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Oxygen abundance from strong-line methods at extremely low metallicities

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Abstract

The determination of oxygen abundance in nebulae requires measuring a significant number of emission lines distributed along a wide spectral range. The required measurements are hard to obtain at high redshift, where sources are very faint, and where the accessible spectral range is limited. These difficulties are often overcome using empirical relationships between the oxygen abundance and the fluxes in a small number of strong lines. The so-called strong-line methods are often the only practical alternative for metallicity estimate at high redshift. In this sense, the low metallicities range is particularly important since high redshift objects are primitive and so of low metallic content. One of the most widely used relationships links the oxygen with the ratio between [NII]6583 and Hα. This relationship shows a large scatter at low metallicity. In an effort to bring down the errors, we re-calibrated the relationship using a large sample of extremely metal-poor galaxies. The SDSS spectra of the galaxies were all analyzed in the same way to minimize systematic errors. To our surprise, the decrease of scatter reveals that the ratio [N II]6583 to Hα seems to be independent of metallicity at low oxygen abundance ($12 + \log[\mathrm{O/H}] < 7.6$). This result casts doubts on the metallicities of high-redshift objects based on the relationship. We explain how the re-calibration was carried (including the sample selection and the abundance determinations). In addition, we try explain what produces the lack of correlation.

1 Introduction

Galaxies with very low metallic content are probably unevolved objects and they provide a readily accessible fossil record from the early universe. These objects are to be expected according to the paradigm of hierarchical galaxy formation, where large galaxies arise through the assembly of smaller ones in an inefficient process leaving may dwarf galaxies as remnant. They seem to be materialized as the extremely metal-poor (XMP) dwarf galaxies observed today which, consequently, would be the closest examples we can find of these elementary primordial units from which larger galaxies assembled [3].

Unfortunately, XMP galaxies are rare. The review by [4] cites only 31 targets with metallicity below one-tenth the solar value, which is the threshold customarily used to define XMP galaxies. The number of known targets has increased with time, but last year a bibliographic compilation [5] showed only 129 such targets. Furthermore, we did a systematic search using k-means [9] and we added only eleven new low-metallicity galaxies. This classification is focused on a spectral region very sensitive to metallicity, this region contains Hα and [NII]$\lambda\lambda$6548,6583 (e.g. [1]).

Because of XMP galaxies are rare, the relationship that links the oxygen abundance and the $N2$ index (Eq. 1) has very few points at low metallicities (see [8]). We want to complete the sample used to calibrate this relationship with the 140 galaxies mentioned in the previous paragraph.

$$N2 = \log \frac{[\mathrm{NII}]6583}{\mathrm{H}\alpha} \tag{1}$$

The $N2$ index was defined by [1] and it is used to obtain oxygen abundance when we do not have all the spectral lines needed to apply the direct method. The relationship with oxygen abundance is calculated using only HII regions with oxygen abundance determined using electronic temperature method.

$N2$ has advantages compared, for example, with R_{23}, which is one of the most used methods (e.g. [10]). $N2$ has a monotonic behaviour with oxygen abundance, and it also uses ratios of emission lines which are close in wavelength, then it does not depend on reddening corrections or flux calibrations.

The main interest of this index is its application to high-redshift galaxies. For these galaxies we do not usually have all the lines needed to determine the oxygen abundance by the direct method.

2 Sample of metal-poor galaxies

Our first objective was to complete the sample of low metallicity galaxies in [8] calibration. For this work we use all low metallicity galaxies with spectrum in SDSS/DR7. From the 140 metal-poor galaxies from [5] we identify 79 with SDSS/DR7 spectrum. Nevertheless, only 46 galaxies have all the lines needed to obtain the oxygen abundance using the direct method, i.e. the electronic temperature method. We apply the same procedures as in [7]. In

