APEX CO observations towards the photodissociation region of RCW 120

M. Figueira¹, A. Zavagno², L. Bronfman³, D. Russeil², R. Finger³, and F. Schuller⁴,⁵

¹ National Centre for Nuclear Research, ul. Pasteura 7, 02-093, Warszawa, Poland
² Aix Marseille Univ, CNRS, CNES, LAM, Marseille, France
³ Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile
⁴ Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121, Bonn, Germany
⁵ Leibniz-Institut für Astrophysik Potsdam (AIP), An der Sternwarte 16, 14482 Potsdam, Germany

Received **, ****; accepted **, ****

ABSTRACT

Context. The edges of ionized (H II) regions are important sites for the formation of (high-mass) stars. Indeed, at least 30% of the galactic high mass star formation is observed there. The radiative and compressive impact of the H II region could induce the star formation at the border following different mechanisms such as the Collect & Collapse (C&C) or the Radiation Driven Implosion (RDI) models and change their properties.

Aims. We study the properties of two zones located in the Photo Dissociation Region (PDR) of the Galactic H II region RCW 120 and discussed them as a function of the physical conditions and young star contents found in both clumps.

Methods. Using the APEX telescope, we mapped two regions of size 1.5'×1.5' toward the most massive clump of RCW 120 hosting young massive sources and toward a clump showing a protrusion inside the H II region and hosting more evolved low-mass sources. The ¹²CO (J = 3 – 2), ¹³CO (J = 3 – 2) and C¹⁸O (J = 3 – 2) lines observed, together with Herschel data are used to derive the properties and dynamics of these clumps. We discuss their relation with the hosted star-formation.

Results. Assuming LTE, the increase of velocity dispersion and T_e are found toward the center of the maps, where star-formation is observed with Herschel. Furthermore, both regions show supersonic Mach number (7 and 17 in average). No strong evidences have been found concerning the impact of far ultraviolet (FUV) radiation on C¹⁸O photodissociation at the edges of RCW 120. The fragmentation time needed for the C&C to be at work is equivalent to the dynamical age of RCW 120 and the properties of region B are in agreement with bright-rimmed clouds.

Conclusions. Despite that the conclusion from this fragmentation model should be taken with caution, it strengthens the fact that, together with evidences of compression, C&C might be at work at the edges of RCW 120. Additionally, the clump located at the eastern part of the PDR is a good candidate of pre-existing clump where star-formation may be induced by the RDI mechanism.

Key words. Stars: formation – H II region – ISM: bubbles – Photon-dominated region – individual objects: RCW 120

1. Introduction

High-mass stars (M_⊙ ≥ 8M_⊙) have a strong impact on the interstellar medium (ISM), galaxies formation and evolution. From the radiation field, ionization pressure, to the explosion as supernovae, they strongly shape their surroundings, due to high energy and momentum budgets of this feedback, and is thought to be a plausible explanation for the presence of OB associations (Blaauw 1964; Preibisch & Zinnecker 2007). Over the years, two mains models explaining the formation of a new generation of stars due to the expansion of an H II region emerged. The first one is the Collect & Collapse (C&C, Elmegreen & Lada 1977; Whitworth et al. 1994) process, explaining the creation and fragmentation of the layer of material and the second is the Radiation Driven Implosion (RDI, Kessel-Deynet & Burkert 2003) model, where the interaction between a pre-existing, stable clump and the H II region induces the star formation. Simulations of H II regions expansion in a turbulent medium, show the formation of pillars and cometary globules (Tremblin et al. 2012); and the expansion in a fractal medium triggers the formation of stars by combining elements from C&C and RDI (Walch et al. 2015). Several theoretical (Bertoldi 1989; Lefloch & Lazareff 1994; Miao et al. 2006) and observational works (Urquhart et al. 2009; Morgan et al. et al. (2014) identified 8000 of these H II regions in the Galactic Plane. When the layer of material surrounding the ionizing stars is dense enough, star formation can be observed in it. This mechanism, where one or several high-mass stars are responsible for star formation is called a triggering mechanism, and is thought to be a plausible explanation for the presence of OB associations (Blaauw 1964; Preibisch & Zinnecker 2007).
2. APEX-SHeFI observations and data reduction

The $^{12}\text{CO} (3-2)$, $^{13}\text{CO} (3-2)$ and $^{18}\text{O} (3-2)$ molecular line transitions were observed with the Atacama Pathfinder EXperiment\(^1\) (APEX) 12-m telescope (Güsten et al. 2006) in service mode and were carried out in October 7, 9, 11 of 2016, June 21 and September 24-25 of 2017. The APEX Swedish Heterodyne Facility Instrument (SHeFI, Vassilev et al. 2008) band 2 receiver (267 GHz – 378 GHz) was used as a frontend and the eXtended bandwidth Fast Fourier Transform Spectrometer (XFFTS, 2.5 GHz bandwidth and 32768 spectral channels) was used as a backend. The receiver was tuned to the $^{12}\text{CO} (3-2)$ transition frequency for the $^{12}\text{CO} (3-2)$ observations and to 329,960 GHz to allow the simultaneous observation of the $^{13}\text{CO} (3-2)$ and $^{18}\text{O} (3-2)$ transition lines. At these frequencies, the beam size ($\theta_{\text{beam}}$) and main beam efficiency ($\eta_{\text{MB}}$) of the telescope are 195.2 and 0.73, respectively. The Precipitable Water Vapor (PWV) measuring the weather conditions during the observations ranged from 0.9 to 1.6 mm. The observations, performed with the raster mode, consist of 121 ON observations distributed as a 11×11 pixels (~105’×105’) mosaic map separated by half a beam with an OFF reference observed after each 3 ON observations in position switching mode. The observed maps are centered (258.03625°,−38.51319°) and (258.17625°,−38.45017°), referred as region A and region B, respectively (see Fig. 1). The integration time, excluding overheads, was 3.1 hours for region A in $^{12}\text{CO} (3-2)$, 3 hours for region A in $^{13}\text{CO} (3-2)/^{18}\text{O} (3-2)$.

\(^{1}\) This publication is based on data acquired with the Atacama Pathfinder Experiment (APEX). APEX is a collaboration between the Max-Planck-Institut für Radioastronomie, the European Southern Observatory, and the Onsala Space Observatory.
1.5 hours for region B in $^{12}$CO (3–2) and 2.8 hours for region B in $^{13}$CO (3–2)/$^{18}$O (3–2). After the first cycle of observations (2016B), the priority was given to region B in $^{13}$CO (3–2)/$^{18}$O (3–2) due to the low abundance of these isotopologue compared to $^{12}$CO (3–2).

Pointings and calibrations were achieved by observing NGC 6302, Mars, RT-Sco and Saturn. The data were further reduced using the CLASS package of the GILDAS software. Baselines modelled as 1$^{st}$ to 3$^{rd}$ order polynomials, depending on the observations, were subtracted. The $^{13}$CO (3–2) and $^{18}$O (3–2) observations were then tuned to their transition frequency. The table and $x_y$ _map_ routines were used to combine the data and create the lmv cubes which were converted into FITS files using the fits routine of the VECTOR package. Finally, the cubes were resampled with a pixel size of 9.5” to the same center and the same size in order to have uniform observations. We ended up with 6 spectral cubes with a resolution of 0.07 km s$^{-1}$ (76 kHz) and a rms of 0.24 K, 0.89 K, 0.47 K, 0.31 K and 0.37 K for region A $^{12}$CO (3–2), $^{13}$CO (3–2), $^{18}$O (3–2) and region B, respectively.

