Chemical Abundances in Gaseous Nebulae:
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Contributed Paper

Abundance estimations in the NLRs of Type 2 AGNs

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Abstract. Chemical abundances of the Narrow Line Regions (NLRs) of Active Galactic Nuclei (AGNs) are still poorly estimated. It is not clear that the methods developed for the study of the gas phase in HII regions are valid and/or provide accurate/realistic estimations of the NLRs abundances. Here we present a brief summary of the work carried out by our group on the study of chemical abundances of the NLRs associated to type 2 AGNs. We used different grids of photoionization models built using the Cloudy code. We derived new indexes to estimate the oxygen abundances of the NLRs using ultra violet and optical emission lines combined with the grids of photoionization models. We also obtained new quantitative determinations of the nitrogen abundance and a consistent relation between the nitrogen and oxygen abundances for a sample of nearby Seyfert 2 galaxies, located at redshift z < 0.1. Our results for N/O vs. O/H abundance ratios derived for Seyfert 2 galaxies are in consonance with those derived for a sample of extragalactic disc HII regions with high metallicity.

Key words: galaxies: abundances — galaxies: ISM — galaxies: active — galaxies: Seyfert

1. Introduction

Active Galactic Nuclei (AGNs) show strong recombination and prohibited emission lines in their spectra such as Hα, Hβ, [OIII]]5007, and the auroral emission lines [OII]3727, [SII]4071, [OIII]4363, [OIII]4959,5007, [SII]6717,6731) between others. These lines are used to estimate densities and temperatures of the gas in wich the lines are originated.

Type-1 AGNs exhibit broad recombination lines that would be produced by the superposition of the contribution from the emission coming from a diffuse gas region, the Narrow Lines Region (NLR), and the emission originated in a denser region called Broad Lines Region. In this type of objects the continuum emission is another factor to take into account to estimate the line fluxes. Prohibited lines are expected to be originated in the NLR in which the gas density is expected to be in the order of $500\,\mathrm{cm}^{-3}$ (see e.g. Dors et al., 2014).

Type-2 AGNs do not show prominent continuum emission and present only narrow recombination emission lines that are assumed to be produced in the same

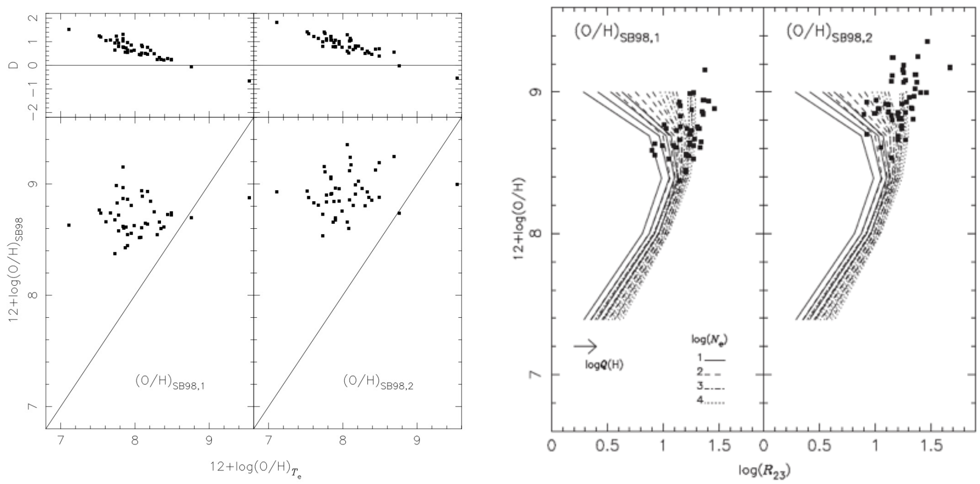

Figure 1. *Left:* Taken from Dors et al. (2015, Fig.1). *Right:* Taken from Dors et al. (2015, Fig.3)

