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Star formation in ringed barred spiral galaxies

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Abstract. In this study, we focused on barred ringed spiral galaxies for two reasons. Firstly, 20% of normal spiral galaxies exhibit this ring pattern in their light distribution. Secondly, the rings of these galaxies are known to harbor systems with a high rate of star formation. Thus, these galaxies can be considered as laboratories for studying H II regions. The six galaxies in our sample were observed with an Hα filter on the SOAR telescope, employing the SAMI adaptive optics system. The primary objective of the study was to obtain photometric catalogs of the H II regions for each galaxy in our sample, as these catalogs enabled the derivation of the physical and geometric properties of these regions. To achieve this goal, the study was divided into three stages: stellar continuum subtraction, physical flux calibration, and the detection and characterization of H II regions using the H IIphot program, which generates the photometric catalog. With this catalog, we were able to obtain the luminosity function, the variation of Hα luminosity as a function of galactocentric distance, the variation of Hα luminosity as a function of the equivalent radius of H II regions, the variation of electron density, the variation of the equivalent width of Hα, the variation of the age of H II regions, and the instantaneous star formation rate (SFR) of the regions. We also present a map of the SFR distribution for each galaxy. Preliminary results indicate that the presence of the bar and ring can disturb the distribution of the equivalent width. H II regions at the edge are younger and exhibit intense star formation. The luminosity function of the galaxies in the sample is consistent with those reported in the literature. Additionally, the ring is identified as a favorable location for the formation of giant H II regions (r>1kpc). From this work, we can conclude that, despite the galaxies being of similar morphological types, there are observed differences in parameters among them.

Resumo. Neste trabalho estudamos as galáxias espirais barradas aneladas por dois motivos. O primeiro é o fato de 20% das galáxias espirais normais apresentarem esse padrão de anel na distribuição da luz. O segundo é que os anéis dessas galáxias são conhecidos por abrigarem sistemas com alta taxa de formação estelar. Dessa maneira, essas galáxias podem ser consideradas como laboratórios para estudar as regiões H II. As seis galáxias da nossa amostra foram observadas com filtro Hα no telescópio SOAR, utilizando o sistema de óptica adaptativa SAMI. O objetivo principal do trabalho foi obter os catálogos fotométricos das regiões H II para cada galáxia da nossa amostra, pois, a partir deles, foi possível derivar as propriedades físicas e geométricas das mesmas. Para alcançar esse objetivo, o trabalho foi dividido em três etapas: a subtração do contínuo estelar, a calibração em fluxo físico e a detecção e caracterização das regiões H II através do programa HIIphot, que gera o catálogo fotométrico. Com este catálogo fomos capazes de obter a função de luminosidade, a variação da luminosidade Hα em função da distância galactocêntrica, a variação da luminosidade Hα em função do raio equivalente das regiões H II, a variação da densidade eletrônica, a variação da largura equivalente de Hα, a variação da idade das regiões H II e a taxa de formação estelar instantânea (SFR) das regiões. Apresentamos também um mapa de distribuição da SFR para cada galáxia. Os resultados preliminares mostram que a presença da barra e do anel podem perturbar a distribuição da largura equivalente. As regiões H II na borda são mais jovens e possuem formação estelar intensa. A função de luminosidade das galáxias da amostra é congruente com as citadas na literatura. Podemos ver também que o anel é um lugar propício à criação de regiões H II gigantes (r>1kpc). Desse trabalho podemos concluir também que, embora as galáxias sejam do tipo morfológico semelhante, há diferenças observadas dos parâmetros entre as mesmas.

Keywords. star formation – H II regions – adaptive optics

1. Introduction

Barred ringed spiral galaxies, classified by de Vaucouleurs, command attention not only for their distinctive visual characteristics but also for their prevalence and intricate internal dynamics. According to literature estimates, around 20% of spiral galaxies exhibit this specific ring pattern in their light distribution, designating it as a morphological type with a noteworthy prevalence (Buta & Combes 1996). Due to the inherent dynamics within these galaxies, the rings function as sanctuaries for systems characterized by a high rate of star formation. Consequently, these galaxies serve as invaluable laboratories for an in-depth exploration of H II regions. Those regions, characterized by clouds of gas and dust enveloping massive O and B-type stars, emit a potent ultraviolet radiation field, thereby ionizing molecular hydrogen. The detection of these regions typically involves observing them through a narrow filter centered on Hα (6563Å). This selection is grounded in the fact that, in this specific spectral region, emission lines are notably intense, whereas the stellar continuum provides a subtle backdrop (Maciel 2002). Consequently, the emission of Hα emerges as one of the most reliable indicators of massive star formation within galaxies (Zaragoza-Cardiel et al. 2015).

2. Data

Our sample consists of six galaxies: NGC 2223, NGC 2835, NGC 3275, NGC 3513, NGC 4639, and NGC 4902. These were observed using the SOAR telescope (Southern Astrophysical Research Telescope). The telescope is equipped with an adaptive optics system called SAM (SOAR Adaptive Module), the GLAO (Ground-layer Adaptive Optics) variety, providing high angular resolution over a large field of view. SAM has a field of view of 3 arcmin. The SAMI (SAM Imager) produces corrected images with a resolution between 0.30″ and 0.40″ , where the theoretical diffraction limit is 0.031″ with λ = 5000Å (Tokovinin et al. 2016). The main objective of this study was to obtain photometric catalogs of H II regions for each galaxy in our sample. These catalogs were instrumental in deriving the physical and geometric properties of these regions. They include positions, sizes, Hα luminosity, etc., of the detected regions. Consequently, we were able to investigate the following aspects: Luminosity function; the variation of Hα luminosity as a function of galactocentric distance; the variation of Hα luminosity with the equivalent radius of H II regions; the variation of electron density; the variation of Hα equivalent width; the variation of the age of the regions; and the star formation rate (SFR).

