NEBULAR DIAGNOSTICS FOR YOUNG STELLAR POPULATIONS: PHOTON ESCAPE VS ATMOSPHERE BLANKETING

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Abstract  Emission lines in ionized nebulae can provide strong and useful constraints on the properties of both ionizing and non-ionizing stellar populations in regions with star formation, provided that stellar evolution and stellar atmosphere models can be used in a selfconsistent way. Recently, the application of these techniques has shown important discrepancies between predicted and observed nebular spectra that point to stellar atmosphere models of WR stars which are too energetic and/or to a significant leakage of high energy photons. In this contribution these two alternatives are analyzed in detail.

1. Introduction.

Young stars produce a great impact on their surrounding gas which gets ionized exhibiting a characteristic emission line spectrum (ELS). The analysis of this spectrum can be used to extract relevant information about the stellar population ionizing the region.

Three are the parameters that characterize a stellar population: age, metallicity and initial mass function (IMF). The metallicity can be derived from the ELS provided the determination of the electron temperature of the gas can be made and the age can be constrained if spectral features corresponding to stars in a specific evolutionary stage are observed. Then, if a given IMF is assumed, the spectral energy distribution (SED) of the ionizing population can be synthesized. This spectrum, when used as input to a photo-ionization model should reproduce the observed ELS. But, is this the case?
2. Application of the method

We have applied this method to three giant extragalactic HII regions (GEHR): H13 in NGC 628, CDT3 in NGC 1232 and 74C in NGC 4258. For these regions the elemental abundances have been derived using ion-weighted temperatures determined from the corresponding auroral to nebular line intensity ratios. Details of the observations and abundance determinations can be found in Díaz et al. (2000) and Castellanos, Díaz & Terlevich (2002a). All three regions show WR features in their spectra which provides a reliable age constraint for the ionizing stellar population from WR population synthesis models (Schaerer & Vacca 1998). These models consistently fit both the intensities and the equivalent widths (EW) of the WR features under the assumptions of a single star burst and a Salpeter IMF.

With the derived metallicity and age for a given HII region, we have synthesized the SED of the corresponding ionizing clusters using the STARBURST99 code (Leitherer et al. 1999) and then we have used the photo-ionization code CLOUDY (Ferland 1999) to calculate the ELS. Constant density and ionization bounding have been assumed. The details of the procedure can be found in Castellanos, Díaz & Tenorio-Tagle (2002), whose results can be summarized as follows: (1) WR feature intensities and equivalent widths imply young ages for the three observed regions: 4-4.1 Myr for H13, 3.1-3.5 Myr for CDT3 and 4.5 Myr for 74C. (2) The synthesized SED corresponding to these clusters DO NOT reproduce the observed ELS; they result too hard. This can be seen in Figure 1 (left panel) where three SED for CDT3 in NGC 1232 are shown. The cluster 3.3 Myr old reproduces the observed WR features but results too hard to reproduce the ELS. The cluster with 2.8 Myr is able to reproduce the ELS but do not have WR stars. It is also possible to reproduce the ELS with a combination of clusters with different ages: 2.8 Myr and 4.8 Myr. In this case however, the intensity and EW of the WR features are underpredicted by factors of about 15 and 25 respectively (Castellanos, Díaz & Terlevich 2002b).

3. Discussion

Which could be the agents producing this discrepancy? Several possibilities can be considered: (1) The stellar evolutionary tracks used in the synthesis models are not correct. (2) The IMF is not the Salpeter one. (3) The stellar atmospheres are not adequate. (4) The HII regions are not ionization bounded.

The fact that the intensities and EW of WR features are very well reproduced by Schaerer and Vacca’s models seems to indicate that both
stellar evolutionary tracks and the assumed IMF are rather adequate. Since these are the same assumed also by the STARBURST99 models, they cannot be the source of the discrepancy. The third possibility is related to the uncertainties involved in the modelling of the atmospheres of O and WR stars. Our results point to an overestimate of the hardness of the SED of the stars in the WR phase which is more evident for intermediate to high metallicity. The fact that atmosphere models for WR stars used by the STARBURST99 code do not include blanketing seems to indicate that their assumed SED could be indeed too hard, at least for metallicities higher than about 1/2 solar. Recently (Smith et al. 2002) have computed models for O and WR stars including the effects of blanketing. These models have already been implemented in the STARBURST99 code. We have therefore synthesized the SED of the clusters able to reproduce the WR features of our observed HII regions using these blanketed atmosphere models. A comparison of the “old” and “new” models for the cluster of 3.3 Myr reproducing the WR features in CDT3 can be seen in Figure 1 (right panel). Blanketed models are indeed softer at energies higher than 3 Ryd. They are, however, still too hard at energies between 1 and 3 Ryd thus yielding a [OIII]/Hβ line ratios which is higher than observed by a factor of about 3.5.

On the other hand, there are several indirect evidences that GEHR might be matter bounded (e.g. Beckman et al. 2000; Collins & Rand 2001). To test this hypothesis, we have run photo-ionization models using as ionizing source the SED of the clusters which reproduce the observed WR features, but relaxing the assumption of ionization bounding
Figure 2. Left: Scheme of the modelling procedure. Right: Results for region CDT3 in NGC 1232.

(see scheme in Figure 2, left panel). The results can be seen in Figure 2 (right panel) where the run of the emission line intensities relative to Hβ, as well as the Hβ luminosity and EW, as a function of the ionized shell thickness is plotted. The observed values are shown by horizontal bars. Models in which all photons are absorbed (most right hand points in the figure) lead to large departures from all observed values, it is therefore possible to find a consistent fit only if the regions are matter bounded, i.e. if there is an important escape of ionizing radiation from the nebula. Total values of escaping hydrogen ionizing photons range between 10% and 70% of the incident values.

This work shows (1) the potential of using nebular diagnostics to infer the properties of the ionizing stellar populations and (2) the importance of detecting WR features in HII region spectra in order to obtain an independent constraint for the age of the ionizing cluster.

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