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The role of spiral arms in Milky Way star formation

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Abstract. The role of environment, particularly the effect of spiral structures, is a long-standing challenge to star formation theory. Unbiased Galactic plane surveys of the Milky Way are an important tool with which to study large scale spatial variations in star formation. The Herschel Infrared Galactic Plane Survey (Hi-GAL) supplies an essential part of the observational description of the conditions necessary for star formation in the Milky Way. With a new catalogue of over 10^5 compact sources, we examine how star formation varies with Galactocentric radius and proximity to spiral arms. We revisit some long-standing questions about the effect Galactic properties have on star formation on parsec scales.

Key words. Stars: formation - ISM: clouds - Galaxies: ISM

1. Introduction

The molecular gas in spiral galaxies is largely concentrated in arm structures, but there is still an open debate as to whether the arms themselves have any direct influence on the star formation that takes place within molecular clouds. To date, most studies of the effect of spiral arms have focused on nearby spiral galaxies, but the Milky Way, although susceptible to source confusion within the dusty plane, provide a unique laboratory to study spatial trends in the properties of star forming clumps with position.

2. Measuring star formation

The role played by spiral arms in star formation is a long-standing question. One of the major factors in why this is such a difficult question to address is that the numerous methods by which star formation is quantified do not necessarily agree and sometimes lead to contradictory interpretations. In the Milky Way, the situation has been improving with the increase in the number of sensitive, unbiased surveys of the Galactic plane in the infrared and millimetre wavelength regime.

The recent release of the Herschel Infrared Galactic Plane Survey (Hi-GAL) compact source catalogue (Elia et al. 2017) has been a major step forward in characterising the properties of the cold, dense clumps most directly associated with star formation at its initial phases. The presence of a 70μm counterpart in a dense clump is a reliable indicator of embedded star formation. In Ragan et al. (2016) we defined the quantity "star-forming fraction" (SFF) as the fraction of clumps in a given area with a 70μm counterpart. The overall SFF of the inner Galaxy is 0.25. The SFF is a straightforward metric by which trends over kiloparsec scales can be examined.

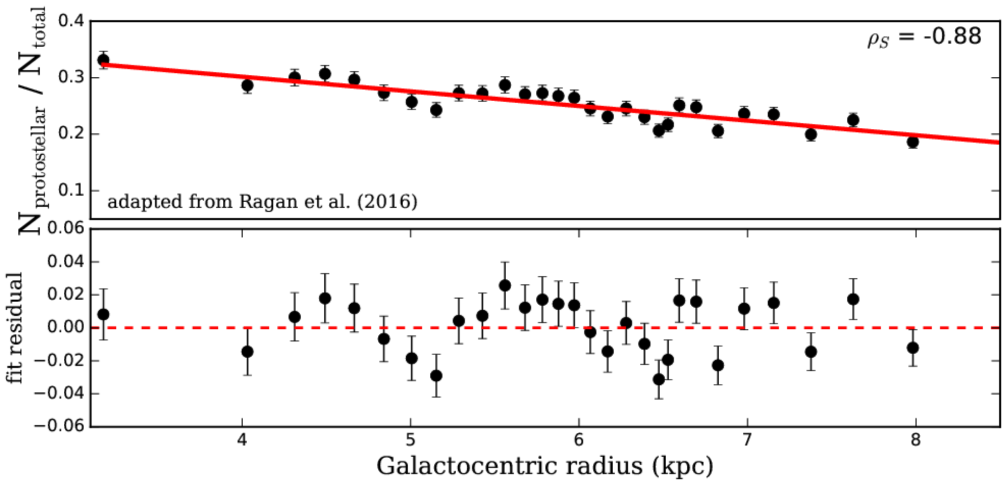

Fig. 1. *Top panel:* The fraction of all Hi-GAL sources with a 70 μm counterpart (also known as the star-forming fraction, SFF) as a function of Galactocentric Radius, R_{GC}. The points are spaced such that an equal number of Hi-GAL sources are represented by each point between 3 kpc < R_{GC} < 8.5 kpc. The Spearman rank test indicates that there is a significant negative correlation ($p < 10^{-9}$, $\rho_S = -0.88$). The best linear fit to the relationship (shown in the red line) is SFF = $(-0.026 \pm 0.002)\, R_{GC} + (0.406 \pm 0.003)$ [kpc^{-1}]. This figure is adapted from Ragan et al. (2016). *Bottom panel:* the residuals after the model is subtracted from the data.

2.1. SFF versus Galactrocentric radius

In Figure 1 we show the relationship between the SFF and Galactocentric radius between 3 and 8 kpc. The bins are spaced such that they contain an equal number of sources. The Spearman rank test indicates that there is a significant anti-correlation between these two variables, with ρ_S =-0.88. The trend persists when considering the first and fourth quadrants individually (Ragan et al. 2016).

