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On the origin of nitrogen: Clues from measurements in Damped Lyman α Systems

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Abstract. Determinations of N abundance in astrophysical sites of low metallicity and at high redshift are of great importance in understanding the origin and early chemical enrichment of this element. Damped Ly-α systems (DLAs) are perfect targets for this kind of investigation. Here we discuss the N/Si ratios in DLAs in the largest sample studied up to now. These ratios are distributed in two groups: 75% of the DLAs show a mean value of [N/Si] = –0.85 ± 0.20 while the remaining 25% shows [N/Si] = –1.45 ± 0.05. The low ratios correspond to the lowest N abundance ever observed in any astrophysical site (low-N DLAs). We argue that the low N/Si values together with the very small dispersion may suggest a modest production of primary N in massive stars. In this framework low-N DLAs would be very young objects, caught before the ejection of primary N by intermediate mass stars. High-N DLAs would be older ones, caught after the lag time for the ejection of primary N by intermediate mass stars.

Key words. elemental abundances – chemical evolution of galaxies – QSOs absorption lines

1. The importance of measuring N in damped Ly-α systems

Determinations of N abundance in astrophysical sites of low metallicity and at high redshift play an important role in understanding the origin and early production of nitrogen. Damped Ly-α systems (DLAs) — the quasar absorbers with the highest H I column densities — with relatively low metallicities and observable up to the redshift of the most distant quasars, are perfect targets for this type of investigation.

The synthesis of N in the CNO cycle during hydrogen burning is reasonably well understood, but the characteristics of the stars that produce this element (range of masses, stage of evolution, etc.) are not completely clear.

N has mostly a *secondary* origin produced in the CNO cycle from seed C and O

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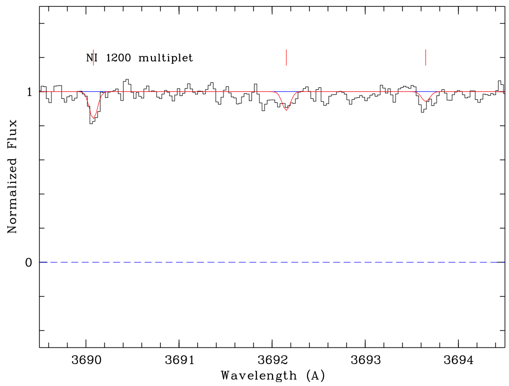

Fig. 1. The NI 1200 multiplet of the $z_{\rm abs}$=2.0762 DLA in Q2206–199

nuclei created in earlier generation of stars. However, at low metallicities N has a *primary* origin produced when freshly synthesized C in the helium-burning shell penetrates into the hydrogen-burning shell during the asymptotic giant branch phase of the star. N is believed to be mainly produced (*primary* and *secondary* origin) in intermediate mass stars (4-8 $M_\odot$). Primary N production at low metallicities by massive stars ($M > 8M_\odot$) has also been proposed, but a general consensus is lacking.

A classic method used to obtain clues on the nucleosynthetic origin of nitrogen consists in comparing the observed N/O versus O/H ratios with the predictions of chemical evolution models. Since the determination of nitrogen abundance in stars is relatively difficult, the bulk of the N/O data used for this purpose are measurements in H II regions of dwarf irregulars (Kobulnicky & Skillman ref (1996); Izotov & Thuan ref (1999)) and spiral galaxies (compilations in Henry et al. (ref 2000) and Pilyugin et al. ref (2002)). N measurements in high redshift DLAs are of great importance since their metallicities extend over a much lower range than those of metal-poor H II regions in dwarf galaxies, allowing us to probe the early N nucleosynthesis.

