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Ionization of the diffuse gas in galaxies: hot low-mass evolved stars at work

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Abstract. We revisit the question of the ionization of the diffuse medium in late type galaxies, by studying NGC 891. The most important challenge for the models considered so far was the observed increase of [O III]/Hβ, [O II]/Hβ, and [N II]/Hα with increasing distance to the galactic plane. We propose a scenario based on the *expected* population of massive OB stars and hot low-mass evolved stars (HOLMES) in this galaxy to explain this observational fact. In the framework of this scenario we construct a finely meshed grid of photoionization models. For each value of the galactic latitude z we look for the models which simultaneously fit the observed values of the [O III]/Hβ, [O II]/Hβ, and [N II]/Hα ratios. For each value of z we find a range of solutions which depends on the value of the oxygen abundance. The models which fit the observations indicate a systematic decrease of the electron density with increasing z. They become dominated by the HOLMES with increasing z only when restricting to solar oxygen abundance models, which argues that the metallicity above the galactic plane should be close to solar. They also indicate that N/O increases with increasing z.

Keywords. galaxies: individual (NGC 891) — galaxies: ISM — galaxies: abundances — stars: AGB and post-AGB

1. Introduction

The Diffuse Ionized Medium (DIG) was detected through its optical line emission outside the classical H II regions (Reynolds 1971) and turns out to be a major component of the interstellar medium in galaxies (Reynolds 1991). Most specialist agree that OB stars in galaxies likely represent the main source of ionizing photons for the DIG (see Haffner *et al.* 2009). However, an additional ionizing source is suggested by reported increase of such emission line ratios as [N II]/Hα, [S II]/Hα with galactic height. Several sources of additional ionization/heating have been suggested without complete success.

2. Proposed Scenario

The extraplanar DIG is destributed in clouds (for simplicity represented by rectangles) that are ionized by two star populations:1) OB stars located in the thin disk and whose ionizing radiation escape from the disk through small "holes", which ionize the "bottom" part of the gas clouds. They constitute only a small fraction of the entire population of

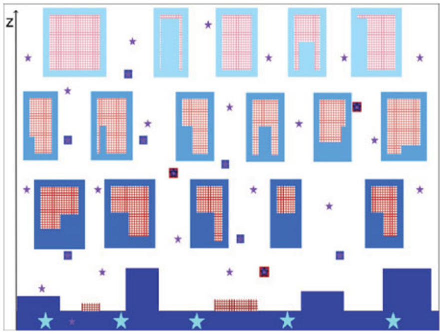

Figure 1. Schematic representation of the extraplanar gas and ionizing stars. Ionized gas is represented in plain shade and neutral gas in a pattern shade. For both components, a darker shade indicates gas of higher density. The big stars in the plot represent OB stars. The small stars represent the HOLMES, which can be either central stars of present-day planetary nebulae, or hot pre-white dwarfs.

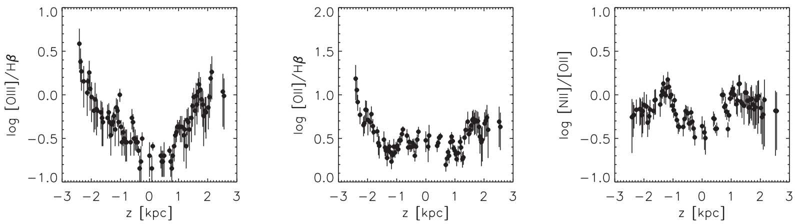

Figure 2. Observed values of [O III]/Hβ, [O II]/Hβ and [N II]/[O II]in NGC 891, as a function of the distance to the galactic plane. The data are from Otte *et al.* (2001).

the OB stars in the disk. 2) HOLMES, which are distributed in the galaxy thick disk and halo. Their influence with respect to that of OB stars increases away from the galacti plane. Figure 1 shows the datails of the proposed scenario.

3. Observational Data

We chose to focus on the edge on spiral galaxy NGC 891, a galaxy that has been extensively observed, especially in optical emission lines (Figure 2), providing the best diagnostics for our scenario.

