CYANOACETYLENE: NEW LINES AND SOURCES IN THE GALAXY

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Abstract. Microwave emission from the $J = 8 \rightarrow 7$ through the $J = 11 \rightarrow 10$ rotational transitions of HC_3N has been detected in the directions of Sgr(NH_3A), Sgr B2, and Orion A. A map of the $J = 8 \rightarrow 7$ emission around Sgr B2 shows that the emitting region extends at least 2′ in galactic longitude and 3′ in galactic latitude. Column densities may be comparable to those of HCN in some sources. This molecule is thus more abundant in the interstellar medium than would be expected from its complexity, and may provide clues to formation processes where it is found.

With a reasonable model for excitation of the rotational levels, we have used the ratio of antenna temperatures of these 2 lines to derive a value for the molecular density in the region where the lines originate. For Sgr B2, this yields $N_{H_2} \approx 10^6$, and for Sgr(NH_3A), $N_{H_2} \approx 6 \times 10_4$.

The pursuit of information about physical conditions in opaque dust clouds has proceeded primarily through surveys of radio frequency molecular lines. In this presentation, we suggest that cyanoacetylene is especially useful as a probe of these clouds because of its large abundance and large number of detectable rotational lines. Four previously unobserved rotational lines of HC_3N(H–C≡C–C≡N) were detected, with at least one line appearing in four of the eight sources surveyed. The implied abundances of cyanoacetylene are large enough that a study of its chemistry and formation processes may supply needed clues about why large interestellar molecules exist in detectable quantities.

Astrophysically speaking, cyanoacetylene is a relatively large molecule. With four heavy atoms, it has the greatest number of large atoms seen together in a single molecule. However, it is a linear molecule with a simple ladder of rotational energy levels corresponding to end over end rotation just like a diatomic molecule. The resulting rotational spectrum of HC_3N is uncomplicated and happens to be quite accessible to present radio receivers.

The molecule was discovered as an interstellar constituent in 1970, when Turner (1971) observed the $J = 1 \rightarrow 0$ line in the direction of Sgr B2. His search for the same transition in many other sources yielded negative results, probably because of the

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relatively low optical depth of this line for most excitation conditions. The three new sources reported here from observations of higher lying transitions are on his list of negative results. With various assumptions Turner derived a column density of 2×10^{16} cm^{-2} for Sgr B2. For comparison, this is larger than ammonia and an order of magnitude larger than formaldehyde in the same source.

We report observations of four successive rotational lines of HC_3N:

$$\begin{aligned} J = \ & 8 \rightarrow 7 \ \text{at} \ 72.8 \ \text{GHz} \\ & 9 \rightarrow 8 \ \text{at} \ 81.3 \ \text{GHz} \\ & 10 \rightarrow 9 \ \text{at} \ 91.0 \ \text{GHz} \\ & 11 \rightarrow 10 \ \text{at} \ 100.1 \ \text{GHz}. \end{aligned}$$

The observations were made in February, May and June, 1972 with the Kitt Peak 36′ radiotelescope of the National Radio Astronomy Observatory. At least one of these lines was detected in four of the eight sources studied. Full details of the observations will be published later.

In Sgr B2, all four lines were seen and although a complete analysis remains to be done, several things can be readily deduced. First, a density of at least 10^6 particles cm^{-3} is needed to produce the observed $J = 9 \rightarrow 8$ and $8 \rightarrow 7$ line intensities if

