Lost and Found: The Damped Lyman Alpha Absorbers in the QSO OI 363 [1]

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ABSTRACT

The galaxy giving rise to the damped Lyα absorbing system in the QSO OI 363 with $z = 0.221$ has been found. A galaxy which is probably associated with the second DLA in this same QSO at $z = 0.0912$ has also been found. Neither galaxy is very luminous, and neither galaxy shows signs of extensive current star formation, a massive disk or lots of gas. The impact parameters for each of the two galaxies with respect to the QSO are reasonable. If most DLA absorbers arise in such low luminosity galaxies, it will be difficult to pick out the correct galaxy giving rise to DLA systems at high redshift within the large projected areal density on the sky of faint galaxies around distant QSOs.

Subject headings: quasars: absorption lines; quasars: individual (OI 363); galaxies: halos

1. Introduction

A long series of investigations reviewd by Weymann, Carswell & Smith (1981) (see Bergeron & Boissé 1991, Steidel *et al.* 1997, Churchill *et al.* 1999 for a current update) has established that when the HI column density is sufficiently large ($N(HI) > 10^{15}$ atoms cm^{-2}), Lyα absorption seen in the spectra of QSOs is often accompanied by absorption in the CIV doublet at 1550Å. At somewhat higher column densities ($N(HI) > 10^{17}$ atoms cm^{-2}), C II, Si II, Al II, Fe II, and Mg II are often detected. Furthermore, the origin of the low-ionization absorbing gas can usually be identified as a luminous galaxy whose redshift matches that of the absorbing gas and which has an impact parameter of $\lesssim 150h^{-1}$ kpc with respect to the QSO. Chen *et al.* (1998) present recent results on identifying the galaxies that give rise to the lower column density Lyα forest absorption. Such studies are a key way of probing gas in the outer regions of galaxies.

The damped Lyα absorbers (DLAs) are those rare cases with the highest HI column densities, $N(HI) > 10^{20}$ atoms cm^{-2}. It is thus somewhat puzzling that one of the nearest DLAs, the system with $z = 0.0912$ seen in the spectrum of the QSO OI 363, remains unidentified. This DLA was discovered by Rao & Turnshek (1998) (henceforth RT) during a large survey program to scrutinize HST spectra of QSOs taken in the UV described in Rao & Turnshek (2000). However, they were unable to identify the galaxy producing the absorption. By chance there is a second DLA in the spectrum of this QSO, at $z = 0.2212$, and they were also unable to establish the origin of this DLA. The HI from these two systems has been detected in absorption at 21 cm by Lane *et al.* (1998) and by Chengalar & Kanekar (1999).

Rao & Turnshek (1998) present a deep image of the field of this QSO, and obtained a spectrum of the brightest galaxy within 30 arcsec of the QSO (galaxy G11, using their identifications - see figure 4 of their paper), which shows pronounced spiral arms. Galaxy G11 turned out to be a foreground object at $z = 0.06$ not associated with either of the DLA systems. The most likely remaining candidate for the DLA, identified in the deep imaging survey of Le Brun *et al.* (1993), was too faint for them to obtain a spectrum. They state that with the elimination of G11, there is no candidate galaxy bright enough to produce these two DLA systems, and that this indicates an inconsistency with the standard model developed by Prochaska & Wolfe (1998) for DLAs arising in large HI disks of galaxies.

2. New Spectroscopy in this Field

I have obtained spectra of the two next brightest candidates within 30 arcsec of the QSO with the hope of identifying the absorbing galaxy in each of the two low-z DLA systems seen in the QSO OI 363. The properties of the four brightest galaxies near this QSO are listed in Table 1. A more complete census of the galaxies near OI 363 can be found in RT.