3. Analysis

3.1. Spatial and velocity distribution of CO (3–2), $^{13}$CO (3–2) and $^{18}$O (3–2)

The velocity distribution of the spatially integrated emission and the velocity integrated maps for the three isotopologues and both regions are shown in Figs. 2, 3. Due to the abundance, the integrated intensity is decreasing from $^{12}$CO to $^{18}$O with a ratio to the $^{12}$CO peak of 1, 0.51 and 0.20 for region A and 1, 0.51 and 0.18 for region B. The $^{12}$CO and $^{13}$CO double peaks behaviour could either indicates the presence of two clumps or a strong self-absorption. Since this is not observed in the optically thin $^{18}$O transition, the double peak feature is a signature of self-absorption, clearly observed in $^{12}$CO due to high optical depth ($\tau$). It was also observed by Anderson et al. (2015) in $^{12}$CO (1 – 0) using MOPRA observations. The optical thickness of $^{12}$CO ($\tau_{12}$) can be estimated by comparing the intensity ratio of $^{12}$CO to $^{13}$CO to their relative abundance (Haworth et al. 2013). Assuming a $^{12}$CO and $^{13}$CO abundance of 8x10$^{-5}$ and 2.7x10$^{-6}$, respectively (Magnani et al. 1988; Pineda et al. 2008), the abundance ratio is ~ 30, much higher than the average line intensity ratio of 2.4, indicating a high optical depth for $^{12}$CO. The $^{13}$CO presents some self-absorption features, especially toward region A, in agreement with the fact that clump 1 is the densest of RCW 120.

The gaussian fit of $^{18}$O indicates that this molecular line is centred at $-6.9$ km s$^{-1}$ for region A and $-7.0$ km s$^{-1}$ for region B, respectively. RCW 120 having a $V_{LSR}$ of $-7$ to $-8$ km s$^{-1}$, these two emissions are associated with its PDR.

In the southern-east part of region A, two features are observed. A small peak is detected only in $^{12}$CO at $-15$ km s$^{-1}$ (white pixels on Fig. A.1) with a $T_{MB}$ less than 5 K. This feature may be too weak to be detected in other isotopologues. It could be due to line of sight contamination as it does not appear to be related to the PDR or the ionized region. The other feature can be seen at $-12.5$ km s$^{-1}$ and located in the north-western part of the region, where the ionized gas is, and being weaker toward the PDR. Its location on the blue side part of the spectrum may represents the $^{12}$CO gas moving toward us due to the ionization pressure. They can only be weakly seen on the spatially averaged profile (Fig. 2) at $-14.5$ and $-12$ km s$^{-1}$. Toward region B, we note the non gaussian profile with asymmetry on the blue part. Except from the main one, three other components can be seen at $-12$, $-10$ and $-1$ km s$^{-1}$, discussed in Sect. 3.6.

We constructed the mean velocity and velocity dispersion maps$^3$, also known as first and second moment maps, of the $^{13}$CO and $^{18}$O and a clip at 3$\sigma$ (Fig. 4). The mean velocity of the $^{13}$CO and $^{18}$O in region A ranges from $-8.3$ to $-5.5$ km s$^{-1}$ with an average of $-7$ km s$^{-1}$. While a range of different velocities is observed, the interval is too small and no clear gradients or particular features are observed. The average velocity dispersion of 0.7 km s$^{-1}$ for $^{18}$O, in good agreement with the velocity dispersion of 0.8 km s$^{-1}$ found toward the PDR of RCW 120 with MOPRA CO (1–0) data (Anderson et al. 2015). It also seems in agreement for $^{13}$CO with an average of 1.4 km s$^{-1}$ (see their Fig. 9). On the velocity dispersion maps, the center of region A stands out with a velocity dispersion of 2.6 and 1.1 km s$^{-1}$ for $^{13}$CO and $^{18}$O, respectively, and shows the increase of linewidth, through turbulence and thermal contributions from the Class 0 Herschel source 2.

In region B, the mean velocity of the $^{13}$CO and $^{18}$O ranges from $-7.2$ to $-6.6$ km s$^{-1}$ with an equal average of $-6.9$ km s$^{-1}$. In $^{13}$CO, the mean velocity does not seem to be distributed randomly in the map with lower mean velocity toward the H$n$ region and higher toward the clump but, as for region A, the range of velocity is too small to provide any meaningful conclusion. Higher spatial and spectral resolution observations are needed to study gas motions in these two regions. The velocity dispersions of 0.8 and 0.4 km s$^{-1}$, in average, are also consistent with the MOPRA observations. Moreover, there are higher where the evolved low-mass sources are located.

Due to the temperature difference between the most massive core of RCW 120 (labelled as core 2, see Figueira et al. 2017 and Fig. 3) with $T_{dust} = 20.3$ K and the YSOs in region B with $T_{dust} = 34.1$ K, turbulence toward region A should be higher in order to explain the higher velocity dispersion. This is in agreement with the high-mass star formation occurring in this core (Figueira et al. 2018) compared to the low-mass YSOs present in region B.

3.2. Self-absorption correction

The self-absorption feature seen in $^{12}$CO and $^{13}$CO (see Fig. 2) is responsible for the intensity loss at the $V_{LSR}$ of the region ($-7$ km s$^{-1}$) resulting in a lower $T_{MB}$ than expected. To correct the spectra for self-absorption, we performed iterative gaussian fittings using the shoulder of the profile. We began with the upper part of the profile shoulders and iteratively perform fittings by increasing their length until reaching the end of the profile. Secondary peaks are removed during the fitting. As seen on Fig. 5, when using a smaller length (bluer color), the peak tends to be higher compared to larger shoulders’ length (redder color). The uncertainty on the peak value was computed as the standard deviation of the different peak values while it was computed as the $1\sigma$ uncertainty if no self-absorption was observed. Hence, each spectrum could be fitted with a single gaussian and a peak main brightness temperature could be derived for each of them ($T_{MB}^{12}$, $T_{MB}^{13}$ and $T_{MB}^{18}$). As self-absorption decreases, either going from $^{12}$CO to $^{18}$O or from region A to region B where CO is less abundant, the uncertainties on $T_{MB}$ decrease. Toward region B, $T_{MB}$; $M_1 = \int T_{MB} V dV$; $M_2 = \int T_{MB} (V - M_1) dV$ / $\int T_{MB} dV$.

---

$^2$ http://www.iram.fr/IRAMFR/GILDAS

---

$^3$ The mean velocity and velocity dispersion are computed following $M_1 = \int T_{MB} V dV$; $M_2 = \int T_{MB} (V - M_1) dV$ / $\int T_{MB} dV$. 

Article number, page 3 of 15
100% and 34% of the spectra are corrected for self-absorption while 88% and 23% for region A, for $^{12}$CO and $^{13}$CO. In the following, all the peak values are corrected from self-absorption.

