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SiO MASER SOURCES TOWARD THE SAGITTARIUS B2 MOLECULAR CLOUD

SHIGETOMO SHIKI
Department of Astronomy, School of Science, University of Tokyo, Bunkyo, Tokyo 113, Japan
AND
MASATOSHI OHISHI AND SHUJI DEGUCHI
Nobeyama Radio Observatory, National Astronomical Observatory, Minamimaki, Minamisaku, Nagano 384-13, Japan
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ABSTRACT

We have detected six new SiO maser sources toward the Sagittarius B2 molecular cloud. One is identified with an OH 1612 MHz maser source that was previously found by the VLA, and another associated with an *IRAS* source. The other four sources are not associated with any known OH/IR or *IRAS* sources. The spatial density and the kinematic property for these sources are found to be similar to those of the OH/IR sources near the Galactic center. This fact suggests that they are mostly stellar SiO maser sources in front of (or behind) the Sgr B2 molecular cloud. A possibility of association with young stellar objects, however, cannot be completely ruled out for the one SiO source (17450−2808) that is associated with an *IRAS* source exhibiting infrared colors of young objects.

Subject headings: Galaxy: center — ISM: individual (Sagittarius B2) — masers — radio lines: ISM

1. INTRODUCTION

Since the discovery of the first SiO masers in the Orion molecular cloud (Snyder & Buhl 1974), SiO masers have been looked for in molecular clouds. However, most of the SiO sources so far detected are associated with late-type stars (Kaifu, Buhl, & Snyder 1975). Only a few SiO maser sources have been known to be associated with young stellar objects in the Sagittarius B2 and W51 molecular clouds (Hasegawa et al. 1985). Properties of SiO masers associated with young stellar objects are quite different from those found in evolved stars; the intensity ratio of the $v = 1$, $J = 1–0$ to the $v = 2$, $J = 1–0$ transition is often far from unity for sources in molecular clouds (Fuente et al. 1989; Morita et al. 1992), whereas the ratio is nearly unity in late-type stars (Nyman & Olofsson 1986).

During the mapping observations of other molecular line emission in the Sgr B2 molecular cloud complex in 1995–1996 at Nobeyama Radio Observatory, we intended to search for the SiO $v = 1$, $J = 1–0$ masers in the Sgr B2 molecular cloud using the wide-band coverage of the receiver. We found six new SiO maser sources toward this molecular cloud, in addition to the well-known SiO maser source at Sgr B2 MD 5. It is well known that stellar SiO maser sources are extremely densely populated in the Galactic center and bulge region (Lindqvist et al. 1991; Izumiura et al. 1995). Therefore, it is highly probable that the new SiO maser sources we found are associated with late-type stellar maser sources toward the Sgr B2 molecular cloud. In this paper we report the result of these observations and discuss the properties of the newly discovered SiO sources.

2. OBSERVATIONS

The observations in the SiO $v = 1$, $J = 1–0$ transition were made with the 45 m radio telescope at Nobeyama in 1995 April in simultaneous mapping observations of the SiO $v = 0$, $J = 1–0$ line in Sgr B2, using the wide-band coverage of the SIS receiver (about 0.6 GHz). The second observation for confirmation was made in 1996 May in both of the SiO $v = 1$ and $v = 2$, $J = 1–0$ transitions at 43.122 and 42.820 GHz, respectively, using a HEMT receiver. Acousto-optical spectrometers with a high-resolution array (AOS-H) were used, giving the spectral resolution of 37 kHz (or 0.26 km s^{-1}) per two binned channels at 43 GHz. The velocity coverage was about 280 km s^{-1} between $V_{LSR} = -80$ and $V_{LSR} = 200$ km s^{-1} in AOS-H. To check whether high-velocity sources were present, an additional AOS-W with wider velocity coverage (about 1700 km s^{-1} with a velocity resolution of about 1.7 km s^{-1}) was also used. The system temperature was about 300 K for the HEMT receiver and 200–300 K for the SIS receiver. The beam and aperture efficiencies of the telescope were about 0.85 and 0.61, respectively. The integration time at one position in the mapping sequence was about 100 s, and the rms noise level was about 0.15 K in AOS-H. The half-power beamwidth (HPBW) of the telescope was about 40″ at 43 GHz, and the conversion factor from antenna temperature to flux density was about 3.6 Jy K^{-1}. The telescope pointing was checked every few hours using a nearby strong SiO maser source, VX Sgr, and an average pointing accuracy was about 5″.

