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DETECTION OF INTERSTELLAR CYANOACETYLENE

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ABSTRACT

Microwave emission from cyanoacetylene (HC₃N) has been detected in the galactic radio source Sgr B2. Two of the three quadrupole-split transitions of the $J = 0 \rightarrow 1$ transition were observed, the strongest with a strength of ~4 f.u. The emission is not linearly polarized. Within the frequency uncertainty of the transitions the HC₃N lines in Sgr B2 have the same radial velocity, $+62 \text{ km s}^{-1}$, as the formaldehyde absorption. No HC₃N was detected in sixteen other galactic sources in which the molecules OH, H₂CO, and HCN have been detected.

During a search for several interstellar molecules in the frequency range 5–10 GHz conducted with the NRAO 140-foot telescope in 1970 July, line emission was detected from two spectral features in the direction of the galactic source Sgr B2. These spectral features have a frequency difference of 1.27 ± 0.13 MHz and are centered at a frequency of ~9097.7 MHz. On this basis, the line emission is attributed to the $J = 0 \rightarrow 1$ transition of cyanoacetylene (H-C=C-C=N).

Cyanoacetylene is a linear molecule without internal rotation, whose dipole moment is 3.6 debyes (Westenberg and Wilson 1950). The rotational transitions are hyperfinesplit owing to the interaction of the electric-quadrupole moment of the ¹⁴N nucleus (whose spin is unity) with the electronic-charge distribution. In molecules such as cyanoacetylene, in which all electrons are paired to produce no net electronic angular momentum, there is still a magnetic hyperfine splitting arising from the interaction of the magnetic-dipole moment of the H nucleus with the (small) magnetic fields produced by molecular rotation ($I \cdot J$ interactions). However, these hyperfine splittings are typically very small, usually ~ 5 kHz, and may for present purposes be ignored in view of the much broader line widths of the interstellar lines, which result from turbulent and Doppler broadening.

Because of electric-quadrupole hyperfine splitting, the $J = 0 \rightarrow 1$ transition of cyanoacetylene is split into three transitions whose designations, frequencies, and relative intensities are as follows: $F = 1 \rightarrow 1$ (9097.09 MHz; R.I. = 3); $F = 1 \rightarrow 2$ (9098.36 MHz; R.I. = 5); $F = 1 \rightarrow 0$ (9100.32 MHz; R.I. = 1). The frequencies are those measured by Tyler and Sheridan (1963), while the relative intensities are calculated from formulae given by Townes and Schawlow (1955).

At 9098 MHz the 140-foot telescope has an aperture efficiency of 40 percent on the meridian and at the declination of Sgr B2, and a beam efficiency of \sim 53 percent. A flux of 4.8 f.u. corresponds to an antenna temperature of 1° K, based upon an assumed flux of 7.7 f.u. for 3C 123. The beamwidth is 3'.30 \times 3'.15. The feed was a rotatable horn which allowed the measurement of linear, but not circular, polarization. The receiver consisted of an uncooled parametric-amplifier first stage and a tunnel-diode second stage, followed by the 413-channel autocorrelator of the NRAO. The system temperature on cold sky was \sim 350° K. The first local oscillator consisted of the amplified thirty-second harmonic of a frequency synthesizer which was synchronized to a rubidium standard. The spectral width of the first local oscillator was 500 Hz. Frequency switching

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in the first local oscillator was used, and reference spectra obtained off-source were subtracted from the on-source spectra.

Figure 1 is the observed spectrum of the $F = 1 \rightarrow 1$ and $F = 1 \rightarrow 2$ transitions in Sgr B2. The arrows indicate the laboratory-measured separation of these transitions. The $F = 1 \rightarrow 0$ transition was not observed owing to limited observing time. The position used in Sgr B2 is that of the peak of the continuum source, at R.A. $17^{h}44^{m}11^{s}$, decl. $-28^{\circ}22'30''$. This is also the position of maximum optical depth of the formaldehyde in Sgr B2 (Zuckerman *et al.* 1970). The intensity of the $F = 1 \rightarrow 2$ feature is $0.87 \pm 0.094^{\circ}$ K (4.2 ± 0.45 f.u.), while that of the $F = 1 \rightarrow 1$ transition is $0.32 \pm$ 0.094° K (1.5 ± 0.45 f.u.). The ratio ($F = 1 \rightarrow 2$)/($F = 1 \rightarrow 1$) has the value 2.72 \pm 0.85 where the uncertainties are 5 σ . With a high probability the ratio therefore exceeds the LTE value of $\frac{5}{3}$.

