INTERSTELLAR ISOCYANIC ACID

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ABSTRACT

Interstellar isocyanic acid (HNCO) has been detected in emission through the 4_{04}–3_{03} ground-state rotational transition at 3.4 mm. Out of nine galactic sources surveyed, HNCO has been observed only in the direction of Sgr B2 and possibly W51. The Sgr B2 emission pattern is fairly extensive, and our observations indicate that the peak HNCO emission is $\sim 2'$ north of the OH position. A search for the 7–6 transition of interstellar OCS yielded negative results.

Earlier we reported the detection of the 4_{04}–3_{03} transition of interstellar isocyanic acid (HNCO) in emission at 87,925 MHz during an observing period in 1971 May (Snyder and Buhl 1971b). In 1971 December, we completed a preliminary survey for HNCO in a number of galactic molecular sources, and our results are reported here. Both sets of observations were made with the NRAO 36-foot (11-m) radio telescope; the nominal half-power beamwidth at 3.4 mm is 78″ with pointing uncertain by $\pm 10''$. Frequency switching of the first local oscillator was used in the May observations; a ferrite beam switch with 15′ feed separation was used in December. In both sets of observations, the radiometer feed was alternately moved on and off source to subtract a cold-sky comparison spectrum. The single-sideband noise temperature of the radiometer was $\sim 7000°$ K for both observing periods. The filter bank used for the observations has 40 filters spaced 1 MHz apart and covers a velocity range of 136 km s^{-1} at 3.4 mm.

The 4_{04}–3_{03} ground-state rotational transition of HNCO definitely has been detected in Sgr B2 (see fig. 1) and possibly in W51. Our initial identification of interstellar HNCO was based on the excellent agreement between our astronomical rest frequency and the laboratory frequency of $87,925.45 \pm 0.5$ MHz determined by Kewley, Sastry, and Winnewisser (1963); the subsequent detection of the 1_{01}–0_{00} transition at 21,982 MHz (see fig. 2) has confirmed our identification (Buhl, Snyder, and Edrich 1972) and is discussed in the following paper. A nine-point map of the region around Sgr B2(OH) (the OH and H_2O emission position in the direction of Sgr B2) shows that the HNCO emission is fairly extensive over a region $\geq 4'$ in diameter. The observations are summarized in table 1, where the mapping coordinates are listed as displacements from Sgr B2(OH). Column (4) gives the observed antenna temperature (uncorrected for atmospheric extinction), and the last two columns list radial velocity and line width at half-maximum intensity for those spectral features with the best signal-to-noise ratio. The radial velocities are uncertain by ± 1.7 km s^{-1} and temperature calibration by ~ 20 percent. We included the W51 results in table 1, but they must be confirmed by future observations.
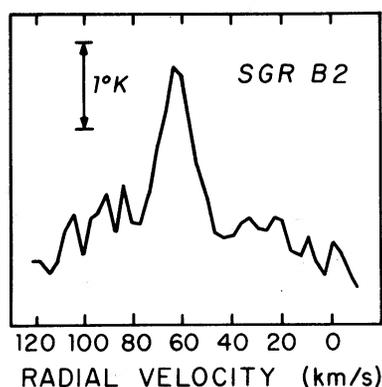
FIG. 1.—The observed emission spectrum of the 4_{04}–3_{03} transition of interstellar isocyanic acid (HNCO) in the direction of Sgr B2(OH) ($\alpha_{1950} = 17^h44^m11^s$, $\delta_{1950} = -28°22'30''$). The ordinate is antenna temperature (not corrected for atmospheric extinction), and the abscissa is radial velocity with respect to the LSR.

