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H_2S $(2_{2,0} - 2_{1,1})$ OBSERVATIONS TOWARD THE SGR B2 REGION

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ABSTRACT

The H_2S $2_{2,0} - 2_{1,1}$ line emission is observed to be strongly localized toward Sgr B2(M), and emissions from other positions in the more extended SgrB2 region are almost negligible. H_2S is thought to form effectively by the passage of the C-type shocks but to be quickly transformed to SO_2 or other sulfur species (Pineau des Forêts et al. 1993). Such a shock may have enhanced the H_2S abundance in Sgr B2(M), where massive star formation is taking place. But the negligible emission of H_2S from other observed positions may indicate that these positions have not been affected by shocks enough to produce H_2S, or if they have experienced shocks, H_2S may have transformed already to other sulfur-containing species. The SO_2 $22_{2,20} - 22_{1,21}$ line was also observed to be detectable only toward the (M) position. The line intensity ratios of these two molecules appear to be very similar at Sgr B2(M) and IRAS 16239-2422, where the latter is a region of low-mass star formation. This may suggest that the shock environment in these two star-forming regions is similar and that the shock chemistry also proceeds in a similar fashion in these two different regions, if we accept shock formation of these two species.

Key words : Interstellar Medium, Gas abundances, H_2S, Galactic Center, Sgr B2

I. INTRODUCTION

Interstellar hydrogen sulfide (H_2S) has been thought to be one of the important tracers of high-temperature chemistry and/or grain surface chemistry because of the endothermicity of the crucial gas-phase reactions leading to the formation of this molecule (Watson & Walmsley 1982; Smith & Adams 1985; Duley et al. 1980). The first detection of H_2S was made by Thaddeus et al. in 1972, via its lowest frequency transition $(1_{1,0} - 1_{0,1})$ near 168 GHz toward GMCs. This molecule was first detected toward cold dark clouds by Minh, Irvine, & Ziurys (1989), who argued that grain surface reactions may play a major role in the synthesis of this species in the sources such as L134N and TMC1. Turner (1996) also argues that steady-state gas phase reactions cannot explain the H_2S abundances in small and relatively quiescent molecular cores, and that grain chemistry may need to be invoked to explain the observed results.

It has been known that some sulfur-bearing molecules, such as H_2S, SO and SO_2, appear to be unusally abundant in clouds where high-mass star formation is occuring, accompanied by shock waves and high temperatures. A systematic survey of H_2S has been made toward several GMCs by Minh et al. (1991, 1990), who found that the fractional abundance of H_2S relative to molecular hydrogen has been enhanced by at least an order of magnitude relative to quiescent cloud values ($\sim 10^{-9}$) for many of the observed sources. Such observations confirm that "shock" or "high-temepraturе" chemistry, i.e., chemistry involving gas-phase reactions with activation energies, is taking place in hot regions and subsequently producing these species (Hartquist et al. 1980; Neufeld & Dalgarno 1989). In the model calculations, Pineau des Forêts et al. (1993) have shown that as a C-type shock passes through the cloud, sulfur is first transformed into H_2S and its abundance increases greatly in the post-shock gas. Along with elevated temperatures, shocks can also cause the partial or complete destruction of dust grains. Such grain destruction could also contribute to the formation of many of these so-called "high-temperature" molecules, since they often contain refractory elements.

In this paper we report the observations of the H_2S $2_{2,0} - 2_{1,1}$ transition (216.7 GHz) toward the Sgr B2 molecular cloud in our Galactic center. The Sgr B2 molecular cloud represents a relatively extreme case of high luminosity star formation taking place in a

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very massive giant molecular cloud and is one of the most extensively studied regions in the Galaxy. The Sgr B2 cloud has a dense central component, the Principal Cloud, $\sim 5-10$ pc in diameter with a relatively high mean density, $n(H_2) = 3-30 \times 10^4$ cm^{-3} (cf. Minh et al. 1998, and references therein). Along the north-south direction of the Principal Cloud, there exist prominent star-forming cores, Sgr B2(N), (M), and (S), which include clusters of compact HII regions having newly born massive stars. This cloud has an extended envelope ~ 40 pc in diameter with a mean density, $n(H_2) = 5 \times 10^3$ cm^{-3}, and the total mass of the Sgr B2 cloud is $\sim 5 \times 10^7$ $M_\odot$ (Scoville, Solomon, & Penzias 1975; Irvine, Goldsmith, & Hjalmarson 1987; Gordon et al. 1993). In our previous study (Minh et al. 1991), we derive a large abundance of H_2S ($N_{\mathrm{column}} \sim 10^{16}$ cm^{-2}) toward Sgr B2(M) using the $1_{1,0}-1_{0,1}$ transitions of H_2S and $H_2{}^{34}S$. Our aim in this study is to search for the extended emission of H_2S to study the shocked gas of Sgr B2 and the H_2S chemistry. In §2 we summarize the observations, the results and discussions are given in §3, and conclusions in §4.

