NH_3 observations of the Central Molecular Zone with Kagoshima 6 meter radio telescope

Toshihiro Handa[1], Toshihiro Omodaka[2], Takumi Nagayama[2], Hayati Bebe Iahak[2] and Naohito Matsuyama[2]

[1] University of Tokyo, Japan

[2] Kagoshima University, Japan

E-mail: handa@ioa.s.u-tokyo.ac.jp

Abstract. We made a wide survey in two Ammonia lines of the major part of the Central Molecular Zone in the Galactic center region. The ammonia emission can be detected at most of the observed positions, which means ammonia emission is extended over the Central Molecular Zone. We identify 4 clouds, which correspond Sgr A 20-km s^{-1} cloud, Sgr A 50-km s^{-1} cloud, sgr B cloud complex, and the 1.3-degree cloud. Besides them diffuse emission can be detected over the Central Molecular Zone. The intensity ratio of the (2,2) transition to (1,1) transition is uniform over most of the observed region and is about 0.7–0.8, which means that the molecular gas is 24–42 K. It means most dense gas in the Galactic center region is as cool as majority of dust there. This cool temperature is consistent to the values derived previously, although their observed coverage was smaller than ours. On $l - v$ plane the NH_3 emitting region is surrounded by clouds with the high intensity ratio of CO (2–1) to CO (1–0) lines. It means the dense molecular gas is surrounded by hot molecular gas in 10–100 pc scale.

1. Introduction

There is a huge molecular cloud complex in the Galactic center region between $-1° \leq l \leq +1.5\,\mathrm{deg}$ called the Central Molecular Zone (CMZ). The CMZ is rich in dense molecular gas and well traced in dense gas tracer such as CS [1]. Several observations in radio and infrared have been done and gas and dust temperatures are estimated. However, there is a discrepancy between gas and dust temperatures; most observations show gas temperature is hotter than dust temperature. The gas temperature is as hot as 60–70 K from millimeter line observations [2], and the dust temperature is as cool as 15–22 K from submillimeter and infrared observations [3, 2].

Ammonia line observations gave a big hint to solve this discrepancy. Hüttemeister et al. shows that temperature from NH_3 (1,1) and (2,2) transitions is about 25 K and temperature from NH_3 (4,4) and (5,5) transitions si about 200 K [4]. However, there is not NH_3 observations which cover the whole CMZ [5, 6]. Here, we present an ammonia map of the whole CMZ.

2. Observations

We have observed a main part of the CMZ using the Kogoshima 6-m telescope, simultaneously observing at the spectral lines of NH_3 (2,2) line at 23.694 GHz and (1,1) line at 23.722 GHz. The full width at half maximum (FWHM) beam size is $9.5'$. The observed region is a rectangular area of $-1° \leq l \leq +1.625°$, and $-0.315° \leq b \leq +0.250°$, which covers most of the CMZ.

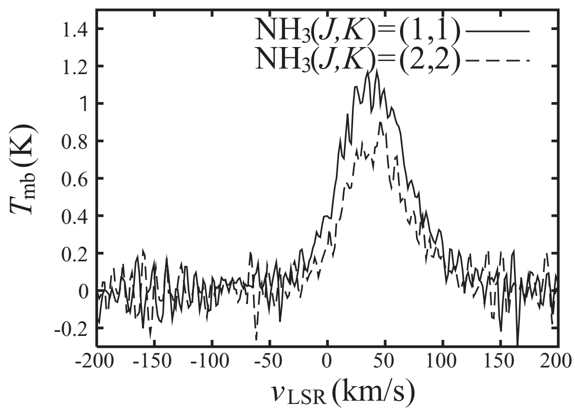

Figure 1. A profiles in NH_3 (1,1) and (2,2) transitions at $(l, b) = (0.750°, -0.125°)$. The velocity resolution is 1.6 km s^{-1}, which is the original resolution of the spectrometer before smoothing process.

The spacing of the observation grid is 0.125°, which corresponds to 18.5 pc at the distance to the galactic center, 8.5 kpc. The main beam efficiency at 23 GHz is 0.59. The velocity resolution at 23 GHz is 1.5 km s^{-1}, although we smoothed all spectra to be with 5 km s^{-1} resolution. The typical rms noise level is 0.047 K at 5 km s^{-1} resolution.

3. Results

3.1. Profiles

An NH_3 inversion transition line has 5 hyperfine components. The outermost hyperfine components are about 20 km s^{-1} separated from the main component and the inter components are about 8 km s^{-1}.

