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# On the origin of nitrogen in low-metallicity galaxies

## Blue compact galaxies versus damped Ly$\alpha$ absorbers

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**Abstract.** A remarkably small scatter in the N/O ratios for the HII regions in low-metallicity blue compact galaxies (BCG) has been found recently. It lead to the conclusion that N and O are both produced by massive stars. Conversely, the N/Si ratios in damped Ly$\alpha$ absorbers (DLA) show a large scatter. This result provides support for the time-delay model of nitrogen production in intermediate-mass stars, nitrogen production in massive stars being not required. The goal of this study is to test whether these observational data are compatible with each other and with the existing ideas on the chemical evolution of galaxies.

We find that it is possible to reconcile the constancy of N/O ratios in low-metallicity BCGs and the scatter of N/Si ratios in DLAs under the following three assumptions: *1*) a significant part of nitrogen is produced by intermediate-mass stars, *2*) star formation in BCGs and DLAs occurs in bursts separated by quiescent periods, *3*) the previous star formation events are responsible for measured heavy element abundances of HII regions in BCGs.

Since the reality of low N/Si ratios in DLAs is not beyond question, the possibility that the nitrogen in low-metallicity BCGs has been produced by massive stars cannot be rejected without additional observations.

**Key words:** galaxies: abundances – galaxies: ISM – galaxies: irregular – galaxies: quasars: absorption lines

### 1. Introduction

The theoretical stellar yields of nitrogen are rather uncertain. It has been found (Renzini & Voli 1981; Marigo et al. 1996, 1998; van den Hoek & Groenewegen 1997) that nitrogen production takes place in the asymptotic giant branch phase of the evolution of intermediate-mass stars, but the mass range of the nitrogen-producing stars and the predicted amount of freshly produced nitrogen depend on poorly known parameters. The theoretical yields of nitrogen by massive stars are essentially unknown. Therefore, an “empirical” approach (analysis of the relation of N/O with O/H) has been widely used to study of the origin of nitrogen (Edmunds & Pagel 1978; Lequeux et al. 1979; Matteucci & Tosi 1985; Garnett 1990; Pilyugin 1992, 1993; Vila-Costas & Edmunds 1993; Marconi et al. 1994; among others).

Pagel (1985) called attention to the large scatter in N/O at fixed O/H in low-metallicity dwarf galaxies. Given the time delay between the injection of nitrogen by intermediate-mass stars and that of oxygen by shorter lived massive stars (the time – delay hypothesis: Edmunds & Pagel 1978) and the hypothesis of self-enrichment of star formation regions (Kunth & Sargent 1986), models for the chemical evolution of dwarf galaxies reproducing the observed scatter of N/O have been constructed (Garnett 1990, Pilyugin 1992, Marconi et al. 1994). A significant part (if not all) of nitrogen was assumed in these models to be produced by intermediate-mass stars. The HII regions with high N/O abundance ratios have been considered to be in early stages of star formation (before self-enrichment in oxygen occured), reflecting the chemical composition of the whole galaxy. The HII regions in advanced stages of the star formation bursts would have small N/O ratios due to self-enrichment in oxygen. These HII regions would then reflect the local chemical composition, and the scatter in their N/O ratios would be caused by different degrees of temporal decrease of N/O ratio within the HII regions. During the interburst period the nitrogen is ejected by the intermediate-mass stars, and the matter ejected by massive and intermediate-mass stars is supposed to be well mixed throughout the whole galaxy. Some scatter in global N/O ratios among dwarf galaxies can be caused by enriched galactic winds (Pilyugin 1993, 1994; Marconi et al. 1994).

In this framework, the chemical composition of low-metallicity dwarf galaxies was expected to be characterised by high N/O ratios with a relatively small dispersion, and the large observed dispersion in the N/O ratios is supposed to be due to a temporary N/O decrease inside HII regions in which the chemical composition is determined spectroscopically.

