Galaxy group at $z = 0.3$ associated with the damped Lyman $\alpha$ system towards quasar Q1127–145

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Accepted 2010 March 11. Received 2010 March 11; in original form 2010 February 17

ABSTRACT

We performed a spectroscopic galaxy survey, complete to $m_{F814W} \leq 20.3$ ($L_B > 0.15L^*_B$ at $z = 0.3$), within $100 \times 100$ arcsec$^2$ of the quasar Q1127–145 ($z_{em} = 1.18$). The Very Large Telescope/Ultraviolet and Visual Echelle Spectrograph (UVES) quasar spectrum contains three $z_{abs} < 0.33$ Mg II absorption systems. We obtained eight new galaxy redshifts, adding to the four previously known, and galaxy star formation rates (SFRs) and metallicities were computed where possible. A strong Mg II system $[W_r(2796) = 1.8 \, \text{Å}]$, which is a known damped Lyman $\alpha$ absorber (DLA), had three previously identified galaxies; we found two additional galaxies associated with this system. These five galaxies form a group with diverse properties, such as a luminosity range of $0.04 \leq L_B \leq 0.63L^*_B$, an impact parameter range of $17 \leq D \leq 241$ kpc and a velocity dispersion of $\sigma = 115$ km s$^{-1}$. The DLA group galaxy redshifts span beyond the 350 km s$^{-1}$ velocity spread of the metallic absorption lines of the DLA itself. The two brightest group galaxies have SFRs of $\sim$few $M_{\odot}$ yr$^{-1}$ and should not have strong winds. We have sufficient spectroscopic information to directly compare three of the five group galaxies’ (emission-line) metallicities with the DLA (absorption) metallicity: the DLA metallicity is one-tenth solar, substantially lower than the three galaxies’ metallicity which ranges between less than 1/2 solar to solar. Hubble Space Telescope (HST)/Wide Field Planetary Camera 2 (WFPC-2) imaging shows perturbed morphologies for the three brightest group galaxies, with tidal tails extending $\sim$25 kpc. We favour a scenario where the DLA absorption originates from tidal debris in the group environment.

Another absorber exhibits weak Mg II absorption $[W_r(2796) = 0.03 \, \text{Å}]$ and had a previously identified galaxy at a similar redshift. We have identified a second galaxy associated with this system. Both galaxies have solar metallicities and unperturbed morphologies in the HST/WFPC-2 image. The SFR of one galaxy is much lower than that expected for strong outflows. Finally, we have also identified five galaxies at large impact parameters with no associated Mg II absorption $[W_r(2796) \lesssim 5.7 \, \text{mA}, 3\sigma]$ in the spectrum of Q1127–145.

Key words: galaxies: haloes – galaxies: interactions – galaxies: ISM – quasars: absorption lines.

1 INTRODUCTION

Absorption lines detected in the spectra of background quasars and gamma-ray bursts remain one of the best probes of intervening multiphase gas throughout the Universe. Pioneering work of Bergeron (1988) and Bergeron & Boissé (1991) led to the first galaxies identified in close proximity to a quasar sightline and at the same redshift as metal-enriched absorption traced by the Mg II $\lambda\lambda 2796, 2803$ doublet. Since then, there have been numerous studies of Mg II absorption-line systems aimed at interpreting the properties of galaxy haloes at a variety of redshifts (e.g. Le Brun et al. 1993; Steidel, Dickinson & Persson 1994; Churchill, Steidel & Vogt 1996; Churchill et al. 2000b; Steidel et al. 2002; Ellison, Mallén-Ornelas & Sawicki 2003; Bouché et al. 2006; Zibetti et al. 2007; Chen & Tinker 2008; Kacprzak et al. 2008; Barton & Cooke 2009; Ménard et al. 2009; Pollack et al. 2009; Rubin et al. 2010).

Mg II absorption lines are ideal for studying a large dynamic range of structures and environments in and around galaxies since they trace low ionization metal-enriched gas with neutral hydrogen column densities of $10^{16} \lesssim N(H I) \lesssim 10^{21}$ cm$^{-2}$ (Churchill et al.
However, in groups the galaxy velocities are smaller and the interactions and mergers more frequent, resulting in increased gas covering fractions of the cool intragroup gas (Zabludoff & Mulchaey 1998).

A significant fraction of strong Mg\textsc{ii} absorption systems are damped Lyman \alpha systems (DLA) (Rao et al. 2003). Since the discovery of DLAs (Wolfe et al. 1986), their host galaxy properties and environments have remained largely unknown. Only a small fraction of DLA hosts have been identified and appear to be isolated galaxies in close proximity of the quasar line of sight (LOS) (Moller et al. 2002; Lacy et al. 2003; Rao et al. 2003; Chun et al. 2006). Models support an array of origins of the DLA absorbing gas from rotating thick discs (e.g. Prochaska & Wolfe 1997, 1998; Prochaska, Ryan-Weber & Staveley-Smith 2002), gas-rich dwarf galaxies (Matteucci, Molaro & Vladilo 1997), irregular protogalactic clumps (Haehnelt, Steinmetz & Rauch 1998) and tidal gas or processes such as supernovae and outflows (Zwaan et al. 2008).

In this paper, we perform a spectroscopic survey of the galaxies in the Q1127−145 quasar field. A VLT/UVES quasar spectrum shows that there are three absorption systems in this field, one of which is a DLA system which has three previously identified galaxies at a similar redshift. However, this field contains many unidentified bright galaxies within 50 arcsec of the quasar LOS. We perform a spectroscopic survey, to a limiting magnitude of $m_{\text{pg}21} < 20.3$, in an attempt to obtain spectroscopic redshifts for the remaining galaxies within the field. In Section 2, we describe our sample and analysis. In Section 3, we present the results of our redshift survey. We discuss morphologies of the galaxies and also compute galaxy star formation rates (SFRs) and emission-line metallicities when possible. We compare galaxy metallicities to the absorption-line metallicity derived for the DLA. In Section 4, we discuss the possible origins of the Mg\textsc{ii} absorption and our concluding remarks are given in Section 5. Throughout, we adopt an $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$ cosmology.

### 2 Target Field and Observations

Q1127−145 is a bright ($V = 16.9$ mag) $z_{\text{em}} = 1.18$, gigahertz-peaked radio source with an $\sim 300$ kpc jet seen in the X-ray and in multifrequency radio observations (see Siemiginowska et al. 2002, 2007). A VLT/UVES spectrum of the quasar contains three Mg\textsc{ii} absorption systems: $z_{\text{abs}} = 0.190\,973$ (Evans et al., in preparation), 0.312 710 (Bergeron & Boissé 1991) and 0.328 266 (Narayanan et al. 2007), respectively. To date, no galaxies have been found to have similar redshift as the $z_{\text{abs}} = 0.190\,973$ Mg\textsc{ii} absorption. One galaxy associated with the $z_{\text{abs}} = 0.328\,266$ absorption system (labelled in this paper as G5) was recently spectroscopically confirmed by Kacprzak et al. (2010).

From a Hubble Space Telescope (HST)/Faint Object Spectrograph (FOS) UV spectrum, $z_{\text{abs}} = 0.312\,710$ was determined to be a DLA with $N_{\text{HI}} = 5.1 \pm 0.9 \times 10^{21}$ cm$^{-2}$ (Rao & Turnshek 2000). Bergeron & Boissé (1991) spectroscopically identified two galaxies (labelled in this paper as G2 and G4) to be at a similar redshift as the $z_{\text{abs}} = 0.312\,710$ absorption system. Since G2 is closer to the quasar LOS and has more significant star formation than G4, G2 was favoured as the absorbing galaxy. Lane et al. (1998) later obtained a spectroscopic redshift of another galaxy, called G1 here, which is also consistent with the absorption redshift and was then favoured as the absorbing galaxy due to its closer proximity to the quasar LOS than G2 and G4. Additional multiband imaging studies
claim to have detected low surface brightness (SB) emission around the quasar and also a possible underlying galaxy 0.6 arcsec from the quasar LOS (Nestor et al. 2002; Rao et al. 2003; Chun et al. 2006). However, it is possible that the low SB signal is coming from a radio-loud/X-ray emitting quasar host galaxy at $z_{\text{host}} = 1.18$ (Siemiginowska et al. 2002, 2007). In either case, this field does not contain the typical isolated galaxy and absorber seen in many quasar absorber fields. (e.g. Steidel et al. 1994, 1997; Guillemin & Bergeron 1997).

