RECENT OBSERVATIONS OF ORGANIC MOLECULES IN NEARBY COLD, DARK INTERSTELLAR CLOUDS

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ABSTRACT. We report recent investigations of the organic chemistry of relatively nearby cold, dark interstellar clouds. Specifically, we confirm the presence of interstellar tricarbon monoxide (C_3O) in Taurus Molecular Cloud 1 (TMC-1); report the first detection in such regions of acetaldehyde (CH_3CHO), the most complex oxygen-containing organic molecule yet found in dark clouds; report the first astronomical detection of several molecular rotational transitions, including the J=18-17 and 14-13 transitions of cyanodiacetylene (HC_5N), the $1_{01}-0_{00}$ transition of acetaldehyde, and the J=5-4 transition of C_3O; and set a significant upper limit on the abundance of cyanocarbene (HCCN) as a result of the first reported interstellar search for this molecule.

1. INTRODUCTION

Throughout most of the history of spectral line radio astronomy those concentrations of the interstellar medium thought to exhibit the most complex chemistry have been the giant molecular clouds, including particularly the region Sgr B2 located near the center of the Milky Way Galaxy and the Orion molecular cloud, the closest such region to the solar system. Such giant molecular clouds are the most massive objects in our Galaxy and are obvious sites of current massive star formation. More recently, however, it has become apparent that some of the less

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massive, more nearby regions known as cold, dark clouds also exhibit a rich organic chemistry which has characteristics of its own. Although such clouds appear to lack embedded massive stars, they can apparently be the sites of solar type star formation. Among the closest is the complex of clouds in the constellation of Taurus. Taurus Molecular Cloud One (TMC-1) is a small condensation which is part of an extended ring-like structure, which itself may be the product of the collapse and condensation of a larger molecular cloud on its way to the formation of multiple solar-type stars (Schloerb and Snell, 1984). Some thirty diatomic and polyatomic molecular species have been identified in TMC-1, and it has become a particularly well examined testing ground for observational and theoretical studies of interstellar chemistry (e.g., Irvine et al., 1984). This chemistry differs significantly from that exhibited in the giant molecular clouds such as Orion, and even from that characterizing other cold, dark clouds such as L134N, because of the relatively high abundance of a variety of acetylene and polyacetylene derivatives, including cyanopolyynes with lengths up to $H(C\equiv C)_4CN$, methylated varieties such as $CH_3C\equiv CCN$ and $CH_3(C\equiv C)_2H$, and several related radicals.

2. OBSERVATIONS AND RESULTS

The observations of HC_5N and C_3O were carried out at the Nobeyama Radio Observatory in Japan, using the 45 m millimeter-wavelength radio telescope and the procedures described by Brown et al. (1984). The observations of acetaldehyde were made at the US National Radio Astronomy Observatory's 43 m telescope in Green Bank, West Virginia (Matthews et al., 1984b). A search was conducted for HCCN using the 14 m antenna of the Five College Radio Astronomy Observatory operated by the University of Massachusetts, for which the HPBW and main beam efficiency are 60 arcsec and 0.55, respectively. The spectrometer was a 256 channel filter bank/spectrum expander, providing a resolution of 50 kHz. System performance was checked by observing the two strongest hyperfine components of the J=1-0 transition of C_2H in TMC-1.

2.1. Tricarbon Monoxide

C_3O was only recently observed for the first time in a terrestrial laboratory and the prediction and verification of its existence in the interstellar medium is an excellent example of the interplay between theoretical quantum chemistry, laboratory microwave spectroscopy, and high frequency radio astronomy. The initial astronomical detection consisted of observations of a single line only, the J=2-1 transition (Matthews et al., 1984a). The conclusive identification of this species in space is now provided by the present detection of the J=5-4 line (Figure 1), as well as by detections of the J=9-8 and 8-7 transitions reported elsewhere (Brown et al., 1984). Tricarbon monoxide is the heaviest oxygen-containing organic molecule yet discovered in the nearby dark clouds. It is similar to the cyanopolyynes ($HC_{2n+1}N$) in being much more prominent in the spectrum of TMC-1 than in any other known

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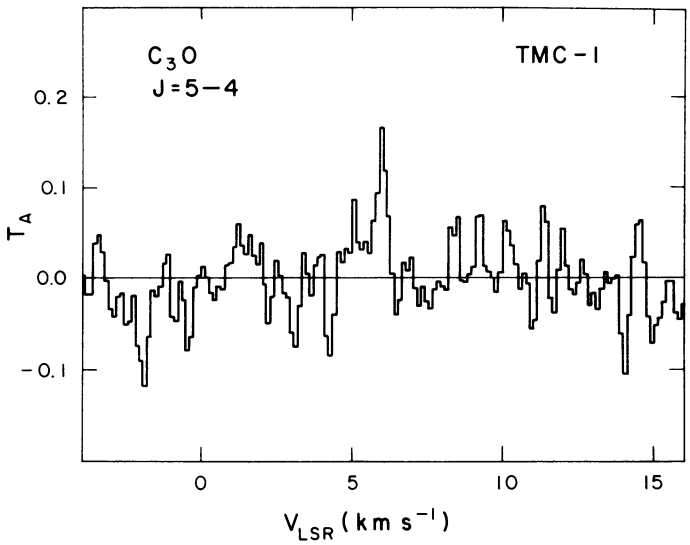

Figure 1. Confirmatory detection of interstellar C_3O (T_A in K).

