Emission Line Abundances of Absorption Selected Galaxies at $z < 0.5$

Sara L. Ellison$^1$, Lisa J. Kewley$^2$†, Gabriela Mallén-Ornelas$^2$,

$^1$University of Victoria, 3800 Finnerty Rd, Victoria, BC, V8P 1A1, Canada
$^2$Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138 USA

26 August 2018

ABSTRACT

We have obtained optical spectra of four galaxies associated with Mg II QSO absorbers at redshifts $0.10 < z < 0.45$. We calculate the gas-phase oxygen abundance of these galaxies using the empirical R$_{23}$ strong line method. The absolute $B$-band magnitudes of the galaxies span $-20.6 < M_B < -18.3$. If the metallicities lie on the R$_{23}$ upper branch ($8.4 < \log(O/H) + 12 < 8.9$), then the metallicities of these absorption selected galaxies span the range between 0.5–1.4 $Z_{\odot}$ and would be consistent with the well-known luminosity-metallicity relation for $0.10 < z < 0.45$ emission-line galaxies. However, such metallicities would be 0.5–1.0 dex higher than those observed in damped Lyman $\alpha$ systems (DLAs) via absorption line measurements at similar redshifts. Conversely, the lower R$_{23}$ branch calibration yields metallicities $Z \sim 1/7 Z_{\odot}$, consistent with the DLA absorption metallicities at low redshifts. In this case, the absorption selected galaxies would lie significantly lower than the luminosity-metallicity relation for emission-line galaxies at $z < 0.5$. We discuss the implications and possible solutions for each scenario.

Key words: quasars: absorption lines – galaxies: abundances – galaxies: ISM

1 INTRODUCTION

Measuring the chemical content of galaxies at early cosmic epochs is an important probe of the history of star formation and the early evolutionary phases of galactic objects. Although galaxy detections are now being pushed out to $z \sim 6$ and beyond (e.g., Hu et al. 2002; Dickinson et al. 2003a; Stanway, Bunker & McMahon 2003; Cuby et al. 2003), only a few high redshift objects are bright enough to be studied in detail (e.g., Pettini et al. 2001, 2002; Teplitz et al. 2000; Kobulnicky & Koo 2000; Steidel et al. 2004). Our direct knowledge of the chemical evolution of galaxies is therefore mostly limited to $z < 1$ where optical nebular emission lines can be used to determine [O/H] (e.g., Kobulnicky & Zaritsky 1999; Kobulnicky et al. 2003; Lilly, Carollo & Stockton 2003; Maier, Meisenheimer & Hippelein 2004; Kobulnicky & Kewley 2004).

Quasar absorption line studies provide an alternative means to measure abundances out to arbitrarily high redshifts. In particular, damped Lyman $\alpha$ (DLA) systems provide a powerful tracer of the chemical history of high redshift galaxies (e.g., Pettini et al. 1997; Prochaska & Wolfe 2002). DLA studies imply that there has been very little evolution in their weighted metallicities between $1.5 < z < 4$, with a mild increase by a factor of a few at lower redshifts (Pettini et al. 1999; Kulkarni & Fall 2002; Prochaska et al. 2003; Khare et al. 2004). This result is somewhat surprising given the rapid build-up in the stellar mass density at $z < 2$ (Dickinson et al. 2003b; Rudnick et al. 2003) and high star formation rates at early times (e.g., Giavalisco et al. 2004 and references therein).

Observational bias has often been invoked in order to explain the apparent lack of observed metals. For example, it has been suggested that dust may be responsible for obscuring QSOs behind the most evolved galaxies (Fall & Pei 1993; Hou, Boissier & Prantzos 2001; Churches et al. 2004). In an attempt to circumvent this bias, Ellison et al. (2001) conducted a DLA survey based on a radio selected sample of QSOs with complete optical identifications. They found at most a factor of two difference in the mass density of neutral gas and number density of DLAs at $z > 2$ compared with optically selected QSO surveys. There is a similarly small effect for Mg II absorption systems at lower redshifts, at least down to $z \sim 0.7$ (Ellison et al., 2004a). Given the good agreement in number density and neutral gas content, Ellison (2000) calculated that the metallicities
of DLAs at $z \sim 2.5$ would have to be $> 0.5Z_\odot$ to account for the mass density of metals predicted from star formation rates (Pettini 1999). However, recent high resolution observations of the unbiased DLA sample of Ellison et al. (2001) confirm that their metallicities are in good agreement with the range of extant abundance measurements, i.e. $10^{-1} - 1/15Z_\odot$ (Akerman et al., in preparation). The same is probably also true of lower redshift absorbers (Ellison et al., 2004a). The results from these ‘complete’ surveys have therefore not provided any support for the hypothesis that dust bias is responsible for the lack of metallicity evolution in DLAs.

In this paper, we present the first results of a project whose aim is to explore the possibility that absorption systems such as DLAs may not trace the bulk of the metals’ reservoir at a given epoch. We would like to address two questions: 1) what is the range of emission line metallicities in absorption selected galaxies at a given redshift and 2) does the absorption line abundance of a given absorption selected galaxy agree with its emission line metallicity? This latter issue has been the focus of considerable debate for the last decade (e.g. Kunth et al. 1994; Kunth, Matteucci & Marconi 1995; Pettini & Lipman 1995), and has seen a recent renewed interest in the literature (Aloisi et al. 2003; Lebouteiller et al. 2004; Lecavelier des Etangs et al. 2004).

