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Diffuse Ionized Gas in Edge-on Galaxies

J. S. Mendes[1] & N. Vale Asari[1,2]

[1] Universidade Federal de Santa Catarina
e-mail: janamendesfsc@gmail.com, natalia@astro.ufsc.br

Abstract. In order to understand the main ionization sources for the extraplanar diffuse ionized gas (eDIG), we use integral field spectroscopy (IFS) data of eight edge-on spiral galaxies observed with the Multi-Unit Spectroscopic Explorer instrument in the Very Large Telescope (MUSE/VLT) to analyze the behavior of emission line ratios as a function of the distance z to the galactic plane. We investigate two potential main sources of ionization for the eDIG: Lyman photons escaping from H II regions, and hot low-mass evolved stars (HOLMES). Our findings for ESO157-49 reveal a decline in the equivalent width of Hα with increasing heights, indicating a slightly less pronounced role of H II-region escape. Collisional-to-recombination line ratios, such as [S II]/Hα, are enhanced for larger values of z, which suggests a harder ionizing field away from the disc. Finally, we compare our emission line measurements with theoretical photoionization models, which will allow us to quantify the contribution of HOLMES to the ionization processes of our sample.

Resumo. A fim de compreender as principais fontes ionizantes por trás do gás difuso ionizado extraplanar (eDIG), nós utilizamos dados de espectroscopia de campo integral de oito galáxias espirais vistas de lado com o instrumento *Multi-Unit Spectroscopic Explorer* no *Very Large Telescope* (MUSE/VLT) para analisar o comportamento das razões de linha de emissão em função da distância z ao plano galáctico. Nossa proposta consiste em duas principais fontes de ionização do eDIG: escape de fótons de Lyman vindos de regiões H II, e estrelas quentes evoluídas de baixa massa (HOLMES, do inglês *hot low-mass evolved stars*). Para ESO157-49, constatamos que a largura equivalente de Hα diminui com a altura, indicando uma contribuição um pouco menor do escape de regiões H II fora do plano. Razões de linhas colisionais e de recombinação, como [S II]/Hα, aumentam para maiores valores de z, o que sugere um campo de ionização mais duro longe do disco. Por fim, comparamos nossas medidas de linhas de emissão com modelos teóricos de fotoionização, o que nos permitirá quantificar a contribuição das HOLMES nos processos de ionização da nossa amostra.

Keywords. Galaxies: ISM – Galaxies: spiral – Galaxies: structure – Techniques: imaging spectroscopy

1. Introduction

The interstellar medium is constituted by dust and gas, and the latter can be detected at different densities. Firstly suggested by Hoyle and Ellis (1963) in the Milky Way, as a result of free-free absorption signatures observed from radio astronomical data, the Diffuse Ionized Gas (DIG) was also detected in an edge-on galaxy, NGC891, using deep Hα imaging (Dettmar, 1990). The DIG consists in an extensive layer of warm (10^4 K) gas composed of ionized hydrogen with low density (10^{-1}cm^{-3}) (Haffner et al, 2009), and can be found in disc galaxies between spiral arms (e.g. Zurita et al. 2000) and at high galactic altitudes. The DIG distinguishes itself from H II regions not only by its lower density but also by its higher ionization. Several potential ionizing sources for the DIG have been suggested (like stellar winds or supernova explosions), yet a consensus on the most significant ones remains elusive.

In this study, we investigate the role by the escape of Lyman photons originating from H II regions emitted by OB stars and HOLMES (HOt Low-Mass Evolved Stars). HOLMES, found abundantly far from the galactic plane, can be a significant contributor to the ionization of the extraplanar DIG (Flores-Fajardo et al., 2011). We analyze a sample of eight nearby edge-on galaxies (see Figure 1) observed with MUSE/VLT (Bacon et al. 2010), with public archival data observed by Comerón et al. (2019). Using integral field spectroscopy (IFS) data, we aim to compare the results obtained with theoretical photoionization models to verify and quantify the contributions of HOLMES and OB stars as a main photoionization sources for the extraplanar DIG.

