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## First detection of [C I] absorption lines toward SGR B2 and W49A

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How to cite:

Sato, K.; Hasegawa, T. and White, G. J. (1997). First detection of [C I] absorption lines toward SGR B2 and W49A. In: Diffuse Infrared Radiation and the IRTS, 11-14 Nov 1996, Sagamihara, Kanagawa, Japan, p. 251.

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Version: Version of Record

Link(s) to article on publisher's website:

<http://cdsads.u-strasbg.fr/abs/1997ASPC..124..251S>

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wavelengths. In this paper, we report the first successful detection of [C I]  $^3P_1$ - $^3P_0$  492GHz absorption line toward Sgr B2(M) and W49A, the brightest sources at this wavelength.

## 2. Observations and Results

Observations were carried out at the James Clark Maxwell Telescope (JCMT), Mauna Kea, Hawaii. The half-power beam width of the telescope was  $10''.6$  and the main beam efficiency was 0.52. The velocity resolution was  $0.19 \text{ km s}^{-1}$ . Typical system noise temperature was  $\sim 10000 \text{ K}$  (SSB).

Spectra were obtained by position-switching. A 750 sec integration made on the continuum peak of Sgr B2(M) (*on-continuum position*) to get an r.m.s. noise level of  $\Delta T_A^* = 0.64 \text{ K}$ . We also observed four positions adjacent to the continuum source (*off-continuum positions*) with offsets  $(\Delta\alpha, \Delta\delta) = (\pm 30'', \pm 10'')$ . W49A was observed only at the on-continuum position. A 2100 sec integration yielded a sensitivity of  $\Delta T_A^* = 0.18 \text{ K}$ . We measured continuum antenna temperatures at the on-continuum positions with beam-switching.

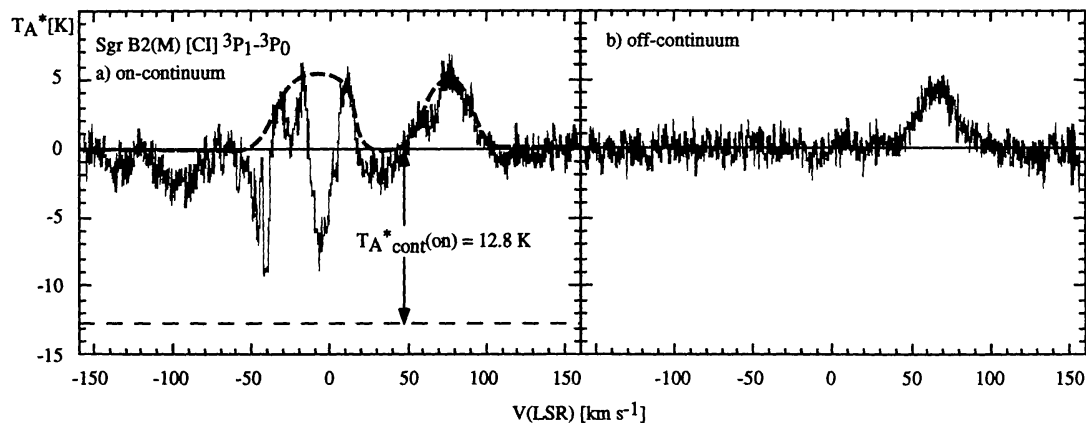


Figure 1. On-(*Left*) and off-(*Right*) continuum [C I] line profiles toward Sgr B2(M). The dashed curve indicates the profile of the unidentified emission line expected when the absorption lines were absent.

Figure 1 shows the [C I] spectra toward on- and off-continuum positions toward Sgr B2(M). We see the [C I] emission of Sgr B2(M) itself at  $V_{\text{LSR}} = +76 \text{ km s}^{-1}$ . The emission features at  $V_{\text{LSR}} = -40 - +20 \text{ km s}^{-1}$  are, most probably, not from a baseline ripple but are due to an unidentified line with a compact spatial distribution. A total of 13 discrete absorption features are identified. They appear at the same velocities as the molecular absorption lines (e.g., Greaves et al. 1992). In the spectrum toward W49A, we recognize the emission from W49A itself at  $V_{\text{LSR}} = +11 \text{ km s}^{-1}$  and two absorption lines at  $+39$  and  $+57 \text{ km s}^{-1}$  associated with the Sagittarius arm.

