THE ASTROPHYSICAL JOURNAL, 340:L41–L44, 1989 May 1

DETECTION OF THE $2_0 \rightarrow 3_{-1}$ TRANSITION OF $^{13}CH_3OH$ AT 14.8 GHz

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Received 1988 November 14; accepted 1989 February 15

ABSTRACT

We have detected the $2_0 \rightarrow 3_{-1}$ *E*-type transition of $^{13}CH_3OH$ at 14.78 GHz toward the continuum sources Sgr A, Sgr B2, and W33. For Sgr B2 and one position in Sgr A, the $^{12}C/^{13}C$ abundance ratio, derived with the simplest assumptions, is about 40, higher than the values (20–25) derived from other molecules. For W33, the obtained value of 50 is lower than the value (100) derived from H_2CO observations but comparable to the value obtained from CO observations.

Subject heading: interstellar: molecules

I. INTRODUCTION

Using the 64 m Parkes radiotelescope, Whiteoak *et al.* (1988) discovered strong CH_3OH absorption in the 12 GHz $2_0 \rightarrow 3_{-1}$ transition toward the bright H II region Sgr B2 and mapped the absorption distribution over the region.The absorption spectra were found to be similar to those of the $2_{1,1} \rightarrow 2_{1,2}$ transition of formaldehyde (H_2CO). The peak opacity exceeded unity, suggesting that the corresponding ^{13}C line might be strong enough to be detected. We have observed Sgr B2 and other prominent H II regions at the frequency of this transition, using the 70 m antenna of NASA's Canberra Deep Space Communication Complex.

The rest frequency of the ^{13}C transition has been measured by Kuriyama *et al.* (1986) to be 14,782.27 $\pm$ 0.01 MHz.

II. OBSERVATIONS

Observations at both ^{12}C and ^{13}C frequencies were made in 1988 April and May. At 12.2 GHz the half-intensity beamwidth was 78″ $\pm$ 4″ and an uncooled receiver yielded a system temperature of around 150 K. For the 14.8 GHz observations, a cryogenically cooled receiver was available, and the corresponding parameters were 66″ $\pm$ 4″ and 70 K. At these frequencies the aperture efficiency of the antenna is about 0.6.

The spectra were obtained with a 10 MHz, 256 channel digital Fourier transform spectrometer, providing a channel spacing of 39 kHz (equivalent to radial velocities of 0.96 and 0.79 km s^{-1} at the ^{12}C and ^{13}C frequencies). To obtain spectra of the wide lines toward the Galactic center region, reference off-source spectra were used. For spectra of narrower lines both "signal" and "reference" spectra were obtained on-source, but offset 2.5 MHz in opposite directions from the true frequency setting; in the difference spectrum a CH_3OH line appeared as two features, one in absorption and the other in emission, 5 MHz apart. Normalization of the spectra by the appropriate continuum intensities yielded line-to-continuum ratios. Uncertainties in the intensity measurements were often responsible for the major uncertainties in the ratios.

III. RESULTS AND DISCUSSION

^{13}C absorption was detected toward four sources. The measured line parameters along with corresponding ^{12}C parameters are listed in Table 1. For Sgr B2 the results are for the continuum peak, at R.A.(1950) = $17^h44^m10^s.6$, decl.(1950) = $-28°22'00''$. The Sgr A observations were made at positions offset from the continuum peak [R.A.(1950) = $17^h42^m29^s.3$, decl.(1950) = $-28°59'20''$] by 2′ east in one case and 4′ south in the other. These positions are near the maxima of "+40 km s^{-1}" and "+20 km s^{-1}" features seen in spectra of $^{12}CH_3OH$ and other molecules.