2. The DLA sample

The sample is an updated compilation of abundances of N and α-elements (O, S or Si) determined from high resolution spectra obtained with 8-10 m class telescopes. Details are given in Centurión et al. ref (2003), where 5 new N abundances are reported. The sample includes abundances reported as part of studies of individual DLAs, as well as recent data given by Pettini et al. ref (2002) and Prochaska et al. ref (2002). Here we present the homogeneous sample of [N/Si] data since Si is the α-element most measured in DLAs, and O, S, Si trace each other rather well. In addition, we present here the redetermination of N abundance in the $z_{\rm abs}$=2.076 DLA in Q2206-199, for which only a conservative upper limit was available ([N/H] < –3.49; Pettini et al. ref (2002)). We noticed that the N abundance which well reproduces the strongest NI 1199.5 Å transition overstimates the profile of the NI 1200.2 Å transition (see Fig. 5 in Pettini et al.). A closer inspection of that figure shows that the 1199.5 Å line is on the bottom of a broader absorption line and therefore contaminated. Our reanalysis of the UVES spectrum, kindly provided by Max Pettini, which takes into account this contamination is fully consistent with the observed 1200 NI multiplet (see Fig. 1), and we obtained [N/H]=–3.78 ± 0.08 (see for more details Molaro et al. **?**).

3. The [N/α] ratios in DLAs

DLAs can be tentatively divided in two groups which differ in the [N/α] ratios by about 0.6 dex. Approximately 75% of DLAs show [N/Si] = –0.85 (± 0.20) (High-N DLAs) while the remainig 25% of DLAs show [N/Si] = –1.45 (± 0.05) (Low-N DLAs) The high values are at the level observed in blue compact dwarf (BCD) galaxies [N/O] = –0.73 (± 0.13) but DLAs extend to lower metallicities. The low values are the lowest ever observed in any astrophysical site, and they show a particularly

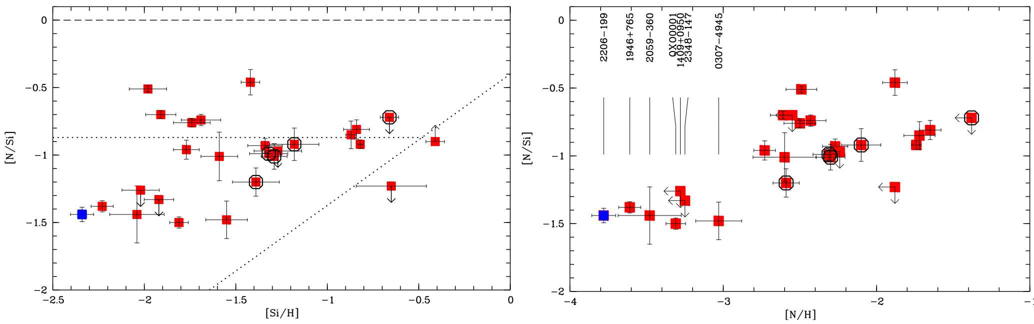

Fig. 2. Left panel: [N/Si] versus [Si/H] in DLAs. Bold octagons indicate our new DLA measurements. The blue point is our redetermination for $z_{\rm abs}$=2.076 DLA in Q2206-199. Dotted lines are empirical representations of the secondary and primary N production. The horizontal line (primary) is plotted at the mean [N/Si] value in DLAs. Right panel: [N/Si] versus [N/H] in DLAs, where measurements seems to be separated in two groups. Bold octagons indicate our new DLA measurements. The blue point is our redetermination for $z_{\rm abs}$=2.076 DLA in Q2206-199.

small scatter. The number of low-N DLAs is still small, but it is worth noting that the increase from 2 measurements plus 1 upper limit (in Prochaska et al.ref (2002)) to 4 measurements plus 3 upper limits (in Centurión et al. ref (2002) still shows the [N/Si] ratios clustered around –1.5 dex with very low dispersion. Moreover one of the upper limits cited above is [N/Si] <–1.16 in the $z_{\rm abs}$=2.076 DLA in Q2206–199 given by Pettini (2002), and our reanalysis (Fig. 1) gives for this DLA [N/Si]=–1.44±0.05 which is precisely the mean value of the lower "plateau".
Low and high values of [N/Si] co-exist at a given [Si/H] (Fig. 2, left panel), while the two groups of DLAs differ in their N abundance, and the present data show a transition which occurs at a nitrogen abundance [N/H] ≈ –3 (Fig. 2, right panel). The origin of the two groups of DLAs appears then related to their N abundance and therefore linked to the nucleosynthesis and enrichment history of this element.

