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Nitrogen Abundances in High-z DLAs

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Abstract

Determination of chemical abundances for elements produced mainly by Type I SNae and intermediate mass stars in high redshift DLAs probes the early chemical build-up on time-scales comparable with their production. Nitrogen shows a peculiar behaviour never detected before in any other class of objects. For [N/H] < −3 there is a plateau with [N/Si] = −1.45 (±0.05). We interpret this as empirical evidence for primary N production by massive stars in young systems where AGB stars have not yet had time to make their contribution. The plateau provides the observational integrated yields for N production by massive stars which are theoretically rather uncertain. High N/Si and solar [α/iron-peak] ratios are observed at high redshift and place at an earlier epoch the onset of star formation. On the other hand, low N/Si, i.e. young objects, are observed also at relatively low redshifts. These evidences suggest that DLAs started to be formed at a very early epoch but their formation has been extended up to later times.

1.1 Introduction

Damped Lyman-α (DLA) absorption systems are neutral clouds with large HI column densities (N(HI) $\geq 2 \cdot 10^{20}$ cm^{-2}). They are likely protogalactic clumps embedded in dark matter halos which are the progenitors of the present variety of galaxian populations. Highly accurate abundances ($\approx 10\%$) are derived for a variety of chemical elements in DLAs showing metallicities in the range $-2.5 <$ [Fe/H] < -1.0 and a mild evolution with redshift (see Prochaska, these proceedings).

Abundances are measured up to $z = 4.4$ or within 1 Gyr from the Big Bang (BB) and less from the reionization epoch. At these redshifts the maximum allowed time elapsed from the unknown epoch of formation of the systems and the observed redshift starts to be comparable with the nucleosynthesis time-scale for certain elements such as those produced mainly by Type I SNae or by intermediate mass stars (IMS). In these proceedings, we focus on the abundances of nitrogen and sulphur in a sample of high redshift DLAS with the purpose of re-examining their [N/α] and [α/Fe] ratios. More details can be found in Centurión et al (2003) and D'Odorico and Molaro (2003).

1.2 Nitrogen

Nitrogen is thought to be produced in intermediate mass stars with masses in the range between 4-8 $M_{\odot}$ which undergo hot bottom burning in the AGB phase. Thus N is restored into the ISM with a delay which depends on the lifetime of the stellar progenitors

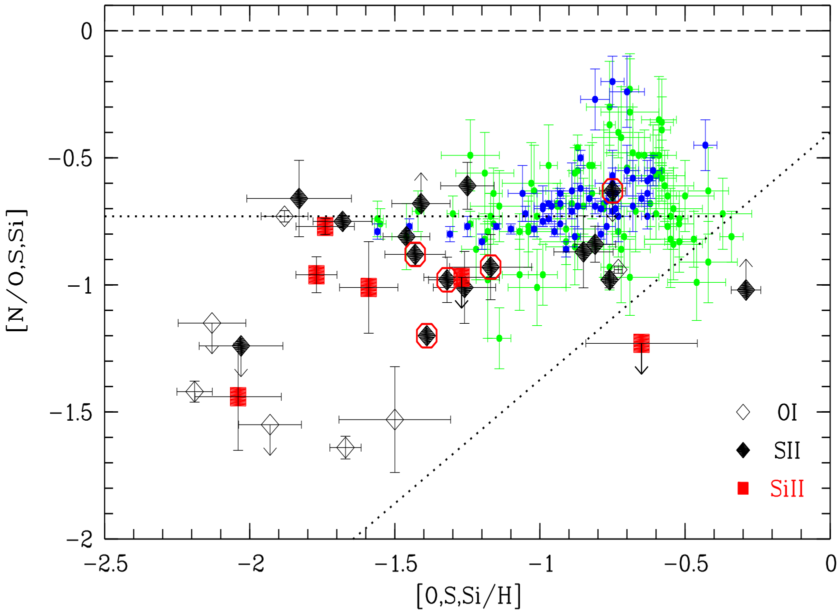

Fig. 1.1. [N/α] ratio versus α-element abundance for DLAs and HII galaxies (small symbols) from Centurión et al. (2003).

which is significantly larger than that of the Type II products. According to Henry et al. (2000) the bulk of N production occurs after $\sim 250-300$ Myr.