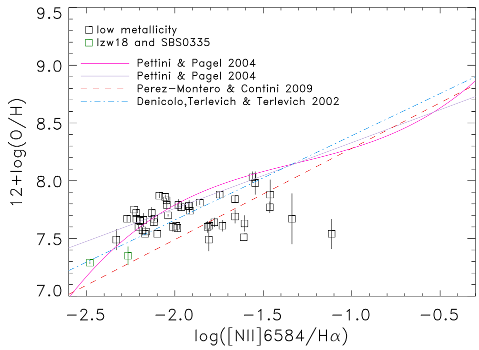

Figure 1: Oxygen abundance versus $N2$ index for the 48 metal-poor galaxies in our sample. Green squares are for IZw18 and SBS0335–052. Black squares correspond to the rest. The lines show different calibrations of the relationship existing in the literature (as indicated in the inset)

addition, we supplemented them with ISIS@WHT spectra for SBS0335–052 and IZw18, the lowest metallicity galaxies known so far. All in all, we gather 48 galaxies in our sample.

3 Results

Figure 1 represents the results for the 48 galaxies. We selected low metallicity galaxies with $12+\log[\mathrm{O/H}] < 7.65$, but we obtain for same galaxies oxygen abundances higher than 7.65. It is not a bias of code used to determine abundances, because if we take the lines fluxes from the literature, our method provides the same values of oxygen abundance in the literature. The discrepancies should be ascribed to the determination of the fluxes.

As shown in Fig. 1, the oxygen abundance has a tendency to be constant with $N2$ at low-metallicities. This tendency could be explained for two reasons:

- Variations in the ionization parameter (U). Figure 2, left, represents [O III]λ5007/Hβ versus $N2$ index for all galaxies, and CLOUDY models [2] with $-3 < \log U < -2$ and $7.16 < 12+\log[\mathrm{O/H}] < 8.16$. We can cover all observational points with these models, consequently, galaxies seem to have ionization parameters between these two values.
- Variations in N/O from galaxy to galaxy may be greater than expected. For this kind of galaxies a $\log[\mathrm{N/O}] \approx -1.6$. Using $N2S2$ index [6], we obtain values for log[N/O] between -1.6 and -1.2 for our galaxies (Fig 2, right)

In order to further understand these two reasons, we modeled with CLOUDY spectra such that, $7.16 < 12+\log[\mathrm{O/H}] < 8.16$, $-3 < \log U < -2$ and $-1.6 < \log[\mathrm{N/O}] < -1.2$.

Prediction of $N2$ in models for differents values of N/O are shown in Fig. 3. With this grid of models is possible to cover all points in our sample. Moreover, knowing N/O and

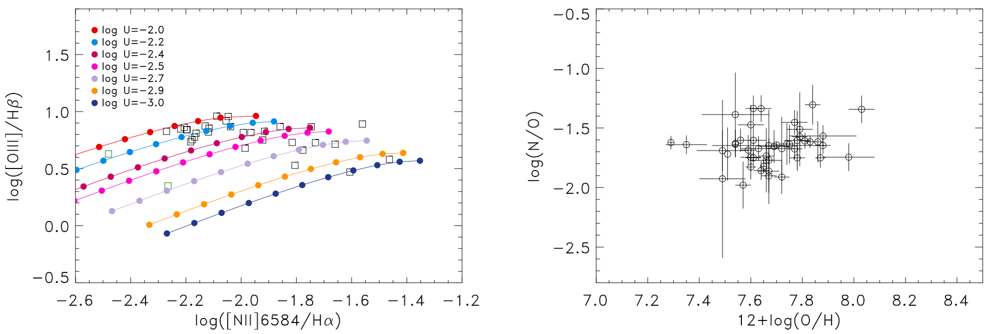

Figure 2: *Left panel:* [O III]λ5007 versus $N2$ index for our 48 galaxies and for the CLOUDY models. Black squares correspond to our galaxies. Each color corresponds to a value of the ionization parameter. Each point of the same color corresponds to a value of the oxygen abundance, with the value increasing from left to right. *Right panel:* N/O for our 48 galaxies versus oxygen abundance.

the oxygen abundance the grid of models allow us known the ionization parameter for our sample of galaxies.

