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Mapping diffuse structures surrounding young clusters I: The case of NGC 3572

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Abstract. The study of star-forming regions within our Galaxy is essential to understanding the formation and early-evolution of structures on galactic scales. In this work, we utilize SOAR Spartan and SAMI imaging to caractherize the interstellar medium (ISM) surrounding NGC 3572: a 3 Myr young stellar cluster located in the Carina region, one of the largest star-forming regions of the Milky Way. Comparative maps of the ISM emission in 10 distinct bands allowed us to highlight known nebular objects, such as PhJa 1, and reveal other diffuse structures. Our methodology has been proving to be useful to identifying shock-fronts regions, gas excitation/ionization levels, and reveal embedded objects.

Resumo. O estudo de regiões de formação estelar na nossa Galáxia é essencial para compreendermos os primeiros estágios de formação e evolução de estruturas em escalas galáticas. Neste trabalho, nós utilizamos imageamentos Spartan e SAMI (SOAR) para caracterizar o meio interestelar (ISM) envolvendo NGC 3572: um aglomerado estelar jovem com cerca de 3 milhões de anos, localizado na região de Carina, uma das maiores regiões de formação estelar da Via-Láctea. Mapas comparativos da emissão do ISM em 10 bandas distintas nos permitiram destacar características nebulares de objetos já conhecidos, como PhJa 1, e revelar novas estruturas difusas. Nossa metodologia tem se provado útil para identificar regiões de frentes de choque, excitação/ionização do gás, e revelar objetos embebidos.

Keywords. Stars: formation – ISM: general – open clusters and associations: general

1. Introduction

Young stellar clusters are associated with star-forming regions and crucial for galactic chemical enrichment. Their significance extends to understanding the formation and evolution of structures on galactic scales. However, the processes related to the formation of clusters and the conditions of the medium in which they evolve are still open questions to be solved.

Carina Complex is ideal to study these kind of structures due to its amount of open clusters, being one of the largest star-forming regions within our Galaxy, rich of gas, dust and young stars chainned by complex dynamical processes.

NGC 3572 is one of these clusters: a ~ 3 Myr old stellar cluster located at ~ 2.5 kpc distance. A colour composition of this cluster is shown on Figure 1. It is possible to note how NGC 3572 is affected by gas, dust and also its own massive stars.

An example of the importance of investigating the interstellar medium (ISM) within our Galaxy is the detailed study of the Crab Nebula's morphology, presented by Loh et al. (2010, 2011), in which they compare near-infrared and visible light emission through SOAR/Spartan and HST narrow-band imaging in H_2, Brγ, [S II] and [O III] bands. Their results show how imaging comparison maps are useful to delineate the gas distribution within the Nebula. Navarete et al. (2014, 2015) also utilize SOAR/Spartan observations to evaluate the H_2 emission morphology around ~ 100 MYSOs and conclude that most of the sample showed jet-like structures supporting the scenario in which massive stars are formed by accretion discs. Beyond that, Riaz et al. (2017) reported the discovery of the HH 1165, a new Herbig–Haro jet driven by a Proto-Brown Dwarf through SOAR narrow-band imaging in the Hα, [S II] and R bands.

Figure 1. MPG/ESO colour composition in the direction of NGC 3572 and observed in the bands B (blue), V (green), R (yellow) and Hα (red).

Comparing the emission at specific wavelenghts/bands to determine physical conditions of the ISM through images and spectra is a tool chosen by several authors. Heathcote et al. (1996) utilize the fluxes ratio [S II]/Hα to identify shock fronts in the jet driven by the HH 47 object. A similar method was adopted by Loh et al. (2011) to evaluate ionization levels on their survey on the Crab Nebula by means of the [S II]/[O III] ratio. Beyond that, Smith et al. (2003) also correlated [S II] and [O III] spectral lines to quantify excitation levels on the PhJa 1 nebular structure, in NGC 3572 – target of this study –, and unveil its true nature.

Aiming to contribute to the current understanding, we conducted a detailed study of the gas conditions surrounding the young stellar cluster NGC 3572 and the stellar feedback effects based on SOAR/SAMI and Spartan imaging.