The Q1127–145 field appears to have an unusually large number of bright galaxies within $100 \times 100$ arcsec$^2$ centred on the quasar LOS. Here we have performed a shallow spectroscopic survey of the field at a limiting magnitude of $m_{B144} \leq 20.3$ in an attempt to identify the remaining absorbing galaxies within the field. At the redshift of the DLA, the $B$-band luminosity limit is $L_B = 0.15L_B^*$.  

2.1 Galaxy spectroscopy

Galaxy spectra were obtained during three nights between 2008 January and 2008 March using the double imaging spectrograph (DIS) at the Apache Point Observatory (APO) 3.5-m telescope in New Mexico. Details of the observations are presented in Table 1. The spectrograph has separate red and blue channels that have plate scales of 0.40 and 0.42 arcsec pixel$^{-1}$, respectively. We used a 1.5-arcsec wide by 6-arcmin long slit with no on-chip binning of the CCD.

The B1200 grating was used for the blue channel resulting in a spectral resolution of 0.62 Å pixel$^{-1}$ with a wavelength coverage of 1240 Å. For the red channel, both the R830 and the R1200 gratings were used. The R830 grating has a spectral resolution of 0.84 Å pixel$^{-1}$ with a wavelength coverage of 1680 Å. The R1200 has a spectral resolution of 0.58 Å pixel$^{-1}$ with a wavelength coverage of 1160 Å. Wavelength centres for each grating (see Table 1) were selected to target $[\text{O} \ II]$, $\text{H} \alpha$ and $[\text{N} \ II]$ emission lines for $z \sim 0.3$ galaxies. The total exposure time per target ranges from 3000 to 10 500 s, and the observations were performed in poor/cloudy weather conditions with a typical seeing of 1–2 arcsec. Four slit positions were obtained and are shown in Fig. 1.

### Table 1. Summary of the galaxy spectroscopic observations obtained with the Astrophysical Research Consortium (ARC) 3.5 m using the DIS. Four different DIS long-slit positions were obtained and their spatial are shown in Fig. 1. The instrument gratings and central wavelengths ($\lambda_c$) were selected to target $\text{H} \alpha$ and $[\text{N} \ II]$ emission lines, on the red channel, and $[\text{O} \ II]$ emission lines, on the blue channel, for $z \sim 0.3$ galaxies.

| Slit position | Grating | $\lambda_c$ (Å) | Date (CT) | Exposure (s) |
|---------------|---------|----------------|-----------|--------------|
| Slit 1        | B1200   | 4500           | 2008 Jan. 16 | 10 500   |
|               | R1200   | 7300           | 2008 Jan. 16 | 4500       |
|               | R1200   | 8500           | 2008 Jan. 16 | 6000       |
| Slit 2        | B1200   | 5220           | 2008 Feb. 01 | 4500       |
|               | R830    | 9040           | 2008 Feb. 01 | 4500       |
| Slit 3        | B1200   | 4700           | 2008 Feb. 01 | 3000       |
|               | R1200   | 5220           | 2008 Mar. 27 | 6000       |
|               | R830    | 9040           | 2008 Feb. 01 | 3000       |
|               | R830    | 9040           | 2008 Mar. 27 | 6000       |
| Slit 4        | B1200   | 5220           | 2008 Feb. 01 | 3000       |
|               | R830    | 9040           | 2008 Feb. 01 | 3000       |

Spectra were reduced using IRAF. External quartz dome-illuminated flat fields were used to eliminate pixel-to-pixel sensitivity variations. Stellar spectra taken in the same field were used as traces to facilitate the extraction of the faint galaxy spectra. Each spectrum was wavelength calibrated using HeNeAr arc line lamps. The galaxy spectra were both vacuum and heliocentric velocity corrected.

A Gaussian fitting algorithm (see Churchill et al. 2000a), which computes best-fitting Gaussian amplitudes, centres and widths, was used to obtain the galaxy redshifts from one or more emission lines. Emission lines used to calculate the galaxy redshift were detected at or above the 3σ level (the galaxy redshifts are listed in Table 3).

Higher resolution spectra of three previously identified galaxies (G2, G4 and G5) were obtained by Kacprzak et al. (2010). Their Keck/ESI spectra have a velocity resolution of 11 km s$^{-1}$ pixel$^{-1}$ and a range of exposure times of 600–4200 s. Details regarding the individual spectra and the data reductions are presented in Kacprzak et al. (2010). Here we present the flux-calibrated spectra for these three galaxies. The spectra were calibrated using IRAF with standard stars taken during the night of the observation. We have made no corrections for slit loss nor reddening.

2.2 Quasar spectroscopy

The absorption properties were measured from the VLT/UVES (Dekker et al. 2000) archival spectra of Q1127–145 obtained on 2002 August 17 [PI Lane, PID 67.A-0567(A)], 2003 August 18 [PI Savaglio, PID 69.A-0371(A)] and 2007 May 3 [PI Miniati, PID 076.A-0860(A)]. The UVES spectrum has a wavelength coverage from 3046 to 4517 Å and from 4622 to 6810 Å. All spectra were taken with 2 × 2 binning using a 1-arcsec wide slit, providing a spectral resolution with a full width at half-maximum (FWHM) of 7 km s$^{-1}$. They were reduced using the standard European Southern Observatory (ESO) pipeline and the custom code UVES Post-Pipel Echelle Reduction (UVES popler$^2$). The spectrum is both vacuum and heliocentric velocity corrected. Analysis of the Mg $\II$ absorption profiles was performed using interactive software (see Churchill et al. 1999, 2000a; Churchill & Vogt 2001) for local continuum fitting, objective feature identification and measuring absorption properties. The absorption redshifts are computed from the optical-depth-weighted mean of the Mg $\II$ absorption profile (see Churchill & Vogt 2001). The typical absorption redshift uncertainty is $\sim 0.3$ km s$^{-1}$. Velocity widths of absorption systems are measured between the pixels where the equivalent width per resolution element recovers to the 1σ detection threshold (Churchill et al. 1999).

2.3 HST imaging

The Wide Field Planetary Camera 2 (WFPC)-2/HST F814W images were obtained from the Hubble Legacy Archive (HLA$^3$) (PI Bechtold). Details of the WFPC-2/HST observations are presented in Table 2. Five sets of four 1100-s exposures were taken over a
Table 2. Summary of the imaging observations of the Q1127–145 field obtained using HST with the WFPC-2. The images were taken with the F814W filter with the quasar centred on chip 3 of the CCD array. The images were taken at a range of position angles (PA) listed below. In Column 6, we list the Proposal IDentification number (PID) of the WFPC-2 observations taken by the PI Bechtold.

| Filter | Quasar chip | PA (deg) | Exposure (s) | Date     | PID |
|--------|-------------|----------|--------------|----------|-----|
| F814W  | WF3         | −11.502  | 4400         | 2001 May 23 | 9173 |
| F814W  | WF3         | −3.102   | 4400         | 2001 Aug. 01 | 9173 |
| F814W  | WF3         | 147.006  | 4400         | 2001 Nov. 16 | 9173 |
| F814W  | WF3         | 147.863  | 4400         | 2001 Nov. 16 | 9173 |
| F814W  | WF3         | 164.698  | 4400         | 2002 Jan. 03 | 9173 |

Galaxy photometry was performed using the Source Extractor (SExtractor) package (Bertin & Arnouts 1996) with a detection criterion of 1.5σ above background. The $m_{F814W}$ magnitudes were computed using the WFPC-2 zero-points taken from table 5.1 of the WFPC-2 Data Handbook and the chip gains obtained from the WFPC-2 Instrument Handbook. All magnitudes are based upon the Vega system.

