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DETECTION OF THE $J = 1 \rightarrow 0$ ROTATIONAL TRANSITION OF VIBRATIONALLY EXCITED SILICON MONOXIDE

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ABSTRACT

The $v = 1, J = 1 \rightarrow 0$ rotational transition of SiO at 43.1 GHz has been detected in the direction of Becklin's star in the Orion Nebula, and in the M-type star W Hya. In Orion two velocity components are observed, one (the stronger) at a radial velocity of 17 km s^{-1}, the other at -7 km s^{-1}; in W Hya a single line is observed at 39 km s^{-1}. In each case a line at the same radial velocity has been observed at 86.2 GHz in the $v = 1, J = 2 \rightarrow 1$ transition, so that the presence of vibrationally excited SiO would seem to be confirmed beyond a reasonable doubt. In the $v = 1$ state, the photon fluxes of the $J = 2 \rightarrow 1$ and $1 \rightarrow 0$ transitions are about equal, suggesting saturated masers occupying the same region of space.

Subject headings: masers — molecules, interstellar — radio lines

Snyder and Buhl have recently detected lines near 86,245 MHz in the direction of Becklin's infrared star in the Orion Nebula, and in a number of late-type stars, which Lovas and Johnson have identified as the $J = 2 \rightarrow 1$ rotational transition of silicon monoxide in its first excited ($v = 1$) vibrational state (Snyder and Buhl 1974, and private communication). The detection of the transition exclusively in stars is strong evidence that one is dealing with new pointlike sources of maser line emission; since the $v = 1$ state lies nearly 1800° K above ground, it is of course hard to see how the sources, if they are really SiO, could be extended over dimensions much larger than stellar atmospheres.

Detection of other transitions in the $v = 1$ rotational ladder ought to provide conclusive confirmation of the identification and valuable additional information on the maser mechanism as well. Davis *et al.* (1974) have found a line in Becklin's star at 129 GHz attributable to the $v = 1, J = 3 \rightarrow 2$ transition, but they detected only one of Snyder and Buhl's seven velocity components in this source, and none of the late-type stars. The purpose of this *Letter* is to report the detection with the University of Texas 16-foot (5-m) telescope[1] of a third transition of vibrationally excited SiO, the $v = 1, J = 1 \rightarrow 0$ transition at 43.1 GHz, which as far as the identification is concerned would seem to remove any doubt left by the previous observations. Although our spectral resolution and signal-to-noise ratio are not adequate to reveal the fine velocity structure reported by Snyder and Buhl in Becklin's star, we do observe their two main velocity components, in particular the negative velocity feature at -7 km s^{-1} which Davis *et al.* failed to detect. Also, in Snyder and Buhl's best stellar source, W Hya, we now find a line which matches the 86-GHz one closely in both velocity and width. A sample of our Orion observations is shown in figure 1. Figure 2 shows the line observed in W Hya. Table 1 summarizes the Orion and W Hya results, and table 2 lists a number of objects where no line was found.

Except for the superheterodyne front end, our receiver was essentially the one used by Davis *et al.* at 129 GHz. The velocity resolution of the filter bank of 40 filters each 250 kHz wide is 1.7 km s^{-1} at 43 GHz, or, as figure 1 shows, about the width of Snyder and Buhl's narrowest features. Our front-end detector was a Control Data Schottky-barrier diode; with an uncooled parametric amplifier as the first intermediate-frequency stage, the double-sideband system temperature was about 1500° K.

Although maser action is strongly implied by the presence of the new SiO lines in the direction of stars, there is as yet little direct observational evidence for it with respect to either angular size, time variation, or polarization. Snyder and Buhl find that the 86-GHz source in Becklin's star is probably smaller than their 70″ antenna beam, and we find from a crude three-point map that the 43-GHz source in the same direction is probably smaller than 7′. As figure 1 and table 1 indicate, we find no gross difference in Becklin's star when the linear polarization is changed from north–south to east–west (although a hint of an effect at a level of about 25% merits further study). To our knowledge there have been no attempts to measure circular polarization in any of the three transitions, and only very crude limits on time variability have been obtained.

