

SiO IN THE SGR B2 REGION

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ABSTRACT

The 2 – 1 and 5 – 4 transitions of SiO have been observed toward the Sgr B2 region, including the Principal Cloud (the GMC containing Sgr B2(M)) and its surroundings. The morphology and velocity structure of the SiO emission show a close resemblance with the HNC Ring feature, identified by Minh & Irvine (2006), of about 10 pc in diameter, which may be expanding and colliding with the Principal Cloud. Three SiO clumps have been found around the Ring, with total column densities $N_{\text{SiO}} \sim 1 \times 10^{14} \text{ cm}^{-2}$ at the peak positions of these clumps. The fractional SiO abundance relative to H_2 has been estimated to be $\sim (0.5 - 1) \times 10^{-9}$, which is about two orders of magnitude larger than the quiet dense cloud values. Our SiO observational result supports the existence of an expanding ring, which may be triggering active star formations in the Principal Cloud.

Key words : ISM:abundances - ISM:individual(Sgr B2) - ISM:molecules

I. INTRODUCTION

The Sgr B2 region in our Galactic center contains giant molecular clouds, which represent extreme cases of high luminosity star formation. The gas is mainly concentrated in a dense central component, $\sim 5 - 10$ pc in diameter with a relatively high mean density, $n(\text{H}_2) \sim 1 \times 10^5 \text{ cm}^{-3}$, “the Principal Cloud” (Irvine, Goldsmith, & Hjalmarson, 1987; Minh et al., 1998). Along the north-south direction there exist three prominent star-forming cores ‘inside’ the Principal Cloud, Sgr B2(N), (M), and (S), which include clusters of compact HII regions having newly born massive stars. The density and temperature structures of this region are extremely complicated (e.g., Martín-Pintado et al., 1999; Rodríguez-Fernández et al., 2002, and references therein). The massive star formations in the core of the Principal Cloud has been suggested to be triggered by cloud collisions (Hasegawa et al., 1994; Mehringer, Palmer, & Goss, 1995; Oka et al., 1998; Sato et al., 2000), although there exist many difficulties in identifying different gas components by using the optically thick lines.

The latest star formation may be occurring at the 2 arcmin north (2’N) position from Sgr B2(M), where the HNC emission peaks probably by the cloud-cloud collision (Minh et al., 1998). The large-scale structure associated with the 2’N HNC peak in Sgr B2 has been further studied by Minh & Irvine (2006), and a ring-like morphology of the HNC emission was found, centered at $(l, b) = (0.7^\circ, -0.07^\circ)$, with a radius of ~ 5 pc and a total mass of $\sim (0.1 - 1.6) \times 10^6 M_\odot$. This structure has been interpreted as an expanding ring which may be colliding with the Principal Cloud of Sgr B2 with an expansion velocity of $30 - 40 \text{ km s}^{-1}$. The morphology suggests that this collision may be triggering the massive star formations in the Sgr B2 cloud. The

existence and the nature of the Ring, however, are not certain yet, and it is difficult to distinguish different gas components toward this very complicated region. To further investigate the nature of this Ring, we have observed the SiO emission, which is a well known shock tracer, since the sputtering of dust grains in shocks, driven by neutral particle impact, can efficiently make Si reside in the gas phase and produce SiO (Downes et al., 1982; Langer & Glassgold, 1990; Schilke et al., 1997).

In this *paper*, we report the observational results of the SiO 2 – 1 and 5 – 4 transitions toward the Sgr B2 region, and discuss the properties of the SiO emission in the HNC Ring.

II. OBSERVATIONS

Observations were carried out using the 15 m Swedish-ESO telescope (SEST*, Booth et al., 1989) on La Silla, Chile, in April 2000. We observed the SiO $v = 0 \text{ J}=2-1$ (86.847 GHz) and $\text{J}=5-4$ (217.105 GHz) transitions, using the dual channel SIS receiver which allows simultaneous observations at 3 mm and 1 mm. Two 1500 channel acousto-optic spectrometers with channel spacing of 0.69 MHz were used but the frequency resolution of the system was approximately 1.2 MHz. The HPBW and main beam efficiency are $57''$ and 0.75, respectively, at 86 GHz, and $22''$ and 0.60, respectively, at 220 GHz.