Here, we make a first step to addressing the former of these questions by measuring the HII region oxygen abundances in DLAs at $0 < z < 5$ and discuss future observations that will tackle the latter issue.

We assume cosmological parameters of $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$, $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$. In this cosmology, 1 arcsec transverse on the sky corresponds to 1.8 $h_{70}^{-1}$ kpc at $z = 0.1$ and 5.4 $h_{70}^{-1}$ kpc at $z = 0.4$.

2 SAMPLE SELECTION, OBSERVATIONS & DATA REDUCTION

Since very few DLA galaxies have been spectroscopically confirmed, we chose to begin our study with a sample of galaxies associated with strong Mg II absorbers selected from the compilations of Guillemim & Bergeron (1997) and Bergeron & Boissé (1991). An advantage of Mg II selection is that these absorbers are more easily identified in QSO spectra at low redshift. The Mg II doublet occurs at a rest wavelength of $\lambda\lambda$ 2796, 2803 Å and is therefore observable in the optical regime for $0.3 < z < 2.5$. DLAs, on the other hand, require UV spectroscopy to confirm their N(H I) at $z < 1.6$ and are consequently less well studied.

Table 1 lists the fields for which we performed galaxy spectroscopy; precise galaxy coordinates can be found in Guillemim & Bergeron (1997) and Bergeron & Boissé (1991). One of the Mg II systems in our sample, towards Q0151+045, has two candidate absorbing galaxies; we have obtained spectra of both galaxies. Our sample therefore consists of three absorption systems with spectroscopy for four galaxies. The H I column densities for 2/3 of the absorbers could be measured from existing HST/FOS archival spectra (Rao & Turnshek 2000; S. Rao, 2004, private communication). For the third QSO, Q0229+13, the presence of a higher redshift Lyman limit system precludes the measurement of N(H I) at $z = 0.417$. We note that the selection of bright galaxies with confirmed spectroscopic redshifts could potentially bias this sample towards higher metallicities. Given that Mg II/DLA galaxies can exhibit a range of luminosities and morphologies (Steidel, Dickinson & Persson 1994; Chen & Lanzetta 2003; Rao et al. 2003), a more extensive survey that includes lower-luminosity systems may reveal a wider range of galaxy metallicities than exhibited by our current sample.

Spectra were obtained using LDSS2 at the Magellan II telescope during runs scheduled between 2003 September 28–30 and November 8–11 under conditions of mixed transparency. Observations were executed at or near the parallactic angle in order to avoid losses which could otherwise introduce significant systematic errors into our flux ratios. We used the medium red and blue grisms with slit widths of between 1.0 and 1.4 arcsec, yielding FWHM resolutions of between 13 and 17 Å, as detailed in Table 1. In addition to the galaxies listed in Table 1, we observed the object which Guillemim & Bergeron (1997) identify as the galaxy causing absorption towards Q0302$-$223. However, our spectrum reveals this object to be stellar and we consider it no further here.

Data were reduced using standard IRAF$^1$ packages; the 2D spectra were bias subtracted, flat-fielded, cleaned of cosmic rays using L.A. Cosmic (van Dokkum 2001) and finally calibrated for wavelength and flux. The final spectra are presented in Figure 1. In order to measure the emission line fluxes, we extracted 1D spectra, produced an average for each galaxy and fit single or double Gaussians using IRAF’s splot (metal lines) and ngaussfit (Balmer lines) taking into account the underlying stellar absorption. IRAF’s ngaussfit allows simultaneous fitting of blended absorption and emission components. First, the continuum around the line is defined and then the emission and absorption are simultaneously fitted through an iterative process by varying the 5 parameters which define each component (continuum zero point, slope, Gaussian amplitude, central wavelength and FWHM). The velocity widths of lines of the same element were tied together in this fitting process. We measured the emission line fluxes of [O II] $\lambda\lambda$3727, 3731 and [N II] $\lambda$6584 for each galaxy. The observed fluxes with Balmer corrections are given in Table 2. Although we detect Hα in most cases, accurate flux measurements of both Hα and [N II]λ6584 were generally not possible due to either nearby telluric absorption or low S/N.

3 ABUNDANCE DETERMINATIONS

We determine abundances using the R$_{23}$ method originally formulated by Pagel et al. (1979) and recently re-calibrated by Kewley & Dopita (2002, KD02). We correct the observed emission line fluxes for dust extinction by estimating a value of $E(B-V)$ and assuming the shape of the extinction curve described by Cardelli, Clayton & Mathis (1989) with an adopted $R_V=3.1$. In the absence of accurate Hα fluxes,

