Fragmentation and molecular outflows in the IRDC core G34.43+00.24 MM1

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Resumen / La fragmentación de grumos de alta masa en los interiores de las nubes moleculares puede dar lugar a la generación de estrellas de alta masa. La nube molecular oscura en el infrarrojo G34.43+00.24, de morfología filamentaria, está ubicada a una distancia aproximadamente de 3.6 kpc. Dicha nube contiene al menos nueve núcleos moleculares denominados MM1 hasta MM9, los cuales se encuentran en distintas etapas evolutivas de formación estelar. En este trabajo se presenta un estudio de la estructura interna del núcleo MM1 llevado a cabo con observaciones de alta resolución angular a 93 GHz obtenidas de la base de datos de ALMA. En el continuo de radio se encontró evidencia de fragmentación del núcleo y en la emisión del HCO^+ J=1–0 se confirmó, con la mejor resolución angular hasta el momento, la presencia de dos outflows moleculares perpendiculares surgiendo de MM1.

Abstract / Massive star formation takes place in molecular hot cores which are the result of the fragmentation of massive clumps. The infrared dark cloud G34.43+00.24, which exhibits a filamentary structure, is located at a distance of about 3.6 kpc. This cloud harbours nine molecular cores, named MM1 through MM9, at different evolutionary stages. This work presents a study of the internal structure of the core MM1 carried out with high angular resolution observations at 93 GHz obtained from the ALMA database. The radio continuum emission shows signatures of fragmentation of the core, and the HCO^+ J=1–0 emission confirms, with the better angular resolution at the present, the presence of two perpendicular molecular outflows arising from MM1.

Keywords / stars: formation — ISM: molecules — ISM: jets and outflows — ISM: individual objects (G34.43+00.24)

1. Introduction

The infrared dark clouds (IRDC) are identified as filamentary silhouettes against the mid-infrared background emission (Simon et al., 2006). They usually harbour objects at different stages of massive star formation, for instance the hot molecular cores (HMCs) (Rathborne et al., 2006). HMCs are massive molecular cores internally heated by the activity of a massive protostar, which exhibit molecular outflow activity and some of them, in their last evolutionary stages, are associated with ultra-compact HII regions (Hernández-Hernández et al., 2014, and references therein).

The IRDC G34.43+00.24, which is located at a kinematic distance of about 3.6 kpc (Tang et al., 2019), harbours nine molecular cores, named MM1 through MM9, at different evolutionary stages (Chen et al., 2011). In particular, evidence of molecular outflows was found towards MM1, MM2, and MM3 (Shepherd et al., 2007; Sanhueza et al., 2010). Shepherd et al. (2004) detected marginally radio continuum emission at 6 cm towards MM1, in agreement with a massive B2 spectral type embedded protostar. On the other hand, several authors, (e.g., Rathborne et al., 2008; Tang et al., 2019), have discussed the absence of fragmentation towards MM1.

In this work, we present a preliminary morphological study of the molecular core MM1 using high angular resolution data at 93 GHz, obtained from the ALMA Science Archive in order to better characterize its internal structure.

2. Data

Data cube with central frequency at 93 GHz was obtained from the ALMA Science Archive* (Project code: #2015.1.00369.S) to analyze the core G34–MM1. The Common Astronomy Software Applications (CASA) package was used to handle and analyse the data. Table 1 presents the main data parameters. The observations were carried out using the following telescope configuration: Min/Max Baseline(m) of 150/460.

The beam size of the 93 GHz data cube provides a spatial resolution of about 0.03 pc ($\sim$ 6000 au) at the distance of 3.6 kpc.

