Onsala Proposal

Kirsanova 0108.F-9313

Timescale of the warm-up phase in massive young stellar objects

Semester: may2021 **Science Cat.: ISM and star formation**

Abstract

We propose to determine the gas temperature and density in massive young stellar objects (MYSOs) at the beginning of the hot core stage using spectral lines of complex organic molecules (COMs). These observations will allow us to create a benchmark data set for astrochemical models of a rare type of objects and to identify similar objects in future. We select three COMs, whose lines allow us to determine parameters of the dense gas in a molecular cloud with MYSOs (CH3OH), parameters of a warmed molecular envelope around a young hot core (CH3CCH) and in a hot core itself (CH3CN). Using abundances of the COMs in the cold gas without star formation and in the hot gas, we will test the chemical warm-up models to confine a timescale of that stage of high-mass star formation process. By comparing the model age with the timescale of the triggered star formation process we will check if external triggering is the driving factor for the formation of these unique MYSOs.

Applicants

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Is this a long term proposal: No

No overall scheduling requirements

Observing runs

run	telescope	instrument	time request (minimal)	frequency (GHz)	weather (pwv)	LST range	comments/constraints
A	APEX	nFLASH230 (200-270 GHz)	3h (3h)	243	any		
B	APEX	nFLASH230 (200-270 GHz)	6h (6h)	214	any		

Targets

Source	RA	Dec	Epoch	Vlsr (km/s)	Duration (min)	Runs	Comments
RCW 120	17:12:10.00	-38:31:25.0	J2000	-7.0	7	A B	

Scientific Rationale

We propose to determine the gas temperature and density in massive young stellar objects (MYSOs) at the beginning of the hot core stage using spectral lines of complex organic molecules (COMs). These observations will allow us to create a benchmark data set for astrochemical models of a rare type of objects and to identify similar objects in future. We select three COMs, whose lines allow us to determine parameters of the dense gas in a molecular cloud with MYSOs (CH_3OH, e. g. Kalenskii et al., 2002; Leurini et al., 2007), parameters of a warmed molecular envelope around a young hot core (CH_3CCH, e. g. Miettinen et al., 2006; Calcutt et al., 2019) and in a hot core itself (CH_3CN, e. g. Kalenskii et al., 2000; Beltrán et al., 2007). These molecules are synthesised mainly on dust grains and appear in the cold gas due to reactive desorption (Vasyunin et al., 2013) or thermal evaporation (Garrod et al., 2006). Using abundances of the COMs in the cold gas without star formation and in the hot gas, we will test the chemical warm-up models to confine a timescale of that stage of high-mass star formation process.

The importance of the proposed observations is related to the lack of knowledge about the initial stage of high-mass star formation process. One of the most massive and well-known dense gas condensations at the border of the H II region RCW 120 contains embedded MYSOs outside the photo-dissociation region (PDR) (Zavagno et al., 2007; Deharveng et al., 2009; Zavagno et al., 2010; Figueira et al., 2020). The most massive of them has $M = 8 - 10 M_\odot$ (Core 2 in Figueira et al. (2017), Core 2 below). The RCW 120 PDR has a ring-like shape, it was formed in a flattened molecular cloud (Anderson et al., 2015; Kirsanova et al., 2019; Zavagno et al., 2020). Therefore, the geometry of RCW 120 allows considering spatial separation of the interface between the PDR and molecular cloud (see Fig. 1). Zavagno et al. (2020) recently confirmed a compression by a shock wave from the H II region at the inner part of the shell using ArTeMiS. Tremblin et al. (2013) suggested that compression by the ionization front played a major role along with gravity in the Core 2 formation.

Recently Kirsanova et al. (2021) analysed emission of CH_3CN and CH_3OH molecules in the Core 2 and also in the second bright YSO, Core 1, in the same gas clump. They estimated gas physical parameters using methanol lines and obtained temperature < 100 K in both regions. They detected the CH_3CN lines corresponding to highly excited transitions ($E_\mathrm{u} > 400$ K) in Core 2, therefore the region might contain hot gas. Relatively low abundances of CH_3CN and CH_3OH molecules and also low CH_3CN/CH_3OH abundance ratio imply that Core 2 is at the warm-up phase prior to the establishing of the hot gas chemistry or at the beginning of the hot core phase. Core 1 might be at an even less evolved evolutionary stage. Therefore, RCW 120 is a suitable target to study the initial stage of massive star formation and also the feedback from the shock wave. By comparing the chemical model age with the timescale of the triggered star formation process (≈ 150000 years), determined for RCW 120 by Luisi et al. (2021), we will check if external triggering is the driving factor for the formation of these unique MYSOs.