$^1$ 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.
**Table 1. Observations and Galaxy/Absorber Parameters**

| Field      | Galaxy Redshift | QSO–Galaxy Sepn (arcsec) | Galaxy $M_B$ | N(H I) $\text{atoms cm}^{-2}$ | Grism | Slit width (arcsec) | Exposure (seconds) | Resolution FWHM (Å) |
|------------|-----------------|--------------------------|--------------|---------------------------------|-------|--------------------|------------------|---------------------|
| 0150−203   | 0.383           | 10.5                     | $-19.52$     | $3 \times 10^{18}$c            | Red   | 1.0                | 8700             | 13                  |
| 0151+045Ab | 0.160           | 6.4                      | $-19.43$     | $7 \times 10^{19}$c            | Blue  | 1.4                | 3600             | 17                  |
| 0151+045Bb | 0.160           | 10.9                     | $-18.32$     | $7 \times 10^{19}$c            | Blue  | 1.2                | 6300             | 14                  |
| 0229+131   | 0.417           | 6.8                      | $-20.58$     | ...                             | Red   | 1.0                | 4200             | 13                  |

a: Calculated from the $m_r$ values in Guillemin & Bergeron (1997) using $k$-correction templates from Sawicki, Lin & Yee (1997) in our cosmology (assuming an Sbc type). b: Two galaxies with redshifts consistent with that of the absorber are found in this field with small impact parameters. It is not clear which is causing the absorption in the QSO. c: S. Rao, private communication, 2004.

**Figure 1.** Galaxy spectra with emission lines marked from left to right: $\text{[O II]} \lambda 3727$, $\text{H}\beta$, $\text{[O III]} \lambda 5007$ and $\text{H}\alpha$.

we use the local $E(B-V)$ to $M_B$ relation (Jansen et al. 2001) converted to our cosmology (R. Jansen, private communication, 2003) to determine the extinction corrections for 0151+045A,B and 0229+131:

$$E(B-V) = -(0.0507 \pm 0.0068) \times M_B - (0.818 \pm 0.127)(1)$$

For 0150−203 we can measure the Hα/Hβ ratio and, by assuming a theoretical value of 2.85 (for case B recombination at T= $10^4$K and $n_e \sim 10^2 - 10^4$ cm$^{-3}$; Osterbrock 1989), directly derive $E(B-V) = 0.17$ from the Balmer decrement. This ‘direct’ determination of the extinction is precisely the value which is predicted by equation 1. Our
Table 2. Observed Galaxy Line Fluxes

| Field     | [O II] λ 3727 | Hβ   | [O III] λ 5007 | Hα   |
|-----------|---------------|------|----------------|------|
| 0150−203  | 1.24×10^{-16} | 4.92×10^{-17} | 4.64×10^{-17} | 6.43×10^{-17} |
| 0151+045A | 1.46×10^{-15} | 6.47×10^{-16} | 2.65×10^{-16} | ...   |
| 0151+045B | 1.83×10^{-16} | 3.89×10^{-17} | 7.51×10^{-17} | ...   |
| 0229+131  | 1.55×10^{-16} | 9.45×10^{-17} | 1.95×10^{-16} | ...   |

a: Values are for relative observed line fluxes in units of ergs s^{-1} Å^{-1}, except for Balmer lines which have been corrected for underlying stellar absorption.

Table 3. Extinction Corrected Galaxy Line Fluxes

| Field     | [O II] λ 3727 | Hβ   | [O III] λ 5007 | Hα   | Log R_{23} |
|-----------|---------------|------|----------------|------|------------|
| 0150−203  | 2.62×10^{-16} | 8.66×10^{-17} | 7.83×10^{-17} | 9.29×10^{-17} | 0.63 |
| 0151+045A | 3.08×10^{-15} | 1.14×10^{-15} | 4.47×10^{-16} | ...     | 0.51 |
| 0151+045B | 2.97×10^{-16} | 5.61×10^{-17} | 1.05×10^{-16} | ...     | 0.89 |
| 0229+131  | 4.16×10^{-16} | 2.03×10^{-17} | 3.96×10^{-16} | ...     | 0.61 |

a: Values are for relative extinction- and Balmer-corrected line fluxes in units of ergs s^{-1} Å^{-1}.

![Figure 2](image-url)  

Figure 2. Luminosity-metallicity relation for z < 0.5 galaxies taken from Kobulnicky & Kewley (2004; open squares, typical error bar shown in bottom right corner) and this work (filled circles). The dotted lines join the upper and lower R_{23} branch metallicities (the range of possible turnover region metallicities is given by the error bars in the case of 0151+045B) for a given galaxy in our sample. The dashed line is the least squares fit to the KZ99 data and has the form 12 + log(O/H) = 6.30 − 0.125 M_{B}. The stars represent the values listed in Table 5 for literature DLAs with measured absorption abundances and galaxy counterparts. The value λ 4959 = 1/3 × [O III] λ 5007. We estimate the metallicity, log(O/H)+12, using three R_{23} calibrations: McGaugh (1991, M91), Zaritsky, Kennicutt & Huchra (1994, ZKH94) and KD02. The typical metallicity error associated with any given calibration is typically ∼ 0.1 dex (see individual references for details). We note in passing that KD02 is the only one of the three calibrations discussed here which solves iteratively for the ionization parameter as well as oxygen abundance. All R_{23} calibrations are double valued with respect to metallicity, resulting in two possible solutions, the so-called ‘upper’ and ‘lower’ branches. In Table 4 we list the metallicities for M91, ZKH94 and KD02 for both the upper and lower R_{23} branches, except for ZKH94 which was only calibrated for the upper branch. The difference between various published calibrations illustrates the typical uncertainties in the empirical methods. By trials with different plausible Balmer absorption and extinction corrections we estimate that these effects contribute a further 0.15 dex uncertainty. We therefore allocate a final error of 0.2 dex to our adopted metallicities (last two columns of Table 4) which are themselves averages of M91 and KD02 (Kobulnicky & Kewley 2004). The adopted metallicity error for 0150−203 is larger and encompasses the local maximum of the R_{23} calibration turnover (see below).

