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FRAGMENTATION OF MASSIVE CORES TOWARD THE GALACTIC HII REGION RCW 120 OBSERVED WITH ALMA

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Abstract. Feedback from high-mass stars (stellar winds, radiation and photoionization pressure, supernova explosions) can strongly modify the surrounding cloud. As a result, the next generation of stars is affected and can present different physical properties. Using ALMA interferometric observations, we characterized the fragmentation occurring inside the massive cores previously detected with Herschel and being good candidates for high-mass star formation. Most of the fragments have a mass higher than predicted by the thermal Jeans mechanism, thus requiring external turbulence to explain it, and some of the fragments have a mass higher than 8 $M_\odot$ which make them interesting targets for further studies. One of the fragment shows different molecular emissions tracing hot core, disk and outflows and is the most promising site for the search of high-mass stars toward RCW 120.

Keywords: HII region, high-mass star, fragmentation

1 Introduction

Despite the numerous studies and surveys performed over the past years, high-mass star ($M > 8\ M_\odot$) formation remains a puzzling field of study. Regions where high-mass stars are born and in which environmental conditions they form is still debated although some points seem to stand out from different studies. High-mass stars form in massive, cold and dense cores ($\geq$70 $M_\odot$, $\sim$0.1 pc, $\sim$10$-$20 K) where the quantity of gas and dust is high enough. Inside these cores, two main mechanisms are proposed to explain how the future stars are gathering their mass. The first one is the model of monolithic collapse, similar to low-mass star formation, where a massive core supported by turbulence and/or magnetic pressure collapses into a massive star. The second one is the competitive accretion model which involve the growth of low-mass cores into high-mass cores thanks to the gas reservoir contained in the parental cloud. Therefore, high-mass prestellar cores do not exist in this model and high-mass stars would come from low-mass structures which would have gained mass throughout the time. High-mass stars are important due to their feedback such as winds, radiation pressure, HII regions and supernova explosions. This feedback injects momentum, energy and metallic elements into the interstellar medium which modify the properties and shape of the surrounding. During the early stages of high-mass star formation, the HII region feedback is the most powerful and easily recognizable due to the formation of an HII region surrounded by a layer of dust and gas, trapped between the ionization and the shock fronts. These so-called HII bubbles are ubiquitous in our Galaxy, with around 8000 of them (Anderson et al. 2014) and therefore important in the star formation field. The most interesting phenomenon is that more than 30% of high-mass Galactic sources are found at the edges of these bubbles, toward the layer of dust and gas (Deharveng et al. 2010; Kendrew et al. 2012, 2016; Palmeirim et al. 2017). Previous mechanisms were studied to understand how the expansion of an HII region could lead to the formation and subsequent fragmentation of this layer. Several exist such as the Collect and Collapse (C&C, Elmegreen & Lada 1977), the Radiation Driven Implosion (RDI, Kessel-Deynet & Burkert 2003), the HII region expansion in a turbulent medium (Tremblin et al. 2012) or the Cloud Cloud Collision (CCC, Torii et al. 2015). On the other hand, simulations tend to show the disruptive effect of the photoionization pressure which lower the SFR and SFE inside this layer of material (Dale et al. 2005;

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Lucas et al. 2017). Thanks to surveys done with the *Spitzer* and *Herschel* space telescopes, numerous massive cores could have been identified and their properties derived. The next step, which is currently undergone, is to observe a significant number of these cores located at the edges of these HII regions, at a sufficient spatial resolution to observe the fragmentation occurring inside (Motte et al. 1998; Bontemps et al. 2010; Palau et al. 2015; Ohashi et al. 2018; Palau et al. 2018). A statistical sample of these fragments at ∼0.01 pc resolution and higher will allow us to assess more accurately the percentage of high-mass stars toward Galactic HII bubbles as well as the fragmentation mechanism at work inside the cores (thermal Jeans, turbulent Jeans mechanism, etc.)

2 The RCW 120 region with Herschel

The Galactic HII region RCW 120 is a well studied and interesting bubble due to its close distance of 1.3 kpc, its almost perfect spherical shape and its location 0.5° above the Galactic Plane, limiting the foreground dust contamination. This HII region is powered by a single O8.5 star located in the south of the center and its expansion swept away the dust and gas initially present in the region, forming the dusty layer which can be seen on Fig. 1 (left). Toward it, several millimetric clumps can be observed and in them, several Young Stellar Objects (YSOs) are detected where the future generation of stars are currently forming. Using the *Herschel* Observations of YSOs (HOBYS), we previously extracted the cores (Fig. 1, middle) using the *getsources* algorithm (Men'shchikov et al. 2012; Men'shchikov 2013) and the recipe described in Tigé et al. (2017) to derive their envelop mass, bolometric luminosity, temperature and volume density using Spectral Energy Distribution (SED) (Figueira et al. 2017). Based on the $L_{\lambda>350\ \mu m}/L_{bol}$ criterion and the $L_{bol} - M_{env}$ diagram, the evolutionary stage of the *Herschel* cores does not seem to be correlated with the projected distance to the ionizing star but rather depends on the density of the clumps which are hosting these cores. Moreover, one of the clump clearly hosts young and massive sources, allowing the formation of high-mass stars according to the usual mass threshold of $\sim 70\ M_\odot$. Therefore, this clump is an interesting target to study the fragmentation mechanism inside massive cores, in order to see if fragments can give rise to high-mass stars.