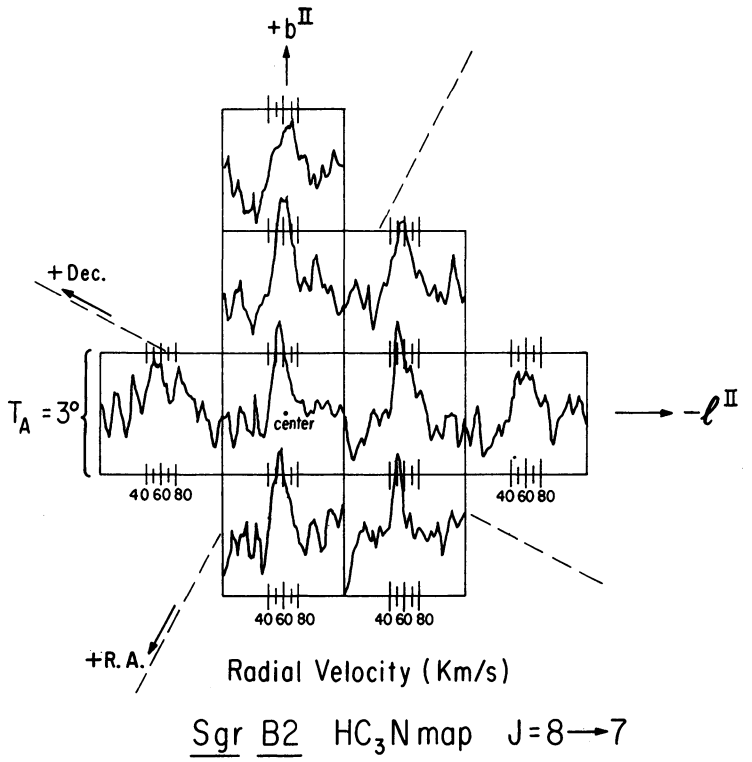

Fig. 1. The $J = 11 \rightarrow 10$ transition of HC_3N in Sgr B2. *Ordinate*, antenna temperature; *abscissa*, radial velocity with respect to the local standard of rest. The velocity resolution is 3.6 km s^{-1}.

collisional excitation is the principal factor in populating the levels. Second, either the $J = 11 \rightarrow 10$ transition is 'anomalously' strong or the $J = 10 \rightarrow 9$ is 'anomalously' weak. Figure 1 shows the $J = 11 \rightarrow 10$ line in Sgr B2. It is displaced in the spectrum in order to facilitate a search for another molecular candidate. A density much higher than 10^6 cm^{-3} is required to significantly populate the $J = 11$ level by collisions. Perhaps another mechanism is at work here, as this line was also relatively strong in Orion A and possibly the only line seen in W51. The excitation is apparently not characterized by thermal populations. However, few interstellar molecules have shown thermal excitation. Statistical equilibrium analyses are almost always necessary, and are definitely needed in this case.

A limited map with points spaced by one arcminute intervals was made of the 72.8 GHz emission in Sgr B2. (Figure 2). The full beam width at half power for the 36 ft telescope at 73 GHz is about 95″, so the emission is clearly extended over a region of about $2' \times 3'$ and perhaps even larger. Given the high molecular hydrogen densities implied by the line ratios at the center point of the map, simple assumptions lead to a total cloud mass of $\geq 10^7$ solar masses. This lower limit can perhaps be increased further when similar and more complete surveys are made in all of these rotational lines. Observations of ammonia (2,1) inversion radiation (Zuckerman *et al.*, 1971) lend support to this surprisingly large total mass for this source. Simplifying assumptions allow calculations to be made which show that for this lower limit to the mass, the cloud is unstable to gravitational contraction. A second feature of our map is that

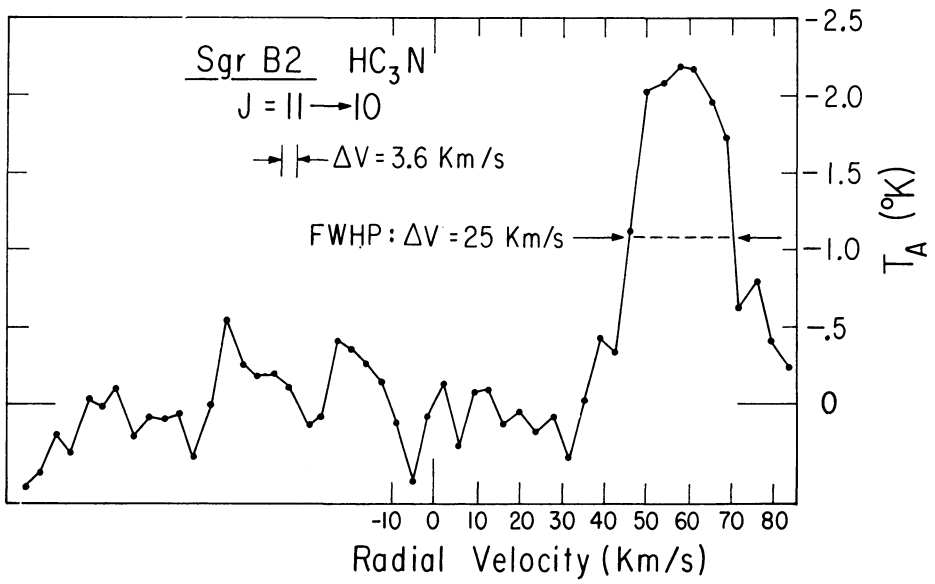

Fig. 2. Map in galactic coordinates of the $J = 8 \rightarrow 7$ emission of HC_3N in Sgr B2. The spectra displayed in each square are spaced by 1′ in each direction: galactic longitude increases from right to left, and galactic latitude increases fro bottom to top. Dashed lines show the equatorial axes for reference. The velocity resolution is 6.2 km s^{-1}.

