OBSERVATIONS OF C_3H_2 (2_{12} - 1_{01})
TOWARD THE SAGITTARIUS A MOLECULAR CLOUD

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ABSTRACT

We have mapped the C_3H_2 $2_{12} - 1_{01}$ transition line toward the Sgr A molecular cloud on a $1'$ grid spacing and derived C_3H_2 column densities of $3 \sim 7 \times 10^{14}$ cm^{-2} for molecular clouds of Sgr A. The fractional abundances of C_3H_2 relative to H_2 are obtained to be $3 \sim 6 \times 10^{-9}$, which are slightly lower than that for the cold dark cloud TMC-1 but are enhanced by factors of 5-60 compared to those for Sgr B2 and the Orion extended ridge. We also estimate from the C_3H_2 column densities total masses of $\sim 10^6$ $M_\odot$ for two clouds (M $- 0.13 - 0.08$ and M $- 0.02 - 0.07$), which are thought to be close to the virial equilibrium. We suggest that the large abundance of C_3H_2 in Sgr A may be partly due to the activities of the Galactic center.

Key Words: interstellar cloud, interstellar molecule - Galactic center.

I. INTRODUCTION

The Sagittarius A molecular cloud which is located within ~150 pc from the Galactic center has been a target for several molecular line observations since the first discovery of the neutral molecular gas from the absorption line studies for OH and H_2O (Bolton *et al.* 1964; Snyder *et al.* 1969). Especially, recent studies for the distributions of NH_3, HNCO, CO isotopes , and $HOCO^+$ have shown that the Sgr A molecular cloud has a complicated structure and is composed of several large clouds. Large line widths ($\Delta V \approx 20 \sim 30$ km s^{-1}) of the observed lines pervade throughout this region, which may indicate systematic motions inside the cloud (Güsten *et al.* 1981; Armstrong & Barnett 1985; Minh *et al.* 1991). Sgr A has been known to be in a hot environment caused by active energetics of the Galactic center, in which there are Sgr A*, a blackhole candidate, IRS16, a compact cluster of late O and early B stars, and Sgr A East, a supernova remnant (cf. Liszt 1988). By observing various sorts of molecular lines toward Sgr A, Minh *et al.* (1992) suggested that the energetic processes of the Galactic center such as shocks, UV radiation, and also the possible interaction of the neutral and the ionized gas around the nucleus may affect the molecular clouds in Sgr A efficiently and result in rich chemistry.

In this paper we report the results of $2_{12} - 1_{01}$ transitions observation of Cyclopropenylidene (C_3H_2) toward the Sgr A molecular cloud. C_3H_2 has been found in various circumstances throughout the Galaxy and is thought to be a good tracer for physical conditions of the interstellar medium (Madden *et al.* 1989). We discuss the distribution, abundance and chemistry of C_3H_2 in the Galactic center. The distance from the Sun to the Galactic center used in this paper is adopted to be 8.7 kpc, at which $1'$ corresponds to 2.53 pc in linear distance.