Galaxy absolute B-band magnitudes, $M_B$, were determined from the k-corrected observed $m_{F814W}$. The k-corrections were computed using the formalism of Kim, Goobar & Perlmutter (1996) using the spectral energy distribution (SED) templates of Kinney et al. (1996).
3 RESULTS

Here we discuss the galaxies identified in our redshift survey along with galaxies identified in previous works. In Fig. 1 we present a $100 \times 100$-arcsec$^2$ portion of the combined WFPC2 image centred on the quasar. The four slit positions used in our new observations are indicated on the image. In Table 3, we list all the galaxies in the quasar field that have $m_{814W} < 20.3$ within a $100 \times 100$-arcsec$^2$ box centred on the quasar (we have included galaxy G1 since it has a spectroscopic redshift and G15 which is beyond the surveyed region).

We have obtained spectroscopic redshifts for eight new galaxies in this work. We have identified (1) a group of galaxies associated with the DLA, (2) a pair of galaxies associated with a weak Mg II absorption system and (3) five non-absorbing galaxies. The offsets of the systemic velocity of the absorbing galaxies from the optical-depth-weighted mean Mg II absorption are also listed in Table 3 and range from $-112$ to $+238$ km s$^{-1}$. In the following subsections, we will discuss the galaxies identified in the Q1127−145 field.

3.1 Non-absorbing galaxies

We have spectroscopically confirmed the redshifts of five non-absorbing galaxies for which we do not detect Mg II absorption to the limits of the UVES spectrum. In Fig. 2 we show $10 \times 10$-arcsec$^2$ images of these galaxies along with their emission-line spectra. Galaxies are listed in increasing impact parameter order. The galaxy redshifts were determined using H$_\alpha$ and/or [O II] emission lines. From the HST image, the non-absorbing galaxies appear to be normal spiral discs and the spectra indicate that they have ongoing star formation.

Three galaxies (G7, G12 and G15) have been spectroscopically confirmed with two emission lines while two galaxies (G9 and G11) have been confirmed with a single line. There is the possibility that the redshifts of galaxies computed with only one emission line may be incorrect. However, given the wavelengths of these lines and the observed apparent magnitudes of the galaxies, it is highly unlikely that these are at different redshifts than the ones quoted here. The redshift of G9 was computed using the [O II] emission line and is reliable since the observed [O II] wavelength is $\sim$4503 Å, which is bluer than any other optical galaxy emission-line rest wavelength and is not likely to be a UV emission line since it would place the galaxy at a redshift $z > 2$. The redshifts of G11 and G14 were computed using only the H$_\alpha$ emission line. If the H$_\alpha$ emission line is incorrectly identified, then the next likely candidate line would be [O III]. This would place the galaxy at redshifts of $z > 0.7$, which would result in $L_B > 1.5 \times 10^9$ with a disc scale-length of $\geq$4.5 kpc. We are therefore confident in these emission-line identifications.

All non-absorbing galaxies have Mg II equivalent width 3σ detection limits of $4.8−5.7$ mA (see Table 3). These equivalent width limits are quite low and imply that these galaxies are not associated with any substantial Mg II absorption along the LOS, which can be interpreted as the quasar LOS passing either outside the galaxies’ Mg II-enriched haloes or through a void within the patchy Mg II halo gas distribution. It is important to note that all the non-absorbing galaxies have impact parameters $D > 118$ kpc. This is consistent with current studies that show that local luminous galaxies at projected distances within $D \sim 120$ kpc are Mg II absorbers while beyond $D \geq 120$ kpc they are not (Churchill, Kacprzak &

### Table 3. Galaxy-absorber sample towards Q1127−145.

| ID  | $\theta$ (arcsec) | $z_{gal}$ | Ref$^a$ | $D$ (kpc) | $m_{814W}$ | $M_B$ | $L_B$ ($L_B^*$) | Group ID | $z_{abs}$ | $W_r$(2796)$^b$ | $\Delta v_r$ $^c$ (km s$^{-1}$) |
|-----|-------------------|-----------|---------|----------|------------|-------|----------------|---------|-----------|-----------------|------------------|
| G1  | 3.81              | 0.312 $\pm$ 0.0003 | 1 | 17.4 $\pm$ 0.1 | 21.55 $\pm$ 0.37 | -17.7 | 0.04 | 1 | 0.312710 | 1.773 $\pm$ 0.006 | -140 |
| G2  | 10.01             | 0.3132 $\pm$ 0.0002 | 2, 3, 4 | 45.6 $\pm$ 0.3 | 18.81 $\pm$ 0.11 | -20.4 | 0.54 | 1 | 0.312710 | 1.773 $\pm$ 0.006 | -112 |
| G3  | 16.23             | 0.32839 $\pm$ 0.0003 | 5 | 76.9 $\pm$ 0.4 | 20.12 $\pm$ 0.20 | -19.2 | 0.18 | 2 | 0.328266 | 0.029 $\pm$ 0.003 | -28 |
| G4  | 17.77             | 0.3124 $\pm$ 0.0001 | 2, 3, 4 | 81.0 $\pm$ 0.3 | 18.64 $\pm$ 0.10 | -20.6 | 0.63 | 1 | 0.312710 | 1.773 $\pm$ 0.006 | +71 |
| G5  | 19.30             | 0.32847 $\pm$ 0.0003 | 4 | 91.4 $\pm$ 0.2 | 18.84 $\pm$ 0.11 | -20.5 | 0.60 | 2 | 0.328266 | 0.029 $\pm$ 0.003 | -46 |
| G6  | 21.76             | 0.31167 $\pm$ 0.0003 | 5 | 99.8 $\pm$ 0.1 | 19.79 $\pm$ 0.17 | -19.4 | 0.22 | 1 | 0.312710 | 1.773 $\pm$ 0.006 | +238 |
| G7  | 27.92             | 0.27921 $\pm$ 0.0007 | 5 | 118.3 $\pm$ 0.8 | 20.22 $\pm$ 0.21 | -18.7 | 0.11 | - | <0.00094 | - |
| G8  | 33.22             | $d$        | - | 20.08 $\pm$ 0.19 | - | - | - | - | - | - |
| G9  | 39.91             | 0.20735 $\pm$ 0.0006 | 5 | 115.2 $\pm$ 0.2 | 19.85 $\pm$ 0.19 | -18.3 | 0.08 | - | - | <0.0050 | - |
| G10 | 37.93             | $d$        | - | 19.94 $\pm$ 0.19 | - | - | - | - | - | - | - |
| G11 | 38.12             | 0.33293 $\pm$ 0.0002 | 5 | 182.3 $\pm$ 0.2 | 19.76 $\pm$ 0.17 | -19.6 | 0.27 | - | - | <0.0048 | - |
| G12 | 42.33             | 0.30515 $\pm$ 0.0004 | 5 | 195.0 $\pm$ 0.6 | 19.50 $\pm$ 0.15 | -19.65 | 0.27 | - | - | <0.0048 | - |
| G13 | 50.08             | -          | - | 20.14 $\pm$ 0.20 | - | - | - | - | - | - | - |
| G14 | 52.54             | 0.31243 $\pm$ 0.0003 | 5 | 240.8 $\pm$ 0.3 | 20.01 $\pm$ 0.19 | -19.2 | 0.18 | 1 | 0.312710 | 1.773 $\pm$ 0.006 | +64 |
| G15 | 68.22             | 0.2473 $\pm$ 0.0002 | 5 | 264.8 $\pm$ 0.3 | 19.00 $\pm$ 0.12 | -19.6 | 0.25 | - | <0.0057 | - |

$^a$Galaxy identification: (1) Lane et al. (1998), (2) Bergeron & Boissé (1991), (3) Guillemin & Bergeron (1997), (4) Kacprzak et al. (2010), (5) This work.

$^b$Equivalent width limits are 3σ.

$^c$Δ$v_r$ is the rest-frame velocity offset between the mean Mg II 2796 absorption line and the galaxy, where $\Delta v_r = c(z_{abs} - z_{gal})/(1 + z_{gal})$ km s$^{-1}$.

$^d$No strong emission lines were detected.