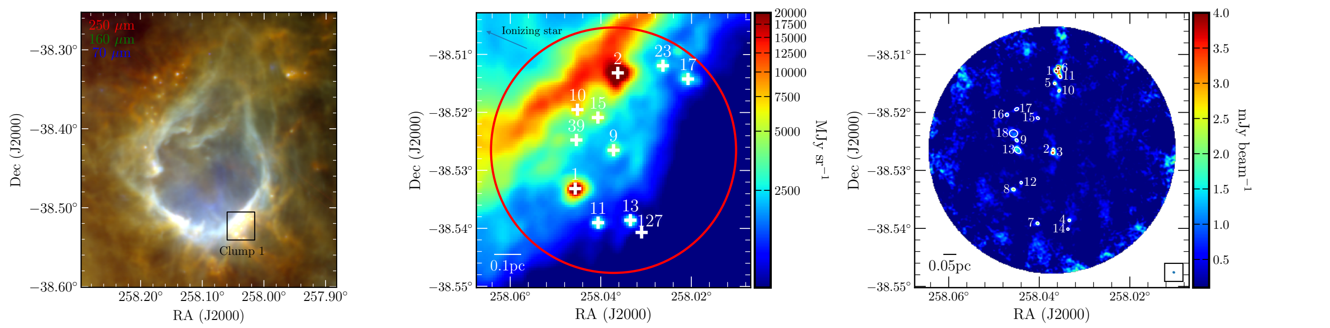

Fig. 1. Left: Composite image of RCW 120 from *Herschel* observations at 70 (blue), 160 (green) and 250 μm (red) with the clump 1 hosting massive cores enclosed by a black rectangle. **Middle:** *Herschel* 70 μm observation toward the clump 1 with the cores' label superimposed (white) and the direction to the ionizing star (grey arrow). **Right:** ALMA 3 mm observation of the clump 1 with the fragment's footprint and labels superimposed (white).

3 Massive cores of RCW 120 observed with ALMA

Observations were performed during the Cycle 4 using 38 of the 40 12 m antennas in nominal configuration C40-3 with baselines ranging from 15 to 459 m. The spectral setup consisted in four spectral windows centred on 93.17 (N_2H^+), 91.98 (CH_3CN), 104.02 (SO_2) and 102.5 GHz (2 GHz band continuum at 3 mm). Imaging was performed with the TCLEAN algorithm of the CASA software using a robust parameter of 0.5 which lead to a synthesized beam of 1.7"×1.5" and a noise level of 0.16 mJy beam^{-1} for the aggregate continuum. The cores and fragments extractions were performed using the *getimages* algorithm (Men'shchikov 2017) prior to the *getsources* extraction. Compared to the extraction in Figueira et al. (2017), the *Herschel* cores are still massive and good candidates for high-mass star formation. The number of fragments ranges from 0 to 5, the most massive *Herschel* core being the most fragmented (Fig. 1, right). Assuming optically thin emission, the mass of the fragments were computed following $M_{frag} = S_{3mm} \times R \times D^2/\kappa_{3mm} \times B_{3mm}(T_{dust}) \times \Omega_{beam}$ and ranges