2. Methodology

In this work, we use SOAR/SAMI and Spartan 10-band imaging (R, Hα, [S II], [O III], Cont.3, H_2, Brγ, J, H, and K) acquired during the observational run ID 2017A-021, complemented with the data from the catalogues Gaia DR3, 2MASS and WISE. Our data covers ~3'×3' fields in 2 distinct pointings.

We use StarFinder to identify punctual sources and extract the background images from each of the exposures. We performed the astrometrical calibrations through Aladin, superposing Gaia DR3 positions and DSS images to our fields. Using TopCat we correlated identified sources in our fields (StarFinder) to Gaia DR3 data to establish membership criteria and determine clusters' members. The adopted criteria are based on fitting Gaussian curves in the distributions of parallax and proper motions in right ascension and declination. The sources within 3σ in parallax and proper motion were selected as cluster members. We estimated ages through CMDs in Gaia DR3 G, G_{BP} and G_{RP} bands. Reddening corrections were made following Cardelli et al. (1989) and O'Donnell et al. (1994) A_λ/A_V relations. All comparative maps were generated through python scripts. The division between images in distinct bands is the adopted technique to highlight structures in the field.

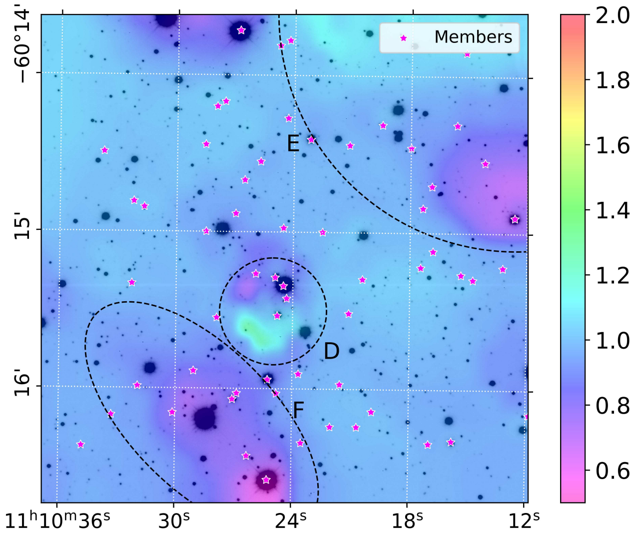

Figure 2. Comparative colour map of the Hα/[S II] ratio, where the main regions (E), (D), and (F) are delimitated by dashed lines.

3. Results

The main structures found in NGC 3572 were revealed through SAMI and Spartan comparative colour maps. The flux in each band is normalised in values ranging from 1 (minimum emission) to 2 (maximum emission). By this way, the ratios obtained from the division between the normalized images range from 0.5 to 2.

Stars targeted as Members in the maps shown on this work are classified as cluster members by following the methodology described in Section 2, and regions (D), (E), (F) and (G) were defined based on visual inspection.

3.1. Comparing imagens obtained with SAMI

In Figures 2 to 4, we show the colour maps centralised on the PhJa 1 structure, a photoevaporating globule globule associated to NGC 3572. There are only optical (SAMI) data available for this region. On these maps, we highlight PhJa 1 (D), a northern diffuse structure (E), and the medium surrouding the massive stars (F).

Firstly identified as a Planetary Nebula, PhJa 1 (D) is being considered to be actually a Photoevaporating Globule after the work by Smith et al. (2003). Our maps reveal that this structure may be ionised from the outside due the action of massive stars within NGC 3572 (F), supporting Smith et al. (2003) hypotesis. This effect can be seen on the comparatives maps of Figures 2 and 3.

The Hα/[S II] index is currently used to trace shock fronts associated to nebular regions. In Figure 2, we identify shock fronts by means of the variation in the Hα/[S II] ratio, from lower to higher values, which are noticed in both regions: (E) where it the border of molecular cloud (see Fig. 1), and (D), showing a gradient in the direction of the massive stars (F).

The gradient observed within PhJa 1 in Figure 2 is indicated by the transition from Hα/[S II] < 1 outside (D), to higher values in its southeast border, then dropping again in the internal region of PhJa 1. These variations are interpreted as the effect of an external source of radiation photo-dissociating the neutral globule from the outside.