### 3.3. Physical properties of the clumps

The solution of the radiative transfer equation can be used to derive several physical properties of the clumps such as the excitation temperature $T_{ex}$, the optical depth $\tau$ or the column density $N$. Assuming that the medium is uniform, the background subtracted solution of the radiative transfer equation can be written explicitly using the Planck law and rearranged to obtain $T_{ex}$ as

---

Fig. 2: Spatially integrated intensity of $^{12}$CO (in blue), $^{13}$CO (in red) and C$^{18}$O (in green) toward region A (a) and region B (b).

Fig. 3: Velocity integrated intensity of the $^{12}$CO (3−2) (first column), $^{13}$CO (3−2) (second column) and C$^{18}$O (3−2) (third column) for region A (top) and region B (bottom). The velocity range used for integration is $-20.1 < V_{LSR} < 8.2$ km s$^{-1}$, $-15.0 < V_{LSR} < 3.1$ km s$^{-1}$ and $-12.0 < V_{LSR} < -2.3$ km s$^{-1}$ for $^{12}$CO (3−2), $^{13}$CO (3−2) and C$^{18}$O (3−2), respectively. Contours represent the emission at 70 μm from Herschel and the cores (labels are slightly shifted from the true position of the cores) which were extracted in Figueira et al. (2017).
Wilson 1996; Haworth et al. 2013): a function of feature.

where $T_v = h\nu/k_B$, $k_B$ is the Boltzmann constant, $h$ is the Planck constant and $\nu$ is the frequency transition of the line considered. The parameters of Eq. 1 can be found in Tab. 1 for the $J = 3 - 2$ transition. As shown in Sect. 3.1, $^{12}$CO is optically thick so $T_{ex}$ can be simplified considering $\tau \rightarrow \infty$. 

Toward region A, $T_{ex}$ is minimal inside the H\textsc{ii} region (6.7 K) where the $^{12}$CO is less abundant, increases along the PDR where star formation is observed, with the highest value (38.3 K) towards the center where the Herschel source 2 is located, with an average of 22.8 K. Toward region B, the excitation temperature is also minimal inside the H\textsc{ii} region (10.5 K) and increases, up to 40.9 K, towards the center of the clump, where evolved low-mass stars are observed, with an average of 20.7 K. These values agrees with $T_{ex} = 23.4$ K from Anderson et al. (2015) and are similar to those toward the mid-infrared bubble S\,44 (Kohno et al. 2018) where ranges of 8–13 K and 8–25 K were found. The locations of the $T_{ex}$ high values (see Fig. 6) are associated with the Herschel sources which, together with the FUV radiation from the H\textsc{ii} region, is another important source of heating.

By inverting Eq. 1 and assuming that Local Thermodynamical Equilibrium (LTE) holds, $\tau_{13}$ and $\tau_{18}$ can be computed through Eq. 2.

$$\tau = -\ln \left[ 1 - \frac{T_{MB}}{T_v \left( \frac{1}{\tau_{13} + 1} - e^{-\tau_{13}/T_{MB}} \right)} \right]$$

(Towards region A, the optical depth of $^{13}$CO and C$^{18}$O follows the same behaviour than $T_{ex}$, with low values outwards the PDR (around 0.2 and 0.1 inside the H\textsc{ii} region) and higher values (up to 2.3 and 0.7) towards the PDR. In average, $^{13}$CO has a larger optical depth compared to C$^{18}$O, the former being moderately thick along the PDR and the latter optically thin everywhere. In region B, the values of $\tau_{13}$ and $\tau_{18}$ ranges from 0.2 and 0.1, inside the H\textsc{ii} region, to 2.7 and 0.4, respectively with a similar average compared to region A. We have to note that the highest values of $\tau$ are always found at the edges of the map and we cannot exclude that the resampling process lowered the quality of the border of the map. If these high values are ...
excluded, $^{13}$CO is moderately thick with $\tau_{13}$ reaching values up to 1.5.

By studying a sample of bright rim clouds (BRCs), Morgan et al. (2009) showed that $T_{ex}^{13}$ can be significantly different from $T_{ex}^{12}$ since C$^{18}$O probes the interior of the clump due to its low optical thickness compared to $^{12}$CO which is mostly representative of the surface of the clump (Takekoshi et al. 2019). Using Eq. 1, an estimation of $T_{ex}$ for C$^{18}$O can be computed by using the average $\tau_{18}$ found with Eq. 2. To make a comparison with $T_{ex}^{12}$, we only take into account the $^{12}$CO pixels where C$^{18}$O is detected. In average, $T_{ex}^{13}$ is higher than $T_{ex}^{12}$ as observed but with a lower temperature difference (2–4 K) than in Morgan et al. (2009). Stars and protostars located inside region A and B could explained this rise of $T_{ex}$ as clumps are not quiescent.

The column density of $^{13}$CO and C$^{18}$O can be obtained with:

$$N = \left( \frac{3k_B}{8\pi^2 B_{12}} \right) \left( \frac{\nu H_{2}/(J+1)\nu T_{ex}}{J_{1} + 1} \right) \int \tau d\nu$$

(3)

$$\int \tau d\nu = \frac{1}{T_{ex} \left( \frac{1}{\nu^{2} \tau_{L_{IR}}} - \frac{1}{\nu^{2} \tau_{MB}} \right)} \tau$$

(4)

Towards region A, N($^{13}$CO) follows the PDR of RCW 120 with the maximum of 5.5×10$^{16}$ cm$^{-2}$ found towards the most massive core of the region. The N(C$^{18}$O) distribution also follows the PDR but with a smaller variation, a maximum of 1.4×10$^{16}$ cm$^{-2}$ toward the massive core and a decrease outwards. Towards region B, the N($^{13}$CO) and N(C$^{18}$O) distributions are well correlated with the dust continuum emission with a value toward the center of 2.7×10$^{16}$ and 4.1×10$^{15}$ cm$^{-2}$. Since the column density calculation depends on $\tau$, a similar issue arises toward the edge of the map, mainly seen for N($^{13}$CO) in both region. The global values of column density found toward this region are in agreement with other star-forming regions (Shimajiri et al. 2014; Paron et al. 2018; Vazzano et al. 2019). Inside the H$\Pi$ region, no $^{13}$CO (3–2) and C$^{18}$O (3–2) are detected. Given the rms of these observations, it translates into an upper limit for the column density of 1.5×10$^{15}$ cm$^{-2}$ and 7.5×10$^{13}$ cm$^{-2}$ for $^{13}$CO and C$^{18}$O, respectively.

### 3.4. Outflows toward RCW 120

#### 3.4.1. Extraction of the wings

During the phase of high-mass star formation, one of the solution proposed to overcome the radiation pressure problem (Wolfire & Cassinelli 1987) was the growth of the star via an accretion disk (Jijina & Adams 1996) such as in the formation of low-mass stars (Coffey et al. 2008). For the angular momentum to be conserved, high-mass stars formed by disk accretion must radiate this excess of momentum via outflows. Observations showed that high-mass star formation are associated with outflows (Arce et al. 2007; Maud et al. 2015; McLeod et al. 2018). Since they release more momentum, energy and spawn a larger distance, they are more easily detectable compared to the low-mass ones. During high-mass star formation, they developed during the hot-core stage preceding the UCH II phase, also associated with the 6.67 GHz class II methanol maser (Caswell 2013). The detection of outflows is mostly done through the identification of wings on spectral profiles but other indirect tracers of outflow exists such as SiO.

