METALLICITIES, DUST, AND MOLECULAR CONTENT OF A QSO-DAMPED Lyα SYSTEM REACHING log \( N(\text{H}i) = 22 \): AN ANALOG TO GRB-DLAs

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Received 2011 December 2; accepted 2012 April 13; published 2012 May 14

ABSTRACT

We present the elemental abundance and H\(_2\) content measurements of a damped Ly\(\alpha\) (DLA) system with an extremely large H\(_i\) column density, log \( N(\text{H}i) \) (cm\(^{-2}\)) = 22.0 ± 0.10, at \( z_{\text{abs}} = 3.287 \) toward the QSO SDSS J081634+144612. We measure column densities of H\(_2\), C\(\alpha\), C\(\beta\), Zn\(\text{ii}\), Fe\(\text{ii}\), Cr\(\text{ii}\), Ni\(\text{ii}\), and Si\(\text{ii}\) from a high signal-to-noise and high spectral resolution VLT-UVES spectrum. The overall metallicity of the system is [Zn/H] = −1.10 ± 0.10 relative to solar. Two molecular hydrogen absorption components are seen at \( z = 3.28667 \) and 3.28742 (a velocity separation of \( \approx 52 \) km s\(^{-1}\)) in rotational levels up to \( J = 3 \). We derive a total H\(_2\) column density of log \( N(\text{H}_2) \) (cm\(^{-2}\)) = 18.66 and a mean molecular fraction of \( f = 2N(\text{H}_2)/[2N(\text{H}_2)+N(\text{H}i)] \) = 10\(^{-3.04 ±0.37}\), typical of known H\(_2\)-bearing DLA systems. From the observed abundance ratios we conclude that dust is present in the interstellar medium of this galaxy, with an enhanced abundance in the H\(_2\)-bearing clouds. However, the total amount of dust along the line of sight is not large and does not produce any significant reddening of the background QSO. The physical conditions in the H\(_2\)-bearing clouds are constrained directly from the column densities of H\(_2\) in different rotational levels, C\(_i\) and C\(_i^\beta\). The kinetic temperature is found to be \( T \approx 75 \) K and the particle density lies in the range \( n_p = 50–80 \) cm\(^{-3}\). The neutral hydrogen column density of this DLA is similar to the mean H\(_i\) column density of DLAs observed at the redshift of \( \gamma\)-ray bursts (GRBs). We explore the relationship between GRB-DLAs and the high column density end of QSO-DLAs finding that the properties (metallicity and depletion) of DLAs with log \( N(\text{H}i) > 21.5 \) in the two populations do not appear to be significantly different.

Key words: ISM: molecules – quasars: absorption lines – quasars: general

Online-only material: color figures

1. INTRODUCTION

Despite accounting for only a small fraction of all the baryons in the universe (see, e.g., Petitjean et al. 1993), the physical state of the neutral and molecular phases of the interstellar medium (ISM) is a crucial ingredient of galaxy formation. These gaseous phases are at any redshift the reservoir of gas available for star formation. At high redshift, most of the neutral hydrogen mass is revealed by the damped Ly\(\alpha\) (DLA) absorption system detected in the spectra of background quasars (see, e.g., Wolfe et al. 2005 for a review). Since DLAs are easy to identify in the universe (see, e.g., Petitjean et al. 2005 for a review), the physical state of the neutral and molecular phases of the interstellar medium (ISM) is a crucial ingredient of galaxy formation. These gaseous phases are at any redshift the reservoir of gas available for star formation. At high redshift, most of the neutral hydrogen mass is revealed by the damped Ly\(\alpha\) (DLA) absorption system detected in the spectra of background quasars (see, e.g., Wolfe et al. 2005 for a review).

Key results of DLAs surveys indicate that the fraction of all the baryons in the universe (see, e.g., Petitjean et al. 1993), the physical state of the neutral and molecular phases of the interstellar medium (ISM) is a crucial ingredient of galaxy formation. These gaseous phases are at any redshift the reservoir of gas available for star formation. At high redshift, most of the neutral hydrogen mass is revealed by the damped Ly\(\alpha\) (DLA) absorption system detected in the spectra of background quasars (see, e.g., Wolfe et al. 2005 for a review).