Separating by ionization parameter our galaxies (Fig. 4, left), it is possible to see that the oxygen abundance trend to be constant could be explained by a charge in the ionization parameter, because the ionization parameter systematically decrease from left to right. Furthermore, an increase in the ratio N/O also explains the observed tendency (Fig. 4, right) Therefore, the trend for the oxygen abundance to be constant with $N2$ index is due to a combination of both effects, decrease in the ionization parameter and an increase in N/O with increasing $N2$.

3.1 Why does the ionization parameter decrease?

In Figure 5, left, we represent a histogram where we have number of galaxies vs equivalent width of Hβ, which is an evolution indicator, i.e., the smaller the more evolved the HII region. Using this histogram we separate the galaxies according to their equivalent widths at $EW(\mathrm{H}\beta) = 2.0$. Figure 5, right, represents galaxies with $EW(\mathrm{H}\beta) < 2.0$ with red points, and galaxies with $EW(\mathrm{H}\beta) > 2.0$ with black points. If we compare Fig. 4, left, and Fig. 5, right, we can verify that the galaxies with the lower ionization parameter are the most evolved too.

4 Conclusions

So far [N II]/Hα has been presented as a useful empirical method to determine oxygen abundance in HII regions, particularly for application to the analysis of star-forming galaxies at high redshift.

When looking for a metallicity indicator employing bright emission lines, as is the

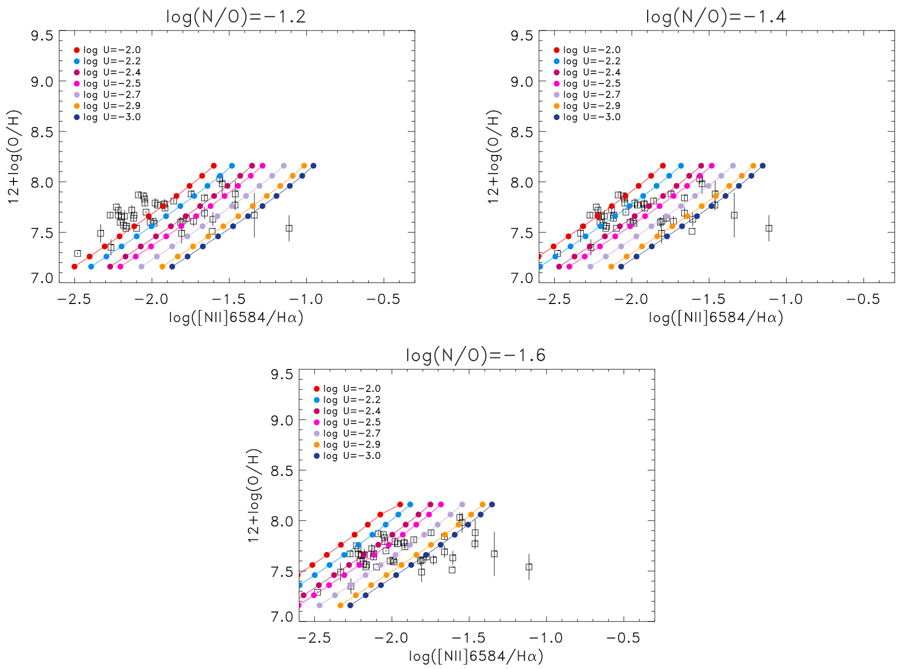

Figure 3: Grids of models for three different values of N/O. Black squares correspond to our galaxies. Each color corresponds to a value of the ionization parameter. Each point of the same color corresponds to a value of the oxygen abundance, with the value increasing from left to right.