Toward region A, the source 2 observed with Herschel is a massive source where high-mass star formation is observed through the hot core phase (Figueira et al. 2018). Several molecular tran-

---

**Table 1: Parameters used to compute $T_{ex}$, $\tau$ and $N$**

| CO (3–2) | $\nu$ (GHz) | $T_{ex}$ (K) | $\exp(-T_{ex}/T_{CMB})$ | B (GHz) |
|---------|----------|-------------|---------------------|--------|
| $^{12}$CO | 345.795 | 16.6 | 0.0022 | 57.635 |
| $^{13}$CO | 330.587 | 15.9 | 0.0029 | 55.101 |
| C$^{18}$O | 329.330 | 15.8 | 0.0030 | 54.891 |

---

**Fig. 6:** $T_{ex}$ toward region A (left) and region B (right) obtained using Eq. 1.
Fig. 7: Column density of $^{13}$CO and C$^{18}$O for region A (first and second columns) and toward region B (third and fourth columns).

Table 2: $T_{ex}$ from $^{12}$CO and C$^{18}$O, optical depth and column density of $^{13}$CO and C$^{18}$O

| Region  | $T_{ex}^{12}$ (K) | $T_{ex}^{18}$ (K) | $\tau_{13}^{LTE}$ | $\tau_{18}^{LTE}$ | $N(^{13}$CO)$^{LTE}$ (cm$^{-2}$) | $M($C$^{18}$O)$^{LTE}$ (cm$^{-2}$) |
|---------|------------------|------------------|------------------|------------------|-------------------------------|-------------------------------|
| Region A | Minimum | 6.7 (18.7) | 14.8 | 0.2 | 0.1 | 2.1×10$^{13}$ | 1.9×10$^{14}$ |
|         | Maximum | 38.3 (38.3) | 39.1 | 2.3 | 0.7 | 5.5×10$^{16}$ | 1.4×10$^{16}$ |
|         | Mean    | 22.8 (28.3) | 24.8 | 0.7 | 0.3 | 2.2×10$^{16}$ | 6.5×10$^{15}$ |
| Region B | Minimum | 10.5 (13.9) | 9.7  | 0.2 | 0.1 | 4.4×10$^{15}$ | 6.2×10$^{14}$ |
|         | Maximum | 40.9 (40.9) | 34.7 | 2.7 | 0.4 | 3.8×10$^{16}$ | 4.1×10$^{15}$ |
|         | Mean    | 20.7 (21.8) | 19.9 | 0.7 | 0.2 | 1.3×10$^{16}$ | 2.1×10$^{15}$ |

sitions (MALT90 survey) such as tracers of hot core (CH$_3$CN and HC$_3$N) as well as a tracer of shock and outflow (SiO) are observed toward the source 2, strongly indicating that an outflow is present. The profile is broad (Kirsanova et al. 2019) and synonym of dynamics toward this core. SiO is also detected toward source 2, strongly indicating that an outflow is present. The profile is broad (Kirsanova et al. 2019) and synonym of dynamics toward this core. SiO is also detected toward source 39. As it is placed at the edge of the map, we will not extract the outflow since the edges are problematic due to the resampling process. However, it may contaminate the properties of the outflow at the location of source 2. Toward Region B where low-mass sources are observed, no wings and no outflow tracers are detected. Sources are classified as Class I, II or Ae/Be stars (Deharveng et al. 2009; Figueira et al. 2017) and due to the more evolved stage of these sources, the outflows, if any, should be weaker compared to region A.

To extract the outflow wings from our spectra, we employed the method of de Villiers et al. (2014) used in the framework of methanol masers as counterpart of the hot core stage, also used in Yang et al. (2018) toward ATLASGAL clumps. The procedure to extract the wings of the spectrum is visually explained on Fig. 8 and the basic idea is to retrieve the part of the $^{13}$CO spectrum which is broader than the C$^{18}$O spectrum. Firstly, the C$^{18}$O spectrum is scaled to the peak of the $^{13}$CO spectrum which is then fitted with a gaussian. In order to remove high velocity features (van der Walt et al. 2007) and correctly fit the spectrum peak, we first performed a fit of the whole spectrum and we iteratively fitted the spectrum by reducing the shoulders length, pixel to pixel (see Fig. 8 left). This modelled scaled C$^{18}$O spectrum is then subtracted from the observed $^{13}$CO spectrum to obtain the $^{12}$CO residuals. The blue and red wings are defined as the part of the $^{13}$CO spectrum corresponding to the $^{13}$CO residuals above 3σ and below the two maxima of the residuals or, said in another way, the part of the $^{13}$CO spectrum which is broader than the scaled C$^{18}$O spectrum (see Fig. 8 right). Toward region A, the $^{13}$CO spectrum was corrected for self-absorption, as explained in Sect. 3.2. When a gaussian fitting was performed, we first convolved the signal using a one dimensional box of 5 pixels in order to remove the fluctuations. By visual inspection, we checked that this process does not smooth the particular features of our spectra (self-absorption, wings, secondary peaks). The $^{13}$CO spectrum was then integrated in the velocity windows defined by the wings. These wings are presented on Fig. 9 where the lowest contour is visually chosen as the one enclosing the wings on the integrated map. As it is difficult to differentiate between the background and the emission wings, this leads to a higher uncertainty when deriving the parameters of the outflow as they depend on the wings mass which depends on the lowest contour used.

3.4.2. Outflow properties

The mass of the blue and red wings, represented in Figs. 8, 9, are computed by integrating the lobes areas on the N($^{13}$CO) map integrated over the wings velocity ranges. Using the abundance of $^{13}$CO relative to H$_2$ from Herschel observations, N($^{13}$CO) is converted into a mass. The total mass of the outflow is obtained by summing the contribution of the blue and red lobes. An estimation of the outflow momentum and energy were obtained by summing each contribution from the velocity channels corresponding to the blue and red wings. The dynamical timescale $t_D$, the mass-loss rate $M_{\text{out}}$, the mechanical force $F_m$, and luminosity $L_m$ of the outflow were then be computed (see Eqs. 4-9 in Yang et al. 2018). The properties of the outflows in region A can be found in Tab. 3. When computing the properties of outflows, we have to account for several parameters which increase their uncertainty (see Sect. 4.3 of de Villiers et al. 2014). One of the most severe
is the inclination of the outflow with respect to the line of sight. If this property is unknown, either the corrections are not done, either they are applied assuming a uniform distribution in the sky ($\theta = 57.3^\circ$). In this paper, we do not correct for the inclination but the reader can refer to Table 4 of de Villiers et al. (2014) and apply the correction factors in case of comparison with other works. The values of the massive core outflow (376 $M_\odot$, 856 $L_\odot$, Figueira et al. 2018) are in relative good agreement with the general values for massive star forming (MSF) clumps derived by Yang et al. (2018) with a sample of 153 ATLASGAL clumps and by de Villiers et al. (2014) from methanol maser associated outflows. Since mass of the wings derived from N(H$_2$) might be overestimated, we account for an uncertainty on the outflow properties between a factor 2–3 relatively to those in de Villiers et al. (2014) and Yang et al. (2018).