Figure 1.1 shows the behaviour of [N/α] ratio versus α-element abundances for a compilation of DLAs from Centurión et al. (2003) compared with those of HII galaxies. The elements representative of the α-element abundances are in order of priority: oxygen, sulphur and silicon. The figure shows the presence of a large scatter in the distribution of the N/α points with several DLAs below the extragalactic HII regions. Prochaska et al. (2002) recently claimed the presence of a bimodal distribution in the [N/Si]-[Si/H] plane, based on high quality Keck observations of two objects found to have similar [N/Si], much lower than the majority of the other DLA systems. There are growing evidences of the existence of such a group with low N/Si values. Very low values are observed towards APM BR J0307-4945 (Dessauges-Zavadsky et al. 2001) and towards Q2059-360 (Centurión et al. 2003). Pettini et al. (2002) provided three stringent limits for N/Si. Thus we have a total of 4 determinations and 3 upper limits which look disconnected from the bulk of the DLAs.

1.3 The case of Q2206-199

The DLA at $z_{\rm abs}$ = 2.07622 towards Q2206-199 is one of the 3 upper limits studied by Pettini et al. (2002). Inspection of their fit for the NI 1200 Å multiplet shows some inconsistency between the two stronger transitions. From their Fig. 5, one notes that the abundance which reproduces the NI 1199.5 Å line is too strong to fit the NI 1200.2 Å transition line. However, a shallow absorption is present at the base of the stronger feature. This relatively broad absorption can be produced by a HI interloper with a column density of log N(HI) = 12.95 ($\pm$ 0.02) and a broadening of b = 40 km s^{-1}. A new N determination which

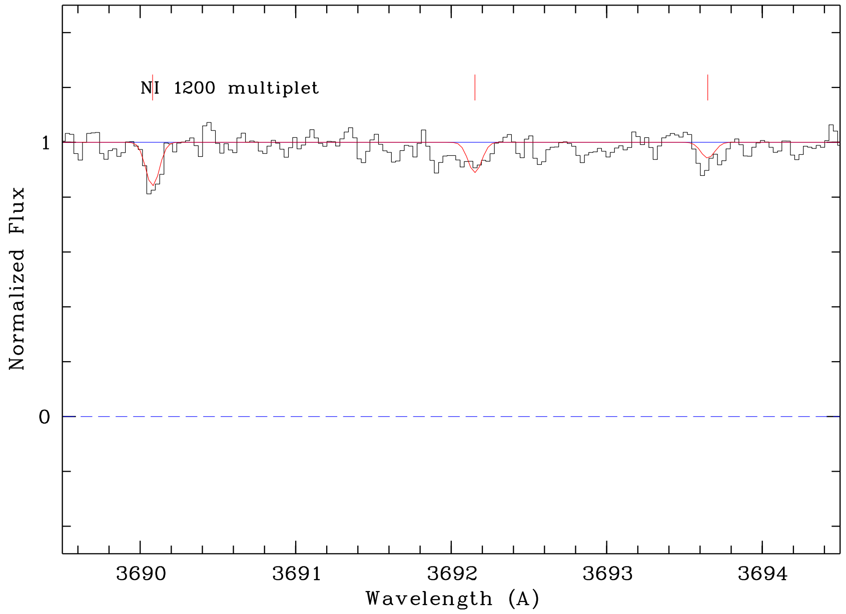

Fig. 1.2. The NI 1200 Å multiplet of the DLA at z_{abs}=2.0762 towards Q2206-199.

accounts for the HI contamination corresponds to log N(NI) = 12.58 ($\pm$0.05) and b = 3 km s^{-1} and is shown in Fig. 1.2. When we combine it with the Si measured in the system we obtain [N/Si] = $-$1.44 ($\pm$0.05). Thus also this system is found to fall precisely onto the low N/Si plateau which is now represented by five systems.