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We observed quasar SDSS J081634+144612 twice, in 2008 September and 2009 April, with the high-resolution
Ultraviolet and Visual Echelle Spectrograph (UVES; Ballester et al. 2000) mounted on the ESO Kueyen VLT-UT2 8.2 m telescope at Cerro Paranal, Chile. Observations have been performed under programs 081.A-0334(A), PI: S. López in visitor mode, and 282.A-5030(A), PI: P. Noterdaeme in service mode. Ten exposures were taken for a total of 12.4 hr exposure time: nine exposures using Dichroic 2 with a setting 437+760 nm plus one 5400 s exposure with the red arm centered at 550 nm that covers the Lyα absorption. A slit width of 1′′ and 2 × 2 pixel binning was used, resulting in a spectral resolution of 50,000.

The quasar spectrum was reduced using the UVES pipeline (see, e.g., Ledoux et al. 2003 for details). The main characteristics of the pipelines are to perform a precise inter-order background subtraction, especially for master flat fields, and to allow for an optimal extraction of the object signal rejecting cosmic rays and performing sky subtraction at the same time. The pipeline products were checked step by step. The wavelength scale of each reduced spectrum was then converted to vacuum-heliocentric values and the spectra rebinned to a constant wavelength step. No further rebinning was performed during the analysis of the whole spectrum. Individual one-dimensional exposures were scaled, weighted, and combined together.

In order to derive the physical parameters of the absorption features, we fit the metal absorption profiles with multiple Voigt profiles using VPFIT (Carswell et al. 1987). The continuum level was obtained locally in the vicinity of each metal absorption feature. Molecular hydrogen features were fitted altogether using fit/Lyman and after normalizing the corresponding region of the Lyα forest. Atomic data for metal species and H2 are, respectively, from Morton (2003) and Bailly et al. (2010). In the following, solar abundances are taken from Lodders (2003).

The origin of the velocity scale (v = 0 km s−1) is set at the redshift of the single C1 component, z = 3.28746.

### 3. ABUNDANCES

#### 3.1. H1 and Metal Content

The neutral hydrogen column density was measured from the fit of the damping wings of the Lyα absorption at z = 3.287. We find log N(HI) (cm−2) = 22.0 ± 0.10. The observed DLA absorption together with the best-fitted Voigt profile is shown in Figure 1. The dashed lines indicate the profiles corresponding to log N(HI) = 21.9 and 22.1.

We detect absorption lines of C1, C*1, Zn ii, Fe ii, Cr ii, Ni ii, and Si ii, spread over about 150 km s−1. As can be seen in Figure 2, the absorption profiles are not strongly saturated except perhaps for Si iiλ1808. We are therefore confident that our column density determinations are robust. The fits to the absorption lines are overplotted in the figure as red solid lines. The singly ionized species are expected to be the dominant contributors to the abundances of the corresponding elements in H1 clouds with such high column densities.

Voigt profile fitting is performed simultaneously for all the absorption lines keeping the same number of components having the same redshifts and Doppler parameters for all singly ionized species. Note that Zn iiλ2026 is blended with Mg iλ2026. The contributions of the latter are taken into account in the fits and found to have negligible influence on the derived N(Zn ii).

Eight velocity components are necessary to model the profiles (see Figure 2). We report in Table 1 the results of the fits, column density, and Doppler parameter, for each of the components. Because of saturation effects, the Si ii column density should be considered a lower limit. However, given the shape of the