### 3.5. Estimation of the Mach number

The turbulence in molecular clouds is an important parameter to take into account in star formation as it can counteract the gravity during the gravitational collapse of a core. The solenoidal and compressive modes of turbulence have different impact on star formation where the latter one is thought to be associated with a higher Star Formation Efficiency (SFE, Federrath & Klessen 2012). The goal here is not to derive the ratio of solenoidal to compressive modes as it has been done in Orkisz et al. (2017) but rather to obtain an estimation of the Mach number $M$. The thermal linewidth of the line $c_T$ is defined by $\sqrt{k_B T/\mu m_H}$ where $T$ is taken to be the maximal temperature between $T_{\text{ex}}$ (from $^{13}$CO) and $T_{\text{dust}}$ (from Herschel observations) as recommended by Orkisz et al. (2017). The non-thermal component of the linewidth is $\sigma_N = \sqrt{\sigma^2 - \sigma_T^2}$ where $\sigma$ is the dispersion of the $^{13}$CO spectra related to the FWHM by $\sigma = \text{FWHM}/\sqrt{8\ln2}$. The Mach number is defined as $M = \sigma_NT/c_s$ where $c_s$ is the sound speed. The median for region A and region B is 17 and 7, respectively. In Orkisz et al. (2017), $M$ can go up to value higher than 20 towards the regions where the FWHM of the $^{13}$CO is high. However, as their observations do not only focus on the star-forming parts of Orion-B but on the whole region, the median $M$ decreases to 6. In our case, observations were centred on two star-forming regions which explain the higher $M$. Such high-values of $M$ have been observed for instance toward Orion A (González Lobos & Stutz 2019), GMF38a (Wu et al. 2018) or quiescent 70 $\mu$m clumps (Traficante et al. 2018).

3.6. Impact of the Hii region on the layer

Contrary to the rest of the ring, region B is the most intriguing due to its particular morphology. As seen on Fig. 10, the 8 $\mu$m observation shows a distorted emission as if a clump was made, either by its particular morphology. As seen on Fig. 10, the 8 $\mu$m observation shows a distorted emission as if a clump was made, either by its particular morphology.
the northern part of the clump, where the SUMSS emission is present, it can also be noted that an 8 μm arc is present, touching the last contour. The tails can also be observed on the velocity integrated image of \(^{13}\)CO (Fig. 3) but this is not really clear as the resolution of the CO observations (∼18.2”) is lower than Spitzer 8 μm and Herschel 70 μm observations.

Using radio continuum emission, the photon flux \(\Phi\) impacting the clump of region B and the corresponding electron density \(n_e\) can be computed with the following equation (Lefloch et al. 1997; Thompson et al. 2004):

\[
\Phi = 1.24 \times 10^{10} \times \left[ \frac{S_v}{\text{mJy}} \right] \times \left[ \frac{T_e}{\text{K}} \right]^{0.35} \times \left[ \frac{\nu}{\text{GHz}} \right]^{0.1} \times \left[ \frac{\theta}{\text{″}} \right]^{-2} \tag{5}
\]

\[
n_e = 122.21 \times \left( \frac{S_v T_e^{0.35} \nu^{0.1}}{\theta^2} \right)^{\frac{1}{7}} \times \left( \frac{\eta R_c}{\text{pc}} \right)^{\frac{2}{7}} \tag{6}
\]

The electron temperature inside the H\(\text{II}\) region computed from Balser et al. (2011) gives \(T_e = 8100\) K, in agreement with the range of \(T_e\) (7×10\(^3\) to 1×10\(^4\) K) used in other works (Anderson et al. 2015). \(\theta\) is the angular diameter where the flux is integrated, \(R_c\) is the radius of clump impacted by the radiation and \(\eta\) is the fraction of the clump which is photoionised. At 835 MHz, the flux is equal to 7 Jy in \(\theta = 506″\), \(R_c\) is taken to be ~0.18 pc and we assume the general value \(\eta = 0.2\) (Bertoldi 1989). The corresponding \(\Phi\) at the interface between the H\(\text{II}\) region is equal to \((8±1)\times10^{12}\) cm\(^{-2}\) s\(^{-1}\). The value of the electron density \(n_e\) at the edge of the clump is \((510±30)\) cm\(^{-3}\) which is far above the electron density value needed to form a Ionized Boundary Layer (IBL). Uncertainties have been estimated by using \(T_e = 7000 – 10000\) K and an uncertainty of 5% for the flux (Murphy et al. 2007). We have to note that the emission at 843 MHz can be optically thick and underestimated. Using the measurement from Caswell & Haynes (1987) at 5 GHz for the whole region and equal to 8.3 Jy, \(\Phi\) and \(n_e\) increase to \((1×10^{10})\) cm\(^{-2}\) s\(^{-1}\) and 600 cm\(^{-3}\).

To understand if the pressure of the H\(\text{II}\) region could have pushed and compressed the clump of region B, we computed the pressure at the edge of the clump due to the ionization, \(P_{\text{ion}}\), and the internal pressure of the clump, \(P_{\text{clump}}\). The ionization pressure of an H\(\text{II}\) region is estimated with \(P_{\text{ion}} = 2\pi T_e\) (Urquhart et al. 2004). The ionization pressure \(P_{\text{ion}}/k_B\) is found to be \((8±2)\times10^6\) K cm\(^{-3}\). This value is similar to the one found toward the horsehead nebula (Ward-Thompson et al. 2006) with an O9.5 star at ∼3.5 pc of distance. The pressure of the clump is computed following \(P_{\text{clump}} = \rho_{\text{clump}} c_S^2\) where \(\rho_{\text{clump}}\) is the clump density and \(c_S (∼1±0.2\) km s\(^{-1}\)\) is the velocity dispersion of \(^{13}\)CO toward the clump. The pressure \(P_{\text{clump}}/k_B\) is around \((8±3)\times10^6\) K cm\(^{-3}\).

If the clump was pre-existent without star-formation, the dispersion would mainly be thermal with \(\sigma_t ∼ 0.2\) (at 10 K), giving an upper limit of \((1×10^6)\) K cm\(^{-3}\) for \(P_{\text{clump}}/k_B\). In this initial configuration, the clump of region B is firstly compressed by the H\(\text{II}\) region pressure, causing the gravitational collapse of the clump, the formation of stars and the increase of \(P_{\text{clump}}\) through the increase of turbulence and temperature. When \(P_{\text{clump}} ∼ P_{\text{ion}}\), the highest density part of the clump stops to be compressed but the less dense part continues to be pushed, forming the wings and the bended shape. The ionization pressure might still be effective towards the low-density northern part of RCW 120, where a campaign flow is observed and toward the south center where bended structured can be observed on Herschel observations. Because \(P_{\text{clump}} \sim P_{\text{ion}}\), Torii et al. (2015) concluded that the ionization pressure cannot create the cavity, making the C&C scenario inconsistent. However, the expansion of the H\(\text{II}\) region might have been compressed the layer and stopped when \(P_{\text{clump}} \sim P_{\text{ion}}\). This is consistent with the fact that we barely detect any motion of the ring, with an expansion velocity between 1.2 and 2.3 km s\(^{-1}\) (Anderson et al. 2015).