1.4 A low-[N/Si] plateau: existence and possible explanation

In Fig. 1.3 all the data points are taken with respect to Si, which although refractory is only mildly depleted and has the advantage of being measured in almost all the DLAs. At face value, it is not clear from Fig. 1.3 whether the bimodal distribution is real or if it is just the result of the small number of observations. Moreover, the presence of some DLAs with intermediate N/Si values such as the case towards Q0841+129B which lies between the two groups suggests some connection between the low and high-N/Si groups. However, a different way of plotting the same data reveals that there are two really distinct groups with different evolutionary behaviour. Following Molaro (2003) we plot in Fig. 1.4 the N/Si ratio versus nitrogen enrichment. The plot clearly shows two different regimes below and above approximately [N/H] ≈ -3. For [N/H] < -3 there are all the low N/Si values with [N/Si] = $-$1.446 ($\pm$0.025), while for [N/H] > -3 there are 17 values providing a weighted mean of [N/Si] = $-$0.75 ($\pm$0.17). A Montecarlo analysis of the errors of the high N/Si plateau gives an expected dispersion of 0.10 ($\pm$0.02) thus providing some evidence for an intrinsic dispersion. For the low N/Si plateau the same analysis gives an expected dispersion which is comparable to and even smaller than the observed one providing no evidence for dispersion.

What is the reason for the different aspect of the two plots of Figures 1.3 and 1.4 ? The α-enrichment depends critically on the SFR and it is plausible that the DLAs have different SF histories. This means that they can reach the same amount of α enrichment at different times.

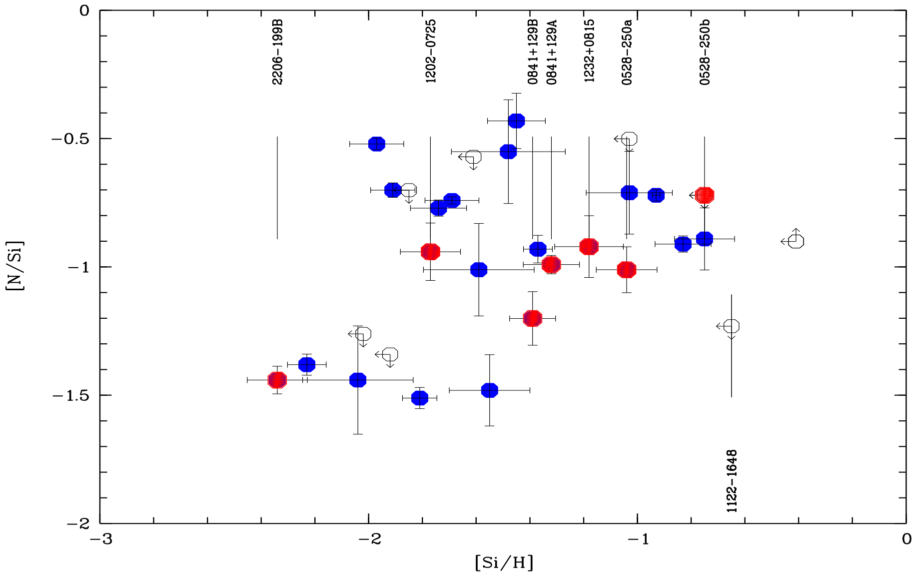

Fig. 1.3. [N/Si] ratio versus [Si/H] abundance for DLAs. Red points (lighter ones in B&W) with the label are the new measurements. Empty circles are limits.

