

DETECTION OF THE 10.464-GHz TRANSITION OF INTERSTELLAR THIOFORMALDEHYDE

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ABSTRACT

The $4_{13} \leftarrow 4_{14}$ transition of thioformaldehyde (H_2CS) at 10.46 GHz has been detected in absorption against the galactic center source Sgr B2. The observed line width of $19.5 \pm 3 \text{ km s}^{-1}$ and velocity of $+63 \pm 3 \text{ km s}^{-1}$ are typical of the molecular cloud at the core of Sgr B2. A comparison with the previously observed $2_{11} \leftarrow 2_{12}$ transition at 3.14 GHz indicates that the population levels in thioformaldehyde are not thermally distributed.

Subject headings: molecules, interstellar — radio lines

Attempts by Evans *et al.* (1970b), and Davies, Booth, and Pedlar (1971) to observe the $1_{10} \leftarrow 1_{11}$ transition of thioformaldehyde (H_2CS) at 1.047 GHz in interstellar space were unsuccessful. In both these papers it was concluded that the abundance ratio of H_2CS to H_2CO was less than the terrestrial abundance ratio of sulfur to oxygen (1:40). However, the subsequent detection of the $2_{11} \leftarrow 2_{12}$ transition of thioformaldehyde at 3.139 GHz in Sgr B2 by Sinclair *et al.* (1973) implied that a nonthermal distribution of the rotational state populations was a more likely explanation of the failure to detect the lower-level transition.

We report here the detection of the $4_{13} \leftarrow 4_{14}$ transition of thioformaldehyde at 10.46397 GHz. The line was observed in absorption at the position of the continuum peak of Sgr B2. The observations were made with the 46-m telescope of the Algonquin Radio Observatory.¹ At this frequency, the telescope has a beamwidth of 2'.6. A cooled parametric receiver was

used. The system temperature, including the continuum contribution from Sgr B2 and at a zenith angle of 75° (Sgr B2 does not rise above a zenith angle of 74° at ARO) is about 130° K . The spectrometer contains 100 filter channels, and has been described by McLeish (1973). It was operated in the total-power mode with a channel width of 100 kHz (2.86 km s^{-1}). Observations consisted of alternating periods of 10 minutes duration on-source and 10 minutes off-source at a point 12^m east of Sgr B2. To reduce the possibility of mistaking a spurious receiver response for an interstellar line, observations were made at two local oscillator frequencies separated by 1.4 MHz. The final spectrum was obtained by averaging all the data collected during 5.5 hours of on-source integration. It is shown in figure 1 with a sinusoidal baseline removed. The frequency scale gives the frequency that would be seen by an observer moving with the local standard of rest.

The spectrum contains, in addition to the thioformaldehyde absorption line near 10462 MHz, two

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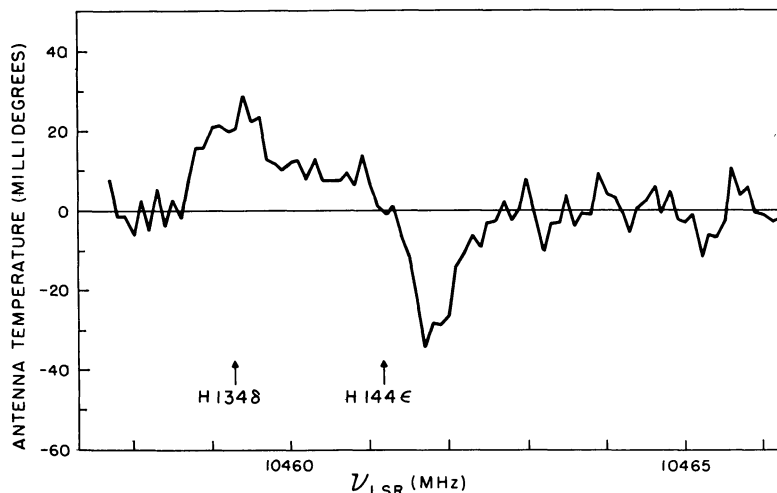


FIG. 1.—The observed spectrum in the region of the $4_{13} \leftarrow 4_{14}$ transition of thioformaldehyde in Sgr B2. The thioformaldehyde absorption line is visible in the center of the figure, along with the recombination lines H 1348 and H 144 ϵ . The frequency scale gives the frequency ν_{LSR} which would be measured by an observer moving with the local standard of rest. Integration time is 5.5 hours on-source.

