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IDENTIFICATION OF PROTOSTELLAR CLUSTERS IN THE INNER PART OF THE MILKY WAY : INTERACTION BETWEEN THE ISM AND STAR FORMING REGIONS.

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Abstract. Interactions between the interstellar medium (ISM) and young stellar objects (YSO) need to be investigated to better understand star formation. We used the Minimum Spanning Tree (MST) method to identify protostellar clusters in the inner part of galactic plane. Using heliocentric distance estimates, we obtained about 230 clusters over a 140×2 square degree region. Most of these clusters are correlated with Infrared Dark Cloud (IRDC) or HII regions. We conclude that clustering is more important for protostars than for prestellar clumps and that a strong correlation can be established between the distribution of HII regions, known star formation complexes and the YSOs identified in the Hi-GAL data.

Keywords: ISM : HII regions – Stars : formation – Stars : protostars

1 Introduction

The Herschel telescope provides us with a new perspective for characterizing Young Stellar Objects (YSOs) in the far-infrared and submillimeter wavelengths. We aim at studying clustering properties of nascent stars and the interaction between the interstellar medium and star forming regions. We use Herschel data from the Herschel Infrared Galactic Plane Survey (Hi-GAL, Molinari et al. 2010) together with information on the environmental conditions such as HII regions and infrared dark clouds (IRDC). The combination of heliocentric distance and Herschel resolutions at the different wavelengths (70, 160, 250, 350 and 500 μm) do not allow us to resolve individual objects as single sources but rather clumps with unresolved internal structure.

Here we consider the $-61° < l < +67°$ portion of the Hi-GAL compact source catalog (Elia et al. 2014, in preparation; for a preliminary example of source property estimation, see Elia et al. 2013), wich is the largest sample available of far-infrared sources, containing the physical properties of about 100000 objects. One of the important physical properties is the evolutionary stage. A general evolutionary classification is reported in this catalog, based on the availability of a detection at 70μm wich indicates the presence of one or more warm sources (protostellar sources, 25% of all objects), or not (starless sources, 75%). Therefore protostellar clumps present ongoing collapse, while starless are quiescent, and can be further classified in gravitationally bound (then prestellar, 60%), and unbound (15%).

Unbound clouds, prestellar and protostellar clumps have different spatial distributions (Fig. 1). In particular, the prestellar clumps are distributed over the major part of the probed sky while protostellar clumps are mainly concentrated on the galactic plane i.e. between -0.5 and 0.5 degrees. It is more difficult to characterize the unbound clump distribution as they may be misidentified with prestellar and protostellar clumps in the middle of the galactic plane. Indeed, we deal with clumps rather than individual objects so if a clump encompasses different classes of objects, the class of the clump will correspond to the warmest object.

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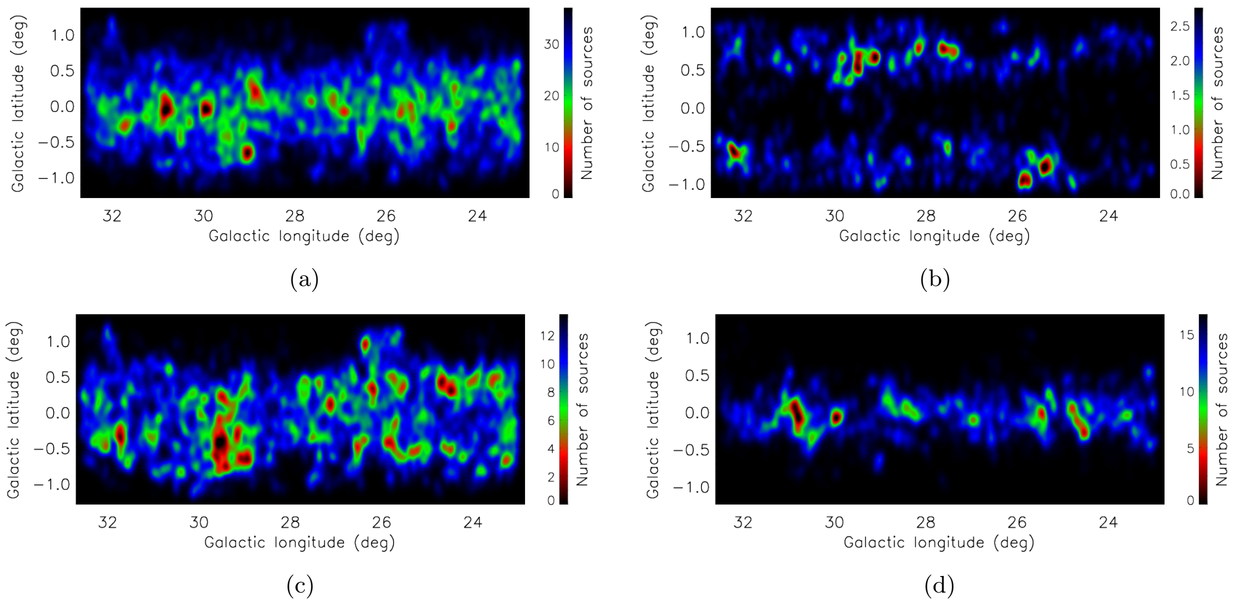


