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Linking massive stars to their natal molecular clouds: a preliminary analysis

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Resumen / Teniendo en cuenta que las estrellas se forman en nubes moleculares, y que las estrellas de alta masa perturban fuertemente su entorno a través de potentes vientos e intensa radiación UV, nos proponemos investigar el impacto que tienen las estrellas masivas sobre sus nubes moleculares parentales. Para esto, utilizamos cubos de CO (J = 1-0) tomados del relevamiento del *Five College Radio Astronomical Observatory* para estudiar la distribución de la emisión del gas molecular en los alrededores de varias estrellas tipo O y Wolf-Rayet ubicadas en el segundo cuadrante Galáctico. Con este fin, analizamos la presencia de gas molecular en el entorno de cada estrella y consideramos la emisión integrada en tres intervalos de velocidad de ancho creciente. Estos intervalos se centraron en el valor de velocidad asociado con la distancia a la estrella según un modelo de rotación de la Galaxia. En base a los resultados obtenidos, comenzamos un estudio estadístico preliminar de la cantidad y distribución de gas molecular en la vecindad de estrellas masivas.

Abstract / Bearing in mind that stars are born in the densest regions of molecular clouds and that massive stars are known to disturb their environment through strong winds and intense UV radiation fields, we aim to research the impact that massive stars have on their parental molecular clouds. In this work, we make use of CO (J = 1-0) data cubes obtained from the Five College Radio Astronomical Observatory survey to study the distribution of the molecular gas emission in the surroundings of several O-type and Wolf-Rayet stars located in the second Galactic quadrant. For this purpose, we analyze the presence of molecular gas around each star, while considering the emission integrated into three velocity intervals of increasing width. These intervals were centered on the velocity value that corresponds to the distance of each star, according to a Galaxy rotation curve model. Based on the results yielded from the image analysis, we carry out a statistical study of the amount and distribution of molecular gas in the vicinity of massive stars.

Keywords / ISM: clouds — stars: massive — radio lines: ISM

1. Introduction

Stars, and particularly massive stars ($M \geq 8\ M_\odot$), are born in the densest regions of molecular clouds. Throughout their evolution, high–mass stars disturb irreversibly their natal cloud through their strong winds and ionizing radiation (Weaver et al., 1977). However, the specific consequences that these stars cause on their environmental gas are still an open question. In an attempt to understand the impact that early-type stars have on their surrounding molecular gas, and how this depends on the characteristics of the stars (spectral type, luminosity, multiplicity, proper motion) and the cloud from which they were born (Galactic position, mass, density), we plan to measure the amount and distribution of remaining CO gas in the vicinity of several O–type and Wolf–Rayet stars. As a preliminary analysis, we present here the results obtained for ten of such stars.

2. Methodology and Data

Our first goal was to set up the sample of early-type stars and relate them to the molecular gas in their surroundings. With this aim, we followed a series of steps:

- We selected 10 stars from the Galactic O Star Catalogue (GOSC; Maíz Apellániz et al. 2013) and from the online compilation of all known Galactic Wolf–Rayet stars (Rosslowe & Crowther, 2015).
- We searched for their distances according to the Gaia EDR3 data (Bailer-Jones et al., 2021).
- Based on the Galactic structure model of Reid et al. (2019), we estimated the radial velocity corresponding to the distance for each star. This model was determined from observational data (trigonometric parallaxes of molecular masers) and takes into account the non-circular motions known to be present in the Perseus spiral arm.

The sample of ten stars chosen for this work is introduced in Table 1. Their spatial distribution projected onto the Galactic plane is shown in Fig. 1.

