NITROGEN ABUNDANCES IN DAMPED Lyα GALAXIES

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ABSTRACT

Nitrogen lines of the N I λ1134 and λ1200 multiplets in the damped Lyα (DLA) galaxies at \( z_{\text{abs}} = 2.309, 2.827, \) and \( 3.025 \) toward the QSOs 0100+1300, 1425+6039, and 0347−3819, respectively, have been detected by means of high-resolution spectra (\( R \approx 2 \times 10^5 \)) obtained with 4 m class telescopes at ESO (La Silla, Chile) and the Observatorio del Roque de los Muchachos (La Palma, Spain). The two N I multiplets offer a considerable range in oscillator strengths and the possibility of disentangling Lyα interlopers. The derived nitrogen abundances for the three damped systems are \( [N/H] = -2.68 \pm 0.11, -1.57 \pm 0.09, -2.07 \pm 0.13 \), respectively. The behavior of nitrogen relative to iron-peak and α elements has been investigated by considering all the extant N I determinations for a total of nine DLA galaxies. We have estimated the fraction of iron locked into dust grains to convert the observed \( [N/Fe] \) ratios into overall (dust plus gas) relative abundances, \( [N/Fe]_{\text{corr}} \). The ratios \( [N/\alpha] \) have been mostly determined by using sulphur as a tracer of α elements that is unaffected by dust. The \( [N/Fe] \) and \( [N/\alpha] \) ratios show high dispersions, of 1 order of magnitude or more, which have no equivalent in other element-to-element ratios in DLA. The lowest values of the \( [N/Fe]_{\text{corr}} \), and \( [N/\alpha] \) ratios are at variance with the values measured in Galactic halo stars of similar metallicity, suggesting that part of the DLA galaxies do not follow the chemical evolution of the Milky Way. The DLA nitrogen abundances and their dispersion show some similarities with those observed in dwarf galaxies. Comparison with chemical evolution models shows that the lowest \( [N/Fe]_{\text{corr}} \) and \( [N/\alpha] \) DLA values are close to what would be expected for a pure secondary origin of nitrogen, whereas higher values are mostly consistent with a primary component. The behavior of nitrogen abundance ratios can be ascribed, in general, to the delayed release of nitrogen in the course of evolution. However it is difficult to conciliate this interpretation with the lowest \( [N/\alpha] \) values measured, since an expected enhancement of α elements with respect to the iron-peak elements is not observed simultaneously in these DLA galaxies. In two cases, relatively high \( [N/\alpha] \) values are observed that require also a more complex chemical evolution to be explained.

Subject headings: galaxies: abundances — galaxies: ISM — quasars: absorption lines — ultraviolet: galaxies

1. INTRODUCTION

Damped Lyα (DLA) systems are complexes of neutral gas detectable in the spectra of background quasars as H I absorption lines with large column densities, \( N(H) > 10^{21.5} \) atoms cm\(^{-2} \) (Wolfe et al. 1986). The damped Lyα absorptions are found at all redshifts \( 0.1 < z_{\text{abs}} < 4.5 \) and are associated with metal lines of low ionization and often high ionized species as well.

Although the exact nature of the DLA systems has yet to be clarified, there is consensus on the fact that they are the progenitors of present-day galaxies. Damped galaxies might be massive rotating disks that will evolve to the present-day spiral galaxies (Wolfe et al. 1986, 1995; Prochaska & Wolfe 1997) or less massive objects progenitors of dwarf galaxies (Tyson 1988; Pettini, Boksenberg, & Hunstead 1990; Meyer & York 1992; Steidel et al. 1995). Understanding which interpretation is the more appropriate has important implications for any theory of galaxy formation and evolution. Imaging in the field of the background quasars suggests that more than a single population of galaxies give rise to the DLAs, even though the results are sometimes ambiguous, especially at high redshift (Briggs et al. 1989; Steidel & Hamilton 1992). At \( z \leq 1 \) the candidate associations include gas-rich galaxies with a variety of morphological types (Le Brun et al. 1997; Lanzetta et al. 1997). Very recently Rao & Turnshek (1998) discovered two DLA absorbers at very low redshift (\( z = 0.091, z = 0.221 \)) and by means of imaging observations they exclude the possibility that they are luminous spiral galaxies.

DLA galaxies have low metallicities, typically between 1% and 10% of solar, a signature of the enrichment of the first stellar generations. The precision obtained in abundance studies of DLAs is remarkable and comparable to that attained in the interstellar studies of our own Galaxy, thus offering important clues for understanding the nature of these objects. Element abundance ratios are tracers of galactic chemical evolution (see, e.g., Lauroesch et al. 1996; Matteucci, Molaro, & Vladilo 1997); however, the results obtained for DLA galaxies are subject to some debate. The typical overabundance of α elements compared to iron-peak elements (\( \alpha/Fe \)) found in Galactic metal-poor stars is observed in DLAs by means of the Si/Fe ratios, which is interpreted as a signature of the first stages of chemical evolution of a spiral galaxy like the Milky Way (Wolfe 1995; Lu et al. 1996a). On the other hand, the \( \alpha/Fe \) ratios in DLA are observed close to solar when a dust-free diagnostic such as S/Zn is used (Molaro, Centurión, & Vladilo 1998, hereafter MCV), or when the observed abundances of refractory elements (such as Fe and Si) are corrected by dust depletion (Vladilo 1998).
Nitrogen is an important element when attempting to understand the chemical history of DLA galaxies. The nucleosynthesis of N, which takes place mainly in low- and intermediate-mass stars, is quite complex and can be used to probe conditions typical of early stages of galactic chemical evolution. Although the dominant processes that lead to the enrichment of N are still not fully understood it seems clear that secondary synthesis of N—which occurs in stars of all masses—plays an important role at high metallicities (Vila-Costas & Edmunds 1993). In this case secondary origin of N refers to its production in the CNO cycle from seed C and O nuclei created in an earlier generation of stars. However, at low metallicity levels, nitrogen observations in halo stars (Carbon et al. 1987; Tomkin & Lambert 1984) and in H II regions of dwarf irregular galaxies (Thuan, Izotov, & Lipovetsky 1995; Kobulnicky & Skillman 1996) require a significant primary component in the synthesis of this element. Primary production of N is obtained in intermediate-mass stars when freshly synthesized C in the helium-burning shell penetrates into the hydrogen-burning shell of the same star where it is converted into N during the asymptotic giant branch phase of their evolution (Renzini & Voli 1981). Even though a general consensus is lacking, it has been suggested that primary N might be also produced—essentially by the same mechanism—in massive stars of low metallicities (Woosley & Weaver 1995). This production is strongly dependent on the assumed treatment of convection in stellar interiors but it seems necessary in order to explain the high N abundances relative to O observed in some dwarf irregular galaxies and some DLAs (Matteucci et al. 1997, and references therein).

A further advantage of N is that it is not depleted onto dust in the Galactic interstellar medium (Savage & Sembach 1996; Meyer, Cardelli, & Sofia 1997); therefore, N abundances measured in DLA systems and in extragalactic H II regions are expected to reflect the real (gas plus dust) N abundances.

