

A multilevel study of ammonia in star forming regions

V. The Sgr B2 region

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Abstract. Maps of the Sgr B2 region covering up to $4'$ have been made in 5 metastable ($J = K$) and 4 non-metastable ($J > K$) NH_3 inversion transitions with a $40''$ resolution. Toward Sgr B2 (M) and (N), spectra of 20 additional inversion transitions have been taken arising from energy levels up to $E/k=1340$ K above ground. From the NH_3 data, we obtained rotational and kinetic temperatures (T_{kin}), cloud sizes, virial masses, NH_3 column densities, spatial densities ($n(\text{H}_2)$), and NH_3 abundances relative to H_2 ($X(\text{NH}_3)$).

In addition to a cool ($T_{\text{kin}} \sim 20$ K) component detected at -40 km s^{-1} (presumably a foreground cloud associated with the 3 kpc arm), seven regions containing gas with $T_{\text{kin}} \geq 100$ K are identified. All are part of the Sgr B2 molecular complex. (1) A low density ($n(\text{H}_2) \sim 10^4 \text{ cm}^{-3}$) molecular cloud at $v_{\text{LSR}} = 50$ to 80 km s^{-1} is shown to be extended over several arcmin in metastable transitions up to at least the (6,6) line. A second cooler component ($T_{\text{rot}} \sim 20$ K) appears to coexist with the warm gas. Together, their area filling factor is almost one. Of all mapped lines from other molecular species, only HC_3N emission from the vibrational ground state may arise from the same two gas components. (2) Another warm low density feature, at $v_{\text{LSR}} \sim 85 \text{ km s}^{-1}$, is detected in the metastable lines toward Sgr B2 (N) and becomes increasingly prominent as J rises. (3) Toward the peak positions Sgr B2 (M) and (N) the metastable lines with $J \leq 5$ show an absorption feature at $v_{\text{LSR}} \sim 0 \text{ km s}^{-1}$. (4) A region with $v_{\text{LSR}} \sim 65 \text{ km s}^{-1}$ has $n(\text{H}_2) \sim 10^5 \text{ cm}^{-3}$ and is observed in non-metastable NH_3 emission lines. It is centered along a ridge $10''$ west of the main continuum sources. (5) Three Ori-KL like hot cores are identified, one at $v_{\text{LSR}} \sim 65 \text{ km s}^{-1}$ toward Sgr B2 (N) and two, at 55 and 65 km s^{-1} toward Sgr B2 (M). Provided that the NH_3 inversion lines are thermalized and that the clouds are approximately in virial equilibrium, these are the three most massive hot cores known to exist in the galaxy. With NH_3 column densities of order 10^{21} cm^{-2} , the 55 km s^{-1} Sgr B2 (M) and the 65 km s^{-1} Sgr B2 (N) cores are particularly outstanding. $X(\text{NH}_3) > 10^{-5}$, suggesting that a substantial fraction of the nitrogen is in ammonia. The large number of ultracompact HII (UCHII) regions

(≥ 19) indicates that the lifetime of a hot core is only $\sim 10\%$ of the lifetime of an UCHII region.

Key words: Galaxy: center – interstellar medium: abundances – ISM: individual: Sgr B2 – ISM: molecules – radio lines: interstellar – stars: formation

1. Introduction

Sgr B2, located at a projected distance of only 100 pc to the galactic center ($D_{\text{GC}} = 8.5$ kpc), is one of the most prominent star forming regions of the galaxy. Very Large Array (VLA) continuum observations (Gaume & Claussen 1990) resolved 19 separate ultracompact HII-regions in the two most outstanding sub-condensations, Sgr B2 (M) and (N). Maps of dust continuum emission have also been made (e.g. Goldsmith et al. 1987a, 1990; Martín-Pintado et al. 1990). The entire complex has a total infrared luminosity of $\sim 1.5 \cdot 10^7 L_{\odot}$ (Goldsmith et al. 1992) and is hence one of the most intense galactic infrared (IR) emitters.

The giant molecular complex associated with Sgr B2 is the most prolific source of complex molecules known in the Galaxy (see the mm-wave spectral scans of Cummins et al. 1986; Sutton et al. 1991; Turner 1991). The region shows a puzzling variety of parameters, depending on which molecular species and transition is observed, and on the angular resolution used (e.g. Goldsmith et al. 1987b; Lis & Goldsmith 1991).