In table 3 we attempt to derive fluxes from the available data for the two dominant velocity components in Becklin's star, and for W Hya. F_ν is the

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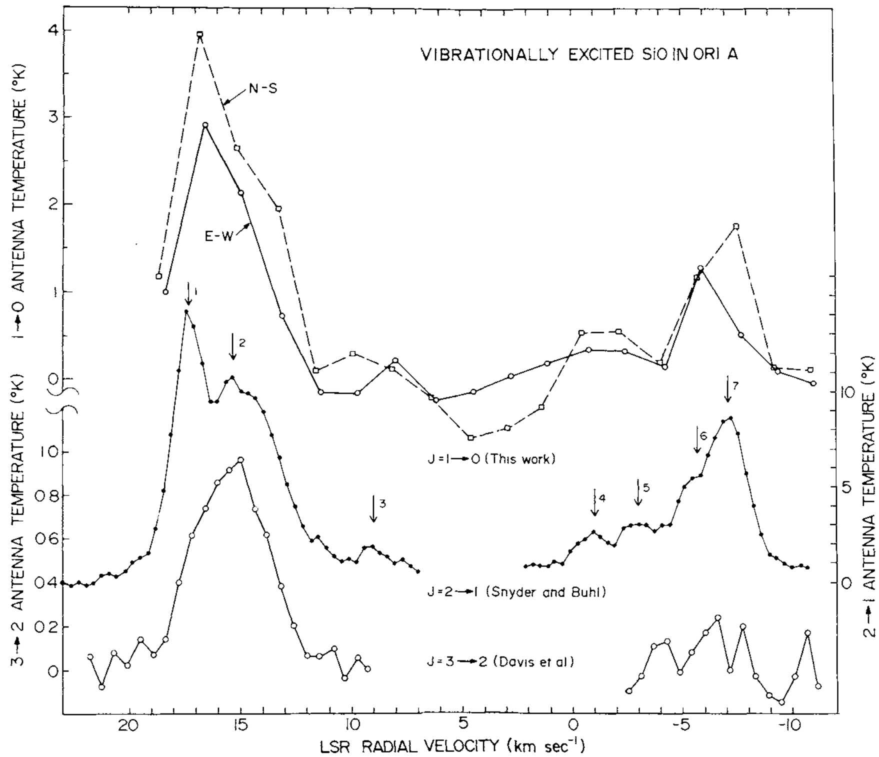

FIG. 1.—The $v = 1, J = 1 \rightarrow 0$ transition of SiO in the direction of Becklin's infrared star. Observations were made with a linear feed with the electric vector either north–south (N–S) or east–west (E–W). The spectrum was obtained by frequency switching over 22 channels, and subtracting off-source observations of about equal length to those on source in order to reduce baseline irregularities; the final spectrum was then shifted by 22 channels and folded to recover information from both frequency switched phases, so only 18 channels are displayed. Previously published observations of the $v = 1, J = 2 \rightarrow 1$ and $J = 3 \rightarrow 2$ transitions are also shown for the purpose of comparison; arrows denote the seven velocity components distinguished by Snyder and Buhl. All antenna temperature scales are corrected for atmospheric absorption.

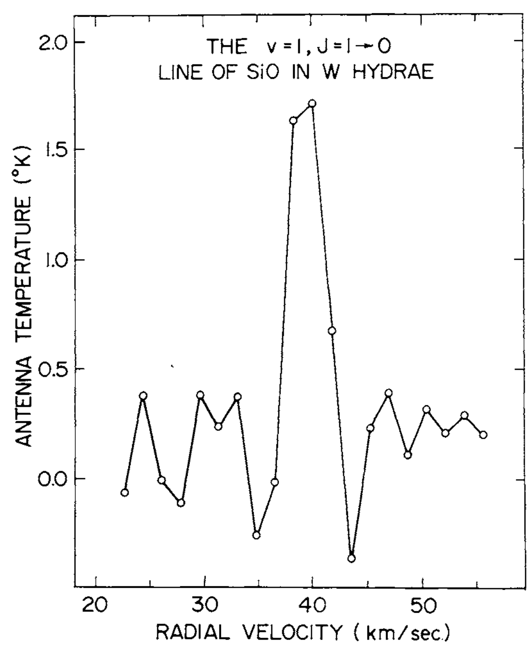

FIG. 2.—The $J = 1 \rightarrow 0$ line of vibrationally excited SiO in the M-type star W Hya