Based on a rest frequency of 9098.36 MHz, the velocity of the HC₃N emission in Sgr B2 is 64.0 ± 1.8 km s⁻¹, close to that of formaldehyde (61.6 km s⁻¹) and of a few fairly strong OH emission features (60-62 km s⁻¹) which, at position R.A. $17^{h}44^{m}10^{s}5 \pm 0^{s}4$, decl. $-28^{\circ}22'15'' \pm 3''$ (Raimond and Eliasson 1969), also lie within the antenna beamwidth. If, instead, the HC₃N is assumed to have the formaldehyde velocity of 61.6 km s⁻¹, then the rest frequency of the $F = 1 \rightarrow 2$ transition is 9098.287 MHz ± 0.055 MHz, or 73 ± 55 kHz lower than the measured value of Tyler and Sheridan (1963). The uncertainties given are $5-\sigma$ values based upon the noise only.

The full line width to half-power of the $F = 1 \rightarrow 2$ feature of HC₃N is 19.0 \pm 1.8 km s⁻¹, considerably less than the width of 26.3 km s⁻¹ reported for H₂CO (Zuckerman *et al.* 1970). The ratio of line widths for HC₃N and H₂CO is probably not consistent with pure Doppler broadening for both molecules, and the spectrum in Figure 1 indicates the presence of many highly blended components. The velocity range covered by the HC₃N emission is ~ 27 to ~ 81 km s⁻¹. This is less than the range $\sim 15-95$ km s⁻¹ covered by the strongest H₂CO feature, but greater than the range $\sim 50-78$ km s⁻¹ covered by the strongest OH emission in Sgr B2.

Neither hyperfine feature of HC_3N shows apparent linear polarization; based on the spectra taken at four position angles, the linear polarization is ≤ 30 percent.

The negative results for the observations of the $F = 1 \rightarrow 2$ and $F = 1 \rightarrow 1$ transitions of HC₃N are summarized in Table 1. Column (1) gives the source; columns (2) and (3) the position used; column (4) the velocity range covered for the $F = 1 \rightarrow 2$ transition relative to the local standard of rest; column (5) the spectral resolution, and column (6) the peak-to-peak noise in the spectrum.



FIG. 1.—Spectrum of HC₃N in the direction of the continuum peak of Sgr B2. Velocity scale refers to the $F = 2 \rightarrow 1$ transition; arrows indicate separation expected between the $F = 2 \rightarrow 1$ and $F = 1 \rightarrow 1$ transitions on the basis of laboratory measurements.

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TABLE 1 SUMMARY OF NEGATIVE RESULTS

The outer two quarters 5 Times RMS Noise 0.12 0.36 0.24 0.13 0.17 0.26 0.46 0.46 0.29 0.20 0.39 0.36 0.31 0.34 0.19 0.24 0.22 Resolution (km/s) The middle one-half of the velocity range covered has the sensitivity indicated. 2.094 1.047 2.094 2.094 2.094 2.094 2.094 1.047 1.047 1.047 1.047 1.047 1.047 1.047 2.094 2.094 2.094 Velocity Range (km/s)* - 96.85 to 114.15 to 107.5 64.4 57.7 to 110.5 to 105.5 to 113.5 to 234.3 to 224.9 to 251.1 to 251.1 to 170.9 to 221.1 to 281.1 to 211.1 to 297.1 to 169.1 to to -171.1 -146.6 -153.3 -100.5 -211.1 -103.5 - 97.5 -125.1 -253.1 - 40.1 -105.5-141.1 -201.1 -197.3 -171.1 -187.9 30 48 30 8 8 8 8 8 53 8 48 8 30 21 -01 55 42 17 -02 00 00 RA (1950) decl (1950) -05 24 38 58 52 39 60 5 56 +14 24 +25 18 +42 12 -20 19 +09 01 -16 12 -58 32 -04 -28 +61 T9+ +42 -29 -27 8 28 28 45 41 55 23 17 38 30 45 00 53 14 47 12 36 Ц 27 20 37 14 24 51 42 42 37 32 39 90 21 21 17 07 21 ង 19 04 05 05 18 19 17 17 17 02 02 20 18 18 23 Sag A (NH₃A) Sag A (NH₃B) Source 2 DR210H Cloud L 134 Sag A Ori A Ori B **DR 21** ◄ HOEW Сав W49 W51 W43 M17 W31 EW *