In the Galactic center region molecular gas shows violent motion within a 9′-beam. It makes hyperfine components to blend into a single line. Figure 1 shows profiles in both NH_3 transitions of Sgr B cloud. Apparent linewidths in both transitions show wider than 50 km s^{-1}. Although we have no chance to separate the satellite lines, such wide lines make it simple. In an optically thin case, apparent NH_3 line widthes in (1,1) and (2,2) shows almost the same apparent linewidths, when intrinsic linewidths are wider than 40 km s^{-1}. (figure 4b in [8]). Actually our profile shapes of these two lines are very similar. Therefore, we can use a blended line as a single line and the gas temperature can be derived from the ratio of (2,2) to (1,1) transitions.

3.2. Overall distribution

Figure 2 shows integrated intensity maps in NH_3 (1,1) and (2,2) lines over -200 km s^{-1} to +200km s^{-1}. The overall distribution is similar to that in CO with the same spatial resolution [7]. Three peaks corresponds to Sgr A clouds (+20 km s^{-1} and +50 km s^{-1} clouds), Sgr B cloud and 1.3-degree cloud.

although most flux is concentrated to these clouds, some diffuse emission is observed. It extends over the whole CMZ. The

3.3. Four major cloud complexes

In the $l - b - v$ data cube we identify 4 clouds, which correspond Sgr A 20-km s^{-1} cloud, Sgr A 50-km s^{-1} cloud, sgr B cloud complex, and the 1.3-degree cloud. Due to violent gas motion in the Galactic center region and our large beamsize, the satellite lines of ammonia emission are highly blended to its main line. Therefore, we cannot estimate opacity of the lines. However, we can estimate the intrinsic line width if we assume that the line is optically thin using the method developed by McGray and Ho [8].

Using the estimated line width we derived the virial masses. From integrated intensity we derive the LTE masses with assumption that NH_3 lines are optically thin and $n(NH_3)/n(H_2) =$

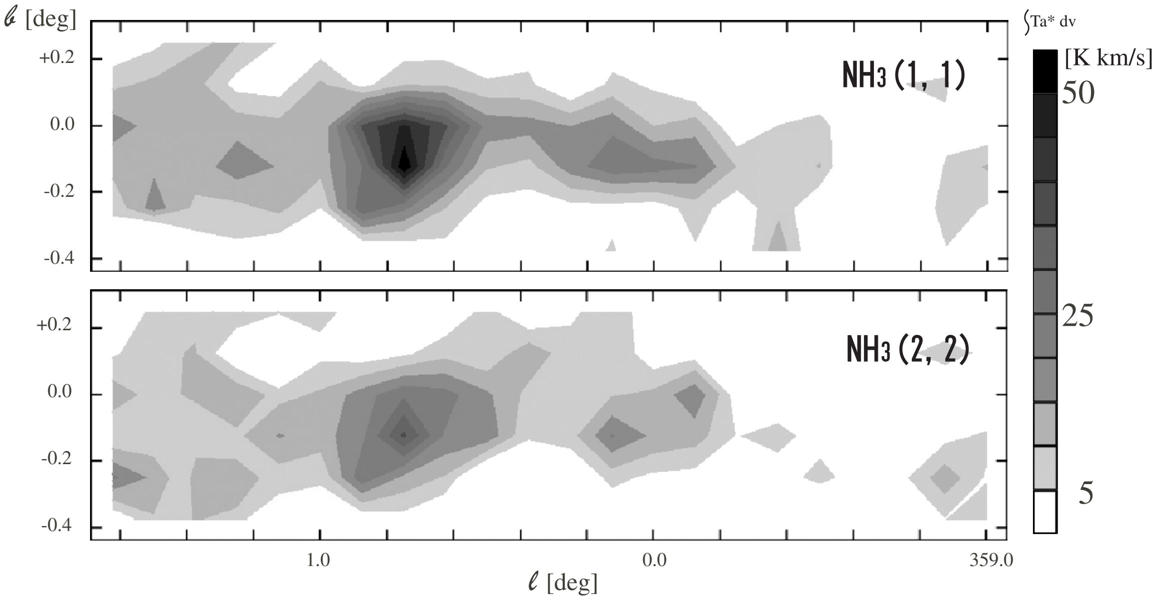

Figure 2. Integrated intensity of NH_3 (1,1) and (2,2) lines over -200 km s^{-1} to +200km s^{-1}. The intensity scale is shown in the figure.