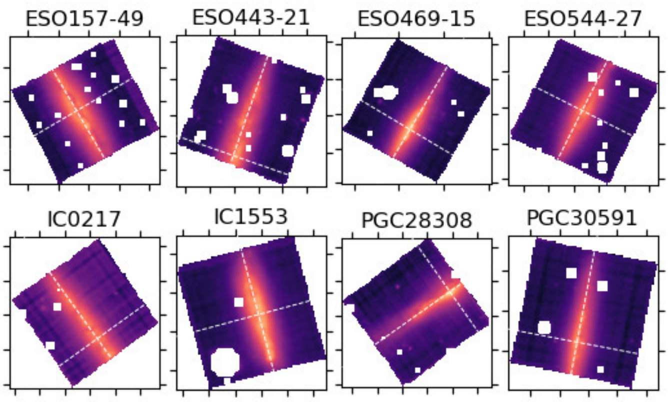

Figure 1. Observed flux maps at 5635 Å for our sample of eight nearby edge-on galaxies observed with VLT/MUSE. The blank spaces are masked objects, and the white dashed lines indicate the perpendicular and parallel axes positions for each galaxy.

2. Preliminary Results

Since we are interested in the ionization of gas, before use the IFS data we remove the stellar contribution to the observed spectra. The stellar population continua were modelled using the code STARLIGHT (Cid Fernandes et al. 2005) and the measurement of emission lines was made using DOBBY (Flórido, 2018). Stars from the Milky Way and other galaxies were also masked for not to interfere in the analysis. The grid of photoionization

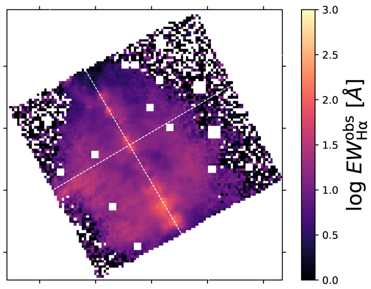

Figure 2. Hα equivalent width map for ESO157-49. The white dashed lines indicate the axes perpendicular and parallel to the plane and blank spaces are masked objects. Values indicates that, even far away from the plane, only HOLMES are not sufficient to explain the ionization of this region.

models was made by Flores-Fajardo et al. (2011) using the code CLOUDY (Ferland et al. 1998), and are included in the Mexican Million Models Database (Morisset, 2009). These models were made for NGC891, maybe being needed some adaptations for our sample.

Hereafter, we show some preliminary results about extraplanar DIG obtained for ESO157-49. Figure 2 shows a map of the equivalent width of the Hα emission line (EWHα), a measure that allows us to diagnose what is the main ionization source of a region. According to Lacerda et al. (2018), regions with EWHα < 3 Å are ionized mainly by HOLMES, while for other values the contribution of other sources, such as OB stars, is required. In this galaxy EWHα is greater than 3 Å even very far from the plane, which means that the ionization source of the extraplanar region is not only by HOLMES.

In the top panel in Figure 3, we show the emission line ratio [S II]/Hα as a function of the distance to the galactic plane z, where points are colour-coded by the distance from the galaxy center normalized by the 25 mag arcsec^{-2} B-band isphote radius. The enhanced values of this measure for larger values of z denotes a harder ionizing field outside of the plane (Flores-Fajardo et al., 2011), reforcing our propose about the role of HOLMES.

Finally, to quantify the contribution of HOLMES and OB stars to the ionization of the extraplanar DIG, we will compare the photoionization models with observational data, obtaining the contribution of ionization by HOLMES ($\Phi_{\rm HOLMES}$) for each pixel and verify if exist some tendencies for this parameter. In Figure 3, we plot the [N II]/Hα versus [O III]/Hβ diagram, where the points and black lines represent, respectively, observed data and a grid of photoioinzation models with metallicity log O/H = −3.3. The points are colour-coded by the distance to the plane z, and the dashed and solid lines indicate the models with constant mean surface flux of the ionizing photons from the OB stars (log $\Phi_{\rm OB}$) and the ionization parameter (log U). This stage is still in progress, but with this plot we can see that the models cover almost all the region of observed data, and models with lower Φ_{OB} are at same region of greater distances to the plane points, indicating a more important role of HOLMES in extraplanar regions.