For Sgr B2, ^{13}C spectra were also obtained for positions offset by 40″ in the four cardinal directions. The shape of the absorption profiles was found to change little with right ascension, but markedly with declination; Whiteoak *et al.* (1988) noted similar trends with ^{12}C spectra. Figure 1 shows ^{13}C spectra for the continuum peak and the positions offset in declination. The relative intensities of the corresponding continuum levels are indicated by vertical lines; the length of the line for "peak" corresponds to 7 K. All spectra contain components centered near velocities of 63 km s^{-1}, and two show an additional feature centered at 78 km s^{-1}. The line-to-continuum ratios at both velocities maximize north of the continuum peak, reaching 0.06 for the component at 63 km s^{-1}. The spectral variations with position are similar to those for the ^{12}C transition, except for the presence of a narrow-band ^{12}C maser at 50 km s^{-1} to the south (see Whiteoak *et al.* 1988).

Figure 2 shows the ^{13}C and ^{12}C spectra toward the continuum peak of Sgr B2, with the latter profile scaled to match the other. The velocity offset is due to plotting this figure using the ^{13}C frequency measured by Haque *et al.* (1974) and tabulated in Anderson, Herbst, and De Lucia (1987). The velocity difference, 2.3 $\pm$ 0.6 km s^{-1}, agrees exactly with the difference between this frequency and the more precise value reported by Kuriyama *et al.* (1986). Figures 3 and 4 show the two Sgr A spectra and their scaled ^{12}C counterparts.

Figure 5 shows superposed ^{13}C and ^{12}C spectra toward the

TABLE 1

COMPARISON OF $^{13}CH_3OH$ AND $^{12}CH_3OH$ RESULTS

SOURCE	RADIAL VELOCITY (km s^{-1})	LINE WIDTH (km s^{-1})	$^{13}CH_3OH$ RESULTS			$^{12}CH_3OH$ RESULTS			τ_{12}/τ_{13}	$[N_{12}]/[N_{13}]$
			Continuum Temperature (K)	Line Temperature (K)	Optical Depth	Continuum Temperature (K)	Line Temperature (K)	Optical Depth		
Sgr B2	63	18	7.0	0.300	0.044	8.3	6.1	1.4	31	40
Sgr A (+2, 0)	46	24	3.1	0.070	0.023	4.5	1.73	0.5	21	28
Sgr A (0, −4)	18	20	1.2	0.052	0.044	1.8	1.29	1.3	29	38
W33	33	5	10.8	0.027	0.003	6.5	0.53	0.09	37	48

peak of W33 [with a nominal position of R.A.(1950) = $18^h11^m17.9$, decl.(1950) = $-17°56'45''$]. The ^{13}C spectrum in this figure was plotted using the line frequency measured by Kuriyama *et al.* (1986). The ^{12}C profile was obtained by Peng Rui Sheng and J. B. Whiteoak (unpublished observations) using the 64 m Parkes antenna and a 120″ beamwidth. This absorption profile should be identical with a profile obtained using the 70 m antenna because the continuum source has an angular size much smaller than the beamwidth of both antennas. The ^{12}C profile differs from its H_2CO counterpart (see, e.g., Fig. 1*b* of Henkel *et al.* 1983) in that the narrow component centered near 33 km s^{-1} is much less prominent relative to the wider component at 36 km s^{-1}. However, the profile resembles that for the $3_{1,2}$–$3_{1,3}$ transitions of $H_2{}^{12}CO$ and the $2_{1,1} \rightarrow 2_{1,2}$ transition of $H_2{}^{13}CO$. The simplest explanation for this is that the excitation of the two components differs, with the narrow component (which probably originates in a foreground cloud) having a lower excitation temperature in formaldehyde.

