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DISCOVERY OF INTERSTELLAR SILICON MONOXIDE

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ABSTRACT

Line emission attributed to the $J = 3 \rightarrow 2$ rotational transition of SiO has been detected in Sgr B2, at a radial velocity comparable to that of other molecules; the estimated column number density of SiO is 4×10^{13} cm^{-2}. The line has not been found in Ori A, IRC+10216, Sgr A, W51, DR 21, or NML Cyg.

Line emission from the galactic radio source Sagittarius B2 has been observed at a frequency of 130246 MHz (with respect to the local standard of rest), which we attribute to the $J = 3 \rightarrow 2$ rotational transition of the silicon monoxide molecule. The signal obtained in the direction of the OH point emission sources in Sgr B2 (Raimond and Eliasson 1969) is shown in Figure 1. A summary of the data here and at one other location where observations were obtained in Sgr B2 is given in Table 1.

Observations were made with the 36-foot antenna of the National Radio Astronomy Observatory[1] on Kitt Peak and the forty-channel filter-bank superheterodyne receiver recently used in other 2-mm observations of molecules (cf. Thaddeus *et al.* 1971). Data were taken by frequency switching the first local oscillator at a frequency of 10 Hz while beam switching (by automatically repointing the telescope) with a period of 1 minute. The half-power beamwidth of the 36-foot antenna at 130 GHz with our feed is slightly over 1 arc minute. The atmospheric attenuation at the elevation of Sgr B2 when the observations were made was estimated from antenna tipping to have been about 10 percent, and the beam efficiency of the 36-foot telescope with our feed is $\sim$0.6; radiation temperatures, $T_R = \frac{1}{2}\lambda^2 I_\nu / k$, are therefore roughly twice antenna temperatures T_A.

The rest frequency of the $J = 3 \rightarrow 2$ SiO transition, calculated from the laboratory measurement of Törring (1968) or that of Raymonda, Muenter, and Klemperer (1970), is 130268.4 ± 0.3 MHz. Based on this frequency the radial velocity of the line with respect to the local standard of rest (LSR) is $+53$ km s^{-1}, which falls within the range of molecular velocities encountered in Sgr B2. Thus there can be little doubt that the new line belongs to SiO, and the remaining discussion will be based on this identification. Conclusive confirmation would be provided by detection of the $J = 2 \rightarrow 1$ or $1 \rightarrow 0$ transitions.

[1] Operated by Associated Universities, Inc., under contract with the National Science Foundation.

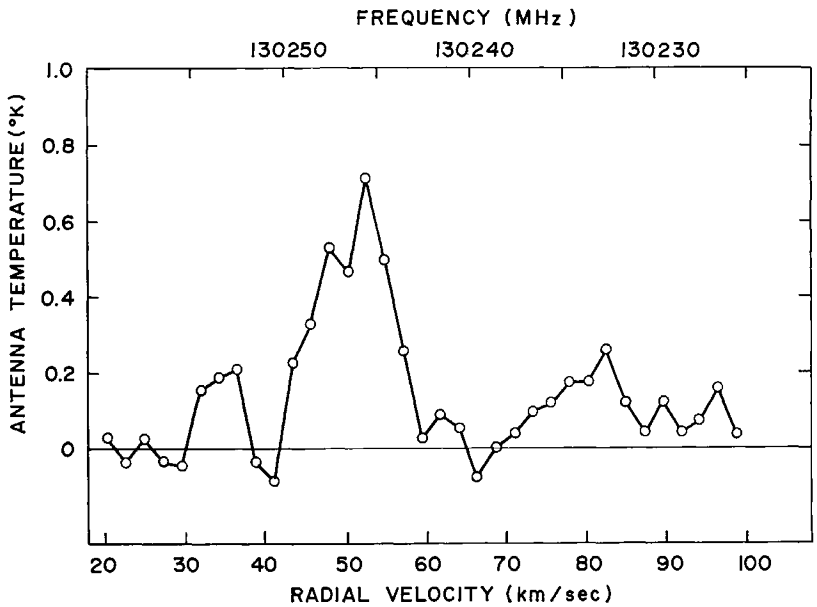

FIG. 1.—The $J = 3 \rightarrow 2$ transition of silicon monoxide in Sgr B2 (OH)—Position 1 in Table 1. The radial velocity and frequency scales are with respect to the local standard of rest. Observations were made on 1971 April 27. Only 35 channels are shown, since two sets of data, taken with the receiver frequency shifted by 5 channels, have been added together.

TABLE 1

SILICON MONOXIDE IN SAGITTARIUS B2

Position	α(1950)	δ(1950)	T_A(° K)	v_{LSR}(km s^{-1})	Δv(km s^{-1})*
1........	$17^h44^m09^s.6$	−28°22′25″	0.7	53	13
2........	17 44 05.0	−28 22 06	~0.7	47	12

* Full line width at half-intensity.

The SiO emission line in Figure 1 is only 13 km s^{-1} wide, and thus much narrower than many molecular lines observed in Sgr B2, particularly those observed at centimeter wavelengths. This difference is probably in part a result of our very high angular resolution and the marked velocity gradients known to exist over the source (cf. Cheung *et al.* 1969), but it may also be an indication that distinct chemical or physical inhomogeneities exist in Sgr B2, and that SiO is produced only under quite special conditions and is not thoroughly mixed throughout the Sgr B2 molecular cloud. It is noteworthy in this regard that $C^{18}O$ (Penzias, Jefferts, and Wilson 1971), OCS, and CH_3CN (Jefferts *et al.* 1971), which are the only other molecules so far observed in Sgr B2 at an angular resolution equal to ours, show velocities in the direction of the OH position that are apparently significantly higher (by about 7 km s^{-1}) than that of SiO, although their line widths are comparable.