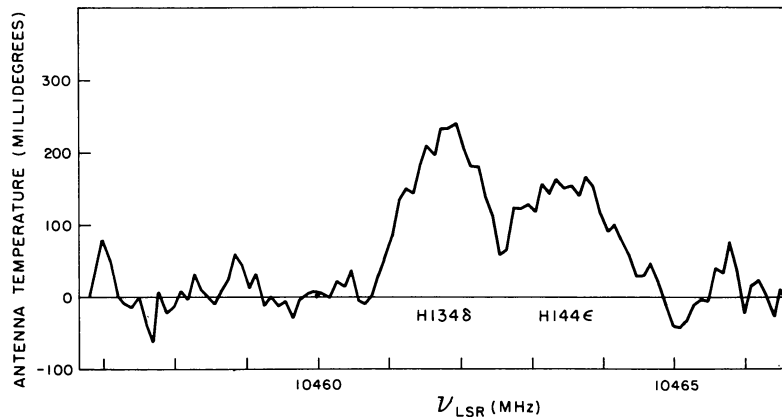


FIG. 2.—The spectrum of Orion A near 10,460 MHz, showing the recombination lines H 134 δ and H 144 ϵ . Integration time is 20 minutes on-source. The frequency scale is similar to that of fig. 1.

hydrogen recombination lines. These are H 134 δ , near 10459 MHz, and H 144 ϵ , which is blended with the absorption line.

A spectrum of Orion A showing the same two hydrogen recombination lines, but no evidence of thioformaldehyde, is shown in figure 2. Observations of H 85 α in both Sgr B2 and Orion A were also made. To within the errors of the individual measurements the ratio of H 85 α line temperatures in the two sources was the same as the ratio of H 134 δ line temperatures. Assuming this same ratio for the H 144 ϵ lines, the value of the blended line in Sgr B2 was calculated from the H 144 ϵ line temperature in Orion. This yielded a value of 0.014° K. For the width of this line we took 1.23 MHz, which is the measured width of the H 85 α line in Sgr B2.

Figure 3 shows the spectrum of figure 1 after subtracting the contributions from the H 144 ϵ and H 134 δ lines. These contributions are shown by dashed lines.

The effect of removing the H 144 ϵ line has been to make the thioformaldehyde absorption line more symmetrical, somewhat broader, and somewhat deeper. The line antenna temperature is $-0.040^\circ \pm 0.004^\circ$ K with a full width at half-power of 0.68 ± 0.10 MHz (19.5 ± 3 km s $^{-1}$). Based on a rest frequency of $10,463.970 \pm 0.005$ MHz (Johnson *et al.* 1971), the velocity with respect to the local standard of rest is 63 ± 3 km s $^{-1}$. The continuum antenna temperature of Sgr B2 at 10.46 GHz is $6.2^\circ \pm 0.3^\circ$ K.

The thioformaldehyde line was not seen in Orion A, W51, or Cas A. Upper limits (5σ) of 0.12°, 0.06°, and 0.06° K, respectively, were established for these sources.

The radial velocity of 63 km s $^{-1}$, reported here for the $J = 4$ transition, agrees with the velocity of H₂CS determined from the observation of the $2_{11} \leftarrow 2_{12}$ transition (60 ± 4 km s $^{-1}$) by Sinclair *et al.* (1973), and with the velocities of other molecules detected in Sgr B2. The observed line width of 19.5 ± 3 km s $^{-1}$ agrees

