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# Identification of organic molecules in the protostellar region NGC 1333-IRAS 4A

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**Abstract.** Here we present the first results of the survey in the protostellar region NGC 1333-IRAS 4A. This object shows the presence of a variety of complexe organic molecules (COMs), such as: $CH_3CCH$, c-$C_3H_2$, $CH_3HOH$, $H_2CCO$, $CH_3OH$ and $HC_3N$. We confirm the detection of COMs and molecules of pre-biotic interest, such as: PN, methyl formate ($HCOOCH_3$), dimethyl ether ($CH_3OCH_3$), formic acid (HCOOH) and acetonitrile ($CH_3CN$). Given the wide range of detected transitions, it is possible to construct the rotational diagrams by estimating the excitation temperatures and column densities of each of these species. The identification of a wide variety of molecules containing C and O, as well as S, N, and P atoms indicates a chemical complexity increase in these so-called "hot cores" objects, for having relatively heated environments (T > 100 K) and high densities.

**Resumo.** Apresentamos os primeiros resultados do survey feito na região protoestelar NGC 1333-IRAS 4A. Este objeto mostra a presença de uma grande variedade de moléculas orgânicas, como: $CH_3CCH$, c-$C_3H_2$, $CH_3HOH$, $H_2CCO$, $CH_3OH$ e$HC_3N$. Confirmamos a detecção de COMs e moléculas com interesse prebiótico, como: PN, formiato de metila ($HCOOCH_3$), dimetil éter ($CH_3OCH_3$), ácido fórmico (HCOOH) e acetonitrila ($CH_3CN$). Dada a ampla gama de transições detectadas, é possível construir os diagramas de rotação estimando as temperaturas de excitação e as densidades colunares de cada uma dessas espécies. A identificação de uma grande variedade de moléculas contendo C e O, além de S, N e P, é indicadora do aumento na complexidade química nesses objetos nomeados de "núcleos quentes", por se tratarem de ambientes relativamente aquecidos (T> 100 K) e apresentarem altas densidades.

**Keywords.** physical data and processes: astrochemistry — ISM: singular object IRAS 4A — Molecules: abundances — Stars: formation

## 1. Introduction

The low-mass class 0 protostellar object NGC 1333 IRAS 4A is a binary source located in the Perseus molecular complex, at the distance of 235 pc. The two components, IRAS 4A1 and IRAS 4A2, have a separation of only about 1.8" (~ 420 AU) and a total luminosity of a few solar luminosities. The IRAS 4A system is associated with a spectacular large-scale (a few arcminutes) bipolar molecular outflow. High-angular resolution observations by Santangelo et al. 2014 have disentangled two distinct molecular jets powered by each of the two components. IRAS 4A is the second hot core protostar identified after IRAS 16293-2422 (Bottinelli et al. 2007). The identification of complex organic molecules (COMs) is of great importance in the study of the first stages of the formation of low mass stellar objects (Taquet et al. 2015). In this work, the molecular content of IRAS 4A was investigated as part of the Large Program ASAI[1] (PIs: B. Lefloch and R. Bachiller), carrying out a highly sensitive, unbiased survey of the spectral windows 72-115GHz, 130-172 GHz, 205-272 GHz using the IRAM 30m telescope (Sierra Nevada, Spain).

## 2. Methodology and Results

Spectral line surveys of the source were carried out with the IRAM 30m telescope over six semesters from September 2012 to March 2015, using the broad-band EMIR receivers E090, E150 and E230, connected to the Fast Fourier Transform Spectrometers (FTS) either in the high (50 kHz) or low (200 kHz) spectral resolution mode. The 3mm (72–116 GHz) and 2mm (126–170 GHz) bands were observed simultaneously. The 1mm (200-276 GHz) band was covered observing both LSB and USB simultaneously using the FTS in its 200 kHz resolution mode. We used the CASSIS software (Vastel et al. 2015) for the line identification, using the CDMS and JPL databases, considering all the lines detected with an intensity higher than $3\sigma$. The diversity of spectral signatures reflects the diversity of excitation and chemical conditions among the source. We examine here the molecular content based on the molecular line identification in the 1, 2 and 3mm bands.