The maps were made in the region $l = +0.3^\circ - +0.8^\circ$ and $b = -0.2^\circ - +0.2^\circ$, with a grid of 2 arcmin. Spectra were taken with the position switching mode using the

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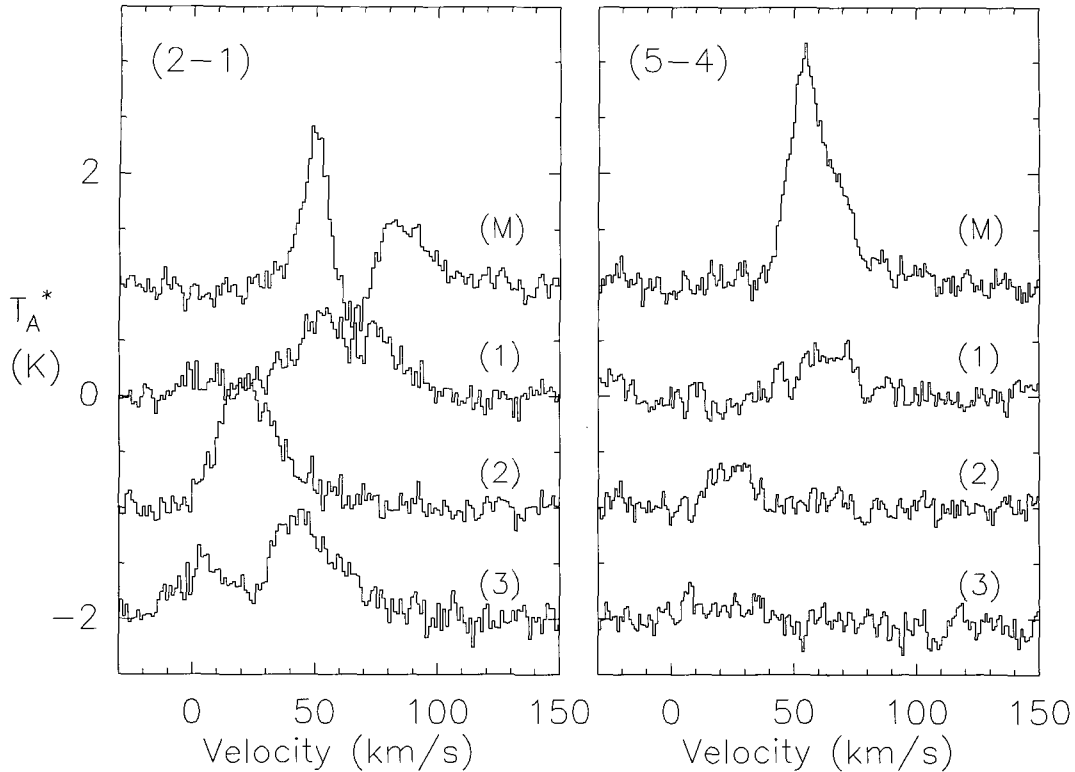


Fig. 1.— Sample spectra of the SiO 2 – 1 (*left*) and 5 – 4 (*right*) lines. The (M) shows spectra obtained roughly toward the Sgr B2(M) position, and other numbers show those obtained toward the peak positions of the three SiO clumps indicated in Fig. 2.

reference position $(l, b) = (0.0^\circ, 2.5^\circ)$. The antenna temperatures T_A^* quoted in this paper have been corrected for antenna and atmospheric losses by means of the standard chopper wheel method, but not for possible beam dilution. The typical system temperatures were about 140 – 180 K (SSB) and 220 – 240 K for the 3mm and 1mm observations, respectively. Typical rms (1σ) of the spectra are ~ 80 mK for 3mm and ~ 120 mK for 1mm observations.

III. RESULTS AND DISCUSSION

(a) Emission Distribution

Fig. 1 shows sample spectra observed for the 2 – 1 and 5 – 4 transitions. The line profiles show complex velocity structures over the whole observed region with line widths of about a few tens km s^{-1} . Near the Sgr B2(M) position the observed 2 – 1 line ($E_u \sim 6.3$ K) shows a strong self-absorption feature at the known systemic velocity ~ 65 km s^{-1} of Sgr B2(M). On the other hand the 5 – 4 transition ($E_u \sim 31.3$ K) at the same position shows at least two velocity components, of $V_{lsr} \sim 53.2$ and 61.5 km s^{-1} with $\Delta V = 11.6$ and 27.4 km s^{-1} , respectively, if fitted by two component gaussians. The Principal Cloud contains massive star-forming cores with high concentration of gas ($n_H \geq 10^4 \text{ cm}^{-3}$), surrounded by the less dense ambi-

ent gas ($n_H \sim 10^3 \text{ cm}^{-3}$) (Irvine, Goldsmith, & Hjalmarson, 1987), which causes the self-absorbed feature of the (M) position at the 2 – 1 transition.