The first attempt to detect nitrogen in DLAs was made by Pettini, Lipman, & Hunstead (1995) who derived a stringent upper limit ([N/H]<−3.15) for the absorber at z = 2.279 toward QSO 2348−1444. The upper limit on the [N/O] ratio in this system (<−1.24) implied the lowest ratio ever found either in stars or galaxies at low metallicity, in line with a secondary origin of nitrogen. Pettini and colleagues argued that this result is consistent with a delayed delivery of N created mainly in intermediate-mass stars compared to O enrichment produced in short-lived massive stars (Edmunds & Pagel 1978; Garnett 1990).

Nitrogen was first detected in the damped absorbers at z = 1.776 toward MC 1331+170 (Green et al. 1995; Kulkarni et al. 1996) and at z = 3.390 toward QSO 0000−2620 (Vladilo et al. 1995; Molaro et al. 1996). In both cases the reported N/O abundance ratio is much higher than the upper limit derived by Pettini et al. (1995). These results gave the first indication of an intrinsic dispersion of nitrogen abundances in DLAs, as pointed out by Vladilo et al. (1996) and Molaro et al. (1996). The high nitrogen abundance ratios are not easy to understand and nonconventional chemical evolution models of the type used for dwarf irregular galaxies have been proposed by Matteucci et al. (1997).

In a subsequent work, Lu et al. (1996a) found a stringent upper limit in the DLA at z = 2.994 toward QSO 1946+7658, in line with the result reported by Pettini and colleagues. Lu et al. (1996a) interpreted this low N/O value as evidence of the first stages of chemical evolution of a spiral galaxy like the Milky Way. More recently, four new nitrogen abundances were obtained by Lu, Sargent, & Barlow (1998) offering further evidence for an intrinsic dispersion of the nitrogen abundances in DLAs. From the analysis of the [N/Si] ratios in DLA galaxies the latter argue that the observed dispersion can be expected considering the time delay between oxygen and nitrogen delivery.

In this paper we describe three new N I abundance determinations in the DLA systems at z = 2.309 toward QSO 0100+1300, at z = 2.827 toward QSO 1425+6039, and at z = 3.025 toward QSO 0347−3819. The detections are based on the six N I lines of the multiplets at 1134 Å and 1200 Å. A preliminary report for the DLA system toward QSO 0347−3819 was given in Vladilo et al. (1996). In §§ 2 and 3 we present our observations and column density measurements that also include S II, Si II, O I, and Fe II determinations. Abundance measurements for all the DLAs with nitrogen detections are compiled from our data and from the literature and are presented in § 4. Element-to-element ratios in particular N/Zn, N/Fe, and N/S are discussed in § 5 in connection to the origin of N in the framework of chemical evolution models. The implications for our understanding of the nature of DLA galaxies are summarized in § 6.

2. OBSERVATIONS AND DATA REDUCTION

As part of a search for nitrogen absorptions in DLAs we obtained optical spectra of QSO 0100+1300 (V = 16.6), QSO 1425+6039 (V = 15.8), and QSO 0347−3819 (V = 17.3). The spectra of the first two QSOs were obtained with the Utrecht Echelle Spectrograph (Walker & Diego 1985) at the Nasmyth focus of the 4.2 m William Herschel Telescope of the Observatorio del Roque de los Muchachos on La Palma island. The spectra of QSO 0347−3819 were obtained with the CASPEC spectrograph at the Cassegrain focus of the ESO 3.6 m telescope at La Silla, Chile (Pasquini & D’Odorico 1989). In both spectrographs an echelle grating of 31.6 grooves mm−1 and a 1024 × 1024 Tektronik CCD with square pixels of 24 μm in size were used. The CCD was binned at a step of 2 pixels along the dispersion, and the slit width was set at 2.1 (CASPEC) and 2.2 (UES) in order to project the slit onto 2 binned pixels of the detector. The slit width matched the seeing, which was around 2" during the observations. The full width at half-maximum of the instrumental profile, Δλinstrumental, was measured from the emission lines of the thorium-argon lamp spectra recorded frequently during the observations. The resulting resolving power R = λ/Δλinstrumental was R ≈ 27,000 (UES spectra) and 19,500 (CASPEC spectra), corresponding to a velocity resolution of Δv ≈ 11.5 and 15.4 km s−1, respectively. The journal of the observations is given in Table 1.

The spectra taken on different nights were reduced separately and then averaged using weights according to the square of their signal-to-noise ratios. Cosmic ray removal, sky subtraction, optimal order extraction, and wavelength calibration were performed using the ECHELLE routines implemented within the MIDAS software package developed at ESO. Typical internal errors in the wavelength calibrations are of ≈ 0.01−0.02 Å. The wavelength scale of the spectra was corrected to vacuum heliocentric scale. Finally, each order of the spectra was
normalized using a spline to connect smoothly the regions free from absorption features. The signal-to-noise ratios of the final spectra—estimated from the rms scatter of the continuum near the absorptions under study—are typically in the range between 10 and 20. For the two DLAs at higher redshift the O I λ1302, O I λ1355, and Si II λ1304 transitions fall in a part of the spectrum where the signal-to-noise ratios can be as high as 45 thanks to the increase of the CCD quantum efficiency toward the red.

3. COLUMN DENSITIES

Column densities have been derived by best fitting theoretical Voigt profiles to the observed absorption lines via $\chi^2$ minimization. This step was performed using the routines FITLYMAN (Fontana & Ballester 1995) included in the MIDAS package. Before the fit, the theoretical profiles were convolved with the instrumental point-spread function determined from the analysis of the emission lines of the arcs. Portions of the profiles contaminated by intervening Ly$\alpha$ absorbers were excluded from the fit. The FITLYMAN routines determine column densities, broadening parameters ($b$ values), and redshifts of the absorption components, as well as the fit errors for each of these quantities. The laboratory wavelengths of the transitions investigated are listed in Table 2 together with the oscillator strengths adopted for computation of theoretical profiles.

When several unsaturated transitions are detected for a given element, the column density is estimated by applying the fit procedure both to the individual transitions and to the full set of available lines. No differences were found between the mean column density resulting from individual fits and the column density obtained from the simultaneous fit of all the available lines. In these cases we adopted the dispersion from individual measurements as conservative column density errors.

Nitrogen column densities were determined from the six transitions of the two N I multiplets at λ1134 and λ1200 (see Table 2). The N I lines occur in the Ly$\alpha$ forest, but the identification of the absorptions is quite reliable because it is very unlikely that each one of the six transitions is blended with a Ly$\alpha$ interloper. The oscillator strengths span about 1 order of magnitude offering a large dynamical range for the measurement of the column density. The detection of the faintest transitions of the λ1134 multiplet is especially important to get rid of saturation effects. These transitions are not saturated and therefore uncertainties in $b$(N I) do not affect the derived N I column densities.