gas than the prohibited lines. This type of AGNs are preferable to tackle the study of the physical parameteres of gas producing emission lines and associated to an Active Nuclei. Hence we restricted our sample to the Seyfert 2 objects.
Storchi-Bergmann et al. (1998, hereafter SB98) derived two theoretical calibrations based on strong emission-lines to estimate metallicities of NLRs associated to Seyfert 2 objects. They found these objects have solar or super-solar metallicities. Using the Te-method based on emission-line ratios and that is widely used for HII regions, other authors found NLRs metallicities to be solar or under-solar (e.g. Alloin et al., 1992; Zhang et al., 2013). The disagreement between the abundances obtained through these methods is the so-called temperature problem.
Comparing the O/H abundances obtained trough the Te-method and the SB98 relations, Dors et al. (2015) found that, for a sample of 47 objects, the Te-method provides lower O/H abundances by up to about 2 dex with an average value of about 0.8 dex (left panel of Fig.1). These authors argued that temperature problem in the NLRs could be (in part) caused by the presence of a secondary heating source, probably related to shocks, in addition to the radiation from the gas accretion onto the AGN. It is worth to take into account that the Te-method to estimate O/H abundances involves the use of Ionization Correction Factors (ICFs), that are, up to now, estimated for HII regions. The validity of this assumption could (probably) be also responsable of the temperature problem in the metallicity determination of NLRs associated to Seyfert 2 AGNs. Therefore the Te-method is still not providing accurate chemical abundances in this kind of objects.
Dors et al. (2015) also compared the metallicity estimations by the central intersect oxygen abundances of this kind of objects derived from the radial abundance gradients and by the central abundances determined from the spectra of the central regions Ho et al. (1997) through the Storchi-Bergmann et al. (1998) first

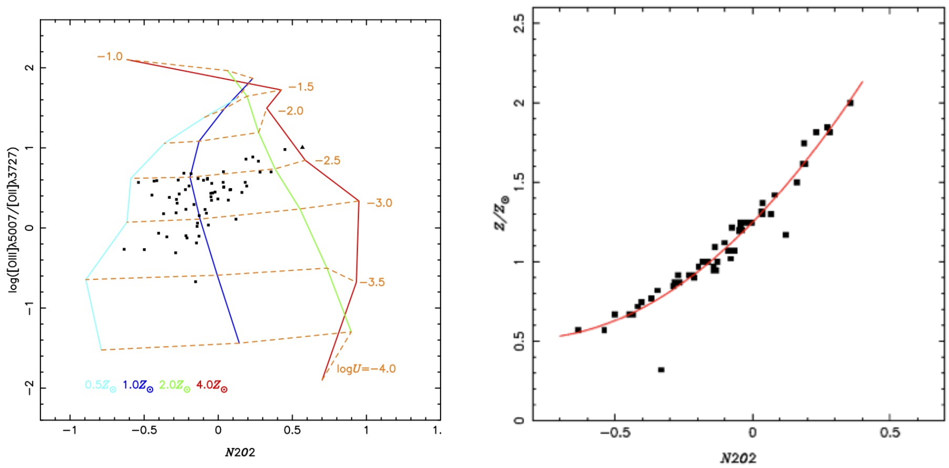

Figure 2. *Left:* Taken from Castro et al. (2017, Fig.3). *Right:* Castro et al. (2017, Fig.4).

calibration for AGNs and through the C_{NS} method (Pilyugin et al., 2006, 2007) for HII-like regions. Dors et al. (2015) found an almost one-to-one correlation between them (see Fig, 3 in Dors et al., 2015).

2. Strong-lines - Empirical calibrations

Empirical emission-line ratios such us R_{23}=([OII]3727+[OIII]4959,5007)/Hβ, are used as metallicity indicators in star-forming regions. It is interesting to explore the use of such emission-line ratios to estimate metallicities in Seyfert 2 NLRs. It has been done taking into account that the relation between this R_{23} parameter and the 12+log(O/H) metallicity indicator is actually calibrated for HII regions.