3. Conclusion

In this study, we analyzed the extraplanar DIG present in the edge-on galaxy ESO157-49, one of the eight in our sample, observed with VLT/MUSE. Hα equivalent width measures shows that even at high altitudes, an ionizing source beyond HOLMES, as the escape of photons from the HII regions plays a important

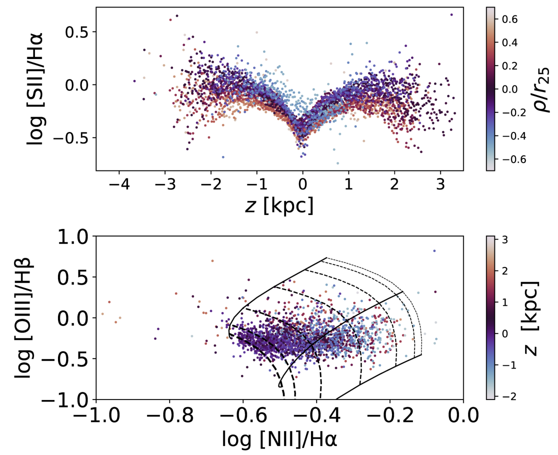

Figure 3. On top: Plot [S II]/Hα versus z, where points represent the observed data, colour-coded by the distance normalized by the isophote radius, ρ/r_{25}. The measure this emission line ratio enhance in relation of distance to the plane indicates the presence of a hardder photoionization source. **On below:** [N II]/Hα versus [O III]/Hβ plot of observed data (now colour-coded by the distance to the plane z) with a grid of photoionization models, where the dashed and solid black lines represent the models with constant log $\Phi_{\rm OB}$ and log U, respectively. The thickness of the dashed lines increases for greater $\Phi_{\rm OB}$ values, indicating the importance of HOLMES as a ionization source of this region.

role in the DIG ionization. On the other hand, [S II]/Hα indicates the existance of a harder photoionization source, like HOLMES. This is also in accordance with the match of models area and observed data: Since the greater values of Φ_{OB} coincids with the observed values points for higher altitudes, indicating that HOLMES gain relevance as we look away from the plane, we aim to quantify their contribution for the ionization of the extraplanar regions.

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References

Bacon R., Accardo M., Adjali L., Anwand H., Bauer S., Biswas I., Blaizot J., et al., 2010, SPIE, 7735, 773508
Cid Fernandes R., Mateus A., Sodré L., Stasińska G., Gomes J. M., 2005, MNRAS, 358, 363
Comerón S., Salo H., Knapen J. H., Peletier R. F., 2019, A&A, 623, A89
Dettmar R.-J., 1990, A&A, 232, L15
Ferland G. J., Korista K. T., Verner D. A., Ferguson J. W., Kingdon J. B., Verner E. M., 1998, PASP, 110, 761
Flores-Fajardo N., Morisset C., Stasińska G., Binette L., 2011, MNRAS, 415, 2182
Flórido, T., 2018, Masther thesis, UFSC.
Haffner L. M., Dettmar R.-J., Beckman J. E., Wood K., Slavin J. D., Giammanco C., Madsen G. J., et al., 2009, RvMP, 81, 969
Hoyle F., Ellis G. R. A., 1963, AuJPh, 16, 1
Lacerda E. A. D., Cid Fernandes R., Couto G. S., Stasińska G., García-Benito R., Vale Asari N., Pérez E., et al., 2018, MNRAS, 474, 3727
Morisset C., 2009, MmSAI, 80, 397
Zurita A., Rozas M., Beckman J. E., 2000, A&A, 363, 9