Following the detection of ammonia (NH_3) in the Sgr B2 complex by Cheung et al. (1969), metastable ($J = K$) emission and absorption lines up to 835 K above the ground state were observed with the $40''$ resolution (~ 2 pc) of the 100-m MPIfR telescope (Winnewisser et al. 1979; Wilson et al. 1982; Mauersberger et al. 1986). A map in the non-metastable (J, K)=(2,1) line with similar beamsize (Mauersberger et al. 1983) showed that the spatial distribution of metastable and non-metastable line intensities can be quite different. Vogel et al. (1987) measured six ammonia inversion transitions with the VLA (synthesized beamwidth $4''$) and found two warm and compact conden-

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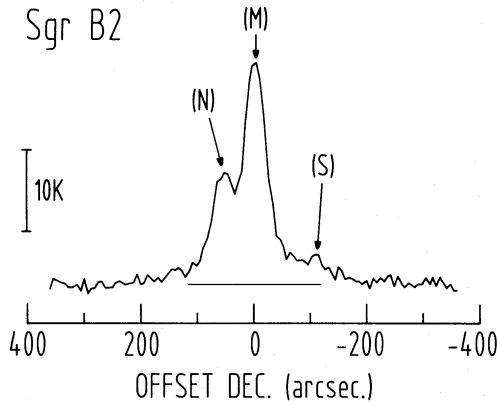


Fig. 1. A continuum scan in declination, taken with the 100-m telescope at 23 GHz. The right ascension is at $\alpha = 17^{\text{h}}44^{\text{m}}10.6^{\text{s}}$; the zero point of the declination is at $\delta = -28^{\circ}22'00''$ (epoch 1950.0). The temperature scale is main beam brightness temperature, T_{MB} , for a $42''$ beam (FWHP)

sations with unusually large NH_3 column densities. Measurements of the (3,2) line with $3.2'' \times 1.5''$ and $0.7'' \times 0.5''$ resolutions (Gaume & Claussen 1990) show emission and absorption features toward Sgr B2 (M) and emission toward Sgr B2 (N).

To date, detections of only a few of the many NH_3 inversion transitions near $\lambda \sim 1.3$ cm have been reported. Since an analysis of NH_3 lines allows the determination of optical depths, column densities, fractional abundances, H_2 densities, and rotational and kinetic temperatures for a large variety of excitation conditions, we have carried out a detailed study which includes spectra from 29 inversion transitions. These data complement the aperture synthesis maps and help to obtain a more realistic model of the central few arcmin of the Sgr B2 cloud. Similar NH_3 multilevel studies have been made for W 31c and NGC 7538 (Wilson et al. 1983), G 34.3+0.2 (Henkel et al. 1987), W51-IRS2 (Mauersberger et al. 1987), Orion-KL (Hermesen et al. 1988), and W 3(OH) (Mauersberger et al. 1988).

2. Observations

All observations were made with the Effelsberg 100-m telescope equipped with a K-band maser receiver. The beamsize at 1.3 cm is $\sim 42''$. For details see e. g. Mauersberger et al. (1986).

2.1. Continuum measurements, pointing, and calibration

To orient a discussion of the line observations, we show in Fig. 1 a 1.3 cm continuum scan in declination, at $\alpha = 17^{\text{h}}44^{\text{m}}10.6^{\text{s}}$. Three sources are distinguished with a $42''$ resolution: Sgr B2(N), (M), and (S). Pointing was checked by continuum cross scans 2–3 times per observing session, in all cases at the beginning and middle and, time permitting, at the end of an observing period. The pointing errors were $< 10''$. To calibrate the spectra in main-beam brightness temperature, T_{MB} , we have scaled the line intensities relative to the peak continuum intensity of Sgr B2 (M), which we take to have a flux density of 16 Jy

