Studying a hot molecular core embedded in a photodissociation region

N.C. Martinez¹,², M.B. Areal¹ & S. Paron¹

¹ Instituto de Astronomía y Física del Espacio, CONICET–UBA, Argentina
² Facultad de Ciencias Exactas y Naturales, UBA, Argentina

Contact / ncmarsan@gmail.com

Resumen / En el primer cuadrante de nuestra galaxia, en l = 33°134, b = −0°091, aparece una extensa región de fotodisociación generada por un complejo de regiones HII. Asociado a esta región se encuentra gran cantidad de gas molecular con grumos en su interior. Embebido en uno de ellos, se localiza un núcleo molecular caliente conocido como G33.133-mm3. Utilizando datos del James Clerk Maxwell Telescope (resolución angular de ∼15″), se estudió el cociente de abundancia ¹³CO/C¹⁸O hacia el grumo molecular mencionado, y su relación con la radiación ultravioleta. Luego, en una escala espacial más pequeña, utilizando datos del Atacama Large Millimeter Array (resolución angular de 0.7″) se caracterizó al núcleo molecular G33.133-mm3, el cual posee un tamaño de ∼2600 ua y es un sitio propicio para la formación de estrellas. En particular, se mencionan algunos puntos sobre su química en base a la emisión del radical nitrilo (CN) y de las moléculas más complejas CH₃OH, CH₃CN, CH₃OCHO, y CH₃CCH.

Abstract / At the first Galactic quadrant, at l = 33°134, b = −0°091, an extended photodissociation region generated by an HII region complex lies. This region is related to abundant molecular gas, and particularly, a hot molecular core, known as G33.133-mm3, appears embedded in a molecular clump. Using data from the James Clerk Maxwell Telescope with an angular resolution of about 15″, we studied the ¹³CO/C¹⁸O abundance ratio towards the mentioned molecular clump and its relation with the ultraviolet radiation. At smaller spatial scales, using data from the Atacama Large Millimeter Array (angular resolution about 0.7″), the hot molecular core G33.133-mm3, that has a size of about 2600 au, and is an appropriate site to form stars, was characterized. In particular, some points about its chemistry are mentioned based on the emission of the cyanide or nitrile radical (CN) and others more complex molecules, such as CH₃OH, CH₃CN, CH₃OCHO, and CH₃CCH.

Keywords / ISM: clouds — (ISM:) HII regions — ISM: molecules — stars: formation

1. Introduction
Hot molecular cores (HMCs) are compact (≤0.1 pc), dense (10⁵−10⁸ cm⁻³), and massive (∼100 M☉) molecular structures related to the earliest phases of high-mass star formation (e.g. Beuther et al. 2007; Motte et al. 2018). HMCs are usually embedded in molecular clouds and filaments (Rathborne et al. 2006; Lu et al. 2018), which in turn can be related to photodissociation regions (PDRs), when complex of HII regions are in the vicinity. Additionally, HMCs are the richest reservoirs of complex organic molecules in the Galaxy, including key species for prebiotic processes (Beltrán & Rivilla, 2018).

2. Presentation of the studied HMC
The HMC G33.133-mm3, with a size of about 2600 au (Paron et al. 2021) is located at a distance of 4.5 kpc and it appears embedded in an extended PDR. G33.133-mm3 is part of a complex of at least four HMCs, suggesting that fragmentation processes of a molecular clump are on going in the region. Figure 1 displays the 8 μm emission obtained from the GLIMPSE/Spitzer survey.

Figure 1: 8 μm emission showing an extended photodissociation regions generated by a complex of HII regions. The position of the HMCs complex (G33.133-mm) is indicated.

Showing the PDRs and the position where the HMCs are located (named G33.133-mm). Given to the location of the HMCs, it is interesting to study the ¹³CO/C¹⁸O abundance ratio, as done for instance by Areal et al. (2018) in many sources, because it gives us informa-
Molecules in a hot molecular core

Table 1: Parameters from the CO isotopes emission at the region where G33.133-mm3 is embedded.

| T_{ex} | \tau_{13} | \tau_{18} | N_{13}  | N_{18}  | X_{13/18} |
|--------|----------|----------|--------|--------|-----------|
| (K)    | (cm^{-2})| (cm^{-2})| (cm^{-2})|        |           |
| 14     | 0.7      | 0.3      | 1.67 \times 10^{16} | 0.43 \times 10^{16} | 3.8       |


3. Data

We used molecular data of the \(^{12}\text{CO}, ^{13}\text{CO}\) and \(C^{18}\text{O}\) J=3–2 emission obtained from the public surveys generated by the 15-m James Clerk Maxwell Telescope: \(^{12}\text{CO}\) J=3–2 data was obtained from the COHRS survey (Dempsey et al., 2013), while the data of the other isotopes were extracted from the CHIMPS survey (Rigby et al., 2016). The angular resolution of the data from each survey is 15'' and 14'', respectively. The higher angular resolution data were obtained from the ALMA Science Archive. We used data from the project 2015.1.01312.S, that was observed in the ALMA Cycle 3 in configurations C36-2 and C36-3 in the 12 m array, at Band 6. We used the calibrated data which passed the second level of Quality Assurance (QA2). The angular resolution of this data set is about 0.7'', and the spectral resolution is 1.13 MHz.

