New quantitative nitrogen abundance estimations in a sample of Seyfert 2 Active Galactic Nuclei

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Accepted 2015 Month 00. Received 2015 Month 00; in original form 2014 December 17

ABSTRACT

We obtained new quantitative determinations of the nitrogen abundance and a consistent relation between nitrogen and oxygen abundances for a sample of Seyfert 2 galaxies located at redshift \( z < 0.1 \). We carried out this analysis using the CLOUDY code to build detailed photoionization models. We were able to reproduce observed optical narrow emission line intensities for 44 sources compiled from the literature. Our results show that Seyfert 2 nuclei have nitrogen abundances ranging from \( \sim 0.3 \) to \( \sim 7.5 \) times the solar value. We derived the relation

\[
\log(N/H) = 1.05(\pm 0.09) \times \log(O/H) - 0.35(\pm 0.33).
\]

Results for N/O vs. O/H abundance ratios derived for Seyfert 2 galaxies are in consonance with those recently derived for a sample of extragalactic disk H II regions with high metallicity.

Key words: galaxies: active – galaxies: abundances – galaxies: evolution – galaxies: nuclei – galaxies: formation – galaxies: ISM – galaxies: Seyfert

1 INTRODUCTION

The spectra of Active Galactic Nuclei (AGNs) present strong emission lines of heavy elements that are easily measured, even in objects at high redshifts. The line intensities can be used to estimate the metallicity of these objects. Therefore, AGN metallicity determinations play a fundamental role in the knowledge of the chemical evolution of galactic nuclei (e.g. Dors et al. 2014; Matsuoka et al. 2004; Nagao et al. 2006). They also provide an indirect understanding of the star formation history for the central parts of galaxies (Hamann & Ferland 1992; 1993; Collin & Zahn 1996; Wang et al. 2011).

The first abundance determinations based on optical emission lines in AGNs were carried out by Osterbrock & Miller (1973) for the radio galaxy 3C 405 (Cygnus A). These authors calculated the abundances of helium and of other heavy elements (relative to the hydrogen abundance) through determinations of the electron temperature of the AGN gas, i.e. using the \( T_e \) method (e.g. Peimbert & Costero 1969). Osterbrock and collaborators, with the goal of increasing the sample, produced a spectrophotometric survey of radio galaxies obtaining the physical conditions of the nuclear gas of several objects. Results of this analysis were published by Costero & Osterbrock (1973) and Koski (1975). After these pioneer works, several authors have addressed efforts in order to determine chemical abundances in AGNs (see Hamann & Ferland 1999 and references therein). However, most of these works have considered only the metallicity parametrized through the oxygen abundance determinations (e.g. Dors et al. 2013; 2014; Richardson et al. 2014; Matsuoka et al. 2009; Nagao et al. 2006; Groves et al. 2006; Storchi-Bergmann et al. 1998; Cruz-Gonzalez et al. 1991).

In particular, the knowledge of the nitrogen abundances in ionized nebulae and AGNs is essential for the study of chemical evolution of galaxies, stellar nucleosynthesis and stellar material ejection in the interstellar medium. This also helps to verify the presence of Wolf-Rayet stars in metal rich environments. Nitrogen abundances are well-known in star-forming regions. In fact, studies based on spectroscopic data of H II regions have shown that this element has a primary origin for the low metallicity regime \((12 + \log(O/H)) \lesssim 8.2\) and a secondary one for the high metallicity regime (e.g. Edmunds 1990; Pérez-Montero & Contini 2004; Pilyugin & Thuan 2011). However, nitrogen abundances are poorly known in AGNs and most abundance determinations of this element in these objects are qualitative.
3 PHOTOIONIZATION MODEL

3.1 Initial parameters

We used the CLOUDY code version 13.04 (Ferland et al. 2013) to build individual photoionization models in order to reproduce the observed emission line intensities for each object of our sample. For each object, we built a first model assuming the following initial parameters:

(i) Number of ionizing photons [Q(H)] - The logarithm of the number of ionizing photons was considered to be equal to 51 dex, a typical value derived for Seyfert galaxies (Riffel et al. 2006).

(ii) Spectral Energy Distribution (SED) - The SED of the ionizing source was modelled as a power law of the form $F_{\nu} \sim \nu^{\alpha}$, where $\alpha$ was assumed to be equal to $\alpha = -1.4$, a typical value for AGNs (e.g. Zamorani et al. 1981).

