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DETECTION OF PREBIOTIC MOLECULES WITH ALMA

I. Villicana-Pedraza[1], J. A. Lemus[2], I. Soto[5], F. Carreto-Parra[3], and J. Saucedo-Morales[4]

RESUMEN

Este trabajo presenta un breve resumen de moléculas prebióticas detectadas con éxito por varios equipos de investigación, principalmente con el Atacama Large Millimeter/submillimeter Array (ALMA). Las moléculas en cuestión se han encontrado en una amplia variedad de entornos astrofísicos: polvo estelar de galaxias, nubes moleculares, protoestrellas, Venus, y Titán. También se presenta una breve discusión sobre las conexiones entre las diferentes moléculas prebióticas, tales como sus proporciones de abundancia, la dependencia con la temperatura y su posible origen o rutas de formación hacia los aminoácidos.

ABSTRACT

This work presents a brief summary of prebiotic molecules successfully detected by several research teams mainly with the Atacama Large Millimeter/submillimeter Array (ALMA). The molecules in question have been found in a wide variety of astrophysical environments: starbust galaxies, molecular clouds, protostars, Venus, and Titan. A short discussion about the connections between the different prebiotic molecules such as their abundance ratios, temperature dependance as well as their possible origin or formation routes toward amino acids are also presented.

Key Words: ALMA — interstellar molecules — pre-biotic astrochemistry

1. GENERAL

A prebiotic molecule is one formed by the elements that make up the molecules of life, these are C, H, O, N, P and S. The CH_3 and NH_3 molecules are also of prebiotic importance since single-celled organisms can be formed.

One example reported by Villicaña-Pedraza et al. (2017) is the prebiotic molecule $HCNH^+$ observed for the first time in the extragalactic medium toward the galaxy NGC 4945 with the APEX telesope (Fig. 1). The HNC/HCN abundance ratio in cold dark clouds is usually larger than 1, for example, a ratio of 1.55 was observed in TMC-1 by Irvine & Schloerb (1984) and even of 4.4 in L134 by Wootten et al. (1991). This is in contrast with the low ratios measured in warm and hot regions. In Orion-KL a ratio of 0.012, and of 0.2 in L1498 were obtained by Schilke et al. (1992), as well as a ratio of 0.45 in L1521E by Hirota et al. (1998). These results indicate a strong temperature dependence of the HNC/HCN abundance ratio (Semaniak et al. 2001). At high temperatures HCN is produced much more efficiently, also, endothermic proton exchange reactions involving H_3O^+ and $HCNH^+$ are important.

The most likely hypothesis for the origin of $HCNH^+$, as suggested by Watson (1974), is that an unusually high HNC abundance in the interstellar medium can be produced through dissociative electron recombination of $HCNH^+$, which is considered to be the precursor of both HNC and HCN. Such hypothesis has been confirmed by the quantum mechanical calculations of Ishii et al. (2006). Bogey et al. (1985) detected in the laboratory the J = 1-0, 2-1, and 3-2 rotational transitions of $HCNH^+$. Using a large velocity gradient (LVG) code, Bogey et al. (1985) derived a column density of $HCNH^+$ of about 4×10^{14} cm^{-2}, yielding a fractional abundance of 3×10^{-10}. This high abundance was surprising, since it is several orders of magnitude greater than the values predicted by ion-molecule models of interstellar chemistry. The high abundance observed of this species, relative to theoretical calculations, suggests that the destruction of $HCNH^+$ by dissociative recombination is slower than expected, or that the formation rate of the ion has been underestimated. From a LTE simulation and the rms noise of the 370 GHz transition (4.9×10^{-3} K), Villicaña-Pedraza et al. (2017) set an upper limit of 35 K to the excitation temperature, consistent with those derived for other molecules at the same band. For this excita-

[1]DACC New Mexico State University, Las Cruces, New Mexico, 88003, United States (ilhui7@nmsu.edu).
[2]Physics Department, University of Sonora, Hermosillo, Sonora, 83000 , México.
[3]Physics Department, New Mexico State University, Las Cruces, New Mexico, 88001, United States.
[4]Departamento de Investigación en Física, Universidad de Sonora, Hermosillo, Sonora, 83000, México.
[5]Departamento de Biología, Universidad de Sonora, Hermosillo, Sonora, 83000 , México.

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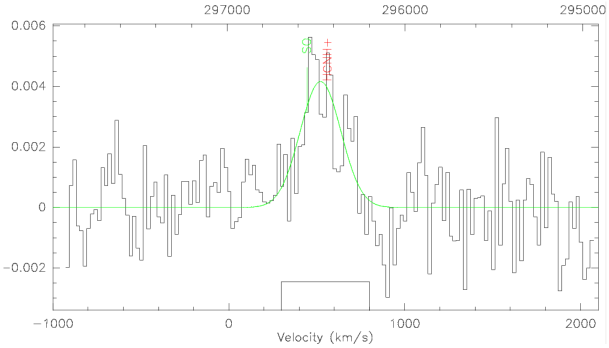

Fig. 1. Spectra of the prebiotic molecule HCNH+ observed with APEX at 1mm.

tion temperature we derived a LTE column density for the 296 GHz transition of 2.41×10^{14} cm^{-2} using a single component. For the H_2 column densities, we estimate an abundance of about 3×10^{-9} which is an order of magnitude larger than the one found in Sgr B2 (Ziurys & Turner 1986).