| z   | v  | b  | C1   | C*1 | C1* | Si ii | Cr ii | Ni ii | Zn ii | Fe ii |
|-----|----|----|------|-----|-----|-------|-------|-------|-------|-------|
| 3.28681 | 68 | 8.1 ± 0.2 | 15.73 ± 0.03 | 13.43 ± 0.02 | 13.87 ± 0.01 | 13.04 ± 0.02 | 15.09 ± 0.04 | |
| 3.28674 | 50 | 8.2 ± 0.3 | 15.99 ± 0.04 | 13.71 ± 0.02 | 14.15 ± 0.01 | 13.12 ± 0.02 | 15.48 ± 0.03 | |
| 3.286998 | 32 | 7.4 ± 1.7 | 14.90 ± 0.10 | 12.68 ± 0.11 | 13.18 ± 0.10 | 12.19 ± 0.10 | 14.79 ± 0.04 | |
| 3.287260 | 14 | 8.7 ± 1.0 | 14.99 ± 0.05 | 12.83 ± 0.06 | 13.44 ± 0.04 | 12.40 ± 0.05 | 14.85 ± 0.04 | |
| 3.287456 | 0 | 7.2 ± 0.2 | 13.43 ± 0.01 | 13.24 ± 0.02 | 12.47 ± 0.07 | 14.90 ± 0.04 | 13.63 ± 0.08 | 13.33 ± 0.03 | 12.40 ± 0.07 | 14.57 ± 0.06 | |
| 3.288098 | 45 | 20.6 ± 0.8 | 15.29 ± 0.04 | 13.23 ± 0.05 | 13.73 ± 0.03 | 12.45 ± 0.06 | 14.91 ± 0.07 | |
| 3.288169 | 50 | 4.4 ± 0.6 | 14.89 ± 0.07 | 12.69 ± 0.09 | 13.23 ± 0.05 | 11.73 ± 0.16 | 14.41 ± 0.13 | |
| 3.288345 | 62 | 6.1 ± 3.7 | 14.30 ± 0.25 | 12.30 ± 0.48 | 11.34 ± 0.38 | 14.82 ± 0.05 | |

| Total | 13.43 ± 0.01 | 13.24 ± 0.02 | 12.47 ± 0.07 | 16.31 ± 0.01 | 14.07 ± 0.02 | 14.54 ± 0.01 | 13.53 ± 0.01 | 15.89 ± 0.02 |

Figure 1. H1 Lyα profile of the DLA at z = 3.286 toward QSO SDSS J081634+144612. The overplotted solid line and accompanying dashed lines correspond to the best-fit solution log N(HI) = 22.0 ± 0.10. The origin of the velocity scale is taken at z = 3.287.

(A color version of this figure is available in the online journal.)

Table 1

Results of Voigt Profile Fitting Analysis

| z   | v  | b  | C1   | C*1 | C1* | Si ii | Cr ii | Ni ii | Zn ii | Fe ii |
|-----|----|----|------|-----|-----|-------|-------|-------|-------|-------|
| 3.28681 | 68 | 8.1 ± 0.2 | 15.73 ± 0.03 | 13.43 ± 0.02 | 13.87 ± 0.01 | 13.04 ± 0.02 | 15.09 ± 0.04 | |
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absorption, we are confident that the true value cannot be much larger. The column density of singly ionized iron, despite their blending, could be reliably measured.

Although the profile decomposition may not be unique, three distinct clumps can be identified (clumps 1, 2, and 3 from blue to red) at mean redshifts of 3.28661, 3.28735, and 3.28814, and made of, respectively, 3, 2, and 3 components. H₂ absorption is detected in clump 1, which is the strongest clump in metal species, but most of the H₂ is found associated with the C1 component in clump 2. Unfortunately, we cannot determine N(HI) in each clump. The mean metallicity⁷ in the cloud, derived by adding the column densities of the eight components are [Zn/H] = −1.10 ± 0.10, [Si/H] ≥ −1.23 ± 0.10, [Cr/H] = −1.58 ± 0.10, [Ni/H] = −1.68 ± 0.10, and [Fe/H] = −1.58 ± 0.10.

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⁷ Metallicities are given relative to solar: [X/H] = log(N_X/N_H)/DLA − log(X/H)_⊙.
3.2. Dust

In the ISM of the Galaxy, zinc is virtually undepleted onto dust grains when Si, Cr, and Ni are. We find in the present DLA mean relative abundances: [Si/Zn] = −0.13 ± 0.03, [Cr/Zn] = −0.48 ± 0.02, [Ni/Zn] = −0.58 ± 0.02, and [Fe/Zn] = −0.48 ± 0.02 indicating that the overall depletion of Si, Cr, Ni, and Fe is similar to what is seen in the gas from the halo of our Galaxy (Welty et al. 1999). This is also typical of DLAs where H$_2$ is detected (Noterdaeme et al. 2008). From Figure 3, which presents the depletion patterns relative to zinc observed component by component, it is clear, however, that the depletion is enhanced in the main H$_2$-bearing component. This situation is similar to that of the H$_2$-bearing component toward Q 0013−004 (Petitjean et al. 2002), where higher depletion factors are seen in the H$_2$ components.