(iii) Electron density ($N_e$) - We assume a constant value for the electron density $N_e$ along the radius of the hypothetical AGN emission region. This value was derived, for each object, by using the observed $[\text{S} \text{II}]/\text{H}$ ratio, obtained from the original work from which the observational data were taken (see Table 1, and using its relation with $N_e$ obtained by Hägele et al. (2008).

(iv) Inner and outer radius - The inner radius ($R_{in}$), defined as being the distance from the ionizing source to the illuminated gas region, was considered to be equal to 3 pc, a typical value for narrow line regions of Seyfert galaxies (e.g. Balmaverde et al. 2016). The outer radius was assumed to be the one where the electron temperature of the gas reaches 4000 K, the default lowest-allowed kinetic temperature by the CLOUDY code. Gas cooler than $\sim 4000$ K does practically not emit optical emission lines.

(v) Metallicity ($Z$) - For each model, we assume an initial value of $Z$ obtained from the calibration proposed by Castro et al. (2017):

\[
(Z/Z_{\odot}) = 1.08(\pm0.19) \times x^2 + 1.78(\pm0.07) \times x + 1.24(\pm0.01),
\]

being $x = \log([\text{N II}]\lambda 6584/[\text{O II}]\lambda 3727)$ calculated from the observational data listed in Table 1.

(vi) Nitrogen and sulphur abundances - The nitrogen ($N/H$) and sulphur ($S/H$) abundances relative to the hydrogen abundance were considered to be 2 and 1 times the solar values, respectively. In the CLOUDY code the solar values $12 + \log(N/H)_{\odot} = 7.93$ and $12 + \log(S/H)_{\odot} = 7.27$ were taken from Holweger (2001) and Grevesse & Sauval (1998), respectively.

3.2 Fitting model methodology

An initial model assuming the input parameters described in Section 3.1 was built in order to reproduce the emission line intensities of each object of the sample. Then, we ran new models varying separately, the $Z$, $N/H$, $S/H$ values considering a step of $\pm 0.2$ dex, typical uncertainty in nebular abundance estimations derived through photoionization models (Dors et al. 2011). From this series of models, we selected one that best reproduces the intensities of all emission lines considered (see Sect. 2) within an uncertainty of $\pm 20\%$, which is a typical observational uncertainty for emission lines (e.g. Kraemer et al. 1994). If no model was able to
reach this criterion, a new series of models was built varying $N_e$, $R_0$, and $\alpha$ with a step of $\pm 0.2$ dex. Only one parameter was varied at a time and the optimization method PHYMIR (van Hoof 1997) was considered to select the best fitting model to the set of emission line intensities. Similar methodology was adopted by Dors et al. (2011) in a study of chemical abundances in H\textsc{ii} regions.

To determine the error in our abundance estimations, a simple model simulation was performed. Initially, we built a photonionization model assuming solar metallicity, $N_e=500$ cm$^{-3}$ (typical electron density value derived for AGNs, see Dors et al. 2015), and the initial parameters listed above. Thereafter, a series of models varying the O/H, N/H and S/H abundances by a factor of $\pm 0.5$ dex (step of 0.05 dex) from the solar values was built. Using these models, we obtained an abundance range for which emission line intensities differ $\pm 20\%$ from the values predicted by the initial model. We found that a variation of about $\pm 0.1$ dex in abundances yields variations of about $20\%$ in the intensities of the emission line considered. This value will be considered as the uncertainty in our abundance estimations.

4 RESULTS AND DISCUSSION

From the 61 objects in our sample, it was possible to obtain detailed photoionization model solutions for 44 of them. The predicted emission line intensities and the final model parameters for these 44 objects are listed in Table 1 and 2, respectively.