In the following, we focus on the data taken toward Sgr B2(M). The line main-beam brightness temperatures at the on- and off-continuum positions,  $T_{\text{mb}}^{\text{line}}(\text{on})$  and  $T_{\text{mb}}^{\text{line}}(\text{off})$ , are related to the optical depth  $\tau$  and excitation tem-

perature  $T_{\text{ex}}$  of the absorbing gas by the following equations:

$$\begin{aligned} T_{\text{mb}}^{\text{line}}(\text{on}) &= [J(T_{\text{ex}}) - T_{\text{mb}}^{\text{cont}}(\text{on}) - J(2.7\text{K})][1 - e^{-\tau}], \\ T_{\text{mb}}^{\text{line}}(\text{off}) &= [J(T_{\text{ex}}) - T_{\text{mb}}^{\text{cont}}(\text{off}) - J(2.7\text{K})][1 - e^{-\tau}]. \end{aligned} \quad (1)$$

Here,  $J(T_{\text{ex}})$  is the specific intensity in temperature units  $(h\nu/kT_{\text{ex}})/[\exp(h\nu/kT_{\text{ex}}) - 1]$ ,  $T_{\text{mb}}^{\text{cont}}(\text{on})$  and  $T_{\text{mb}}^{\text{cont}}(\text{off})$  are the continuum main-beam brightness temperatures at corresponding positions, and  $J(2.7\text{K})$  is the contribution from the cosmic background radiation. We estimate  $T_{\text{mb}}^{\text{cont}}(\text{off}) = 3.4$  K (average for the four positions) from the 800 and 450  $\mu\text{m}$  continuum maps taken at JCMT (Goldsmith et al. 1990) scaled with the present measurement of  $T_{\text{mb}}^{\text{line}}(\text{on})$ .

If the foreground clouds do not have steep structures on a 30" scale and we can use common  $\tau$  and  $T_{\text{ex}}$  for on- and off-positions, the simultaneous equation (1) can be solved to get  $\tau$  and  $T_{\text{ex}}$  independently. The derived optical depths are in a range of 0.1 – 1.6 and the excitation temperatures are about 10 – 20 K. The high [C I] excitation temperatures are in sharp contrast to those of molecular absorption lines for which  $T_{\text{ex}} \approx 2.7$  K is common (Greaves and Nyman 1996).

### 3. Excitation Analysis for Spiral Arm Clouds toward Sgr B2(M)

We can estimate the physical parameters of the *spiral arm clouds* with an aid of the large velocity gradient (LVG) line formation model calculations (e.g., Goldreich and Kwan 1974, Scoville and Solomon 1974). We consider all the three fine structure levels in the ground state and adopted the collision rate between  $\text{H}_2$  and neutral carbon calculated by Schröder et al. (1991) with an ortho/para ratio of 3. The calculations were done for gas kinetic temperatures  $T_{\text{k}} = 15, 20, \text{ and } 30$  K because the excitation temperatures of *spiral arm clouds* toward Sgr B2(M) are higher than 10K.

The observations are reproduced if the [C I] absorption lines arise in gas with densities  $n(\text{H}_2) \approx 100 - 600 \text{ cm}^{-3}$ . This is consistent with the density upper limit of  $\sim 600 \text{ cm}^{-3}$  estimated from the CS  $J=2-1$  and  $3-2$  absorption at 0,  $-25$ , and  $-40 \text{ km s}^{-1}$  (Greaves 1995). The [C I] absorption lines originate from less dense molecular gas.

### 4. [C I] fractional abundance relative to molecular hydrogen

The [C I] column densities toward Sgr B2(M) are in the range of  $10^{17}$  – a few  $\times 10^{18} \text{ cm}^{-2}$ . To derive fractional abundance of atomic carbon,  $[\text{C I}]/[\text{H}_2]$ , we adopt the  $\text{H}_2$  column densities estimated by Greaves and Nyman (1996).  $N(\text{H}_2)$  is in a range of  $9.0 \times 10^{20} - 1.6 \times 10^{22} \text{ cm}^{-2}$ . As  $N(\text{H}_2)$  increases, the fractional abundances of CS, HNC, and  $\text{C}_3\text{H}_2$  change systematically by a factor of 2-3 (Greaves and Nyman 1996). In contrast, the [C I] fractional abundance is remarkably constant at  $10^{-4.01 \pm 0.06}$ . The homogeneous photodissociation models for translucent clouds (van Dishoeck and Black 1988) predict that  $[\text{C I}]/[\text{H}_2]$  reaches a maximum at  $N(\text{H}_2) = (2 - 3) \times 10^{21} \text{ cm}^{-2}$ . The present observations do not show such a trend, and improvements of the models (e.g., introduction of the clumpiness, Spaans 1996) may be required.