From the flux-calibrated SDSS spectrum, it is also possible to estimate the reddening induced by the presence of dust in the DLA to the background QSO light, following the method described in Noterdaeme et al. (2009). In Figure 4, we show that the SDSS spectrum of J081634+144612 is well matched with the SDSS composite spectrum from Vanden Berk et al. (2001), shifted to the same emission redshift and reddened using a Small Magellanic Cloud (SMC) extinction law (Gordon et al. 2003) at $z = 3.286$ with $E(B−V) = 0.05 ± 0.06$. The associated uncertainty is obtained from the dispersion measured for a control sample of 163 SDSS QSOs from Schneider et al. (2010) with emission redshift within ±0.02 to that of J081634+144612. This means that there is no significant reddening of the quasar J081634+144612. Overall, the measured extinction-to-dust ratio, $A_{
u}/N$(H$1$) < 5 × 10$^{-23}$ cm$^2$ (2σ), is typical of that of the general DLA population (Vladilo et al. 2008). This, together with the presence of H$_2$ in a component with higher depletion factor, suggests that appreciable fraction of H$1$ may be associated with components that do not have H$_2$.

3.3. H$_2$ Content

Molecular hydrogen is detected in two distinct sub-systems at $z_{abs} = 3.28667$ and 3.28742, separated by ~52 km s$^{-1}$ with absorption lines from rotational levels up to $J = 3$ (see Figure 5). The results of the fits to the numerous absorption lines are given in Table 2. The $z_{abs} = 3.28742$ component alone contains about 90% of the total H$_2$ column density in the absorber, log $N$(H$_2$) = 18.62, and coincides with the C$1$ component. This is expected because the energy of the photons that ionize C$1$ is close to that of photons that dissociate H$_2$. The total H$_2$ column density
integrated over the two components and all rotational levels is \( \log N(\text{H}_2) = 18.66 \pm 0.27 \text{ (cm}^{-2}\text{)} \) corresponding to a molecular fraction of \( \log f = \log 2 \times N(\text{H}_2)/(2 \times N(\text{H}_2) + N(\text{H}1)) = -3.04 \pm 0.37 \) if we assume that the totality of neutral hydrogen is associated with the H\(_2\) components. This value is among the lowest observed in H\(_2\) bearing DLAs with metallicities \([\text{Zn}/\text{H}] > -1.3\) (Petitjean et al. 2006; Noterdaeme et al. 2008). This again may indicate that appreciable fraction of H\(_1\) may be associated with components that do not have H\(_2\) (see also Noterdaeme et al. 2010; Srianand et al. 2010, 2012).

4. PHYSICAL STATE OF THE GAS

4.1. Excitation of H\(_2\)

From the detection of H\(_2\) in different rotational levels (\( J = 0 \) to \( J = 3 \), see Table 2), it is possible to put constraints on the physical state of the gas. The excitation temperature \( T_{0J} \) between rotational levels 0 and \( J \) is defined as

\[
\frac{N(J)}{N(0)} = \frac{g(J)}{g(0)} e^{-E(0J)/kT_{0J}},
\]

where \( g(J) \) is the statistical weight of the rotational level \( J \); \( g(J) = (2J + 1)(2I + 1) \) with nuclear spin \( I = 0 \) for even \( J \) (para-H\(_2\)) and \( I = 1 \) for odd \( J \) (ortho-H\(_2\)), \( k \) is the Boltzmann constant, and \( E(0J) \) is the energy difference between level \( J \) and the ground state (\( J = 0 \)). If the excitation processes are dominated by collisions, then the populations of the rotational levels follow a Boltzmann distribution described by a unique excitation temperature for all rotational levels. This is generally the case for low rotational levels which have a de-excitation timescale larger than the collision timescale. Indeed, \( T_{0J} \) is a
good indicator of the kinetic temperature (Roy et al. 2006; Le Petit et al. 2006) especially in clouds similar to the one we study here (log N(H2) > 18). However, because of the small energy difference between the J = 0 and J = 1 levels, the value of T(J) is very sensitive to uncertainties on N(H2, J = 0) and N(H2, J = 1) and the use of higher rotational levels may help derive a better constraint on T(J). From Figure 6, it can be seen that the population of J = 0 to J = 2 levels can be described by a unique excitation temperature T(ex) = 69±8 K and T(ex) = 79±14 K for the first and second components, respectively.