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 H_2S $2_{2,0}-2_{1,1}$ transition (216.7 GHz) and the ^{13}CO $2-1$ (220.4 GHz) transitions, using the SIS receiver. 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 22″ and 0.60, respectively, at 220 GHz.

The maps were made with a grid of 2 arcmin in the region of $l = +0.4° - +0.8°$ and $b = -0.13° - +0.07°$ for the ^{13}CO $2-1$ line, and $l = +0.4° - +0.8°$ and $b = -0.2° - +0.13°$ for the H_2S line. The observed points are shown as dots in Figs. 1 and 3. Spectra were taken in the position switching mode with the reference position $(l,\ b) = (0.0°,\ 2.5°)$. 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 230 K (SSB), and the typical rms of the spectra is about 80 mK.

III. RESULTS AND DISCUSSION

Fig. 1 shows the integrated intensity map of the ^{13}CO $2-1$ transition. As shown in this figure, the gas appears to be extended in the whole observed area but concentrated mainly around Sgr B2(M), which is known as the column density peak. The (M) and (N) are prominent cores, where massive star formation is taking place. The (N) core, which is located about 1′ north of the (M) position, shows signs of grain chemistry, as suggested by a large abundance of saturated molecules, such as CH_3CN and C_2H_3CN (eg. Nummelin 1998). On the other hand, compared to the (N) core, the (M) core appears to have larger abundances of SiO, SO, SO_2, etc., which used to be called "high-temperature species" (Neufeld & Dalgarno 1989; Turner & Ziurys 1988).

Since we have mapped the Sgr B2 region with a 2′ spacing, we do not expect to differentiate "small scale" emission structures, such as the (N) position, where the H_2S $1_{1,0}-1_{0,1}$ transition has been detected with a weaker intensity than toward the (M) position by Minh et al. (1991). Instead we search the whole Sgr B2 cloud for "large scale" emission features of H_2S, in order to trace possible shocked gas, since H_2S is thought to be a representative high-temperature tracer, and consequently an effective shock tracer. Fig. 2 shows the spectrum obtained toward Sgr B2(M), and their line parameters are included in Table 1. Unexpectedly we found that the H_2S $2_{2,0}-2_{1,1}$ emission is strongly localized toward the (M) position, and emissions from other positions are almost negligible. Where it is detected, this extended H_2S emission implies an abundance relative to H_2 similar to that found in cold, dark clouds by Minh, Irvine, and Ziurys (1989). Fig. 3 is the integrated intensity map of the observed H_2S $2_{2,0}-2_{1,1}$ line, made by excluding the emission from the (M) posi-

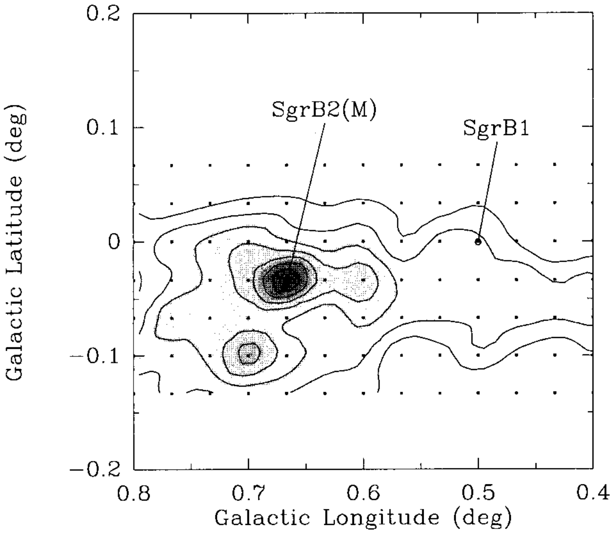

Fig. 1.— Integrated intensity ($\int T_A^* dv$) map of the ^{13}CO $2-1$ transition, the contour lines increase by 30 K km s^{-1} from the lowest 100 K km s^{-1}. Dots are the observed points.