II. OBSERVATIONS

Observations of the C_3H_2 $2_{12} - 1_{01}$ transition ($\nu = 85.33889$ GHz) toward Sgr A were carried out in Chile with the Swedish-ESO 15 m telescope (SEST) equipped with a cryogenic Shottky diode mixer, in 1988 June. Spectra were detected with the wide band acousto-optic spectrometer of 0.69 MHz resolution and 728 channels. The HPBW and main beam
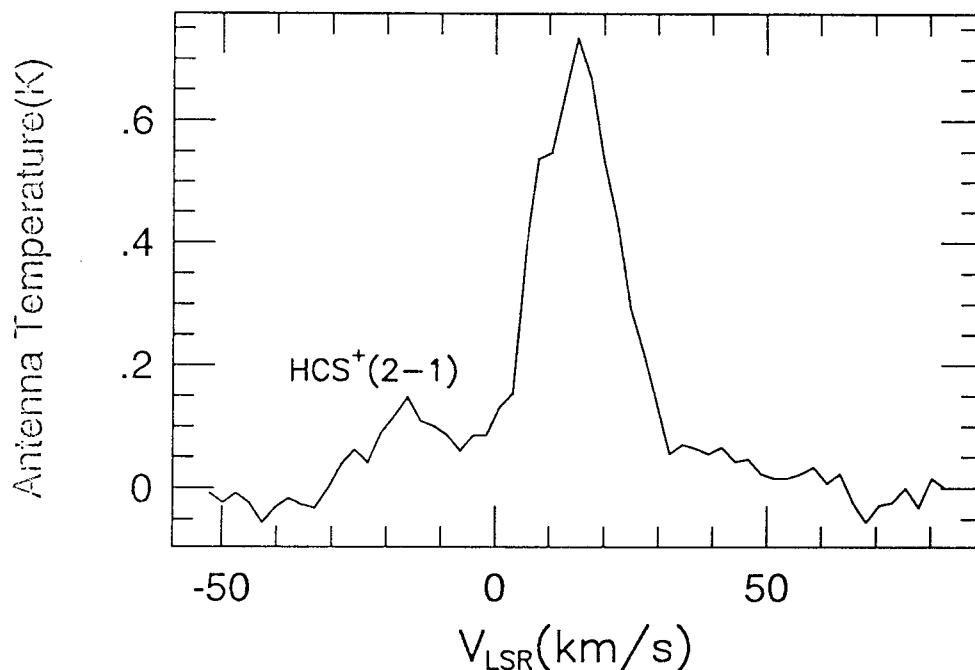
Figure 1. Sample spectrum of the C_3H_2 2_{12} - 1_{01} transition obtained toward the core of the cloud M-0.13-0.08. The 2-1 transition of HCS^+ is included in the spectrum.

efficiency are 56 arcsec and 0.73, respectively (Booth *et al.* 1989). For the correction of the sky intensity, we used double beam switching with the beam separation being approximately 12' on the sky. We then corrected antenna and atmospheric losses by making use of the standard chopper wheel method to obtain the antenna temperature ΔT_A^*. The typical system temperature was about 350 K. We observed a total of 139 points which are denoted in dots in Figure 2. Figure 1 shows a sample spectrum obtained toward the core of M − 0.13 − 0.08. The typical rms value of the spectra is about 20 mK.

III. RESULTS

(a) Distribution of C_3H_2

We made maps of the C_3H_2 $2_{12} - 1_{01}$ transition in the Sgr A region on a 1' grid spacing. The integrated intensity map is shown in Figure 2 and the velocity map in Figure 3, superposed on the integrated intensity contour.

It is interesting that global emission features of the clouds seen in the intensity map are very similar to those for NH_3 (Güsten *et al.* 1981; Armstrong & Barrett 1985), and $HOCO^+$ (Minh *et al.* 1991). Implications for the similarity among the abundance distributions of these molecules will be discussed in the section IV-(b).

The integrated intensity map shows emission peaks at the center of M − 0.13 − 0.08, M − 0.02 − 0.07, M 0.07 − 0.08, M 0.11 − 0.08, and M 0.25 + 0.01. The strongest peak among these clouds appears at the center of M − 0.13 − 0.08, known also as a '20 km s^{-1} cloud', which has the largest column density among those observed. The velocity contour shows that this condensation has the lowest velocity and the steepest velocity gradient of $\sim$ 2.2km s^{-1} pc^{-1}. The remaining area of $l^{II} \approx -3'$ to 9' has rather a uniform velocity of 50 $\sim$ 60 km s^{-1}.

