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Star formation and ionized regions throughout the inner Galactic plane

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Abstract. We present a comprehensive statistical analysis of star-forming objects located in the vicinity of 1360 bubble structures throughout the inner Galactic Plane. The compilation of ~70 000 star-forming sources, detected in both Hi-GAL and GLIMPSE surveys, provided a broad overview of the different evolutionary stages of star-formation in bubbles, from prestellar objects to more evolved Young Stellar Objects (YSOs). Surface density maps reveal a clear evolutionary gradient and ~80% more sources per unit area in the direction of the bubbles compared with the surrounding outer fields. We derived dynamic ages and clump formation efficiencies for a subsample of 182 bubbles and found that younger bubbles are typically more efficient at forming clumps. Approximately 23% of the Hi-GAL clumps are located in the direction of a bubble, with 15% for prestellar clumps and 41% for protostellar clumps. We argue that the high fraction of protostellar clumps may be due to the acceleration of the star-formation process caused by the feedback of the bubbles.

1. Introduction

A growing body of evidence suggests that feedback from massive stars may play a relevant role in the formation of a large fraction of stars in our Galaxy. Feedback from massive stars interact with the surrounding cold molecular medium and generate bubble structures in the interstellar medium (ISM), which may trigger star formation.

We present an unprecedented statistical study of ~70 000 star-forming sources found in the proximity of the ionized (HII) bubbles and detected in both Hi-GAL (Molinari et al. 2010) and GLIMPSE surveys (Spitzer Science 2009), which provided a broad overview of the different evolutionary stages of star-formation in bubbles, from prestellar objects to more evolved young stellar objects (YSOs).

2. Results

We made use of the The Milky Way Project (MWP) catalog (Simpson et al. 2012) of bubbles extracted from Spitzer-GLIMPSE 8 μm and 24 μm maps and selected 1 360 bubbles with radii larger than 72″ to ensure that the bubbles were resolved in the *Herschel* maps. We searched for all star-forming sources that were found within four times the effective ra-

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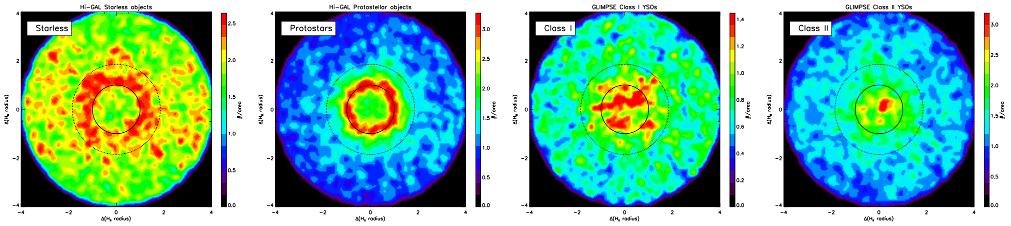

Fig. 1. Surface density maps for all star-forming objects - Hi-GAL clumps and GLIMPSE YSOs - associated with the bubble sample. The spatial scales of the maps are normalized by the bubble radius (solid black circle). The dashed black circle represents the average shell radius.

dius of a bubble. Based on the physical Hi-GAL source catalog (Elia et al. 2017) we found a total sample of 25 911 prestellar and 14 918 protostellar clumps. The YSO candidates were selected from the GLIMPSE catalog by following the approach as Gutermuth et al. (2009), and further classified into different evolutionary stages Class I and Class II according to both their infrared spectral index and their position in the IRAC color-color diagram. This led to a total sample of 10 694 Class I and 18 209 Class II sources. Surface density maps were generated for the entire star-forming source sample (see Fig 1). We find that star-forming sources follow a clear evolutionary trend where more evolved star-forming objects are found spatially located near the center, while younger star-forming objects are found at the edge of the bubbles. Considering that the 1 360 bubbles are at different stages of their expansion we derived dynamic ages for a subsample of 182 HII regions for which kinematic distances and radio continuum flux measurements were available by following the approach presented in Tremblin et al. (2014). As a result we find that younger bubbles have a higher efficiency in forming protostellar clumps. We interpret this trend as a possible increase in the formation rate from the prestellar to protostellar phase at the early stages of the bubble expansion, which would eventually decrease as the impact of the expansion and the ionization weakens.

Furthermore, we estimate that ~23% of the total sample of Hi-GAL star-forming clumps (~15% and ~41% for prestellar and protostellar clumps, respectively) located in the inner part of the Galactic plane are found projected toward a bubble.

3. Conclusions

Surface density maps reveal a clear evolutionary gradient and ~80% more sources per unit area in the direction of the bubbles compared with the surrounding outer fields. We argued for the pre-existence of dense structures in the medium prior to the bubble expansions as in simulations performed in Walch et al. (2015). Furthermore, the high fraction of protostellar clumps may be due to the acceleration of the star-formation process caused by the feedback of the bubbles. For more details see Palmeirim et al. (2017).

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