We have found that the HNCO emission is strongest at a position 2' north of Sgr B2(OH) but at 4' north the intensity drops sharply. Interestingly enough, Cheung *et al.* (1969) found similar behavior for the (3, 3) transition of NH_3. They observed maximum (3, 3) intensity 2' north of their map center (displaced from our center by only $\Delta\alpha = -10^s$ and $\Delta\delta = +54''$) and a sharp intensity drop at 4' north. The HNCO emission is located in the direction of the H_2CO Cloud 10 observed by Scoville, Solomon, and Thaddeus (1972), and the peak emission falls within the region of highest H_2CO optical depth and equivalent width (30 km s^{-1}). The HNCO emission
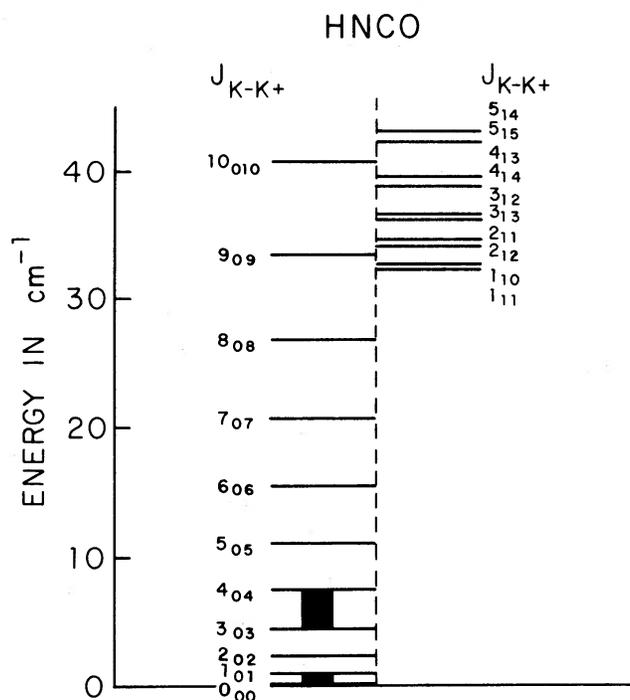

FIG. 2.—The lowest ground-state rotational energy levels of HNCO. The rotational transitions which we have detected to date are illustrated by bars connecting the appropriate J_{0J} levels.

TABLE 1

SUMMARY OF HNCO EMISSION FEATURES

Source (1)	α_{1950} (2)	δ_{1950} (3)	Antenna Temperature (°K) (4)	Radial Velocity (km s^{-1}) (5)	Line Width (km s^{-1}) (6)
Sgr B2(OH)...........	$17^h44^m11^s$	$-28°22'30''$	1.88	+61	17
Displacement.......	0	+2'	~2.4*	~61	
Displacement.......	0	-2'	~1.7	~61	
Displacement.......	+8^s	0	~1.8	~61	
Displacement.......	-8^s	0	~1.5	~61	
Displacement.......	0	+4'	<1.1	...	
Displacement.......	0	-4'	<1.3	...	
Displacement.......	+16^s	0	<1.3	...	
Displacement.......	-16^s	0	<1.5	...	
W51................	$19^h21^m27^s$	$+14°24'30''$	0.9?	+63	10

* HNCO emission peak.

peak is also near the position of the dense core region in Sgr B2 where the (2, 1) transition of NH_3 originates (Zuckerman et al. 1971) and within the beamwidth (~5'.3) used for their observations. Moreover, the radial velocity of the (2, 1) line of NH_3 at the point of maximum emission (62 km s^{-1}) appears to be within the observational uncertainty of the 61 km s^{-1} velocity which we have determined for the HNCO. On the other hand, the peak HNCO emission does not appear to coincide with any significant change in the emission intensity of $^{12}C^{16}O$ (Penzias, Jefferts, and Wilson 1971). We have determined an excitation temperature T_e of 12.8° K from the intensity ratio of the 4_{04}–3_{03} to the 1_{01}–0_{00} transition by assuming that the HNCO depth is small. A minimum T_e of 7.4° K was found if the optical depth at the 4_{04}–3_{03} transition is very high. The projected density for the 3_{03} level in the optically thin case is given by

