Formation Pathways of Interstellar Complex Organic Molecules

KEYWORDS — astrochemistry, complex organic molecules (COMs), interstellar medium

INTRODUCTION

Interstellar organic molecules with more than one carbon atom exist in two distinct flavors: saturated complex organic molecules (COMs, referring to carbon-containing molecules with more than five atoms), such as C_3H_7CN, and unsaturated carbon chains, such as HC_3N (Fig. 1). These two families of interstellar organics are not well-understood, but they may provide insight to a more complex, prebiotic chemistry. For instance, detected COMs and carbon chains in the interstellar medium are candidates for amino acid precursors or even amino acids themselves (i.e. glycine,[1] although the integrity of these detections has been challenged[2]). Moreover, studying interstellar molecules light-years away can be thought of as astronomical archaeology which allows scientists to observe various stages of stellar and planetary chemical evolution and perhaps even the origin of life.

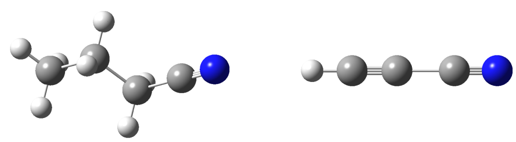

Figure 1: Models of C_3H_7CN (left) and HC_3N (right).

The formation pathways of COMs in the interstellar medium are not well-constrained, making their formation a particularly interesting problem in astrochemistry. COMs are suggested to form through ice grain surface chemistry pathways.[3] Conversely, carbon chains are theorized to form in the gas-phase, perhaps from radicals produced from the sublimation of methane from ice grain surfaces or via a cold-gas ionic chemistry.[4] Additionally, it is not yet understood whether organic molcules form exclusively via one type of pathway or by multiple and even combinations of multiple pathways.

RESEARCH OBJECTIVES

I propose to investigate COM formation pathways by coupling studies of site-specific reactions using stable isotopes with radio astronomical measurements. Studying site-specific reactions yields (1) identification of active site atoms in interstellar chemical reactions, (2) observation of intermediate species within proposed COM formation pathways, and (3) identification of target molecules for astronomy observations. Integrating laboratory and observational astrochemistry techniques allows proposal of formation theories and testing of these theories in interstellar environments.

PRELIMINARY RESULTS

I investigated COM and carbon chain abundances of six protostars at the Harvard-Smithsonian Center for Astrophysics. We found that abundances of unsaturated carbon chains and methanol (representing relative COM abundances[5]) do not appear related; this is consistent with chemical theory that carbon chains and COMs do not form through similar pathways. Tentative correlations between gas-phase and grain surface abundances of hydrocarbons, however, challenged this theory.[6]

My work as a Fulbright fellow at the Universität zu Köln in Germany further challenges the theory that COMs form exclusively on the surfaces of interstellar ice grains. I conducted a submillimeterwave survey of molecules formed from CH_3CN (methyl cyanide) precursor discharged in plasma under low pressures (10-23 μbars) to emulate interstellar conditions. We detect three COMS (C_2H_5CN, C_3H_7CN, C_4H_9CN), suggesting that **COM formation pathways are not exclusive to ice grain surfaces**.

Methods Overview & Support

Reactions between COM and COM precursor isotopologues (containing carbon-13, deuterium, and nitrogen-15) will be observed under interstellar conditions (e.g. pressures below 50 μbar) in the gas phase. Using spectroscopy, I will observe the formation of and identify new species, if any. One prospective COM for study is aminoacetonitrile (NH_2CH_2CN). Aminoacetonitrile, a possible direct precursor of glycine with confirmed detections in space,[7] has three proposed formation pathways to be tested.[8]

After meeting Geoff Blake from the California Institute of Technology, I am particularly interested in studying such reactions at Caltech where I would have access to a variety of spectrometers available for frequencies from microwave to Terahertz ranges.

Radio astronomical observations will be conducted using sensitive telescopes ideal for detecting interstellar molecules, for example the Green Bank Telescope (GBT), the IRAM 30m Telescope, and the Atacama Large Millimeter Array (ALMA). All of my prospective research groups frequently secure telescope time; hence, I would have access to guidance from experienced observers when determining telescope settings.

Finally, both the laboratory and astronomy portions of this project require molecular spectroscopy catalogs, the two most-respected of which are the Jet Propulsion Lab (JPL) database and the Cologne Database for Molecular Spectroscopy (CDMS). Caltech directly manages JPL, and I am currently working with the group in Cologne that maintains the CDMS. Therefore, I have access to support when using either of these catalogs.

Intellectual Merit & Broader Impacts

This project will provide insight to unraveling elusive COM formation pathways by mapping the evolution of interstellar molecules, specifically those that may be precursors to life. In addition to expected journal publications and conference presentations, this project will also be a platform for public outreach. Anticipated outreach media include middle and high school classroom visits and involvement in summer camps (e.g. Project Scientist for young girls hosted at Caltech).

References

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