Table 1: Main data parameters.

	beam size (arcsec)	FoV ($arcsec^2$)	Δv km s^{-1}	rms Noise (mJy $beam^{-1}$)
Cont. 93 GHz	2.1 × 1.4	45×45	-	0.3
HCO^+ J=1–0	1.9 × 1.4	45×45	1.5	5.0

*http://almascience.eso.org/aq/

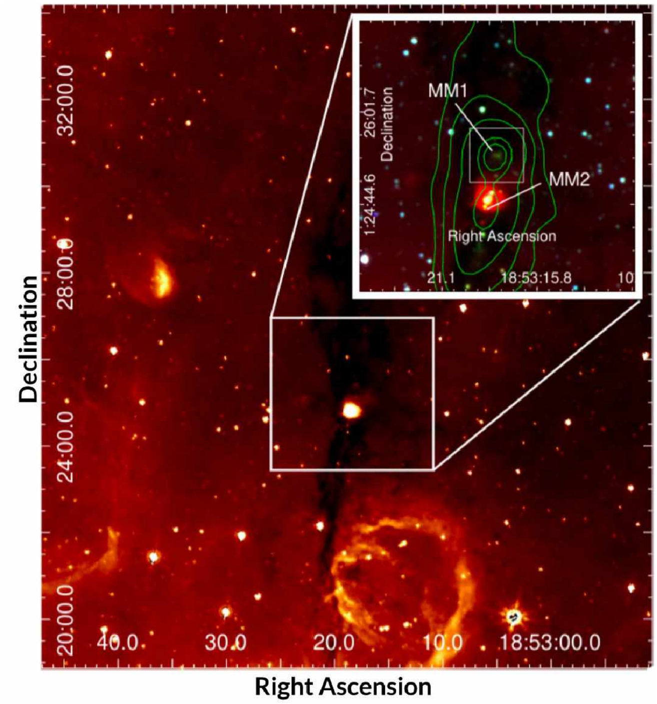

Figure 1: IRDC G34.43+00.24 as seen at 8 μm (from the Spitzer Telescope). The close-up view shows a GLIMPSE three-color image (3.6, 4.5, and 8 μm, in blue, green, and red, respectively) of the core MM1. The green contours represent the ATLASGAL emission at 870 μm. Levels are at 0.4, 0.7, 1.5, 2.5, and 4.5 Jy beam^{-1}. The white box in the close-up view indicated the region mapped at 93 GHz. (See data the APEX Telescope Large Area Survey of the Galaxy (ATLASGAL) in `https://atlasgal.mpifr-bonn.mpg.de/cgi-bin/ATLASGALDATABASE.cgi`).

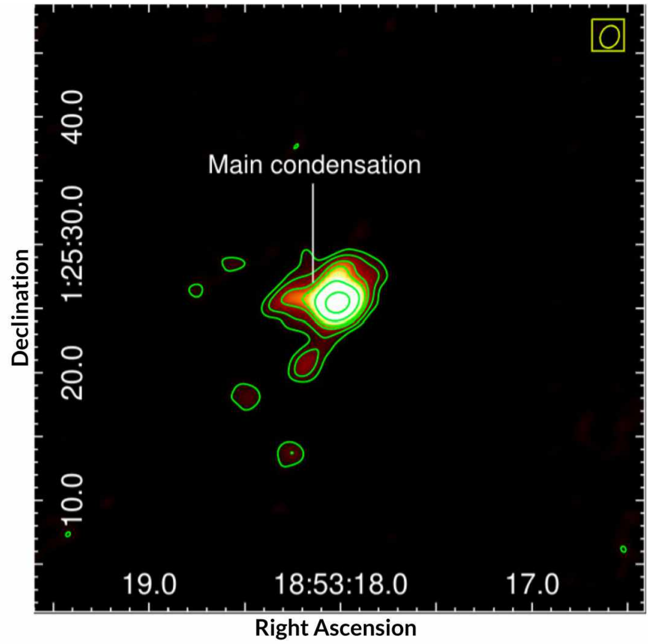

Figure 2: Continuum emission at 93 GHz. The contours levels are at 1, 2, 4, 5, 12, 30 mJy beam^{-1}. The beam is indicated at the top right corner.