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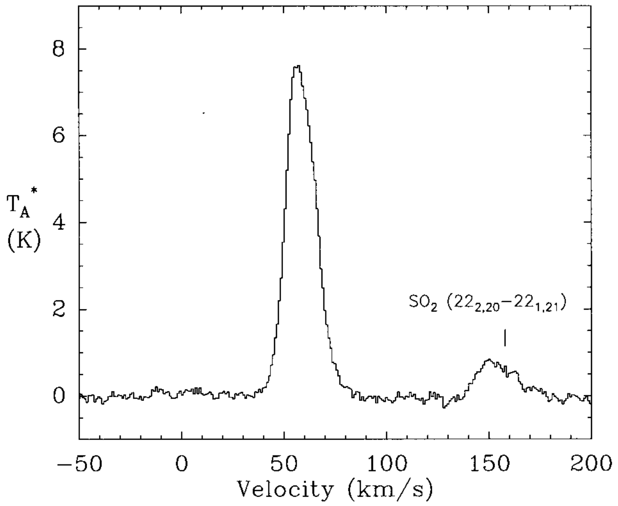

Fig. 2.— H_2S $(2_{2,0} - 2_{1,1})$ spectrum obtained toward Sgr B2(M). Their line parameters are listed in Table 1.

tion since the emission from the (M) position dominates excessively the emission from other positions.

One possible reason for the lack of extended H_2S emission can be an excitation problem for the observed transition. Since the energy of the H_2S $2_{2,0}$ level is about 84 K from the ground state, the excitation of this line might not be sufficient in the quiescent cloud region surrounding the compact continuum core, Sgr B2(M), to be detected in our observations. However, if the rotation temperature of H_2S changes from 100 K to 50 K or 20 K without an abundance change, the line intensity will change by only 20 – 60 %, which would still be easily detectable in our observations. We think, therefore, that the excitation cannot be a major reason of the very steep decrease of the observed line intensity away from Sgr B2(M).

Since the typical H_2S abundances in star forming regions cannot be well explained with the steady-state quiescent chemistry, either the grain chemistry or the high-temperature (shock) chemistry have been suggested to explain the observed H_2S values (Minh, Irvine, & Ziurys 1989; Minh et al. 1990, 1991; Turner 1996). The large line wings of the H_2S spectrum obtained toward Orion-KL (Minh et al. 1990) indicate that the molecular outflow in the KL region (the Plateau), where shock chemistry prevails, must be a main site for the H_2S formation. However, in the Hot Core of Orion-KL, where grain surface chemistry prevails, the H_2S fractional abundance relative to H_2 was found to be similar with that of the Plateau from an analysis using Gaussian decomposition of the $1_{1,0} - 1_{0,1}$ spectra of H_2S and $H_2{}^{34}S$ (Minh et al. 1990). In Sgr B2, the H_2S emission appears to be stronger in the (M) position where the hot-temperature chemistry is thought to prevail than in the (N) position where grain chemistry seems to predominant (Minh et al. 1991), which may suggest that H_2S forms effectively by shocks, generated by the massive star cluster located in the (M) position. Although it is still not certain which process plays the major role in the formation of H_2S, it does seem to form effectively by the passage of the non-dissociative C-type shocks and the shock formation model seems to explain the observed intensity well, at least in the shock prevalent region (Neufeld & Dalgarno 1989; Pineau des Forêts et al. 1993).