These temperatures are slightly smaller than what was found in previous studies of H2-bearing DLAs (e.g., Ledoux et al. 2003, T ~ 90 to 180 K; Srianand et al. 2005, T ~ 153 ± 78 K), but similar to what is measured in the ISM of our Galaxy (77 ± 17 K; Rachford et al. 2002) and in the Magellanic Clouds (82 ± 21 K; Tumlinson et al. 2002), where H2 column densities are also large. Note that temperatures observed through high latitude Galactic sight lines are also larger (124 ± 5 K; Gillmon et al. 2006 or ranging from 81 K at log N(H2) = 20 to 219 K at log N(H2) = 14; Wakker 2006).

The population of J = 3 rotational level is in turn enhanced compared to the Boltzmann distribution, which indicates the presence of additional excitation processes such as UV pumping (e.g., Noterdaeme et al. 2007a) and/or turbulent dissipation (as possibly indicated by the larger b-values for higher-J levels seen by Noterdaeme et al. 2007b).

### 4.2. Density

Absorption lines produced by neutral carbon are seen only in one component at z(abs) = 3.28746 (see Figure 2) and are associated with the strongest H2 component.

We used the relative populations of the two first sub-levels of the C i ground state to derive the excitation temperature of the C i fine-structure level, according to the Boltzmann equation (see Equation (1)). We have adopted the energy difference between the C i excited (C i*: 2S^22P^0 3P1) and true ground-state (2S^22P^0 3P0) levels, ∆E(C i) = 23.6 K. The population ratio N(J = 1)/N(J = 0) of the C i fine-structure level corresponds to an excitation temperature of T(ex) = 15.4 ± 0.1 K. This is higher than the temperature expected in the case the excitation is dominated by the cosmic microwave background radiation (T(CMBR) = 11.7 K at z = 3.287) indicating that excitation by collisions is important. Using the results shown in Figure 12 of Srianand et al. (2005), we derive that the particle density, n(Hi), is in the range 50–80 cm⁻³.

### 5. DISCUSSION

We have presented a detailed analysis of a QSO-DLA system with an extremely large column density, log N(Hi) = 22.0 ± 0.10, at z(abs) = 3.287 toward the quasar SDSS J081634+144612. The velocity structure of associated metal absorption lines indicates the presence of eight components grouped into three sub-systems centered at z = 3.28611, 3.28375, and 3.28814, respectively, spanning ~115 km s⁻¹. C i is detected in the z = 3.28735 sub-system while H2 is detected in both the z = 3.28661 and 3.28735 sub-systems. From the H2 excitation, we derive a kinetic temperature of T(K) ~ 75 K and the observed column density ratio N(C i)*/N(C i) yields a particle density in the range n(Hi) ~ 50–80 cm⁻³. The depletion of metals onto dust grains measured in the strongest H2 component located at z(abs) = 3.28735 is similar to what is observed in the disk of the Galaxy. All this shows that this system, apart from having unusually large N(Hi), has properties consistent with that of a typical H2-bearing DLA (see Ledoux et al. 2003; Noterdaeme et al. 2008).

While log N(Hi) ≥ 22 DLAs are very rarely seen in front of QSOs, several have already been detected in the optical afterglow spectrum and at the redshift of long-duration GRBs. Two of them (toward GRB 050401, GRB 080607, and GRB 060926) even have log N(Hi) > 22.5 (Watson et al. 2006; Prochaska et al. 2009; Jakobsson et al. 2006). It is not surprising to observe a strong DLA at the redshifts of GRBs since these objects are expected to be associated with star-forming regions where the gas is likely to be found in large