Table 1. Summary of the observations

Transition (J,K)	E/k^a K	Number of points	Band- width MHz	Channel spacing km s^{-1}	Map spacing arcsec
(1,1) ^b	23	84	12.5	0.8	40
(2,2) ^b	64	84	12.5	0.8	40
(3,3) ^e	123	1	10	0.8	–
(4,4) ^e	199	1	10	0.8	–
(5,5)	294	45	25	0.8	30
(6,6)	406	49	10	0.8	30
(7,7)	535	27	12.5	0.4	40
(8,8) ^e	683	1	10	0.8	–
(9,9) ^e	848	1	10	0.8	–
(2,1) ^c	80	39	10	0.8	30
(3,2) ^c	150	49	10	0.8	30
(4,3) ^d	237	2	25	0.6	–
(4,2)	264	15	50	0.8	30
(5,4) ^d	342	2	25	0.6	–
(5,3)	380	16	50	0.8	30
(5,2) ^f	407	1	50	1.6	–
(6,5) ^d	465	2	25	0.6	–
(6,4) ^d	513	2	25	0.7	–
(6,3) ^d	550	2	12.5/25	0.7/0.2	–
(7,6) ^d	605	2	12.5	0.3	–
(7,5) ^d	664	2	25	0.7	–
(7,4) ^d	712	2	25	0.8	–
(8,7) ^d	764	2	12.5	0.3	–
(8,6) ^d	833	2	25/12.5	0.7	–
(9,8) ^d	940	2	25	0.6	–
(9,7) ^d	1020	2	25	0.7	–
(9,6) ^d	1089	2	25	0.8	–
(10,9) ^d	1133	2	25	0.6	–
(11,10) ^d	1344	2	25	0.6	–

a) Energy of inversion doublet above the ground state

b) Measured simultaneously

c) The given resolution and bandwidth refer to the maps; additional single spectra (Figs. 6 and 7) were measured with a bandwidth of 25 MHz.

d) Measured toward Sgr B2 (M) and (N). In case of different channel spacings or bandwidths, the values for (M) are given first.

e) Observed toward Sgr B2 (M).

f) Observed toward Sgr B2 (N).

(Martín-Pintado et al. 1990). For a $42''$ beam, this corresponds to $T_{\text{MB}}=21$ K.

2.2. Spectral line observations

Spectral line measurements were made using an autocorrelation spectrometer. The on-source integration times were 1–3 minutes per scan. The reference position was taken at 3 or 5^{m} in α west of the on-source position or the center of the map. The channel spacing, the number of positions, the spacings between spectra, and the energies of the observed transitions above the ground state are displayed in Table 1.

We have mapped the $(J, K) = (1,1)$, (2,2), (5,5), (6,6) and (7,7) inversion lines of metastable NH_3 and the (2,1), (3,2), (4,2) and (5,3) inversion lines of non-metastable NH_3 . Single spectra have been measured in 15 additional non-metastable lines to-

