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Delving into the gas-phase of the CALIFA galaxies to trace O and N gradients

Enrique Pérez-Montero[1], Rubén García-Benito[1], José M. Vílchez[1] and the CALIFA collaboration

[1]Instituto de Astrofísica de Andalucía - CSIC. Glorieta de la Astronomía s/n E-18008 Granada, Spain

Abstract. We study the radial distribution of oxygen and nitrogen abundances in H II regions in 350 galaxies observed in the CALIFA survey using the semi-empirical N-sensitive code HII-CHI-MISTRY. A separate analysis of N/O when using [N II] is justified as the dispersion in the O/H-N/O diagram is very large. In fact different O/H and N/O slope distributions and flattening in the outskirts are obtained.On the other hand there is a tight correlation between O/H and N/O when the values of the fittings at the effective radius are considered as representative of each galaxy.

Keywords. ISM: abundances, galaxies: evolution, H II regions

1. Motivation and sample

The analysis of the spatial distribution of chemical abundances in the gas-phase of galaxies can provide an invaluable amount of information to understand their formation and evolution. It is known that most spiral galaxies present a negative gradient of oxygen abundances and that the slope of this gradient is quite similar when it is normalized by the effective radius (e.g. Díaz 1989).

Other chemical species different to oxygen can also provide a complementary information on the formation of galaxy disks. Nitrogen is produced and ejected to the interstellar medium (ISM) mainly by low- and intermediate-mass stars so its presence is produced with a certain delay with respect to oxygen, ejected to the ISM by short-living massive stars. Although for the high metallicity regime of the H II regions in disk galaxies most of N has a secondary origin (i.e. its yields production depends on metallicity), the O/H-N/O has a large dispersion whose study can be related with different star formation histories and efficiencies (e.g. Mollá *et al.* 2006). On the other hand, many recipes to derive metallicity based on the measurement of strong emission lines lie on the detection of [N II] emission lines, so a previous derivation of N/O is important to reduce the uncertainty of O/H in these cases (Pérez-Montero & Contini 2009).

The advent of integral field units (IFUs) has provided the community with a new technique to obtain observational data of the emission-line regions in spiral disk galaxies with a complete coverage. This helps to better sample the abundance gradient structure.

The CALIFA (Calar Alto Legacy Integral Field Area survey) (Sánchez *et al.* 2012) has used the IFU PMAS in the CAHA 3.5 m. telescope of several hundreds of galaxies of the Local Universe ($0.005 < z < 0.03$) around 1 of diameter in the optical spectral range that we used for our analysis of radial abundance distributions.

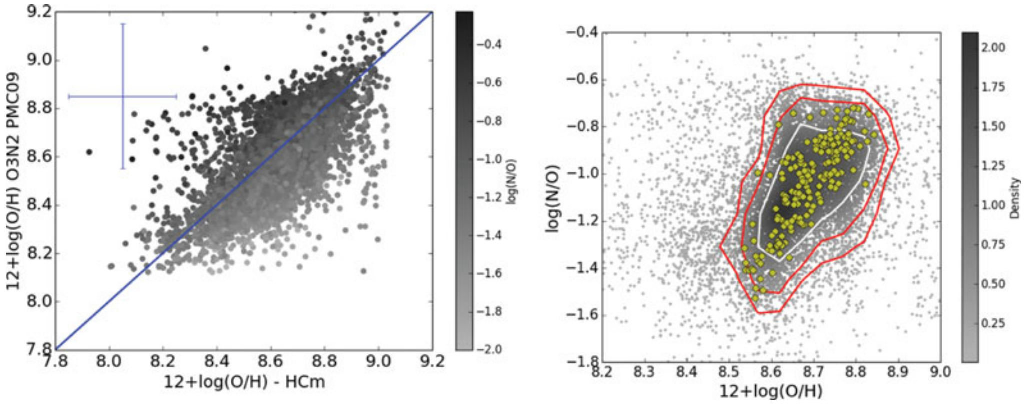

Figure 1. At left, comparison between the derived O/H using the O3N2 parameter calibrated by Pérez-Montero & Contini (2009) and using HCm for the selected CALIFA H II regionsy. The color codes for N/O as derived by HCm. At right, O/H-N/O for the same H II regions in grey density-coded and the characteristic values at the effective radius as white points.

2. Abundance and gradient derivation

For this work, following Pérez-Montero *et al.* (in press) we analyzed 15 757 emission-line regions extracted from the resulting reduced PMAS data cubes (García-Benito *et al.* 2015) and their emission lines were measured, after stellar continuum subtraction. The star forming H II regions were selected using both diagnostic diagrams to separate AGNs (i.e. [O III]/Hβ vs. [N II]/Hα) and imposing that at least a 30% of the stellar mass has an age younger that 500 Myr. This leaves a total of 8 196 H II regions.