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**Table 2** Molecular Hydrogen Column Densities and Excitation Temperatures

| z(abs)  | v(abs) (km s\(^{-1}\)) | J  | log N(H2,J) (cm\(^{-3}\)) | b  | T(ex) (K) |
|--------|------------------------|----|--------------------------|----|-----------|
| 3.28667 | 55.0                   | 0  | 16.59 ± 0.50             | 5  | 2.5 2    |
| 1       | 17.55 ± 0.30           | 2  | 14.71 ± 0.20             |
| 2       | 15.13 ± 0.10           | 3  | 6.5 ± 0.4               |
| 3.28742 | 2.5                    | 0  | 18.19 ± 0.35             | 1  | 2.5 2    |
| 1       | 18.4 ± 0.20            | 2  | 16.2 ± 0.25              |
| 2       | 15.75 ± 0.10           | 3  | 6.5 ± 0.4               |

Notes.

a With respect to C1.

b Total log N(H2) = 17.60.

c Total log N(H2) = 18.62.

d The errors on the H2 column densities correspond to the best fits using the range of b-values.

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**Figure 6.** H2 excitation diagram for the two components observed toward SDSS J081634+144612. Triangles correspond to z(abs) = 3.28667 and squares to z(abs) = 3.28742. The column density N(H2) divided by the statistical weight, g, is plotted for the J = 0 up to J = 3 H2 rotational levels on a logarithmic scale against the excitation energy, E(abs), in K. The J = 0 to J = 2 points have been fitted with straight lines using Equation (1) giving the excitation temperatures T(ex) indicated in Table 2.
quantities. Although QSO-DLAs are located close to regions where stars form as indicated by the presence of metals, the detection of C\textsuperscript{ii} absorption, and galaxy-like kinematics (Wolfe et al. 2003), their exact nature is not completely elucidated. Some should be associated with the ISM of galaxies especially when molecules are detected (Noterdaeme et al. 2008), whereas others are probably located in the outskirts of galactic halos (Möller et al. 2002; Möller et al. 2004; Fox et al. 2007; Pontzen et al. 2008; Rauch et al. 2008; Rahmani et al. 2010; Fynbo et al. 2010, 2011).

The difference between the populations of GRB-DLAs and QSO-DLAs is apparent because (1) the mean H\textsc{i} column density is higher in GRBs than in DLAs easily reaching well beyond 10\textsuperscript{21} cm\textsuperscript{-2} in the former case (see, e.g., Jakobsson et al. 2006; Fynbo et al. 2009) while QSO-DLA with log N(H\textsc{i}) \geq 22 are very rare (Noterdaeme et al. 2009) and (2) the mean metallicity is larger for GRB-DLAs (Savaglio 2006; Fynbo et al. 2006, 2008; Prochaska et al. 2007) about 0.1 solar at z > 2 (to be compared to \sim 0.03 solar for intervening DLAs). Note that molecules (H\textsubscript{2}, CO) have been detected in a number of QSO-DLAs (Noterdaeme et al. 2008, 2011; Srianand et al. 2008), whereas they are rarely seen in GRB-DLAs (Ledoux et al. 2009). This may be a consequence of few statistics, however, (see Fynbo et al. 2006; Prochaska et al. 2009) and possibly of inadequate data as high spectral resolution in the blue is usually needed (see Ledoux et al. 2009).

If these differences exist when comparing the overall populations, they may not be that apparent if we restrict ourselves to high H\textsc{i} column density systems. This is why it is interesting to compare the properties of SDSS J081634+144612 with those of GRB-DLAs. In Figure 7, we plot the logarithm of the H\textsc{i} column density versus metallicity for QSO-DLAs where H\textsubscript{2} is not detected (open circles), QSO-DLAs where H\textsubscript{2} is detected (filled circles), and the same for GRB-DLAs (squares) and SDSS J081634+144612 (filled diamond). It can be seen that there is a lack of systems with both a high metallicity and a high column density. This is well known for QSO-DLAs and could be a consequence of these DLAs being missed because of the high-induced attenuation which makes the QSO drop out of the sample (e.g., Boissé et al. 1998). Although GRB afterglows are for a little while much brighter than quasars, the presence of a dust-bias could also affect their statistics (see, e.g., Fynbo et al. 2009; Ledoux et al. 2009; Greiner et al. 2011). A possibility is that GRB-DLA metallicities could be higher than measured as often only lower limits are derived from intermediate resolution observations (see Prochaska 2006; Petitjean & Vergani 2011). This can, however, probably not explain this lack of systems completely. SDSS J081634+144612 is located at the limit of the region where systems are missing and within the region where GRB-DLAs are located. In Figure 8, the logarithm of the H\textsc{i} column density is plotted for the same systems versus the depletion of iron onto dust grains. We have scaled the depletion of chromium in SDSS J081634+144612. It can be seen here again that the DLA toward SDSS J081634+144612 is well within the region where GRB-DLAs are located. Therefore, our study indicates that extremely large H\textsc{i} column density DLAs found toward QSOs have properties similar to those of GRB-DLAs.