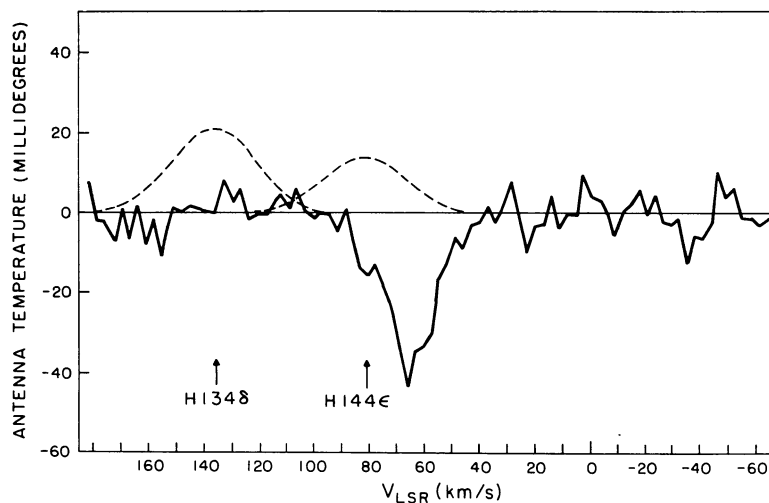


FIG. 3.—The $4_{13} \rightarrow 4_{14}$ line of thioformaldehyde, in absorption against Sgr B2, after subtracting the two hydrogen recombination lines H 134 δ and H 144 ϵ . The recombination lines which were subtracted are shown as dashed lines, with their centers indicated by labeled arrows. The velocity scale indicates the velocity of the thioformaldehyde line with respect to the local standard of rest. Integration time is 5.5 hours on-source.

well with that of the $2_{11} \leftarrow 2_{12}$ transition (20 km s^{-1}). It also agrees with the line widths quoted by Morris *et al.* (1973) for the non-metastable states $J = 2, K = 1$, and $J = 3, K = 2$ of NH₃. It is slightly smaller than the value of 26.3 km s^{-1} found for the $1_{10} \leftarrow 1_{11}$ transition of H₂CO (Zuckerman *et al.* 1970) and for the $2_{11} \leftarrow 2_{12}$ transition of H₂CO (Evans, Cheung, and Sloanaker 1970*a*). It is much smaller than the line widths of NH₃ metastable ($J = K$) rotational levels, which range from 38.0 to 51.8 km s^{-1} (Morris *et al.* 1973) and those of the CH₃OH $J = 1 \rightarrow 0$ transition (Barrett *et al.* 1972) and the H₂S $1_{10} \rightarrow 1_{01}$ transition (Thaddeus *et al.* 1972). One interpretation of these results is that H₂CS is confined to a central region of Sgr B2 whereas the other molecules are more widely dispersed through a region of varying velocity. Morris *et al.* (1973) have hypothesized a core-halo model in which this central region would be at a higher temperature and where excitation to higher rotational levels would be more efficient.

The observation of the second line of H₂CS enables us to discuss thermal equilibrium of this molecule in the Sgr B2 region. The optical thicknesses τ_J and $\tau_{J'}$ for two K -doubling transitions with $K = 1$ and corresponding to J and J' , respectively, are related by the following approximate formula

$$\frac{\tau_J}{\tau_{J'}} = \frac{(2J+1) T_{J'}}{(2J'+1) T_J} \times \exp \left[- \frac{\bar{B}h\{J(J+1) - J'(J'+1)\}}{kT_0} \right], \quad (1)$$

where $\bar{B} = (B+C)/2$ is a rotational constant, T_J and $T_{J'}$ are excitation temperatures for the J and J' K -doublet levels, respectively, and T_0 is the excitation temperature for the equilibrium between the J and J' rotational levels. In deriving equation (1) it has been assumed that $h\nu_J \approx (B-C)J(J+1)/2$ is much smaller than kT_J for both J and J' .

For the $J = 4$ and $J = 2$ K -doublets, equation (1) gives

$$\frac{\tau_4}{\tau_2} = \frac{9 T_2}{5 T_4} \exp \left(- \frac{11.54}{T_0} \right). \quad (2)$$

If it is assumed that the H₂CS cloud uniformly covers the continuum source Sgr B2, that the diameter of the H₂CS cloud is greater than the beamwidth of the telescope, and that the optical depth is $\ll 1$, then

$$\Delta T_L = \eta_B \left(T_J - T_{BB} - \frac{\Omega_s}{\Omega_B} T_s \right) \tau_J, \quad (3)$$

where ΔT_L is the observed brightness temperature of the line; η_B is the telescope beam efficiency; T_{BB} is the brightness temperature of the microwave background radiation; Ω_s and Ω_B are the solid angles subtended by the continuum source and the beam, respectively; and T_s is the brightness temperature of the continuum radiation from Sgr B2.

The product $\eta_B(\Omega_s/\Omega_B)T_s$ is equal to the observed continuum antenna temperature of the source.