Both total oxygen abundance and nitrogen-to-oxygen ratios were calculated for the CALIFA selected H II regions using the semi-empirical routine HII-CHI-MISTRY v. 2.0 (HCm, Pérez-Montero 2014). In this method, the abundances are calculated as the means of the χ^2 weighted distributions calculated as the difference between a set of observed reddening-corrected optical emission lines ([O II] 3727Å, [O III] 5007Å, [N II] 6584Å, and [S II] 6717,6731 Å) with the predictions of a grid of photo-ionization models covering a large range in the input O/H N/O and ionization parameter (log U). In absence of the auroral [O III] 4363, which is the case for almost all the selected H II regions, the grid is constrained to follow an empirical O/H - log U relation what makes this method to be consistent with the direct method. HCm firstly calculates N/O, what allows the use of [N II] emission lines to derive O/H, reducing the uncertainty due to the dispersion in the O/H-N/O relation as can be seen in left panel of Fig. 1 comparing the O/H abundances derived by HCm and the O3N2 parameter.

The resulting O/H-N/O plot for the selected H II regions is shown in right panel of Figure 1, where it can be seen that the range of variation of N/O [-1.8,-0.4] is much larger than for O/H [8.3,8.9]. As the associated errors are similar for both ratios (i.e. 0.22 dex for O/H and 0.16 for N/O) this implies that N/O is much more accurate. Although there is a certain correlation ($\rho_s = 0.39$) due to the fact that most of the ejected N has a secondary origin, the dispersion is very large, what demonstrates the need of a previous N/O determination before using [N II] emission lines to derive O/H.

The fittings to the radial gradients were performed over the 201 non-interacting galaxies with 10 or more H II regions using a robust error-weighted linear fitting over the whole radial range. The number of analyzed galaxies with 10 or more H II regions for this work is 201.

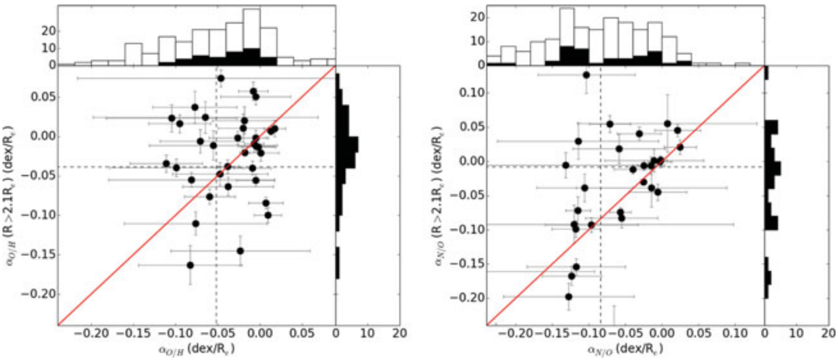

Figure 2. Scatter plots and histograms of the resulting slopes for O/H (at left) and N/O (right) of the linear fittings for all the radial range (x axis) and for R > 2.1·R$_e$ (y axis) in the 40 galaxies with 10 or more H II regions in this last range. Dashed lines represent the average of the distributions and white histograms represent the distributions for the 201 analyzed galaxies.

3. Discussion

Figure 2 shows the distribution of slopes both for O/H and N/O, which have in average negative values (i.e. $\alpha_{O/H}$ = -0.053 dex/R$_e$ and $\alpha_{N/O}$ = -0.105 dex/R$_e$). However, a non-negligible fraction of the galaxies present a flat or even a positive gradient (i.e. between 10% and 20% for O/H and between 4% and 10% for N/O depending on if the associated error totally excludes a negative slope).

The correlation between O/H and N/O slopes is not very good (i.e. $\rho_s = 0.38$), as in the case of abundances for individual H II regions. However, when we consider a characteristic abundance value as that from the linear fitting at the effective radius, we find a tighter correlation, as can be seen in right panel of Figure 1 ($rho_s = 0.89$). These characteristic values could be considered as typical for the whole galaxy and show a very precise correlation with other integrated properties of the galaxies.

Regarding galaxies outskirts, a certain flattening of the gradient can be observed at outer radii. The weight of the outer H II regions is negligible in the averages for the studied galaxies, but it is observed that the slopes are flatter when only H II regions at R > 2.1 R$_e$ are used. Figure 2 shows the comparison between the slopes in this range and for all radii for the 40 CALIFA galaxies with at least 10 H II regions in the outskirts. The flattening is much more evident for N/O than for O/H (i.e. $\alpha_{O/H}$ = -0.035 dex/R$_e$ and $\alpha_{N/O}$ = -0.008 dex/R$_e$). This difference could be the consequence of a larger relative production of primary N at lower metallicities, different star formation efficiencies than in the nuclear regions or the product of gas interchanges with the intergalactic medium, which affects differently to O/H and N/O. In any case, this also should be considered when the O/H is analyzed using [N II] emission lines. Very similar results to Marino *et al.* (2016) are obtained when no N/O dependence is assumed in the models.

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