4. Modeling

The ionizing spectral energy distribution (SED) from OB stars is obtained using the code Starburst99 (Leitherer *et al.* 1999), considering a continuous star formation. The SED of HOLMES is obtained using the code PEGASE (Fioc & Rocca-Volmerange 1997) considering a instantaneous starburst at look back after 10 Gyr. The photoionization models for the DIG were computed with Cloudy (Ferland *et al.* 1998). Each one is defined by the ratio of the surface fluxes: $\Phi_{\mathrm{HOLMES}}/\ (\Phi_{\mathrm{OB}} + \Phi_{\mathrm{HOLMES}})$, the ionization parameter U, O/H and N/O.

Figure 3 shows the location of the observaional points in the [O III]/Hβ vs [O II]/Hβ diagram, with respect to our "reduced" grid of models. The dashes lines join models with same values of log Φ_{OB} (equal to 3.5, 4, 4.5, 5, 5.5, 6, 6.5), while the continuous line join models with the same values of U (equal to -4, -3.5, -3). Form left to right, each panel corresponds to a different value of log O/H (-3.9, -3.3, -2.9). The value of N/O is the

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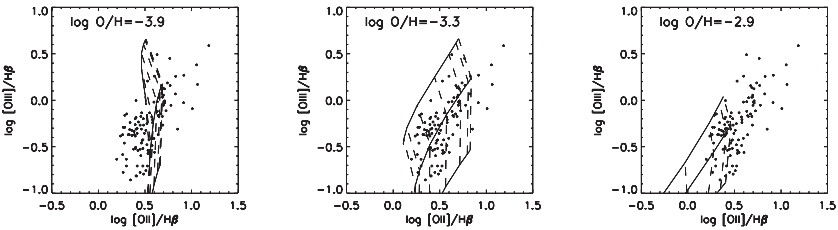

Figure 3. "Reduced" grids (the full grid is 5 time more resolved) of models in the [O III]/Hβ vs. [O II]/Hβ plane, for various values of O/H. See text for details on the varying parameters. The observational points are superimposed on the grid.

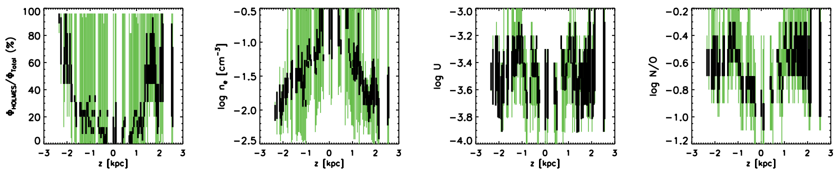

Figure 4. $\Phi_{\rm HOLMES}/\Phi_{\rm OB}$, $n_{\rm e}$, U and N/O vs z for the models that fit the observational [O III]/Hβ, [O II]/Hβ, and [N II]/Hα simultaneously. The light shade bars indicate the range of the values for which the models in the grid fit the observations. The dark bars show the same, but restricting to solar abundances models.

same in all the panels, namely -0.5 dex. The observational points that have the highest values of [O III]/Hβ and [O II]/Hβ correspond to the largest values of $\Phi_{\rm HOLMES}/\Phi_{\rm total}$.

5. Results

For each observational point in the DIG of NGC 891 we select the models of our finely meshed grid that reproduce simultaneously the values of [O III]/Hβ, [O II]/Hβ and [N II]/Hα within the observational uncertainties. We find solutions for each value of z. In Figure 4 we show the acceptable ranges of $\Phi_{\rm HOLMES}/\Phi_{\rm total}$, U, $n_{\rm e}$ and N/O as a function of z. The models clearly indicate a systematic decrease of the electron density with increasing z. If we restrict to solar metallicity (dark bars in Fig. 4), we find that the models which fit the observations become dominated by the HOLMES as z increases. Turning the argument around, this might be an indication that the metallicity of the DIG is roughly solar. Our models also indicate that N/O increases with increasing destance to the galactic plane, at least until $|z| \sim 1.5$ kpc.

6. Conclusions

Our scenario, which considers both the population of OB stars and that of HOLMES, is able to explain the long standing problem of the ionization of the DIG (see Flores-Fajardo *et al.* 2011).

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