---

**Fig. 9:** Outflow contours in region A for the red and blue wings (continuous red and dashed blue contours) overlaid on the \(^{13}\)CO (3−2) velocity integrated intensity image.

**Fig. 10:** Observation of region B from Spitzer at 8 μm where the red dashed line represents the circle which follows the 8 μm emission, the black contours represent the free-free emission from SUMSS (contours from 0.01 to 0.04 Jy beam\(^{-1}\)) and the orange arrow indicates the direction of the ionizing radiation. The clump with the tails are inside the circle.
4. Discussion

4.1. Dynamics of the region

Both regions contain protostars, either at the beginning of their evolution (region A) or more advanced YSOs (region B), at different projected distance from the ionizing star and therefore, differently impacted by the UV radiation. The Mach number of region A and B are high compared to the literature, indicating that turbulence is significant in these regions. In region A, this turbulence can be explained by the impact of UV radiation on the clump, by the ongoing star-formation and by the outflow toward the massive $\sim 300 M_\odot$ Herschel source. It can explain the mass of the fragments at 0.01 pc scale (Figueira et al. 2018), in disagreement with the thermal Jeans mechanism. In region B, the turbulence is less important and could be explained by the lowest impact of stellar feedback from low-mass stars. Indeed, the spectral profile is not broad and no traces of shock have been detected using the MALT90 survey. In addition, the clump being farther away, the impact of UV radiation should be less significant.

We tried to understand the impact of UV radiation on the abundance of $^{13}$C and $^{18}$O, and on the photodissociation of $^{13}$CO. Using the mass derived from the Herschel column density map, the abundance of $^{13}$CO and $^{18}$O are found to be lower compared to the general ISM values ($2.7 \times 10^{-6}$ and $1.7 \times 10^{-7}$, respectively, Goldsmith et al. 1997; Magnani et al. 1988; Pineda et al. 2008). However, several bias have to be taken into account before drawing any conclusions about these values. Firstly, the $N(H_2)$ mass differs from the one estimated by Deharveng et al. (2009) by a factor of 3 at most, hence the abundance would increase by the same factor. Secondly, $^{13}$CO being moderately thick toward the densest parts, the derived $N(^{13}$CO) represents a lower limit. Accounting for this mass uncertainty on $^{18}$O does not rule out a possible photodissociation. The average ratio of $^{13}$CO to $^{18}$O is equal to 4.6 and 7.4 for region A and B, respectively. These values of 5.5 for the solar system and far from the high ratio observed towards Orion-A of 16.5 and the maximum of 33 Shimajiri et al. (2014). By looking at the ratio maps, we observed that the value is lower towards the densest part of the region and higher toward the edges. Unfortunately, as noted by Shimajiri et al. (2014), this ratio is affected by the beam filling factor which could be as low as 0.4 as well as being non uniform over the area due to the different structures observed (Paron et al. 2018). The resolution of our observations does not allow us to conclude about the dissociation of $^{18}$O towards the PDR of RCW 120.

4.2. Induced star formation toward RCW 120

4.2.1. C&C mechanism

The interplay between the ionizing radiation from massive stars and the turbulent medium was analysed by Tremblin et al. (2012) using hydrodynamical simulations. They showed that the probability density function (PDF) of the gas can be used to trace the unperturbed and shocked gas. The PDF of the highest density clump (region A) is well-fitted by a power-law, showing the relation between the ionization pressure and the compression of this clump (Tremblin et al. 2014). Studies of Thompson et al. (2012) and Minier et al. (2013) also indicates that this clump is likely to be triggered by the H$\alpha$ region. This compression would have locally increase the density and lead to the gravitational collapse of the layer. However, it is not clear what is the mechanism responsible for the formation of this clump where most of all the massive cores are found. As seen on Fig. 1, this clump does not seem to be pre-existent as the interface between the PDR and the H$\alpha$ region is not distorted. Therefore, the spatial distribution of the dust and gas in this region would be visually in agreement with the C&C mechanism. We note that the CCC model would give the same ring-like dust distribution but star formation would not be the result of any compression as the ring would have formed before emission of UV radiation.

To better understand if the C&C process could be at work, we compared the dynamical age of the H$\alpha$ region $t_{dyn}$, to the time needed for the layer to fragment $t_{frag}$. Such comparisons were already performed: towards S 233 (Ladevyschikov et al. 2015) and S 24 (Cappa et al. 2016), the C&C mechanism does not seem to be possible while toward Sh2-39 (Dunoea et al. 2015), Sh2-104 (Xu et al. 2017), Sh2-212 (Deharveng et al. 2008), Gum 31 (Dunoea et al. 2015) or Sh 217 (Brand et al. 2011), the C&C model appears to be plausible. In this work, we estimated $t_{dyn}$ using the model of Tremblin et al. (2014). We use the same set of equations as in their work, from Martín-Hernández et al. (2005):

$$N_{LyC} = \frac{7.603 \times 10^{46} \text{s}^{-1}}{b(v, T_e)} \left(\frac{T_e}{10^4 \text{ K}}\right)^{-0.33} \left(\frac{D}{\text{kpc}}\right)^2$$ (7)

$$b(v, T_e) = 1 + 0.3195 \log \left(\frac{T_e}{10^4 \text{ K}}\right) - 0.2130 \log \left(\frac{v}{\text{GHz}}\right)$$ (8)

The thermal radio-continuum emission of RCW 120 is equal to 5.81 and 8.52 Jy at 8.35 and 14.35 GHz, respectively (Langston et al. 2000). The value of $\log(N_{LyC})$ is found to be 48.14 $\text{s}^{-1}$. The radius of the bubble is taken to be 1.8 pc (277" at 1.34 kpc).

The last parameter is the initial density of the medium $n_0$. We estimated $n_0$ by assuming that all the mass was initially gathered in a sphere of $\sim 1.8$ pc radius. The mass of RCW 120 at 870 $\mu$m, assuming $T = 20$ K, is $\sim 2000 M_\odot$ (Deharveng et al. 2009). However, observations with APEX-LABOCA suffer from loss of large scale emission. Using the maps combined with Planck data (Csengeri et al. 2016) to correct from this emission loss, the mass of RCW 120 (contour of 0.6 Jy beam$^{-1}$, $T = 20$ K) increases to 2600 $M_\odot$. Using the column density map of RCW 120 (Figueira et al. 2018), the mass of the layer is 6000 $M_\odot$ and increases to 10$^4 M_\odot$ if we consider the whole region.