The mapping was made in a trianglar area of roughly about half of a 30′ × 30′ region of Sgr B2 as shown in Figure 1. The separation between the mapping points is 40″ (approximately the beam size at 43 GHz). The total area surveyed was 0.154 square degrees. The survey in the whole cloud was made only in the SiO $v = 1$, $J = 1–0$ transition. After finding five new sources, we made confirmimg observations in the $J = 1–0$ transitions in both $v = 1$ and $v = 2$ vibrational states at the detected positions and secured the detections. After finishing the confirmation, we noticed that a weak signal was present in two adjacent positions in the scan, indicating that a SiO source (source 7 in Table 1) was present, probably at the middle between the two mapping positions. We have added this source as a detection but have not yet confirmed the result in two SiO transitions. We list these detected sources in Table 1 together with the already known Sgr B2 MD 5 SiO source (as source 3). The detected line was divided into spectral components by Gaussian fitting until the residual was smaller than 3 σ of the noise level. The observed spectra were shown in Figure

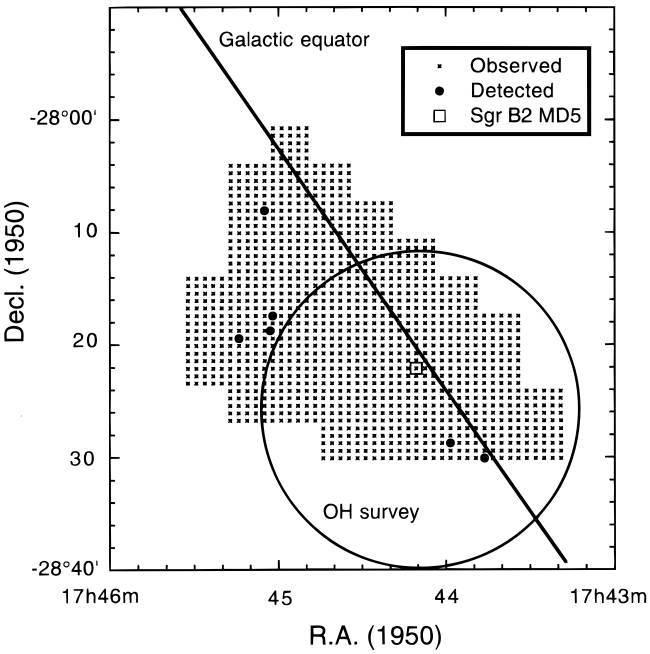

FIG. 1.—Area surveyed in the 1995 observation by the SiO $v = 1$, $J = 1$–0 transition. Crosses indicate the mapped points, filled circles the SiO sources detected, and the open square the position of Sgr B2 MD 5 (an already known SiO source). The large circle indicates the area surveyed by OH 1612 MHz.

2. We have confirmed that there is no signal above the noise level in mapping scans adjacent to the detected positions (except for source 7). Therefore, the accuracy of the position in Table 1 (epoch 1950) is within about 20″ (half of the HPBW).

In the Sgr B2 molecular cloud, an SiO maser source associated with a young star (=Sgr B2 MD 5) is already known (Hasegawa et al. 1985). We also detected this source, and the spectra are shown in Figure 3. The position of this source has been measured by the Nobeyama Millimeter Array (Morita et al. 1992).