$$n_L = \frac{3ck}{(1 - T_b/T_e)8\pi^3\nu^2|\mu_{3_{03}\to4_{04}}|^2}\frac{\Delta T\Delta\nu}{\eta},$$

where ΔT is the measured antenna temperature, $\Delta\nu$ the line width, η the beam efficiency, and $|\mu_{3_{03}\to4_{04}}|$ the dipole-moment matrix element. Adapting $T_b = 3°$ K for the microwave background, $\eta = 0.45$, and $T_e = 12.8°$ K, we find n_L for the 3_{03} level of HNCO to be 1.2×10^{14} cm^{-2} at the Sgr B2(OH) position in table 1. The total HNCO projected density N_L may be estimated from the bounds established by a Boltzmann distribution over all levels and a distribution truncated at the 4_{04} level. Thus for a rotational excitation temperature of 12.8° K we find 4.5×10^{14} cm$^{-2} < N_L < 6.4 \times 10^{14}$ cm^{-2}. We can estimate the volume density, $N(HNCO)$, from the ~2' angular radius of the emission region. If the distance to Sgr B2 is 10 kpc and the HNCO is spherically distributed, then 1.2×10^{-5} cm$^{-3} < N(HNCO) < 1.8 \times 10^{-5}$ cm^{-3}. This estimate can be greatly improved when more is known about the HNCO excitation and spatial distribution in the Sgr B2 region.

In order to compare our Sgr B2 results with other observations, we estimated the minimum H_2 density, $N(H_2)$, required to collisionally excite HNCO against the microwave background from

$$N(H_2) = \frac{A_{43}[\exp(-h\nu/3k) - \exp(-h\nu/kT_e)]}{\sigma\bar{u}[1 - \exp(-h\nu/3k)][\exp(-h\nu/kT_e) - \exp(-h\nu/kT_K)]}.$$

If we use $T_K = 150°$ K for the Sgr B2 kinetic temperature (Solomon et al. 1971), $\bar{u} \approx 10^5$ cm s^{-1}, $\sigma = 1.2 \times 10^{-15}$ cm^2, $T_e = 12.8°$ K, and $A_{43} = 8.91 \times 10^{-6}$ s^{-1},

then $N(H_2) = 1.8 \times 10^5$ cm^{-3}. The HNCO emission region has a linear diameter greater than 11.6 pc which for $N(H_2) > 1.84 \times 10^5$ cm^{-3} corresponds to a total mass greater than $7.4 \times 10^6 M_\odot$. Thus our result is consistent with, but does not uniquely verify, the conclusion of Zuckerman et al. (1971) that the core of Sgr B2 has a total mass of at least $10^6 M_\odot$ because the presence of radiation sources such as the far-infrared emission peak at 100μ observed in the Sgr B2 region by Hoffmann, Frederick, and Emery (1971) or electron densities ~ 1 cm^{-3} could reduce these mass estimates. At present it is not possible to determine whether the 100-μ source corresponds to the OH emission peak, the HNCO peak, or neither because both positions fall within the 12' beamwidth of the infrared observations.

Our negative results for the 4_{04}–3_{03} transition are summarized in table 2. The first three columns list source, right ascension, and declination (epoch 1950); column (4) gives the estimated peak-to-peak noise in degrees Kelvin, and column (5) lists the radial-velocity range searched. The last column gives the radial velocity of the HCN emission line observed for each source. During a portion of our observations the lower sideband was tuned to the $J = 7$–6 transition of carbonyl sulfide (OCS) at 85,139 MHz (calculated rest frequency) while the upper sideband was used for the HNCO search. Thus the HNCO results found for IRC+10216, W49, and DR 21(OH) may be converted to negative results for the $J = 7$–6 transition of OCS by subtracting 22 km s^{-1} from the radial-velocity ranges in column (5). Our peak-to-peak noise limit is 0.7° K for Sgr B2(OH) over the velocity range from -70 to $+166$ km s^{-1}. This negative result is consistent with the detection of the 9–8 transition of OCS at 109,462.4 MHz reported by Jefferts et al. (1971); given their antenna temperature of 0.7° K and a rotational excitation temperature of 21° K with no beam dilution, we would expect an antenna temperature between 0.4° and 0.6° K for the 7–6 transition of OCS in the optically thin case.