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Figure 2. 10 × 10-arcsec$^2$ WFPC-2 F814W images of the non-absorbing galaxies G7 (image size of 42.4 × 42.4 kpc$^2$), G9 (34.0 × 34.0 kpc$^2$), G11 (47.8 × 47.8 kpc$^2$), G12 (45.1 × 45.1 kpc$^2$) and G15 (38.8 × 38.8 kpc$^2$). The galaxies are shown in increasing impact parameter order and have the same orientation as in Fig. 1. The H$\alpha$ and/or [O II] galaxy emission lines used to spectroscopically confirm the galaxy redshift are shown. Three galaxies (G7, G12 and G15) have been identified using two emission lines while two galaxies (G9 and G11) have been identified with one. The blue dashed lines are the fits to the continuum and the red solid curves are fits to the data. The green dotted lines are the 3$\sigma$ detection limits.

Steidel 2005; Zibetti et al. 2007; Chen & Tinker 2008; Kacprzak et al. 2008).

3.2 $z_{\text{abs}} = 0.328$ galaxies

We have spectroscopically confirmed one new galaxy (G3) at $z = 0.328$ in addition to G5, which was spectroscopically identified by Kacprzak et al. (2010). Both galaxies have strong H$\alpha$ and N$\lambda$ emission lines shown in Fig. 3. G3 has the smallest impact parameter of $D = 76.9$ kpc and an H$\alpha$ rest equivalent width of 32.0 Å. G5 has an impact parameter of $D = 91.4$ kpc and an H$\alpha$ rest equivalent width of 29.5 Å. Both galaxies appear to have normal unperturbed morphology. G3 is a compact core $0.2L_B^*$ galaxy with ongoing star formation while G9 is a $0.6L_B^*$ galaxy with a large bar and a sizable...
bright bulge similar to a local SBb galaxy. The major differences between the two galaxies are that G9 is much brighter than G3 and exhibits spiral arms.

The \( z_{\text{abs}} = 0.328 \) Mg II absorption was first reported by Narayanan et al. (2007) and is presented in Fig. 4. This weak system is composed of two single clouds with a velocity separation of 124 km s\(^{-1}\) and has a total equivalent width of \( W_r(2796) = 0.029 \) Å. No significant Mg I is detected \( (3\sigma, W_r \leq 0.003 \) Å). In Fig. 4, we also show the galaxy systemic redshifts (triangles) relative to the absorption system. Note that both galaxies have redshifts that are bracketed with both absorption clouds.

Galaxy G5’s rotation curve was obtained by Kacprzak et al. (2010) and the error bars in Fig. 4 indicate its observed maximum rotation velocities. With a projected velocity span of \( \sim 160 \) km s\(^{-1}\), G5’s dynamics is consistent with both absorption cloud velocities. In particular, Kacprzak et al. (2010) show that the two cloud velocities align with each side of the rotation curve, but that pure disc models are unable to reproduce the observed Mg II absorption velocities. If we were able to obtain a rotation curve for G3, both galaxy kinematics would likely be consistent with both absorption clouds. Thus, in these circumstances, it is difficult to disentangle which galaxy is associated with this particular absorber. Yet associating the absorption with one galaxy or the other may result in a difference in conclusions regarding the origins of the absorption. We discuss the implications of this in Section 4.

### 3.3 \( z_{\text{abs}} = 0.313 \) Galaxies

Three previously spectroscopically confirmed galaxies associated with the DLA are G1, G2 and G4. G1 is the closest galaxy to the quasar LOS having an impact parameter of \( D = 17.4 \) kpc. This faint 0.04L\(_e\) compact core galaxy was identified from [O III] emission lines (Lane et al. 1998). The next closest galaxy to the quasar LOS is G2 with \( D = 45.6 \) kpc. This 0.54L\(_e\) edge-on spiral displays asymmetries on both sides of the galaxy, and its H\(_\alpha\) rest equivalent width is 17.3 Å. The G4 galaxy has a major dust lane and a large bulge. Given that we detected no strong emission lines, this galaxy could be classified either as Sa or as an early-type S0 galaxy.

It has a luminosity of \( L_B = 0.63L_B^* \) with an impact parameter of \( D = 81.0 \) kpc.

We have spectroscopically confirmed two new galaxies (G6 and G14) at a similar redshift to the \( z_{\text{abs}} = 0.313 \) DLA in addition to the three previously discovered galaxies G1, G2 and G4 (Bergeron & Boissé 1991; Lane et al. 1998). All five galaxies are shown in increasing impact parameter order in Fig. 5. The galaxy emission-line strengths are shown in Table 4. The newly spectroscopically confirmed galaxy G6 has an impact parameter of \( D = 99.8 \) kpc and an H\(_\alpha\) rest equivalent width of 32.4 Å. This 0.22L\(_e\) spiral galaxy has asymmetric spiral arms. G14 has an impact parameter of \( D = 240.8 \) kpc and an H\(_\alpha\) rest equivalent width of 34.8 Å. This 0.18L\(_e\) galaxy has a perturbed early-type morphology. Both newly identified galaxies are at larger impact parameters than the previously known ones (G1, G2 and G4), suggesting that the galaxy environment is more group-like and much larger than previously thought.

The galaxy group has five confirmed galaxies that have a luminosity range of \( 0.04 \leq L_B \leq 0.63L_B^* \). The group of at least five galaxies has a velocity dispersion of \( \sigma = 115 \) km s\(^{-1}\) centred at a redshift of \( z_g = 0.312 \).36.

The velocity spread of the galaxy group is comparable to the velocity spread of the Mg II gas as seen in Fig. 6. The galaxies cover a full velocity range of 350 km s\(^{-1}\). The Mg II absorption seems to occur in two separate kinematic components: the large, saturated component has a large velocity spread of 235 km s\(^{-1}\) and the much weaker absorption blueshifts of the saturated component comprises several clouds with a velocity spread of 68 km s\(^{-1}\). The Mg II absorption redshift is offset 80 km s\(^{-1}\) redwards of the galaxy group redshift of \( z_g = 0.312 \).36. In Fig. 6, we show the rotation velocity ranges for G2 and G4 from Kacprzak et al. (2010). These galaxies are the brightest two in the group. The maximum observed projected rotational velocity for G2 is 204 km s\(^{-1}\) and G4 has a maximum observed projected rotational velocity of 90 km s\(^{-1}\). The rotation velocities of both G2 and G4 alone cover the full range of the absorption velocities. Kacprzak et al. (2010) note that, using a simple disc model, a large fraction of the absorption velocities could be explained by the halo gas of G2 and G4 rotating as thick discs. However, the disc model is quite unrealistic since it assumes that the
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Figure 5. Same as Fig. 2 except for the G1, G2, G4, G6 and G14 galaxy group associated with the $z = 0.313$ DLA. G1 was spectroscopically confirmed by Lane et al. (1998), and we do not have a spectrum of this galaxy to show here. The spectra of G2 and G4 were obtained with Keck/ESI and are flux calibrated. The images are $45.9 \times 45.9 \text{kpc}^2$ in size at the redshift of the DLA absorption. For G4, we show the Na I absorption feature for reference since it was also used to confirm the redshift since the [O II] line is quite weak.

Using the Mg I profile, one can study the individual clouds that are saturated in Mg II. The majority of the Mg I gas is aligned with the saturated Mg II component. Only a very weak Mg I cloud is detected in a second kinematic component at $-150 \text{ km s}^{-1}$. All detectable Fe II lines are highly saturated (see Fig. 6). The absorption velocity structure is more apparent in the Ca II, Mn II and Ti II lines where five to six kinematically distinct absorption features are apparent. These features do not align with the five galaxy redshifts in the group, making it difficult to determine the origin of the absorbing gas.