In Figs. 2 and 3 we show the total velocity integrated intensity map and the velocity channel maps integrated over the 20 km s^{-1} velocity widths, respectively. The positions of Sgr B2(M) and Sgr B1 are indicated as filled squares in the figure. Sgr B1 is an HII region complex (LaRosa et al., 2000), and the associated cloud, which does not have an internal heating source, forms a part of the Ridge connecting the Galactic center radio Arc and the Sgr B2 cloud (Lis et al., 2001). Sgr B1 shows relatively weak molecular line emissions in our observations and no specific relation to the star forming activities of Sgr B2. In this paper we focus on the gas cloud complex associated with Sgr B2(M) and its surroundings.

The SiO 2 – 1 data shows clumpy feature, and we can distinguish three different velocity components, as labeled from (1) to (3) in the Fig. 2(*left*). The depression of the 2 – 1 line intensity toward Sgr B2(M) is mainly resulted from the self-absorption feature at this position, which is also clearly shown in the panel (e) of Fig. 3, integrated in the velocity range of $60 - 80 \text{ km s}^{-1}$. The SiO emission distribution, in general, looks quite similar to the HNC emission, which was claimed to show a ring-like feature, centered at $(l, b) = (0.7^\circ, -0.07^\circ)$

with a radius ~ 5 pc (Minh & Irvine, 2006).

Clump-1 in Fig. 2 roughly coincides with the HNC “2N Cloud”, which is elongated almost perpendicularly to the Principal Cloud, indicating that it is not an extended envelope of the Principal Cloud. The 2N Cloud and the Principal Cloud may be colliding with each other and triggering star formations in Sgr B2(S), (M), (N) and possibly to (2N) positions sequentially (Minh et al., 1998; Minh & Irvine, 2006). This collision between clouds may enhance the SiO emission largely in this clump. Clumps 2 and 3 coincide with the “Peak2” of HNC and the continuum source “OF38 Cloud” (Odenwald & Fazio (1984)’s FIR 38), respectively (Minh & Irvine, 2006, ; and see this paper for more discussions on these sources). The velocities of these clumps of about 30 km s^{-1} (Fig. 3(c)) are also similar with those suggested from the HNC line as part of the expanding ring. The overall morphology and velocity structure of the observed SiO emission show good correlations with the HNC Ring, expanding with a velocity of about $30 - 40 \text{ km s}^{-1}$ and interacting with ambient dense gas clouds (Minh & Irvine, 2006). The HNC Ring may be under shocks as traced by the SiO emission.

(b) SiO abundance

Excitation temperatures of $\sim 9 \text{ K}$ are derived near the line centers of the observed spectra at the peak positions of three clumps in Fig. 2, by comparing the 2–1 and 5–4 line intensities. However, the self-absorbed part of the Sgr B2(M) spectrum gives $T_{\text{ex}} \sim 15 - 30 \text{ K}$, which may trace a denser and warmer component in the Principal Cloud. In this analysis we focus on the three clumps, found around the Ring. Total SiO column densities $N_{\text{SiO}} \sim 1 \times 10^{14} \text{ cm}^{-2}$ have been derived at the peaks of three clumps as lower limits and listed in Table 1, assuming $T_{\text{ex}} = 10 \text{ K}$, LTE, and optically thin emission.

The heavy elements, such as silicate, are largely locked up in refractory materials in interstellar space, active phenomena are necessary to return these elements into the gas phase through sputtering or grain-grain collisions (Sofia et al., 1994). And since the major formation reactions of SiO in the gas phase are mostly endothermic, SiO has been known as a good shock tracer (Langer & Glassgold, 1990; Schilke et al., 1997). SiO has been observed to show extremely low abundances in the quiescent components of dense clouds or in photon dominated regions (PDRs) to be $\leq 10^{-11}$ (Ziurys, Friberg, & Irvine, 1989; Schilke et al., 2001). On the other hand SiO appears to be enhanced by a few orders of magnitudes in molecular outflows, for example, the fractional SiO abundance, relative to the total hydrogen density, $f_{\text{SiO}} \sim$ a few 10^{-7} in the high velocity gas of the L1448 outflow, which is about 4 orders of magnitude larger than the value obtained in the ambient medium (Bachiller et al., 1991). Recent studies for other sources also show large enhancements of