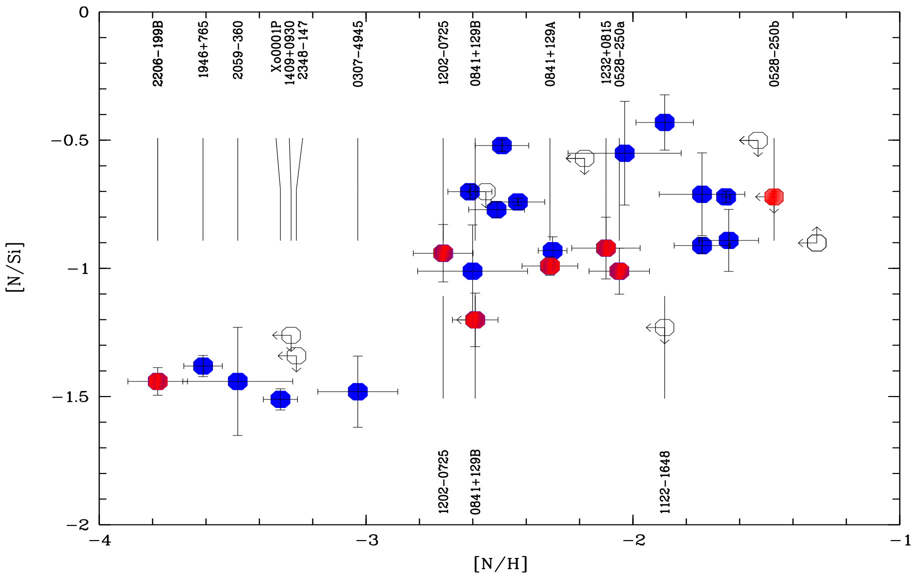

Fig. 1.4. [N/α] ratio versus nitrogen abundance for DLAs. Red points (lighter ones in B&W) are the new measurements.

On the other hand, N production depends more critically on the lifetime of its progenitors rather than on the SFR. Thus plotting the N/Si versus the nitrogen enrichment is closer to a true temporal evolution and the degeneracy that we see in the N/Si-α/H plane is resolved in the N/Si-N/H plane.

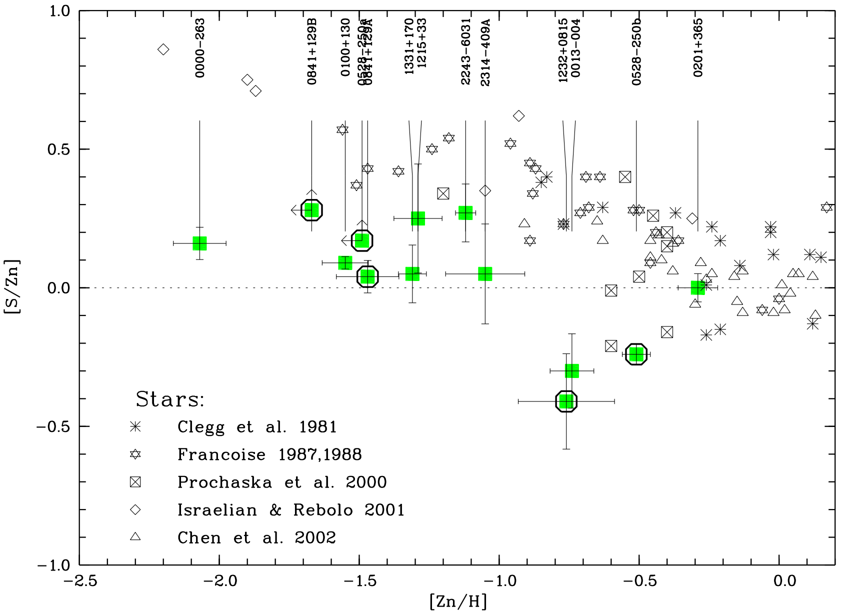

Fig. 1.5. [S/Zn] ratios. Circles highlight the new measures from Centurión et al. (2003)

Low N/Si values have been generally ascribed to young systems and high N/Si to DLAs in a more evolved status. However, the presence of a plateau is not easy to reconcile with this interpretation, since we expect a distribution rather than a plateau.