Fig. 1: Density map for the three classes of objects for the region from 20 to 32 degrees in galactic longitude. (a) - All objects. (b) - Unbound objects. (c) - prestellar cores. (d) - protostellar cores.

We focused our study on protostellar clumps because they exhibit a more clustered spatial distribution. Our study will be extended in Beuret et al. (2014, in preparation) to prestellar and unbound clumps.

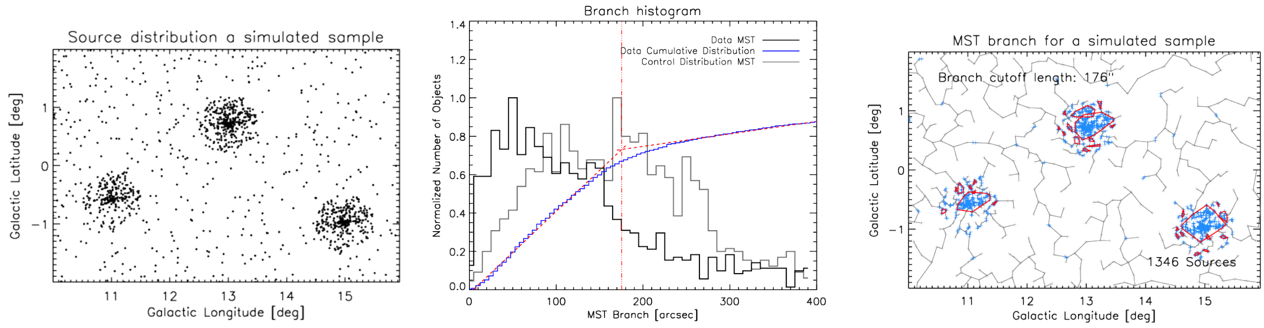
In section 2 we introduce the MST method used to characterize the spatial distribution. Then we present our first results including all protostellar clumps. Section 4 deals with the role of the heliocentric distance estimates in our analysis. Finally, we conclude and discuss the results.

2 Minimum spanning tree method

We used the minimum spanning tree method (MST) to find clusters (e.g. Gutermuth et al. 2009 and Billot et al. 2011). This method aims at connecting all points with branches without creating closed loops while minimizing the total length of the branches. The solution of the MST analysis is unique. Then we compare the branch length distribution of the sources with a reference distribution (randomly distributed sources). It yields the estimation of a cut-off branch length by fitting segments on the cumulative distribution (Fig 2.b). Source overdensities are identified as a group of sources connected by branches shorter than the cut-off branch length. This procedure provides us with a cut-off criterion determined by the algorithm itself. Figure 2.c shows the result for these simulated clusters. The main clusters clearly appear in the result although they can break down into several smaller units.

3 Preliminary results

We applied the MST analysis to all protostellar clumps since those show the strongest clustering. Following Gutermuth et al. 2009, we define a cluster as a group with more than 10 sources. We found about 450 clusters. A good correlation can be established between the distribution of star forming clumps identified in Herschel data, HII regions from Paladini et al. (2003) in Figure 3, and IRDCs from Peretto et al. (2009) in Figure 4. About 75 % of clusters found with the MST method have one or more HII regions into an area of twice the cluster radius. In addition, we find that 78 % of MST clusters have one or more IRDCs in that area. Furthermore, some large clusters seem to have many sub-structures. That suggests these clusters would actually be a set of smaller structures.



(a) (b) (c)

Fig. 2: (a) - Simulated sample with three simulated clusters. This simulated field was generated with randomly distributed sources for the background and a Gaussian distribution for clusters. (b) - Histogram of MST branch length. The blue line is the cumulative distribution. The two dashed red lines are the fitted segments. The dashed-dot line shows the cut-off branch length. (c) - Clusters found by MST method. The gray and blue color represent isolated and clustered sources, respectively. Red polygons are clusters with more than 10 sources.

