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Complex molecules in the Orion Kleinmann-Low nebula

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Abstract. In the framework of the delivery to the early Earth of extraterrestrial molecules, we have studied complex molecular species toward the Orion Kleinmann-Low nebula. This nebula is rich in molecules as well as in nascent stars and planetary systems. We focus here on $HCOOCH_3$, CH_3OCH_3 and deuterated methanol. Upper limits on species of prebiotic interest like glycine were also obtained.

1 Introduction

Molecules important for the origin of life on Earth may have been brought to the early Earth in sizeable amounts by solar system small bodies (comets and asteroids) and their fragments (meteorites and micrometeorites). The molecular content of these small bodies is reminiscent of that of interstellar clouds from which stars and planetary systems form (e.g. Bockelée-Morvan et al 2000, A&A 353,1101). Note that to precise the role, possibly crucial, played in prebiotic chemistry by the extraterrestrial delivery of molecules, many difficult questions will have to be answered. For example, we need to understand the full chemical evolution from the original interstellar cloud to the evolved planetary disk and to determine quantitatively if extraterrestrial molecules reached the early Earth in sufficient amount.

We address here the question of the molecular complexity reached by interstellar chemistry, and of the formation processes of complex species. We selected for that purpose the Kleinmann-Low (KL) infrared nebula, located at the heart of the Orion Nebula. It is one of the richest regions in detected interstellar molecules and the host to many forming and young stars. The study of the spatial distribution of the molecules allows us to constrain their origin and their formation mechanism. Are the molecules produced in the gas-phase, on icy grain mantles, or through a combination of both processes ? Did shocks from the recent (< 1000 yr) explosive event play a role in their formation?

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We present selected results from a spectroscopic study of Orion KL with high spatial resolution (1-2",400-800 AU). The observations have been undertaken at millimetre wavelengths with the IRAM Plateau de Bure Interferometer and conducted for several years. We have studied methyl formate HCOOCH3 (ref. [1]), deuterated methanol (CH_3OD et CH_2DOH; ref. [2]), dimethyl ether CH_3OCH_3 (ref. [3,4]) and acetone CH_3COCH_3 (ref. [5]).

2 Results

Methyl formate $HCOOCH_3$ (ref [1]). In addition to the determination of the physical properties of the gas (temperature, structure in space and velocity) this study has shown a likely association of the spatial distribution of this molecule with that of excited H_2 2.12 μm emission, a tracer of the fast shock waves (40-200 km/s) present in this region.

Deuterated methanol CH_3OD and CH_2DOH (ref.[2]). We have shown that the ratio CH_2DOH/CH_3OD is rather constant over the region – this contrasts with the present day spread in physical conditions and suggests a formation and storage of deuterated methanol (and, likely, of methanol itself) in the ice mantles of the interstellar grains at a time where the nebula was more homogeneous. The value of the ratio we found, <1, confirms the strong difference between Orion KL and the surroundings of low-mass stars found by Rataczack et al (2011, A&A 528, L13).

Dimethyl ether CH_3OCH_3 (ref. [3,4]). Comparaison of CH_3OCH_3 with $HCOOCH_3$ has shown a remarkable correlation of their spatial distributions - which is not found with ethanol CH_3CH_2OH or with formic acid HCOOH (the latter is anticorrelated). The simplest interpretation is that both species are formed from a same precursor. Two main models have been proposed to form these species : on grain mantles (e.g. Bisschop et al 2007, A&A 465,913; Oberg et al 2010, ApJ 716, 825) or in the gas phase (e.g. Neill et al 2010, J.Ph.Ch. A 115, 6472). The precursor would be respectively CHO• or $CH_3OH_2^+$.

In the latter case $HCOOCH_3$ is formed from HCOOH. Another reaction producing $HCOOCH_3$ from H_2CO has been proposed (Blake et al 1988, Lect. Note. Phys 315,132), but has been shown to have a too high energy barrier (128 kJ/mol ~ 15000 K ~ 1.2 eV). Could the kinetic energy provided in a shock (V_{shock} ~ 30-40 km/s) overcome the energy barrier and make this reaction possible ?

"Prebiotic" species. Some molecules of direct interest for prebiotic chemistry, a pre-sugar CH_2OHCHO (glycolaldehyde), aminoacetonitrile NH_2CH_2CN (a precursor of glycine) and the simplest amino acid, glycine itself NH_2CH_2COOH, have been searched for, but only upper limits have been obtained (Guélin et al. 2008, Ap&SS 313,45 ; ref [1]). Note that the first two species have been found in other young stellar environments.

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