In Fig. 1 bottom part of each panel, the observational emission line intensities (with respect to H$\beta$) are compared with those predicted by the detailed photoionization models, for each of the 44 fitted object of the sample. Also in Fig. 1 top part of each panel, the ratio between the observed and the modelled intensities as a function of the ob-
Table 1. Dereddened fluxes (relative to Hβ=1.00) for a sample of Seyfert 2 nuclei. The observed values compiled from the literature are referred as "Obs." while the predicted values by the photoionization models as "Mod." (see Sect. 3 of the Letter). The redshift and the references of the compiled sample (given below) are presented in the last columns, respectively. The redshift values were taken from the NASA/IPAC Extragalactic Database (NED). Full table is available online.

| Object   | [O II]λ3726,29 Obs. | [O II]λ5007 Obs. | [N II]λ6584 Obs. | [S II]λ6716+31 Obs. | redshift | Ref. |
|----------|---------------------|------------------|------------------|---------------------|----------|------|
| I Zw 92  | 2.63                | 2.65             | 10.12            | 9.19                | 0.97     | 1.01 | 0.77 | 0.74 | 0.0378 | 1    |
| NGC 3393 | 2.41                | 2.61             | 16.42            | 13.15               | 4.50     | 4.42 | 1.53 | 1.37 | 0.0125 | 2    |

Table 2. Assumed model parameter values used to fit the emission lines observed in the 44 modeled Seyfert 2 nuclei. Full table is available online.

| Object   | log(O/H)  | log(N/H)  | log(S/H)  | N_e (cm⁻³) | log(Q(H)) | α    |
|----------|-----------|-----------|-----------|------------|-----------|------|
| I Zw 92  | −3.4256   | −4.1850   | −4.9190   | 822        | 51.27     | −1.4 |
| NGC 3393 | −3.0583   | −3.4935   | −4.3300   | 4162       | 50.55     | −1.0 |

Figure 2. Histogram containing the oxygen (left panel) and nitrogen (right panel) abundance distributions predicted by our photoionization models for the 44 fitted objects of our sample (see Sect. 4).

In Fig. 2 we present a histogram containing the oxygen and nitrogen abundances relative to the hydrogen abundance, predicted by our photoionization models for the 44 fitted objects of our sample (listed in Table 2). Analyzing the obtained oxygen abundance distribution, we found that ~70% of the objects present O/H abundances in the range 8.6 ≤ 12 + log(O/H) ≤ 9.0 (or metallicities in the range 1.0 ≤ (Z/Z⊙) ≤ 2.0). This result is in consonance with the results found by Castro et al (2017) and Dors et al (2014), who considered a different methodology to estimate the metallicity for a similar sample of objects.

In Fig. 4, the predicted N/O as a function of O/H values for the AGN sample is compared with those derived for a sample of H II regions by Pilyugin & Grebel (2016), who used the C-method (Pilyugin et al. 2012) to calculate the oxygen and nitrogen abundances. In this plot, the value for the solar abundance is also indicated. We can see that the N/O estimations for the Sy2 objects are in agreement with those for the metal richest H II regions. Moreover, the N/O values of the objects of our sample are, in most cases, higher than the solar value.

5 CONCLUSION

We compiled from the literature narrow optical emission line intensities for a sample of Seyfert 2 galaxies. Standard pho-
Figure 3. log(N/H) vs. log(O/H) predicted by the models. The line represents a linear regression fitting the points, given by log(N/H) = (1.05 ± 0.09) × log(O/H) − (0.35 ± 0.33). Error bars represent the uncertainty 0.2 dex in our abundance estimations (see Sect. 3.2).

Figure 4. log(N/O) vs. 12+log(O/H) abundance ratio values. The red points are values predicted by the individual photoionization models for our sample of Sy2 objects (see Sect. 4), while the black points are estimations for HII regions derived by Pilyugin & Grebel (2016) using the C-method (Pilyugin et al. 2012). The value for the solar ratio abundance taken from Holweger (2001) and Grevesse & Sauval (1998) is also indicated in the plot with a blue symbol.

toionization models were built in order to reproduce the intensities of these emission lines. We present new results of nitrogen and oxygen abundances calculated for a large sample of Seyfert 2 galaxies. We found a very wide range for the N/H abundances in this kind of active nuclei, varying between about 0.3 and 7.5 times the solar value. We derived a relationship between the nitrogen and oxygen abundances for Seyfert 2 AGNs. We find that N/O abundance ratios in Seyfert 2 galaxies are similar to those recently derived for a sample of extragalactic HII regions with high metallicity.

ACKNOWLEDGMENTS

We are grateful to the referee, Dra Marcella Contini, for her useful comments and suggestions, which have helped us to substantially clarify and improve the manuscript. O.L.D. is grateful to FAPESP (2016/04728-7) and CNPQ (306744/2014-7).

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