A top-heavy or truncated IMF has been suggested by Prochaska et al. (2002) to explain the low N/Si plateau. However, N in the low N/Si plateau is found to increase in lockstep with the α-elements by one order of magnitude, with no detectable dispersion. We thus interpret the low N/Si plateau as an evidence for primary N production by massive stars. If the systems are younger than the characteristic time-scale for the N production by AGB stars then there is no need to invoke any change in the initial IMF. The high N/Si values result from the AGB N production in relatively older systems. With this interpretation we do not expect to find any object below the low N/Si plateau, but some in between the two plateaux may be present. Indeed, Q0841+129B with an intermediate N/Si value could be one of these cases.

Theoretically, N is not expected to be produced in standard models of massive stars unless C in the He-shell mixes with the H burning shell (Heger & Woosley 2002). Rotation can induce this mixing leading to N production (Meynet and Maeder 2002). The prediction for massive stars (8-120 $M_\odot$) with vsin i = 400 km s^{-1} and metallicity $Z=1\cdot10^{-5}$ solar is [N/O]=−1.5 and about 0.7 dex below the full mass production (Meynet et al. 2003). Also the PopIII yields for massive stars of Limongi and Chieffi (2002), computed adopting a high $^{14}C(\alpha,\gamma)^{16}O$ rate (Caughlan et al. 1985) can make N. These models coupled with those for the IMS from Chieffi et al. (2002) computed with a mass loss parameter η = 6 are able to match the observations. In fact the integration with a Salpeter IMF over the full mass

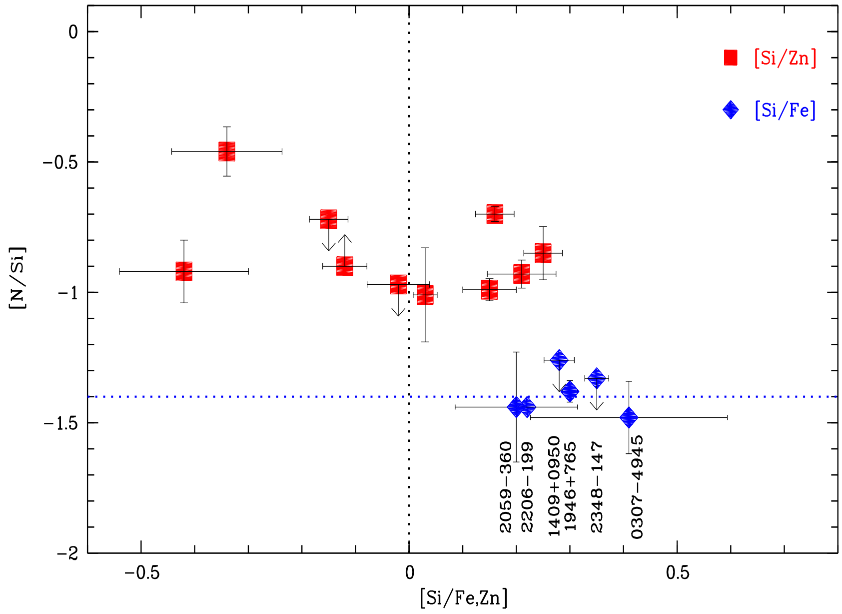

Fig. 1.6. [N/Si] ratios versus [Si/Fe] for diamons or [Si/Fe] squares.

spectrum (4-80 $M_\odot$) gives [N/O]≈–0.85, while the integration over only the more massive stars (15-80 $M_\odot$) gives [N/O]≈ −1.5.

We would like to emphasize that for the first time the observations of DLAs offer empirical guidelines to the theoretical yields for nitrogen production in massive stars.

1.5 The [α/Fe] ratios

The presence of an [α/Fe] enrichment in DLAs has recently been the subject of a debate. The problem is that the presence of dust in DLAs complicates the interpretation since it depletes the elements differentially. When dust has been corrected for or when the interpretation relies on non-refractory elements only, the DLAs show a moderate or even absent [α/Fe] enhancement. The new S observations highlighted with circles in Fig. 1.5 provide new evidence for solar and even subsolar ratios in the DLAs.