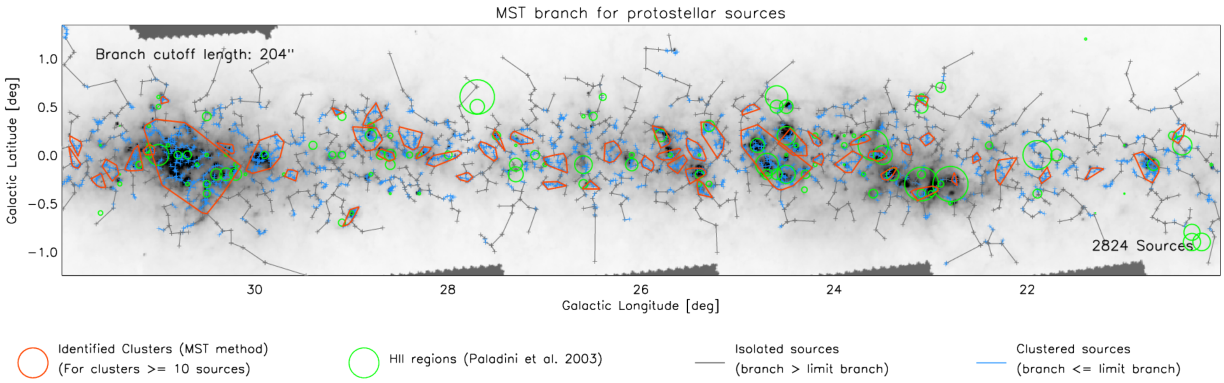


Fig. 3: Comparison between the distribution of clusters obtained from the MST analysis and HII regions from 20 to 32 degrees in galactic longitude. The background image shows the 70 μm surface brightness.

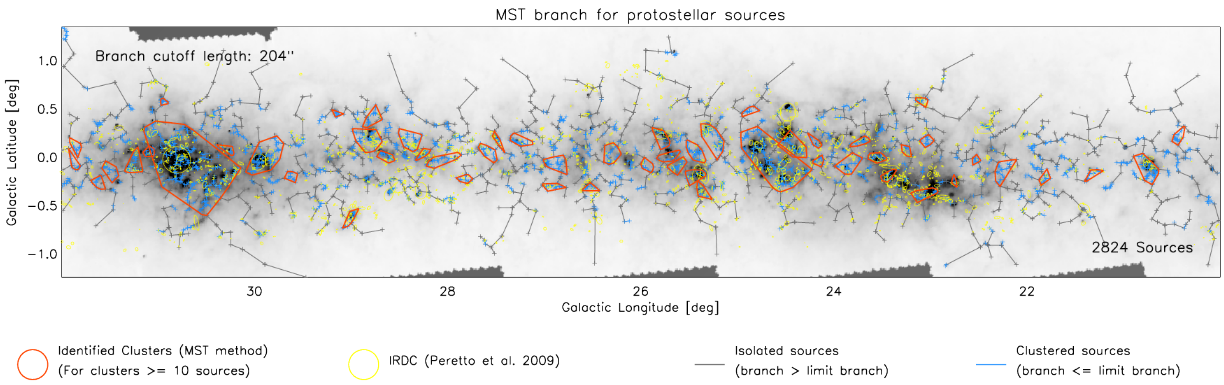


Fig. 4: Same as figure 3, but for IRDCS.

4 Heliocentric distances

The knowledge of distance helps at characterizing physical cluster properties. 63% of the protostellar sources, i.e about 16000 sources, have heliocentric distance estimates (For a preliminary example of heliocentric distance estimatations, see Russeil et al. 2011). As for the MST analysis without using heliocentric distances, we split the data into several 2D-boxes along the galactic longitude. All data have to be splitted again following the distance histogram distribution. An example is shown in the figure 5 which corresponds to the region between 20 and 32 degrees in galactic longitude. We smoothed the histogram to only accentuate the large overdensity of protostellar sources. Two or three regions in the histogram can be identified depending on the galactic longitudes probed because each box refers to different parts of the Milky Way especially for the spiral arms. This technique allows us to characterize cluster properties and to extract more physical clusters although it decreases their total number as it filters sources along the line of sight. Especially it allows us to only keep protostellar sources at the same distance within a cluster and so to compare physical cluster properties.