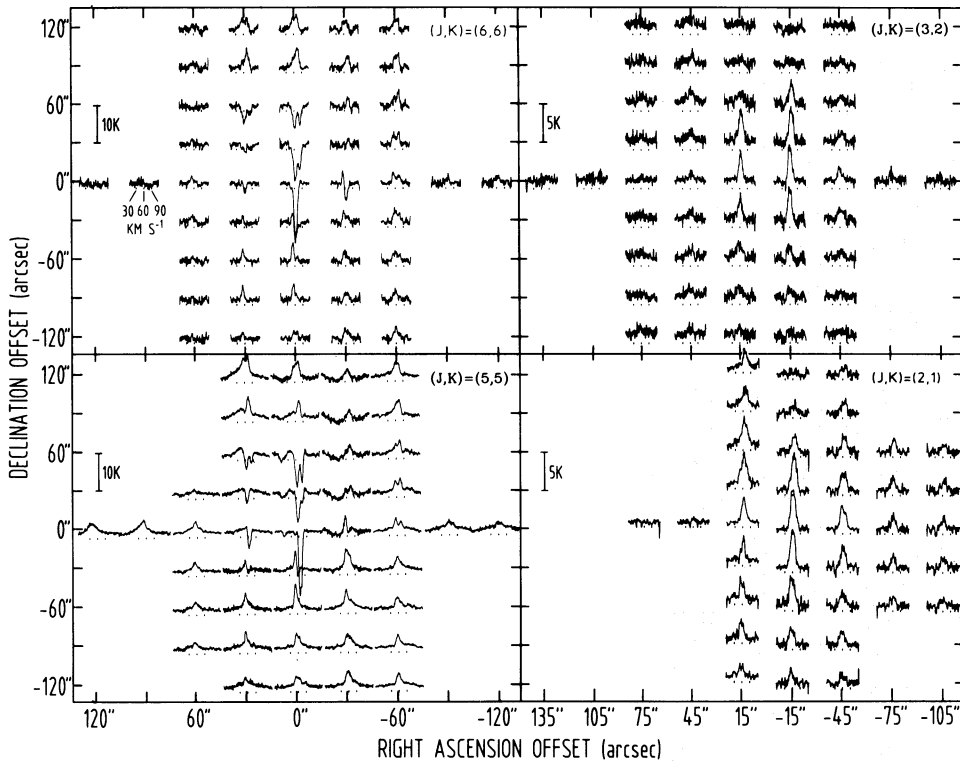


Fig. 2. Line profiles of inversion transitions of ammonia which have been mapped. These are shown on (α, δ) axes. The zero point is at the position of Sgr B2 (M), $\alpha = 17^{\text{h}}44^{\text{m}}10.6^{\text{s}}$, $\delta = -28^{\circ}22'00''$. The main beam temperature scale for the NH_3 lines was obtained from continuum cross scans of Sgr B2 (M) (see Sect. 2.1). All radial velocities are on a v_{LSR} scale. The absorption is observed toward the compact HII regions Sgr B2 (M) at $(0'', 0'')$ and (N) at $(0'', 40'')$. At the assumed distance to the complex, 8.5 kpc, $40''$ is equivalent to 1.7 pc

ward Sgr B2 (M) and 16 toward Sgr B2 (N). Some of these data have appeared previously: The (2,1) and (7,7) maps, the (3,3), (4,4), (8,8), and (9,9) profiles toward Sgr B2 (M), and the (5,2) spectrum toward Sgr B2 (N) have been published by Wilson et al. (1982), Mauersberger et al. (1983, 1986), and Walmsley et al. (1984).

3. Results

Figures 2 and 3 show the distribution of selected line profiles as a function of (α, δ) offset relative to Sgr B2 (M). Figures 4 and 5 display maps of T_{MB} integrated over various velocities. The quantum numbers (J, K) of the inversion transitions and velocity ranges are shown in the upper left and right hand corners of each map.

From Figs. 2 and 4 one sees that for metastable transitions, there are deep absorption lines toward the HII regions Sgr B2 (M) and (N). Such marked absorption lines are not observed in maps of the non-metastable transitions. Also, the (1,1) and (2,2) metastable emission lines are extended over the entire region mapped. The more highly excited metastable lines, such as the (6,6) line, also arise from an extended region. Of particular interest is the fact that the non-metastable (2,1) and (3,2) transitions are present over a smaller region.

In Figs. 6 and 7 we have collected the NH_3 profiles measured toward Sgr B2 (M) and (N). These profiles show, once again, the marked difference between metastable (only absorption) and non-metastable (mostly emission) lines. In many spectra the most prominent emission or absorption feature is observed at $\sim 65 \text{ km s}^{-1}$. Metastable lines also show components at -40 ,

0, and 85 km s^{-1} . In the more highly excited non-metastable transitions toward Sgr B2 (M) we find an absorption line at $\sim 55 \text{ km s}^{-1}$.

4. Hyperfine satellite ratios and optical depths

Because of the interaction with the quadrupole moment of the ^{14}N nucleus, each of the NH_3 inversion transitions (except $(J, K)=(3, 2)$, see Townes & Schawlow 1955) is split into five components spaced by $\gtrsim 10 \text{ km s}^{-1}$, a “main component” and 4 symmetrically placed “satellites”. This will be referred to as quadrupole hyperfine (HF) structure. For NH_3 , the four satellite HF components are predicted to have nearly equal intensities, if the excitation follows Local Thermodynamic Equilibrium (LTE). This is observed to be the case in most (but not all) sources; the deviations are understood in terms of line overlap (see e.g. Stutzki & Winnewisser 1985). On this basis, one can determine the line optical depth from the ratios of the intensities of the satellite ($T_{\text{L}}(S)$) to the main ($T_{\text{L}}(M)$) HF components, given the theoretical ratio of the components, α , for an optically thin population in equilibrium:

$$\frac{T_{\text{L}}(M)}{T_{\text{L}}(S)} = \frac{1 - e^{-\tau}}{1 - e^{-\alpha\tau}} \quad (1)$$

The details of this fitting procedure are given in Pauls et al. (1983). A list of α values (that is, the ratio of satellite to main intensities), from our calculations, is given in Table 6 (see Appendix A1). These values do *not* include the magnetic HF splitting, which is of order $< 0.2 \text{ km s}^{-1}$.