2.1. 12+log(O/H)–R_{23} calibration

Using photoionization models with an AGN-source model as SED, and comparing their results for the R_{23} parameter as a function of the oxygen abundances, with the estimations of the oxygen abundances of the objects in their sample obtained trough the Storchi-Bergmann et al. (1998) relations, Dors et al. (2015) concluded that a better agreement is obtained when the abundances are determined through the first relation of Storchi-Bergmann et al. (1998) (see the right panel of Fig. 1).

2.2. $Z/Z_\odot$–N2O2 calibration

Another parameter used as metallicity indicator in HII regions is the N2O2=log([NII]λ6584/[OII]λ3727) emission-line ratio. In the work by Castro et al. (2017) we derived a new relation between the metallicity of NLRs of type-2 AGNs and the N2O2 parameter for NLRs of type-2 AGNs. The calibration of the N2O2 parameter was performed trough the observational data of 58 objects (taken from the literature) and trough a diagram containing the observational

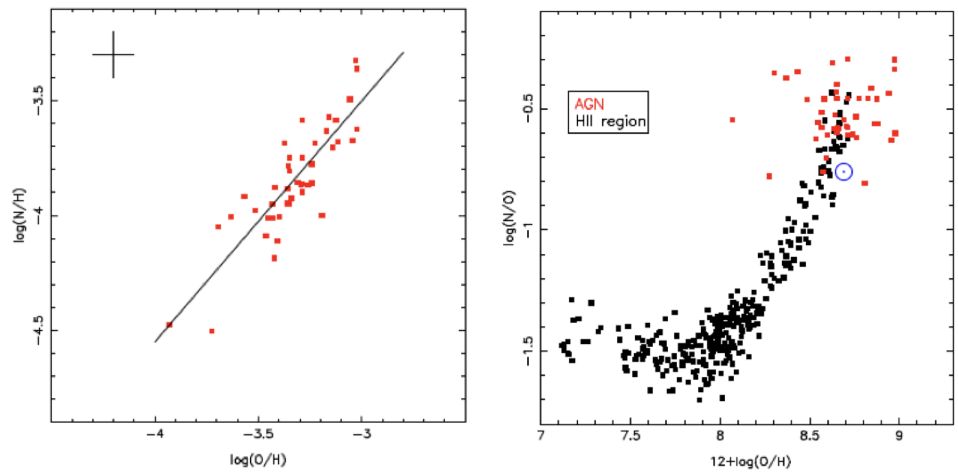

Figure 3. *Left:* Taken from Dors et al. (2017, Fig.3). *Right:* Dors et al. (2017, Fig.4).

data and the results of a grid of photoionization models (see the left panel of Fig. 2. The calibration found:

$$(Z/Z_{\odot}) = 1.08(\pm0.19) \times \mathrm{N2O2}^2 + 1.78(\pm0.07) \times \mathrm{N2O2} + 1.24(\pm0.01)$$

is shown in Fig.2 (right panel). In this work we also found that NLRs of Seyfert 2 AGNs show metallicities in the $0.3 \leq Z/Z_{\odot} \leq 2.0$ range with a median value of $Z \sim Z_{\odot}$.
Thomas et al. (2019) investigated the relation between the NLRs metallicity and the host galaxy stellar mass. They performed detailed models including NLR excitation together with H II exitation. They found that their $M/M_{\odot}$ vs. Z relation was very similar to the one found estimating metallicities with the N2O2 parameter calibrated by Castro et al. (2017), concluding that N2O2 is a very robust metallicity diagnostic for NLRs of Seyfert 2s.