To estimate isotope abundance ratios, for similar ^{12}C and ^{13}C velocity profiles, the usual relationship between optical depth τ and the column density $N_{3,-1}$ of the lower level of the transition gives

$$\frac{N(12)_{3,-1}}{N(13)_{3,-1}} = \frac{\tau(12)}{\tau(13)} \times \frac{\nu(13)}{\nu(12)} \times \frac{T_{tr}(12)}{T_{tr}(13)} \times \frac{|\mu(13)|^2}{|\mu(12)|^2}, \quad (1)$$

where T_{tr} is the excitation temperature of the $2_0 \rightarrow 3_{-1}$ transition and $|\mu|^2$ is the dipole matrix element. If both the excitation temperatures and the dipole matrix elements are similar for the two isotopes, then

$$\frac{N(12)_{3,-1}}{N(13)_{3,-1}} = 1.21 \times \frac{\tau(12)}{\tau(13)}. \quad (2)$$

The ratio of the total column densities $N(12)/N(13)$ is then given by

$$\frac{N(12)}{N(13)} = \frac{N(12)_{3,-1} \exp[-11.33/T_{ex}(13)]Q(12)}{N(13)_{3,-1} \exp[-11.66/T_{ex}(12)]Q(13)} \quad (13)$$

if it is assumed that the populations of the different levels in each ladder follow Boltzmann distributions with excitation temperature T_{ex}. The energy level information was obtained from Lees *et al.* (1973) and from Anderson, Herbst, and De Lucia (1987). The partition function Q has been discussed by Lees (1973). $T_{ex}(12)$ and $T_{ex}(13)$ values that are similar and below about 20 K might be expected for the molecular clouds of Sgr B2 (see Menten *et al.* 1986). For these circumstances, calculations showed that $Q(13)$ is marginally greater than $Q(12)$. However, in equation (3) the inequality is reduced by the ratio of the exponential terms, and the isotope abundance ratio is approximately equal to the ratio derived in equation (2).

For a CH_3OH cloud of optical depth τ overlying continuum emission of antenna temperature T_c, if the excitation temperature T_{tr} associated with the $2_0 \rightarrow 3_{-1}$ transition is assumed to be similar to the universal microwave background (see Whiteoak *et al.* 1988), then the line absorption temperature T_L is given by

$$T_L = T_C \times [1 - \exp(-\tau)]. \quad (4)$$

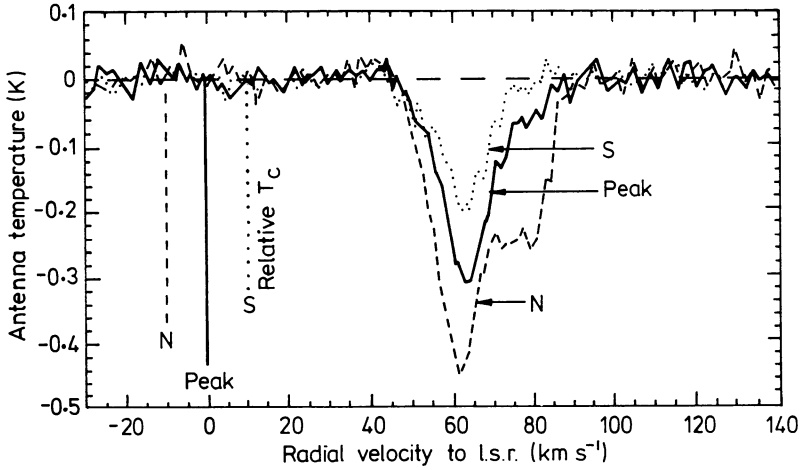

FIG. 1.—$^{13}CH_3OH$ spectra for Sgr B2, showing profiles observed toward continuum peak and at positions offset 40″ N and S of peak. Vertical bars show relative continuum intensities.