In Table 2, we have applied fits using results from Table 6 to all the inversion transitions displayed in Figs. 6 and 7. In some

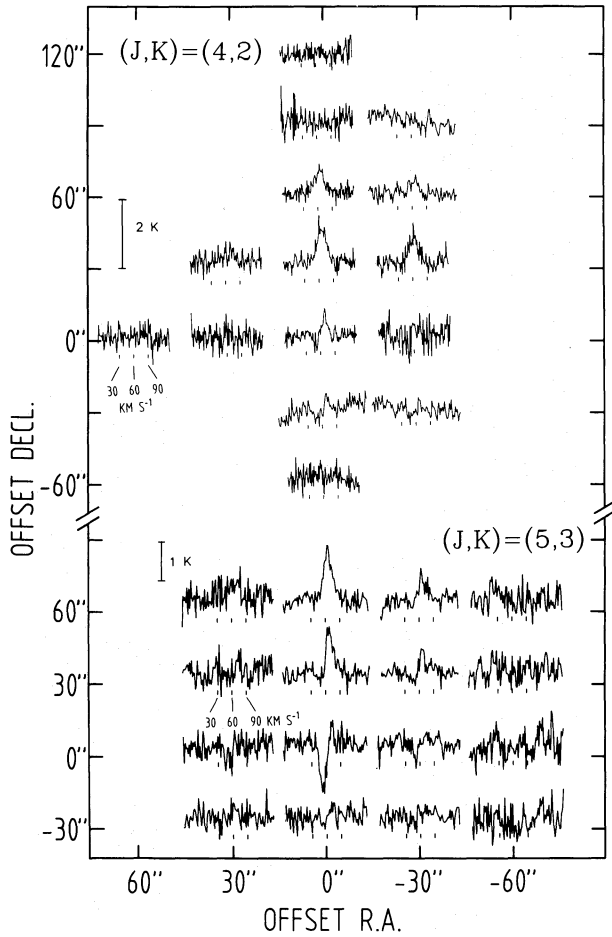


Fig. 3. Line profiles of highly excited non-metastable lines of NH_3 on (α, δ) axes. The zero point of the coordinate system and the temperature and velocity units are as in Fig. 2

cases, the HF satellites are too close to the main HF component. Then there is too much blending to allow a unique fit. In other cases, our signal-to-noise ratios from the HF satellites are too small to limit the range of optical depths by more than a factor of a few. In Table 2 we have marked these cases with an ‘?’. Toward Sgr B2 (M) and (N), many fits were obtained by fixing the width of the unsaturated HF components to 10 and 9.5 km s^{-1} , respectively. These are the intrinsic linewidths obtained from the profiles with highest signal-to-noise ratios (e.g. the (7,6) profile) and it is assumed that these values are representative for the weaker lines. In Fig. 8, we show examples of HF fits, made assuming that the unsaturated lineshape is gaussian. The fits to the (7,6) and (7,5) lines demonstrate that the lineshapes cannot be represented by a single saturated gaussian. It is likely that the profiles of the non-metastable lines are produced by an ensemble of optically thick clumps, moving with a Maxwellian velocity distribution.

From absorption line observations one can obtain the *apparent* optical depths, τ_{app} , of the absorbing cloud components (see Eq. 10 of Appendix A2). If the excitation temperatures T_{ex} (that is, the relative populations of the upper and lower levels of a

doublet) are approximately equal for different metastable transitions, as is suggested by the calculations of Danby et al. (1988), the relative column densities can be calculated. In Table 3, we list apparent optical depths and N/T_{ex} values for the observed $-40, 0, 65$, and 85 km s^{-1} components. In the profiles toward Sgr B2 (N), hyperfine components of both the 65 and 85 km s^{-1} features have been detected. From fits to the $\sim 65 \text{ km s}^{-1}$ HF components, the total optical depth (including all HF components) is ~ 1 in the (1,1) line, i.e. the optical depth of the main group of HF components is ~ 0.5 . From the line-to-continuum ratio, we obtain an apparent optical depth of 1.4. This discrepancy is caused by blending of the HF satellites with an emission line (Figs. 1 and 3 of Winnewisser et al. 1979, which show such an emission component).

5. Distribution, temperature, density, and kinematics of the ammonia clouds

The maps and profiles displayed in Figs. 2–7 show the complex and inhomogeneous distribution of the molecular material associated with the core of the Sgr B2 region. Over the velocity range between -60 and $+100 \text{ km s}^{-1}$ we classify the NH_3 spectra as: (1) metastable absorption lines at $-40, 0, 65$ and 85 km s^{-1} toward the two main continuum sources Sgr B2 (M) and Sgr B2 (N); (2) The metastable emission lines at 65 km s^{-1} , which are found over large parts of our maps; (3) The more compact non-metastable emission lines and (4) the non-metastable absorption component at $\sim 55 \text{ km s}^{-1}$ found in Sgr B2 (M). We now discuss these features in order, starting with the metastable absorption spectra. An analysis of these spectra is required to explain the properties of the gas giving rise to the metastable line emission. Results from previous NH_3 studies of Sgr B2 are incorporated. Important source parameters are summarized in Table 4.