For the purpose of measuring the amount and distribution of remaining molecular gas around the stars, we used the following procedure: first, we analyzed the CO emission data cubes in the $J = 1-0$ transition obtained from the Five College Radio Astronomical Observatory (FCRAO) survey (Heyer et al., 1998). These cubes have a spatial and spectral resolution of 45" and 0.98 km s^{-1}, respectively, and cover a range of Galactic

Poster contribution

ID	l (°)	b (°)	ST	Dist (pc)	Vel (km/s)
1	128.29	1.82	O9.7 II	3697.6	–46.1
2	127.88	–1.35	O7.5 III	2471.0	–31.6
3	124.65	–2.41	WN2b	3566.2	–44.7
4	122.57	0.12	O7 V	4001.7	–49.6
5	122.08	1.9	WN4b	3021.1	–37.8
6	115.9	–1.16	O6 V	2810.5	–33.2
7	115.03	0.11	WN7h	4601.3	–54.6
8	109.32	–1.79	O8.5 III	1780.3	–16.7
9	103.85	–1.19	WC6	4739.9	–48.7
10	134.99	–1.75	O4.5 I	2429.6	–30.6

Table 1: Stars sample.

longitudes from 102°.49 to 141°.54, and latitudes from –3°.03 to 5°.41. Second, we integrated the CO emission in three different velocity intervals of widths 5, 10, and 20 km s^{-1}, centered on the radial velocity associated with each star (see Table 1). These intervals were chosen with the aim of analyzing the distribution of molecular gas possibly related to the star both at velocities close to that of the star and also at wider ranges, which would allow, for example, the detection of expanding structures. In turn, the intervals take into account the uncertainty in the estimated radial velocity for each star.

For each integrated image, we computed the H_2 column density and the hydrogen mass, M_{H_2}, around every star, considering the CO emission at 3σ level inside three different circles of 2, 10, and 30 pc of radius, centered at the spatial coordinates of the star. We defined these search radii bearing in mind the typical sizes of H II regions, with our goal being to study the molecular gas distribution in a roughly wide range of distances to the star. Then, the molecular mass present within each region was estimated as $M_{H_2} = 4.2 \times 10^{-20}\ N_{H_2}\ D^2\ \Omega$, where D is the distance in parsecs, N_{H_2} is the H_2 column density, Ω is the solid angle of the molecular emission expressed in steradians and the H_2 mass is in units of $M_\odot$. This estimation assumes a CO-H_2 conversion factor for the column density of $X = 1.8 \times 10^{20}$ cm^{-2} K^{-1} km/s^{-1} (Nguyen et al., 2015). Finally, we have estimated the percentage of the surface occupied by CO emission in relation to the total area of each circle (i.e. the surface filling factor).

3. Results and Discussion

After analyzing the images and values obtained, we found that only one star (ID 1) presents molecular gas inside the three circles, in all three velocity ranges. Only one star (ID 3) has no remaining gas, within any distance (at least up to 30 pc, which is the furthest distance we considered). The other eight stars, all present diverse amounts of molecular gas emission at some point, within some (or all) range/s of velocity, but always outside the 2 pc circle. Fig. 2 shows the CO emission distribution in the surroundings of stars ID 1 and 6, for reference.

Considering the values obtained we present here some general results:

From the images integrated along 5 km s^{-1}, we find that:

- Star ID 1 has 91 % of the surface inside the 2 pc radius filled with molecular gas that corresponds to $\sim$ 385 $M_\odot$.
- Three stars (including ID 1) show CO emission inside the 10 pc radius, but for two of them, it represents less than 1 % of the surface.
- Nine stars (all except ID 3) have molecular gas inside their 30 pc circle, but eight of them have less than 2 % of the surface covered.

From the images integrated along 10 km s^{-1}, we find that:

- Star ID 1 has 85 % of the surface inside the 2 pc radius filled with molecular gas, which corresponds to $\sim$ 481 $M_\odot$.
- Four stars (including ID 1) show CO emission inside the 10 pc radius, but for three of them, it represents less than 1 %. These low percentages correspond to only a few tens of $M_\odot$.
- Nine stars have molecular gas inside their 30 pc circle. Five of them have less than 1 % of the surface covered. The other four, less than 8 %.

Lastly, from the images integrated along 30 km s^{-1}, we find that:

- Star ID 1 has 79 % of the surface inside the 2 pc radius filled with molecular gas.
- Five stars present CO emission inside the 10 pc radius but for four of them, it represents less than 1 %.
- Eight stars have molecular gas inside their 30 pc circle. Four of them have less than 1 % of surface covered. The other four, less than 15 %. Star ID 6 shows the highest amount of H_2 mass: $\sim$ 35 600 $M_\odot$, which corresponds to 13 % of the surface covered.