Figure 3 shows the [S II]/[O III] map that is often used as an indicative of ionization and excitation levels in diffuse regions. The concentrations of gas under low-ionization conditions are mainly found in regions (E) and (D) with [S II]/[O III] > 1.

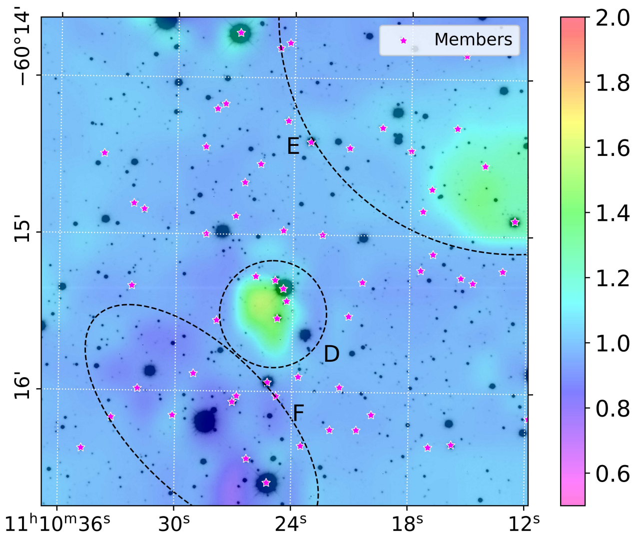

Figure 3. The same as Figure 2 for the [S II]/[O III] ratio.

In Figure 4, we present the Hα/[O III] map. That highlights the concentration of neutral gas when compared to the ionized gas. The ISM surrounding the massive stars (F), which seem to be the sources of ionization in the central globule (D), reveals a predominantly ionised emission, which is expected in O/B stars enviroments. When compared to the ISM within (D), this feature also supports the hypothesis of PhJa 1 being an embedded young object, composed mostly by neutral gas, being photo-ionised by the massive stars in (F), instead of a planetary nebula.

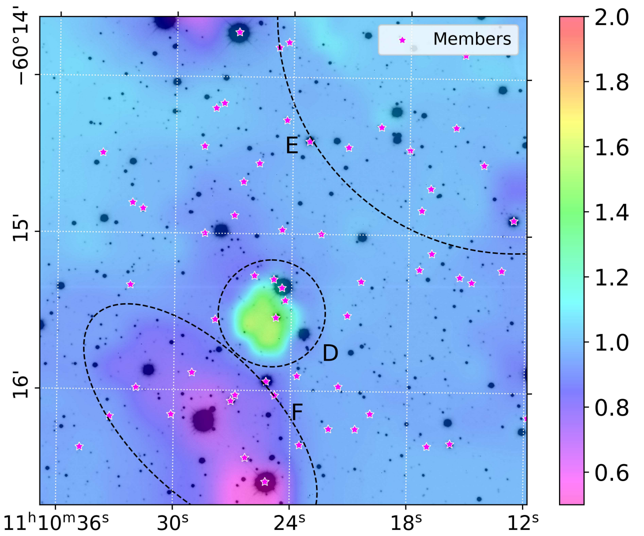

Figure 4. Comparative colour map of the Hα/[O III] ratio. Note how only regions (D) and (F) highlight distinct features on this map.

3.2. Fluxes ratios obtained from optical and infrared images

The whole set of SAMI and Spartan data (10 filters in total) was acquired for the region that have an offset of 12" to the West, in comparison with the maps discussed in Section 3.1.

The images using filters H_2, Brγ, Cont.3, J, H, and K revealed a new infrared object not detected through optical maps. This new object is more evident when comparing optical and infrared emission.

When comparing Hα to H_2 emission in Figure 5, the region (G) appears as a dense H_2 core, which can be related to a very young object that is still embedded.