Our current spectra are insufficient to constrain the metallicities to either the upper or lower R_{23} branch. The [N II]λ6584/Hα ratio is commonly used to break the R_{23} degeneracy (e.g. Maier, Meisenheimer & hippoclein 2004). Unfortunately, we only have a reliable Hα flux for one galaxy and no trustworthy [N II]λ6584 measurements. One galaxy, (0151+045B) lies in the turn-around region of R_{23}; its metallicity is 8.3 < log(O/H) + 12 ≤ 8.7 (but note that this is one of two candidate galaxies for the absorber). For the remaining three galaxies, the metallicities may lie on the upper or lower R_{23} branch. We discuss each possibility below.
Emission Line Abundances of Absorption Selected Galaxies at $z < 0.5$

3.1 Metallicities on the upper $R_{23}$ branch

If one or more metallicities of our Mg II systems lie on the upper branch, those metallicities and luminosities would be consistent with the well-known luminosity-metallicity (LZ) relation for emission-line galaxies at similar redshifts (Figure 2). We note that for one of the Mg II galaxies presented here (0151+045A), independent emission-line spectroscopy which includes a nitrogen detection indicates that, at least for this one galaxy, the upper $R_{23}$ calibration is appropriate (Christensen et al. 2004). In Figure 2 we show the upper and lower-branch metallicities of our Mg II galaxies compared with the $z < 0.5$ emission-line galaxy LZ relation from Kobulnicky & Kewley (2004).

If our Mg II system metallicities lie on the upper branch, then their metallicities would be significantly higher than the DLA absorption metallicities by 0.5 – 1.0 dex. Such a large discrepancy can not be explained by the differences between different emission-line diagnostics (0.1 – 0.3 dex; Garnett, Kennicutt & Bresolin 2004; Kobulnicky & Kewley 2004). A combination of strong abundance gradients and considerable QSO–galaxy impact parameters is one potential solution to this dilemma. Our spectra only cover the nuclear regions of the Mg II systems, whereas the impact parameters correspond to $\sim 15 – 50 \ h_{70}^{-1}$ kpc. If a Mg II system has a strong metallicity gradient, then emission-line and absorption-line abundances at these impact parameters could deviate significantly. To further illustrate this point, we have plotted LZ data in Figure 2 for four DLAs or sub-DLAs from the compilation of Chen & Lanzetta (2003). For these four absorbers we plot the metallicity based on DLAs absorption line measurements and the absolute $B$-band magnitude of the identified galaxy counterpart (see Table 5 for galaxy and DLA parameters). We have converted the $AB$ magnitudes given in Chen & Lanzetta (2003) to the Vega scale and corrected for our adopted value of $H_0$. We follow Prochaska et al. (2003) in preferentially using the abundance, $[X/H]^{Z KH94}$ [Zn/H] or [Si/H] if possible, otherwise adopting [Fe/H]+0.4 as an indication of metallicity. As noted previously by Pettini et al. (2000), Q0058+016, whose impact parameter is only $8 \ h_{70}^{-1}$ kpc, lies within the LZ range of field galaxies at moderate redshifts. The other three DLAs are significantly more metal poor for their luminosity than field galaxies at $z < 0.5$, but their impact parameters are also substantial ($\sim 20 \ h_{70}^{-1}$ kpc). We are currently investigating quantitatively the effect of abundance gradients with a combination of theoretical Monte Carlo simulations and detailed metallicity gradient data. The results of this theoretical work will be published in a future paper.

To summarise this subsection, if $Z \sim Z_{\odot}$ nebular abundances are confirmed in a larger sample of DLA galaxies with sub-solar absorption abundances, this would be evidence that although the DLAs are representative of gas cross-section, they may not trace the major repositories of metals, possibly due to substantial impact parameters and metallicity gradients. In one case (0151+045A) spectroscopy by Christensen et al. (2004) agree with our upper branch metallicity and support an approximately solar metallicity for this galaxy.

3.2 Metallicities on the lower $R_{23}$ branch

If one or more metallicities of our systems lie on the lower branch, those metallicities would be consistent with the DLA absorption metallicities at similar redshifts. However, in this case, our Mg II absorption selected galaxies would deviate significantly (and uniquely amongst star-forming galaxies at this epoch) from the star-forming LZ relation. If the LZ relation is representative of the galaxy population as a whole at redshifts $0.1 < z < 0.5$, then it is unlikely that random intervening galaxies in QSO sightlines would preferentially isolate a population of galaxies with a unique LZ relation. On the other hand, if the emission-line metallicities of our Mg II systems lie on the lower $R_{23}$ branch, this would support the hypothesis that DLA absorption metallicities are representative of the galaxy population as a whole at redshifts $0.1 < z < 0.5$. An implication of such a result would be that the emission-line LZ relation is not representative of the galaxy population. Such a scenario might hold if, for example, sample selection caused the LZ relation to be biased towards high metallicity galaxies.