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the radial velocity changes from 54 km s^{-1} to 71 km s^{-1} in the direction of increasing galactic latitude. The same general velocity distribution has been noticed for other large molecules such as methyl alcohol in this source (Turner *et al.*, 1972).

The other three sources containing detectable amounts of cyanoacetylene are Sgr (NH_3A), Orion A, and W51. Projected densities were calculated assuming that the rotational levels are thermalized at 50 K. They range from 3×10^{13} cm^{-2} in Orion A to 3×10^{14} cm^{-2} in Sgr B2. These values are lower by a large factor than a previous estimate based on the $J = 1 \rightarrow 0$ transition in Sgr B2 (Turner, 1970) suggesting that the $J = 1 \rightarrow 0$ transition may be inverted. Deviations from thermal excitation in the states which we have observed will probably not affect the projected density estimates significantly.

Our observations make it apparent that HC_3N will be quite useful for obtaining a detailed picture of the physical conditions in large interstellar molecular clouds. First, with the plethora of available lines, the excitation of this molecule can be almost completely determined. This would present an opportunity for ascertaining the collisional and radiative contributions to the excitation, and thus very useful estimates of density, kinetic temperature, and radiation temperature throughout the source. The $J = 5 \rightarrow 4$ line will soon be searched for at Kitt Peak, and if it is seen, then a total of 8 of the 11 lowest lying rotational transitions will have been detected. This situation can be compared to that of ammonia, where the inversion radiation from within several rotational levels has been seen, although transitions between the rotational levels are inaccessible and at present undetected.

A second advantage of HC_3N as a probe is that surveys can be made with relatively high resolution. At 3 or 4 mm wavelengths where our transitions were seen, the 36-ft telescope beamwidth is of order 1′. In comparison, the most complete formaldehyde surveys of large molecular clouds have been made with 6′ resolution, but the tremendous optical depths in the large molecular clouds make it possible to view only the extreme outer layers. CS may overcome these difficulties since 3 of its transitions are now tractable. In the densest clouds, cyanoacetylene seems to offer the best advantages.

Considerations of the chemistry of HC_3N suggest a comparison with HCN in the sources studied. The following table lists R, the apparent ratio of the projected density of HCN to that of HC_3N in four sources:

	$R\left(\frac{HCN}{HC_3N}\right)$
Sgr B2	0.1
Sgr (NH_3A)	0.6
W51	0.8
Orion A	6.8

It is assumed that the $J = 1 \rightarrow 0$ HCN transition is thermalized and that the level populations fall off rapidly above the $J = 1$ state. Because the excitation of these molecules is uncertain, these ratios should be regarded as rough estimates. The sign-

ificance of these values lies in showing that the abundance of HCN relative to cyanoacetylene may vary by almost 2 orders of magnitude. This is possibly a density effect related to either the chemistry or the excitation of these molecules. Under non-interstellar conditions at least, an appreciable fraction of HCN can be converted to HC_3N in the presence of acetylene via a surface reaction, though more realistic experiments remain to be done before this mechanism for formation can be presumed.

We also consider more saturated hydrocarbons related chemically to cyanoacetylene. Vinyl cyanide results with the addition of 2 hydrogen atoms. We searched for the $3_{13} \rightarrow 2_{02}$ transition of this molecule without success, though little can be said about the existence of a molecule from a single negative result.

Finally, we note the possibility of studying isotopic variations. The preferential placement of C^{13} in any of the three slots in HC_3N would be an important clue to the formation process, but this is expected to be small and probably awaits the advent of highly sensitive receivers in the millimeter-wavelength range. The rotational transitions of $H^{12}C^{13}C^{12}CN$ and $H^{12}C^{12}C^{13}CN$ are nearly coincident in frequency. The velocity width of these lines in several sources causes a frequency overlap of the lines of these two species. This increases the optical depth by a determined amount. Ideally, observations of the three C^{13}-substituted variations will thus yield the optical depth. The C^{13}/C^{12} isotope ratio can then be obtained in sources where the line is strong such as the galactic center where this ratio is presently in question.

In summary, these observations suggest the potential use of cyanoacetylene for the study of both the physics and chemistry of large molecular clouds. The molecules which have accessible radio frequency transitions will collectively be excellent probes for interstellar conditions in regions that are optically obscured.

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