3. DISCUSSION

3.1. *Association with Known Objects*

To identify the newly discovered SiO sources, we have checked the *IRAS* Point Source Catalog (PSC) and the SIMBAD database to determine whether there are any known objects near the SiO maser positions. Also, an extensive survey of OH 1612 MHz sources in the area within $\sim 0.5^\circ$ from the Galactic center has been made with the VLA (Lindqvist, Habing, & Winnberg 1992a). Half of the surveyed region in SiO overlaps with the OH-surveyed region (see large circle in Fig. 1; Lindqvist et al. 1992a). It is very curious that five of six newly detected sources have no *IRAS* PSC association. This is probably due to the incompleteness of the *IRAS* PSC in this area due to contamination by infrared objects overlapped in the *IRAS* beam. Also only one source (No. 2) is found to be associated with the previously detected OH 1612 MHz source. In the surveyed area, six OH/IR sources that were previously detected by the VLA are found to have no SiO association: OH 0.517+0.050 No. 1 (167.2 km s^{-1}), OH 0.517+0.050 No. 2 (167.7 km s^{-1}), OH 0.589−0.108 (−200.0 km s^{-1}), OH 0.692−0.171 (15.3 km s^{-1}), OH 0.713+0.084 (96.8 km s^{-1}), and OH 0.738+0.036 (−133.6 km s^{-1}), where the center velocity, $V_{\rm LSR}$, of the OH doubly peaked line was shown in parentheses. We have carefully inspected the spectra at the expected velocity in the corresponding scans of these positions, but we found no SiO signal corresponding to these OH/IR sources.

We discuss the new SiO sources here individually. We have named the sources by the *IRAS* convention.

1. SiO 17437−2830.—The closest known *IRAS* source at this position is one of the bright infrared sources (F_{12} = 32 Jy), IRAS 17438−2832, which is located about 2′.5 away from this SiO source. The *IRAS* source shows an infrared property of a typical nearby late-type star (Volk et al. 1991). A survey in the OH 1612 MHz line (te Lintel-Hekkert et al. 1991) gave a negative result for this *IRAS* source. Because of the large separation of 2′.5 from the *IRAS* source, the association of the SiO source with this *IRAS* source is doubtful.

TABLE 1
LIST OF DETECTED SiO SOURCES

			$v = 1$			$v = 2$		
Number	R.A.[a] (hms)	Decl.[a] (° ′ ″)	I (Jy)	$V_{\rm LSR}$ (km s^{-1})	ΔV (km s^{-1})	I (Jy)	$V_{\rm LSR}$ (km s^{-1})	ΔV (km s^{-1})
1	17 43 46.3	−28 30 05	1.4	56.5	6.49	2.1	56.6	1.33
2[b]	17 43 58.5	−28 28 45	36.6	−25.7	1.17	34.3	−25.7	1.46
			6.2	−23.2	2.01	11.6	−23.1	3.32
3[c]	17 44 10.6	−28 22 05	3.5	82.3	2.06	...	...	...
			4.55	86.5	2.11	...	...	...
			2.6	93.0	3.25	...	...	...
4	17 45 02.1	−28 17 25	2.4	80.9	1.32	2.2	78.9	1.47
5	17 45 14.2	−28 19 05	2.3	81.0	1.31	1.8	80.7	3.36
6[d]	17 45 05.0	−28 08 05	3.5[e]	101.2	2.14	2.0	101.2	1.71
7	17 45 03.0	−28 18 45	1.2	−38.7	1.66	[f]	...	...
			2.1	−36.2	1.63	[f]	...	...

[a] Epoch of 1950.
[b] OH 0.548−0.059 ($17^{\rm h}43^{\rm m}58^{\rm s}.987$, −28°28′52″).
[c] IRAS 17441−2822 = Sgr B2 MD5 (known SiO source).
[d] IRAS 17450−2807 ($17^{\rm h}45^{\rm m}05^{\rm s}.6$, −28°07′57″).
[e] Detected only in 1995, but not in 1996.
[f] No data were obtained.

