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BOUNDARY CONDITIONS FOR THE PALEOENVIRONMENT: CHEMICAL AND PHYSICAL PROCESSES IN THE PRE-SOLAR NEBULA

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Principal Investigator: William M. Irvine
Co-Principal Investigator: F. Peter Schloerb

Current Research

Detailed study of the first interstellar hydrocarbon ring, cyclopropenylidene (C_3H_2), is continuing by Irvine, graduate student S. Madden, and H. Matthews and L. Avery (National Research Council of Canada). We have successfully observed the singly deuterated isotope of this molecule, C_3HD, in several cold interstellar clouds. In the same plus additional sources the ^{13}C-isotopic form has also been observed, together with the main isotopic variant. As a result, the optical depth of the observed transitions can be accurately determined, given reasonable assumptions about the $^{13}C/^{12}C$ ratio. A very high degree of deuterium fractionation is found. Initial estimates indicate that $C_3HD/C_3H_2 \sim 0.05$ in at least some cold clouds, which is among the highest degrees of fractionation ever observed in interstellar chemistry. This result places severe constraints on models of the formation of C_3H_2, apparently requiring gas phase formation via ion-molecule chemistry, with acetylene as a possible precursor.

A paper containing the results of a large survey for C_3H_2 in galactic sources of various types is nearing completion. It appears that cyclopropenylidene is present in virtually all interstellar clouds of at least moderate density. An

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indepth study of four specific clouds of differing types is being pursued by S. Madden as part of her Ph.D. dissertation. Multiple transition maps of these sources are currently being taken at both FCRAO (University of Massachusetts) and NRAO (Green Bank, WV).

In order to make the first determinations of the CO_2/CO abundance ratio in interstellar sources, we have been pursuing observations of protonated CO_2 (since CO_2 itself has no permanent electric dipole moment, and hence no allowed rotational transitions). Following extensive observations at 21 GHz at NRAO and 85 GHz at FCRAO, we have been able to detect HCO_2^+ in only one molecular cloud. Interestingly enough, in that source it appears both relatively abundant and extended over a considerable region in space. Column densities and abundances are currently being calculated by graduate student Y. Minh. It appears that $CO_2/CO \ll 1$ in all sources surveyed.

A proposal by Irvine and colleagues in Canada and Sweden to systematically measure the spectrum from 18.5 to 22 GHz for several interstellar clouds has been accepted by the NRAO, and the project has begun. Particular attention is being given to the cold, dark clouds TMC-1 and L134N, which may be formation sites for solar mass stars. These two clouds, which are very similar in physical characteristics (temperature and density), exhibit interesting differences in their chemistry, particularly in regard to the polyacetylenes and their derivatives. A number of unidentified emission lines have been discovered. Identification will be pursued by looking for patterns of emission and for additional transitions that are predicted by hypotheses concerning the carrier of the observed lines.

Graduate student Y. Minh, in collaboration with astronomers from the Daeduk Radio Astronomical Observatory in Korea, has been studying a new phenomenon of maser emission from molecules of methanol in certain interstellar clouds. New sources of this emission have been detected, and a careful search has been carried out for polarization. Detection of polarization might provide clues as to the excitation mechanism.

Irvine, Ziurys, and L. Avery (National Research Council of Canada) have been pursuing the identification of several presently unidentified but strong emission lines in the millimeter-wavelength spectrum of the cold cloud TMC-1. Additional emission features have been discovered, the distribution of emission in TMC-1 has been determined, and comparisons made with the spectrum of the giant molecular cloud Sgr B2.

Schloerb and colleagues at both the University of Massachusetts and the University of Wyoming have been carrying out high angular resolution observations of the material outflowing from the infrared source in the dark cloud L1551. The bi-polar nature of this outflow suggests the presence of a circumstellar disk around this (presumably) young or protostellar object. It appears that the outflow has evacuated a cavity in the ambient interstellar material.

Since molecular hydrogen is not directly observable in cold interstellar clouds (because of its symmetry, it exhibits only electric quadrupole transitions, the lowest of which is still quite high in energy above the ground state), two tracers of molecular material have traditionally been used by radio astronomers: carbon monoxide rotational transitions and thermal emission from dust. Schloerb and colleagues at the University of Massachusetts have completed a comparison of the 1 millimeter continuum emission from dust with the column density of carbon monoxide as determined from the rare $C^{18}O$ isotope for 4 molecular clouds in our Galaxy. The results are consistent with a constant gas-to-dust ratio among these clouds. This result is important, since it argues against significant depletion of CO from the gas phase onto the particulate grains in regions of high density in these clouds. In addition, the results show that observations at this wavelength do provide a useful tracer of the total amount of mass in an interstellar cloud.

Note that the longest wavelength IRAS band is still at too short a wavelength to detect dust in cold, dark interstellar clouds.

