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EXOTIC MOLECULES IN SPACE: A COORDINATED ASTRONOMICAL, LABORATORY, AND THEORETICAL STUDY

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Principal Investigator
Professor Patrick Thaddeus

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SMITHSONIAN INSTITUTION
ASTROPHYSICAL OBSERVATORY
CAMBRIDGE, MASSACHUSETTS 02138

Director: Irwin I. Shapiro

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The NASA Technical Officer for this grant is L. J. Caroff, Code SZF, NASA Headquarters, Washington, DC 20546

NASA NAGW-1030
Annual Progress Report 2/15/96 through 2/14/98

The past year has been a period of spectacular progress in our investigation of exotic molecules of astrophysical interest. During this period an entirely new spectrometer for the investigation of reactive molecules was finished: a Fourier-transform microwave spectrometer with a supersonic molecular beam. The instrument is operating almost flawlessly, and during the above period of less than two years has discovered the 23 new carbon chain and ring-chain molecules shown in the attached Figure. Seventeen research papers, nearly all in leading refereed journals such as the *Astrophysical Journal* and the *Journal of Chemical Physics* have been published. At least five more papers are being prepared for publication.

Already four of our new molecules have been detected in space with large radio telescopes. In many ways the most interesting of these is $HC_{11}N$, which now ranks as the largest molecule definitely identified beyond the solar system. Nearly all the other new molecules are candidates for astronomical detection, and we will be disappointed if a number of them are not found as more sensitive receivers and larger telescopes are constructed.

During the next year we expect this wave of discovery to continue, and to insure rapid progress we have designed an even more sensitive spectrometer which will operate at the temperature of liquid helium. The goal of this system is to enhance the sensitivity of Fourier-transform spectroscopy by a further factor of 20 to 50, achieving this by reducing the amplifier and thermal noise to levels routinely achieved in radio astronomy. This new instrument offers a number of technical challenges in cryogenic and microwave engineering, but none of these appears to be insurmountable, and our current schedule is to have the helium cooled system operating within the next six months.

A number of investigations continued with our conventional free space spectrometer, which remains a powerful complement to our new FTM instrument. We are particularly excited by the discovery of the ring-chain molecules shown in the Figure, and we will concentrate especially on the search for this class of compounds, because of their great astronomical and chemical interest.

PUBLICATIONS: Feb 1996-Dec 1997

1. "Structure of the Cumulene Carbene Butatrienylidene: H_2CCCC," M. J. Travers, W. Chen, S. E. Novick, J. M. Vrtilek, C. A. Gottlieb, and P. Thaddeus, 1996, *Journal of Molecular Spectroscopy*, **180**, 75.

2. "Laboratory Detection of the C_8H Radical," M. C. McCarthy, M. J. Travers, A. Kovacs, C. A. Gottlieb, and P. Thaddeus, 1996, *Astronomy and Astrophysics*, **309**, L31.

3. "Laboratory Detection of the C_7H Radical," M. J. Travers, M. C. McCarthy, C. A. Gottlieb, and P. Thaddeus, 1996, *Astrophysical Journal Letters*, **465**, L77.

4. "Laboratory Detection of the C_9H Radical," M. C. McCarthy, M. J. Travers, P. Kalmus, C. A. Gottlieb, and P. Thaddeus, 1996, *Astrophysical Journal Letters*, **467**, L125.

5. "Laboratory Detection of the Linear Cyanopolyyne $HC_{11}N$," M. J. Travers, M. C. McCarthy, P. Kalmus, C. A. Gottlieb, and P. Thaddeus, 1996, *Astrophysical Journal Letters*, **469**, L65.

6. "Laboratory Detection of the Cyanopolyyne $HC_{13}N$," M. J. Travers, M. C. McCarthy, P. Kalmus, C. A. Gottlieb, and P. Thaddeus, 1996, *Astrophysical Journal Letters*, **472**, L61.

7. "Two New Cumulene Carbenes: H_2C_5 and H_2C_6," M. C. McCarthy, M. J. Travers, A. Kovacs, W. Chen, S. E. Novick, C. A. Gottlieb, and P. Thaddeus, 1997, *Science*, **275**, 518.

8. "Detection of a New Linear Carbon Chain Radical: C_7H," M. Guélin, J. Cernicharo, M. J. Travers, M. C. McCarthy, C. A. Gottlieb, P. Thaddeus, M. Ohishi, S. Saito, and S. Yamamoto, 1997, *Astronomy and Astrophysics*, **317**, L1.

9. "Microwave Spectroscopy of the Carbon Chain Radical $C_{11}H$," M. C. McCarthy, M. J. Travers, P. Kalmus, C. A. Gottlieb, and P. Thaddeus, 1996, *Chemical Physics Letters*, **264**, 262.

10. "First Astronomical Detection of the Cumulene Carbon Chain Molecule H_2C_6 in TMC-1," W. D. Langer, T. Velusamy, T. B. H. Kuiper, R. Peng, M. C. McCarthy, M. J. Travers, A. Kovacs, C. A. Gottlieb, and P. Thaddeus, 1997, *Astrophysical Journal Letters*, **480**, L63.

11. "Eight New Carbon Chain Molecules," M. C. McCarthy, M. J. Travers, A. Kovacs, C. A. Gottlieb, and P. Thaddeus, 1997, *Astrophysical Journal Supplement*, in press.