I have established that the $z = 0.2212$ DLA system originates in galaxy G1 which is only 6 arcsec from the QSO. This is the galaxy suggested as the possible DLA host by Le Brun *et al.* (1993). The measured redshift of this galaxy from a 1500 sec exposure taken on March 6, 2000 with the Low Resolution Imaging Spectrograph (Oke *et al.* 1995) at the Keck Observatory using a 1.5 arcsec slit with a 300 g/mm grating (spectral resolution 15Å) is $z = 0.221$. The luminosity of G1 is $M_R = -19.3$ (1/7 L^*_R). [1]. The impact parameter with respect to the QSO is $13h^{-1}$ kpc.

The spectrum of G1 is shown in Figure 1. Absorption in the H+K doublet of CaII is strong, and a pronounced 4000Å break is seen, as well as the G band of CH and the ultraviolet CN band. No emission lines were detected, with an upper limit to the equivalent width for the 5007 Å [OIII] line of 5 Å, and that for Hα of 10 Å. The SNR in the continuum per spectral resolution element is 45 at about 4885 Å (rest frame 3990 Å) and ~37 at rest frame 3790Å, i.e. just above and below the H+K doublet.

The origin of the absorption for the $z = 0.0912$ DLA system is still unclear. Galaxy G10 is probably associated with this gas in some way, but is not directly the source. This galaxy, which RT describe as an "early type galaxy", is 28 arcsec from the QSO. The color of G10 is somewhat bluer in $B - R$ than that of G11 (Monet *et al.* 1999). The redshift of G10 is $z = 0.106$. With this redshift, G10 has an impact parameter of $\sim 35h^{-1}$ kpc and a luminosity of $M_R = -18.2$ (1/14

[1]We adopt $H_0 = 70$ km s^{-1} Mpc^{-1} and $\Omega_M = 0.3$

L_R^*). Its spectrum (a 1000 sec exposure with the same instrumental configuration as for G1) is also shown in Figure 1. It appears similar to that of G1, but the 3968 Å line is stronger relative to that at 3933Å than in galaxy G1. The G band of CH appears to be present in the spectrum of G10. The [OII] emission line at 3727Å is beyond the blue end of the spectrum; the range is 4200 to 8900 Å. The SNR here in the continuum per spectral resolution element is between 35 and 40 at wavelengths just below and just above the H+K doublet of CaII. There is a possible detection of Hα with an equivalent width of $\sim$3 Å. The velocity difference between G10 and the DLA itself is uncomfortably large ($\sim$4000 km s^{-1}) and G10 itself cannot be the origin of the DLA absorption.

Thus the three brightest galaxies within 30 arcsec of the QSO, G1, G10 and G11, have now been observed spectroscopically, and none appear to be the source for this DLA gas. The next brightest galaxy, assuming that no mistake was made by RT in separating stars from galaxies, within this area is more than a magnitude fainter than G1, which is the faintest of the three already observed spectroscopically. (The field is at a rather low galactic latitutde ($b^{II} = 23.6°$), so there are many stars in this magnitude range as well.)

Perhaps G10 is a member of a cluster, and one of the other galaxies in that group is the actual host for the absorbing gas. Hopefully planned future observations of some of the fainter galaxies nearer the QSO than G10 will reveal the culprit for this DLA shortly, but the upper limit on its luminosity is now constrained to be (1/30 L_R^*).

3. Discussion

As emphasized by Steidel, Dickinson & Persson (1994), all normal field galaxies can give rise to QSO absorption lines, albeit generally of lower total column density than those characteristic of DLAs. Steidel *et al.* (1997) find that in the regime $z \sim 0.5$ any galaxy over a wide range of morphological types, from late spirals to S0s, with $L > L^*/10$ can produce MgII absorption and an associated Lyα forest line. The HI column densities required for a DLA system are, however, several orders of magnitude higher.

Identifications are available for a few other low-z DLAs. Lanzetta *et al.* (1997) have established that the galaxy responsible for the $z = 0.1638$ absorption in the spectrum of QSO 0850+4400 is a moderate luminosity ($L_B^*/2.3$) S0 galaxy. However, the HI column density for this system ($\log N(HI) = 19.81$) is just below the cutoff normally adopted for DLAs. The closest known DLA, studied by Miller, Knezak & Bregman (1999), arises in the outer part of NGC 4203, with Ton 1480 as the background QSO. NGC 4203 is an isolated E3 galaxy (de Vaucouleurs, de Vaucouleurs & Corwin 1976) with $M_B \approx -19.2$, which corresponds roughly to $1/3L_B^*$.