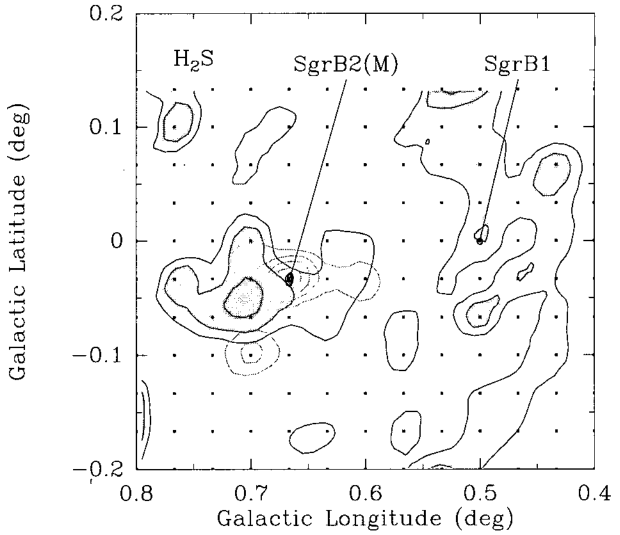

Fig. 3.— Integrated intensity ($\int T_A^* dv$) map of the observed H_2S $2_{2,0} - 2_{1,1}$ line excluding the emission from the (M) position. The contour increases by 1.0 K km s^{-1} from 1.5 K km s^{-1}. The thin contour lines are from the ^{13}CO $2 - 1$ line map of Fig. 1. Dots are the observed points.

According to the model by Pineau des Forêts et al. (1993), the H_2S abundance increases quickly in the shocked gas, but H_2S is converted to SO_2 or other sulfur species on a time scale less than 10^3 years. If we accept this H_2S formation model, the abundance of H_2S will be enhanced largely only in the region under the influence of shocks "at present", such as the region very near to the Sgr B2(M) position; and its abundance decreases quickly after the passage of the shock. We think that the shock model of Pineau des Forêts et al. (1993) explains our observed results toward Sgr B2.

Together with the H_2S $2_{2,0} - 2_{1,1}$ line in Fig. 2, the SO_2 $22_{2,20} - 22_{1,21}$ line was detected in the same spectrum. This SO_2 line is also detectable only toward the (M) position. The line parameters of this line are also included in Table 1. Since the energy level of this SO_2 line ($22_{2,20}$) is about 248.6 K above the ground state, it can be excited only in high-temperature shocked gas, such as that at the (M) region. In the line survey re-

TABLE 1
LINE PARAMETERS OF THE OBSERVED SPECTRA IN FIG. 2.

Molecule (transition)	V^{a}_{LSR} (km s^{-1})	FWHM^{a} (km s^{-1})	$\mathrm{T}^{*}_{\mathrm{A}}$ ^{a} (K)	$\int \mathrm{T}^{*}_{\mathrm{A}}\mathrm{dv}$ (K km s^{-1})	rms^{b} (K)
H_2S ($2_{2,0} - 2_{1,1}$)	58.2	16.6	7.7	135.7	0.08
SO_2 ($22_{2,20} - 22_{1,21}$)	60.3	19.7	0.8	14.1	0.08

NOTE.—^{a}Gaussian fit results. ^{b}R.m.s.(1 σ) value of the observed spectra.

sults of Blake et al. (1994), the same spectral range has been published for a low-mass star forming region, IRAS 16293-2422. Interestingly, the line intensity ratio of these two molecules between Sgr B2(M), a massive star-forming region, and IRAS 16293-2422, a low-mass star-forming region, appears to be very similar, which may suggest that the shock chemistry proceeds in similar fashion in these two different regions. If these two species form in the same shocked gas but with different time scales as was suggested by Pineau des Forêts et al. (1993), the intensity ratios of these two species will be an interesting diagnostic for the shock chemistry.

IV. CONCLUSION

We observed the H_2S $2_{2,0} - 2_{1,1}$ line toward Sgr B2 and found that the emission is strongly localized toward the (M) position, and emission from other positions is almost negligible. H_2S is thought to form effectively by the passage of C-type shocks but to be quickly transformed to SO_2 or other sulfur species (Pineau des Forêts et al. 1993). This shock process may have enhanced the H_2S abundance in Sgr B2(M), where massive star formation is taking place. The other observed positions, showing negligible emission of H_2S, may have not been affected by shocks enough to produce H_2S, or, if they have experienced shocks, H_2S may have been transformed already to other species. The SO_2 $22_{2,20} - 22_{1,21}$ line was also observed in the same spectrum as the H_2S $2_{2,0} - 2_{1,1}$ line. This SO_2 line is also detectable only toward the (M) position. The line intensity ratio of these two molecules appears to be very similar at Sgr B2(M) and IRAS 16293-2422, which may suggest that the environment of shock conditions in these two star-forming regions may be similar and the shock chemistry may proceed in a similar fashion in these two different regions, in spite of the significant difference in their luminosities.

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