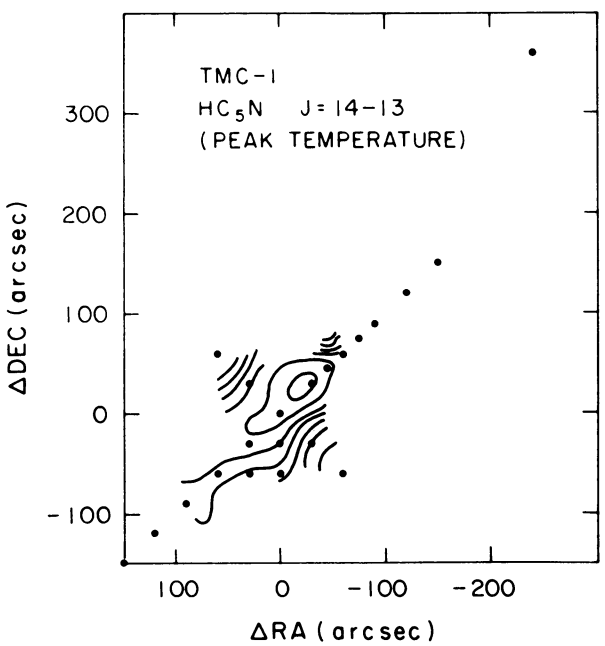

Figure 2. Contour map of HC_5N emission about cyanopolyyne peak.

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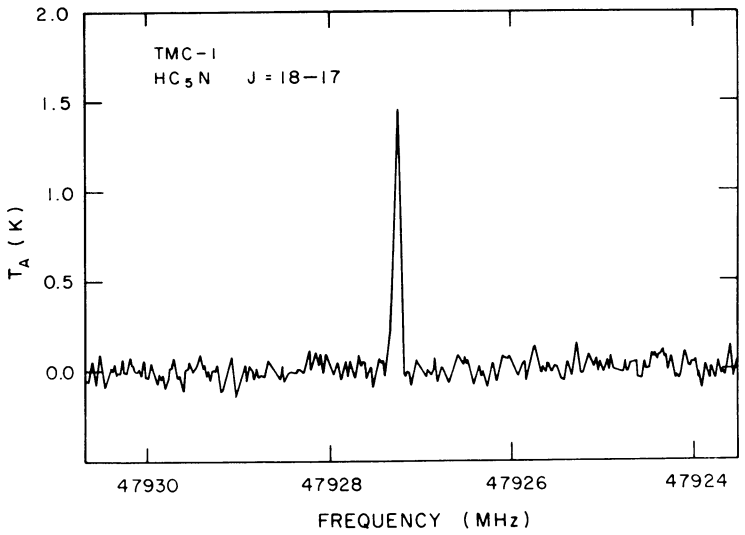

Figure 3. A new rotational transition of cyanodiacetylene.

interstellar molecular cloud, but unlike the latter molecules in not being observed in the extended envelope of the evolved carbon star IRC+10216. The calculated abundance of C_3O agrees very well with models of purely gas phase ion-molecule interstellar chemistry in TMC-1 (Brown et al., 1984).

2.2. Cyanodiacetylene

This linear molecule provides an interesting probe of physical conditions in those Taurus clouds where it can be detected, and has provoked considerable interest in the chemical processes determining its abundance (e.g., Snell et al., 1981; Schloerb et al., 1981). Figure 2 is a contour map of the peak temperature of the J=14–13 rotational transition in TMC-1, and illustrates the narrow width of this cloud that has been found in the emission from a number of molecular species. Figure 3 illustrates the first astronomical detection of the J=18–17 rotational transition for HC_5N, which was observed to monitor telescope pointing and spectrometer frequency stability during the C_3O study.

2.3. Acetaldehyde

Heretofore CH_3CHO has been detected in the interstellar medium only in the giant molecular cloud located near the center of our galaxy, Sgr B2. Unlike many other complex organic species, it does not seem to be present in the closest such giant molecular cloud, that in Orion (Irvine et al., 1984). Figure 4 illustrates our detection of both the A and E symmetry species of CH_3CHO in two nearby cold clouds.