An HST/Space Telescope Imaging Spectrograph (STIS) E230M spectrum was also taken of this quasar (PI: Bechtold). The Zn II present in the spectrum has the same velocity structure as the Ca II and the measured Zn II column density is $13.45 \pm 0.08 \text{ cm}^{-2}$. 

halo rotates at constant velocity, set by the maximum galaxy rotation velocity, independent of scaleheight. Therefore, it is unlikely that all of the absorption is produced by corotating halo gas from both galaxies G2 and G4.
### Table 4
The emission-line rest frame equivalent widths and emission-line fluxes for the absorbing galaxies. The \[\text{[O~II]}\] equivalent width was not published by Lane et al. (1998). Only the Keck/ESI spectra of G5, G2 and G4 are flux calibrated.

| ID    | \(z_{\text{gal}}\) | \(\text{[O~II]}\) | H\(\beta\) | \(\text{[O~III]}\) | \(\text{[N~II]}\) | H\(\alpha\) | \(\text{[N~II]}\) | \(\text{[O~II]}\) | H\(\beta\) | \(\text{[O~III]}\) | \(\text{[N~II]}\) | \(\text{[N~II]}\) |
|-------|---------------------|------------------|-----------|------------------|------------------|-----------|------------------|------------------|-----------|------------------|------------------|-----------|
| G3    | 0.32839             | \(<5.1\)         | \(<0.5\)  | \(<1.2\)         | 32.7 ± 1.9       | 11.0 ± 1.1 | \(<0.4\)         | \(<0.4\)         | \(<0.4\)  | \(<0.1\)         | \(<0.1\)         | \(<0.1\)  |
| G5    | 0.32847             | \(<2.0\)         | \(<2.0\)  | \(<1.2\)         | 7.4 ± 1.8        | 29.5 ± 2.3 | 22.1 ± 2.3       | \(<7.6\)         | \(<8.0\)  | \(<8.0\)         | \(<8.0\)         | \(<8.0\)  |

\(z_{\text{abs}} = 0.313\) Group

| ID    | \(z_{\text{abs}}\) | \(\text{[O~II]}\) | H\(\beta\) | \(\text{[O~III]}\) | \(\text{[N~II]}\) | H\(\alpha\) | \(\text{[N~II]}\) | \(\text{[O~II]}\) | H\(\beta\) | \(\text{[O~III]}\) | \(\text{[N~II]}\) | \(\text{[N~II]}\) |
|-------|--------------------|------------------|-----------|------------------|------------------|-----------|------------------|------------------|-----------|------------------|------------------|-----------|
| G1    | 0.3121             | –                | –         | –                | –                | –         | –                | –                | –         | –                | –                | –         |
| G2    | 0.3132             | 5.8 ± 0.5        | \(<0.4\)  | \(<0.4\)         | 17.3 ± 1.3       | 9.0 ± 0.8  | \(<0.4\)         | \(<0.4\)         | \(<0.4\)  | \(<1.4\)         | \(<1.5\)         | \(<1.0\)  |
| G4    | 0.3124             | 2.4 ± 1.0        | \(<0.5\)  | \(<0.6\)         | \(<1.4\)         | \(<1.5\)  | \(<1.0\)         | \(<1.0\)         | \(<1.0\)  | \(<1.0\)         | \(<1.0\)         | \(<1.0\)  |
| G6    | 0.31167            | \(<4.2\)         | –         | –                | \(<2.9\)         | 32.4 ± 1.9 | 11.1 ± 1.1       | \(<0.6\)         | \(<0.6\)  | \(<0.6\)         | \(<0.6\)         | \(<0.6\)  |
| G14   | 0.31243            | –                | –         | \(<2.5\)         | 35.8 ± 3.9       | \(<5.1\)  | –                | –                | –         | –                | –                | –         |

Figure 6. The observed metal-line absorption from the \(z_{\text{abs}} = 0.313\) DLA obtained from the UVES quasar spectrum. The dashed line is a fit to the continuum and the solid line near zero is the flux error spectrum. The Mg\(\text{II}\)\(\lambda 2796\) absorption redshift is the zero-point of the velocity scale. The range of velocities over which significant absorption is detected is shaded for each transition; for Mg\(\text{II}\)\(\lambda 2796\), the detection threshold was set at 5\(\sigma\) while a lower threshold of 3\(\sigma\) is set for all other transitions. The redshifts of all five galaxy group members are indicated by the triangles and are shown as a function of the impact parameter. The maximum observed rotation velocities of G2 and G4 obtained from Kacprzak et al. (2010) are shown by the error bars. Note that the redshift distribution of the galaxy group spans all of the absorption velocities. The observed rotational kinematics of G2 and G4 alone also span the absorption velocities.
(Kanekar, private communication). We discuss the metallicity of this DLA in greater detail in Section 3.5.

Lane et al. (1998) detected 21-cm absorption at a similar redshift to the DLA. A higher signal-to-noise ratio and higher resolution 21-cm absorption spectra taken by Chengalur & Kanekar (2000) revealed that the broad feature detected by Lane et al. (1998) breaks up into five to six narrow components. The full velocity width of the absorption is \(\sim 120 \text{ km s}^{-1}\), which is comparable to the velocity widths of the Ca\(\text{II}\), Ti\(\text{II}\) and Zn\(\text{II}\). The individual 21-cm absorption components also have similar velocities to the heavy metal absorption components. The 21-cm profile was found to vary on short time-scales of a few days, and models that reproduce the variable 21-cm absorption profile required small-scale variations of the optical depth of the absorber (Kanekar & Chengalur 2001a).

### 3.4 Galaxy morphologies

In Fig. 7 we show a zoomed-in contour plot of the galaxies in the field. The axes are set to the physical scale at the redshift of the DLA. The WFPC-2 F814W filter is comparable to the rest-frame Kron–Cousins \(R\) filter at the \(z = 0.313\) absorption redshift. Four of the galaxies in the \(z = 0.313\) group are visible here along with both \(z = 0.328\) galaxies. We plot SB contours ranging between 23.3 and 24.2 mag arcsec\(^{-2}\). The image has an SB limit of \(~25\) mag arcsec\(^{-2}\).

Upon inspecting the galaxies in the \(z = 0.313\) group, one notes that both G2 and G4 seem to exhibit tidal disturbances. G2 contains either a strong warp in the disc or tidal tails from previous interactions. The rest-frame \(R\)-band optical streams extend up to 25 kpc away from the galaxy. These features suggest at least one merger/harassment event. The small galaxy situated below the semimajor axis of G2 in projection does not have a spectroscopic redshift. Using broad-band photometry, Chen & Lanzetta (2003) derive a redshift of \(z = 0.53\) for this faint object. However, if this object is undergoing an interaction with G2, then its colours may not be consistent with the standard spectral templates used to derive the photometric redshift. The redshift of this galaxy is in need of spectroscopic confirmation.

**Figure 7.** Smoothed SB contour plot of the quasar field. The contours are in 0.3 mag arcsec\(^{-2}\) intervals: 23.3 (blue), 23.6 (green), 23.9 (red) and 24.2 (black) mag arcsec\(^{-2}\). The SB limit of the image is roughly 25 mag arcsec\(^{-2}\). The axes indicate the projected distance away from the quasar in kpc (assuming \(z = z_{\text{abs}} = 0.31271\)) along with the right ascension and declination in units of degrees. Note the extend optical streams – possibly tidal tails – seen for G2 and G4.
The S0-like galaxy G4 exhibits a strong dust lane and also has an extended optical stream extending \( \sim 30 \) kpc projected in length towards the east from the galaxy centre. This potential tidal stream is suggestive of previous interactions, possibly with G2. There are also several unidentified, large, low SB blobs above and below the stream, which may be associated with the tidal debris or high-redshift low SB galaxies. The asymmetric spiral G6 may have some tidal debris as well since it has some optical structures in its vicinity but they could potentially be galaxies at different redshifts. The morphologies of the galaxies seen here suggest that this group has undergone some interactions in the past.

It has been noted in the literature (Rao et al. 2003), and can be seen here, that there appears to be a significant level of SB around the quasar. Rao et al. (2003) suggest that the low SB feature is potentially a low SB galaxy that is responsible for the DLA absorption. However, no evidence yet exists to support this possibility. It also remains possible that the emission seen in Fig. 7 is associated with the \( z_{\text{em}} = 1.18 \) quasar host galaxy, which has extended radio and X-ray emission that overlap quite well with the extended quasar optical emission (see Siemiginowska et al. 2002, 2007). There are many faint galaxies/structures that remain unidentified in this field, several of which reside in close proximity to the quasar LOS, that may also contribute to the absorption.