3.3 Discussion

Quasar absorption lines potentially offer an unbiased and representative census of gas-phase metal abundance. However, some observations indicate that random sightlines through DLAs do not sample the regions where star formation and chemical enrichment have been rife. For example, there is a serious shortfall between measured absorption abundances and the predicted abundances from both star formation rates (Pagel 1999; Pettini 1999 and recently re-assessed by Wolfe, Gawiser & Prochaska 2003) and from smoothed particle hydrodynamic (SPH) galaxy simulations (e.g., Nagamine, Springel & Hernquist 2003). One solution to this ‘missing metals’ problem is if a significant fraction of metals actually exist outside the cool, diffuse gas phase.

Table 4. Galaxy Abundances

| Field    | log(O/H)+12, upper | log(O/H)+12, lower | log(O/H)+12 | log(O/H)+12 |
|----------|--------------------|--------------------|-------------|-------------|
|          | M91 ZKH94 KD02     | M91 KD02           | upper adopted | lower adopted |
| 0150–203 | 8.69 8.88 8.91     | 7.92 8.11          | 8.8±0.2     | 8.0±0.2     |
| 0151+045A| 8.75 9.00 9.00     | 7.87 8.04          | 8.9±0.2     | 8.0±0.2     |
| 0151+045B | 8.35 8.45 8.54    | ...                | 8.4±0.3     | ...         |
| 0229+131 | 8.74 8.82 8.88     | 7.81 8.05          | 8.8±0.2     | 7.9±0.2     |

\[ a: \text{Only a turnover region metallicity is quoted with error bars indicative of the large uncertainty in metallicity.} \]

\[ 2 \text{ In the usual notation, } [X/H]= \log (N(X) / N(H)) - \log (X/H)_{\odot}. \]
Figure 3. Metallicities of DLAs (solid circles) based on UV absorption lines in QSOs taken from Prochaska et al. (2003), emission line galaxies (open circles) taken from Kobulnicky & Zaritsky (1999) and Lilly, Carollo & Stockton (2003) and absorption selected galaxies (open stars/filled triangles) from this sample (assuming upper/lower branch metallicities) and Schulte-Ladbeck et al. (2004) (one DLA at $z \sim 0$). Note that 0151+045B is in the turnover region so its open star and error bars represents the range of possible metallicities for this galaxy. The dashed region shows the locus of the majority of star forming SDSS galaxies with $0.1 < z < 0.3$ (Schulte-Ladbeck et al. 2003) and the solid square is the metallicity of low redshift DLAs based on the SDSS composite from Nestor et al. (2003).

Table 5. Properties of Literature DLA Absorbers and Galaxies

| QSO     | Galaxy  | DLA $M_B^n$ | DLA [X/H]$^b$ | X    | Metallicity | Reference         | Impact Parameter $(h^{-1}_70$ kpc) |
|---------|---------|-------------|---------------|------|-------------|-------------------|----------------------------------|
| Q0058+019 | −18.2   | 0.613       | +0.08 ± 0.21  | Zn   | Pettini et al. (2000) | 8.1                        |
| Q0302–223 | −19.9   | 1.009       | −0.73 ± 0.12  | Si   | Pettini et al. (2000) | 26.6                       |
| Q1122–165 | −19.4   | 0.682       | −1.00 ± 0.05  | Fe+0.4 | Ledoux et al. (2002) | 25.2                       |
| Q1328+307 | −20.7   | 0.692       | −1.20 ± 0.12  | Zn   | Ledoux et al. (2002) | 17.7                       |

$^a$ Magnitudes taken from Chen & Lanzetta (2003) and converted to our cosmology
$^b$ Absorption line metallicity based on element X, with correction of 0.4 dex in the case of Fe to account for dust depletion (e.g. Prochaska et al. 2003).

For example, the hot ISM component may contain a significant fraction of a galaxy’s metals. The local starburst galaxy NGC 1569 has a metallicity of $Z = 1/3Z_\odot$ from HII regions, but approximately solar abundance in a hot metal-loaded wind (Kobulnicky & Skillman 1997; Martin, Kobulnicky & Heckman 2002). Alternatively, Dunne, Eales & Edmunds (2003) have claimed that most of the metals in high redshift galaxies are actually locked in the dust phase. A more persistent and troubling concern is that DLAs are observed to be metal-poor at all redshifts and show little evolution with time (e.g. Pettini et al. 1999). Therefore, regardless of the metals budget, DLAs consistently represent regions which have experienced little chemical enrichment. Given that dust bias can apparently be ruled out as the culprit for this (Ellison et al. 2001; Ellison et al. 2004a; Akerman et al. in preparation) we are left to ponder if absorption-selected galaxies are fundamentally metal-poor, or whether random sight-lines preferentially probe metal poor gas.

One way in which to address this question is to examine the range of emission line metallicities at a given...
epoch and compare with those determined from absorption lines. In this work, we have made a first step towards this goal by estimating oxygen abundances for a small sample of galaxies selected on the basis of strong Mg II absorption in nearby (i.e., with impact parameters of 5–10 arcseconds) QSOs. Figure 2 indicates that there is a conflict between the emission-line LZ relation and DLA metallicities in three out of four systems (open squares, compared with open stars) between 0.1 < z < 0.5. Clearly, there is no way to resolve the emission-line LZ relation with the DLA metallicities, regardless of whether our galaxies lie on the upper or lower branch. The solution of the $R_{23}$ degeneracy could potentially make a significant impact on either LZ relation studies, or on QSO absorption studies.