If we consider the standard scenario for massive star formation, we would expect at least some rem-

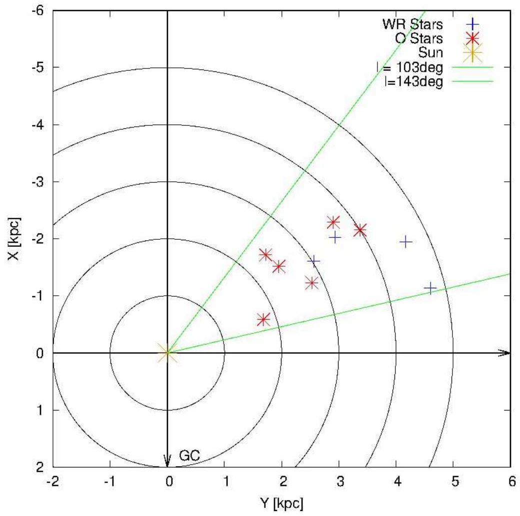

Figure 1: Distribution of the ten massive stars on the Galactic plane. Red asterisks indicate O–type stars, while blue crosses correspond to WR stars. Green lines mark the Galactic longitude values of l = 103° and l = 143°, limiting the region where CO data are available. The black circles have a radius of 1, 2, 3, 4, and 5 kpc and are centered at the Sun.

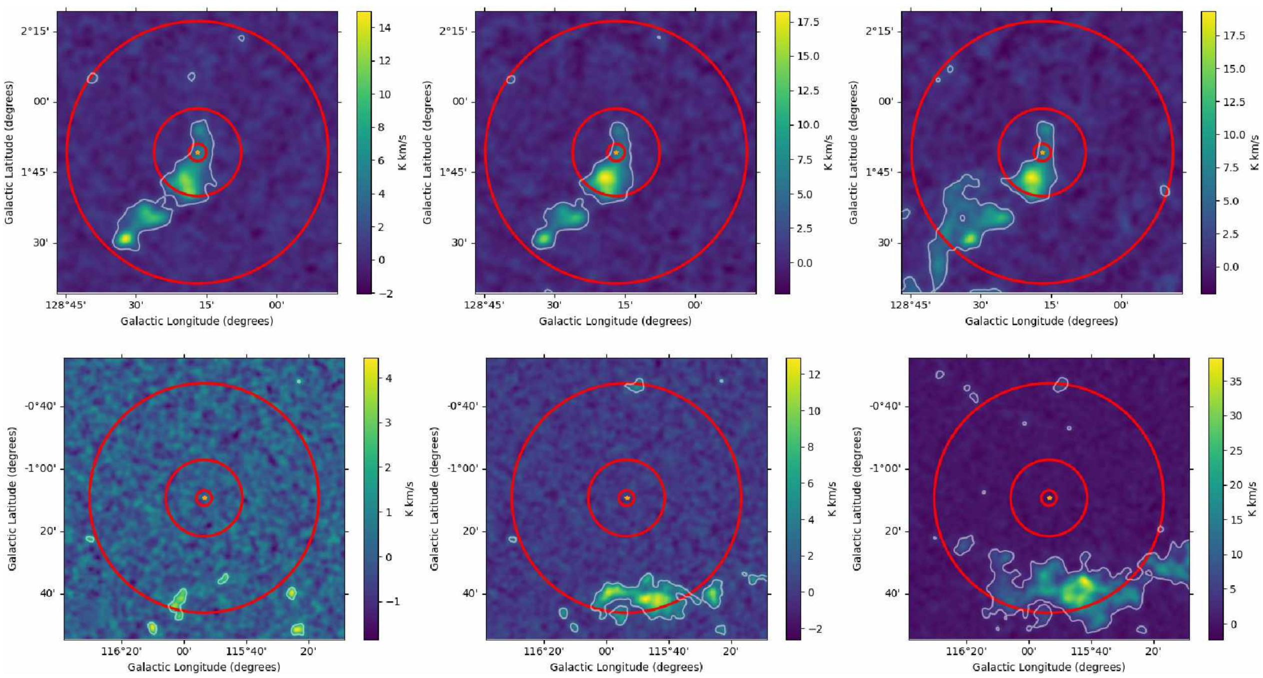

Figure 2: CO (J = 1-0) emission distribution maps around stars 1 (*upper row*) and 6 (*bottom row*). The three columns show $\Delta V = 5$, 10, and 20 $\mathrm{km\,s^{-1}}$. The white contour lines show the CO emission at 3σ level. The red circles have a radius of 2, 10, and 30 pc and are centered at the position of each star.