The mass from LABOCA+Planck (lower limit) and from $N(H_2)$ (upper limit) found give an initial density of 1.85 $10^3$ and 7.13 $10^3$ cm$^{-3}$, respectively. From the statistical study of Palmeirim et al. (2017) with Hi-GAL (Molinari et al. 2010), H$\alpha$ regions in the Galactic plane have density ranging from $\sim 10$ to $\sim 2300$ cm$^{-3}$ and most of the simulations takes initial density between 1000 and 3000 cm$^{-3}$ (Arthur et al. 2011; Walch et al. 2015; Mackey et al. 2016; Marsh & Whitworth 2019). Therefore, the initial density of 7.13 $10^3$ cm$^{-3}$ seems too high compared to the usual values found toward H$\alpha$ regions. In the model of Tremblin et al. (2014), the input density is given by the average density at 1 pc. To compute the dynamical age, we used the nearest grid values to the estimations (8000 K, 1.8 pc and 10$^{48}$ s$^{-1}$). Uncertainties were estimated by using the grid values below and above the estimations. The results are plotted on Fig. 1. The dynamical age as well as those taken from other
Table 4: Age of RCW 120

| Reference                        | \(n_0\) \((\text{x}10^3 \text{ cm}^{-3})\) | Age \((\text{Myr})\) |
|----------------------------------|---------------------------------------------|------------------------|
| This work                        | 1.9 - 7.1                                   | 0.96±0.25              |
| Martins et al. (2010)\(^{*}\)    | < 5                                         | 0.75±0.13              |
| Arthur et al. (2011)             | 1                                           | 0.2                    |
| Marsh & Whitworth (2019)         | 1 - 3                                       | 0.23 - 0.42            |
| Zavagno et al. (2007)            | 3                                           | 0.4                    |
| Pavlyuchenkov et al. (2013)      | 3 - 10                                      | 0.17 - 0.32            |
| Akimkin et al. (2017)            | 1                                           | 0.26 - 0.63            |

Notes. In Martins et al. (2010), the estimation is obtained using isochrones.

We have to note that the normalization constants used in Whitworth et al. (1994) are extreme values, chosen to maximize the mass of the fragments. For the density normalization, a most realistic value proposed in the same work is 100 cm\(^{-3}\), used in Eq. 9, leading to a factor of 0.35 for \(t_{\text{frag}}\). Such \(n_0\) has been used by Palmeirim et al. (2017) for instance.

On first approximation, \(c_s\) depends on the temperature of the shell which is 28.3 K for region A based on CO observations, giving \(c_s = 0.3 \text{ km s}^{-1}\). However, this is a lower limit as turbulence and sub-Lyman radiation leaking through the PDR could enhance it. \(N_{\text{LyC}}\) does not have a lot of weight with respect to \(t_{\text{frag}}\), leading to a change of ±0.3 Myr for a difference of one order of magnitude. An increase will lower \(t_{\text{frag}}\) as the column density threshold necessary for fragmentation would be reached faster. The dependence of \(t_{\text{frag}}\) with respect to the mass of RCW 120 (equivalently, \(n_0\)) is plotted on Fig. 11. As for \(N_{\text{LyC}}\), a higher \(n_0\) decreases \(t_{\text{frag}}\) since the column density threshold is reached faster. We also computed \(t_{\text{frag}}\) using \(c_s = 0.2 - 0.4\) to quantify the difference.

For a mass of 2600 \(M_\odot\), \(t_{\text{frag}} = 0.5 - 0.7 - 0.8\) Myr (see Fig. 11). Since \(t_{\text{dyn}} < t_{\text{frag}}\), the C&C mechanism seems be the explanation for the fragmentation of the surrounding shell around the ionizing star. Simulations of Akimkin et al. (2017) and Zavagno et al. (2007) are also favorable to the C&C mechanism at a density of \(3 \times 10^3 \text{ cm}^{-3}\). However, Kirsanova et al. (2014) found the C&C mechanism to be unlikely unless the density reaches \(7 \times 10^4 \text{ cm}^{-3}\). This difference can explained by the choice of normalization for \(n_0\).

Indeed, the dynamical age in their work at \(\sim 3000 \text{ cm}^{-3}\) is 2 Myr, which would be reduced to 0.7 Myr with a normalization of 100 cm\(^{-3}\). The comparison of \(t_{\text{dyn}}\) and \(t_{\text{frag}}\) in this work would support the idea of triggering but, as we see in Tab. 4, the age of RCW 120 in the literature might be as low as 0.17 Myr, which would make the C&C inconsistent.

Dale et al. (2009) showed that, without pressure confinement, the thickness of the layer increases with time, as observed towards H\(\Pi\) bubbles (Churchwell et al. 2007), but the simulations do not agree with the thin shell approximation used in the analytical model. Additionally, the magnetic field should also be taken into account (Fukuda & Hanawa 2000).

Therefore, conclusions from this model, even if it supports the idea of triggered star-formation, must be taken with caution. Detailed analysis of the interplay between the H\(\Pi\) region and the PDR (Tremblin et al. 2014; Figueira et al. 2018; Zavagno et al. 2020) might be a better indicator but are also not exempt of some uncertainties (Dale et al. 2015) regarding to induced star-formation.

4.2.2. RDI process toward region B

Several works have studied the impact of the photoionization pressure on pre-existing clumps, inducing the formation of stars. The study of Urquhart et al. (2009) on a sample of 45 clouds (Sugitani et al. 1991; Sugitani & Ogura 1994) allow to understand the difference, in term of physical properties, between clouds where RDI is happening and where it is unlikely. For instance, an IBL through hydrogen recombination and a
PDR through PAH emission at 8 μm should be observed. As UV radiation should heat the cloud, $T_{ex}^{12}$ should be higher and higher than $T_{ex}^{18}$. Moreover, some clouds triggered by the RDI mechanism show multiple components in CO, indicative of shocked/moving gas. In term of stars, as the ionization front propagates into the clump, sequential star formation might be observed. Additionally, RDI is thought to be efficient, leading in priority to an high-mass star or a cluster of intermediate mass stars (Sugitani et al. 1991; Morgan et al. 2008) toward the center of the clump (Kessel-Deynet & Burkert 2003). Estimations of the turbulence from NH$_3$ (Morgan et al. 2010) showed a clear bimodality with a higher turbulence in the triggered sample of BRCs.

On the H$_\alpha$ observations from SHS (SuperCOSMOS H$\alpha$ Survey, Parker et al. 2005), the H$\alpha$ emission stops where the 8 μm emission is located but no clear IBL is observed, despite a high $n_e$. On the other hand, the curved rim is very well seen at 8 μm, tracing the PDR and indicating a strong interaction between the clump and the UV radiation. It should be noted that, as Herbig Ae/Be stars may be present in region B (source 24 and 28), the PAH present around them can be partially due to their own FUV radiation (Seok & Li 2017).

As discussed previously (see Tab. 2), $T_{ex}^{12}$ is found to be ~21 K on average which is in agreement with Urquhart et al. (2009) for the sample of triggered BRCs. The values of $T_{ex}^{18}$ are found to be quite similar to $T_{ex}^{12}$ which might be explained by evolved YSOs inside region B (Deharveng et al. 2009), heating the clump.

Several CO observations pointed out that multiple components, representing the dynamics, can be observed towards triggered BRCs. Different components (~12, ~10 and ~1 km s$^{-1}$) are observed toward region B (Fig. A.1) but likely correspond to cloud emission on the line of sight (see Fig. 11 of Anderson et al. 2015). We have to note that multiple components observations is not a requirement for star formation to be triggered by RDI process. The sample of southern BRCs studied by Urquhart et al. (2009) was classified between spontaneous and triggered candidates based on the association with a PDR or an IBL. SFOs 51 and 59, part of the spontaneous sample show multiple components but SFOs 64 and 65 show only a single component while being considered as triggered candidates.