2.3. N/H vs. O/H relation

We also derived new quantitative determinations of the nitrogen abundance and a consistent relation between nitrogen and oxygen abundances for NLRs of a sample of Seyfert 2 galaxies located at redshift z< 0.1 using the Cloudy code to build detailed photoionization models for 44 selected objects (Dors et al., 2017).

$$\log(N/H) = (1.5 \pm 0.09) \times \log(O/H) - (0.35 \pm 0.33)$$

We found that N/O abundance ratios in Seyfert 2 galaxies are similar to those derived by Pilyugin & Grebel (2016) for a sample of extragalactic H II regions with high metallicity.

2.4. Metallicities from UV lines: the C43 parameter

For the Seyfert 2 AGNs observed in the UV it is also possible to estimate their NLR metallicity using e.g. N V 1240, C IV 1549 and He II1640, between others. The

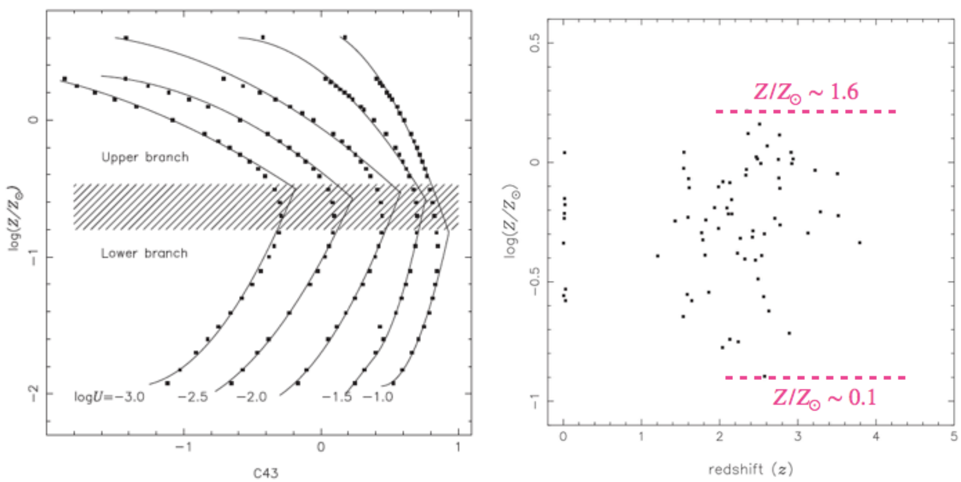

Figure 4. *Left:* Taken from Dors et al. (2014, Fig.4). *Right:* Taken from Dors et al. (2014, Fig.7).

N V 1240/C IV 1549 emission-lines ratio generally used as metallicity indicator for AGNs (Hamann & Ferland, 1992) can yield uncertain Z estimations since the N V emission-line could be enhanced by Lyα photons scattered from a broad absorption line wind (Hamann et al., 2002).

On the other hand, the C IV1549/He II1640 ratio proposed by Nagao et al. (2006) as metallicity indicator is dependent on the ionization parameter U. In the work by Dors et al. (2014), we found that the introduction of a lower ionization stage in the C IV/He II ratio weakens this dependence with U. Hence, in that work we proposed the new index: C43 = log[(C IV +C III])/He II] as a metallicity indicator. The relation between the C43 parameter with the metallicity $Z/Z_\odot$ is shown in Fig. 4 and it has the general form:

$$\log(Z/Z_\odot) = a \times C43^2 + b \times C43 + c$$

(see the a and b values in Dors et al., 2014).

In the same work, we used the C43 parameter to investigate the metallicity range of the NLRs of Type-2 AGNs and the existence of a metallicity evolution. We selected from the literature a sample of 81 objects with z between 0 and 4 and found that the metallicities of the objects in the sample are in a similar range than that found with the N2O2 parameter (see Fig. 4, right panel). We do not found a correlation between the metallicity and the redshift, even though we found the objects in our sample with redshifts between 1 and 3 show metallicities $Z/Z_\odot$ lower than 0.2.

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