

# A SEARCH FOR INTERSTELLAR MOLECULAR LINES IN THE FREQUENCY RANGE 8.6 TO 9.2 GHz

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## Abstract

An unsuccessful search has been made in the directions of Sagittarius B2, Sagittarius A, and Orion A for molecular lines of formyl, pyridine, formaldehyde, acrolein, and formamide in the frequency range 8.6 to 9.2 GHz. The failure to detect the formyl line in particular provides evidence about the possible modes of formation of interstellar formaldehyde.

A search in the frequency range 8.6 to 9.2 GHz has failed to detect lines of formyl (HCO), pyridine (C<sub>5</sub>H<sub>5</sub>N), formaldehyde (H<sub>2</sub>CO), acrolein (CH<sub>2</sub>CHCHO), or formamide (NH<sub>2</sub>CHO) in the directions of the molecular sources Sagittarius B2, Sagittarius A (NH<sub>3</sub>), and Orion A. The observations were carried out in November 1971 using the Parkes 64 m radio telescope. At this frequency the antenna has an aperture efficiency of 38% and a beamwidth of 2'.5 arc. The receiver consisted of a tunable cryogenic parametric amplifier (Kerr 1972) giving a system temperature of ~180 K, followed by a bank of 64 filters each of 100 kHz bandwidth and with approximately Gaussian passbands (Batchelor *et al.* 1969). The filter outputs were connected via a set of integrate-and-hold circuits to a multiplexer and on-line computer. The computer controlled the receiver, switching it between the feed horn and a cryogenic termination and switching on the calibration noise source at preselected intervals. In addition it carried out the synchronous detection, normalization, and accumulation of data.

The telescope was positioned on Sgr B2 and Orion A by maximizing the continuum signal. On Sgr A (NH<sub>3</sub>) the telescope was pointed at the nominal position using corrections determined for Sgr B2. Pointing was always within 0'.3 arc of the nominal position. Observations were made by integrating for 20 min at the line frequency while following the source. A reference spectrum was then obtained on a blank region of sky chosen so that the telescope traversed the same range of zenith and azimuth angles. Such source and reference profiles were accumulated by the computer for a total of several hours, and their difference was taken.

The molecules and the transitions unsuccessfully searched for are listed in Table 1, together with the sources observed for each transition and the peak-to-peak, channel-to-channel noise expressed as antenna temperature. The noise was between 0.07 and 0.11 K for each observation except that for formamide in Orion A. In this case the

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frequencies were outside the nominal operating range of the receiver and the noise was 0.16 K.

The system was checked by observing a group of recombination lines at 8.88 GHz (Fig. 1). Since the antenna temperature of the strong H 113 $\beta$ , H 129 $\gamma$  complex had been established previously by comparison with an accurate noise step (R. X. McGee, unpublished data), this line was used to calibrate the temperature scale. Figure 1 also shows that any signal from the formaldehyde 7<sub>25</sub>-7<sub>26</sub> transition was below the noise level.

Three of the molecules searched for warrant discussion, because of either their known occurrence in molecular sources or their similarity with other molecules known to occur.

TABLE 1  
MOLECULES AND TRANSITIONS SEARCHED FOR UNSUCCESSFULLY

Molecule	Transition	Rest frequency‡ (GHz)	Source	Noise§ (K)	Refer- ence			
Formyl	HCO	2 <sub>11</sub> -2 <sub>12</sub> , J(5/2-5/2), F(2-2)	8.6210(4)	Orion	0.09	1		
							Sgr B2	0.11
							Sgr B2	0.10
Pyridine*	C <sub>5</sub> H <sub>5</sub> N	1 <sub>01</sub> -0 <sub>00</sub> , F(1-1)	8.76284(10)	Orion	0.11	2		
							Sgr B2	0.08
							Sgr(NH <sub>3</sub> ) A	0.11
Formaldehyde	H <sub>2</sub> CO	7 <sub>25</sub> -7 <sub>26</sub>	8.88483(4)	Orion	0.07	3		
<i>s-trans</i> -Acrolein†	CH <sub>2</sub> CHCHO	1 <sub>01</sub> -0 <sub>00</sub>	8.90214(20)	Orion	0.11	4		
				Sgr B2	0.09			
Formamide	NH <sub>2</sub> CHO	3 <sub>12</sub> -3 <sub>13</sub> , F(3-3)	9.23511(5)	Orion	0.16	5		
							F(4-4)	9.23703(3)
							F(2-2)	9.23770(5)

\* A six-membered aromatic ring with one nitrogen atom. † A simple unsaturated aldehyde.

‡ Estimated uncertainties are shown in parentheses. § Peak-to-peak, channel-to-channel.

|| References to transition frequencies: 1, Bowater *et al.* (1971); 2, Sørensen (1967); 3, Kirchhoff *et al.* (1971); 4, Wagner *et al.* (1957); 5, Johnson *et al.* (1971).