In contrast with previous measurements, Thuan et al. (1995) and Izotov & Thuan (1999) have found a remarkably small scatter in the N/O ratios of the HII regions in low-metallicity (with 12+logO/H $\leq$ 7.6) BCGs. Izotov & Thuan concluded that these galaxies are presently undergoing their first burst of star formation, and that nitrogen in these galaxies is produced by massive stars only. Since the intermediate and low-mass stars certainly do not make an appreciable contribution to oxygen production, the N/O ratio corresponding to the ejecta of mas-

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*Send offprint requests to*: L.S. Pilyugin sive stars and observed in low-metallicity BCGs is a lower limit for the global N/O ratios. This conclusion is in conflict with the fact that the nitrogen to $\alpha$-element abundance ratios measured in some DLAs are well below than the typical value observed in low-metallicity BCGs (Lu et al. 1998, and references therein). [Since oxygen abundance measurements are not available for DLAs, $[N/S]$ or $[N/Si]$ ratios are considered instead of $[N/O]$. This is justified by the fact that there is no reason to believe that the relative abundances of O, S and Si which are all produced in Type II supernovae are different from solar in DLAs.] However, as suggested by Izotov & Thuan (1999), the nitrogen to $\alpha$-element abundance ratios in DLAs can be significantly underestimated if the absorption lines originate in the HII instead of the HI gas. Nevertheless, the possibility of a truly low nitrogen abundances in some DLAs cannot be excluded without additional observations, and these DLAs with low nitrogen to $\alpha$-element abundance ratios do not confirm the idea that the N/O ratio in low-metallicity BCGs is a lower limit for the global N/O ratio in galaxies.

The best way to find the lower limit of N/O ratio and hence the amount of nitrogen produced by massive stars would be to determine the N/O ratios in galactic halo stars. Unfortunately, at the present state their N/O ratios cannot be determined with a precision better than a factor 2 or 3. The only firm conclusion is that nitrogen has a strong primary component (Carbon et al. 1987).

The goal of this study is to test whether the constancy of the N/O ratios in low-metallicity BCGs and and the scatter of the N/Si ratios in DLAs are compatible with each other and with the existing ideas on the chemical evolution of galaxies.

## 2. Possible interpretation of nitrogen abundances in BCGs and DLAs

Here we will demonstrate that the constancy of the N/O ratios in low-metallicity BCGs and the scatter of the N/Si ratios in DLAs can be reconciled under the following three assumptions: *1*) a significant part of nitrogen is produced by intermediate-mass stars, *2*) star formation in BCGs and DLAs occurs in bursts separated by quiescent periods, *3*) the previous star formation events are responsible for heavy element abundances observed in the HII regions of the BCGs.

As it was discussed in Introduction, there are no crucial arguments in favor of or against assumption *1*.

Assumption *2* - that star formation in BCGs and DLAs occurs in bursts separated by quiescent periods - is commonly accepted in the case of BCGs after it was initially suggested by Searle & Sargent (1972). In order to reproduce the observed properties of low-metallicity BCGs, only a few (in some cases only one or two) star formation bursts during their life are required (Tosi 1994). Papaderos et al. (1998) have found that the spectrophotometric properties of SBS 0335-052 can be accounted for by a stellar population not older than $\sim 100$ Myr. The possibility of an underlying old (10 Gyr) stellar population with mass not exceeding $\sim 10$ times that of young stellar population mass hawever cannot be definitely ruled out on the basis of the spectrophotometric properties. In other words, the time interval between possible previous and current star formation events can be as large as $\sim 10$ Gyr. In the case of DLAs, assumption *2* seems to be also acceptable, despite the fact that DLAs do not constitute an homogeneous class of galaxies but belong to the wide variety of morphological types of galaxies (Le Brun et al. 1997). Star formation in a given region in galaxies of any morphological type seems to be episodic. The DLA observations sample the general interstellar medium at random times along random lines of sight and may or may not see a region where a star formation event occured in a recent past.