Table 1. Estimated mass of the 4 clouds

name	Sgr A +20km s^{-1}	Sgr A +50km	Sgr B	the 1.3 degree
size	18 pc	33 pc	33 pc	42 pc
Δv(obs)	35 km s^{-1}	45 km s^{-1}	70 km s^{-1}	20 km s^{-1}
Δv(int)	25 km s^{-1}	39 km s^{-1}	70 km s^{-1}	9 km s^{-1}
$N(NH_3)$	6.6×10^{14}cm^{-2}	5.9×10^{14}cm^{-2}	1.7×10^{15}cm^{-2}	3.8×10^{14}cm^{-2}
$M_{\rm virial}$	$2.8 \times 10^6 M_\odot$	$1.2 \times 10^7 M_\odot$	$4.0 \times 10^7 M_\odot$	$8.5 \times 10^5 M_\odot$
$M_{\rm LTE}$	$1.1 \times 10^6 M_\odot$	$3.3 \times 10^6 M_\odot$	$1.0 \times 10^7 M_\odot$	$3.3 \times 10^6 M_\odot$

10^{-8}. The resultant masses are shown in table 1. The virial mass and LTE mass are consistent in the order of magnitude. Therefore, the NH_3 lines are not so opaque for these clouds.

4. Discussion

4.1. Molecular gas temperature derived from two NH_3 lines

The intensity ratio of the (2,2) transition to (1,1) transition is uniform over most of the observed region and is about 0.7–0.8, which means that the molecular gas has uniform in temperature.

Although we cannot estimate the opacity of the line, we can estimate the gas temperature using the method developed by Morris et al. [6]. The derived temperature from the line intensity ratio of NH_3 (2,2) to (1,1) is almost independent of gas density, but depends on opacity of the line. A high spatial resolution observations show that optical depth is about $\tau \sim 3-10$ for dense cloud cores [5], and $\tau = 2.3 \pm 1.0$ for weak sources and $\tau \sim 4$ for intense clouds [4]. Because our observations are more biased to weaker extended sources, optical depth may be much smaller than these results. So we estimated the temperature in both $\tau \ll 1$ and $\tau = 10$ cases. The estimated gas temperature corresponded to the ratio of 0.7–0.8 is 36–42 K in optically thin case and 24–34 K in optically thick case. This is consistent to the previous estimation of 25 K for the selected clouds [4]. Our full survey of CMZ show that the dense molecular gas in CMZ is dominated by gas as cool as majority of dust there.

For 4 major clouds we estimate average intensity ratio of NH_3 (2,2) to (1,1) lines using the

Table 2. Estimated temperature of the 4 clouds

name	Sgr A +20km s^{-1}	Sgr A +50km	Sgr B	the 1.3 degree
$R_{NH_3(2,2)/(1,1)}$	0.72 ± 0.07	0.75 ± 0.06	0.68 ± 0.02	0.82 ± 0.06
$T_K(\tau \ll 1)$	37 ± 3	38 ± 3	35 ± 1	42 ± 3
$T_K(\tau = 10)$	26 ± 4	28 ± 4	23 ± 1	34 ± 6

correlation plot between these two lines. The estimated ratio and derived temperature are shown in table 2.

4.2. A cool dense cloud complex with a hot molecular envelope

Although we cannot estimate the molecular gas temperature where no NH_3 emission is detected, we can make rough evaluation using other spectral lines, such as CO. The intensity ratio of CO ($J = 2-1$) over CO ($J = 1-0$), $R_{CO(2-1)/(1-0)}$, is a good indicator of gas pressure, n(H_2 T_K, for molecular clouds in the Galactic center region [7].

Our NH_3 observations are made with the same beamsize and the same sampling grid as observations in CO ($J = 1-0$) with the CfA 1.2-m telescope and in CO ($J = 2-1$) with Tokyo-Nobeyama 60-cm telescope [9, 7]. Therefore, we can make direct comparison with $R_{CO(2-1)/(1-0)}$ distribution.

Figures 3 and 4 show the longitude–velocity diagram of our observations overlaid on the distribution of $R_{CO(2-1)/(1-0)}$. The diagram shows that NH_3 emitting regions do not correspond to high $R_{CO(2-1)/(1-0)}$ regions. When the co-existing molecular gas is under pressure equilibrium, NH_3 gas is the same pressure as CO gas whose pressure is indicated by $R_{CO(2-1)/(1-0)}$. The NH_3 emitting region contains a dense molecular gas, because NH_3 is a dense gas tracer. Therefore, the NH_3 emitting region is not so hot. This is consistent to the estimation from the NH_3 line intensity ratio in section 4.1.

Most of the high $R_{CO(2-1)/(1-0)}$ region surrounds the NH_3 emitting region. It seems that only the blue-shifted edge of Sgr B cloud ($l = 0.9°$) has no high $R_{CO(2-1)/(1-0)}$ region. However, at $v = 0\mathrm{kms}^{-1}$ the CO data are strongly affected by foreground gas in the Galactic disk and the low $R_{CO(2-1)/(1-0)}$ should not be real.