In this paper we present a review of prebiotic molecules observed with ALMA since 2015.

2. PREBIOTIC MOLECULES FROM CDMS

We used the Cologne Database Molecular Spectroscopy catalog to obtain information about prebiotic molecules in space. In Fig. 2 we present the results of our search.

Prebiotic molecules from the CDMS.

Interstellar Medium	Interstellar Medium	Interstellar Medium	Extragalactic Medium	Extragalactic Medium
CP	NH_2CHO	$HOCH_2CN$	HNCO	CNCHO
PN	CH_3NCO	$H_2NC(O)NH_2$	$HC(O)NH_2$	CH3CH2OH
PO	HOCN	$CH_3C(O)NH_2$	*HCNH+	C3H2O
NH_3	HSCN	CH_3NHCHO	NH_2CHO	
PH_3	HC(O)CN	$NH_2CH_2CH_2OH$	NH_3	
HNCO	HC(O)SH	HCNH+		

Fig. 2. Prebiotic molecules obtained from the CDMS

3. REVIEW OF PREBIOTIC MOLECULES OBSERVED WITH ALMA SINCE 2015

Meier et al. (2015) observed during cycle 0 in 2011 toward the starburst galaxy NGC 253 at 3mm to obtain a molecular survey. Meier and his team reported the tentative detection of the prebiotic molecule Acetaldehyde (CH_3CHO) and formamide (NH_2CHO). Formamide was confirmed with 1mm observations in 2015 and reported by Villicaña-Pedraza et al. (2019) toward the same source. Formamide may be precursor of the amino acid Glycine (NH_2CH_2COOH). Saladino et al. (2006) state that NH_2CHO can be related with the origin of life on Earth. There are two scenarios for the formation of formamide: the first, is the one proposed by Cordiner & Charnley (2021) in which the reaction of HNCO+H+H can derive in NH_2CHO on dust grain ice regions; the second, proposed by Kahane et al. (2013) is that warm gas, through the reaction $H_2CO + NH_2$ derives in NH_2CHO + H, with a column density of the order of 1×10^{15} cm^{-2}.

Palmer et al. (2016) obtained observations toward Titan and found vinyl cyanide (C_2H_3CN) in the South Pole using ALMA. C_2H_3CN can be part of membranes named as azotosomes with similar properties to the lipid membranes of the cells on our Planet.

Carney et al. (2017) observed toward HD 163296 in 2014 and studied formaldehyde (H_2CO) in order to obtain the contribution of gas and solid phase formation pathway to obtain organics.

Ligterink et al. (2021) observed toward IRAS 16293–2422 in 2016 and found CH_2NH, concluding that the amino acid formation routes from this molecule are plausible.

Coutens et al. (2018) observed toward the protostar IRAS16293 at band 7 (1mm). The Coutens team detected the deuterated forms of NH_2CHO (NH_2DO, cis and trans NHDCHO), supporting the idea that NH_2CHO and HNCO are related through grain surface formation.The column density is of the order of 1×10^{14} cm^{-2}.

Lykke et al. (2018) carried out observations in the bands 7, 6 and 3, as part of a survey of IRAS 16293-2422, detecting ethylene oxide (c C_2H_4O), propanal (C_2H_5CHO) and acetone (CH_3COCH_3) for the first time.

Bogelund et al. (2019) observed using band 7 in 2016. The team reported the first detection of CH_3NH_2 towards NGC 6334I. They concluded there is a main formation pathway via radical recombination on grain surfaces.

Hsu et al. (2020) observed toward the Orion Molecular Cloud Complex in band 6 in 2018. The team detected NH_2CHO, and HNCO. Their estimated column densities are of the order of 1×10^{14} cm^{-2} and 1×10^{15} cm^{-2}, respectively.

Nixon et al. (2020) observed toward Titan in bands 6 and 7 in 2016. Nixon's team detected cyclopropenylidene (c- C_3H_2) with a column density of the order of 1×10^{12} cm^{-2}.

Gorai et al. (2020) observed toward the G31.41+0.31 molecular core at 3mm in 2016.

The team of Gorai found methyl isocyanate (CH_3NCO), precursor of prebiotic molecules, methanol (CH_3OH), methanethiol (CH_3SH), and methyl formate (CH_3OCHO).

Ligterink et al. (2021) observed toward the protostar Serpens SMM1-a and IRAS 16293B from 217 to 234 GHz. Ligterink et al. found Methyl isocyanate (CH_3NCO) and glycolonitrile ($HOCH_2CN$), these are prebiotic molecules that can be involved in the peptide structures, their formation, and the nucleobase adenine.

Manna et al. (2020) observed Venus in the 245-262 GHz frequency range, detecting glycine with a column density of the order of 1×10^{14} cm^{-2}.

Van der Mare et al. (2021) observed toward Oph IRS 48 in band 7 in 2018, and studied the molecules H_2CO and CH_3OH and found a link to the presence of a dust trap.

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