Id	α	δ	T_{env}	M_{env}	L_{bol}	n_{H_2}	M_{Jeans}	N_{frag}	M_{frag}
	J2000 (°)		(K)	($M_\odot$)	($L_\odot$)	(cm^{-3})	($M_\odot$)		($M_\odot$)
1	258.04577	-38.53338	17.0 ± 0.2	85 ± 6	234 ± 28	(3.0±0.2) ×10^5	0.8	2	10.6 ± 0.7
2	258.03624	-38.51317	16.9 ± 0.2	376 ± 21	856 ± 93	(1.3±0.1) ×10^6	0.4	5	73 ± 3.6
9	258.03749	-38.52663	13.1 ± 0.2	97 ± 14	49 ± 12	(3.4±0.5) ×10^5	0.5	2	25.8 ± 1.6
10	258.04524	-38.51956	11.1 ± 0.4	252 ± 41	46 ± 17	(8.7±1.4) ×10^5	0.3	2	15.5 ± 1.4
11	258.04073	-38.53926	14.2 ± 0.4	31 ± 9	24 ± 11	(1.1±0.3) ×10^5	1.1	1	7.4 ± 0.5
13	258.03352	-38.53886	16.3 ± 0.8	8 ± 3	23 ± 9	(2.8±1.0) ×10^4	2.5	2	6.8 ± 0.8
15	258.04084	-38.52110	12.8 ± 0.5	81 ± 15	38 ± 15	(2.8±0.5) ×10^5	0.5	1	3.5 ± 0.6
39	258.04560	-38.52532	12.8 ± 0.3	97 ± 17	42 ± 13	(3.4±0.5) ×10^5	0.5	3	72.2 ± 2.7
17	258.02078	-38.51440	12.8 ± 0.2	122 ± 17	51 ± 13	(4.2±0.6) ×10^5	0.4	0	0
23	258.02648	-38.51204	11.9 ± 0.4	130 ± 21	37 ± 13	(4.5±0.7) ×10^5	0.4	0	0
127	258.03146	-38.54054	10.8 ± 0.3	80 ± 17	12 ± 5	(2.8±0.6) ×10^5	0.4	0	0

Table 1. Properties of the *Herschel* cores using the *getsources* (+*getimages*) algorithm. (1) Identification number, (2,3) J2000 coordinates, (4) envelope temperature, (5) envelope mass, (6) bolometric luminosity, (7) volume density, (8) Jeans mass, (9) number of fragments inside the core, and (10) total mass of the fragments.

from 2 to 32 $M_\odot$ which makes several of them massive enough for high-mass stars to form. The mechanism responsible from the appearance of these fragments is thought to be the Jeans mechanism where above a certain mass threshold, called the Jeans mass (M_{Jeans}), the core becomes gravitationally unstable. The mechanism of fragmentation in the cores is still debated: several studies show that the thermal Jeans mechanism could be at work with fragments mass in agreement with M_{Jeans} (Palau et al. 2015) while in other regions, the mass of the fragments are above this limit and addition of turbulence and/or magnetic field as a support against collapse is needed. In Tab. 1, we show the properties of the different *Herschel* cores as well as M_{Jeans} computed with the temperature derived using SED as in Figueira et al. (2017). In most of the cases, M_{Jeans} is too low to explain the mass of the fragments in the *Herschel* cores. Using the N_2H^+ molecular line transition, we computed the turbulent linewidth σ_{turb} and, assuming a Mach number of 4 in the PhotoDissociation Region (PDR), we estimated M_{Jeans} accounting from this turbulence following the model of Mac Low & Klessen (2004). For the *Herschel* cores, M_{Jeans} accounting from turbulent support can increase up to 100 $M_\odot$. This value is high enough to explain the mass of the fragments and could also explain why some of the cores have not fragmented yet.

Toward the most massive core 2, 5 fragments are observed and 3 of them have a mass higher than 15 $M_\odot$. Using the other spectral windows, one of the main fragment in this core exhibits CH_3CN and SO_2 emissions, which are tracer of hot core and outflows, respectively. In other words, this fragment shows high-mass star formation signposts which could reveal the formation of an high-mass star at the edges of RCW 120. Using a rotational diagram constructed with the *CASSIS* software, we found that the best fit was obtained with a two temperature model indicating a hot and cold component for this fragment of 210 and 40 K, respectively. Moreover, the $CH_3CN(J = 5 - 4, K = 4)$ transition is higher than expected from Local Thermodynamical Equilibrium (LTE) conditions which could mean that another molecular transition is present. Based on the CDMS database, $CH_3^{18}OH$ would be at the right frequency and furthermore, this transition line is often found where high-mass stars are forming. Using observations obtained during Cycle 5, we also detect CS emission toward this fragment, which is a tracer of high density and disk. Therefore, there is probably an accretion disk around the possible high-mass star represented by the fragment 1.

4 Conclusions

Using interferometric observations, we studied the most massive cores, potentially future sites of high-mass stars, located in the most massive millimetric clump of the Galactic HII region RCW 120. Continuum observations at 3 mm reveals that the *Herschel* cores are divided up to 5 fragments and that turbulence should be added to the common Jeans mechanism in order to explain the high-mass of these fragments. Consequently, several fragments are massive enough to host high-mass stars. Toward the most massive core of RCW 120 where 5 fragments are detected, one of them shows emission of CH_3CN, SO_2 and CS which indicates that the star forming there is in the hot core stage, with an accretion disk and outflows emission. More analysis have to be carried out in order to characterize the properties of this particular fragment such as the disk model, the accretion rate, the outflow energy and momentum released and the mass of the future high-mass star. An high-mass star forming at the edge of a bubble, such as in RCW 79, will maintain the debate on the net influence the HII region can have on the new generation of stars in the layer.

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