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Prebiologically Important Interstellar Molecules

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Abstract. Understanding the organic chemistry of molecular clouds, particularly the formation of biologically important molecules, is fundamental to the study of the processes which lead to the origin, evolution and distribution of life in the Galaxy. Determining the level of molecular complexity attainable in the clouds, and the nature of the complex organic material available to protostellar disks and the planetary systems that form from them, requires an understanding of the possible chemical pathways and is therefore a central question in *astrochemistry.* We have thus searched for prebiologically important molecules in the hot molecular cloud cores: Sgr B2(N-LMH), W51 e1/e2 and Orion-KL. Among the molecules searched: Pyrimidine is the unsubstituted ring analogue for three of the DNA and RNA bases. 2H-Azirine and Aziridine are azaheterocyclic compounds. And Glycine is the simplest amino acid. Detections of these interstellar organic molecular species will thus have important implications for *Astrobiology.* Our preliminary results indicate a tentative detection of interstellar glycine. If confirmed, this will be the first detection of an amino acid in interstellar space and will greatly strengthen the thesis that interstellar organic molecules could have played a pivotal role in the prebiotic chemistry of the early Earth.

1. Introduction

Currently over 130 molecular species have been identified in interstellar space, and most of them are organic in nature; among these molecules are many with biological significance, such as NH_3, H_2CO, CH_3OH, C_2H_5OH, NH_2CHO, $(CH_3)_2CO$, and CH_3COOH. The rich, growing inventory of organic molecules found in interstellar clouds similar to that in which the Solar System formed, when compared to the composition of comets and meteorites, suggests that one

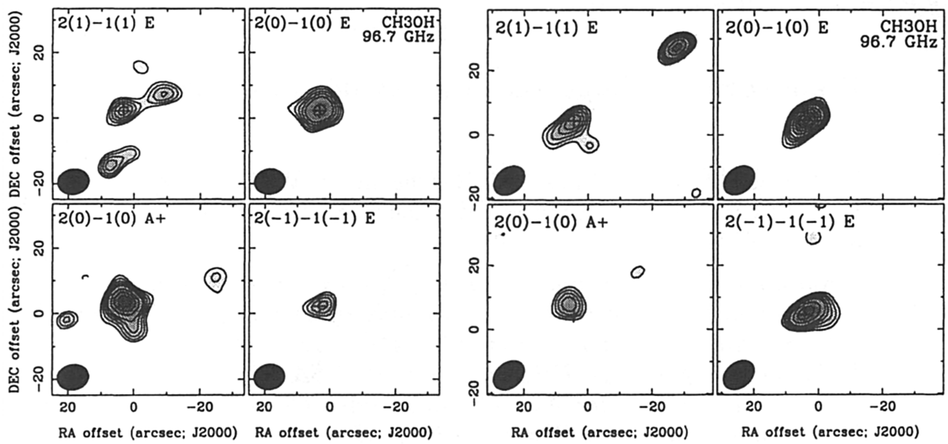

Figure 1. BIMA interferometric maps of integrated CH_3OH emission of Comet Hale-Bopp in two epochs: March 31 (left) and March 27, 1997 (right). Note the extended structure and gas clump visible at the 2_1-1_1 E1 transition to the northwest of the nucleus (marked by "+") along the dust tail. This suggests methanol may evaporate from dust grains in the dust tail directly as predicted by grain chemistry.

could in principle trace the Earth's prebiotic chemistry back to the parent molecular cloud. Observations of recent bright comets show that they have a molecular inventory consistent with their ices being largely unmodified interstellar material (see our related article on Comet Hale-Bopp this meeting, and Fig. 1). Many simple interstellar molecules have important functions in terrestrial biochemistry (aldehydes, acids, ketones and sugars) and could also have been important in prebiotic synthesis. If more complex organics such as amino acids can be formed and survive in interstellar space, then they may have *"jump started"* prebiotic chemistry on the early Earth, and probably also on other (extra-solar) planets.