The spectra exhibit many different molecular lines with presences of isotopologues, reflecting the evolutionary stage and the physical conditions of the source. This is illustrated in Figure 1, which displays the emission in the spectral bands 86–89.5 GHz (top), 144–147 GHz (center), 250.25–252.75 GHz (bottom). In this context, the number of detected isotopologues and molecular lines are indicators of the excitation conditions, whereas the number of main isotopologues traces the molecular complexity of the source (see Table 1).

### 2.1. Carbon chains

We identifided carbon chains of the polyyne type, with a maximum of 4 carbon atoms. Both linear and cyclic conformations of these species were observed. In addition, it was also observed that the number of identified lines is higher for hydrogen-rich carbon chains (see Table 2). Furthemore, the identification of isopologues species is an indicative of the presence of the deuterated fossil stage (Codella et al. 2012) in the outflowing gas (see Table 1).

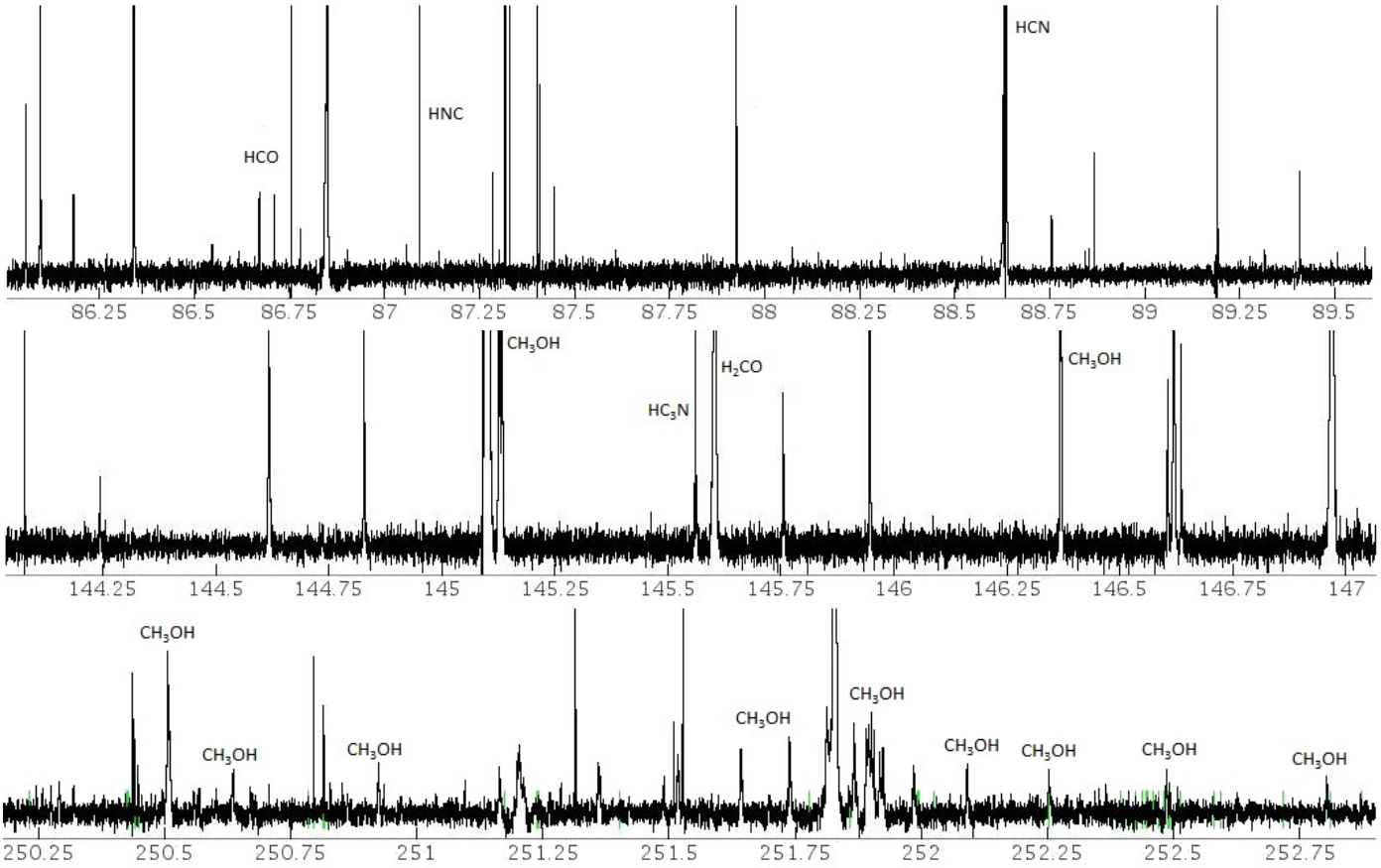


**Figure 1.** Example of molecular line emission detected with ASAI in IRAS 4A in the spectral bands 86–89.5 GHz (top), 144–147 GHz (center), 250.25–252.75 GHz (bottom)

**Table 1.** Number of lines identified for each species (selected isotopologues included) per spectral band. The identified species were distributed in four groups according to the main atom. Being observed that oxygenated species are dominant in the three spectral bands studied in IRAS 4A. The $\xi$ letter denotes S, Si and P.

| Species | 3mm | 2mm | 1mm | Total |