Solar [α/Fe] ratios imply that most DLAs are old enough to cause the Type Ia to have already mixed their products in the medium and have lowered the α-Fe ratios significantly.

It is rather interesting to study the α over iron ratios in the systems with low N/Si. If these are young systems, as we propose, we should see a marked [α/Fe] enhancement. The [Si/Fe] shown in Fig. 1.6 are enhanced by about 0.3 dex, almost in line with the other DLAs. Unfortunately, Zn is not measured thus preventing an assessment of the presence of dust. The case of Q0841+129B is rather interesting. As we mentioned before, this system looks like a transition object and its age should be very close to the characteristic time for N enrichment by AGBs. Thus, it is rather encouraging to find that [Si/Zn] > 0.35 providing in this case a hint of genuine enrichment as expected, which remains rather unique so far.

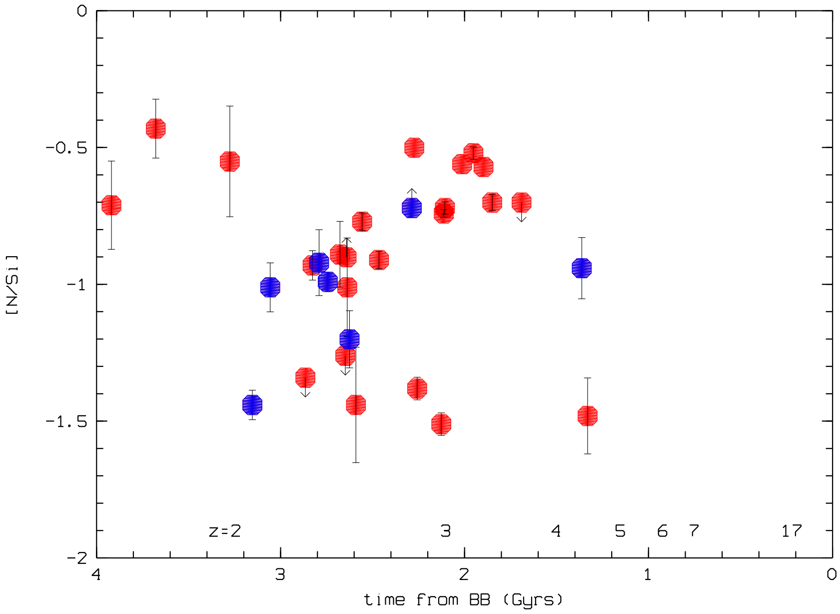

Fig. 1.7. [N/Si] ratios versus time. Blue points (darker ones in B&W) are the new measurements

1.6 The epoch of DLA formation

Statistically, the fraction of low-N/Si DLAs is about 25% of the total, counting also the 2 upper limits. This is consistent with a picture of young systems younger than 250 Myrs and old systems older than about 1 Gyr on average, or more if the time for the full N release is greater than 250 Myrs. In Fig. 1.7 the N/Si values are plotted versus time since BB (or redshift) according to present-day cosmology. It is possible to see that high and low N/Si are observed at any time in the range spanned by the observations. If we consider 250 Myrs as a representative time for the full release of N by IMS (it is longer for rotational models) a high N/Si value such as the one observed towards Q1202-0725 at $z = 4.4$ put the onset of star formation at $z > 6$ or less than 1 Gyr from the BB. A similar indication comes from the observation of solar [α/Fe] ratios in high redshift DLAs, when we consider the evolutionary time-scales for the Type Ia. On the other hand, a low N/Si value such as the one observed towards Q2206-199 at $z = 2.0$ implies that the star formation in this system took place at $z < 2.5$. These results indicate a continuous formation of DLAs rather than a specific epoch for their formation.

1.7 Acknowledgements

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