The fits of nitrogen lines for the three DLA systems under investigation are shown in Figures 1, 2, and 3 and the resulting column densities are reported in Table 3. In the same table we list the rest of extant determinations of N I column densities or upper limits taken from the literature. In total there are nine N I detections available: four from our project, one from Kulkarni et al. (1996), four from the recent measurements reported by Lu et al. (1998). In addition there are eight upper limits (Pettini 1995; Lu et al. 1998).

In order to understand the nucleosynthetic origin of nitrogen it is necessary to compare its abundance with that of other elements. In addition to the nitrogen lines, we therefore searched for transitions of important species such as...
FIG. 2.—N I lines of the \( z_{\text{abs}} = 3.0250 \) DLA system in the normalized spectrum of QSO 0347—3819. Top and bottom as in Fig. 1. Smooth lines: Synthetic spectrum obtained by fitting the cores of all the line profiles, with the exception of the bluest line of the \( \lambda 1134 \) multiplet.

as O I, Si II, S II, and Fe II, which fall in the wavelength range of our spectra (see Table 2). Column densities and \( b \) values of these elements for the DLAs toward QSO 0347—3819 and QSO 1425+6039 are reported in Table 4 and for the system toward QSO 0100+1300 are given in MCV.

For saturated transitions, lower limits to the column density were estimated from the equivalent width obtained from the best fit to the absorption. For undetected transitions, upper limits to the column density were derived from upper limits of the equivalent width. In both cases the conversion from equivalent widths to column densities was performed in the optically thin limit (linear part of the curve of growth).

Oxygen column densities in DLAs are generally uncertain by more than 1 order of magnitude owing to the saturation of the O I \( \lambda 1302 \) line that is present even at low metallicities. In order to constrain the O I column density we fitted the O I \( \lambda 1302 \) line by adopting the \( b \) value obtained from the analysis of the N I multiplets, which is expected to trace the same neutral gas as O I. The \( b \) value of both atoms should in fact be very similar: for pure O I \( b_{\text{OI}} \approx 0.94 \) and for N I \( b_{\text{NI}} \approx 0.94 \).

**TABLE 3**

| QSO      | \( z_{\text{abs}} \) | \( \log N(\text{H I}) \) | Reference | \( \log N(\text{N I}) \) | \( b \) | Reference |
|----------|----------------------|-------------------------|-----------|-------------------------|------|-----------|
| 0000—2620 | 3.3901               | 21.40 ± 0.10            | 1         | 14.68 ± 0.14            | 13.7±1.8 | 2         |
| 0100+1300 | 2.3090               | 21.40 ± 0.05            | 4         | 14.69 ± 0.07            | 11.2±1.0 | 5         |
| 0347—3819 | 3.0250               | 20.70 ± 0.10            | 7         | 14.60 ± 0.05            | 17.9±1.1 | 5         |
| 0930+2858 | 3.2353               | 20.18                   | 6         | 13.82b                  | ...     | 6         |
| 1053+4611 | 3.3172               | 20.34c                  | 6         | \( \leq 14.00^b \)     | ...     | 6         |
| 1202—0725 | 4.3829               | 20.60 ± 0.12            | 8         | \( \leq 14.30^b \)    | ...     | 6         |
| 1331+1700 | 1.7764               | 21.18 ± 0.05            | 9         | 14.5 ± 0.10             | ...     | 10        |
| 1425+6039 | 2.8268               | 20.30 ± 0.04            | 3         | 14.70 ± 0.04            | 23.00±1.8| 5         |
| 1946+7658 | 2.8443               | 20.27 ± 0.06            | 3         | 12.53b                  | ...     | 6         |
| 2212—1626 | 3.6617               | 20.20 ± 0.08            | 3         | \( \leq 13.58^b \)    | ...     | 6         |
| 2233+1310 | 3.1493               | 20.00b                  | 6         | \( \leq 14.32^b \)    | ...     | 6         |
| 2237—0608 | 4.0803               | 20.52 ± 0.11            | 3         | \( \leq 14.28^b \)    | ...     | 6         |
| 2343+1230 | 2.4313               | 20.34c                  | 6         | 14.67b                  | ...     | 6         |
| 2344+124   | 2.5379               | 20.43 ± 0.09            | 12        | \( \leq 13.81 \)      | ...     | 12        |
| 2348—1444 | 2.2794               | 20.57 ± 0.09            | 7         | \( \leq 13.47 \)      | ...     | 13        |

a Error bar not reported by the author.
b \( N(\text{N I}) \) obtained from \( [\text{N/H}] \) value reported by the authors who used \( \log (\text{N/H})_0 = -3.95 ± 0.04 \).
c Multiple components.

References.—(1) Savaglio, D'Odorico, & Moller 1994; (2) Molaro et al. 1996; (3) Lu et al. 1996a; (4) Pettini et al. 1990; (5) this paper; (6) Lu et al. 1998; (7) Pettini et al. 1994; (8) Lu et al. 1996b; (9) Wolfe 1995; (10) Green et al. 1995; (11) Kulkarni et al. 1996; (12) Lipman 1995; (13) Pettini et al. 1995.
TABLE 4
COLUMN DENSITIES OF OTHER SPECIES

| QSO        | \(z_{\text{abs}}\) | \(\log N(\text{S ii})\) | \(b\) | \(\log N(\text{Si ii})\) | \(b\) | \(\log N(\text{O i})\) | \(b\) | \(\log N(\text{Fe ii})\) | \(b\) |
|------------|---------------------|---------------------------|------|---------------------------|------|---------------------------|------|---------------------------|------|
| 0347–3819  | 3.02476             | 14.77 \(\pm\) 0.08       | 17.9 \(\pm\) 3.3 | 15.07 \(\pm\) 0.43 | 21 \(\pm\) 5 | 16.07 \(\pm\) 0.90 | \(\leq\) 17.95 \(^a\) | 17.9 \(\pm\) 3.3 | 14.35 \(\pm\) 0.10 | 17.9 |
| 1425+6039  | 2.82680             | ... \(^b\)                | ... \(\geq\) 14.32 | 23.0 \(\pm\) 0.43 | \(\leq\) 17.85 \(^a\) | 14.45 \(\pm\) 0.06 | 25.2 \(\pm\) 1.8 |

\(^a\) From the upper limit on the \(\text{O i} \lambda 1355\) line.
\(^b\) Not detected due to contamination by the \(\text{Ly} \alpha\) forest.

thermal broadening and \(b_{\text{O i}} = b_{\text{N i}}\) for pure turbulence. The other accessible \(\text{O i}\) transition at 1356 Å is extremely weak (\(f_{\lambda} = 1.248 \times 10^{-6}\)) and is not detected in the DLA systems under study (see, e.g., Figs. 4 and 5). The derived upper limits are given in Table 4.

Measurements of \(\text{S ii}\) column densities are derived from the \(\text{S ii}\) triplet at 1254 Å, which is generally unsaturated. This triplet, however, can be contaminated by the \(\text{Ly} \alpha\) forest, and we have been able to measure the sulphur column density only for two of the three DLA systems under study. As far as iron is concerned, there are six \(\text{Fe ii}\) transitions available, listed in Table 2. For each of the three DLA galaxies studied here, there are one or two \(\text{Fe ii}\) unsaturated lines, and free from blends, which have allowed us to derive reliable iron column densities. Silicon transitions in the available spectral ranges are usually heavily saturated, which hampers attempts to derive accurate \(\text{Si ii}\) column densities. More details on the measurements performed in individual systems are given in the next subsections.