M 0.25 + 0.01 which lies at the edge of the area surveyed by us seems to have a well bounded core. Although this cloud has been suggested as a part of the "bridge" between Sgr A and Sgr B2 (Güsten & Downes 1980, Güsten *et al.* 1981), it is not clear whether this cloud is physically correlated with the other condensations in Fig. 1.
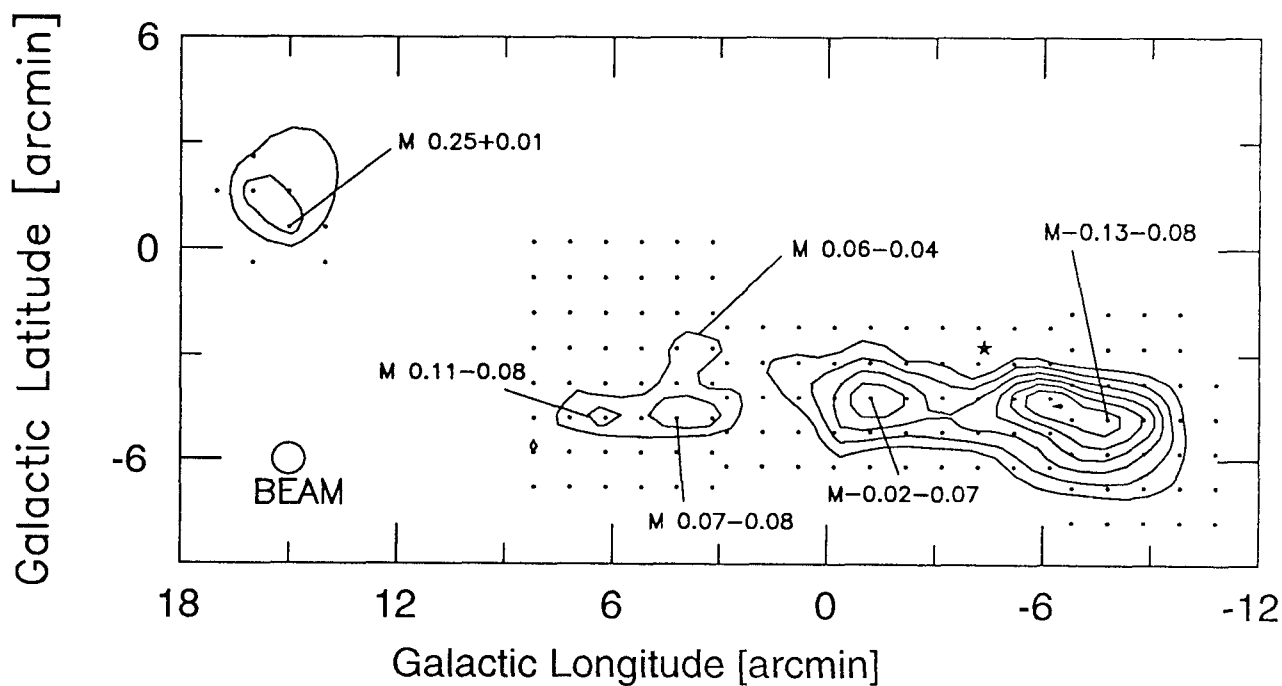
Figure 2. Integrated intensity $\left(\int T_A^* dv\right)$ map of the C_3H_2 $2_{12} - 1_{01}$ transition. Contour levels are from 4.0 to 18.0 K km s^{-1} with an increment of 2.0 K km s^{-1}. Dots indicate observed points and the asterisk is the position of the physical Galactic center.
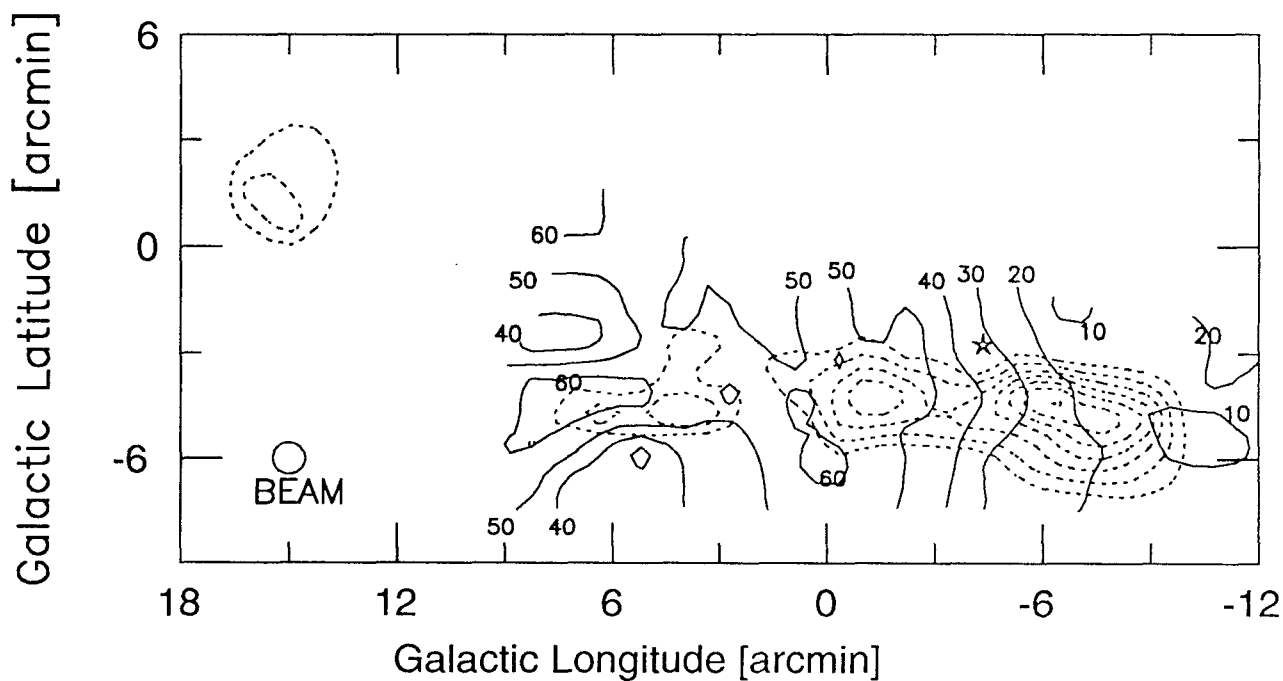
Figure 3. Velocity map of the C_3H_2 $2_{12} - 1_{01}$ transition (solid lines) superposed upon the integrated intensity map (dashed lines) from Fig. 2.