4. Results

4.1. The \(^{13}\text{CO}/C^{18}\text{O}\) abundance ratio

Figure 2 displays spectra of the CO isotopes obtained towards the molecular clump in which G33.133-mm3 is embedded. Given to the data beam size and considering the distance to the region, these spectra are probing molecular gas at a spatial scale of about 0.3 pc. By assuming local thermodynamic equilibrium (LTE), and following the typical formulae (see for instance Areal et al., 2018) we calculate the \(^{13}\text{CO}\) and \(C^{18}\text{O}\) column densities (\(N_{13}\) and \(N_{18}\)) at the position of G33.133-mm3 to obtain the \(^{13}\text{CO}/C^{18}\text{O}\) abundance ratio (\(X_{13/18} = N_{13}/N_{18}\)). The obtained results, including the excitation temperature (\(T_{ex}\)) and the optical depths (\(\tau\)) are presented in Table 1. The obtained \(X_{13/18}\) is compatible with values obtained at the borders of the densest regions within molecular clouds active in high-mass star formation (Paron et al., 2018). This ratio could be mapping the external gaseous layers of the dense clump in which G33.133-mm3 and others cores are embedded, where the ultraviolet radiation, responsible of the PDRs, is impinging.

4.2. Complex molecules in G33.133-mm3

Figure 3 displays spectra of the complex molecules detected towards the HMC G33.133-mm3 from the ALMA data. These spectra are probing gas at a spatial scale of about 0.02 pc. After converting the observed frequency

---

**http://almascience.eso.org/aq/**
to rest frequency, and following the NIST database, molecular species and their transitions were determined. They are indicated in the Figure 3.

![Figure 3: Spectra of the complex molecules detected towards G33.133-mm3.](image)

From the ALMA data set, molecules such as methanol (CH$_3$OH), methyl formate (CH$_3$OCHO), and acetonitrile (CH$_3$CN) were detected. Additionally, in the spectrum of CH$_3$CN, emission of propyne (CH$_3$CCH) is also observed, while in the CH$_3$OCHO spectrum, it is also observed emission from the nitrile or cyanide radical (CN$^-$$)$. The emission of these molecular species confirms the presence of high density gas, which is in agreement with the $X^{13/18}$ value discussed above. The observation of CN$^-$ at G33.133-mm3 encouraged the analysis of this radical towards a sample of HMCs presented in [Paron et al. (2021)], in which it was concluded that the presence of CN$^-$ seems to be ubiquitous along the different star formation stages.

It is known that CH$_3$CN, CH$_3$OCHO, and CH$_3$OH are well tracers of hot molecular cores/corinos (e.g. Areal et al. 2020). These complex molecular species form in the dust grain surfaces, and when the temperature increases, they thermally desorb from the dust. Particularly, when the temperature of a molecular core reaches about 90 K, CH$_3$OH thermally desorbs from the grain mantles, and its gas-phase abundance is enhanced close to the protostars (Brown & Bolina 2007). In the case of propyne, this molecular species is formed on the grain surface through successive hydrogenation of physisorbed C$_3$ (Hickson et al., 2016), and it is an important molecule for large comparison studies of chemical diversity among star-forming regions (Taniguchi et al., 2018).

G33.133-mm3 is part of a large sample of HCMs whose chemistry and their relation with star-forming processes will be studied in future works by this group.

Acknowledgements: This work was partially supported by grants PICT 2015-1759 - ANPCYT, and PIP 2021 1122020100012 - CONICET. The authors, specially N.C.M., thank to the scientific committee of the Asociación Argentina de Astronomía (AAA) Annual Meeting for the mention given to the poster presented during the meeting. These results are part of the work done by N.C.M. during the 2021 summer AAA fellowship program.

References

Areal M.B., et al., 2018, A&A, 612, A117
Areal M.B., et al., 2020, A&A, 641, A104
Beltrán M.T., Rivilla V.M., 2018, E. Murphy (Ed.), Science with a Next Generation Very Large Array, Astronomical Society of the Pacific Conference Series, vol. 517, 249
Beuther H., et al., 2007, B. Reipurth, D. Jewitt, K. Keil (Eds.), Protostars and Planets V, 165
Brown W.A., Bolina A.S., 2007, MNRAS, 374, 1006
Dempsey J.T., Thomas H.S., Currie M.J., 2013, ApJS, 209, 8
Hickson K.M., Wakelam V., Loison J.C., 2016, Molecular Astrophysics, 3, 1
Lu X., et al., 2018, ApJ, 855, 9
Molet J., et al., 2019, A&A, 626, A132
Motte F., Bontemps S., Louvet F., 2018, ARA&A, 56, 41
Paron S., Areal M.B., Ortega M.E., 2018, A&A, 617, A14
Paron S., et al., 2021, A&A, 653, A77
Rathborne J.M., Jackson J.M., Simon R., 2006, ApJ, 641, 389
Rigby A.J., et al., 2016, MNRAS, 456, 2885
Taniguchi K., et al., 2018, ApJ, 866, 150