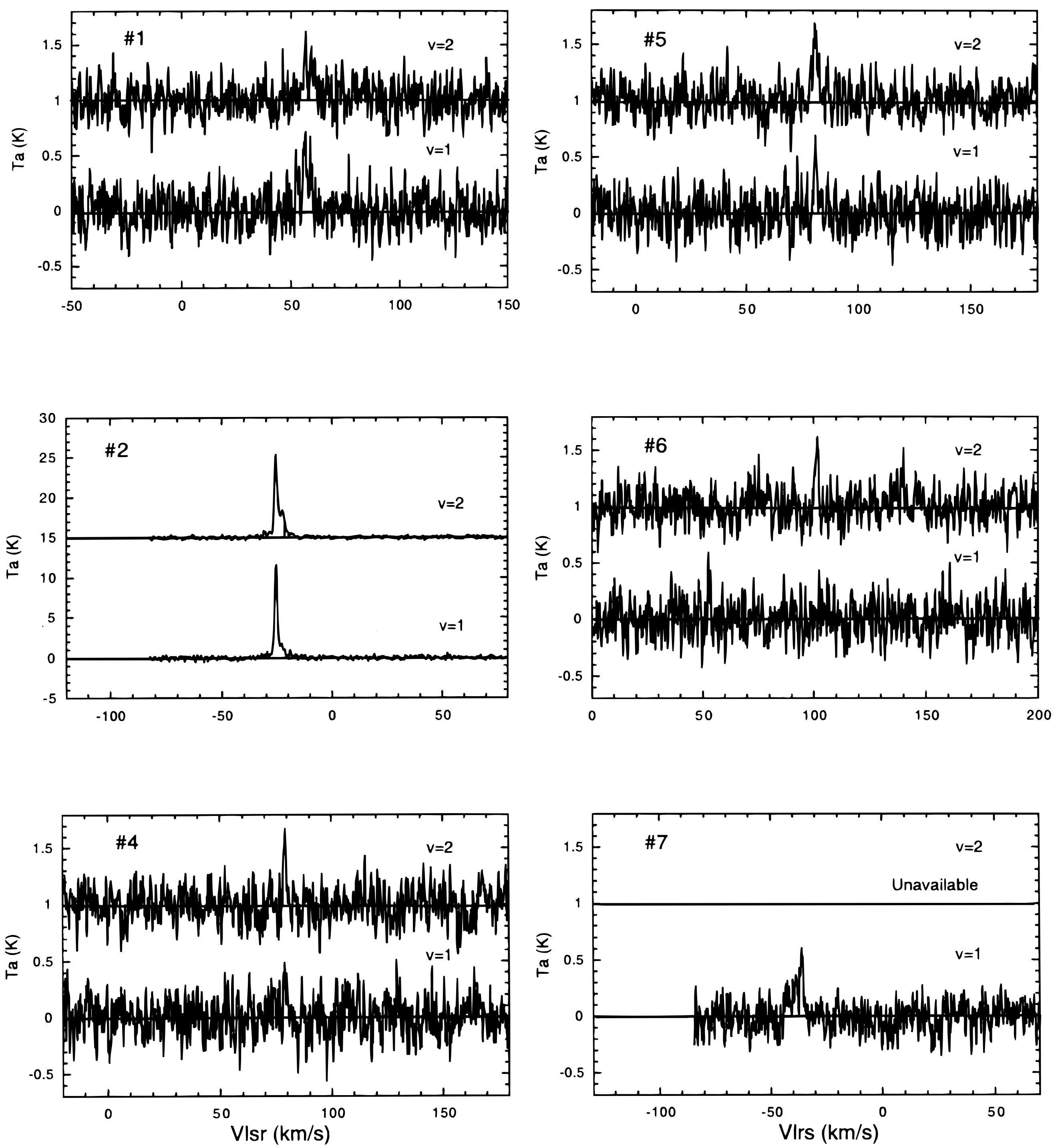

FIG. 2.—Observed spectra of the SiO $v = 1$ and $v = 2$, $J = 1$–0 transitions for the new SiO masers toward the Sgr B2 molecular clouds. The number that appears at the left of each panel corresponds to the source listed in Table 1. The spectra shown here were taken in the 1996 observation, except for source 7. The $v = 1$, $J = 1$–0 emission in source 6 was detected in 1995 but not in 1996.

2. SiO 17439−2828.—The strong intensity ($T_a = 10$ K) of SiO emission of this source at $V_{\rm LSR} = -26$ km s^{-1} suggests that this is a foreground source (within a few kiloparsecs from the Sun). The position agrees well with the OH 1612 MHz source (OH 0.548−0.059) within 10″ (Lindqvist et al. 1992a), and the center velocity of the SiO line agrees well with the average velocity (-32.3 km s^{-1}) of double peaks of OH emission. It is quite strange that no *IRAS* source is found at this position. The expansion velocity of the shell (deduced from OH double peaks) is about 31 km s^{-1}, indicating that this source is a supergiant.

3. SiO 17441−2822.