We propose to map the entire molecular clump with MYSOs in CH_3OH emission lines and in lines of CH_3CCH and CH_3CN (see Fig. 3). Maps of the CH_3CN integrated emission at 3 mm (obtained as a part of MALT 90 survey Jackson et al., 2013) reveal emission of that molecule in the region of our interest (see Fig. 2). Unfortunately, the MALT 90 data have low signal-to-noise ratio which does not allow us to determine column densities of CH_3CN. Spectra, observed in separated positions by Kirsanova et al. (2021) do not allow us to obtain spatial distribution of the emission of CH_3OH and highly excited CH_3CN around Core 2. Comparison of the newly obtained CH_3CN and CH_3CCH spectra will allow us to study gas temperature and molecular abundances on the warmed extended envelope of the hot core(s) and build reliable physical model of the objects. Comparison of the CH_3CCH abundance with the abundance of SiO (obtained simultaneously with the main lines, see Table 1) will allow us to better confine the evolutionary stage of the hot core(s) as the CH_3CCH/SiO ratio increases with age (Miettinen et al., 2006). Moreover, we will be able to obtain spatial distribution of H_2CO molecules (see

	setup 1 $f = 214$ GHz USB	setup 2 $f = 244$ GHz LSB
signal	$CH_3CN(12_K\text{-}11_K)$, $CH_3CCH(13_K\text{-}12_K)$, SiO(5-4), H_2CO(3-2)	$CH_3OH(5_K\text{-}4_K)$, $C^{34}S$(5-4)
image	$CH_3CN(11_K\text{-}10_K)$, $CH_3CCH(12_K\text{-}11_K)$, $H_2C^{18}O$(3-2)	SiO(6-5)

Table 1: Frequency setup

Table 1) – precursors of CH_3OH and more complex organic molecules. Additional maps of the SiO emission will be used together with the methanol emission maps to find molecular outflows (see the extended line wings in Fig. 1) and obtain the SiO and methanol abundance there.

Facilities Requested

APEX telescope is the only one single-dish telescope on the southern sky, which can be used to resolve the compressed molecular shell in RCW 120 thanks to the possibility to observe at high frequencies.

Observing Requirements

We have used the OTF observing time calculator at APEX V9.3 to estimate the total time needed to achieve our goal. We plan to do an OTF of 140 x 85 arcsec (see the area in Fig. 3) and for the calculation we assume a dumptime of 1 seconds and a sampling corresponding to 1/3 of the beam. According to Kirsanova et al. (2021), noise level of 14 mK[Ta*] is sufficient for the CH_3CN lines, but the methanol lines are brighter, therefore our goals can be achieved with higher noise level of 20 mK[Ta*].

Using NFLASH230 tuned to 243 GHz in the LSB (setup 1), selecting a spectral resolution of 0.3 km s^{-1} and assuming a typical source elevation of 45 deg and a typical PWV of 2.0 mm, we could get down to a noise of 20 mK[Ta*] in 3.34 hours (including telescope and calibration overheads). Using NFLASH230 tuned to 214 GHz in the USB (setup 2), selecting a spectral resolution of 0.3 km s^{-1} and assuming a typical source elevation of 45 deg and a typical PWV of 2.0 mm, we could get down to a noise of 14 mK[Ta*] in 6.4 hours (including telescope and calibration overheads).

Therefore, the total program requires $\approx$ 10 hours (including telescope and calibration overheads).

References

• Anderson L.D. et al., ApJ, 800, 101, 2015 • Beltrán M. T. et al., A&A, 615, 141, 2018 • Calcutt H. et al., A&A, 631, 137, 2019 • Deharveng L. et al., A&A, 496, 177, 2009 • Figueira M. et al., A&A, 600, A93, 2017 • Figueira M. et al., A&A, 639, 93F, 2020 • Garrod R., Herbst E., A&A, 457, 927, 2006 • Jackson S. V. et al., PASA, 30, 57, 2013 • Kalenskii S. V. et al., ARep, 44, 725, 2000 • Kalenskii S. V. et al., ARep, 46, 96, 2002 • Kirsanova M. S. et al., MNRAS, 488, 5641, 2019 • Kirsanova M. S. et al., MNRAS, 503, 633, 2021 • Leurini S. et al., A&A, 466, 215, 2007 • Luisi M. et al., Science Advances, 7, 15, 2021 • Miettinen O. et al., A&A, 460, 721, 2006 • Tremblin P. et al., A&A, 564, A106, 2014 • Vasyunin A. I., Herbst E., ApJ, 769, 34, 2013 • Zavagno A., A&A, 472, 835, 2007 • Zavagno A., A&A, 518, 81, 2010 • Zavagno A. et al., A&A, 638, 7Z, 2020