3.1. System at \(z_{\text{abs}} = 2.309\) toward QSO 0100+1300

The \(\text{N i}\) column density of this system was measured via the simultaneous fit of the two lines at shorter wavelength of the \(\text{N i} \lambda 1354\) multiplet. As one can see in Figure 1, the reddest transition of this multiplet is in fact contaminated by a \(\text{Ly} \alpha\) interloper. The \(\text{N i} \lambda 1200\) multiplet presents strong contamination and is highly saturated.

The column density that we derive—\(\log N(\text{N i}) = 14.69(\pm 0.07)\)—is at variance with the one found by et al. (1998), \(\log N(\text{N i}) = 15.29 \pm 0.35\) (see Table 3). These authors obtained this result by means of Keck HIRES data, but details on the measurement are deferred to a subsequent paper. The large error bar reported by Lu et al. (1998) suggests that \(N(\text{N i})\) was obtained from the \(\lambda 1200\) multiplet. In fact, the \(\lambda 1134\) multiplet falls below the spectral range...
usually covered by HIRES observations (see Table 1 in Lu et al. 1996a). We stress that our measurement relies instead on the analysis of the unsaturated N i absorptions at $\lambda 1134.1$ and 1134.4.

The main absorption component of the system toward QSO 0100 + 1300 falls at $z_{\text{abs}} = 2.30907$ in our spectra. A secondary component at $v_D = 35 \text{ km s}^{-1}$ has also been detected in the most intense absorption lines of this system (Wolfe et al. 1994; MCV). Analysis of the most intense N i lines does not yield information on this component, owing to Lyα contamination. However, close inspection of our spectrum redward of the N i 1134.41 line shows a portion free from Lyα contamination without traces of absorption exceeding the noise level. Therefore the $v_D = 35 \text{ km s}^{-1}$ component—if present in N i at all—must be negligible compared to the main one.

Wolfe et al. (1994) in their higher resolution ($\Delta v = 8 \text{ km s}^{-1}$) spectra at redder wavelengths (4427–6900 Å) revealed an asymmetric profile of the main component, which suggests the presence of an additional component at $v \sim 8 \text{ km s}^{-1}$. The effect of this double structure of the main component on the column density of N i is negligible. In fact, using a two-cloud model the N i fit gives a total column density within 0.01 dex of the one-cloud model. Abundances of other elements like S ii, Fe ii, Mg ii, Mn ii, P ii (from our data), and Zn ii (from Wolfe et al. 1994) in this system are discussed in MCV.

3.2. System at $z_{\text{abs}} = 3.025$ toward QSO Q0347 – 3819

The intense Si ii $\lambda 1304$ and O i $\lambda 1302$ absorptions outside the Lyα forest show two components; the stronger lying at $z_{\text{abs}} = 3.02476$ and the weaker at $z_{\text{abs}} = 3.02562$ (see Fig. 4). The column density of the secondary component is less than 10% of that of the main one for both species. For N i, Fe ii, and S ii, only the main component is clearly detected. In these cases we used a single component fit and adopted the resulting column density as the total column density.

The N i multiplets are clearly identified, but some contamination from Lyα absorption is visible, particularly in the vicinity of some lines of the $\lambda 1134$ multiplet. To minimize contamination we measured the column density by fitting the central parts of the line profiles. The weakest line of the $\lambda 1134$ multiplet—noisy and apparently contaminated—was excluded from the fit. Results are shown in Figure 2 and in Table 3.

The column density of Si ii was estimated from the analysis of the $\lambda 1304$ line, which falls outside the Lyα forest and has the lowest oscillator strength among the available Si ii transitions. This fit gives log $N($Si ii$) = 15.07 \pm 0.43$ and $b = 21 \pm 5 \text{ km s}^{-1}$. An attempt to fit also simultaneously the $\lambda 1193$ transition, which appears to be unblended, yields instead log $N($Si ii$) = 15.50 \pm 0.69$ and $b = 17 \pm 4 \text{ km s}^{-1}$. Silicon abundance must obviously be treated with some caution.

The analysis of N i and Si ii yields consistent values of the broadening parameter, although the value $b = 17.9 \pm 1.1 \text{ km s}^{-1}$ derived from the N i multiplets is more precise. We adopted this value, with a 3 $\sigma$ error ($\pm 3.3 \text{ km s}^{-1}$), to fit species for which the $b$ value is undetermined.

There is only one transition of the Si ii triplet that is not contaminated by Lyα interlopers, namely, the one at 1260 Å. The identification is supported by the perfect coincidence...
of the redshift and by the narrowness of the absorption profile. We obtain $\log N(\text{S\ II}) = 14.77 \pm 0.06$ where the error is the fit error at a fixed value of $b$. An additional $\pm 0.06$ error results when the above mentioned range of possible $b$ values is taken into account. The S\ II column density is fairly independent of the adopted value of the broadening parameter.

Many Fe\ II transitions of this system are potentially present in the spectral range of our spectra (see Fig. 4). However, all these lines lie in the Ly$\alpha$ forest and many of them are expected to be close to the noise level. We clearly detect the $\lambda$1144 line and a hint of absorption in correspondence with other Fe\ II transitions. Our analysis is mostly based on the $\lambda$1144 line, but the synthetic spectra were superposed to all the other lines for a consistency check. By excluding a few pixels of the violet wing of the $\lambda$1144 absorption—which we suspect is affected by Ly$\alpha$ contamination—we obtain $\log N(\text{Fe\ II}) = 14.35 \pm 0.1$ at $b = 17.9$ km s$^{-1}$. The $\lambda$1096 line gives a firm upper limit at $\log N(\text{Fe\ II}) \leq 14.45$, clearly indicating that the stronger $\lambda$1144 line cannot be significantly saturated. By fitting the full absorption profile of the $\lambda$1144 line without adopting the above quoted value of $b$, we obtain $\log N(\text{Fe\ II}) = 14.45$ at $b = 30$ km s$^{-1}$.

We estimated the O I column density from the $\lambda$1302 line. By constraining the range of broadening values between $b = 14.6$ km s$^{-1}$ and $b = 21.2$ km s$^{-1}$ we derive $\log N(\text{O\ I}) = 16.97 \pm 0.39$ and $\log N(\text{O\ I}) = 15.61 \pm 0.19$, respectively. The central value for the oxygen column density given in Table 4 corresponds to the adoption of $b = 17.9$ km s$^{-1}$, our best estimate of the O I broadening parameter.

### 3.3. System at $z_{\text{abs}} = 2.82680$ in QSO 1425 + 6039

The N I column densities of this system were measured via the simultaneous fit of two lines of the N I $\lambda$1134 multiplet. The reddest transition of this multiplet is in fact contaminated by a Ly$\alpha$ interloper (see Fig. 3). The N I $\lambda$1200 multiplet is clearly saturated and presents contamination in its weakest line. From the analysis of the $\lambda$1200 multiplet alone Lu et al. (1996a) derived a lower limit [log $N(\text{N\ I}) \geq 14.62$] that is consistent with the result [log $N(\text{N\ I}) = 14.70 \pm 0.04$] provided here (cf. Table 3).