—This is the well-known SiO maser source at the position of Sgr B2 MD 5. The radial velocity and the broad-line profile in the $v = 1$ line are consistent with those obtained by the previous observations (Fuente et al. 1989; Morita et al. 1992). This source is associated with IRAS 17441−2822, and the *IRAS* color is that of a typical young stellar object [$(C_{12}, C_{23}) = (0.95, 2.28)$] (Weintraub 1990), where C_{12} and C_{23} are the logarithmic intensity ratios of *IRAS* 25 to 12 μm and *IRAS* 60 to 25 μm, respectively. (Late-type stars exhibit colors in ranges of $-0.6 < C_{12} < 0.3$ and $-0.8 < C_{23} < 0.2$; e. g., van der

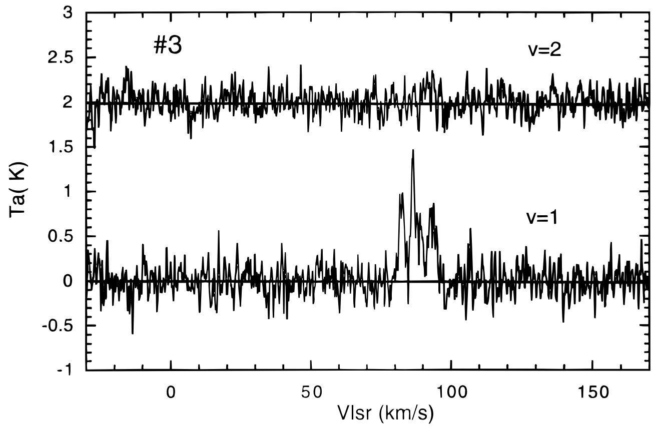

FIG. 3.—Spectra of the SiO $v = 1$ and $v = 2$, $J = 1$–0 transitions for the previously known SiO source, Sgr B2 MD 5.

Veen & Habing 1988.)

4. SiO 17450−2817.—The closest known source at this position is the *IRAS* source IRAS 17448−2815, which is located about 3′ away. It is doubtful that the SiO source can be associated with this *IRAS* source.

5. SiO 17452−2819.—The position of this source is close to the SiO source 4 (about 2′ away), and the radial velocity of the line is similar (90 km s^{-1}). Therefore, we have inspected the $v = 1$, $J = 1$–0 spectra of all 20 scans at the middle positions between these two sources and found no emission above the noise level. Therefore, these two sources are different objects, not artifacts of a sidelobe of the telescope beam.