Although many organic molecules can be produced in gas phase reactions, large organic molecules are expected to be catalyzed on grains; reactions on the surfaces of cold interstellar dust grains are probably the major source of complex organic material. Theoretical chemical models have demonstrated that many of the organic species observed are not the products of grain surface reactions but are synthesized in the warm gas from simpler species that are surface reaction products. Gas phase observations of hot molecular cores (HMCs) near protostars, where icy grain mantles have recently been evaporated, offer the prospect of studying the products of grain surface chemistry directly, and would reveal the level of molecular complexity attainable by interstellar organic chemistry hence their possible chemical pathways.

2. Observations and the Molecules Searched

We have conducted an astronomical search for biologically important molecules predicted by grain-surface chemistry in the HMC Sgr B2(N-LMH), W51 e1/e2 and Orion KL, using the former NRAO 12-m and JCMT 15-m (sub) millimeterwave radio telescopes.

Four different molecules were searched. Pyrimidine, c-$C_4H_4N_2$, is the unsubstituted ring analogue for three of the DNA and RNA bases: thymine, cytosine and uracil. Substitution of nitrogen atoms for two carbon atoms in a benzene ring yields Pyrimidine. Interstellar Pyrimidine may form on grains by an addition reaction involving HCN and CH_2CHCN. The cyclic isomers 2H-Azirine, c-C_2H_3N, and its reduced form Aziridine, c-C_2H_5N, are azaheterocyclic compounds which play a limited role in biochemistry; however, they are some of the smallest organic rings in a group that includes Imidiazole, Cyanoform and Pyrrole. 2H-Azirine and Aziridine are predicted by grain-surface chemistry to be present in the HMCs arising from O and N additions to the vinyl radical C_2H_3 (Charnley & Rodgers 2002).

Glycine, NH_2CH_2COOH, is the simplest biologically important amino acid, which is the building block of life. Recent theories of grain surface chemistry predict the existence of aminoalcohols ($NH_2C_nH_{2n}OH, n = 1, 2, ...$) in grain mantles (Charnley 1997). Analogous reactions between protonated aminoalcohols and formic acid, a known and abundant mantle molecule, could produce glycine as follows (Charnley, Ehrenfreund, & Kuan 2001):

$$NH_2CH_2OH_2^+ + HCOOH \longrightarrow NH_2CH_2COOH_2^+ + H_2O \tag{1}$$

3. Results and Discussion

Our search for Pyrimidine did not yield any positive result. The upper limits of total column density are found as: N_{tot}(c-$C_4H_4N_2$) $\lesssim 1.1\times10^{14}$ cm^{-2} for Sgr B2(N-LMH); and $\lesssim 9.7\times10^{14}$ cm^{-2} for W51 e1/e2. Of the many transitions of the azaheterocyclic compounds searched, we have tentatively detected a couple of Aziridine and 2H-Azirine lines. Though it may not be conclusive at the moment, our results are quite encouraging still. The total column densities derived are: N_{tot}(c-C_2H_3N) = 9.1×10^{12} cm^{-2} for Sgr B2(N-LMH), and 8.2×10^{12} cm^{-2} for Orion KL; and N_{tot}(c-C_2H_5N) = 1.7×10^{13} cm^{-2} for Orion KL, and 2.5×10^{13} cm^{-2} for W51 e1/e2. Here the rotational excitation temperature T_{rot} = 50 K is assumed for all molecules except for glycine.