Dickinson and Gottlieb (1971) have recently obtained an upper limit of ~1° K on T_A for the 87-GHz, $J = 2 \rightarrow 1$ line of SiO at our Position 1.[2] We will therefore now

[2] These authors have informed us of an error in calibration that necessitates doubling the upper limits quoted in Table I of their article.

estimate the intensity of this line and that of the $J = 1 \rightarrow 0$ line which would be expected from our observations, and we will also estimate the column number density of SiO molecules in Sgr B2. To make these estimates it is necessary to make some assumption as to the excitation temperature of SiO, since our observations cannot distinguish between an optically thin line whose excitation temperature is high and an optically thick one whose temperature is low.

Because SiO appears to be scarce (Table 2), and because other molecules such as OCS and CH_3CN are well excited in Sgr B2 (Table 2), we find it is most reasonable to suppose that the $J = 3 \rightarrow 2$ transition in Sgr B2 is optically thin, and that its excitation temperature is large with respect to 1.4° K, the radiation temperature T_R of the line in Position 1. To be definite, let us further suppose that as a result of frequent collisions the rotational populations are approximately in equilibrium with the gas kinetic temperature, which we will take to be 30° K. (This assumption may cause an overestimate in the SiO density, but one not likely to exceed a factor of 2–3.)

The column number density in terms of T_R for an optically thin emission line is

$$N = \frac{8\pi\nu\Delta\nu k T_R}{hc^2 A f}, \tag{1}$$

where $\Delta\nu$ is the line width, A is the rate of spontaneous radiative decay, and f is the fractional population of the upper level; at the assumed 30° K excitation, $f = 0.15$, 0.12, and 0.085 for the $J = 3$, 2, and 1 levels of SiO, respectively. Applying equation (1) to the $J = 3$ level, and taking the data from Position 1, then yields

$$N_{\rm SiO} \sim 4 \times 10^{13}\ {\rm cm}^{-2}, \tag{2}$$

which is 10–100 times less than the formaldehyde column density in Sgr B2 (Zuckerman *et al.* 1970). If equation (1) is applied to the $J = 2$ and $J = 1$ levels and equation (2) is used for $N_{\rm SiO}$, we find that

$$T_R(2 \rightarrow 1) \sim 0.6^\circ\ {\rm K} \tag{3}$$

and

$$T_R(1 \rightarrow 0) \sim 0.16^\circ\ {\rm K}. \tag{4}$$

Equation (3) is evidently consistent with the negative result of Dickinson and Gottlieb (1971); it and equation (4) suggest that the lower-frequency lines of SiO may not be easy to detect. Alternatively, if these lines are found to be more intense than equations (3) and (4) indicate, our estimate of the SiO excitation and density will require some revision.

Table 2 is a self-explanatory list of negative results obtained from a preliminary

TABLE 2

SUMMARY OF NEGATIVE RESULTS ON SILICON MONOXIDE

Source	α(1950)	δ(1950)	LSR Velocity Range (km s^{-1})	Upper Limit on T_A(° K)*
Ori A	$5^h32^m46\overset{s}{.}9$	− 5°23′56″	− 60 to + 55	0.4
IRC+10216	9 45 14.8	13 30 40	−104 to + 80	0.5
Sgr A(NH_3A)	17 42 28.0	−29 01 30	− 31 to +153	0.4
W51	19 21 27.0	14 24 30	− 1 to +113	0.5
DR 21(OH)	20 37 13.9	42 12 00	− 58 to + 56	0.8
NML Cyg	20 44 33.0	39 56 06	− 60 to +124	1.2

* Peak-to-peak noise.

search for SiO in other sources. Limitations in observing time have so far prevented a search in the direction of late-type stars (Knacke *et al.* 1969; Fertel 1970; Cudaback, Gaustad, and Knacke 1971) and infrared objects such as VY CMa (Gillett, Stein and Solomon 1970), where vibration-rotation bands of SiO have been reported.

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REFERENCES

Cheung, A. C., Rank, D. M., Townes, C. H., Knowles, S. H., and Sullivan, W. T. 1969, *Ap. J. (Letters)*, **157**, L13.
Cudaback, D. D., Gaustad, J. E., and Knacke, R. F. 1971, *Ap. J. (Letters)*, **166**, L49.
Dickinson, D. F., and Gottlieb, C. A. 1971, *Ap. Letters*, **7**, 205.
Fertel, J. H. 1970, *Ap. J. (Letters)*, **159**, L7.
Gillett, F. C., Stein, W. A., and Solomon, P. M. 1970, *Ap. J. (Letters)*, **160**, L173.
Jefferts, K. B., Penzias, A. A., Wilson, R. W., and Solomon, P. M. 1971 (to be published).
Knacke, R. F., Gaustad, J. E., Gillett, F. C., and Stein, W. A. 1969, *Ap. J. (Letters)*, **155**, L189.
Penzias, A. A., Jefferts, K. B., and Wilson, R. W. 1971, *Ap. J.*, **165**, 229.
Raimond, E., and Eliasson, B. 1969, *Ap. J.*, **155**, 817.
Raymonda, J. W., Muenter, J. S., and Klemperer, W. A. 1970, *J. Chem. Phys.*, **52**, 3458.
Thaddeus, P., Wilson, R. W., Kutner, M., Penzias, A. A., and Jefferts, K. B. 1971, to be published.
Törring, T. 1968, *Zs. f. Naturforschung*, **23A**, 777.
Zuckerman, B., Buhl, D., Palmer, P., and Snyder, L. E. 1970, *Ap. J.*, **160**, 485.