Figures

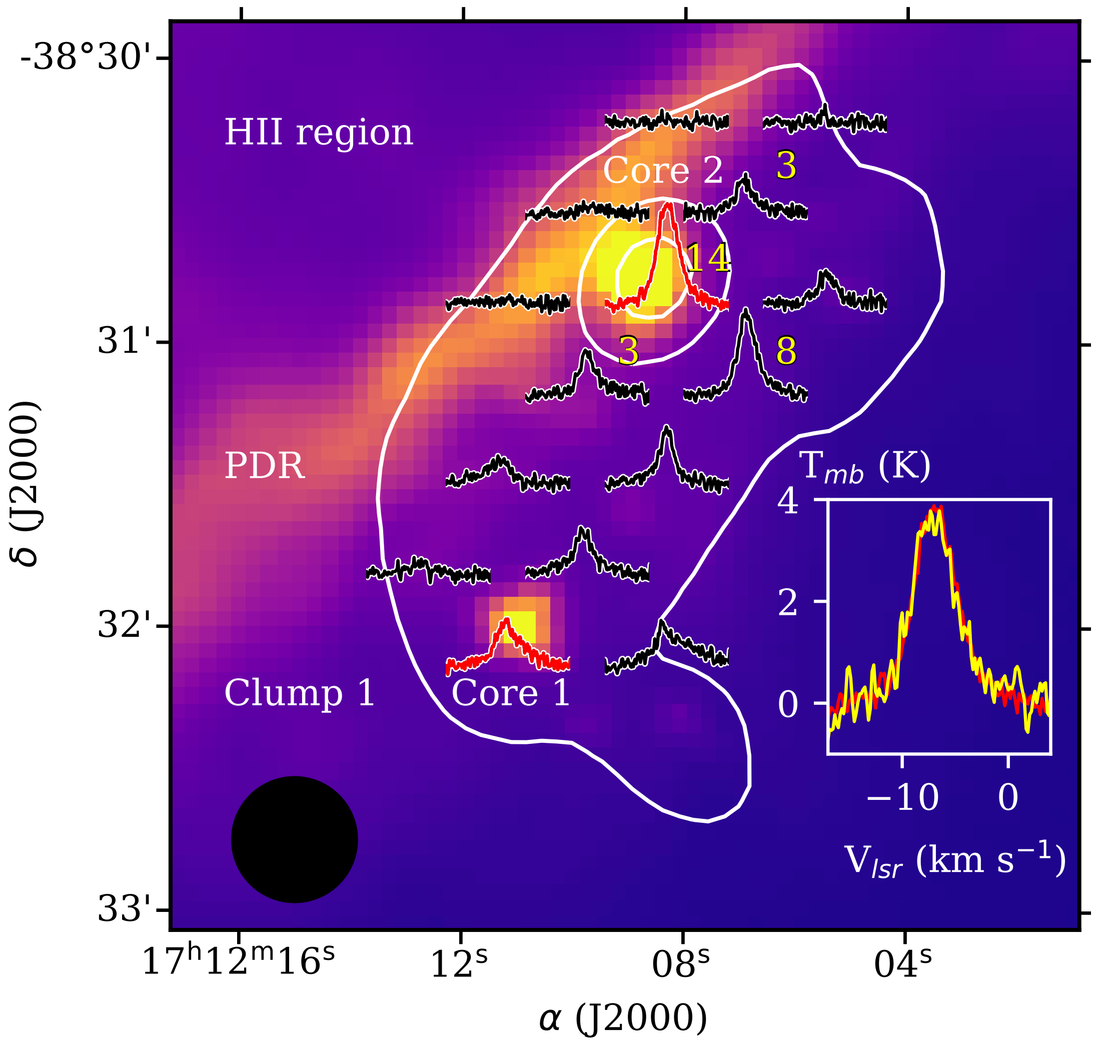

Figure 1: *Herschel* image of the south-west border of RCW 120 at 70 μm and ATLASGAL 870 contours for 1, 5 and 10 Jy beam^{-1} are shown in orange. The methanol spectra at 241791.431 MHz in the observed positions are shown by black. The spectra towards Core 1 and Core 2 are shown by red colour. The methanol line (red) and the (5–4) line (yellow, multiplied by a factor of 20) are also shown towards Core 2 are shown in the separate bottom frame. The line brightness and the velocity scales are shown on the frame for the spectrum towards source 2. The numbers above four of eight spectra show N_{CS} in units cm^{-2}/10^{13}. The figure is from Kirsanova et al. (2021).