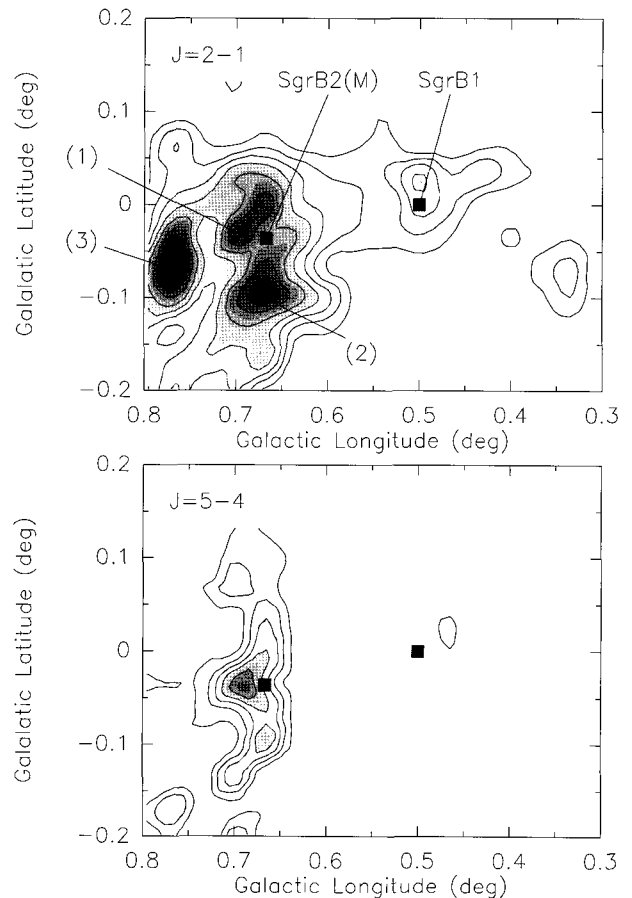


Fig. 2.— Velocity integrated intensity ($\int T_A^* dv$) maps of the observed SiO lines. (*Left*): The 2–1 line. Contour lines start from 5 K km s^{-1} and increase by 5 K km s^{-1} . (*Right*): The 5–4 line. Contour lines start from 1 K km s^{-1} and increase by 2 K km s^{-1} . The Sgr B2(M) and Sgr B1 positions are indicated as filled squares.

SiO in outflows (e.g., Cabrit et al., 2007). Most of the observed SiO emissions closely follow the shock feature associated with the molecular outflows (e.g., Martín-Pintado, Bachiller, & Fuente, 1992; Hirano et al., 2006). SiO is thought to be produced at the back of the shock, where the cooling neutral gas is being compressed.

We derive $f_{\text{SiO}} \sim (0.5 - 1) \times 10^{-9}$ toward the peak positions of three SiO clumps, which is larger by about 2 orders of magnitude than that in dense quiet regions. This abundance enhancement may result from the shocks, occurred by interactions between the expanding Ring and the ambient clouds.

IV. SUMMARY

We have observed the 2–1 and 5–4 transitions of SiO toward the Sgr B2 region, including the Principal Cloud and its surroundings. Three SiO clumps have been found at the positions of the “2N Cloud”, “Peak2”, and “OF38 Cloud” found in the previous