nant of the parental molecular cloud present around the young stars. How much gas remains, and how is it distributed, are questions that we first attempt to respond to here. Although in this work we present a preliminary analysis considering only ten stars, the small amount of gas detected in their surroundings is striking. In particular, we want to address the issue of star ID 3, which shows a complete lack of molecular gas. On the one hand, an inspection of the whole CO data cube reveals the presence of emission neighboring the star at a velocity of -24 $\mathrm{km\,s^{-1}}$, this is, shifted about 20 $\mathrm{km\,s^{-1}}$ from the velocity assumed for the star (see Table 1). On the other hand, this particular star has been cataloged as a candidate runaway star by Tetzlaff et al. (2011), based on the proper motion values of $\mu_\alpha = -12.8$ $\mathrm{mas\,yr^{-1}}$ and $\mu_\delta = 7.18$ $\mathrm{mas\,yr^{-1}}$, taken from the Hipparcos catalogue (van Leeuwen, 2007). However, no IR bow-shaped emission has been detected related to this star (Peri et al., 2015). In fact, the new values for the stellar proper motion, taken from the Gaia EDR3 data, are considerably lower: $\mu_\alpha = -3.36$ $\mathrm{mas\,yr^{-1}}$ and $\mu_\delta = -1.42$ $\mathrm{mas\,yr^{-1}}$. Furthermore, these are in better agreement with the Tycho–2 catalogue values ($\mu_\alpha = -3.8$ $\mathrm{mas\,yr^{-1}}$ and $\mu_\delta = -3.3$ $\mathrm{mas\,yr^{-1}}$, see Høg et al. (2000)). Based on the Gaia measurements, we calculate the star's peculiar motion, following the procedure from Comerón & Pasquali (2007). We obtain $V_{\mathrm{pec_l}} = -7.18$ $\mathrm{km\,s^{-1}}$ and $V_{\mathrm{pec_b}} = -16.32$ $\mathrm{km\,s^{-1}}$, which yields a tangential velocity value of $V_T = 17.83$ $\mathrm{km\,s^{-1}}$. This casts doubt on this star being a runaway star. Nevertheless, considering that star ID 3 is a WR star, i.e. an evolved star, it is likely that it traveled long enough to move away from its natal cloud, either due to gravitational interactions with its stellar group or because of the impulse given by the supernova explosion of some companion star (Meyer et al., 2020).

The specific characteristics of the results we find regarding WR stars in comparison to those of O-type stars, and the differences we expect when dealing with runaway stars, are something we plan on investigating further in detail along with a larger sample of massive stars as our next step.

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References

Bailer-Jones C.A.L., et al., 2021, VizieR Online Data Catalog, I/352
Comerón F., Pasquali A., 2007, A&A, 467, L23
Heyer M.H., et al., 1998, ApJS, 115, 241
Høg E., et al., 2000, A&A, 355, L27
Maíz Apellániz J., et al., 2013, *Massive Stars: From alpha to Omega*, 198
Meyer D.M.A., et al., 2020, MNRAS, 496, 3906
Nguyen H., et al., 2015, ApJ, 812, 7
Peri C.S., Benaglia P., Isequilla N.L., 2015, A&A, 578, A45
Reid M.J., et al., 2019, ApJ, 885, 131
Rosslowe C.K., Crowther P.A., 2015, MNRAS, 447, 2322
Tetzlaff N., Neuhäuser R., Hohle M.M., 2011, MNRAS, 410, 190
van Leeuwen F., 2007, A&A, 474, 653
Weaver R., et al., 1977, ApJ, 218, 377