The N I absorptions in our spectra occur at $z_{\text{abs}} = 2.82680$. Lu et al. (1996a) found an absorber subcomplex at $z_{\text{abs}} = 2.83058$ ($\Delta v \approx 300$ km s$^{-1}$) with an H I column density at 5% that of the main component. The shift in radial velocity of this secondary component prevents contamination of the $\lambda$1134 multiplet from which we derived the N I column density.

In Figure 5 we show the spectral regions of the Si II, S II, Fe II, and O I transitions. Three out of the four Si II transitions available are severely blended with other absorptions. The only saturated Si II $\lambda 1304$ line could be fitted, providing a lower limit to the Si abundance as explained in § 3.

All three S II lines present contamination by the Ly$\alpha$ forest, which makes it impossible to estimate or even to derive a reliable upper limit to the sulphur column density in this DLA.

Only the $\lambda$1143 and $\lambda$1144 transitions were used to derive the Fe II column density since the other lines are severely blended (see Fig. 5). The $b$ value derived from the iron lines $(25.2 \pm 1.8$ km s$^{-1}$) is in good agreement with that obtained from the nitrogen lines $(23.0 \pm 1.8$ km s$^{-1})$. The iron column density that we infer—log $N(\text{Fe\ II}) = 14.45 \pm 0.06$—matches very well the result reported by Lu et al. (1996a) for this system, namely, log $N(\text{Fe\ II}) = 14.48 \pm 0.04$.

The O I $\lambda$1302 transition is heavily saturated and blended. In this case we simply estimate an upper limit to the O I column density from the undetected $\lambda$1356 transition.

### 4. ELEMENTAL ABUNDANCES

Table 5 lists measurements of the N, S, Si, O, Fe, and Zn abundances taken from our search and from the literature for all the DLAs with available nitrogen abundance determinations. The elemental abundances are scaled to the solar reference value by using the standard definition $[X/H] = \log (X/H)_{\text{obs}} - \log (X/H)_{\odot}$. The column density ratio $(X/H)_{\text{abs}}$ is obtained by using the H I column densities given in Table 3. The solar system values adopted for all the elements discussed here are the meteoritic abundances reported by Anders & Grevesse (1989), with the exception of N and O for which we adopt the most recent solar photospheric values given by Grevesse & Noels (1993) (see Table 5). The Zn abundances are included in Table 5 because Zn is a good indicator of the system’s metallicity since it is practically unaffected by the presence of dust (Pettini et al. 1994, 1997a). The conversion from column densities to abundances requires several logical steps that are briefly discussed in the following subsections.

#### 4.1. Ionization Corrections

DLA systems have large column densities—$N(\text{H\ I}) > 2 \times 10^{20}$ cm$^{-2}$—and are optically thick to interstellar or intergalactic ionizing photons with $h\nu > 13.6$ eV in the absorber rest frame. Detailed ionization calculations indicate that species with ionization potential IP > 13.6 eV, such as N I, O I, S II, Si II, Fe II, and Zn II, are the dominant ionization states and can be used to infer directly the elemental abundance (Fan & Tytler 1994; Lu et al. 1995). We assume that ionization corrections are negligible for these species.

#### 4.2. Contributions from Intervening H II Regions

If the galaxy associated to the DLA system hosts an intervening H II region, the ionized gas may produce an extra contribution to the column densities of species with IP > 13.6 eV. This effect should not alter the abundances of species with IP very close to 13.6 eV, such as Si II, O II, Fe II, and Zn II, since these species will be ionized in an intervening H II region but could increase the apparent abundances of other species with higher ionization potentials, such as Si II, S II, Fe II, and Zn II. The net result would be an artificial decrease of the [N/Fe] and [N/S] ratios and an increase of the apparent metallicities [Fe/H] and [S/H] that are discussed in § 5. The effect should only be important when the intervening H II gas has the same radial velocity and comparable column density of the H I region. Ionized regions with $N(\text{H\ II}) < 2 \times 10^{19}$ cm$^{-2}$ would not affect the abundance analysis in any case. The intervening H II regions will have in general a different kinematics from the H I gas, and this will lead to differences in the radial velocity profiles of neutrals (originated only in H I gas) and singly ionized species (originated both in H I and H II gas). Therefore careful analysis of the absorption profiles of metal lines...
should help disentangle the contribution of the ionized gas, if at all present. From the analysis of our data we do not find systematic differences between the b values derived from neutral nitrogen and those derived from singly ionized species. Inspection of the highest quality spectra available (see, e.g., Lu et al. 1996a) does not reveal systematic differences between the profiles of neutral and low ionization species, which suggests that contributions from H II regions are generally negligible.

4.3. Dust Depletion

A fraction of the elements in DLAs are expected to be in the form of dust grains, thus reducing the gas-phase abundance, which is precisely what we are measuring. The evidence for dust in DLAs is manyfold. One is the differential reddening of quasars with and without foreground damped absorption (Pei, Fall, & Bechtold 1991). Another piece of evidence comes from the apparent enhancement of the Zn to Cr abundance ratio in DLA systems (Pettini et al. 1994, 1997a). Based on the expectation that Zn tracks Cr, Pettini and colleagues interpret the observed [Zn/Cr] enhancement as a signature of chromium depletion onto dust grains. Vladilo (1998) calculated dust-to-gas ratios in DLAs with Fe, Cr, and Zn measurements and found quantitative agreement with the dust-to-gas ratios based on the reddening determinations by Pei et al. (1991). The detection of the $\lambda 2175$ emission bump in high redshift MgII absorbers (Malhotra 1997) and the realization that Type II supernovae (SNe) can produce dust (Danziger et al. 1991) also suggest that dust is present in the early stages of galactic evolution. Depletions in DLA absorbers are expected to be lower than in the Galactic ISM since the dust-to-gas ratios in DLAs are between $\approx 2\%$ and $\approx 25\%$ (Vladilo 1998) that of the Galactic ones. However, care must be taken when converting column densities into abundances while considering elements that are known to be depleted from gas to dust.

There are different pieces of evidence that indicate that nitrogen is not depleted in the interstellar medium. From the theoretical point of view, the large activation energy of N$_2$ prevents involvement of nitrogen in the gas-phase reactions that lead to dust formation in stellar atmospheres (Gail & Sedlmayr 1986), and hence interstellar accretion of N onto dust grains is not expected. From the observational point of view, two recent works confirm that interstellar N is not depleted into dust grains. On the one side, interstellar Hubble Space Telescope observations of the N I $\lambda 1160$ doublet (Meyer et al. 1997) show that the gas-phase abundance of nitrogen does not decrease in sight lines with higher H$_2$ fraction that are indicative of self-shielding environments more hospitable to grains. On the other, Infrared Space Observatory observations of the N-H stretch spectral region at $2.96 \mu m$ limit the solid-state of N abundance to log (N/H)$_{\text{dust}} < -6$, corresponding to a N depletion lower than 0.01 dex, for the line of sight to Cyg OB2 No. 12 which is known to be heavily reddened (Whittet et al. 1997).