5.1. The metastable absorption lines

From (1,1) to (4,4) absorption spectra toward Sgr B2 (M), Winnewisser et al. (1979) concluded that the region of deepest absorption contains two features, at ~ 63 and 68 km s^{-1} . Our (5,5) and (7,7) profiles confirm this. Since both components appear to arise from gas with similar excitation conditions, they will be summarized as the ‘ 65 km s^{-1} component’. Toward Sgr B2 (N), this line splitting is not observed; there is, however, another prominent absorption component, at 85 km s^{-1} .

Weak absorption is also observed toward the positions adjacent to Sgr B2 (M) and (N); presumably this is caused by the size of our $40''$ beam and by small pointing errors. The (1,1), (2,2), and (5,5) lines of metastable NH_3 show an absorption component at 0 km s^{-1} and the (1,1) and (2,2) lines show a narrow absorption feature at -40 km s^{-1} toward Sgr B2 (M). The -40 km s^{-1} component shows a hint of HF structure. The result of fits to the absorption components are given in Table 2, while apparent optical depths calculated by using the line to continuum ratio are given in Table 3. These τ_{app} values are accurate if $T_{\text{ex}} \ll T_{\text{C}}$, where T_{C} is the main beam continuum temperature

Table 2. Results of HF fits on selected lines and positions. Values for the relative intensities of HF-components are given in Table 6.

Offset ($\Delta\alpha, \Delta\delta$) arcsec	(J, K)	v_{LSR} km s ⁻¹	T_{MB} K	$\Delta v_{1/2}$ km s ⁻¹	τ_{tot}^a
(0,0)	(1,1)	62.5(0.4)	-18	7.7(0.7)	<0.5
		70.0(0.4)	-15	6.5(0.7)	<0.5
	(2,2)	61.7(0.3)	-19	5.2(0.4)	1.3(0.5)
		68.8(0.4)	-16	7.8(0.6)	<0.7
	(2,1)	63.2(0.2)	4.4	10 ^b	3.0(0.9)
	(4,3)	66.6(0.3)	2.6	16.3(1.6)	1.4(0.9)?
	(5,4)	65.2(0.4)	1.7	10 ^b	9?
	(6,5)	54.6(0.4)	-0.8	10 ^b	7.0(1.2)
		63.9(0.6)	0.5	10 ^b	5.4(0.7)
	(6,4)	58.1(0.9)	-0.4	10 ^b	15.9(6.9)?
		66.2(0.5)	0.5	10 ^b	<1?
	(6,3)	53.7(0.7)	-0.4	10 ^b	8.4(2.2)?
		64.5(0.9)	0.4	10 ^b	2.0(0.9)?
	(7,6)	55.9(0.7)	-0.7	10 ^b	28.9(11.4)?
		65.3(0.7)	0.7	10 ^b	2.3(1.1)?
	(7,5)	50.2(0.6)	-0.6	10 ^b	6.4(1.9)
	(7,4)	54.5(0.6)	-0.2	10 ^b	4?
	(8,6)	55.3(0.8)	-0.7	10 ^b	4.5(1.2)
	(9,8)	55.2(0.9)	-0.5	10 ^b	<1?
	(9,7)	55.2(1.1)	-0.3	10 ^b	2?
	(10,9)	55.9(0.9)	-0.4	10 ^b	1?
	(11,10)	58.8(1.0)	-0.3	10 ^b	<1?
(0,40)	(2,1)	66.2(0.3)	3.4	9.5 ^b	9.6(1.7)
	(4,3)	66.5(0.3)	1.2	9.5 ^b	>30?
	(5,4)	63.5(0.4)	0.7	9.5 ^b	>30
	(6,5)	66.7(0.8)	0.9	9.5 ^b	31(12)
	(6,4)	62.7(0.4)	1.8	9.5 ^b	4.7(1.0)
	(7,6)	65.7(0.3)	1.1	9.5 ^b	55.1(5.5)
	(7,5)	68.8(1.0)	0.5	9.5 ^b	>30
	(8,7)	63.7(0.5)	1.1	9.5 ^b	2.5(1.1)?
	(8,6)	63.4(0.4)	1.5	9.5 ^b	1.6(0.7)?
	(9,8)	64.9(0.6)	0.7	9.5 ^b	10.2(5.1)?
	(10,9)	61.8(0.5)	0.8	9.5 ^b	3.0(1.1)?
	(11,10)	60.8(0.6)	0.8	9.5 ^b	<1 (?)
(0,45)	(5,2)	64.1(0.2)	0.17	6.3(0.2)	25(3)
(40,-120)	(1,1)	48.7(0.1)	8.0	4.0(0.2)	7(1)
		55.2(0.7)	3	40(7)	<1
	(2,2)	59.3(0.2)	8.0	6.8(0.2)	7(1)
(40,-80)	(1,1)	52.6(0.2)	6	8.1(0.6)	6(1)
		59.3(0.8)	6	40(3)	<1
	(2,2)	54.9(0.2)	8	10.3(0.2)	>10 ^c

