Star Formation at the tips of the Milky Way Bar with Hi-GAL

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Abstract

We present the physical properties of two large sky areas at the tips of the galactic bar in the first $(18^{\circ} < 1 < 34^{\circ})$ and fourth $(340^{\circ} < 1 < 351^{\circ})$ quadrant, observed by the Herschel/Hi-GAL survey. The goal of the analysis is to study the high mass star formation occurring in that regions of the sky, focusing on the role of the galactic bar in the process. We first study the evolutionary stage and star formation rate (SFR) of the entire set of young protostars detected by Hi-GAL, and then compare it with the star forming regions located at the intersections between the bar and the galactic arms on both sides. We particularly focus on the farthest side of the bar, since it is the less studied due to a lack of data covering the area. Ancillary 13CO NANTEN data are used to identify molecular complexes harbouring protostars.

Context

The star formation activity nearby the Milky Way (MW) center is not well known, partially because the particular configuration of the Galactic rotation might alter the normal dynamics of gas and interstellar medium (ISM), and partially because photometric observations of the center and the bar are biased by source overlap along the line of sight. Observations of the W43 HII region, located at the edge of the bar in the first galactic quadrant, suggest a local star formation activity higher than the rest of the MW. According to the information available nowadays, the galactic bar intersects the Scutum-Centaurus arm in the first quadrant at a heliocentric distance of 6 kpc, and the Perseus arm in the fourth quadrant at 11 kpc from us. If there is a triggering effect at the edges of the bar, we should expect the two sides to show similar properties. We make use of a protostar counting method to estimate the SFR on both sides of the galactic bar and then compare the results with values obtained by including all the sources in the fields.

The method

The SFR of a set of sources is estimated by means of a star counting method. We apply the McKee et al. 2003 evolutionary model to extrapolate the final stellar mass, given a certain envelope mass and luminosity of the initial clump. In previous works (Veneziani et al. 2012, Elia et al. 2013) the extrapolation has been done assuming each clump to collapse into a single high mass star, applying the evolutionary tracks estimated by Molinari et al. 2008 (M08). In this work, the final masses are extrapolated taking into account the possibility, more realistic, for the clump to collapse into a cluster of stars. The SFR correspondent to an initial clump of a given mass and luminosity, are then estimated through a Monte Carlo analysis over all the possible final cluster configurations.

The Hi-GAL survey is a photometric observation of the entire Galactic Plane (GP) in $2^{\circ}x2^{\circ}$ tiles, with PACS and SPIRE in parallel mode, from 70 to 500 µm.

- Protostars (blue dots) are identified as the sources with fluxes detected in three contiguous bands and S(70) >0. They are 3069 in the 1st quad and 1677 in the 4th quad.
- Prestellar objects (red dots) are identified as the sources with fluxes detected in three contiguous bands, S(70) = 0 and



The evolutionary tracks are calculated by M08, based on the model of McKee et al. 2003. Full line: best fit of M08 high mass correspondent to class 1 sources. Dashed line: best fit of M08 high mass correspondent to class 0 sources. The sources at the two sides of the bar show similar properties.



gravitationally bound. They are 7607 in the 1st quad and 5071 in the 4th quad.



Results at the tips of the bar

The sources located at the intersection between the edges of the bar and the galactic arms have heliocentric distances: 5 < d < 7 kpc (1st quad) and 10 < d < 12 kpc (4th quad) (black boxes in Fig. 1). At that distances, there are 332 candidate YSOs in the 1st quad and 272 candidate YSOs in the 4th quad.

The SFR at the tips of the bar is: $0.13\pm0.03 \text{ M}_{\odot}/\text{yr/kpc}^3$ (1st quad) and $0.20\pm0.04 \text{ M}_{\odot}/\text{yr/kpc}^3$ (4th quad).

- The two values are significantly higher than the ones obtained by averaging the entire set of sources in the fields, indicating that star formation is particularly active in this areas.
- The two values are quite consistent with each other within 2σ .

Based on 13CO NANTEN contours we identify 5 molecular complexes located at the tip of the bar in the 4th quad.

W43 (for comparison): SFR = $1.1\pm0.2 \text{ M}_{\odot}/\text{kyr}$ $\delta = 209 \text{ pc}$

Table 4: SFR Regions in the 4 ^t				ⁱⁿ quadrant	
	Reg	gl	gb	δ	SFR
		(deg)	(deg)	(pc)	(M _☉ /kyr)
	1	349.7	0.13	17.7	0.12 ± 0.02
	2	348.7	0.15	306.4	1.9 ± 0.3
	3	347.85	-0.3	39.0	0.32 ± 0.05
	4	347.5	0.1	185.4	1.0 ± 0.2
	5	246 15	0.05	20.0	0.15 . 0.02

39.9

 0.15 ± 0.03

340.15 0.05

Here we show the SFR as a function of the galactic longitude, normalized by the volume of each tile. All the sources along the line of sight are considered. The peaks in the first quadrant correspond to the most famous SF regions (W43, W42, W41). The overall SFR values are: $2.4\pm0.05\cdot10^{-3} \text{ M}_{\odot}/\text{yr/kpc}^3$ (1st quad) and $0.73\pm0.13\cdot10^{-3} \text{ M}_{\odot}/\text{yr/kpc}^3$ (4th quad).



Conclusions

We estimated the physical properties and SFR of high mass clumps located in 18°<1<34° and 340°<1<351°, focusing on the sources at the tips of the galactic bar. For this analysis we mainly use the Herschel/Hi-GAL FIR data. 13CO NANTEN data are also used to identify molecular complexes in the farthest side of the bar, which is the most poorly studied due to a lack of data. Our main results are the following:





- The SFR at the tips of the bar is significantly larger than the one averaged over the entire fields.
- The SFR in the two sides are consistent with each other.
- CO contours, even with a low resolution, indicate star forming complexes at the edge of the bar in the 4th quadrant which are comparable, in terms of SFR and dimensions, with the ones in the 1st quad. The correspondence of CO contours with dust emission at 250 µm and the location of YSO is good.