Even though the sample is small, it is clear that gas rich galaxies with extensive current star formation and with luminosities $L > L^*/3$ are not the dominant origins of the low-z DLA systems. Galaxies of moderate luminosity and without obvious signs of high gas content from their optical morphology or spectra appear to give rise to DLA systems when there is a background QSO at a suitable impact parameter.

A possible origin for DLA gas is low luminosity, gas rich dwarf galaxies such as the Local Group member NGC 6822, which has a large HI halo with a mass of about 1.5×10^8 $M_\odot$ in HI (Roberts 1972) in spite of its low luminosity of $M_V \sim -16.0$. However, the admittedly small sample of known low-z DLA galaxies are not gas rich dwarfs.

At intermediate redshift, many DLA candidates are identified from HST imaging surveys, with few spectroscopic confirmations. Le Brun *et al.* (1997) and Steidel *et al.* (1995) suggest that the most probable DLA candidates are galaxies of moderate luminosity. The latter group finds that the probable identification for the DLA with $z = 0.8596$ along the line of sight to PKS 0454+0356 has $M_B = -18.7$, corresponding to $L^*_B/4$, ignoring any evolution in luminosity of L^*_B with redshift.

At high redshift, the suggestion that DLAs arise in dwarf galaxies has been made by York *et al.* (1986), and more recently by Matteucci, Molaro & Vladilo (1997), while Jimenez, Bowen & Matteuci (1999) have suggested low surface brightness galaxies as the culprits. On the other hand, McDonald & Miralda-Escude (1999) and Haehnelt, Steinmetz & Rauch (1998) view the DLAs at high redshift as resulting from the formation of protogalaxies and ascribe the velocity widths to turbulence, rather than ordered motions in normal rotating galactic disks. Ground baesd long slit spectroscopy at rest-frame Hα and HST imaging (Bunker *et al.* 1999 and Kulkarni *et al.* 2000, respectively) demonstrate that suspected DLA absorbers at high redshift appear to have small sizes and low star formation rates.

Thus the model of Prochaska & Wolfe (1998) of massive rotating disks does not correspond to the observed properties of most of the galaxies that give rise to DLA systems at low redshift, and this may also hold true at high redshift.

The fact that the identifications for low-z DLA systems seem to be low luminosity galaxies which are not starbursts or other very gas rich systems is rather unexpected. It implies that searches for the galaxies producing DLA systems at high redshift will be quite difficult, as unveiling the right galaxy from the projection through a long line of sight of the galaxy luminosity function will not be easy. Furthermore, since the majority of field galaxies occur in groups out to at least $z \sim 1.1$ (Cohen *et al.* 2000), one may misidentify the distant DLA gas with a galaxy which is in fact not the true source of the gas, but some brighter member of the same group or cluster.

Perhaps the selection effects attributed to dust discussed by Ostriker & Heisler (1984) and applied to DLA systems in particular by Fall & Pei (1993) and most recently by Boissé *et al.* (1998) are responsible. They suggest that the higher mean extinction within massive galaxies with high dust content and high metallicity act to limit our ability to detect the background QSOs. Since dust absorption is higher in the UV, another consequence of dust would be a limitation in our ability to obtain UV spectra of the background QSOs to identify the absorption line systems, an effect dependent on z(QSO) – z(DLA). Such a selection effect would skew the probability that a galaxy produces a detectable DLA system away from one based only on the galaxy's gas column density and impact parameter to the QSO. Another consequence of dust might be to bias calculations based on QSO absorption features of the contribution of the neutral gas to the cosmological mass density. If the next few identifications of low-z DLA systems continue to be low luminosity galaxies, these selection effects due to dust may be playing an important role.