In the high $R_{CO(2-1)/(1-0)}$ region is not dense, because NH_3 emission is absent there. This means gas temperature there should be high.

At $b = 0°$ Sawada et al. gives gas pressure distribution [7]. For the NH_3 emitting region, $nT_K = (5-10) \times 10^4\mathrm{Kcm}^{-3}$ from their LVG result and $T_K = 40\mathrm{K}$ from our NH_3 ratio. On the other hand, for the high $R_{CO(2-1)/(1-0)}$ region $nT_K > 10^5\mathrm{Kcm}^{-3}$ from their LVG result and $nH_2 < 10^3\mathrm{cm}^{-3}$ because of absence of NH_3 emission. These value means $T_K > 100\mathrm{K}$ for the high $R_{CO(2-1)/(1-0)}$ region. This means that the high $R_{CO(2-1)/(1-0)}$ region is "hot molecular envelope".

This gives us a view that the hot molecular envelope surrounds the cool dense clouds. It suggests that the envelope may be heated by irradiation of intense interstellar radiation field or intense X-ray in the Galactic center.

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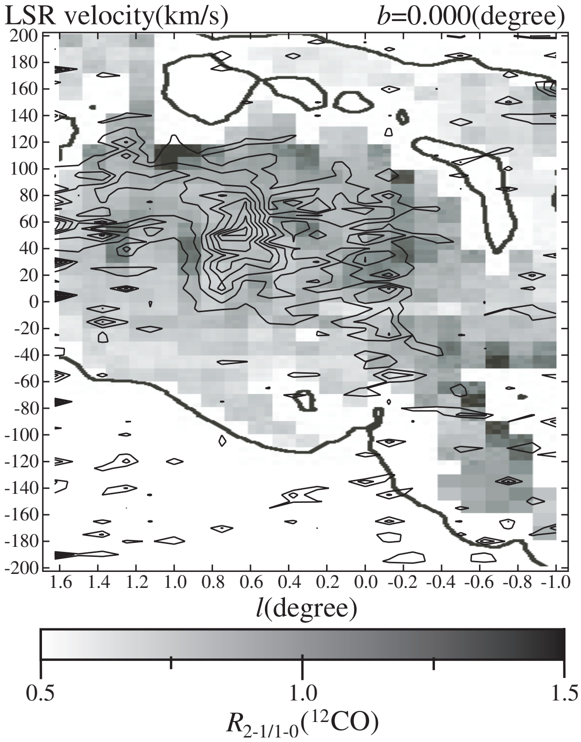

Figure 3. The longitude–velocity diagram of NH_3 (1,1) at $b = 0.000\,\mathrm{deg}$ (contour) superposed on CO intensity ratio (gray-scale) [7]. Both the lowest contour and the contour step are 0.095 K.

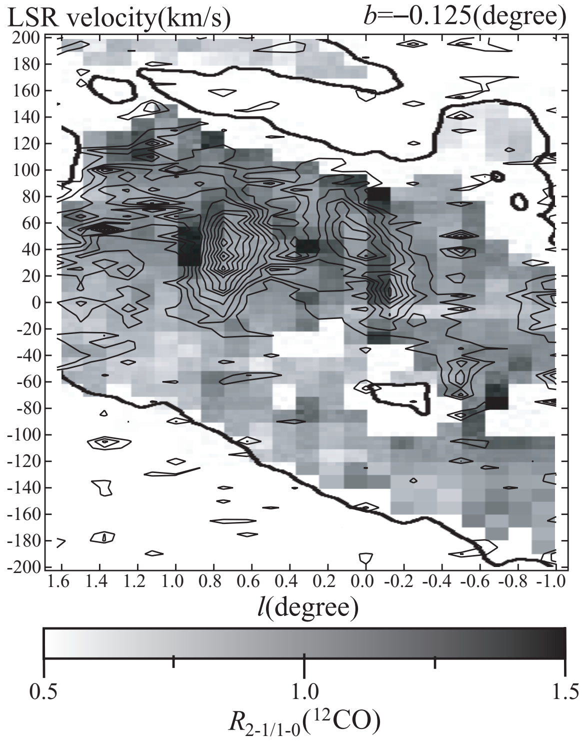

Figure 4. The longitude–velocity diagram of NH_3 (1,1) at $b = -0.125\,\mathrm{deg}$ (contour) superposed on CO intensity ratio (gray-scale) [7]. Both the lowest contour and the contour step are 0.095 K.

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