Multiple components observations of YSOs in Deharveng et al. (2009), sources in region B are Class I-II (Deharveng et al. 2009) so star-formation is likely to be coeval in that clump. As the UV radiation interacts with the edge and propagates inside the clump, sequential star-formation or similar YSOs at the same location can be expected. From the analysis of the $L_{bol}$ vs $M_{env}$ diagram in Figueira et al. (2017), we also note that they are the most evolved YSOs in RCW 120 and were probably formed before the majority of the sources found in the PDR. This strengthens the idea that the clump in region B was pre-existing and star formation begins there when the rest of layer was still assembling.

The star formation efficiency is difficult to estimate since the stellar masses are not known. However, we can estimate the core formation efficiency (CFE) based on the mass of the cores and dust. Following Figueira et al. (2017), the total mass of the cores is 23 $M_\odot$ and the mass of the clump is between 90 and 200 $M_\odot$. The CFE varies between 12 and 26% and since part of the envelope will be swept away during the formation of the stars, the final star formation efficiency will be lower than these values. Toward the Cepheus B population, Getman et al. (2009) found that RDI is likely to have triggered star formation and that the SFE is between 35 and 55%, well above the values found for region B. In the case of RCW 120, the H$\alpha$ region interaction might have formed stars in a shorter time but no high SFE is observed.

We compared our results with the RDI simulations developed by Miao et al. (2009) and, in particular, the cloud A of the first set ($n_0 = 2672$ cm$^{-3}$, $R = 0.5$ pc). At the end of the simulations, the pressure of the clump is ~10$^6$ K cm$^{-3}$. A core is formed with a density 10$^5$ cm$^{-3}$, a temperature of 28 K, a mass of 15 $M_\odot$ and is found up to 0.3 pc from the surface layer. Compared to the region B, the pressure of the cloud is lower but may be due to the difference of initial density. Several cores have formed at the clump surface but we often observed multiple stars forming instead of one unique core at the top of the cloud if the BRC is not symmetrical (Sicilia-Aguilar et al. 2014). Regarding to the CFE, it rises to 38% and is well above the value of 12 to 26% estimated above.

Finally, the formation of the BRC into a A-type morphology and the collapse of the core takes about 0.4 Myr. This is in agreement since the dynamical age of RCW 120 is above this value. During the remaining 0.5 Myr after the formation of the BRC, the cores evolved into Class I-I YSOs/stars and the ionization pressure increases the density of the clump, leading to a higher clump pressure. As already found by Lelloch & Lazareff (1994), Miao et al. (2009) showed that clouds located closer to the ionizing source will evolve to a type-A BRC. This is in agreement with the slightly curved clump of region B.

Compared to the simulations of Kinnear et al. (2015), the time needed for the formation of a BRC is much lower (~0.1 Myr). However in that case, the total core mass produced is lower (~1.5$M_\odot$) and the resulting CFE is around 5%.

Simulations of Haworth et al. (2013) show a curved morphology of the CO distribution after the interaction with the H$\alpha$ region. This is observed at 8 μm but not in CO as the resolution might be too low (~18″). Depending on the strength of the ionizing flux and the viewing angle, the CO profiles can have multiple components, representing the dynamics of the clump. As we stressed before, CO profiles of triggered BRCs can show multiple components Urquhart et al. (2009); Morgan et al. (2009) but this is not a requirement as it can depend on the viewing angle and ionizing flux strength.

The variation of the line profile symmetry parameter δ (Mardones et al. 1997) was also studied as a function of the viewing angle. Considering the profile of $^{12}$CO and $^{13}$CO, we found $\delta \sim 0.2$, corresponding to an angle of ~20° which indicate that the ionizing star should be in front of the dusty ring. This is in agreement with the PAH emission at 8 μm which appears face on while it would be unobservable if UV emission was coming from behind, as stated by Urquhart et al. (2009).

5. Conclusions

In this work, we analysed the $^{12}$CO, $^{13}$CO and C$^{18}$O in the $J = 3 - 2$ molecular transition toward two sub-regions located in the PDR of the Galactic H$\alpha$ region RCW 120. The region A corresponds to a high-mass clump where young high-mass cores were detected with Herschel and ALMA while evolved low-mass YSOs were found in region B. Derivation of the velocity dispersion maps show an increase in both regions where star formation is observed and, assuming LTE, $T_{ex}$ is also found to increase toward the same locations. The estimated Mach number for both regions shows the supersonic motions inside the PDR, due to the impact of FUV and feedback from star-formation occurring there. The properties of the outflow toward the massive
Tremblin, P., Audit, E., Minier, V., Schmidt, W., & Schneider, N. 2012, A&A, 546, A33
Tremblin, P., Schneider, N., Minier, V., et al. 2014, A&A, 564, A106
Urquhart, J. S., Morgan, L. K., & Thompson, M. A. 2009, A&A, 497, 789
Urquhart, J. S., Thompson, M. A., Morgan, L. K., & White, G. J. 2004, A&A, 428, 723
van der Walt, D. J., Sobolev, A. M., & Butner, H. 2007, A&A, 464, 1015
Vazzano, M. M., Cappa, C. E., Rubio, M., et al. 2019, Rev. Mexicana Astron. Astrofis., 55, 289
Walch, S., Whitworth, A. P., Bisbas, T. G., Hubber, D. A., & Wünsch, R. 2015, MNRAS, 452, 2794
Ward-Thompson, D., Nutter, D., Bontemps, S., Whitworth, A., & Attwood, R. 2006, MNRAS, 369, 1201
Whitworth, A. P., Bhattal, A. S., Chapman, S. J., Disney, M. J., & Turner, J. A. 1994, MNRAS, 268, 291
Wolfire, M. G. & Cassinelli, J. P. 1987, ApJ, 319, 850
Wu, B., Tan, J. C., Nakamura, F., Christie, D., & Li, Q. 2018, PASJ, 70, S57
Xu, J.-L., Xu, Y., Yu, N., et al. 2017, ApJ, 849, 140
Xu, J.-L., Zavagno, A., Yu, N., et al. 2019, A&A, 627, A27
Yang, A. Y., Thompson, M. A., Urquhart, J. S., & Tian, W. W. 2018, ApJS, 235, 3
Zavagno, A., Andrés, P., Schuller, F., et al. 2020, arXiv e-prints, arXiv:2004.05604
Zavagno, A., Pomarès, M., Deharveng, L., et al. 2007, A&A, 472, 835
Zavagno, A., Russeil, D., Motte, F., et al. 2010, A&A, 518, L81
Appendix A: Pixel spectra

Fig. A.1: $^{12}\text{CO}$, $^{13}\text{CO}$ and $^{18}\text{O}$ spectra at each pixel of the maps toward regions A (first column) and B (second column). Pixel spectra have the same axis range within the same map but differ from one region and isotopologue to another. Pixels with white edges indicate where a second component is seen at $-15$ km s$^{-1}$. 