In Figure 3, we show metallicity vs. redshift for our four absorption-selected galaxies (two of which are candidates for the same Mg II system, but this does not affect our conclusions), for the low-redshift DLA galaxy SBS 1543+593 (Schulte-Ladbeck et al. 2004), for star-forming galaxies at z < 1 (KZ99; Lilly, Carollo & Stockton 2003), and for a sample of DLAs (Prochaska et al. 2003). We have included both upper and lower $R_{23}$ branch values, using the ‘adopted’ value from Table 4. If the upper branch calibration is appropriate, as tentatively indicated from the LZ relation, our small sample of galaxies have abundances ∼ 1 dex larger than low redshift DLAs. If the lower $R_{23}$ branch is appropriate, the galaxies have metallicities consistent with the DLAs. Figure 3 also emphasizes the need for more low-redshift DLA abundance measurements. We note that the galaxies selected for this pilot sample are relatively bright, so may represent the more metal-rich end of the distribution.

The galaxies in our sample are selected based on Mg II absorption and at least 3 of them have H I column densities below the canonical limit for DLAs (2 × 10$^{20}$ cm$^{-2}$). However, Péroux et al. (2003) find that ‘sub’-DLAs (which include absorbers with N(H I) down to 10$^{19}$ cm$^{-2}$) have metallicities consistent with the higher column density systems. Mg II systems are clearly strongly related to the DLAs, but likely occur at slightly larger impact parameters (Steidel 1993; Ellison et al 2004b). There is consequently no evidence to suggest that the absorbers selected for this study should have systematically different metallicities to the DLAs, although extending this work with canonical DLAs systems is desirable for an entirely equal comparison.

The next important step in this work is to compare the emission and absorption line abundances for a given galaxy. Although we can not make this comparison with our current data, we note that if QSO sightlines are truly a random probe of representative galaxy metallicities at a given epoch, the apparent dichotomy between emission and absorption abundances is intriguing (modulo the caveats above). Is this dichotomy due to the different phases of the ISM probed by emission and absorption line techniques? Nebular abundances within dwarf galaxies are usually highly uniform, implying that local self-enrichment is not significant (e.g. Skillman 2003 and references therein). We might therefore expect emission and absorption abundances to be in good agreement, at least on scales of a few kpc. In the Milky Way, this is apparently the case: oxygen abundances in Orion’s HII regions (e.g. Bautista & Pradhan 1995) are in good agreement with those measured from UV absorption lines in the local interstellar medium (e.g. Moos et al.2002). At high redshift, Lyman break galaxies also exhibit nebular abundances commensurate with those determined from absorption lines (e.g. Pettini et al. 2002). There is some discussion concerning self-enrichment in local dwarf galaxies (Aloisi et al. 2003; Lecavelier des Etangs 2004; Lebouteiller et al. 2004), but since disagreement has arisen in some cases for the same dataset, these results warrant further investigation.

Ruling out convincing evidence for self-enrichment of HII regions for the time being, we suggest that a possible explanation for a discrepancy between absorption and emission line abundances indicated by Figure 3 is a radial dependence on metallicity. Abundance gradients are commonplace in local spirals (e.g. Vila-Costas & Edmunds 1992; ZKH94) with magnitudes around 0.05–0.1 dex/kpc. Studies of the extreme outer parts of disc galaxies find oxygen abundances down to at least 1/10 to 1/15 of the solar value (Ferguson et al. 1998; Kennicutt, Bresolin & Garnett 2003), in good agreement with DLA metallicities. Simulations of sightlines through galaxies with abundance gradients and random inclinations can well reproduce the observed distribution of DLA metallicities (Ferrini, Molla & Diaz 1997; Mathlin et al. 2001), although diverse star formation histories and formation redshifts will also play a role. The QSO impact parameters of the four galaxies in our sample range from approximately 15 – 50 h$^{-1}_{70}$ kpc, so the absorption abundances may be lower (by up to a few dex, depending on galaxy type, age and impact parameter) than in the global emission line spectra which are representative of the central 5–10 kpc of a galaxy. (Kobulnicky, Kennicutt & Pizagno 1999). In §3.1 (and Figure 2) we showed that DLA galaxies with absorption line metallicity determinations lie below the LZ relation of z < 0.5 galaxies. If abundance gradients existed in these four DLA galaxies with similar magnitudes as those seen by Vila-Costas & Edmunds (1992) and ZKH94, this would imply an upward correction on the order of ~ 1 – 1.5 dex, bringing these galaxies into good agreement with the field galaxy LZ relation. We will address the issue of abundance gradients quantitatively in a forthcoming paper.