Our preliminary results indicate unambiguous detections of $\gtrsim$ 10 glycine lines in the three sources searched (Fig. 2). The rotational temperatures obtained by fitting *rotation diagrams* are $T_{rot} = 80\pm^{33}_{18}$ K for Sgr B2(N-LMH), $93\pm^{72}_{28}$ K for Orion KL, and $99\pm^{59}_{27}$ K for W51 e1/e2, accordingly. The total column densities derived are $N_{tot}(NH_2CH_2COOH) = 3.83\pm^{2.83}_{1.63}\times10^{14}$ cm^{-2} for Sgr B2(N-LMH), $5.54\pm^{5.14}_{2.67}\times10^{14}$ cm^{-2} for Orion KL, and $1.80\pm^{1.31}_{0.76}\times10^{14}$ cm^{-2} for W51 e1/e2. The well-delineated fits of the rotation diagrams indicate glycine emission is in LTE; on the other hand, it also provides a strong constraint on the spectral lines identified to be indeed from glycine emission. If confirmed, this will be the first detection of an amino acid in interstellar space.

Recently simple amino acids, such as glycine, alanine and serine, were successfully synthesized when ice mixtures in a simulated deep space environment were UV radiated (cf. Bernstein et al. 2002). An implication of this experiment is that amino acids could be everywhere, wherever there are stars and planets.

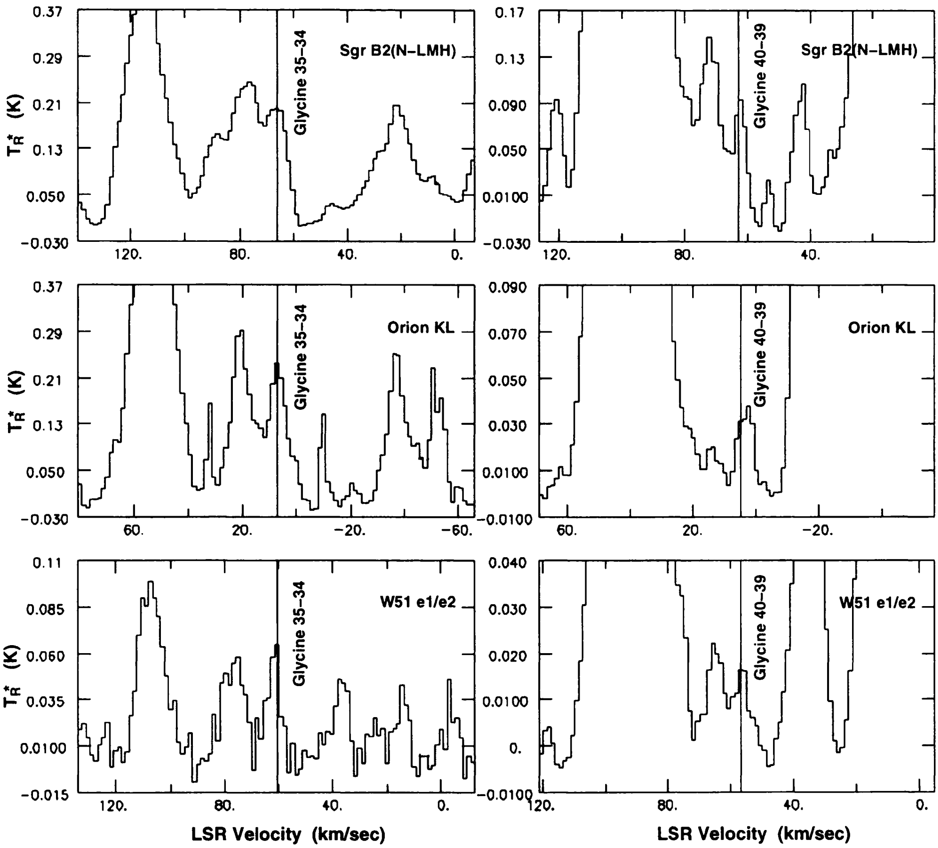

Figure 2. Sample glycine spectra at 1.4 mm (lefe panels) and at 1.2 mm (right panels) observed with the former NRAO 12-m telescope. Vertical lines denote the spectral lines of glycine.

Together with our findings, it will shed light on the questions of how, where, and when the life began.

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