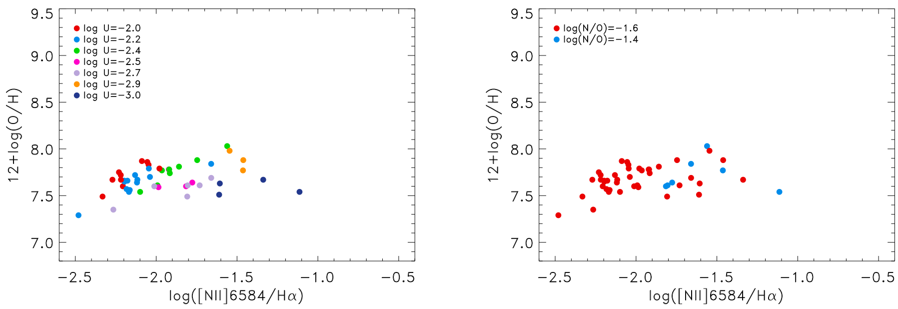

Figure 4: *Left panel:* Oxygen abundance versus $N2$ index separated by color according to their ionization parameter. *Right panel:* Oxygen abundance versus $N2$ index separated according to N/O.

case of $N2$, is intended to have the chemical abundance as the only dependence, which is improbable, because physical conditions o ionized gas are controlled for other parameters.

Ionization parameter, defined as the ratio between the number of ionizing photons and density of hydrogen atoms, is the parameter that causes more internal variation. [1] note in

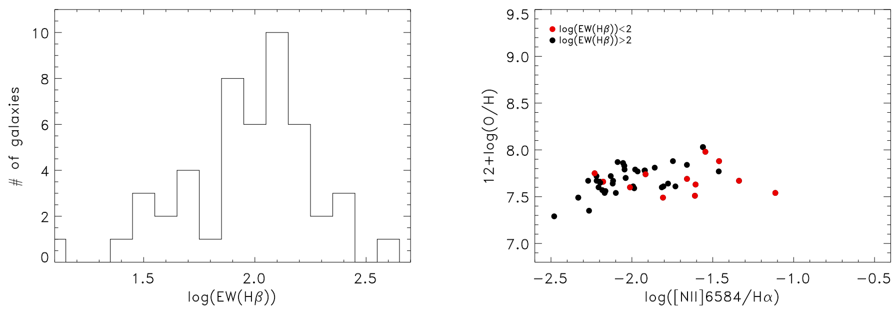

Figure 5: *Left panel:* Histogram with number of galaxies with a given Hβ equivalent width. *Right panel:* Oxygen abundance versus $N2$ index color-coded according to the Hβ equivalent width.

their work the large dispersion associated with the parameter $N2$, caused by the dependence of the ionization parameter, whose variation in giant HII regions is due to the age distribution of ionizing clusters. On the other hand, there is also a high level of uncertainty because of the variation of the ratio between nitrogen and oxygen abundances. This uncertainty is increased at low metallicities because the nitrogen has a primary origin and therefore does not depend on metallicity.

Therefore, the work presented here suggest that $N2$ index is not useful at low-metallicities. The oxygen abundance has tendency to constant with $N2$ because of two functional parameters affects the behavior of the index in a significant way.

References

[1] Denicoló, G., Terlevich, R., & Terlevich, E. 2002, RevMexAA Conf. Ser., 12, 257

[2] Ferland, G. J., Korista, K. T., Verner, D. A., et al. 1998, PASP, 110, 761

[3] Izotov, Y. I. & Thuan, T. X. 2004, ApJ, 602, 200

[4] Kunth, D. & Östlin, G. 2000, A&ARv, 10, 1

[5] Morales-Luis, A. B., Sánchez Almeida, J., Aguerri, J. A. L., & Muñoz-Tuñón, C. 2011, ApJ, 743, 77

[6] Pérez-Montero, E. & Contini, T. 2009, MNRAS, 398, 949

[7] Pérez-Montero, E. & Díaz, A. I. 2003, MNRAS, 346, 105

[8] Pettini, M. & Pagel, B. E. J. 2004, MNRAS, 348, L59

[9] Sánchez Almeida, J., Aguerri, J. A. L., Muñoz-Tuñón, C., & de Vicente, A. 2010, ApJ, 714, 487

[10] Shi, F., Kong, X., Li, C., & Cheng, F. Z. 2005, A&A, 437, 849