The lower panel of Figure 1 shows the residual after the modelled SFF versus R_{GC} is subtracted from the data. While there are no statistically significant deviations from the trend, there are hints of excesses near R_{GC} of 4.5 and 5.6 kpc.

2.2. SFF at tangent point longitudes

From our position in the Galaxy, spiral arms inside the solar circle define characteristic tangent points where our line of sight aligns with the path the arm traces in the Galactic disc. The longitudes of the tangent points are uncertain and are tracer-dependent. We adopt the positions of the tangent points derived by Hou & Han (2015). The top panels of Figure 2 show the number counts of Hi-GAL sources as a function of longitude (see also Elia et al. 2017). We see that the tangent point longitudes, indicated by the vertical shaded regions, show only minor enhancements in source counts compared with adjacent bins.

The light grey histogram shows the full catalogue over the range $15° < |l| < 65°$, and the dark grey histogram shows the distribution after the sources associated with the 25 brightest ATLASGAL cluster regions (Urquhart et al. 2014) are removed from the catalogue. This amounts to 9.5% of the Hi-GAL catalogue. The purpose of removing the brightest clusters is to determine whether the peaks we do see are attributable to a small number of clusters, which to some degree appears to be the case, particularly in $|l| < 30°$.

If the spiral arms are responsible for directly triggering star formation, then we would

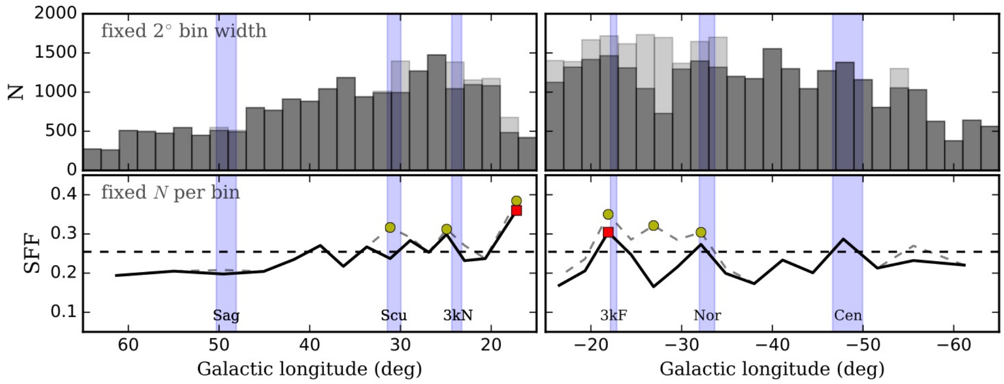

Fig. 2. *Top panels:* Number counts as a function of longitude calculated over equally-spaced 2 degree-wide bins. The light grey histogram shows all Hi-GAL sources, and the dark grey histogram shows the sources after the 25 brightest ATLASGAL clusters (Urquhart et al. 2014) are removed. The shaded blue regions are the locations of the spiral arm tangent points for the Sagittarius (Sag), Scutum (Scu), 3 kpc-Near (3kN), 3 kpc-Far (3kF), Norma (Nor) and Centaurus (Cen) arms. *Bottom panels:* SFF as a function of longitude, shown over bins populated with an equal number of sources. The dashed line is the full Hi-GAL catalogue and the solid black line shows the catalogue with the brightest ATLASGAL clusters removed. The yellow circles are longitude bins which are significantly ($> 3\sigma$) above the mean SFF for the main catalogue (dashed line) and the red squares are the peaks that remain after editing (solid black line). The horizontal dashed line is the mean SFF of the sample, 0.25. This figure is adapted from Ragan et al. (in prep.).

expect that a metric such as the SFF would show distinct peaks at the tangent point longitudes. The lower panels of Figure 2 show the SFF as a function of Galactic longitude calculated now over bins distributed to have an equal number of sources in each. Before the removal of the brightest clusters we see six peaks of significance above the mean SFF. After the removal of the brightest clusters, all but two of these peaks (red squares) disappear. The peaks that remain are the ones nearest to the centre of the Galaxy, or at the ends of the Galactic bar. Otherwise the arm tangent points do not exhibit convincing peaks in SFF (see also Moore et al. 2012; Eden et al. 2015).

3. Summary

We have examined trends in the SFF as a function of Galactocentric radius and proximity to spiral arms. While there is a gradual decline in SFF with $R_{\rm GC}$ to the tune of 2.6% per kpc, we do not see any convincing evidence that the prevalence of star formation (as measured by the SFF) is enhanced in spiral arms.

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