The importance of the HNCO K-type doublets (right-hand side of fig. 2) for studying collisional pumping models was first noted by Townes and Cheung (1969). We have found two of the $J_{0J} \rightarrow J - 1_{0J-1}$ transitions (left-hand side of fig. 2) to be quite detectable, and the excitation energies required for other transitions of this type are low. There are perhaps 10 of these transitions which are of immediate interest to radio astronomy, but only four measurements are reported in the *Microwave Spectral Tables* (1968). Hence to facilitate the study of the interstellar excitation of HNCO we have used the parameters of Kewley et al. (1963) to compute frequencies for six other

TABLE 2
SUMMARY OF HNCO NEGATIVE RESULTS

Source (1)	α_{1950} (2)	δ_{1950} (3)	Peak-to-Peak Noise (°K) (4)	Radial-Velocity Range Searched (km s^{-1}) (5)	HCN Velocity* (km s^{-1}) (6)
W3(OH)†	$2^h23^m14^s$	$+61°38'30''$	0.28 ‡	$-114 \rightarrow +16$	-49
Orion A	5 32 47	-5 24 21	0.56	$-55 \rightarrow +75$	$+12$
NGC 2024	5 39 12	-1 55 42	0.53 ‡	$-56 \rightarrow +73$	-9
VY CMa	7 20 55	-25 39 54	0.53	$-65 \rightarrow +65$	...
IRC+10216	9 45 15	$+13$ 30 41	0.56	$-67 \rightarrow +63$	-24
W49	19 07 53	$+09$ 01 00	2.10	$-42 \rightarrow +88$	$+6$
DR 21(OH)	20 37 14	$+42$ 12 00	0.92	$-71 \rightarrow +58$	-1

* Taken from Snyder and Buhl (1971a) or from Snyder and Buhl (1972).

† This is the H_2O emission position reported by Buhl et al. (1969) for W3(OH).

‡ Because of an error, the cold-sky spectrum was not subtracted from this scan; hence detectable HNCO emission could be masked by systematic noise.

TABLE 3
Isocyanic Acid Transitions between J_{0J} Levels

Transition	Frequency (MHz)	Transition	Frequency (MHz)
1_{01}–0_{00}	$21{,}981.7 \pm 0.02*$	6_{06}–5_{05}	$131{,}855.52 \pm 0.5\dagger$
2_{02}–1_{01}	$43{,}963$	7_{07}–6_{06}	$153{,}865$
3_{03}–2_{02}	$65{,}944$	8_{08}–7_{07}	$175{,}844$
4_{04}–3_{03}	$87{,}925.45 \pm 0.5\dagger$	9_{09}–8_{08}	$197{,}822$
5_{05}–4_{04}	$109{,}905.90 \pm 0.5\dagger$	10_{010}–9_{09}	$219{,}798$

* *Microwave Spectral Tables* (1968).

† Kewley *et al.* (1963).

transitions. The complete set of frequencies for the HNCO transitions between the levels on the left-hand side of figure 2 are listed in table 3.

In conclusion, our observations indicate that the core of the HNCO excitation is not coincident with the OH position in Sgr B2 but is $\sim 2'$ north in declination. The position of the HNCO excitation peak falls within the region of greatest H_2CO opacity and may coincide with the dense core region which supports the excitation of the (2, 1) transition of NH_3. Thus we suggest that the peak HNCO position be examined for other molecules to determine if it might be the central region for molecular formation in Sgr B2 and hence of potentially greater astrochemical importance than the Sgr B2(OH) position which has long been an established source of molecular excitation.

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