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HIERARCHY OF CLUMPS FRAGMENTS : A DEN FOR THE FORMATION OF LOCAL STAR-CLUSTERS USING A GRAPH THEORY-BASED APPROACH

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Abstract. Young Stellar Objects (YSOs) form in molecular clouds from densest gas cores. Spatial distribution of YSOs features evidence of pristine multi-scale hierarchy through clusters and multiplicity, most probably inherited from their parental cloud on a larger scale. We design a graph theory-based approach to characterise the properties of fragmentation and apply it to Herschel multi wavebands observations of NGC2264. Spatial distribution of structures in NGC2264 revealed that hierarchical nested fragmentation is primary observed in the high density central part of NGC2264 and features a fractal law of fragmentation.

Keywords: fragmentation, NGC2264, stellar multiplicity, hierarchy, network

1 Introduction

Properties of local mini star-clusters (Joncour et al. 2018) are suspected to hint pristine imprints of star formation process, and highlighted two regimes of cloud fragmentation. In this work, we propose to check the existence of a hierarchical cascade of fragmentation in the NGC2264 molecular cloud, and assess its statistical properties. NGC2264 is an active star forming region located at 720pc (Cantat-Gaudin et al. 2018) which is composed of two massive hubs that incubate most of the YSOs (Rapson et al. 2014). Using Herschel multi-wave bands observation (Motte et al. 2010), five specific scales can be monitored associated to [8.4, 13.5, 18.2, 24.9, 36.3]" resolution. The massive dense clumps (MDCs) are extracted using the source extraction algorithm *getsf* on density maps (Men'shchikov 2021). The resulting physical spatial scale span from 5kAU to 30kAU, which are the scales where the fragmentation is suspected to occur (Joncour et al. 2018). In addition, we selected class 0/I YSOs from Rapson et al. (2014) observed by Spitzer in order to assess the final steps of the fragmentation process. As a result, 6 scales of fragmentation are available.

2 Network representation

The available 6 scales are organised in levels of fragmentation and we use them as reference to construct a directed network going from large scale to low scale, in which one node is a fragment (MDC or YSO) belonging to one specific level. Two nodes are connected if one of them is included into the other at 75% of its area. The nested node is considered as a child and the incubator node is considered as a parent. The last children are labeled sinks (see Figure 1) The resulting global network representing the whole data set (see Figure 2) is then composed of multiple components, which are independent sub-networks disconnected from each other. These components are identified as structures which can be hierarchical (number of sinks > 1), linear ($= 1$) or isolated ($= 0$) for which examples are given in Figure 1.

3 Hierarchy in NGC2264

Using the previous definitions, we extracted 151 structures for 81 YSOs and 414 MDCs. 10% of these structures are hierarchical and contain respectively 62% and 40% of YSOs and MDCs. Linear structures, however, represent 57% of the structure population with respectively 57% et 22% of YSOs and MDCs. Two striking properties are : 1) the presence of YSOs where fragments are located and 2) the dominance of hierarchical structures in terms of fragment number despite their under-representation (see Figure 2). In addition, hierarchical structures happens to be exclusive to densities above $3.10^{22} H_2/cm^2$, while there is a mix of hierarchical and linear below. Isolated structures are concerned for the less dense regions of the cloud ($< 10^{22} H_2/cm^2$).

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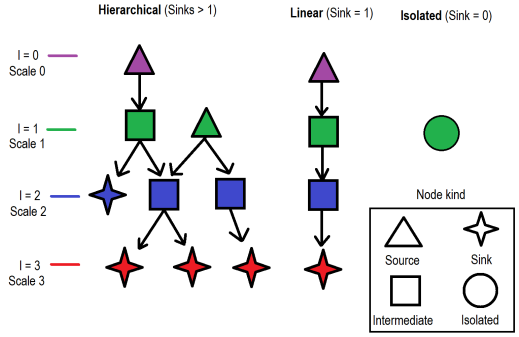

Fig. 1. Example of 3 types of networks to represent the data. MDCs and YSOs are represented as nodes along multiple levels of fragmentation. Nodes are labelled differently regarding of inheritance whether they possess parent or child. Each network component is labelled according to their number of sinks.

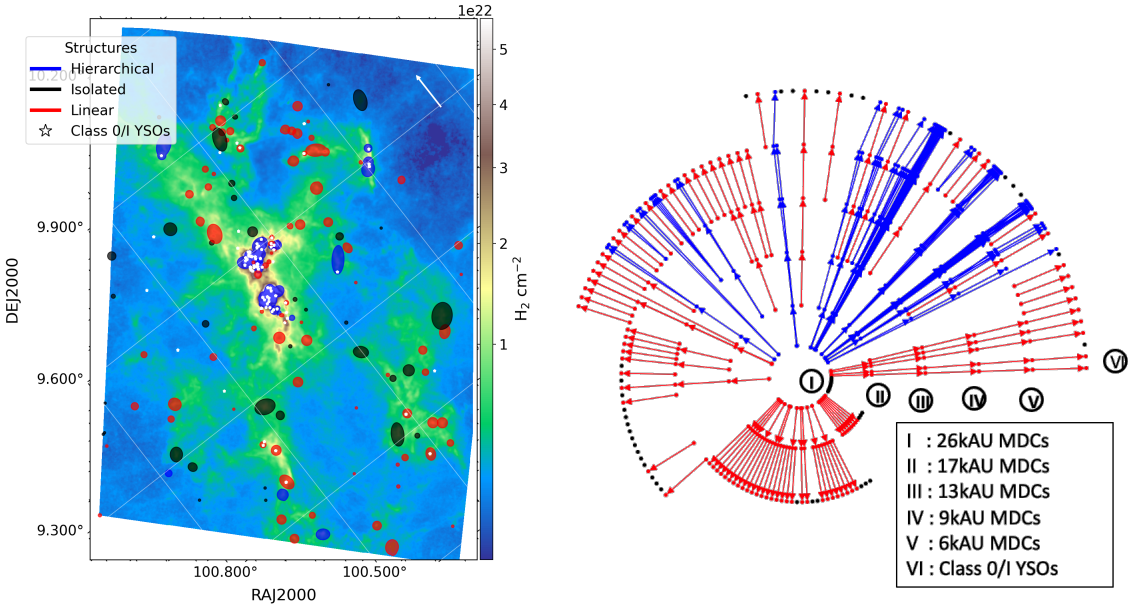

Fig. 2. Left: Map of NGC2264 overlapped with extracted structures. North is indicated by white arrow. Each structure type is represented with a color according to the legend. **Right:** Global network that represents all the fragments in NGC2264. The fragmentation cascade from the inner ring (high scale) to the outer ring (low scale). One structure is one component of the network. Color legend is the same as in the **Left** Figure.

4 Conclusion

Using Herschel 5 multi-wave bands data coupled with class 0/I observed by Spitzer (Rapson et al. 2014) of NGC2264, we designed a graph-theory based approach to describe and analyse the fragments extracted by *getsf* algorithm (Men'shchikov 2021). We were able to define hierarchical structures which assert their dominance in the densest regions of the cloud ($> 3.10^{22} H_2/cm^2$) and that contains half of the whole fragment population.

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