Our data suggest that most galaxies in the \( z = 0.313 \) group have undergone interactions in the past. One way to differentiate between these and the many possible origin scenarios for the DLA gas is by studying the galaxy SFRs and by comparing the metallicity of the surrounding galaxies and of the absorption.

### 3.5 Metallicities and star formation rates

In an effort to better understand the origins of the metal-enriched absorption, we compute, when possible, the galaxy SFRs and metallicities.

We can only compute SFRs for galaxies that have Keck/ESI spectra which have been flux calibrated. The APO/DIS data were taken in poor/cloudy weather conditions and we are unable to flux calibrate them. We compute the galaxy SFRs using the H\(_\alpha\) (Kewley et al. 2002) and [O \( \text{II} \)] (Kewley, Geller & Jansen 2004) emission-line relations. We do not apply any dust corrections since we are unable to measure the Balmer decrement. We do not apply slit-loss corrections. Thus, the SFRs quoted here are lower limits.

In contrast with the SFR calculations, we are able to compute metallicities for additional galaxies using only the equivalent widths of H\(_\alpha\) and N \( \text{II} \) emission lines. Since both H\(_\alpha\) and N \( \text{II} \) are only 20.66 \( \AA \) (at rest wavelengths) apart, the continuum flux levels are approximately the same and are insensitive to dust reddening. Thus, the metallicity indicator \( N_2 = f(N \text{\ II})_{6583}/f(H\alpha) \), which is a ratio of emission-line fluxes (\( f \)), becomes just the ratio of equivalent widths. This technique has been demonstrated to work for other metallicity indicators such as \( R_2 \) (see Kobulnicky \& Phillips 2003). We apply the \( N_2 \) metallicity relation from Pettini \& Pagel (2004), where 12 + log(O/H) = 8.90 + 0.57 \( \times N_2 \). Note that the \( N_2 \) metallicity indicator becomes unreliable above roughly solar since the \( N_2 \) index saturates as nitrogen becomes the dominant coolant (see Erb et al. 2006, and references therein). We assume a solar oxygen abundance of log(O/H)\( _{\odot} \) = 8.736 \( \pm 0.078 \) (Holweger 2001). The SFRs and metallicities are listed in Table 5.

For the \( z = 0.313 \) group, we are able to measure SFRs for galaxies G2 and G4. For G2, we compute SFR([O \( \text{II} \)]) = 0.44 M\(_{\odot}\) yr\(^{-1}\) and SFR(H\(_\alpha\)) = 1.52 M\(_{\odot}\) yr\(^{-1}\). For G4, we compute SFR([O \( \text{II} \)]) = 0.045 M\(_{\odot}\) yr\(^{-1}\). Again, we have not applied any dust corrections which are probably the source of the difference between the SFRs derived from H\(_\alpha\) and [O \( \text{II} \)]; the H\(_\alpha\) SFR is more reliable since it is less affected by dust extinction than [O \( \text{II} \)]. Since the galaxy SFRs are not corrected for dust extinction, the SFRs quoted are lower limits. We note that both of these galaxies have typical SFRs and are not likely to have strong winds. Even if dust corrections were applied, it would at most increase the SFRs by a factor of \( \sim 2 \) which is still lower than expected for galaxies with strong winds. The S0-like morphology of G4 is consistent with low SFRs and no strong outflow winds. Given that G2 and G4 are the brightest galaxy group members closest to the quasar LOS, it is unlikely that the absorption is coming from winds. We can compute the metallicities for three of the galaxies in the group: [O/H] = 0.00 \( \pm 0.09 \) for G2, [O/H] = −0.10 \( \pm 0.09 \) for G6 and a limit of [O/H] < −0.31 for G14. These galaxies are roughly solar in abundance except for G14 which is less than 1/2 solar.

The DLA absorption metallicity was initially derived from the amount of photoelectric absorption due to metals present in the quasar X-ray spectrum. The derived metallicity ranged from zero to solar (Bechtold et al. 2001; Turnshek et al. 2003). Although zero metallicity is unlikely due to the observed metal lines in absorption (Fig. 6), it can only be concluded that there is no evidence for a relatively high metallicity DLA (Turnshek et al. 2003). Kanekar et al. (2009) used STIS E230M quasar spectra to compute the absorption metallicity using the Zn \( \lambda \lambda 2026 \) and \( 2062 \) lines. Zn abundance measurements give metallicity estimates relatively free of depletion effects since Zn is relatively undepleted on to dust grains. Kanekar et al. (2009) compute a metallicity of the \( z_{\text{abs}} = 0.313 \) DLA to be [Zn/H] = −0.90 \( \pm 0.11 \) relative to solar.

To compare the metallicity of this DLA to the general population of DLAs, we use the work of Kulkarni et al. (2005) who computed the N(H)\(_\gamma\)-weighted mean [Zn/H] metallicity for 20 DLAs between 0.09 < \( z \) < 1.37. They derived a mean [Zn/H] = −0.86 \( \pm 0.11 \) for their maximum-limits sample and [Zn/H] = −1.01 \( \pm 0.14 \) for their minimum-limits sample. The maximum-limits sample treats the Zn limits as detections and the minimum-limits sample treats the Zn limits as zeros. The Q1127−145 \( z = 0.313 \) DLA has roughly typical metallicity.

To summarize the metallicity comparison, we find that the gas in absorption is relatively metal poor compared to the galaxies for

| Galaxy | SFR([O \( \text{II} \)]) (M\(_{\odot}\) yr\(^{-1}\)) | SFR(H\(_\alpha\)) (M\(_{\odot}\) yr\(^{-1}\)) | 12+log(O/H) | [O/H]\(^a\) |
|--------|---------------------------------|---------------------------------|----------------|----------------|
| G3     | –                               | 8.64 \( \pm 0.05 \)             | −0.10 \( \pm 0.09 \) |
| G5     | –                               | 8.83 \( \pm 0.06 \)             | 0.09 \( \pm 0.1 \)  |
| G1     | 0.44                            | 1.52                            | 8.74 \( \pm 0.05 \) | 0.00 \( \pm 0.09 \) |
| G4     | 0.045                           | –                               | –               | –               |
| G6     | –                               | 8.64 \( \pm 0.05 \)             | −0.10 \( \pm 0.09 \) |
| G14    | –                               | <8.43                           | −0.31           |

\(^a\)Here [X/Y] = log(X/Y)−log(X/Y)\( _{\odot} \).
which we could compute metallicities. We obtain roughly solar metallicity for the galaxies and one-tenth solar for the absorption system. For the \( z = 0.328 \) galaxy pair, we compute the SFR for G5 using the \( H \delta \) emission lines resulting in an SFR(\( H \delta \)) = 1.44 \( M_\odot \) yr\(^{-1}\). The galaxy has an SFR much lower than would be expected for strong outflows (Weiner et al. 2009). We are able to measure the metallicities for both galaxies (G3 and G5) associated with the \( z = 0.328 \) absorption. G3 has \([\text{O} / \text{H}] = -0.10 \pm 0.09 \) and G5 has \([\text{O} / \text{H}] = 0.09 \pm 0.1 \). That is, the galaxies have similar metallicity which is approximately solar. Unfortunately, since the absorption system is quite weak, we cannot measure an absorption metallicity for this system for direct comparison. Furthermore, from the \( HST/FOS \) G160L quasar spectrum (see Rao \& Turnshek 2000) it is apparent that the \( z = 0.328 \) Ly\( \alpha \) absorption is embedded within the \( z_{\text{abs}} = 0.312 \) DLA Ly\( \alpha \) absorption and cannot be deblended.