In collaboration with astronomers at the University of Illinois, Ziurys has completed a study of the abundance of the HCO radical in cold, dark interstellar clouds. The results are consistent with theoretical models, which predict a maximum abundance in regions of intermediate density.

Ziurys has been continuing her study of "high temperature" interstellar chemistry in order to investigate possible differences with respect to that in cold, quiescent clouds, where ion-molecule reactions are assumed to dominate. A particularly interesting source for these investigations is the supernova remnant IC443, where it is apparent that the supernova blast wave has created dense, shocked regions in the ambient gas. The chemistry in such clumps is being studied at FCRAO. Another region where high temperatures clearly occur is in the vicinity of the infrared source IRc2 in the Orion molecular cloud. This region is being investigated through study of vibrationally excited HCN, whose excitation requires unusually hot and dense gas and/or strong infrared radiation, and through studies of the silicon-containing molecules SiO and SiS, whose abundance is anomalously high. The latter effect may be due to destruction of silicate grains, with resultant liberation of Si into the gas phase.

Madden presented a paper describing observations of C_3H_2 isotopes at the 169th meeting of the American Astronomical Society in January, 1987.

Papers supported by this grant and published during the period of report:

1. "CO Mapping of the Orion Molecular Cloud: the Influence of Star Formation on Cloud Structure", Schloerb, F.P., Snell, R.L., Goldsmith, P.F., and Morgan, J.A., in <u>Summer School on Interstellar Processes</u>, ed. D. Hollenbach and H. Thronson (NASA Tech. Mem. 88342), 27 (1986).

2. "High Resolution Observations of the L1551 Biopolar Outflow", Snell, R.L., Moriarty-Schieven, G., Strom, S., Schloerb, P., Strom, K., and Grasdalen, G., in <u>Summer School on Interstellar Processes</u>, ed. D. Hollenbach and H. Thronson (NASA Tech. Mem. 88342), 5 (1986).

3. "Variations in the HCN/HNC Abundance Ratio in the Orion Molecular Cloud", Goldsmith, P.F., Irvine, W.M., Hjalmarson, Aa., and Ellder, J., Astrophys. J. 310, 383 (1986).

4. "Studies of organic Molecules Containing Methyl Groups in Dark Clouds", Friberg, P., Irvine, W.M., Madden, S.C., Hjalmarson, Å., in Astrochemistry (IAU Symp. 120), ed. M.S. Vardya and S.P. Tarafdar (D. Reidel), pp. 201-202 (1986).

5. The Chemistry of Cold Dark Interstellar Clouds", Irvine, W.M., in Astrochemistry (IAU Symp. 120), ed. M.S. Vardya and S.P. Tarafdar (D. Reidel), pp. 245-252 (1986).

6. "New Interstellar Detections: Implications for Shock Chemistry", Ziurys, L.M., and Turner, B.E., in Astrochemistry (IAU Symp. 120), ed. M.S. Vardya and S.P. Tarafdar (D. Reidel), pp. 289-292 (1986).

7. "Detections of ^{13}C-Substituted C_3H_2 in Astronomical Sources", Madden, S.C., Irvine, W.M., and Matthews, H.E., Astrophys. J. (Lett.), 311 L29 (1986).

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9. "A Search for Interstellar H_3O^+", Wootten, A., Boulanger, F., Bogey, M., Combes, F., Encrenaz, P., Ziurys, L.M., and Gerin, M., Astron. Astrophys., 166, L15 (1986).

10. "Studies of Interstellar Vibrationally Excited Molecules", Ziurys, L.M., Snell, R.L., Erickson, N.R., in Summer School on Interstellar Processes, ed. D. Hollenbach and H. Thronson (NASA Tech. Mem. 88342), 153 (1986).

11. "Exobiology in Earth Orbit", Tarter, J., DeFrees, D., Brownless, D., Usher, D., Klein, H.P., and Irvine, W.M., Fifth ISSOL Meeting, Berkeley, CA., July, (1986).

12. "Multitransition Studies of C_3H_2", Madden, S.C., Irvine, W.M., Matthews, H.E. and Avery, L.M., in Summer School on Interstellar Processes, ed. D. Hollenbach and H. Thronson (NASA Tech. Mem. 88342), 155 (1986).

13. Madden, S.C., Irvine, W.M. and Matthews, H.E., "Multi-level Study of C_3H_2, the First Interstellar Hydrocarbon Ring Molecule", Bull. Amer. Astron. Soc. 18, 4 (1986).

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1. "Observations of SiO Toward OMC-1: a New Outflow Source 1.5' South of Orion-KL?", Ziurys, L.M. and Friberg, P., Astrophys. J. (Lett.), in press.