4. Discussion

Current models of chemical evolution can reproduce the *high* N/α values observed in BCD and in the majority of DLAs, with the primary N production by intermediate mass stars (Pilyugin ref (1999); Henry et al. **?**; Maynet & Maeder ref (2002); Chiappini et al. ref (2002); Calura et al. ref (2002)). These models pass through the *low* [N/α] ratios, but do not give a plateau at –1.5 dex. If further DLAs measurements give more values clustered at –1.5 dex, the models will need to take this feature into account.

A top heavy initial mass function (IMF) or an IMF truncated below $M \simeq 7M_{\odot}$ in the low-N DLAs has been invoked by Prochaska et al. (2002) to explain the observed lower plateau. We argue that in low-N DLAs the very low N abundances and very small dispersion of the **low** N/α ratios (Fig. 2) may suggest a (modest) production of primary nitrogen in massive stars (Molaro 2003, Centurión et al. 2003). In fact, if massive stars produce primary N, no time delay between the N injection and that of O is expected, and a plateau of the N/O ratios with small scatter is predicted (Pilyugin 1999). In the case of primary N from massive stars, the measured N/O values must constitute a lower envelope to any N/O ratio observed in galaxies, because the intermediate mass stars can only increase the N/O at a later time. The

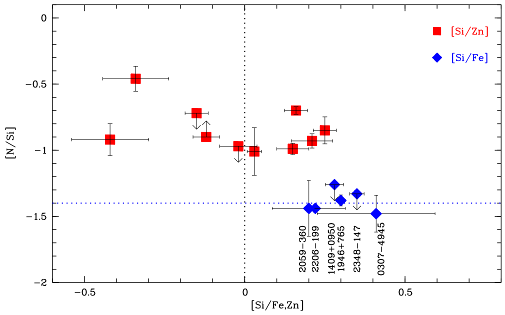

Fig. 3. The NI 1200 multiplet in the z_{abs}=2.0762 DLA in Q2206–199

observations show that the low [N/α] ratios in DLAs are clustered around $\simeq -1.5$, no lower [N/α] values are observed (even though the present detection limit should allow to detect them), therefore these ratios may indeed represent the first observational evidence of primary N production by massive stars. The issue of primary production of nitrogen by massive stars is not settled, but there are models for massive stars which predict N/O and O/H ratios in agreement with those observed in the low-N DLAs (Maynet & Maeder 2002, Umeda et al.2000). These results at least indicate that primary N production in massive stars is possible at the low level observed in the low-N DLAs. In this framework low-N DLAs would be very young objects, caught before the ejection of primary N by intermediate mass stars. High-N DLAs would be older ones, caught after the lag time for the ejection of primary N by the intermediate mass stars. The transition between the low-N and high-N DLAs could be linked to the short lag time ($\simeq$ 250 Myr, see, e.g., Henry et al. 2000) of the primary N enrichment by intermediate mass stars. If primary production of N in massive stars are responsible for the low N/α plateau an enhancement of the α-elements, relative to Fe-peak elements is expected in these DLAs. Fe ejected in longer time scales, mainly by type-Ia SNe, should lag behind O (and N in this case) produced in the short-lived massive stars. Unfortunately, none of the low-N DLAs have abundance determinations of Zn, the iron-peak element free from dust depletion. For low-N DLAs [Si/Fe] $\simeq +0.2/+0.4$ (Fig. 3), which in absence of dust would imply an α enhancement. However without the Zn information this result is not conclusive.

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