4 DISCUSSION

4.1 \( z_{\text{abs}} = 0.313 \) galaxies

Under most circumstances, DLAs are produced from quasar LOSs passing either through or near isolated galaxies (e.g. Møller et al. 2002; Lacy et al. 2003; Rao et al. 2003; Chun et al. 2006). However, in the case of the \( z = 0.313 \) DLA, the environment is more complex. Here we find a group of galaxies associated with the DLA system containing at least five members with a velocity dispersion \( \sigma = 115 \) km s\(^{-1}\) offset 80 km s\(^{-1}\) bluesward of the Mg\( \ II \) absorption redshift. The DLA associated with the \( z = 0.313 \) group has \( W_z(2796) = 1.773 \) Å. The group has a luminosity range of \( 0.04 \leq L_B \leq 0.63 L^\odot \) and an impact parameter range of \( 17.4 \leq D \leq 240.8 \) kpc. The galaxy redshift distribution is consistent with the Mg\( \ II \) absorption velocity distribution, along with the other metals. Furthermore, measured projected rotation curves of two of the galaxies (G2 and G4) also cover the entire absorption velocity range.

From the derived galaxy emission-line metallicities and the DLA absorption metallicity, at first it appears unlikely that the absorption is produced by metal-enriched winds or tidal debris from these two galaxies. Recent metallicity gradient measurements, derived from local early-type galaxies, have been shown to be quite shallow and extend for several galaxy effective radii; Spolaor et al. (2010) find an average stellar absorption metallicity gradient of \(-0.22 \pm 0.14\) per effective radius for their sample. G2 has an effective radius of \( 8.1 \pm 0.6 \) kpc (Kacprzak et al. 2007) which, with this metallicity gradient, would imply that the metallicity at the quasar LOS would be \([\text{O} / \text{H}] = -1.2 \pm 0.7\). Although the errors are large, this is consistent with the absorption system metallicity observed. This result is similar for G6. Thus, it is possible that the absorption is produced by an extended disc that has a shallow metallicity gradient. However, it has not been demonstrated that these metallicity gradients can be smoothly extrapolated beyond a few disc effective radii into the halo.

The only other direct comparison of galaxy emission line and quasar absorption-line metallicity was by Bowen et al. (2005) at redshift \( z = 0.009 \). The DLA has an impact parameter of 3.3 kpc from the absorbing dwarf galaxy and the galaxy and the DLA have very similar metallicities, perhaps implying a relatively flat radial abundance gradient. This makes it difficult to determine if the gas originates in the galaxy disc or outflows. Chen, Kennicutt \& Rauch (2005) attempted to compare host galaxy/absorber metallicities for three systems and found that the galaxy metallicity derived from \([\text{O} / \text{H}]\) is greater than the absorption metallicity derived from \([\text{Fe} / \text{H}]\). They proposed radial metallicity gradients to explain their results. However, these results remain uncertain because the absorption metallicities were derived using iron, which has variable degree of dust depletion. Undepleted elements such as Zn provide much more robust metallicity estimates which can be more reliably compared to \([\text{O} / \text{H}]\) metallicities derived for galaxies.

The outflow scenario is supported by Bouché et al. (2006) who found a statistical anticorrelation between the Mg\( \ II \) absorption-line equivalent width and the mass of the halo hosting the absorbers by cross-correlating absorbers with luminous red galaxies in the Sloan Digital Sky Survey. They claim that this is direct evidence that absorbers are not virialized in gaseous haloes of the galaxies. They suggest that the strongest absorbers — those with \( W_z(2796) \geq 2 \) Å, somewhat stronger than the one associated with the \( z = 0.313 \) group — are statistically more likely to trace superwinds.

Strong winds can be seen directly in absorption. For example, stacking 1400 DEEP2 galaxy spectra at \( z \sim 1.4 \), Weiner et al. (2009) found 300–1000 km s\(^{-1}\) winds in Mg\( \ II \) and Mg\( \ I \) absorption in galaxies with high SFRs and that both Mg\( \ II \) equivalent width and the outflow velocities are correlated with galaxy SFRs. At lower redshifts (\( z \sim 0.6 \)), Tremonti et al. (2007) reported Mg\( \ II \) absorption blueshifted 500–2000 km s\(^{-1}\) relative to 14 post-starburst host galaxies. Although some of these systems may not be DLAs, Rao, Turnshek \& Nestor (2006) showed that \( \sim 35 \) per cent of (Mg\( \ II \)-selected) absorbers with Mg\( \ II \)\( \lambda 2796 \) and Fe\( \ II \)\( \lambda 2600 > 0.5 \) Å are DLAs. We find low SFRs in the two brightest galaxy members of the \( z = 0.313 \) group (G2 and G4) and would not expect to see strong winds as discussed above. However, we do not have SFR estimates for galaxy G1 which is at the closet projected distance to the quasar LOS. If this faint galaxy has/had high SFRs, then according to the Bouché et al. (2006) results, this galaxy may have a high probability of being a major contributor to the Mg\( \ II \) absorption. If the gas was travelling at moderate wind speeds of \( 100 \) km s\(^{-1}\), then it would only take \( \sim 0.2 \) Gyr to reach the quasar LOS from G1. Though this is a plausible argument, the tidal features seen for galaxies G2 and G4 suggest a different story.

This is not the first group discovered to be associated with Mg\( \ II \) absorption. Whiting, Webster \& Francis (2006) detected a group of five galaxies (\( z = 0.66 \)) with a velocity dispersion of \( \sigma = 430 \) km s\(^{-1}\) associated with an Mg\( \ II \) absorption system with a velocity width of \( 250 \) km s\(^{-1}\). Four of the five galaxies have impact parameters less than \( 100 \) kpc with the smallest at \( 51.2 \) kpc. They report that it is difficult to associate a given galaxy with the absorption system and that debris produced by interactions may be producing the absorption. DLAs originating from tidal gas in galaxy groups are further supported by Nestor et al. (2007), who found that very strong Mg\( \ II \) absorbers often arise in fields with multiple galaxies in close proximity to the quasar LOS. They do not have galaxy redshifts in the quasar fields, yet they argue that the likely origin of the high equivalent width Mg\( \ II \) absorption is kinematically disturbed gas around interacting galaxies. However, both studies used only ground-based imaging and were not able to directly study the morphologies of the group members.

For the \( z_{\text{abs}} = 0.313 \) galaxy group, two of the brightest members (G2, G4 and possibly G6) exhibit perturbed morphologies and several extended optical streams. These streams extend for \( \sim 25 \) kpc and may reflect the recent merger/interaction history of this galaxy group; they may comprise tidal debris. The interactions producing the tidal debris seen here may also be responsible for producing the complex absorption system. The absorption could arise directly from the tidal debris or from dwarf galaxies that form in these tidal tails (Knierman et al. 2003).
Physical properties of the DLA absorbing gas are further constrained by Kanekar et al. (2009), who derived a 21-cm gas covering fraction of 0.9 and a gas spin temperature of $T_s = 820 \pm 145$ K. Spin temperatures of $T_s \sim 300$ K are typical for local spiral galaxies and the Milky Way. Higher spin temperatures are associated with smaller objects such as dwarf galaxies, low SB galaxies or objects with low metallicity/pressure that have a larger fraction of warm gas and where physical conditions are not suitable for producing the cold phase of H$\text{I}$ (Wolfire et al. 1995). However, the majority of DLAs (including the $z_{abs} = 0.313$ DLA) have far higher spin temperatures: $T_s > 500$ K (Carilli et al. 1996; Kanekar et al. 2009).

It has been debated that the high temperature estimates for DLAs may arise due to the difference between radio and optical gas covering fractions (Curran et al. 2005) and/or wavelength-dependent beam size or sightline (Wolfe, Gawiser & Prochaska 2003). Although these effects may play a role, a recently reported correlation between DLA [Z/H] and $T_s$ may suggest that there is no wavelength dependence on the observations (Kanekar et al. 2009). Given the large extended structure observed in the radio for the Q1127–145 quasar, including the radio jet, it is possible that this system may suffer from such wavelength-dependent effect, thereby making it difficult to compare optical and 21-cm absorption data. It has been mentioned in the literature that quasar Q1127–145 is a peculiar case, since it has a rather large 21-cm absorption profile velocity width and a high spin temperature (Kanekar & Chengalur 2001b), suggesting that this system is different from standard DLAs. Thus, it is plausible that the both the optical and 21-cm absorption may arise in structures such as tidal streams, infall and/or outflows.