|---|---|---|---|---|
| O-bearing | 55 | 85 | 104 | 244 |
| N-bearing | 13 | 1 | 25 | 39 |
| C-bearing | 30 | 27 | 48 | 105 |
| $\xi$-bearing | 5 | 9 | 11 | 25 |
| *Isotopologues* | | | | |
| $D_2CO$ | 1 | 1 | 5 | 7 |
| $DCO^+$ | - | 1 | 1 | 2 |
| $^{13}CH_3OH$ | 9 | 8 | 14 | 31 |
| $^{34}SO$ | 3 | 3 | 5 | 11 |
| c-$C_3HD$ | 4 | 5 | - | 9 |

## 3. Conclusions

The number of identified lines in the source shows that IRAS 4A is a region dominated by O-bearing species, which is characteristic of a hot core. Polyyne species with up to 4 carbons were identified, showing an upper limit to their abundances, x, of $10^{-11}$ to $10^{-13}$. Our preliminary results show that the source IRAS 4A is rich in complex organic molecules, species that play an important role in the formation of pre-biotic molecules in young objects.

**Table 2.** Carbon chains identified per spectral band and the results obtained from the Rotational Diagram.The x letter denotes the relative abundances with respect $H_2$ assuming an $H_2$ column density in the hot core of N($H_2$)= $1.6x10^{24}$ $cm^2$ (Bottinelli et al 2004)

| Species | Total lines | $T_{ex}$ (K) | N ($cm^2$) | x |
|---|---|---|---|---|
| $C_2H$ | 11 | 5.3 | $1.4x10^{14}$ | $8.8x10^{-11}$ |
| c-$C_3H$ | 15 | 6.5 | $1.9x10^{12}$ | $1.2x10^{-12}$ |
| l-$C_3H$ | 9 | 5.9 | $5.9x10^{11}$ | $3.7x10^{-13}$ |
| $C_4H$ | 8 | 5.5 | $6.2x10^{13}$ | $3.9x10^{-11}$ |
| c-$C_3H_2$ | 28 | 15.4 | $3.7x10^{12}$ | $2.3x10^{-12}$ |
| $CH_3C_2H$ | 34 | 31.7 | $5.3x10^{13}$ | $3.2x10^{-11}$ |

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