EMPIRICAL DIAGNOSTICS OF HII REGIONS BASED ON SULPHUR EMISSION LINES

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Abstract
Spectrophotometry constitutes a unique way to obtain the whole diagnostics (density, temperature, ionic abundances) of ionized gas nebulae, thus providing invaluable information about the objects where they reside. If such nebulae are in the low excitation regime, the diagnostics have to rely on the observation of the more intense emission lines. We have compiled data for a sample of HII regions, GEHR and HII galaxies and compared them with results derived from photoionization models whose parameters cover the physical conditions of the nebulae. Our results confirm a lower uncertainty for the diagnostics when using empirical methods based on the strong lines of [SII] and [SIII] replacing and complementing those based on the [OII] and [OIII] lines.

Introduction
The most accurate method to ascertain chemical abundances in ionized gas nebulae relies on the measurement of the auroral lines and the determination of the electron line temperatures. Since the nature of these lines is collisional, in low excitation nebulae, where the electron temperature is low as well, it is often difficult to detect them in the optical. There are many studies in the literature that propose and analyze new empirical calibrators, based on strong emission lines in the optical ([OII], [OIII], [NII]), where the auroral lines are too weak. The flux of these lines is governed, as the inner ionization structure of the HII regions, by the metallicity of the gas, the effective temperature of the ionizing radiation and the ionization parameter, \(U\) (i.e. the rate between Lyman ionizing photons and the density of particles) which takes
The goal of the our models is to isolate the dependence of the lines on the metal content of the nebula. In this work, we have compiled a sample of diffuse HII regions in the Galaxy, giant extragalactic HII regions and HII galaxies, all of them with a direct determination of the oxygen abundance and measurements of the strong lines of [OII], [OIII], [NII], [SII] and [SIII] in the optical and near-infrared. We have compared these data with the results from photoionization models (Cloudy: Ferland, 1996) under realistic physical conditions using as ionization spectra those provided by Co-Star stellar model atmospheres and we have studied the dependence on the three functional parameters of the strong line intensities.

1. The $O_{23}$ (or $R_{23}$) parameter

It is defined as the sum of the lines $\lambda\lambda 3727\AA$, [OIII]$\lambda\lambda 4959,5007\AA$ relative to H$\beta$. The main features of this parameter are its two-valued nature (see upper figure, at left) and its dependence on ionization parameter (at right, the ratio [OII]/[OIII] depends on log $U^{-1}$). At high metallicities, the low electron temperatures cause the strong oxygen lines to decrease, and, on the contrary, at low metallicities the increasing oxygen abundance cause the line fluxes to be stronger. We have therefore an upper branch of the relation, for $12+\log(O/\text{H}) > 8.4$, where almost no direct determinations of abundances exist and that has to be calibrated with the help of theoretical models. Our photoionization models predict an uncertainty of 0.2 dex in the oxygen abundance derived in this regime. In the lower branch, for $12+\log(O/\text{H}) < 8.0$, whose dependence on ionization parameter can be considered explicitly, our models predict 0.15 dex of uncertainty. The uncertainty associated to the oxygen abundance determination in the intermediate regime $8.0 < 12+\log(O/\text{H}) < 8.4$, where the calibration reverses, can be high however much larger than this ($\approx 0.5$-0.6 dex. Unfortunately, about 40% of the objects (and about 80% of the HII galaxy sample) lie on this zone.
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2. The N2 parameter

This parameter is defined as the ratio of $\lambda$[NII]6584Å and H$\alpha$. In the figure below (top left) it can be seen that the parameter is single-valued for all metallicities, but Denicoló et al. (2001) point out its strong dependence on ionization parameter (top right) and the uncertainty due to N/O variations. Nevertheless N2 represent an improvement for objects located in the turn over region of the oxygen abundance vs $O_{23}$ relation. Our models predict an uncertainty of 0.3 dex associated to the abundances determined through this parameter at any metallicity.

3. The $S_{23}$ parameter

Defined as the sum of the strong lines of [SII]$\lambda\lambda$6717,6731Å and [SIII] $\lambda\lambda$9069,9532Å and used as a metallicity calibrator by Díaz & Pérez-Montero (DPM00: 2000). It has a lower dependence on ionization parameter as can be seen below (bottom right) and it remains single-valued until metallicity about 1.5 times solar ($12+\log(O/H)_{\odot} = 8.69$). Both facts are confirmed by our models, from which and using the com-
piled set of data together with those in DPM00 we deduce the relation:

\[ 12 + \log(O/H) = 8.29 + 2.02 \log S_{23} + 0.72(\log S_{23})^2 \]

with an uncertainty of 0.15 dex. Some authors (Oey & Shields, 2000) have suggested a modified parameter \( S_{234} \) that would include the contribution of the [SIV] \( \lambda 10.5 \mu \) line. This contribution would be relevant only for high excitation objects and, since very few data exist at present, it could be calculated only from photo-ionization models. Therefore the uncertainty would not be decreased.

4. The \( S_{23}/O_{23} \) parameter

Finally, we think that this parameter is very promising to provide a consistent abundance calibration over the whole range of metallicities and therefore. In fact, it can be very useful to describe large trends, such as the behaviour of abundance gradients in spiral galaxies. Our models predict a rather strong dependence on ionization parameter (due to \( O_{23} \)) but a preliminary calibration can be given (below, left):

\[ 12 + \log(O/H) = 9.2 + 0.8 \cdot \log \left( \frac{S_{23}}{O_{23}} \right) - 0.6 \cdot \log^2 \left( \frac{S_{23}}{O_{23}} \right) \]

(1)

that applied to the disk of spirals, such as M101 (Garnett et al., 1997) shows the exponential nature of the abundance distribution (below, right).

References

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