12. "Detection of $HC_{11}N$ in the Cold Dust Cloud TMC-1," M. B. Bell, P. A. Feldman, M. J. Travers, M. C. McCarthy, C. A. Gottlieb, and P. Thaddeus, 1997, *Astrophysical Journal Letters*, **483**, L61.

13. "Laboratory Detection of the Ring-Chain Molecule C_5H_2," M. J. Travers, M. C. McCarthy, C. A. Gottlieb, and P. Thaddeus, 1997, *Astrophysical Journal Letters*, **483**, L135.

14. "Laboratory Detection of the Ring-Chain Molecule C_7H_2," M. C. McCarthy, M. J. Travers, C. A. Gottlieb, and P. Thaddeus, 1997, *Astrophysical Journal Letters*, **483**, L139.

15. "Laboratory Detection of a New Carbon Chain Radical: H_2CCCCN," Wei Chen, M. C. McCarthy, M. J. Travers, E. W. Gottlieb, M. R. Munrow, S. E. Novick, C. A. Gottlieb, and P. Thaddeus, 1997, *Astrophysical Journal*, in press.

16. "Organic Molecules in the Interstellar Gas," P. Thaddeus, 1997, in *Enciclopedia Italiana Treccani: Frontiere della Biologia*, in press.

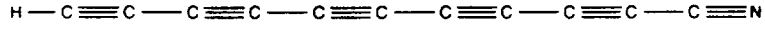
17. "Laboratory Detection of the Carbon Chains $HC_{15}N$ and $HC_{17}N$," M. C. McCarthy, J.-U. Grabow, M. J. Travers, W. Chen, C. A. Gottlieb, and P. Thaddeus, 1997, *Astrophysical Journal Letters*, in press.

FIGURE CAPTION

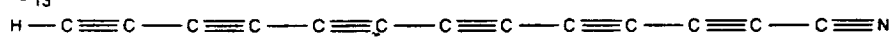
The twenty-three new carbon chain molecules detected with the FTM molecular beam spectrometer. The four detected in space are indicated by a star. The largest chains here have a molecular weight more than twice as large as glycine, the simplest amino acid.

Cyanopolyynes

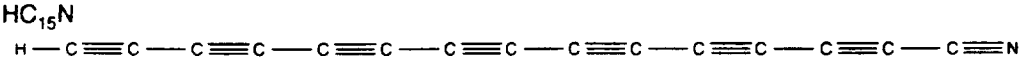
* $HC_{11}N$



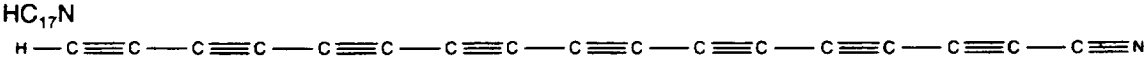
$HC_{13}N$



$HC_{15}N$



$HC_{17}N$



Isocyanopolyynes

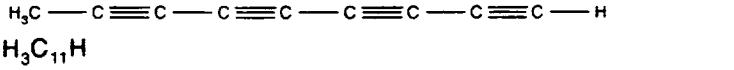
HC_4NC

HC_6NC

Methylpolyynes

H_3C_9H

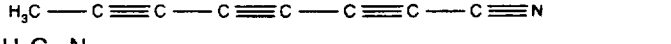
$H_3C_{11}H$



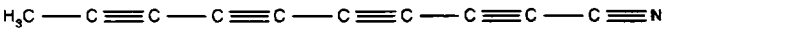
Methylcyanopolyynes

H_3C_8N

$H_3C_{10}N$



$H_3C_{12}N$

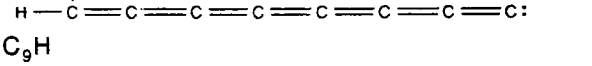


Free Radicals

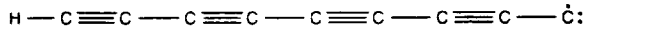
* C_7H

* C_8H

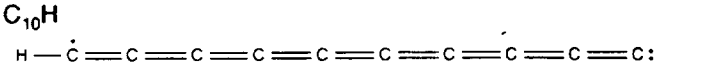
C_9H



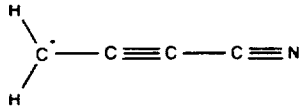
$C_{10}H$



$C_{11}H$

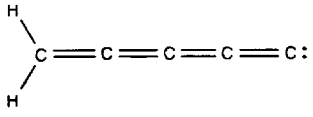


H_2C_4N

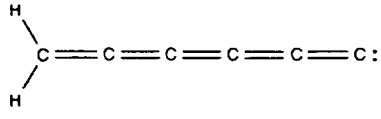


Cumulene Carbenes

H_2C_5

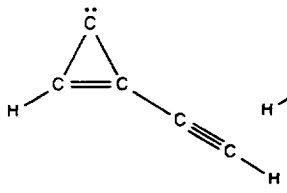


* H_2C_6

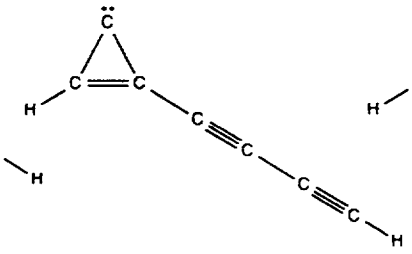


Ring-Chain Carbenes

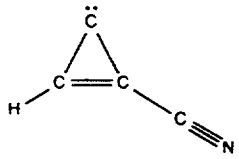
C_5H_2



C_7H_2



HC_4N



HC_6N