate was observed

b This QSO exhibits some BAL characteristics. The damped candidate at $z=3.26$ is tentative as it falls at the same wavelength as OVI at $z=4.0$. 

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**TABLE 7**

APM DAMPED LYMAN-α ABSORPTION SURVEY

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