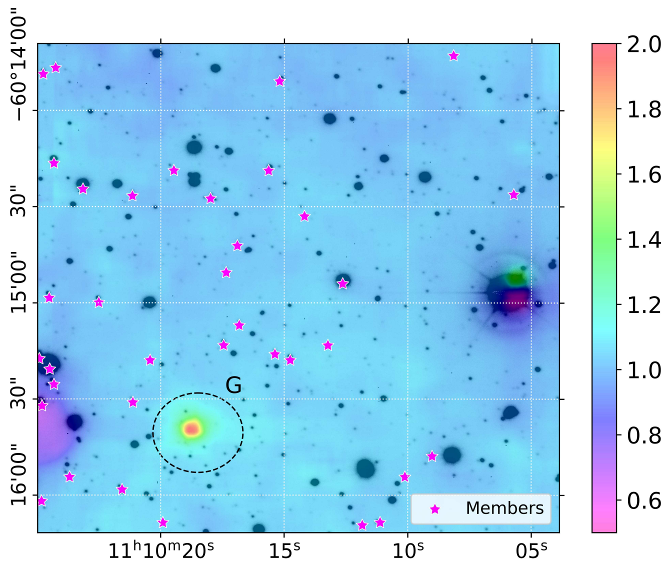

Figure 5. Colour map of the H_2/Hα ratio. Note the PhJa 1 globule partially seen to the East of the object (G).

On the other hand, low levels of H_2 emission is observed in part of region (D) that is the border of the PhJa 1 globule. In Figure 5, it appears in purple shades (H_2/H$\alpha < 0.6$).

Figure 6 shows the comparison between Hα and Brγ emission. Here, both (G) and (D) have shown distinct structures: while the photo-ionised globule shine in Hα emission, the embedded object shine in Brγ emission.

The object (G) is not reported in the literature and even though its origin remain uncertain, the comparative maps on the Figures 5 and 6 make it clear we are facing completely distinc structures: one is brighter in optical wavelenghts, surrounding some young stars (~3Myr) already identified by our group, while the other seems to be a colder envelope without visible star. The true nature of the object (G) is still being analised by our group.

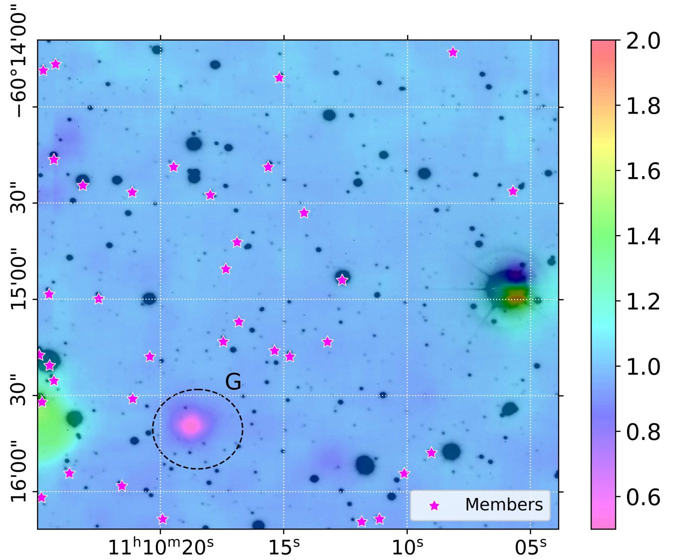

Figure 6. The same as Figure 5 for the Hα/Brγ ratio.

Regarding membership and cluster physical parameters, our analysis has shown that NGC 3572 is located at 2.56±0.03 kpc. Troper motion of the group is (-6.25, 2.04)±0.15 mas/yr and the age determined by PARSEC isochrones point to only 3 Myr old.

4. Conclusions

The maps comparing optical and infrared images proved to be a powerful tool to reveal diffuse and dense regions, allowing the discovery of new conspicuous objects. In this work, we highlight the presence of four different gas distributions in NGC 3572: a photoevaporating globule, the medium around the massive stars, a cloud in the northwest and a small infrared core. The globule has a radial gradient of emission, supporting the hypothesis described by Smith et al. (2003) in which the structure is ionized from the outside by the action of massive stars on the field. Furthermore, we identified the presence of a peculiar region that is bright only in infrared bands, which could possibly be associated to an embedded young object not previously found in the literature.

The next steps of this work include investigating the nebular structure of PhJa 1 through IFU spectroscopy and acquire data of the ISM surrounding NGC 3572 in other spectral bands, such as radio and X-rays, the studies will allow us to reveal other conspicuous features and describe in more detail the nature of the structures found in this work.

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