3. Methodology

The research was structured into three principal stages. Initiating with the removal of the stellar continuum from the Hα image using the method outlined by Kennicutt et al. (2008). To accomplish this, it was imperative to utilize an R-filter image. The result of the substraction is a Hα+[NII] continuum free image. The second stage involved the calibration of physical flux in the Hα and R images, employing the methodology of Gavazzi et al. (2002). During this phase, standard stars observed on the same night - LTT 4816, LTT 6248, Hiltner 600 (Hamuy et al. 1994) - were utilized for calibration purposes. Finally, the HIIphot program, developed by Thilker et al. (2000), was applied to the sample images. HIIphot, an IDL (Interactive Data Language) program, not only facilitates precise photometric characterization of H II regions but also adapts to the morphology of each region. This adaptive capability stems from an iterative growth process initiated from what the program identifies as its seeds. The choice of HIIphot was motivated by its automated technique, proficiently determining parameters such as flux, position, size, orientation, etc., of H II regions in galaxies (Thilker et al. 2000).

4. Results and discussion

The number of detected H II regions in each galaxy ranges from 153 to 1103. The equivalent radius of the H II regions in the sample varies between 14 pc and 827 pc. According to the classical *Strömgren* sphere model, Hα luminosity is proportional to the volume of the H II region. However, such a relationship was not observed in our sample. By plotting the logarithmic scale between luminosity and equivalent radius, we obtained a slope ranging from 1.21 to 2.51, a result analogous to that found by Guitérrez et al. (2011). The values of the luminosity function in our sample fluctuate between α = -1.96 and α = -2.28. A critical luminosity value, or *Strömgren* luminosity, is discussed in the literature, equal to L(Hα) = 38.6 dex (Guitérrez et al. 2011). In our sample, this value ranged between L(Hα) = 38.4 dex and L(Hα) = 39.2 dex. There is still no consensus on the physical interpretation of this value. To find it, it is recommended to create the cumulative luminosity function. The star formation rate (SFR) is displayed in the form of a color map, as seen in de Souza et al. (2018). The SFR density is the SFR divided by the unit area of the H II region (SFR). Overall, $\sum$SFR is homogeneous in the galaxy. In the galaxies NGC 4639 and NGC 4902, the H II regions in the ring show higher SFR densities compared to the rest of the galaxy. Using *Starburst* 99 (Leitherer et al. 1999), we have determined the age of the different H II regions. The results of the ages of the H II regions initially indicate that there may be two or three populations in the same galaxy, although the age difference between them is small. This result can be refined using other metallicities and a different initial mass function value. In summary, this study encompassed six galaxies, from which important parameters present in the literature were derived and compared, based on the photometric catalog.

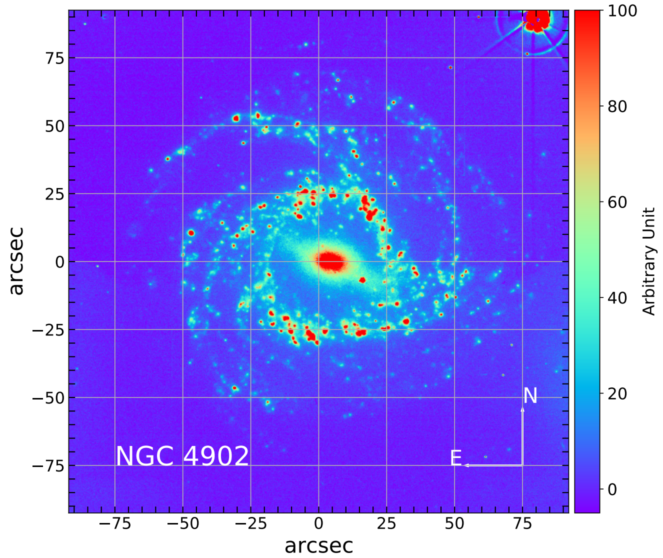

Figure 1. The Hα + [NII] image of the galaxy NGC 4902 on an arbitrary unit.

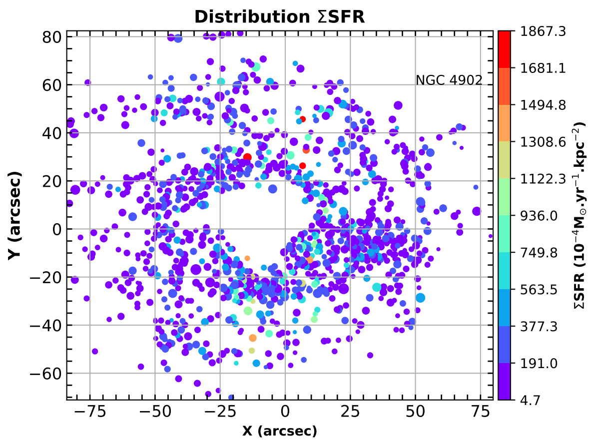

Figure 2. The distribution of the star formation rate density (Σ SFR). Each circle represents an H II region, with its size proportional to the area.

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