Table 1. Abundances of C_3H_2 at the cores of the condensations

Cloud	$N(H_2)$[a] (cm^{-2})	$N(C_3H_2)$ (cm^{-2})	$N(C_3H_2)/N(H_2)$
M-0.13-0.08	2.2×10^{23}	6.6×10^{14}	3.0×10^{-9}
M-0.02-0.07	8.8×10^{22}	4.6×10^{14}	5.2×10^{-9}
M 0.07-0.08	9.0×10^{22}	2.7×10^{14}	3.2×10^{-9}
M 0.11-0.08	4.9×10^{22}	2.8×10^{14}	5.7×10^{-9}

[a] From the $N(^{13}CO + C^{18}O)$ Map of Armstrong & Barrett (1985) and the assumptions of $[^{13}CO]/[H_2] = 2 \times 10^{-6}$ (Dickman 1978) and $[^{13}CO]/[C^{18}O]=8.6$ (Güsten et al. 1985).

(b) Column densities and Abundances of C_3H_2

The observed antenna temperature ΔT_A^*, after correcting for the background radiation temperature T_{bg}, is expressed with the equation of radiative transfer as

$$\Delta T_A^* = \eta_B \Phi [J(T_{ex}) - J(T_{bg})](1 - e^{-\tau_\nu}), \tag{1}$$

where η_B is the main beam efficiency, Φ the beam filling factor, τ_ν the optical depth at frequency ν, T_{ex} the excitation temperature of the C_3H_2 line, and $J(T)$ the Planckian function in temperature unit expressed as $J(T) = h\nu/k(e^{h\nu/kT} - 1)$.

Assuming optically thin emission and the filling factor $\Phi = 1$, the column density for the upper level of the transition N_U is determined from the following ;

$$N_U = 8\pi\nu^2 k \Delta V \Delta T_A^* C_{bg}/hc^3 \eta_B A, \tag{2}$$

where ν is the line frequency, k the Boltzmann constant, ΔV the FWHM, $C_{bg} = (1 - J(T_{bg})/J(T_{ex}))^{-1}$ the background correction factor, c the light speed, h the Planck constant, and A the Einstein spontaneous emission coefficient. Then the total column density of the molecule N_T can be found from

$$N_T = (N_U/g_U)Q(T_{ex}) \ e^{E_U/kT_{ex}}, \tag{3}$$

where g_U is the degeneracy of upper level, and $Q(T_{ex})$ is the rotational partition function assuming a Boltzmann population distribution.