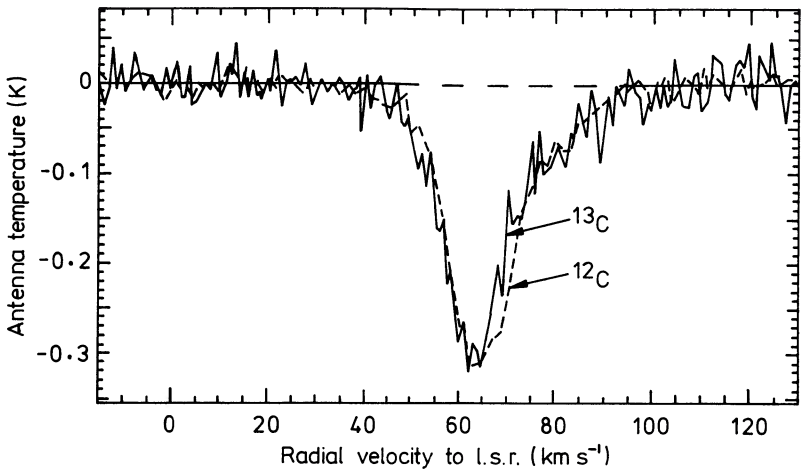

FIG. 2

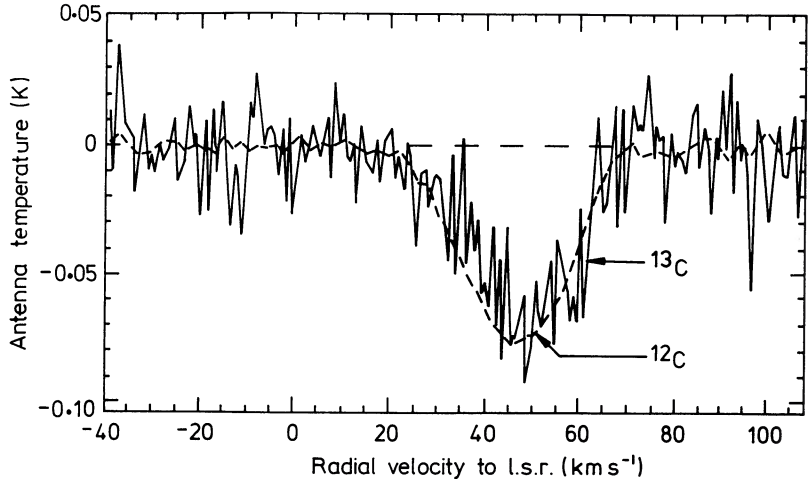

FIG. 3

FIG. 2.—$^{13}CH_3OH$ absorption profile towards the continuum peak of Sgr B2 with superposed scaled ^{12}C profile for same position. The ^{13}C profile is shifted by $+2.3$ km s^{-1} from its correct velocity because the figure was prepared using the line frequency tabulated by Anderson *et al.* (1987).

FIG. 3.—$^{13}CH_3OH$ absorption profile in direction 2′ east of continuum peak of Sgr A, with superposed scaled ^{12}C profile for same position