The full velocity range of 350 km s$^{-1}$ for the Mg $\text{II}$ absorption profiles (along with Fe $\text{II}$) remains difficult to reproduce in kinematic models. The cloud velocity distribution simulations of Prochaska & Wolfe (1997) suggest that DLA velocity profiles are driven by rapidly rotating thick discs. Also, 21-cm observations of low-mass galaxies, such as the Large Magellanic Cloud, display lower velocity widths than observed for typical DLAs (Prochaska et al. 2002). This supports the idea that DLAs are massive rotating extended discs of galaxies. However, hydrodynamical simulations of Hachnelt et al. (1998) showed that irregular protogalactic clumps can reproduce the DLA absorption-line velocity width distribution equally well. They conclude that the absorption velocity widths can be driven by a variety of structures, which are a superposition of rotation, random motions, infall and merging. Additional 21-cm studies of Zwaan et al. (2008) demonstrated that the DLA velocity widths do not originate from rotating gas discs of galaxies similar to those seen in the local universe. These results further support that DLAs are often associated with tidal gas produced by galaxy interactions or superwinds and outflows.

Given the data we have acquired, and the arguments we have presented, we favour the interpretation that the DLA absorption arises from tidal debris produced by galaxy interactions, which are likely more important in the $z = 0.313$ group environment we have identified. However, we cannot completely rule out other scenarios such as outflows originating from the galaxy group members, faint unidentified galaxies near the quasar LOS or small satellite galaxies in front of the quasar LOS.

4.2 $z_{abs} = 0.328$ galaxies

The $z = 0.328$ pair of galaxies is associated with a weak Mg $\text{II}$ absorption system. Both galaxies, G3 and G5, are within the fiducial Mg $\text{II}$ halo size of $\sim 100$ kpc. G5 is roughly 2.5 times more luminous than G3. Both galaxies have velocities that are consistent with the absorption velocities (see Fig. 4), which makes it difficult to associate one particular galaxy with the absorption system. The SFR of G5 is typical of a normal spiral galaxy and would not be expected to have strong outflows (e.g. Heckman 2002, 2003; Weiner et al. 2009).

Both galaxies have similar metallicities which are roughly solar. Even if we had the metallicity of the absorption system, we would not be able to identify the host galaxy. For reference, Narayanan et al. (2008) analysed 100 weak Mg $\text{II}$ absorbers and found, using ionization modelling, that the metallicity in a significant fraction of systems is constrained to values of solar or higher. If this was true for this particular case, both galaxies would be in agreement with the absorption metallicity. There is no clear evidence of strong disruptions in the morphology of either galaxy, indicating no recent merger or interaction activity. Given that the absorption system is very weak, it could arise in a wide array of structures associated with the environment of the pair of galaxies.

5 CONCLUSIONS

We have performed a spectroscopic galaxy survey to a limiting magnitude of $m_{F814W} \leq 20.3 (L_B > 0.15 L_\odot$, at $z = 0.3$) within 100 × 100 arcsec$^2$ of the quasar Q1127–145. This field has a large number of bright galaxies near the quasar LOS and has three Mg $\text{II}$ absorption systems detected in the quasar spectrum, including one DLA. Here we have obtained spectroscopic redshifts for eight galaxies in this field, adding to the four previously identified (Bergeron & Boissé 1991; Guillemin & Bergeron 1997; Kacprzak et al. 2010).

Our main results can be summarized as follows.

(i) We have identified two galaxies (G6 and G14) associated with the DLA at $z = 0.313$, which, in addition to the three known galaxies, form a group of at least five galaxies. The group has a luminosity range of $0.04 \leq L_B \leq 0.63 L_\odot$ and an impact parameter range of $17.4 \leq D \leq 240.8$ kpc. The group velocity dispersion is $\sigma = 115$ km s$^{-1}$ having a full velocity range of $\sim 350$ km s$^{-1}$. The group redshift is offset 80 km s$^{-1}$ bluewards of the Mg $\text{II}$ absorption redshift. The galaxy redshift distribution spans the entire range of the absorption velocities. Furthermore, the rotation curves of G2 and G4 alone cover the entire range of absorption velocities.

SFRs of two of the brightest galaxy members are too low to drive strong winds, reducing the likelihood that winds are responsible for the absorbing gas. Metal-enriched winds are also unlikely since the DLA metallicity is one-tenth solar, whereas three of the five galaxies have metallicities ranging between less than 1/2 solar to solar. Although stellar metallicity gradients in the literature are consistent with our findings, it is yet to be demonstrated that these gradients can be extrapolated to 50 kpc. The favoured scenario for the origin of the absorption is from tidal debris. The deep WFCPC-2 F814W imaging shows the perturbed morphologies for three galaxies and optical tidal tails extending $\sim 25$ kpc away from the disc. These features suggest merger/harassment events, consistent with the more frequent galaxy harassment/merging expected in the group environment we have identified.

(ii) We have identified a galaxy (G3), in addition to previously identified G5 (Kacprzak et al. 2010), associated with the $z = 0.328$ weak Mg $\text{II}$ absorption system, $W_c(2796) = 0.029$ Å. There is no evidence of recent interactions since both galaxies have unperturbed morphologies and they are separated by 140 kpc. Even armed with the SFR and rotation velocities of G5 and the metallicities of both galaxies, it remains difficult to determine which galaxy hosts the absorber. We can only conclude that this weak absorption system
can arise in a variety of cosmic structures in either or both haloes of the galaxy pair.

(iii) We have identified five galaxies (G7, G9, G11, G12 and G15) with $0.21 \leq z \leq 0.33$ that are not associated with any detectable Mg II absorption ($3\sigma$ detection limits of 4.8–5.7 mÅ). These galaxies appear to be normal star-forming spiral discs. All non-absorbing galaxies have impact parameters $D > 118$ kpc. This is consistent with previous results on Mg II halo sizes, which suggest that we should not expect to detect absorption beyond impact parameters of ~120 kpc.

The DLA galaxy group at $z = 0.313$ is quite different from the standard examples in the literature of DLA-plus-(apparently) isolated galaxy (e.g. Moller et al. 2002; Lacy et al. 2003; Rao et al. 2003; Chun et al. 2006). The group of galaxies associated with the $z = 0.313$ DLA suggests that interactions, which are common in groups of galaxies, might be responsible for at least some DLA absorption systems as well. This may explain why searches for host galaxies of DLAs and strong Mg II systems have a low success rate of 30–40 per cent using small field of view IFUs (e.g. Bouché et al. 2007). It is likely that we need to survey further out from the quasar LOS if there are many other cases where tidal debris produces the absorption. It is also interesting to note that if this galaxy group was at a slightly higher redshift, we would not be able to detect the 0.04$\sigma_L^2$ galaxy that is closest to the quasar LOS, which could even be the DLA host. Given the low redshift of the DLA and even using the deep HST imaging, SFRs and metallicities, it is difficult to understand this complex system and determine the origins of the absorbing gas. We emphasize that we should take caution in concluding the origins of absorbing gas drawn from studies of individual DLAs at higher redshifts.

ACKNOWLEDGMENTS

We thank Frank Briggs for his useful comments and for carefully reading this paper. We thank Greg Wirth for his help and advice with ESI/Keck. MTM thanks the Australian Research Council for a QEII Research Fellowship (DP0877998). CWC was supported by the National Science Foundation under grant number AST-0708210. This work is based on observations obtained with the APO 3.5-m telescope, which is owned and operated by the Astrophysical Research Consortium. Observations were also made with the NASA/ESA HST or obtained from the data archive at the Space Telescope Institute. Other observations were made with the ESO VLT at the Paranal Observatories. Based on observations made with the NASA/ESA HST and obtained from the data archive at the Space Telescope Science Institute (STScI/NASA), the Space Telescope European Coordinating Facility (ST-ECF/ESA) and the Canadian Astronomy Data Centre (CADC/NRC/CSA). Some of the data presented herein were obtained at the W. M. Keck Observatory, which is operated as a scientific partnership among the California Institute of Technology, the University of California and the National Aeronautics and Space Administration. The Observatory was made possible by the generous financial support of the W. M. Keck Foundation.

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