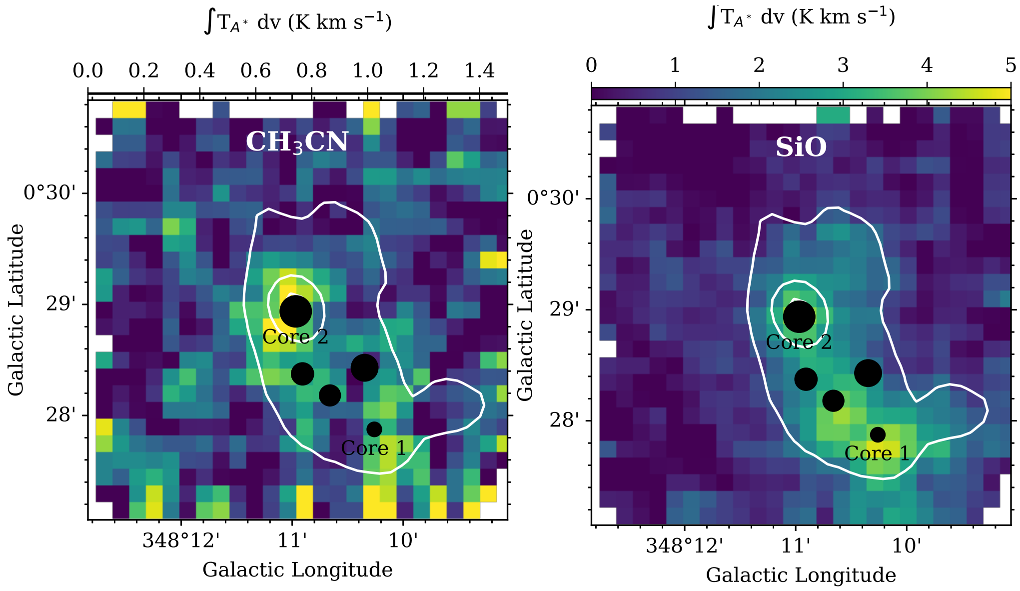

Figure 2: Integrated intensities of CH_3CN and SiO emission lines at 3 mm from MALT 90 survey. ATLASGAL 870 contours for 1, 5 and 10 Jy beam^{-1} are shown in white. Black circles represent young stellar objects, where size of circle is proportional to the mass of the object.

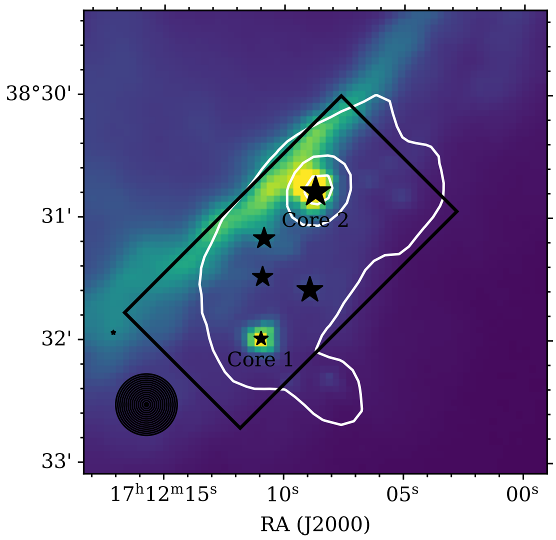

Figure 3: *Herschel* image of the south-west border of RCW 120 at 70 μm and ATLASGAL 870 contours. The proposed area is shown by black rectangle. The telescope beam at 200 GHz is shown by black circle. Black stars represent young stellar objects, where size of symbol is proportional to the mass of the object.

No PhD Students involved

Linked proposal submitted to this TAC: Yes

0107.F-9318, the proposal was approved but has not observed yet. We asked about 30 min to observe 13CO(6-5) at the position of shock wave in the RCW 120 PDR.

Linked proposal submitted to other TACs: Yes

ESO cycle 108, proposal # 108.22HL, spectral line survey at the positions of Core 1 and Core 2. We proposed deep integrations down to the noise level of 6 mK[Ta*] at the two selected positions in order to detect the high excitation CH3CN lines (with E_up > 400K). The ESO project does not contain maps in contrast with this project. The ESO project is independent from the current one. While the ESO proposal can enhance the breadth of the study of RCW120, we emphasize that the success of the project proposed here does not depend on the outcome of other observations.

Relevant previous Allocations: Yes

0103.F-9301, 2 hours, we found a thin layer of shocked gas visible in the CO(6-5) line, publication is in preparation. We also asked about the map of 13CO(6-5), but the line was not observed. Therefore, we submitted the project 0107.F-9318.

Additional remarks

Related publications: Kirsanova M. S. et al., MNRAS,488, 5641, 2019; Kirsanova M. S. et al., MNRAS, 503, 633, 2021; ESO=kirsanova

Observing run info :