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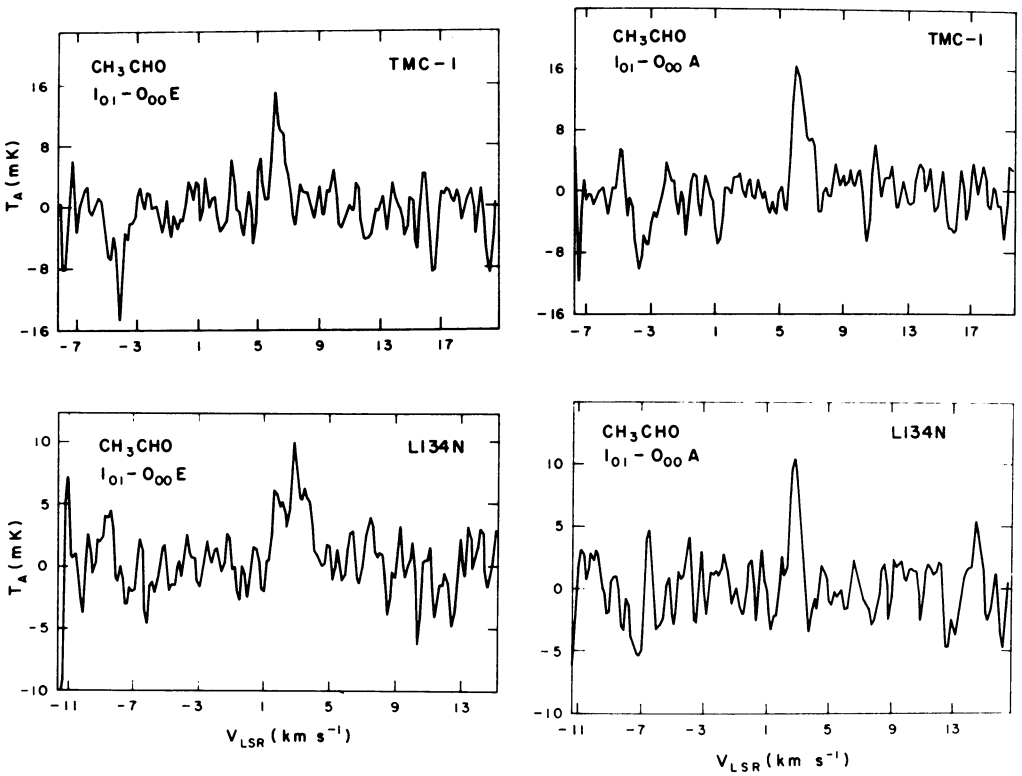

Figure 4. Detection of acetaldehyde in two cold, dark clouds.

The line strengths are quite comparable in both TMC-1 and L134N, indicating comparable abundances in these two sources. This is of considerable chemical interest, since many unsaturated or only slightly saturated organic compounds are considerably more abundant in TMC-1 than in physically similar clouds outside the Taurus region (specifically including the cyanopolyynes, related radicals such as C_3N and C_4H, and methylated relatives such as CH_3C_3N and CH_3C_4H; e.g., Irvine et al., 1984). On the other hand, some oxygen-containing molecules such as SO_2 appear to be more abundant in L134N. The reasons for these differences are not clear at present, but the detection of acetaldehyde in TMC-1 at a comparable abundance to that in L134N indicates that the chemistry of the former source is not restricted to highly unsaturated species or oxygen-deficient molecules. The present data represent the first astronomical detection of the 1_{01}-0_{00} transitions of acetaldehyde.

2.4. Cyanocarbene

It is apparent from the above discussion that polyacetylene deriv-

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atives play an important role in the chemistry of TMC-1. Although the detection of deuterated isotopic varieties at least for the lighter cyanopolyynes supports the gas phase production for some of these molecules, exact processes remain a matter of controversy. For example, several authors have proposed mechanisms in terms of reactions involving acetylene (HCCH) or acetylenic ions, with the result that the unsaturated carbon chains would be lengthened primarily by even units, which would be consistent with the observation of the cyanopolyynes (Schiff and Bohme, 1979). On the other hand, Suzuki (1983) has proposed that such species form in regions where carbon is partially ionized and has suggested a mechanism involving reactions with C^+. In this case, chain lengths intermediate to those observed thus far in interstellar clouds would also be abundant. Very recently the simplest such species (HCCN) has been observed in the laboratory (Saito et al., 1984), and we are able to report here the first astronomical search for this radical. We obtained a 3σ upper limit on antenna temperature T_a^* of 40mK for the N,J=4,5-3,4 transition at 87.8 GHz. Although the electric dipole moment for HCCN has not been measured, it seems likely that it will be intermediate between those for HCN and HC_3N. Assuming that we would not have resolved any nitrogen hyperfine splitting, and adopting a rotational temperature of 5K (similar to that for HC_3N), we calculate an upper limit on the column density towards the position of maximum cyanopolyyne emission in TMC-1 of $N \lesssim 1(10)^{12}$ cm^{-2}. As this value is considerably below the corresponding column density for HC_3N and HCN (Irvine et al., 1984), our results seem to support those chemical models in which acetylene and related ions play an important role in the production of heavier, linear molecules.

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