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Initial gas structure in a cold, massive clump: cluster formation in its earliest stages

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Abstract. The two main models for high-mass star formation predict different internal structures for cluster forming clumps only in the very earliest stages. The best way to distinguish between these models is to identify a cold, cluster-forming clump and measure its internal structure directly. Using dust continuum surveys and MALT90 molecular line information, we have found a single clump, IRDC G331.372-00.116, which satisfies all the requirements for a cluster-forming clump in a very early stage. Here we present ALMA observations of the continuum, and molecular line toward this clump, which have allowed us to measure its internal structure identifying the potential candidates for high-mass cores.

1. Introduction

High-mass stars (> 8 $M_\odot$) typically form in clusters surrounded by a large number of lower mass stars. While the formation of low-mass stars is well understood, the mechanism for the formation of high-mass stars is shrouded in uncertainty. Currently, there are two major contending models: 'core accretion' (McKee & Tan 2002) and 'competitive accretion' (Bonnell et al., 2001), but definitive observational tests to distinguish between them have remained elusive. In 'core accretion,' high-mass stars form 'top-down' from the fragmentation of a molecular cloud into small 'cores' (0.1 pc) that collapse to form single stars or binary systems. In this scenario, all of the mass accreted onto the final high-mass star originates locally, at birth, within the core. In contrast, in the 'competitive accretion' model high-mass stars form 'bottom-up.' At early times a molecular cloud fragments into a swarm of small cores, each with a mass roughly equal to the Jeans mass 1$M_\odot$. As gas funnels down the potential well of the much larger molecular clump, those cores near the centre of the potential receive a fresh supply of gas from afar and grow via Bondi-Hoyle accretion. Because these models differ most in the very earliest stages, to test these theories we must measure the initial structure of a cluster-forming clump in a very early stage.

2. Identifying proto-cluster candidates

Recent Galactic plane survey tracing the dust continuum – e.g., ATLASGAL (Schuller et al., 2009, Contreras et al., 2013) and Hi-GAL (Molinari et al. 2010) – and the molecular line emission – e.g. MALT90 (Jackson et al., 2013) – are an excellent finding chart for proto-

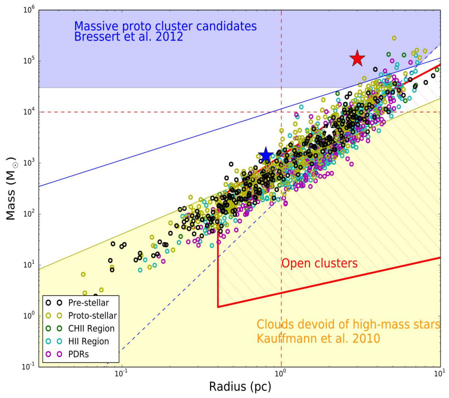

Fig. 1. Mass size plots for the clumps observed by MALT90 at different evolutionary stages (see Contreras et al. 2017) for a colour version of this figure). In this figure G331 is marked with a while star. As reference in the upper right corner a red star mark the location of "The Brick" (see Rathborne et al., 2015) and the lower left star shows G305 (Garay et al., 2015). Both clumps have similar volume densities as G331.372-00.116.

cluster candidates, providing their dust temperature, column density, mass, volume density, bolometric luminosities and sizes (see Contreras et al. 2017; Guzman et al. 2015; Rathborne et al. 2016 and Whitaker et al. submitted). With the combination of the data provided by this survey Contreras et al. (2017) identified the clumps that have the physical properties necessaries to evolve into harbouring high-mass stars. Figure 1 shows the mass-size relationship plot for the clumps observed by MALT90. In this plot the parameter space for massive proto-cluster candidates is highlighted in blue (Bressert et al. 2012), the parameter space for solar neighbourhood clouds devoid of high-mass stars is shown in yellow (Kauffmann et al., 2010), and the typical mass-radius space for open clusters is shown in the red dashed region (see Longmore et al., 2014). Most of the clumps observed by MALT90 have physical properties consistent with clumps that will evolve into clusters harbouring high-mass stars. Moreover, several clumps are identified to be in very early evolutionary stages, representing excellent candidates for future ALMA observations. Using this mass size relationship, we identified one of the best proto-cluster candidates for detailed observations of their internal structure with ALMA: IRDC G331.372-00.116. This clump has a low dust temperature (15 K), high average column density (5×10^{22} cm^{-2}), high average volume density (1.2×10^4 cm^{-3}), high mass (3×10^3 M$_\odot$), and relatively close distance (5.0 kpc) fullfiling all the requirement of a cluster-forming clump in an early evolutionary stage.

3. IRDC G331.372-00.116

ALMA observations toward IRDC G331.372-00.116 suggests that its structure is very hierarchical and filamentary, resembling to the structure seen in "The Brick" (Rathborne et al., 2015). We have detected dozens of embedded cores (0.1 pc size), with masses ranging between 1 to 22 M$_\odot$. While the total mass of this clump suggest that it contains sufficient material to harbour high-mass stars, the most massive core does not have sufficient mass yet to form a high-mass star. We also found that the location of the most massive core is not coincident with the peak of the dust continuum emission seen in ATLASGAL. The molecular line emission suggest that this core is still accreting material from its environment, thus it might evolve into a high-mass star. Thus, this might be the best candidate found so far of a high-mass core in a very early evolutionary stage (Contreras et al., submitted).

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