a) τ_{tot} values which are uncertain, are indicated by a '?' sign.

b) In these fits, the full width to half power linewidth, $\Delta v_{1/2}$, has been fixed to the value given (see Sect. 4 for details).

c) The broad velocity component may simulate the optical depths since the HF components are not resolved.

Table 3. Parameters of the metastable absorption components

Offset ($\Delta\alpha, \Delta\delta$) arcsec	v_{LSR} km s ⁻¹	(J, K)	$T_{\text{L}}/T_{\text{C}}$	τ_{app}^a	N/T_{ex}^b 10 ¹³ cm ⁻² /K
(0,0)	65	(1,1)	0.75	1.4(0.3)	29(6)
		(2,2)	~0.9	>2	>31
		(3,3) ^c	0.8	1.6(0.4)	22(5)
		(4,4) ^c	0.5	0.7(0.1)	8.9(1.3)
		(5,5)	0.67	1.1(0.2)	13(2)
		(6,6)	0.62	0.96(0.18)	11(2)
		(7,7)	0.40	0.51(0.07)	5.9(0.8)
		(8,8) ^c	0.08	0.08(0.01)	0.9(0.1)
		(9,9) ^c	0.11	0.11(0.01)	1.2(0.1)
	0	(1,1)	0.12	0.12(0.02)	2.4(0.4)
		(2,2)	0.16	0.17(0.02)	2.6(0.3)
		(5,5)	0.07	0.07(0.1)	0.8(0.1)
	-40	(1,1)	0.16	~0.17	~3.5
		(2,2)	0.04	~0.04	~0.6
(0,40) ^d	65	(1,1)	0.75	1.4(0.4)	29(8)
		(2,2)	0.9	>2.3	>31
		(4,4) ^e	~0.7	1.2(0.4)	15(5)
		(5,5)	0.54	0.77(0.15)	9.4(1.8)
		(6,6)	0.65	1.0(0.3)	12(4)
		(7,7)	0.29	0.34(0.04)	4.0(0.5)
	85	(1,1)	0.33	0.40(0.05)	8.0(1.0)
		(2,2)	0.52	0.73(0.10)	11(2)
		(4,4) ^e	0.5	0.7(0.1)	8.9(1.3)
		(5,5)	0.22	0.24(0.03)	2.9(0.4)
		(6,6)	0.40	0.51(0.07)	6.1(0.8)
		(7,7)	0.30	0.35(0.05)	3.5(0.6)

a) The errors of τ_{app} are based on the assumption that $T_{\text{L}}/T_{\text{C}}$ has an uncertainty of 10%.

b) For beam filling factors close to unity (see Sects. 5.1 and 5.2), the N/T_{ex} values are not only representative for the gas in front of the continuum sources but can also be taken as beam averaged quantities.

c) τ_{app} taken from Mauersberger (1986)

d) The (5,5) and (6,6) spectra taken at (0'',30'').

e) taken from Winnewisser et al. (1979)

of the source, and the source covering is close to unity (see Appendix A2). Both of these assumptions require justification. For the Sgr B2 (M) 65 km s⁻¹ component, the $|T_{\text{L}}/T_{\text{C}}|$ ratio of the (2,2) line nearly reaches a value of 1, indicating that the entire continuum source must be absorbed by NH₃. Also, emission from metastable inversion lines is seen at all positions close to the continuum sources. This is the case for the other metastable lines as well (see Sect. 5.2). If the conditions over $\gtrsim 1'$ are the same, T_{ex} must be less than 21 K (the main-beam brightness temperature of the background source) for absorption to be present.