Among the elements considered here, O, S, and Zn are also almost unaffected by depletion in Galactic interstellar clouds, their typical deficiency with respect to solar values being in the range $[-0.19, 0.00], [0.00],$ and $[-0.25, -0.13]$ dex, respectively (Meyer, Jura, & Cardelli 1998; Savage & Sembach 1996; Roth & Blades 1995). By contrast, refractory elements such as Si and Fe are known to be depleted by 1 or 2 dex in the Galactic ISM. In particular, a fraction of iron as high as about 94% is locked in dust grains in the warm gas of the Galactic disk, and a fraction even greater in cold clouds (Savage & Sembach 1996). These elements are expected to be depleted also in DLAs, and in §5 we discuss how to estimate the amount of depletion.
The nitrogen abundances in Galactic halo dwarfs are typically $-0.2$ dex lower in B-type stars than in the solar system, and some authors prefer to use two-thirds of the solar system values as a standard for "cosmic" abundances (see Savage & Sembach 1996; Mathis 1996). Adoption of this abundance reference would yield dust depletions consistently lower in absolute values.

The average interstellar abundance of nitrogen, $\langle \log (N/H) \rangle_{\text{ISM}} = -4.12 \pm 0.02$ (Meyer et al. 1997), is slightly deficient with respect to the solar value, $\log (N/H)_\odot = -4.03 \pm 0.07$ (Grevesse & Noels 1993), yielding an under-abundance $\langle [N/H] \rangle_{\text{ISM}} = -0.09 \pm 0.07$. Also nearby B stars show a similar underabundance, with $\langle \log (N/H) \rangle_{\text{B stars}} = -4.17 \pm 0.17$ (Venn 1995). These results indicate nondepletion of N into interstellar grains if the B-type star reference is adopted, or depletion of $\approx -0.1$ dex if the solar pattern is adopted. Meyer et al. (1997) pointed out that limitations in deriving $[N/H]$ in the Galactic ISM no longer lie in the measurement itself, but in the accuracy of the oscillator strengths and in the solar photospheric determinations. Because of these uncertainties the authors claimed that it is still premature to rule out an interstellar N abundance either equal to or two-thirds of solar. We adopt here the solar reference pattern, and for nitrogen we adopt the solar photospheric value of Grevesse & Noels (1993) quoted above. This is not in sharp contrast with the fact that we assume nitrogen to be undepleted in DLAs because the expected absolute value for Galactic depletion less than 0.1 dex would become negligible at the low dust-to-gas ratios typical of DLA absorbers. Consequences of adopting the B stars as standard for the abundances are considered in the next section.

5. Discussion

The absolute nitrogen abundances in DLA absorbers shown in Table 5 span more than 2 orders of magnitude, with $-3.7$ dex $<[N/H]<-1.6$ dex. From the point of view of chemical evolution models, relative abundances are more reliable than absolute abundances because they generally depend only on the elemental nucleosynthesis and stellar lifetimes, whereas absolute abundances are affected by specific assumptions underlying the models. Here we discuss the abundance of nitrogen relative to the iron-peak and to $\alpha$ elements, which are the main products of Type Ia SNe and Type II SNe, respectively. We compare measurements of $[N/Fe]$ and $[N/\alpha]$ ratios in DLAs and in other astrophysical sites of similarly low metallicity, namely, Galactic halo stars, blue compact galaxies, and dwarf irregular galaxies. These abundance ratios are then compared with predictions of galactic chemical evolution models.

5.1. The $[N/Fe]$ Abundance Ratio

The nitrogen abundances relative to iron measured in DLA systems are plotted versus $[Fe/H]$ in Figure 6. The filled symbols represent our data, and open symbols denote measurements taken from the literature. The $[N/Fe]$ values are deficient compared to the solar ratio and do not exhibit a trend with metallicity. The measurements show a relatively high amount of dispersion, with one value as low as $[N/Fe] = -1.3$ ($z = 2.84$ toward QSO 1946 $+7658$) and several high values around $[N/Fe] = -0.3$. There is also a hint of a possible higher dispersion at lower metallicities.

The dotted lines in Figure 6 indicate the range of measurements in Galactic halo dwarfs with $-3 \leq [Fe/H] \leq 0$ (Carbon et al. 1987). The solid line is the regression found by these authors with a scatter of $\sigma = \pm 0.19$ dex. The large scatter in the stellar measurements reflects the difficulties in deriving N abundances from NH bands. The nondependence of $[N/Fe]$ with stellar metallicity has been considered as evidence for a primary component of nitrogen (Pagel 1985; Carbon et al. 1987).

The dot symbols in Figure 6 represent the measurements in blue compact galaxies (BCGs) taken from the sample of Thuan et al. (1995). BCG’s abundances take up about the same region of metal-poor stars. However, most of them lie below the linear regression of stellar data and closer to DLA galaxies. At the lowest metallicities there are no BCGs to compare with DLAs.

At first glance there is general consistency between DLA, BCG, and halo star measurements, with the exception of a few cases in which the $[N/Fe]$ are lower in DLAs. However, the interpretation of the observed $[N/Fe]$ ratios must take into account that iron is one of the most refractory elements, whereas nitrogen is undepleted, as we discussed in §4.3. Before drawing any conclusions from the comparison of the $[N/Fe]$ ratios it is hence necessary to take into account the presence of dust.

The $[N/Fe]$ values corrected for dust depletions are shown in Figure 7, where we use the same symbols for DLAs as in Figure 6. The net effect of the correction is a diagonal shift of the points—at different lengths for each object—which results from the increase in Fe abundance at invariant N abundance.

The iron depletions were estimated with two methods. For the DLAs that have both Fe and Zn abundance measurements we estimated the amount of depletion by...
assuming that zinc tracks closely iron, $[\text{Zn}/\text{Fe}] \approx 0$, as is indeed observed in Galactic stars with metallicities $-2.9 \leq [\text{Fe}/\text{H}] \leq -0.2$ (Sneden, Gratton, & Crocker 1991) and in the Large Magellanic Cloud stars (Russel & Dopita 1992), and by assuming that dust in DLAs is of the same type as the Galactic one. With both assumptions we estimated the Fe and Zn depletions starting from the Galactic interstellar values $\delta(\text{Fe}) = -1.2$ dex and $\delta(\text{Zn}) = -0.19$ dex (Savage & Sembach 1996; Roth & Blades 1995). This approach is similar to that employed by Pettini et al. (1994, 1997a), with the difference that we take into account not only iron depletion, but also that of zinc. The two DLAs with both Fe and Zn measurements available are indicated in Figure 7 with a filled triangle (system toward QSO 0100 + 1300) and a star (system toward QSO 1331 + 1700).