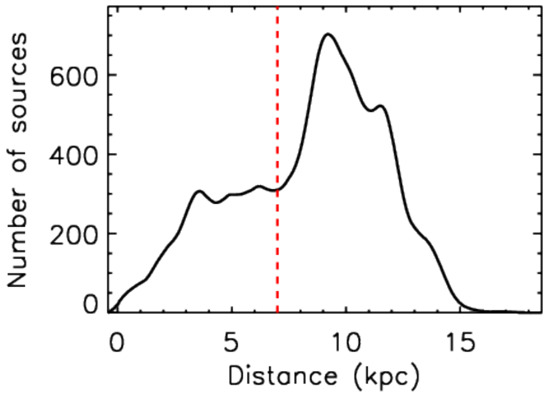
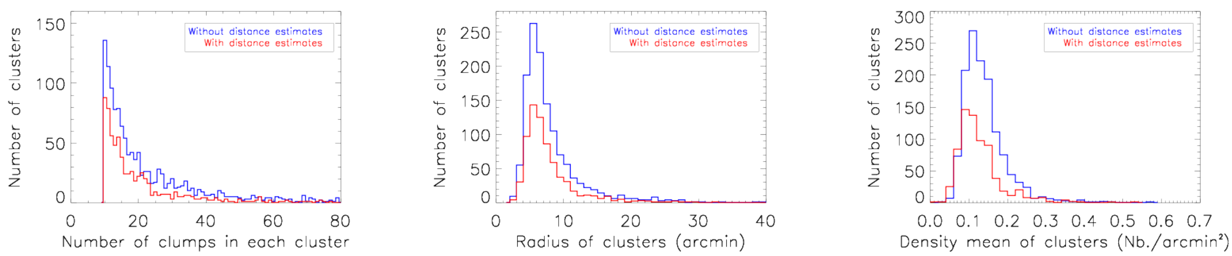


Fig. 5: Smoothed histogram of heliocentric distances for protostellar clumps into the range [20,32] (galactic longitude). Red dashed-dot lines is cut-off heliocentric distances.

Figure 6 presents the cluster distribution obtained with and without the heliocentric distance estimates. The average density is lower when the heliocentric distances are taken into account because we extract sources that really belong to the clusters. In fact the radius of each cluster is not significantly affected.



(a) (b) (c)

Fig. 6: Comparison between clusters found using heliocentric distance estimates (red) or not (blue). (a) - Histogram of the number of protostellar clumps in each cluster. (b) - Histogram of clusters radius in arcmin. (c) - Histogram of average source density per cluster in number of sources by arcmin^2.

Figure 7 compares the distribution of the MST clusters, the HII regions and the IRDCs. There are fewer clusters than on the distribution without distances as explained above. We find about 230 clusters with more than 10 sources. About 82 % of clusters found with the MST method have one or more HII regions located within twice the cluster radius. In addition, we found that 93 % of clusters have one or more IRDCs in that area. There is a stronger correlation between IRDCs, HII regions and clusters using heliocentric distance estimates than without these distances.

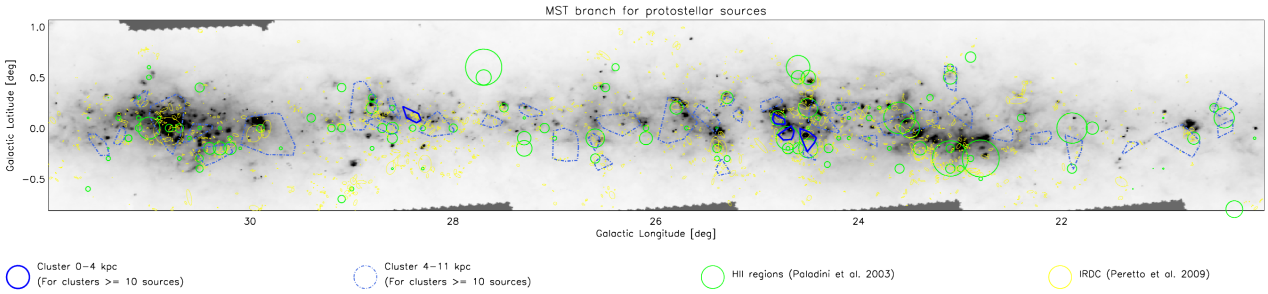


Fig. 7: Same as figures 3 and 4 but for clusters found with heliocentric distance estimates.

5 Conclusion

Heliocentric distance estimates are essential to characterize the physical cluster properties and to remove the sources that do not belong to the clusters. The correlation between the protostars, HII regions and IRDCs spatial distribution is better with these radial distances. HII regions are produced by massive stars so they can be related to high-mass star forming regions. These regions could actually explain the triggered stars formation. Furthermore, IRDCs are associated with star forming regions, especially for massive star formation. This correlation should help us identify the interaction between the interstellar medium and star forming regions, especially for massive star formation. The next step is to focus our study on clusters exhibiting interactions with the ISM. It will eventually allow us to improve our knowledge of triggered stellar formation.

We benefited from the progresses that have been made in this topic by the Hi-GAL team such as the large number of sources and the physical properties for each source. In the future, we should benefit from a larger sample of sources with heliocentric distance estimates leading to a better set of clusters.

The impact of the source spatial distribution on the efficiency of the MST method, the physical cluster properties and the role of prestellar clumps have not been discussed here. These points will be addressed in Beuret et al. (2014, in preparation).

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