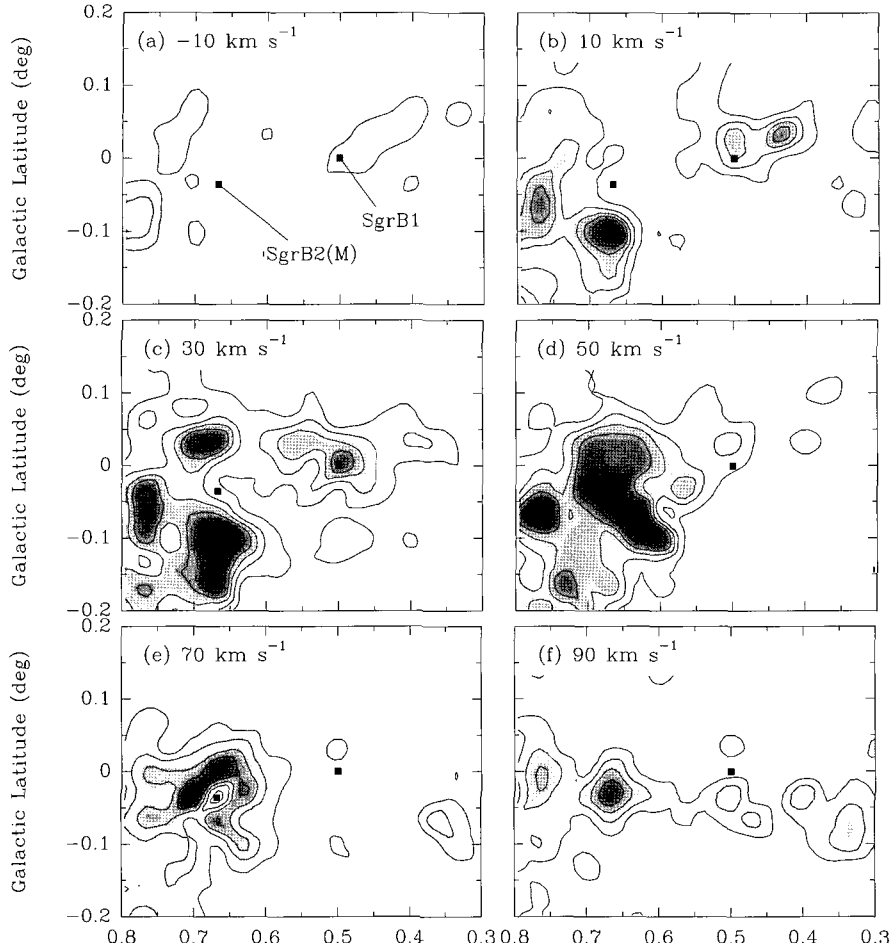


Fig. 3.— Velocity channel maps for the observed SiO $J=4-3$ line, integrated over the width 10 km s^{-1} from the central velocity indicated in the top left of each panel. Contour lines increase by 2 K km s^{-1} from 1 K km s^{-1} .

HNCO observations (Minh & Irvine, 2006). The morphology and velocity structure of the SiO emission show a close resemblance with the HNCO Ring feature. Using the excitation temperatures of about 10 K estimated from the observed two transitions, total column densities of about $1 \times 10^{14} \text{ cm}^{-2}$ are derived toward the peak positions of three SiO clumps. We also estimate the fractional SiO abundance, relative to H_2 , $f_{\text{SiO}} \sim 1 \times 10^{-9}$, which is about two orders of magnitude larger than the quiet dense cloud values.

Our SiO observational result supports the existence of an expanding ring in the Sgr B2 region, found in the HNCO observations (Minh & Irvine, 2006). As traced by the SiO emission, the whole Ring may be under shocks, resulted from the collision with the ambient cloud, especially with the Principal Cloud, containing the Sgr B2(M).

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TABLE 1
PHYSICAL PARAMETERS OF THE THREE SiO CLUMPS.

Clump	Position ^a (<i>l</i> , <i>b</i>)	Size ^b (pc)	T _{ex} ^c (K)	N _{SiO} ^d (cm ⁻²)	f _{SiO} ^e
(1)	(0.70°, -0.03°)	18 × 18	8.9	7.9 × 10 ¹³	0.5 × 10 ⁻⁹
(2)	(0.67°, -0.10°)	12 × 18	9.3	8.3 × 10 ¹³	1.0 × 10 ⁻⁹
(3)	(0.77°, -0.07°)	9 × 16	8.3	1.0 × 10 ¹⁴	1.0 × 10 ⁻⁹

^a Position of the peak emission in galactic longitude and latitude.

^b Width of the emission area measured at the half maximum of the SiO 2 – 1 peak strength (FWHM), assuming a distance of 8.5 kpc.

^c By comparison of the SiO 2 – 1 and 5 – 4 line intensities near the line center, assuming optically thin emission. Over the whole line profiles in Fig. 1, T_{ex} ~ 6 – 11 K have been derived except the self-absorbed part of the (M) spectrum (see discussions in §3.2).

^d Total column density of SiO, derived assuming T_{ex} = 10 K and optically thin emission, using the 2 – 1 line. Observational 1σ uncertainties give about 5 – 7% error in the N_{SiO} calculations. And if the T_{ex} = 5 and 15 K are applied, the uncertainties of N_{SiO} are ~ 7 and 22 %, respectively, from the listed values.

^e Total column density ratio, N_{SiO}/N_{H₂}. The total hydrogen column density was estimated from the HNC0 data in Minh & Irvine (2006).

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