For the remaining DLAs without Zn but with Fe measurements available we estimated the correction for dust depletion from equation (17) by Vladilo (1998) by adopting the average dust-to-metals ratio in DLAs $\langle \log (k/Z) \rangle = -0.21 \pm 0.16$ given there. The resulting $[\text{N/Fe}]_{\text{corr}}$ values are indicated in Figure 7 with a 45 degree error bar that corresponds to the above quoted dispersion in the dust-to-metals ratio. The left and up arrows shown in Figure 7 for the absorber toward QSO 0000 - 2620 (filled square) were derived from the stringent Zn upper limit available for the system (see Table 5), i.e., by taking $[\text{Fe}/\text{H}]_{\text{corr}} \approx [\text{Zn}/\text{H}]_{\text{obs}}$ and $[\text{N/Fe}]_{\text{corr}} \approx [\text{N/Zn}]_{\text{obs}}$, respectively.

Since the data points are now corrected for the presence of dust, the spread observed in Figure 7 reflect intrinsic differences in the relative nitrogen abundance. Particularly relevant is the DLA at $z = 3.390$ toward QSO 0000 - 2620 (filled square) for which $[\text{N/Fe}]$ remains significantly higher than in the other two DLAs with zinc available. This spread is specific to N and has no equivalent in other abundance ratios measured in DLAs, which are remarkably similar both at face values (see, e.g., Fig. 23 by Lu et al. 1996a) and after correction for dust depletion (Vladilo 1998).

As can be seen in Figure 7 most of the $[\text{N/Fe}]_{\text{corr}}$ measurements in DLAs fall well below those of the metal-poor halo stars. The slight underabundance of the measurements taken at face value shown in Figure 6 is in fact amplified after correction for dust depletion. This conclusion still holds if we use the B star abundances, instead of the solar ones, as a reference for the "cosmic" abundances since, in this case, the $[\text{N/Fe}]$ ratio remains unchanged and the data points in Figure 7 shift along the x-axis by only $+0.18$ dex.

In blue compact galaxies, the $[\text{N/Fe}]$ determinations are based on observations of emission lines from H II regions where dust is also known to be present but is not accounted for (Garnett et al. 1995). If the presence of dust is considered, the BCG data points of Figure 6 would shift in the same direction as the DLA points in Figure 7. Therefore, we cannot exclude the possibility that $[\text{N/Fe}]$ measurements in BCGs are consistent with DLA determinations, as they were before the correction for the presence of dust.

After correction for dust depletion the majority of the DLA data are in line with a pure secondary origin of nitrogen, which in Figure 7 is sketched as a dashed line passing through the solar point. This is particularly clear at least in two cases: namely, the DLAs toward QSO 0100 + 1300 (triangle) and toward QSO 1331 + 1700 (star). This behavior is quite different from that of halo metal-poor stars that show a constant $[\text{N/O}]$ with metallicity, consistent with a primary origin of nitrogen. The difference between the nitrogen abundances of Galactic metal-poor stars and DLAs suggests that the chemical enrichment history of these DLAs has been somewhat different from that experienced by our own Galaxy. However, there is at least one remarkable exception for QSO 0000 - 2620 where the nitrogen remains particularly high, at the level observed in Galactic halo stars.

5.2. The $[\text{N}/\alpha]$ Abundance Ratio

The $[\text{N}/\alpha]$ ratio is an important tool when unraveling the nucleosynthetic history of nitrogen. The abundances for the $\alpha$ elements S, Si, and O are reported in Table 5. Unfortunately it is quite difficult to obtain accurate oxygen abundances in DLAs, as we have discussed in § 3. This problem has often been circumvented by taking S or Si as a proxy for O, under the assumption that the $[\text{O}/\alpha]$ ratio does not evolve with metallicity. S and Si are $\alpha$ elements produced in the same massive stars that produce O, and therefore the ratios between these elements are predicted to vary little, if at all, with time (Timmes, Woosley, & Weaver 1995).

However, some caution must be taken when using silicon as a proxy of oxygen. From the theoretical point of view, Type I SNe produce more silicon than oxygen (Nomoto, Thielemann, & Yokoi 1984; Thielemann, Nomoto, & Ashimori 1993). The observations indicate that Si traces O in Galactic stars (Kilian-Montenbruck, Gehren, & Nissen 1994; Venn 1995), but is slightly underabundant relative to O in extragalactic H II regions (Garnett et al. 1995). This underabundance is interpreted as due to Si depletion onto dust grains. In addition to the uncertainty due to silicon depletion, we remark that Si lines are often saturated at the low column densities typical of DLAs. For these reasons we prefer to adopt sulphur as a tracer of the $\alpha$ elements.
elements. Sulphur is found to track closely oxygen in Galactic stars (see references in Lauroesch et al. 1996), in dwarf galaxies (Garnett 1989; Skillman & Kennicutt 1993; Skillman et al. 1994) and in BCGs (Thuan et al. 1995) in the entire range of metallicities explored. Sulphur is not depleted and, when detected, its lines are unsaturated. Hence, we consider it safe to assume that \([N/O] \approx [N/S]\) in DLAs.

In Figure 8 we compare \([N/O]\) measurements in DLA systems, in Galactic stars, and in dwarf irregular galaxies with predictions emerged from chemical evolution models. Unless stated otherwise, DLA measurements have been derived from sulphur by assuming \([O/S] = 0\). Larger sized symbols represent DLA measurements, and filled symbols highlight the determinations obtained by our group. The dashed line represents the mean trend of the \([N/O]\) ratio in Galactic stars of all metallicities (Tomkin & Lambert 1984). The dots represent the dwarf galaxies compiled by van Zee et al. (1996), van Zee, Haynes, & Salzer (1997), and by Kobulnicky & Skillman (1996), which include the BCGs of Thuan et al. (1995).

The solid lines are theoretical predictions of \([N/O]\) from a chemical evolution model for the solar neighborhood under different assumptions for the nucleosynthesis of nitrogen, described in detail by Matteucci et al. (1997). The curve labeled “S” assumes purely secondary nitrogen produced in stars of all masses. The “P” curve assumes some amount of primary production in intermediate-mass stars according to Renzini & Voli (1981) and with a convective scale length \(a = 1.5\). The “Pmassive” curve with a plateau assumes primary N both in intermediate-mass stars and in massive stars, where in all the other tracks it is secondary.

As can be seen in the figure, the \([N/x]\) ratios in DLAs are highly scattered and the majority of the measurements have no precedents, at a comparable level of metallicity, in Galactic stars. Instead, intrinsic dispersion is observed in dwarf galaxies, with a range of \([N/O]\) values similar to those found in DLA galaxies. Since both N and S depletions are expected to be negligible, the new plot provides further evidence—in addition to Figure 7—that the dispersion of N abundances is real and not due to different amounts of dust among the DLAs.