Substituting observed values from the present work ($J = 4$) and from Sinclair *et al.* ($J = 2$) and setting $T_{BB} = 2.7^\circ \text{ K}$, we obtain

$$\frac{\tau_4}{\tau_2} = 0.109 \frac{(45.3 - T_2)}{(10.6 - T_4)}. \quad (4)$$

Equations (2) and (4) cannot be solved uniquely, but a relationship between T_4 , T_2 , and T_0 can be obtained. A plot of T_4 as a function of T_2 , for several values of T_0 , is shown in figure 4. Several comments can be made concerning this figure: (1) The fact that both lines are seen in absorption means that $T_4 < 10.6^\circ \text{ K}$ and $T_2 < 45.3^\circ \text{ K}$. These limits define the boundaries of the figure. (2) T_4 and T_2 lie to the right of the line $T_0 = \infty$, since it is unlikely that T_0 is negative. (3) The lines $T_4 = T_2$ and $T_4 = T_0$ do not intersect, and consequently no thermal solution exists. (4) If $T_0 = 3^\circ \text{ K}$ as suggested by Sinclair *et al.*, then T_4 is appreciably lower than T_2 ($0.2T_2 > T_4 > 0.1T_2$). For all values of $T_0 \leq 10^\circ$, $T_4 < T_2$. Thus, the $J = 4$ K -doublet transition probably has a lower excitation temperature than the $J = 2$ K -doublet transition, and this introduces a constraint on any proposed cooling mechanism.

We have reexamined the data given by Evans *et al.* (1970*b*) and Davies *et al.* (1971) in an attempt to account for their failure to detect the $1_{10} \leftarrow 1_{11}$ line of

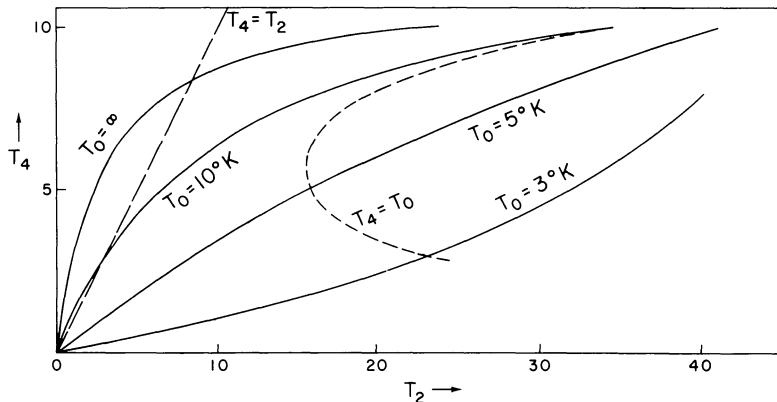


FIG. 4.— T_4 , the excitation temperature of the $4_{13} \leftarrow 4_{14}$ transition of thioformaldehyde, versus T_2 , the excitation temperature of the $2_{11} \leftarrow 2_{12}$ transition, for several values of T_0 , the excitation temperature governing the population of the $J = 4$ and $J = 2$ levels.

H₂CS. We believe that beam dilution, which was apparently ignored by Davies *et al.*, and insufficient sensitivity can probably account for the results of Davies *et al.* without invoking anomalous abundances or excitation temperatures. Beam dilution is, we believe, underestimated by Evans *et al.*, but probably not by enough to reduce their predicted line temperature below their stated observational limit. Their predictions, however, are based on a comparison with formaldehyde observations, since thioformaldehyde had not at that time been observed.

A relationship similar to equation (4) but involving T_1 instead of T_2 has been determined. The data for the $J = 1$ transition has been taken from the experiment

of Evans *et al.* (1970b). The molecular cloud in front of the galactic center source Sgr B2 has been assumed to have a diameter of 7', in general agreement with the results of Sinclair *et al.* (1973). Based on this analysis, it appears the 1047-MHz transition would appear in absorption if $T_1 < 179^\circ$ K and in emission if T_1 is higher than this value. Considering only the absorption case and assuming $T_0 = 3^\circ$ K, a lower limit for T_1 is found to be significantly higher than T_4 and equal to or higher than T_2 . This is suggestive of the relationship already noted between T_4 and T_2 and may indicate a progressive decrease of excitation temperature with increasing value of J .

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