4 SUMMARY

As stated in the introduction, the fundamental question which we wish to address is whether QSO absorption and emission line metallicity indicators provide the same abundance measurement for a given galaxy. As such, the work presented here is merely a first step. Our work shows that there is a discrepancy between absorption metallicities and the LZ relation for galaxies between 0.1 < z < 0.5. For each Mg II galaxy in our sample either (1) the metallicities lies on the $R_{23}$ upper branch, consistent with the LZ relation, but significantly discrepant from the majority of DLA metallicities, or (2) the metallicity lies on the lower branch, consistent with the DLA metallicities, but significantly different from the LZ relation for emission-line galaxies (e.g. KZ99). If the metallicities lie on the upper branch, a combination of abundance gradients and impact parameters is a possible resolution to the discrepancy. If the metallicities lie on the lower branch, this would suggest severe difference in the sample selection effects on metallicity between galaxies studied for the LZ relation and absorption-selected galaxies.

Ideally, one would like to compare emission and
absorption-line abundances in the same DLA systems. A direct comparison between emission and absorption line abundances at low redshifts requires a combination of optical galaxy spectroscopy and UV QSO spectroscopy. In order to determine the absorption metallicity, it is preferable to target a non-refractory $\alpha$ element so that a fair comparison can be made with the nebular oxygen abundance. Oxygen lines in the UV are often problematic since they are either very strong and consequently saturate even at low column densities (e.g. O I $\lambda 1302$) or extremely weak (e.g. O I $\lambda 1355$). The S II $\lambda 1251$, 1254, 1269 triplet presents a more viable option. Bowen et al. (in preparation) have recently determined the absorption metallicity for SBS 1543+593 via HST.

References

Aloisi, A., Savaglio, S., Heckman, T. M., Hoopes, C. G., Leitherer, C., Sembach, K. R., 2003, ApJ, 595, 760
Bautista, M. A., & Pradhan, A. K., 1995, ApJ, 442, L65
Bergeron, J., & Boissé, P., 1991, A&A, 243, 344
Cardelli, J. A., Clayton, G. C., & Mathis, J. S., 1989, ApJ, 345, 245
Chen, H.-W., Lanzetta, K., 2003, ApJ, 597, 706
Churches, D. K., Nelson, A. H., & Edmunds, M. G., 2004 MNRAS, 347, 1234
Christensen, L., Schulte-Ladbeck, R., Sanchez, S. F., Becker, T., Jahnke, K., Kelz, E., Roth, M. M., Wisotzki, L., 2004, A&A, submitted
Cuby, J.-G., LeFevre, O., McCracken, H., Cuillandre, J.-C., Magnier, E., Meneux, B., 2003, A&A, 405, 19
Dickinson, M., et al. 2003a, ApJL, 600, L99
Dickinson, M., Papovich, C., Ferguson, H., Budavari, T., 2003b, ApJ, 587, 25
Dunne, L., Eales, S., & Edmunds, M. G., 2003, MNRAS, 341, 589
Ellison, S. L., 2000, PhD thesis, University of Cambridge
Ellison, S. L., Churchill, C. W. C., Rix, S. A., Pettini, M., 2004a, ApJ, accepted, astro-ph/0407237
Ellison, S. L., Ibata, R., Pettini, M., Lewis, G. F., Aracil, B., Petitjean, P., Srianand, R., 2004b, A&A, 414, 79
Ellison, S. L., Yan, L., Hook, I., Pettini, M., Wall, J., Shaver, P., 2001, A&A, 379, 393
Fall, S. M., Pei, Y., 1993, ApJ, 402, 479
Ferguson, A. M. N., Gallagher, J. S., Wyse, R. F. G. 1998, AJ, 116, 673
Ferrini, F., Molla, M., & Díaz, A. I., 1997, ApJ, 487, L29
Garnett, D. R., Kennicutt R. C., & Bresolin, F., 2004, ApJ, 607, 21
Giavalisco, M., et al., 2004, ApJ, 600, L103
Guillemin, P., & Bergeron, J., 1997, A&A, 328, 499
Holweger, H., 2001, in Solar and Galactic Composition, ed. R. Wimmer-Schweingruber, (Berlin: Springer), 23
Hou, J. L., Boissier, S., Prantzos, N., 2001, A&A, 370, 23
Hu, E. M., Cowie, L. L., McMahon, R. G., Capak, P., Iwamuro, F., Kneib, J.-P., Maihara, T., Motohara, K., 2002, ApJ, 568, 75
Jakobsson, P., et al., 2004, A&A, in press, astro-ph/0407439
Jansen, R. A., Franx, M., & Fabricant, D. 2001, ApJ, 551, 825
Kennicutt, R. C., Bresolin, F., & Garnett, D. R., ApJ, 2003, 591, 801
Kewley, L. J., & Dopita, M. A., 2002, ApJS, 142, 35 (KD02)
Kewley, L. J., Keller, M. J., & Jansen, R. A. 2003, AJ, 127, 2002
Khare, P., Kulkarni, V. P., Lauroesch, J. T., York, D. G., Crotts, A. S. P., Nakamura, O., 2004, ApJ, accepted, astro-ph/0408139
Kobulnicky, H. A., Kennicutt, R. C., Jr., Pizagno, J. L., 1999, ApJ, 514, 544
Kobulnicky, H. A., & Kewley, L. J., 2004, ApJ, in press, astro-ph/0408128
Kobulnicky, H. A., & Koo, D., 2000, ApJ, 545, 712
Kobulnicky, H. A., et al., 2003, ApJ, 599, 1006
Kobulnicky, H. A., & Zaritsky, D. 1999, ApJ, 511, 118
Kulkarni, V. P., Fall, S. M., 2002, ApJ, 580, 732
Kunth, D., Lequeux, J., Sargent, W. L. W., Viallefond, F., 1994, A&A, 282, 709
Kunth, D., Matteucci, F., & Marconi, G., 1995, A&A, 297, 634
Lamareille, F., Mouchine, M., Lewis, I., Maddox, S., 2004 MNRAS, 350, 396
Lebouteiller, V., Kunth, D., Lequeux J., Lecavelier des Etangs A., Desert J.-M., Hebrard G., Vidal-Madjar, A., 2002, ApJ, 580, 732
Ledoux, C., Bergeron J., & Petitjean, P., 2002, A&A, 413, 131
Lilly, S. J., Carollo, C. M., Stockton, A. N., 2003, ApJ, 597, 730
Maier, C., Meisenheimer, K., & Hippelein, H 2004, A&A, 418, 475
Martin, C. L., Kobulnicky, H. A., Heckman, T. M., 2002, ApJ, 574, 663
Mathlin, G. P., Baker, A. C., Churches, D. K., Edmunds, M. G., 2001, MNRAS, 321, 743
McGaugh, S. S., 1991, ApJ, 380, 140 (M91)
Moos, H. W., et al., 2002, ApJS, 140, 3
Emission Line Abundances of Absorption Selected Galaxies at $z < 0.5$