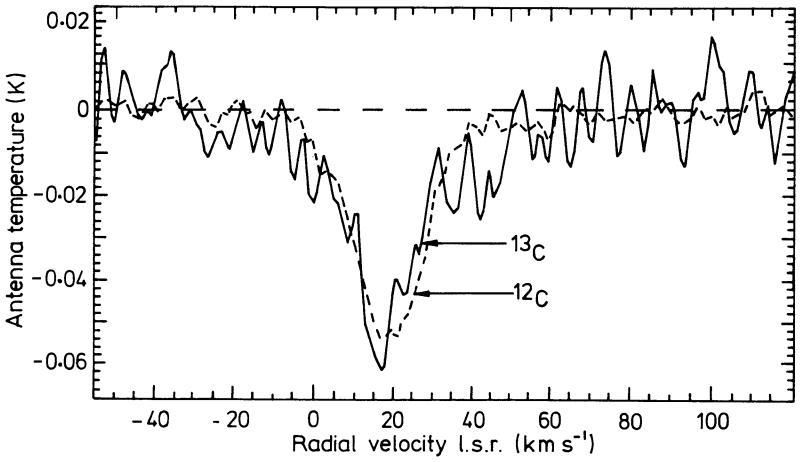

FIG. 4

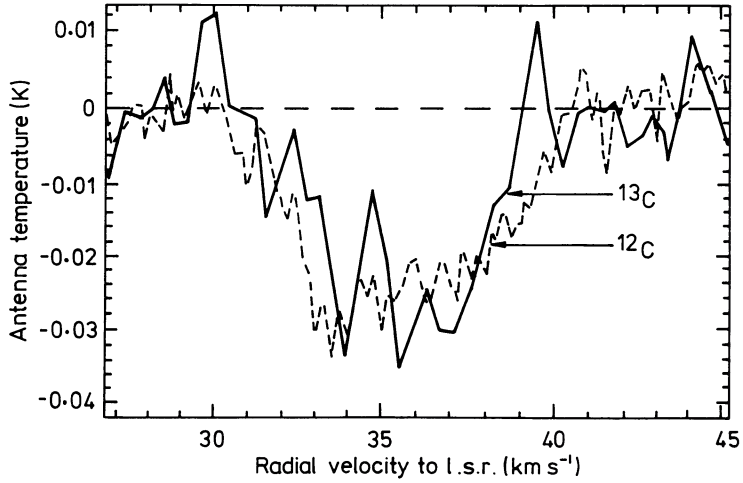

FIG. 5

FIG. 4.—$^{13}CH_3OH$ absorption profile in direction 4′ south of continuum peak of Sgr A, with superposed scaled ^{12}C profile for same position

FIG. 5.—$^{13}CH_3OH$ absorption profile toward the continuum peak of W33 with superposed scaled ^{12}C profile for the same position. In this figure, the rest frequency reported by Kuriyama *et al.* (1986) was used to plot the ^{13}C data.

Optical depths calculated using this equation are listed in Table 1. Using these values and equations (2) and (3), we calculated the isotope abundance ratio $[N_{12}]/[N_{13}]$ for each of the sources in the table.

For Sgr B2 and Sgr A (+2, 0), the CH_3OH isotope abundance ratios listed in Table 1 are higher than expected. The ratios for the $1_{1,0} \rightarrow 1_{1,1}$ transitions of H_2CO (Gardner and Whiteoak 1979; Henkel *et al.* 1983) and many other species (Wannier 1980) are about 25, whereas our CH_3OH values at these positions are about 40. Whiteoak *et al.* (1988) have suggested a correspondence between the excitation conditions for the $2_0 \rightarrow 3_{-1}$ transition of $^{12}CH_3OH$ and the $2_{1,1} \rightarrow 2_{1,2}$ transition of $H_2{}^{12}CO$. Under such conditions, the difference in the derived abundance ratios may be considered as evidence of radiation trapping effects in the CH_3OH results. Before a definite conclusion can be drawn, a full statistical equilibrium calculation should be made, taking into account the differences between the energy level structures of the two isotopes.

The CH_3OH ratio of about 50 for W33 is lower than the value of 80–100 derived from H_2CO by Henkel *et al.* (1983) but agrees well with the ratio derived from CO observations (Wannier 1980).

IV. CONCLUSIONS

Observations of the $2_0 \rightarrow 3_{-1}$ transition of $^{12}CH_3OH$ and $^{13}CH_3OH$ yielded the following results:

1. The ^{13}C transition was detected toward sources Sgr A, Sgr B2, and W33.

2. A comparison of ^{12}C and ^{13}C line profiles toward Sgr B2 suggests that the ^{13}C rest frequency is $14{,}782.27 \pm 0.03$ MHz, as reported by Kuriyama *et al.* (1986).

3. For two of the Galactic center sources, the $^{12}C/^{13}C$ isotope abundance ratios, calculated using relatively simple assumptions, were about 40, higher than the values obtained for other molecules. The disparity may reflect a need for radiation trapping corrections.

The research described in this *Letter* was carried out in part by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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