Assuming T_{bg} of 10 K and T_{ex} of 30 K (see Minh et al. 1991, 1992 for discussion), we derive total C_3H_2 column densities of $2.8 \sim 6.6 \times 10^{14} cm^{-2}$ at the cores of the condensations as listed in Table 1.

The fractional abundances of C_3H_2 relative to H_2 are also listed in the last column of Table 1. Those fractional abundances ($3.0 \sim 5.7 \times 10^{-9}$) are higher than these for Sgr B2 and Orion KL Extended Ridge by factors of $5 \sim 60$ (Irvine et al. 1987; Blake et al. 1987) but are slightly lower than that for the cold dark cloud TMC-1 (Irvine et al. 1987) which has unusually large abundances of carbon-bearing species.

IV. DISCUSSION

(a) Cloud Mass

We estimate the masses of $M - 0.13 - 0.08$ and $M - 0.02 - 0.07$ by summing the column densities of C_3H_2 using the abundance ratio of $[C_3H_2]/[H_2]$ derived at the cores of the clouds. The boundary of a cloud is obtained by an extrapolation of the curve for the integrated C_3H_2 mass within the radius of a circle whose area is equal to a contour area (Figure 4). The calculated masses are $2.3 \times 10^6 M_\odot$ for $M - 0.13 - 0.08$ and $1.0 \times 10^6 M_\odot$ for $M - 0.02 - 0.07$.

We also derive the virial masses of $M - 0.13 - 0.08$ and $M - 0.02 - 0.07$. We used the following equation useful for characterizing the size of a system that lacks a sharp boundary, ignoring the effects of the magnetic field and the external pressure, (Binney & Tremaine 1987)

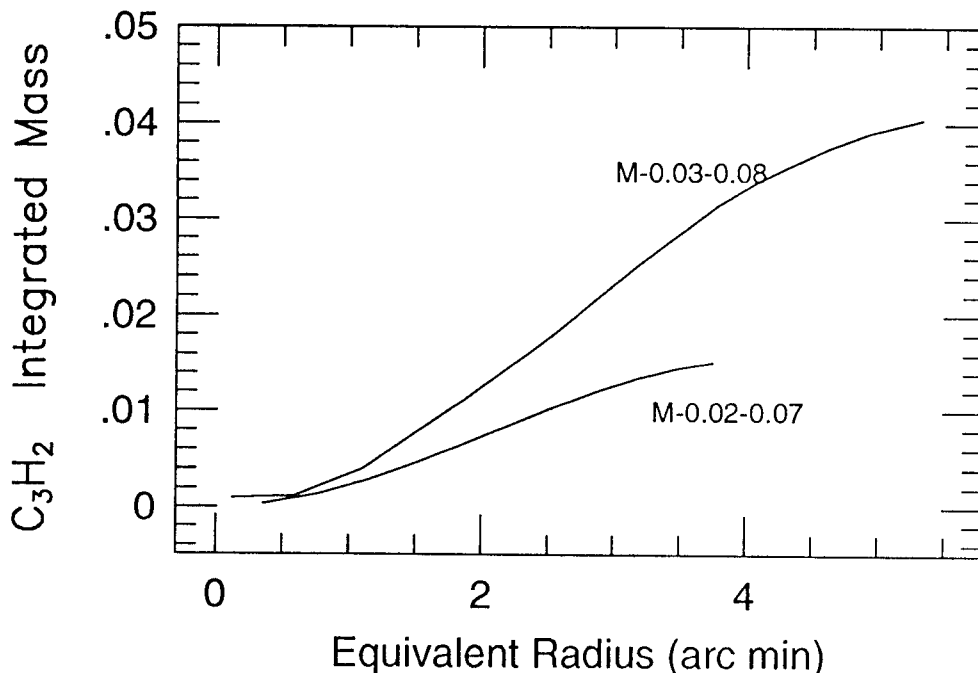$$M_V \approx \frac{r_h \ <V_{rms}^2>}{0.4 \ G}, \tag{4}$$