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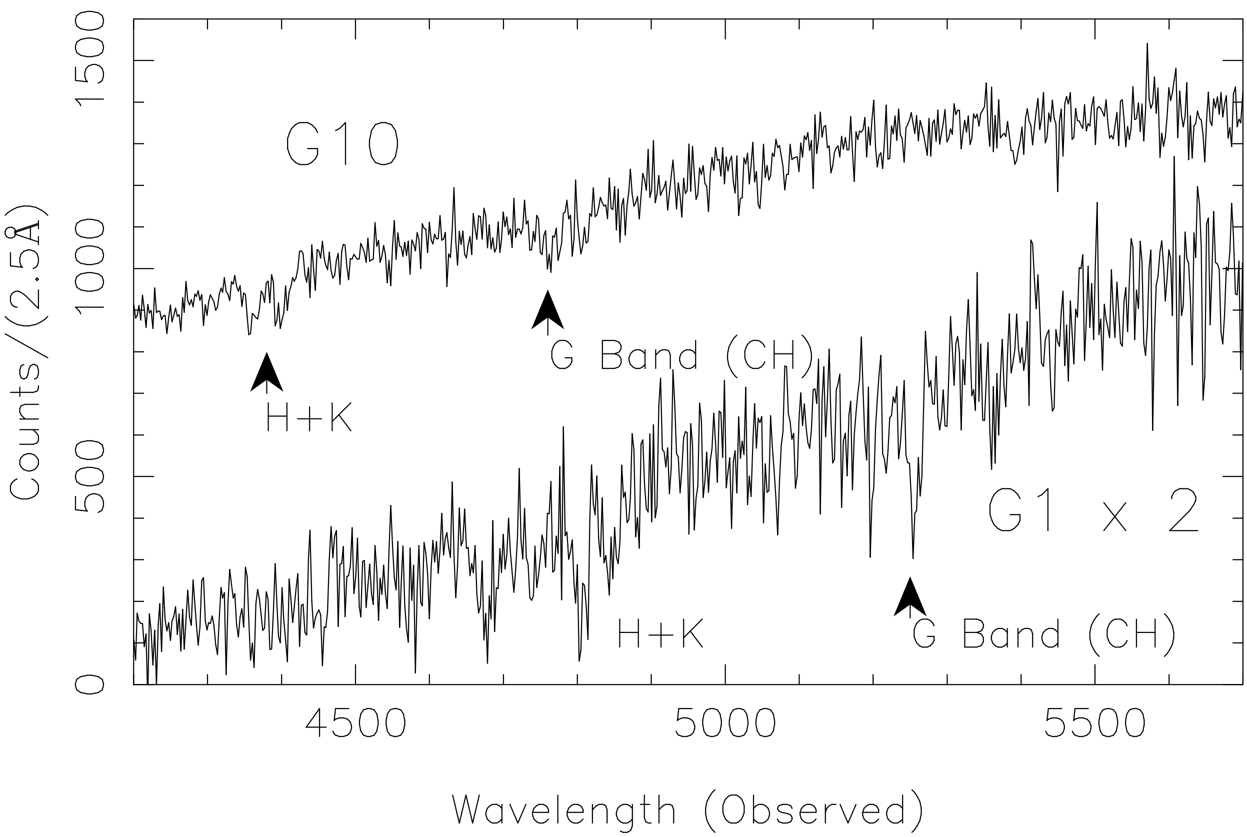

Fig. 1.— The LRIS spectra of galaxies G1 and G10 near the QSO OI 363 are shown. The vertical axis is counts/pixel, with 2 detected electrons producing 1 count. The spectrum of galaxy G1 has been multipled by a factor of 2.0 and there is a vertical offset of 800 counts between the two spectra.

Table 1. Properties of the Four Brightest Galaxies Near the QSO OI 363

ID	R^{a} (mag)	z	M_R (mag)	$\Delta(\theta)^{a}$ (arcsec)
G11	17.1	0.06[a]	−20.3	31
G10	19.8	0.106	−18.9	28
G1	20.8	0.221	−19.6	6
G6	22.0	...	...	16

[a]From Rao & Tunshek (1998)