Nagamine, K., Springel, V., & Hernquist, L., 2003, MNRAS, in press

Nestor, D. B., Rao, S. M., Turnshek, D. A., Vanden Berk, D., 2003b, ApJ, 595, L5

Osterbrock, D. E. 1989, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei (Mill Valley; University Science Books)

Pagel, B. E. J., 1999, Low Surface Brightness Universe, ASP Conference Series, Edited by J.I. Davies, C. Impey, and S. Phillipps. Astronomical Society of the Pacific (San Francisco), 170, 375

Pagel, B. E. J., Edmunds, M. G., Blackwell, D. E., Chun, M. S., Smith, G., 1979, MNRAS, 189, 95

Pettini, M., 1999, Chemical Evolution from Zero to High Redshift, Proceedings of the ESO Workshop, edited by Jeremy R. Walsh, Michael R. Rosa. Berlin: Springer-Verlag, 233

Pettini, M., Ellison, S. L., Steidel, C. C., Bowen, D. V., 1999, ApJ, 510, 576

Pettini, M., Ellison, S. L., Steidel, C. C., Shapley, A. E., & Bowen, D. V. 2000, ApJ, 532, 65

Pettini, M., & Lipman, K., 1995, 297, 63

Pettini, M., Rix, S., Steidel, C., Adelberger, K., Hunt, M., Shapley, A., 2002, ApJ, 569, 742

Pettini, M., Shapley, A., Steidel, C., Cuby, J.-G., Dickinson, M., Moorwood, A., Adelberger, K., Giavalisco, M., 2001, ApJ, 554, 981

Pettini, M., Smith, L.J., Hunstead, R.W., King, D.L., 1994, ApJ, 426, 79

Pettini, M., Smith, L.J., King, D.L., & Hunstead, R.W. 1997, ApJ, 486, 665

Prochaska, J. X., Gawiser, E., Wolfe, A. M., Castro, S., Djorgovski, S. G., 2003, ApJ, 595, L9

Prochaska, J. X., & Wolfe, A., 2002, ApJ, 566, 68

Rao, S. M., Nestor, D. B., Turnshek, D. A., Lane, W. M., Monier, E. M., Bergeron, J., 2003, ApJ, 595, 94

Rao, S.M., & Turnshek, D.A. 2000, ApJS, 130, 1

Rudnick, G., et al., 2003, ApJ, 599, 847

Sawicki, M. J., Lin, H., Yee, H. K. C., 1997, AJ, 113, 1

Schulte-Ladbeck, R. E., Rao, S. M., Drozdovsky, I. O., Turnshek, D. O., Nestor, D. B., Pettini, M., 2004, ApJ, 600, 613

Schulte-Ladbeck, R. E., Miller, C. J., Hopp, U., Hopkins, A., Nichol, R. C., Voges, W., Fang, T., 2003, Proceedings of the ESO/USM/MPE Workshop on ‘Multiwavelength Mapping of Galaxy Formation and Evolution’ [astro-ph/0312069]

Skillman, E. D., 2003, ASP conference proceedings, 297, 121

Stanway, E., Bunker, A., & McMahon, R., 2003, MNRAS 342, 439

Steidel, C. C. 1993, ASSL Vol. 188: The Environment and Evolution of Galaxies, 263

Steidel, C. C., Dickinson, M., & Persson, E., ApJ, 1994, 437, L35

Steidel, C. C., Shapley, A., Pettini, M., Adelberger, K., Erb, D., Reddy, N., Hunt, M., 2004, ApJ, 604, 534

Teplitz, H., et al. 2000, ApJ, 542, 18

van Dokkum, P., 2001, PASP, 113, 142

Vila-Costas, M. B., & Edmunds, M. G., 1992, MNRAS, 259, 121

Wolfe, A., Gawiser, E., & Prochaska, J. X., 2003, ApJ, 593, 235

Zaritsky, D., Kennicutt, R. C., Jr., Huchra, J. P., 1994, ApJ, 420, 87 (ZKH94)