Figure 4. Curves of the integrated C_3H_2 masses inside circular radii for $M - 0.13 - 0.08$ and $M - 0.02 - 0.07$. The mass is expressed in solar mass units.

where G is the gravitational constant, r_h the median radius which is defined to be the radius within which lies half a cloud mass and V_{rms} the root mean square speed. The median radius r_h is obtained from the curve of Fig. 4, within which lies half of the total C_3H_2 mass of a cloud, and $< V_{rms}^2 > \approx 0.541\Delta V^2$, where ΔV is the FWHM. We obtain the virial masses of $1.7 \times 10^6 M_\odot$ for $M - 0.13 - 0.08$ and $1.9 \times 10^6 M_\odot$ for $M - 0.02 - 0.17$. It is noted that if we consider the large uncertainties in deriving the column density, the agreement between mass estimates by two methods is fairly good. Thus the two clouds $M - 0.13 - 0.08$ and $M - 0.02 - 0.07$ may be close to virial equilibrium.

Our observations were, however, made with a low resolution of $\sim 1'$. The higher spatial resolution observations will probably show clumpier structures than the map in Fig. 1 and result in different virial mass estimates. The high spatial resolution observations for these clouds are strongly recommended to study the structure and density of the Sgr A molecular clouds.

(b) Chemistry of C_3H_2 in Sgr A

Previous results have demonstrated that C_3H_2 is very ubiquitous in various environments throughout the Galaxy and have suggested that C_3H_2 may form easily in a variety of physical environments (Matthews & Irvine 1985; Cox et al. 1987, 1988, 1989; Turner et al. 1989; Madden et al. 1989). The C_3H_2 abundance is thought to be increased by ion-molecule chemistry in conditions with a large carbon abundance and also by shock chemistry.

The ion-molecule synthesis can reproduce the observed abundances of C_3H_2 in the dark cloud TMC-1 by assuming $[C]/[O] > 1$ which results in a large abundance of complex hydrocarbons (C_9H_2, CH_3C_6 etc.) (Herbst & Leung 1989), or by assuming a large abundance of Polycyclic Aromatic Hydrocarbons (PAHs) (Lepp & Dalgarno 1988).

The environment of Sgr A is, however, much different from that of the quiescent cold dark cloud. Sgr A has been known to be in a hot environment due to active energetics of the Galactic center (Listz 1988, Minh et al 1992). The influence of the activities of the Galactic center for C_3H_2 may be also inferred from the the similarity among the abundance distributions of C_3H_2, NH_3 and $HOCO^+$ in Sgr A. In general the ammonia abundance is greatly increased in the active regions such as near the star-forming sites. This molecule seems to be evaporating from the interstellar dust and may trace the activities of the region. Also the $HOCO^+$ molecule has been detected only at the Galactic center molecular clouds, such as Sgr B2

and Sgr A (Minh *et al.* 1988, 1991). This protonated CO_2 ion is thought to be closely related to CO_2 which may form on the grain surface and its abundance may be increased in the hot environments like Sgr A (Minh *et al.* 1988; Greenberg 1991). Therefore the similarity among the abundance distributions of C_3H_2, NH_3 and $HOCO^+$ in Sgr A may indicate that C_3H_2 is also related to the activities of the Galactic center. Moreover the high abundance of SiO, a typical shock indicator, in Sgr A (Minh *et al.* 1992) may be another evidence for the influence of the activities of the Galactic center.

Although the current shock chemistry models are rudimentary, they are fairly successful in reproducing several observational results including C_3H_2 in Sgr A (Mitchell 1984; Pineau des Forêts *et al.* 1987). The shock model of Mitchell (1984) shows high post shock abundances of C_3H_2 ($10^{-7} \sim 10^{-9}$) in 10^5 years after the passage of a nondissociating shock. The nature of shocks is, however, quite uncertain and we only suggest that the large abundance of C_3H_2 in Sgr A may partly result from the activities of the Galactic center. The physical and chemical conditions of the neutral gas around the Galactic center should be studied further and high- spatial resolution observations are necessary in these studies.

ACKNOWLEDGEMENTS

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