Assumption *3* - that previous star formation events are responsible for the observed heavy element abundances in BCGs - is equivalent to say that the element abundances of HII regions in BCGs are not yet polluted by the stars of the present star formation event, and that their abundances reflect the average N/O in the galaxy, which results from cumulative previous star formation. Martin (1996) has found that the current event of star formation in the most metal-poor known blue compact galaxy I Zw 18 started 15–27 Myr ago. The duration of current star formation burst in another extremely metal-poor blue compact galaxy SBS 0335-052 (Papaderos et al. 1998) is also in excess of the lifetime of the most massive stars. Therefore, a selection effect in favor of observations of young HII regions in which the massive stars had not yet have time to explode as supernovae cannot be only reason why the HII regions are not observed as self-enriched. Massive stars in the current star formation burst have often had time to synthesize heavy elements and to eject them via stellar winds and supernova explosions into the surrounding interstellar gas. Kunth & Sargent (1986) suggest that the heavy elements produced in this way initially mix into H II region only, i.e. the giant H II regions are self-enriched. However, it is possible that the nucleosynthetic products of massive stars are in high stages of ionization and do not make appreciable contribution to the element abundance as derived from optical spectra (Kobulnicky & Skillman 1997, Kobulnicky 1999). Indeed, the oxygen abundance in SBS 0335-052 has been measured within the region of 3.6 kpc (Izotov et al. 1997). There is a supershell of radius $\sim 380$ pc. There is no difference in oxygen abundances inside and outside the supershell as it should be expected since $\sim 1500$ supernovae are required to produce this supershell (Izotov et al. 1997). Other star-forming galaxies, which are chemically homogeneous despite the presence of multiple massive star clusters, are reported by Kobulnicky & Skillman (1998). This can be considered as evidence that the nucleosynthetic products of massive stars in giant HII regions are hidden from optical spectroscopic searches because they are predominantly found in a hot, highly – ionized superbubble. It should be noted however that some fraction of supernova ejecta can mix with dense clouds changing their chemical composition. If such cloud survives and produces a subgroup of stars shortly, the star formation region will have sub-generations of stars with different chemical composition. This seems to be the case in the Orion star formation region (Cunha & Lambert 1994, Pilyugin & Edmunds 1996).

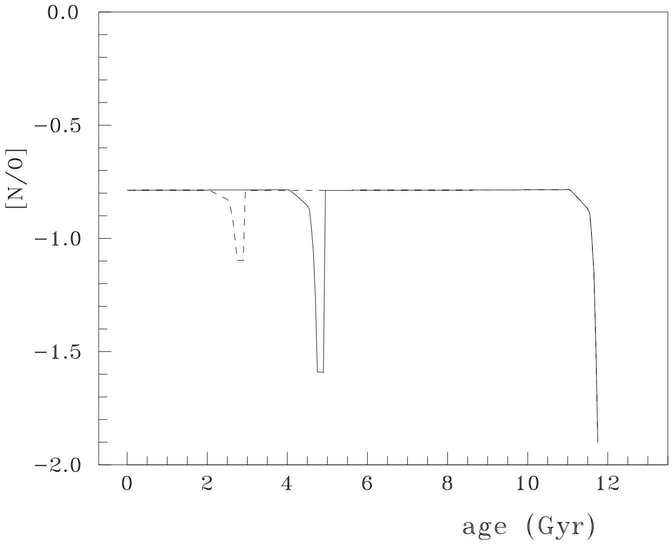

**Fig. 1.** The $[N/O]$ as a function of time for two models with different star formation histories. The dashed line corresponds to the evolution of a system in which two star formation bursts of equal intensities occured 12 Gyr and 3 Gyr ago. The solid line corresponds to the evolution of a system in which two star formation bursts occured 12 Gyr and 5 Gyr ago, the second star formation event being 5 times stronger than the first one.