TABLE 1

POSITIVE RESULTS

Source	α(1950)	δ(1950)	Polarization	v_{LSR} (km s^{-1})	Δv (km s^{-1})	T_A (° K)
Ori A.......	$5^h32^m47^s$	$-5°24'25''$	E-W	17	4.5	3.0±0.2
			N-S	17	5.0	4.0±0.4
			E-W	−6	2.5	1.4±0.2
			N-S	−7	3.5	1.8±0.4
W Hya......	13 46 12	−28 07 06	E-W	39	4	1.8±0.2

NOTE.—The 16-foot telescope is equatorially mounted, and the polarization (electric vector) was set either east-west (E-W) or north-south (N-S) during an observation. The radial velocity with respect to the local standard of rest, v_{LSR}, is based on Törring's (1968) measured rest frequency of 43122.03 ± 0.10 MHz. Δv is the full line width at half-maximum intensity. T_A is the line antenna temperature corrected for atmospheric absorption, and the quoted uncertainty is an estimated 1 standard deviation.

TABLE 2

NEGATIVE RESULTS

Source	α(1950)	δ(1950)	Polarization	Peak-to-Peak Noise (° K)	LSR Velocity Range (km s^{-1})
IRC+10011.....	$01^h03^m48^s$	$+12°19'48''$	E-W	2.0	−18 to 36
Orion A.........	05 32 47	− 5 24 25	E-W	2.0	−39 −12
			E-W	1.0	18 33
		− 5 30 25	N-S	1.4	−12 18
		− 5 18 25	N-S	1.4	−12 18
IC 2162.........	06 10 09	18 00 00	E-W	2.1	− 8 24
R Leo...........	09 44 54	11 39 48	E-W	2.0	2 61
W Hya..........	13 46 12	−28 07 06	E-W	1.0	12 22
RX Boo.........	14 22 00	25 55 54	E-W	1.5	−37 −63
			E-W	0.9	−64 −97
			N-S	1.4	−79 −129
R Aql...........	19 04 00	08 09 06	E-W	1.6	32 64
DR 21 (OH).....	20 37 14	42 12 00	E-W	1.9	−32 25
NML Cyg.......	20 45 18	40 00 40	E-W	1.3	−35 − 3

TABLE 3

FLUXES IN THE v = 1 SiO LINES

SOURCE	v_{LSR} (km s^{-1})	$F_\nu \times 10^{21}$ (ergs cm^{-2} s^{-1} Hz^{-1})			$F_\nu \Delta\nu / h\nu$ (photons cm^{-2} s^{-1})		
		1→0	2→1	3→2	1→0	2→1	3→2
Ori A......	15	7.2	7.9	2.1	17.2	16.5	4.4
	− 7	3.3	4.9	$\lesssim$0.4	5.0	8.0	$\lesssim$0.8
W Hya.....	39	3.4	6.1	$\lessapprox$1.6	7.0	~10	$\lessapprox$2.4

NOTE.—F_ν is the flux at the peak intensity of the line, corrected for atmospheric absorption and antenna efficiencies.

flux at the peak of the indicated velocity component, and $F_\nu \Delta\nu/h\nu$ is the integrated photon flux. Because of blending and the difficulty in determining the line width $\Delta\nu$, the integrated photon flux is probably accurate to no more than 30 percent, but even so it is noteworthy that in the two lowest-frequency transitions the photon fluxes are about equal in all three cases. An obvious interpretation of this equality is that in both transitions we are dealing with saturated masers in the same volume of space, and that whenever an SiO molecule by whatever means is deposited in the $v = 1, J = 2$ level, it rapidly surrenders a quantum to first the $J = 2 \rightarrow 1$, and then the $J = 1 \rightarrow 0$ maser, before undergoing any other transition.

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REFERENCES

Davis, J. H., Blair, G. N., Van Till, H., and Thaddeus, P. 1974, *Ap. J.* (*Letters*), **190**, L117.
Snyder, L. E., and Buhl, D. 1974, *Ap. J.* (*Letters*), **129**, L31.
Törring, T. 1968, *Zs. f. Naturforschung*, **23A**, 777.

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