6. SiO 17450−2808.—The position of this source coincides with that of IRAS 17450−2807 within 10″. Te Lintel-Hekkert et al. (1991) gave a negative result for OH 1612 MHz emission from this source. The *IRAS* color of this source, $(C_{12}, C_{23}) = (0.36, 0.19)$, falls in the area of young stellar objects in the two-color diagram (for example, see Weintraub 1990). The radial velocity of this object, 101 km s^{-1}, indicates that it may be associated with the Sgr B2 molecular cloud. On the other hand, the possibility of the source being a late-type star cannot completely be excluded; the *IRAS* variability index of this source is 97, suggesting that the *IRAS* intensity is variable; this source might be a Mira-type variable star. In this source, we have detected emission of the $v = 1$, $J = 1$–0 transition in the 1995 observation, but only the $v = 2$, $J = 1$–0 line was detected in the 1996 observation.

7. SiO 17450−2818.—The closest *IRAS* source to this position is IRAS 17449−2821, which is located 2′.5 away. The intensity of this *IRAS* source is 6.5 Jy at 12 μm. This *IRAS* object is probably not associated with the SiO source.

3.2. *Density of Stellar SiO Maser Sources toward Sgr B2*

We have surveyed the SiO maser sources at $l = 0^\circ.5$ over the 0.154 square-degree area and detected six new sources. This corresponds to the SiO maser density of about 39 sources per square degree. It is known that the stellar maser sources are densely populated near the Galactic center region. Lindqvist et al. (1992b) surveyed the OH 1612 MHz masers in the region within 0°.6 from the Galactic center and detected 134 sources in the area of about 1.12 square degrees. The resulting density of OH/IR sources is 119 sources per square degree on average in the whole surveyed area. They showed that the stellar density is quickly decreasing with the distance from the Galactic center. Their contour map of the number density of sources shows about 2×10^{-2} pc^{-2} at $l = 0^\circ.6$, indicating 45 sources per square degree. This number is approximately equal to the SiO maser density we found in the present survey. Lindqvist et al. (1991) detected 11 SiO masers in 34 OH/IR sources which they found by the VLA OH 1612 MHz survey. If the detection rate of SiO is about one-third that of OH, our detection rate of SiO seems too high. However, our previous experience on statistics for the Galactic bulge SiO sources (Jiang et al. 1995) indicates that approximately one-third of both OH and SiO observed sources are detected in both OH and SiO masers. Therefore, we have to conclude that the spatial density of SiO sources is similar to the density of OH/IR sources in this region.

3.3. *Velocity*

It is well known that the radial velocity of SiO masers indicates the stellar velocity, i.e., the velocity of the central star (Jewell et al. 1991; Jiang et al. 1995). The average velocity of the six new SiO sources is $\langle V_{LSR} \rangle =$ 42.9 km s^{-1}, and the velocity dispersion is 59.0 km s^{-1}. Lindqvist et al. (1992b) found that the linear regression of the (l-v) diagram for their 134 OH/IR sources is about $v = -7 + 180$ (l/deg) km s^{-1}. This gives an average $\langle V_{LSR} \rangle$ of 101 km s^{-1} at $l = 0^\circ.6$. The linear law of the regression line given by Lindqvist et al. (1992b) is more or less biased on the sources near the Galactic center where the rotational velocity is high. The average velocities of the sources that are located farther than 60 pc from the Galactic center are less than 100 km s^{-1}, and the rotation curve becomes somewhat flat at this position (and the dispersion increases). Therefore, the average velocity of SiO maser sources found in the present paper is not inconsistent with the rotational law of OH/IR sources in this region.

4. CONCLUSIONS

We have detected six new SiO maser sources toward the Sgr B2 molecular cloud. Four of six new sources do not have any association with *IRAS* point sources or OH 1612 MHz sources found in the previous VLA survey. The spatial density and kinematic properties of these sources are consistent with those of OH/IR sources that were found near the Galactic center region.

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