With assumptions *1* and *2* the behaviour of the N/O ratio is described by models of type suggested by Garnett (1990), Pilyugin (1992), Marconi et al. (1994). Fig. 1 illustrates the time behaviour of N/O in the interstellar medium of a galaxy in the case when all the nitrogen is produced by intermediate-mass stars (see also Fig. 7 in Pilyugin 1992). Since only low-metallicity galaxies are considered here, the adopted total astration level in the models is small (less than 0.05), and the nitrogen yield is assumed to be independent on metallicity. The nitrogen yields by stars in the mass interval 3÷4M$_\odot$ were taken from Renzini & Voli (1981). As can be seen on Fig. 1, the N/O ratio increases for about 1 Gyr after the star formation burst and then remains constant. This is due to the assumption that nitrogen is not produced by stars with masses less than $\sim 3M_\odot$ (Renzini & Voli 1981). If stars with masses less than $\sim 3M_\odot$ also make some contribution to the nitrogen production (Marigo et al. 1996, van den Hoek and Groenewegen 1997), this does not change appeciably the picture because the amount of nitrogen ejected decreases strongly with decreasing stellar mass (Renzini & Voli 1981, Marigo et al. 1996, van den Hoek and Groenewegen 1997). Therefore, low-metallicity systems with a large time interval (more than $\sim$ 1 Gyr) between successive star formation events will have close values of N/O ratios before the current star formation event (Fig. 1).

With this behaviour of the N/O ratio and taking into account assumption *3*, the nitrogen abundances in BCGs and DLAs can be interpreted in the following way. The low-metallicity BCGs are systems with a small amount of old (with age $> 1$ Gyr) underlying stellar population over which the current star formation burst is superposed; only the stars from the previous star formation event(s) are responsible for the observed chemical composition in the giant HII regions in these galaxies. The DLAs with low nitrogen to $\alpha$-element ratios correspond to systems probed less than 1 Gyr after the last local star formation event, but after a time sufficient for disappearance of the superbubble and mixing of the freshly produced heavy elements in the interstellar medium. Conversely, the DLAs with nitrogen to $\alpha$-element ratios close to that in low-metallicity BCGs correspond to systems in which the time interval after last star formation event is sufficiently large for intermediate-mass stars to have substantially enhanced the nitrogen to $\alpha$-element abundance ratios.

## 3. Discussion and conclusions

We have shown that the observed nitrogen abundances in both BCGs and DLAs can be reproduced if a significant part of nitrogen is produced by intermediate-mass stars. If one assumes instead that the nitrogen abundances measured in low-metallicity BCGs is produced by massive stars, the observational data for BCGs and DLAs are incompatible with each other. Can this be considered as a crucial argument in favor of dominant production of nitrogen by intermediate-mass stars? Since the low nitrogen to $\alpha$-element abundance ratios obtained in some DLAs is not beyond question, the possibility that nitrogen in low-metallicity BCGs is produced by massive stars cannot be excluded.

The crucial argument in favor of dominant production of nitrogen by intermediate-mass stars would be the reliable proof of the existence of systems with low N/O ratios. Solid determinations of nitrogen abundances in damped Ly$\alpha$ absorbers can clarify this matter. The Zn/S abundance ratios in DLAs with low measured nitrogen to $\alpha$-element abundance ratios can also tell us something about the reality of low N/O ratios in these objects. The measured value of $[Zn/S]$ in DLA associated with QSO 0100+130 is close to solar ratio (Prochaska & Wolfe 1998, Lu et al. 1998), indicating that Type I supernovae have already contributed to the zink abundance. The measured $[N/S]$ in this DLA is close to the $[N/O]$ ratio in low-metallicity BCGs. If values of Zn/S in DLAs with low N/O ratios are close to the solar ratio, this will be a strong argument in favor of an underestimation of the nitrogen to $\alpha$-element abundance ratios. The time scale for nitrogen enrichment is shorter than the time scale for iron enrichment, and a system with high Fe/O ratio should not have a low N/O ratio. If values of $[Zn/S]$ in DLAs with measured low N/O ratios are close to $[Fe/O]$ ratios in the galactic halo stars, this can be considered as an argument in favor of genuinely low nitrogen to $\alpha$-element abundance ratios in these DLAs.

Of course, the best way to find the amount of nitrogen produced by massive stars would be an undisputable determination of N/O ratios in galactic halo stars.

In summary:

If a significant part of nitrogen is produced by intermediate-mass stars, it is possible to reconcile the observational data for BCGs and DLAs.

If nitrogen is mainly produced by massive stars, the observational data for BCGs and DLAs are incompatible with each other. Since the low nitrogen to $\alpha$-element abundance ratios obtained in some DLAs are not beyond question, the possibility that nitrogen measured in low-metallicity BCGs is produced by massive stars cannot however be completely excluded.

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