2. "Interstellar Molecules and Astrochemistry", Turner, B.E., and Ziurys, L.M., in Galactic and Extragalactic Radio Astronomy, ed. K. Kellerman and G. Verschurr (Springer-Verlag: Berlin, Heidelberg, and New York), submitted for publication.

3. "Observations of OCS and a Search for OC_3S in the Interstellar Medium, Matthews, H.E., MacLeod, J.M., Broten, N.W., Friberg, P. and Madden, S.C., Astrophys. J., in press (1987).

4. "Observational Astrochemistry", Irvine, W.M. and Hjalmarson, Å., Adv. Space Sci., in press.

5. "Chemical Abundances in Molecular Clouds", Irvine, W.M., Goldsmith, P.F., and Hjalmarson, Å. in Interstellar Processes, ed. D. Hollenbach and H. Thronson (Dordrecht: Reidel), in press.

6. "1300 μm Continuum and $C^{18}O$ Line Mapping of the Giant Molecular Cloud Cores in Orion, W49 and W51", Schloerb, F.P., Snell, R.L., and Schwartz, P.R., Astrophys. J., in press (1987).

7. "High Resolution Images of the L1551 Bipolar Outflow: Evidence for an Expanding Accelerated Shell", Moriarty-Schieven, G., Snell, R.L., Strom, S.E., Schloerb, F.P., Strom, K.M., and Grasdalen, G.L., Astrophys. J., in press (1987).

8. "SiS in Orion-KL: Evidence for "Outflow" Chemistry", Ziurys, L.M., Astrophys. J., in press.

9. "HCO Emission from HII/Molecular Cloud Interfaces", Schenewerk, M.S., Snyder, L.E., Hollis, J.M., Jewell, P.R., and Ziurys, L.M., Astrophys. J., submitted.

Future Plans

Research will continue on the abundance and distribution of cyclopropenylidene in interstellar sources. The goal is to obtain accurate abundances for this species under a variety of interstellar conditions, to investigate formation mechanisms, and to determine the extent to which C_3H_2 emission and absorption can be used as a probe of physical conditions in molecular clouds.

The systematic investigation of the spectrum of cold, dark interstellar clouds will continue in an effort to identify new chemical constituents of these regions, determine accurate abundances (particularly for heavier species), and to investigate differences in chemical composition among molecular clouds. Additional observing time has been scheduled at NRAO for the coming spring.

We anticipate observations at the Onsala Space Observatory in Sweden in order to pursue our investigation of unidentified lines in TMC-1 in the 7 mm region. In addition, important transitions of C_3H_2 can be studied in this wavelength band with the particularly sensitive equipment available at that Observatory.

Madden and Irvine will continue their study of methanol in cold, dark interstellar clouds. The lowest rotational transitions will be observed using the facilities of the Onsala Space Observatory in Sweden, in collaboration with P. Friberg and Å. Hjalmarson of the Chalmers University of Technology. Combining this data with the 3 millimeter observations obtained at FCRAO will enable the excitation and the abundance of CH_3OH to be accurately determined.

Ziurys will continue to pursue radio astronomical studies of high temperature chemistry through the detection and study of new interstellar species, and through observations of molecules whose presence and excitation provoide indicators of elevated temperatures. In particular, rotational transitions of metal-containing species such as MgH, CaH, CaOH, and MgOH will be sought.

The study of vibrationally-excited species is also being continued. Ziurys is conducting searches for vibrationally-excited HCO^+ and N_2H^+, using the NRAO 12 meter antenna at 270 GHz. Preliminary results indicate that vibrationally-excited HCO^+ may be present in the hot, shocked gas of Orion-KL, but not nearly with the abundance found for vibrationally-excited HCN by Ziurys and Turner. Such data suggests that, in very hot, dense gas, molecular ions tend to be destroyed.

Ziurys and M. Claussen are pursuing studies of vibrationally-excited HCN and CS in both carbon and oxygen rich circumstellar envelopes, using the FCRAO telescope. Past theoretical studies have suggested that vibrationally-excited molecules with large dipole moments are collisionally-excited under non-LTE conditions. Ziurys and Claussen have evidence that this may be the case for HCN, and may also find this the situation for CS.

Ziurys and Kulkarni (U.C. Berkeley) plan a survey of the J=1-0 transition of CO towards clouds in the galactic plane where atomic hydrogen absorption lines have been detected. The purpose of the measurements is to find a correlation between CO and atomic hydrogen, and thereby help establish the atomic vs. molecular content of dense clouds.

Schloerb is continuing the study of the structure and kinematics of nearby molecular clouds in order to study the process of star (and presumably) planetary formation, and the resulting disruptive effects of these processes on the initial molecular clouds.

William M. Irvine
Principal Investigator

F. Peter Schloerb
Co-Principal Investigator

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