### Formyl (HCO)

The presence of formyl in interstellar molecular clouds would be of particular interest because of its possible role either as a precursor of or as a decomposition product from interstellar formaldehyde. The rather low upper limits that have been established for Sgr B2, a region where strong formaldehyde signals are found, lend support to proposals for the formation of interstellar formaldehyde that do not involve gaseous formyl as an intermediate, such as, for instance, reaction between carbon monoxide and hydrogen adsorbed on the surface of dust grains.

### Formaldehyde (H<sub>2</sub>CO)

Although several millimetre-wave emission lines of formaldehyde have been detected in the Orion nebula (Thaddeus *et al.* 1971), these did not involve rotational energy levels higher than 16 cm<sup>-1</sup>. The subject of the present search, the 7<sub>25</sub>-7<sub>26</sub>

transition, is between energy levels that are approximately  $101 \text{ cm}^{-1}$  above the ground state (Kirchhoff *et al.* 1971). Detection would be likely only if nonthermal conditions existed.

### Formamide ( $\text{NH}_2\text{CHO}$ )

Formamide has been previously detected in the direction of the sources Sgr A and Sgr B2. Two emission lines with  $^{14}\text{N}$  nuclear quadrupole hyperfine splitting have been found in each case, corresponding to the two lowest asymmetry doublets,  $1_{10}-1_{11}$  at a wavelength of 19 cm (Palmer *et al.* 1971) and  $2_{11}-2_{12}$  at 6 cm (Rubin *et al.* 1971). The present search concerns the transition  $3_{12}-3_{13}$ , which is the next highest asymmetry doublet in this series. The microwave spectrum of formamide has been studied extensively and all available data have been analysed by Johnson *et al.* (1971). While the  $3_{12}-3_{13}$  multiplet has not been measured in the laboratory, very

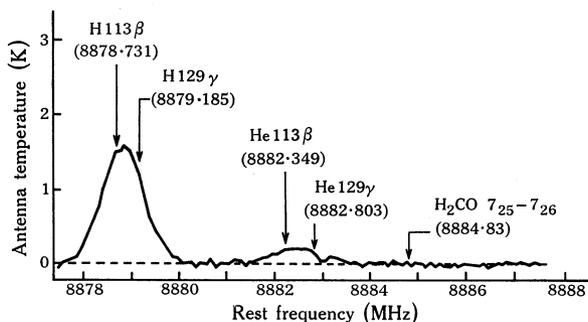


Fig. 1.—Spectral lines H 113 $\beta$ , H 129 $\gamma$ , He 113 $\beta$ , and He 129 $\gamma$  in the direction of Orion A. The non-detection of the  $7_{25}-7_{26}$  transition of formaldehyde is clearly illustrated.

reliable calculated frequencies are given by Johnson *et al.* The upper energy levels in the  $1_{10}-1_{11}$ ,  $2_{11}-2_{12}$ , and  $3_{12}-3_{13}$  transitions are respectively 2.8, 4.3, and  $6.5 \text{ cm}^{-1}$  above the ground rotational state. Since  $6.5 \text{ cm}^{-1}$  is equivalent to  $\sim 10 \text{ K}$ , the low limit established for the  $3_{12}-3_{13}$  line in Sgr B2 is an indication that the effective rotational temperature of formamide in this source is quite low.

Establishment of an upper limit on the radiation received from a molecular transition puts a constraint on the difference in column densities of the molecule in the two relevant energy states. It does not necessarily imply that the molecule is not present in detectable quantities, since other transitions of the same molecule may be found, as in the case of formaldehyde and formamide. For such molecules non-detection of particular transitions throws light on the state of molecular excitation.

### References

- BATCHELOR, R. A., BROOKS, J. W., and SINCLAIR, M. W. (1969).—*Proc. Instn Radio electron. Engrs Aust.* **30**, 39.  
 BOWATER, I. C., BROWN, J. M., and CARRINGTON, A. (1971).—*J. chem. Phys.* **54**, 4957.  
 JOHNSON, D. R., KIRCHHOFF, W. H., and LOVAS, F. J. (1971).—“Microwave Spectral Tables Supplement, Section I: Formamide.” (National Bureau of Standards: Washington D.C.)

- KERR, A. R. (1972).—CSIRO Div. Radiophys. Internal Rep. No. RPL 185.
- KIRCHHOFF, W. H., LOVAS, F. J., and JOHNSON, D. R. (1971).—"Critical Review of Microwave Spectra. Part II. Formaldehyde." (National Bureau of Standards: Washington D.C.)
- PALMER, P., GOTTLIEB, C. A., RICKARD, L. J., and ZUCKERMAN, B. (1971).—*Bull. Am. astr. Soc.* **3**, 499.
- RUBIN, R. H., SWENSON, G. W., JR., BENSON, R. C., TIGELAAR, H. L., and FLYGARE, W. H. (1971).—*Astrophys. J.* **169**, L39.
- SØRENSEN, G. O. (1967).—*J. molec. Spectrosc.* **22**, 325.
- THADDEUS, P., WILSON, R. W., KUTNER, M., PENZIAS, A. A., and JEFFERTS, K. B. (1971).—*Astrophys. J.* **168**, L59.
- WAGNER, R., FINE, J., SIMMONS, J. W., and GOLDSTEIN, J. H. (1957).—*J. chem. Phys.* **26**, 634.