Following Schaye (2001), Krumholz et al. (2009) proposed a radiation-insensitive model—hence applying to both QSO- and GRB-DLAs—where the lack of high-N(H\textsc{i}), high-metallicity is explained by the conversion from atomic to molecular gas. Here, the physical conditions in the H\textsubscript{2}-bearing cloud indicate that we are still observing diffuse gas. This is not in tension with the above model since dense, cold and molecular gas is expected to have a small cross-section and is not easily intercepted by the line of sight. Interestingly, a fully molecular

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure7.png}
\caption{Logarithm of the total neutral hydrogen column density vs. metallicity. Circles correspond to QSO-DLAs (Noterdaeme et al. 2008), squares to GRB-DLAs (Prochaska et al. 2009), triangles to GRB-DLAs (Ledoux et al. 2009), the inverted triangle to the QSO-DLA toward SDSS J113520+001053 (Noterdaeme et al. 2012), and the diamond indicates our measurement for the QSO-DLA toward SDSS J081634+144612. Filled symbols indicate systems in which H\textsubscript{2} is detected, and the filled square corresponds to the GRBO80607 (Prochaska et al. 2009).}
\end{figure}
cloud has been observed in the case of the log $N$(H\textsc{i}) = 22.7 DLA associated with GRB080607 (Prochaska et al. 2009), which could be observed very quickly (<1 hr) after the burst. Therefore, while the absorption properties of high-$N$(H\textsc{i}) GRB and QSO-DLAs appear to be similar, detecting fully molecular clouds will remain challenging in the case of QSOs, because of the random distribution of the lines of sight and the high-induced extinction.

Very little is known about GRB host galaxies at high redshift ($z > 2$; Savaglio et al. 2009). Cosmological simulations show that GRB-DLAs are predominantly associated with halos of mass $10^{10} < M_{\text{halo}}/M_{\odot} < 10^{12}$, an order of magnitude larger than the galaxies responsible for the bulk of QSO-DLAs (Pontzen et al. 2010; see, however, Barnes & Haehnelt 2010), but what is true for the overall QSO-DLA population does not hold for its high-column-density end. We have shown here that DLAs with the highest H\textsc{i} column densities likely arise in gas located in the inner regions of star-forming galaxies of moderate attenuation. This idea should be investigated with larger samples of both QSO- and GRB-DLAs with high column densities. The BOSS survey (Eisenstein et al. 2011) will soon increase the number of such QSO-DLAs by an order of magnitude.

We thank the anonymous referee for helpful comments and suggestions which improved this paper. P.P.J. and R.S. acknowledge the support of the Indo-French Centre for the Promotion of Advanced Research (Centre Franco-Indien pour la Promotion de la Recherche Avancée) under contract no. 4304-2. S.L. is supported by FONDECYT grant no. 1100214.

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The galaxy responsible for the recently found log $N$(H\textsc{i}) ~ 22 DLA toward J1135+0010 was detected at $b \approx 0.1$ from the background QSO (Noterdaeme et al. 2012). In this particular case, Kulkarni et al. (2012) demonstrated that detecting the Ly\alpha emission is even possible from UVES data. Here, the DLA is covered at the edge of two UVES echelle orders and possibly contaminated by scattered light in the red arm, preventing us from putting any meaningful limit on the Ly\alpha flux—within the slit. Follow-up observations specifically tuned to the search of emission lines are thus desirable (see, e.g., Fynbo et al. 2010, 2011; Péroux et al. 2012).