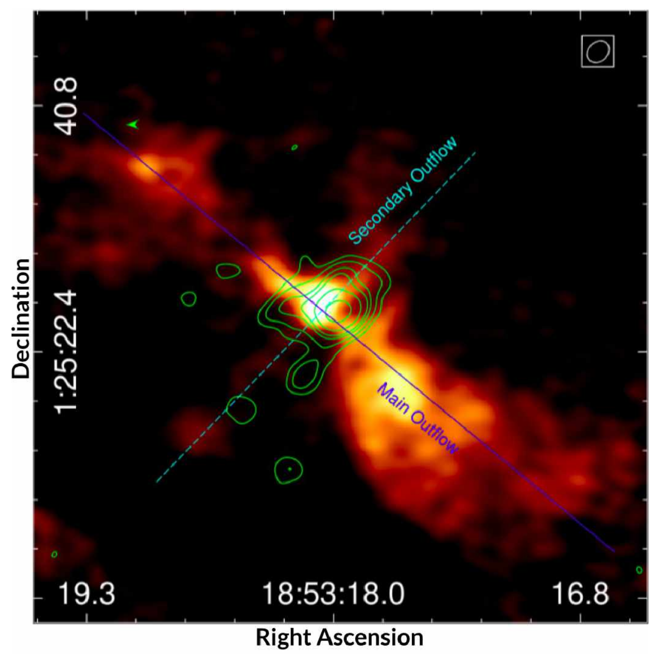

Figure 3: Map of the HCO^+ J=1–0 emission distribution integrated between 40 and 75 km s^{-1}. Green contours represent the continuum emission at 93 GHz. Levels are at 1, 2, 4, 5, 12, 30 mJy beam^{-1}. The beam is indicated at the top right corner.

3. Results

Figure 1 shows the IRDC G34.43+00.24 as seen at 8 μm. The close-up view shows a GLIMPSE** three-color image (3.6 μm in blue, 4.5 μm in green, and 8 μm in red) of the core MM1. The core MM1 exhibits conspicuous extended emission at 4.5 μm, which suggests the presence of molecular outflow activity.

Figure 2 shows the radio continuum emission at 93 GHz. A main dust condensation can be appreciated, which exhibits a conspicuous bulge towards the east, and it seems to be connected to a smaller condensation that extends to the southeast. There are also four minor condensations which appear detached from the main core and are located eastwards (marginally detected) and towards the southeast.

Figure 3 shows the HCO^+ J=1–0 emission integrated between 40 and 75 km s^{-1}. The peak of the continuum emission at 93 GHz appears to be shifted about 2″ from the peak of the integrated HCO^+ J=1–0 emission. Considering that the HCO^+ emission usually traces molecular outflows (e.g. Rawlings et al. 2004) and taking into account the morphology of the emission, we suggest that what it is displayed in Fig. 3 shows the presence of two perpendicular outflows arising from MM1 main dust condensation.

These molecular outflows may correspond to those previously detected at lower angular resolution ($\approx$ 4″) by Shepherd et al. (2007) using the ^{12}CO J=1–0 tran-

**Galactic Legacy Infrared Mid-Plane Survey Extraordinaire,`http://www.astro.wisc.edu/glimpse/glimpsedata.html`.

sition. The main molecular outflows extend in the southwest-northeast direction, and exhibit an asymmetric morphology with respect to its lobes. In particular, they reveal a lower degree of collimation than the secondary and perpendicular molecular outflows, which extend from southeast to northwest. These secondary outflows also show a striking asymmetry between its lobes, with the southeastern one exhibiting a discontinuous structure composed by at least two fragments.

4. Discussion and further work

The IRDC core G34.43+00.24 MM1 was studied using the continuum emission at 93 GHz, from which different condensations were observed, strongly suggesting that fragmentation processes have occurred in G34–MM1. The core also presents emission in the HCO^+ J=1–0 line, showing the presence of a molecular counterpart of the continuum main condensation, together with two perpendicular associated molecular outflows. These outflows coincide with what was detected in previous studies.

Further studies will include an analysis of the radio continuum emission and molecular lines at 334 GHz with an angular resolution of about $0.7''$. The better angular resolution of these observations will allow us to discern the origin of each molecular outflows and identify a possible internal fragmentation of the main dust condensation.

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