The optical depth at the center of the $F = 1 \rightarrow 2$ line is given by

$$\tau = \frac{5}{9} \frac{\lambda^2 A}{8\pi\delta\nu} \frac{g_1}{g_0} N_0 \left(1 - \frac{g_0}{g_1} \frac{N_1}{N_0} \right).$$

Here, the factor $\frac{5}{9}$ arises as the result of hyperfine dilution. N_0 and N_1 are the column densities in the J = 0 and J = 1 states, and $A = 3.79 \times 10^{-8} \text{ sec}^{-1}$ is calculated from the matrix elements for symmetric tops (Townes and Schawlow 1955) and is the same for the $F = 2 \rightarrow 1$ transition as for the overall $J = 1 \rightarrow 0$ transition.

Since the spatial distribution of the HC₃N emission was not determined, we shall assume that it fills the beam of the telescope. Then in the optically thin approximation

$$T_A = \eta_B (T_s - T_c - 3)\tau,$$

where $T_c \simeq 10.0^{\circ}$ K is the continuum temperature of Sgr B2 and the 3° K accounts for the cosmic background. Hence the excitation temperature T_s must be $> \sim 13^{\circ}$ K. On the other hand, it is unlikely to exceed $\sim 50^{\circ}$ K, the rotational temperature estimated for the CO transition $J = 1 \rightarrow 0$ at 115 GHz (Jefferts *et al.* 1970). Since $h\nu/kT_s \ll 1$, and assuming that

$$N = \sum_{J=0}^{\infty} N_J = N_0 \sum_{J=0}^{\infty} (2J+1) \exp\left[\frac{-hBJ(J+1)}{kT_s}\right] \simeq N_0 \frac{kT_s}{hB}$$

(see Townes and Schawlow 1955), we find

$$N = 3.6 \times 10^{14} T_A T_s^2 / (T_s - T_c - 3) \text{ cm}^{-2}$$
.

For $T_s = 50^{\circ}$ K this gives $N = 2.1 \times 10^{16}$ cm⁻² for Sgr B2. By comparison, the column density of formaldehyde at the same velocity in Sgr B2 is 1.8×10^{15} cm⁻², on the assumption that its excitation temperature is 3° K and that the region of absorption fills the measuring beamwidth of ~ 6 arc min (Zuckerman *et al.* 1970).

The above value of N for HC₃N is very uncertain owing to the assumptions made. If the size of the emission region is assumed to be smaller than the beamwidth, for which there was some observational evidence, then the value of N is a lower limit if T_s is larger than T_c and positive. However, if T_s is negative, then we will have overestimated N. At present there is no reason to suppose that T_s is negative; the pumping schemes that have been proposed for OH and H₂CO do not seem applicable to the relatively simple energy-level scheme of HC₃N which shows neither Λ -doubling nor asymmetric doubling. Infrared effects may indeed perturb the relative populations of the hyperfine levels in HC₃N, as appears to be indicated by the present observations, but without Λ - or asymmetric doubling these effects seem unable to alter the relative populations of the overall rotational states. However, observation of the $J = 2 \rightarrow 1$ transition at ~ 18.2 GHz is needed to prove this point.

If T_s is indeed positive, then it must exceed the 3° K background, which means that the rate of collisions of the HC₃N molecules with other particles in the cloud must exceed the rate of interaction with the 3° K background photons. Assuming a cross-section for collision with (neutral) particles of $\pi(4.80 \text{ Å})^2$, where the length of the HC₃N molecule is 4.80 Å (Westenberg and Wilson 1950), leads to a total particle density of $> \sim 300$ cm⁻³ if the kinetic temperature is 50° K and the colliding particles have unit molecular weight. This result must be considered a lower limit for the density, since the crosssection is undoubtedly smaller than the assumed geometric value and because the mean molecular weight of the colliding particles must exceed unity. In this regard we note that there is little or no HCN in Sgr B2 (Snyder and Buhl 1970), which indicates that all of the hydrogen must be tied up in the form of acetylene or other molecules.

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