The detailed study of individual cases shows peculiar behaviors with respect to the predictions of chemical evolution models. The \([N/S]\) ratios in the DLAs toward QSO 0100 + 1300 (triangle), QSO 1331 + 1700 (star), QSO 0347 − 3819 (octagon), and the upper limit toward QSO 2348 − 1444 (open square with arrow) are in between the primary and secondary nitrogen evolutionary tracks. The \([N/S]\) value in the DLA toward QSO 0930 + 2858 (Fig. 8, middle open square) is close to the curves that consider a primary component of N either in intermediate and massive stars. The value for the DLA toward QSO 2343 + 1230 (top open square) falls well above the area limited by the evolutionary tracks with secondary plus primary production of nitrogen. This is probably also true for the absorber toward QSO 0000 − 2620. In this case we show in Figure 8 both the lower limit derived from the conservative sulphur upper limit (Lu et al. 1998; filled square with arrows) and the value from the direct oxygen measurement (Molaro et al. 1996; top filled square). This last determination was obtained by constraining the \(b\) value of the saturated oxygen lines from the broadening obtained from the nitrogen lines (see discussion in § 3). Even considering the uncertainty of the oxygen measurement it is clear that nitrogen has an intrinsically high abundance in this DLA.

It is important to note that for specific DLA systems the \([N/x]\) and \([N/Fe]_{corr}\) values are mutually consistent. The same points that show a secondary behavior in \([N/x]\) also show a secondary behavior in \([N/Fe]_{corr}\). We stress that the \([N/Fe]\) and \([N/S]\) results would not lead to consistent results if iron depletion were not taken into account.

The different values of N/O observed at a given O/H metallicity in DLAs may be attributed to a delay between the delivery of O and N into the ISM when the star formation proceeds in bursts (Edmunds & Pagel 1978). This delay has also been suggested by Garnett (1990) to explain the N/O scatter in dwarf irregulars. According to this picture, galaxies that have experienced a recent episode of star formation show low N/O ratios due to the quick production of O in massive stars and the prompt return to the ISM that is over after a few \(10^7\) yr. On the other hand, in galaxies that have been quiescent for a long period, nitrogen would be returned to the ISM after a few \(10^8\) yr mainly as a product of intermediate-mass stars. During the long quiescence the N/O ratio will increase at about constant O/H. In this model, different ages or temporal gaps from recent bursts of star formation are responsible for the dispersion of the N/O ratios, with low values implying a recent burst and high values pointing to a long quiescent period. Skillman (1998) discussed two cases of dwarf irregular galaxies with values of \([N/O]\) around \(-0.7\) for which there is clear evidence of recent star formation, in agreement with the interpretation of a prompt O enrichment of the ISM.
However, some problems arise in this scenario if DLA abundances of other elements are considered. If the delayed model also applies to DLA, then it seems reasonable to expect an overabundance of the $z$ elements relative to iron-peak elements when low values of [N/O] are observed, i.e., in the phase temporally near the starburst. In fact in this phase the elemental production is dominated by Type II SNe that are rich in $z$ elements. The few cases in which a measurement of the [$z$/Fe] ratio and of nitrogen abundances are available do not conform with this prediction. For instance, as discussed in MCV, the DLA galaxies toward QSO 0100 + 1300 and QSO 1331 + 1700 have [S/Zn] $\approx 0$ even if they show the lowest [N/z] values. In the absorber toward QSO 1331 + 1700 it has been suggested that an intervening H II region could lead to an artificially low [N/S] ratio (see § 4.2), since [N/O] $>$ [N/S] in this system (Kulkarni et al. 1996). For the system toward QSO 0100 + 1300 it is improbable that the [N/S] ratio is artificially lowered due to an intercepted H II region since independent fits of the N I and S II lines give consistent $b$ values (see MCV), whereas differences between the profiles of the two species would be expected if contribution from H II regions were present. The low [N/S] value in this DLA absorber is therefore difficult to understand in the framework of the N-delayed model since the expected overabundance of the [$z$/Fe] ratio is not appreciable.

Also the highest [N/z] ratios observed in the DLA in Figure 8 are difficult to reconcile with the delayed nitrogen release. In fact in this model, N/O ratios are expected to lie in the region limited by the tracks of primary and secondary nitrogen production (Vila-Costas & Edmunds 1993). As we mentioned before, the system toward QSO 2343 + 1230, and perhaps also the one toward QSO 0000 — 2620, lies well above the track of primary plus secondary production instead. Matteucci et al. (1997) showed that the highest N/O values observed in DLA galaxies can only be reproduced by chemical evolution models that assume primary production of N in massive stars, together with selective galactic winds that carry away, preferentially, the products of Type II SNe explosions, such as oxygen and other $z$ elements.

We conclude that the time-delay model requires other ingredients (for example selective galactic winds among others) in order to explain some of the N/O ratios observed in DLA, once they are integrated with the other abundances observed in these galaxies. New abundance determinations are needed in order to understand how common the very low and extremely high ratios in DLA galaxies are.

6. SUMMARY

We have presented three new measurements of nitrogen abundances in DLA galaxies, increasing by 50% the number of determinations available in the literature (not including upper limits). The abundances of nitrogen have been discussed in connection with the iron-peak elements (iron and zinc) and $z$ elements (represented by sulphur) for the nine absorbers with available N data. The effect of dust depletion on the abundance determinations has been taken into account. We have compared the nitrogen measurements in DLA galaxies with measurements in other astrophysical sites of low metallicity and with predictions from chemical evolution models. The main results of the present work can be summarized as follows.

1. The N/S and N/Fe abundance ratios show a scatter of 1 order of magnitude or more, at variance with the remarkably low scatter observed for other elemental ratios measured in DLA galaxies.

2. When the presence of dust is considered to correct the iron abundances, a substantial fraction of [N/Fe] values are lower than those in Galactic halo stars. A similar conclusion holds for the [N/z] ratios obtained from the [N/S] measurements that are expected to be unaffected by dust depletion. These results suggest that the chemical evolution of DLA galaxies has been somewhat different from that experienced by the Milky Way.

3. The [N/Fe] ratios in BCGs are similar to those measured in DLA galaxies and this similarity may remain also after correction for the presence of dust, provided this correction is also appropriate for BCGs. The N/O ratios in dwarf galaxies have similar values and exhibit a similar spread to those observed in DLA galaxies.

4. When compared with theoretical evolution models, it is not possible to explain the observations in DLA galaxies by invoking a unique production mechanism. Some cases are consistent with a secondary behavior of nitrogen, whereas others require primary production. This may suggest that DLA absorbers include galaxies with different chemical histories. Most of the scatter of the nitrogen abundances can also be interpreted in the framework of the delayed model for nitrogen production (Edmunds & Pagel 1978; Garnett 1990). However, in this scenario DLA galaxies with low [N/z] values, which should be temporally close to the starburst, are expected to show an enhancement of $z$ elements that is instead not observed, making necessary the addition of new ingredients to the model in order to explain the observed abundance ratios.

5. In one or possibly two DLA galaxies there is evidence for an extremely high N/O ratio, well above the values measured in Galactic halo stars or in extragalactic H II regions. The few DLA systems with N/O ratios higher than those in any other astrophysical site cannot be accommodated in the framework of the delayed nitrogen model: in this case differential galactic winds plus primary N production in massive stars are required as ingredients of the chemical evolution model (Matteucci et al. 1997).

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