To determine the rotational temperatures, T_{rot} (that is, the ratios of the populations of two (J, K) doublets) we have plotted normalized densities per K versus energy above ground in Fig. 9. We refer to these as Boltzmann plots. For metastable levels, T_{rot} is a lower limit to the kinetic temperature, T_{kin} . T_{rot} is constant if the fit is a straight line; excluding the (1,1) and (2,2) line data of the 65 km s⁻¹ components toward Sgr B2 (M) and (N), this is the case. The values of T_{rot} derived from fits to these data (excluding the (1,1) and (2,2) line data) are listed in Table

4. The -40 km s^{-1} component toward Sgr B2 (M) has a T_{rot} of $16 \pm 1 \text{ K}$, from the (1,1) and (2,2) line data. The small uncertainty is a formal error. For all other components, the T_{rot} values are all in the range 100–170 K.

The low excitation of the -40 km s^{-1} component supports the view that it is arising from a foreground cloud, presumably associated with the 3 kpc arm. At these low temperatures, $T_{\text{rot}} \sim T_{\text{kin}}$ (e.g. Walmsley & Ungerechts 1983; Danby et al. 1988) so that here we adopt $T_{\text{kin}} \sim 20 \text{ K}$. As pointed out by Gardner et al. (1988), the component at 0 km s^{-1} is warm. If high T_{kin} represents a physical connection with the galactic center, then gas with $v_{\text{LSR}} \sim 0 \text{ km s}^{-1}$ is also located there. The data for the 65 km s^{-1} feature confirm the results by Wilson et al. (1982) who obtained $T_{\text{rot}} = 175 \text{ K}$ for the absorption toward Sgr B2 (M) from data up to the (9,9) line. The data for the 85 km s^{-1} component toward Sgr B2 (N) may suggest the presence of two components with different T_{rot} . However, more data from highly excited metastable transitions ($J > 7$) are required for confirmation. With the collision rates, T_{rot} , and $T_{\text{ex}} < T_{\text{rot}}$, one can estimate upper limits for $n(\text{H}_2)$ (see Fig. 10 in Appendix A1). For the 65 km s^{-1} components toward Sgr B2 (M) and (N), densities are $\lesssim 10^4 \text{ cm}^{-3}$ (see Table 4). For the 85 km s^{-1} component, the density calculated from virial masses is $4 \cdot 10^4 \text{ cm}^{-3}$. Accounting for the uncertainties in our size estimates and small deviations from virial equilibrium, this density is consistent with that for the 65 km s^{-1} component (see also Table 4 and Sect. 5.3). The combination of low density and high rotational temperature infers that T_{kin} is substantially larger than T_{rot} (e.g. Danby et al. 1988; Schilke 1989). This indicates that T_{kin} is $\gg T_{\text{rot}}$.

5.2. The metastable emission lines

Emission in the (1,1) and (2,2) inversion lines is observed between ~ 20 and 90 km s^{-1} over the whole extent of our maps (Figs. 4 and 5). The lines are strongest close to the continuum sources and become weaker in the eastern and southern parts of the maps. For some positions, e.g. at $(40'', -120'')$, distinct HF components are seen in the (1,1) and (2,2) lines. The intrinsic linewidth at this position is $< 5 \text{ km s}^{-1}$ (Table 2). To the west of Sgr B2, there are hints of double velocity structure, with components at ~ 60 and $\sim 80 \text{ km s}^{-1}$. In the south-east, the peak intensity is at $\sim 50 \text{ km s}^{-1}$, which is consistent with the southern 52 km s^{-1} NH_3 component found by Winnewisser et al. (1979).

The (1,1) and (2,2) inversion transitions may be saturated and self-absorbed. Thus determinations of column densities and T_{rot} for these are difficult. The situation is simpler for the transitions from higher lying states. The (5,5), (6,6), and (7,7) lines (see our Fig. 5 and Fig. 6 of Mauersberger et al. 1986) also show extended emission which is stronger N and W than S and E of the continuum sources. The small peak line temperatures are consistent with small optical depth. It is less likely that this effect is caused by progressively smaller clump sizes, since the metastable absorption line data (Sect. 5.1) are consistent with equal beam filling factors in all metastable lines.

An estimate of the rotational temperature (see Fig. 9) can be made by a direct comparison of our maps in the (5,5) and

(6,6) lines, assuming optically thin line emission and LTE population. Within the uncertainties the (5,5) and (6,6) lineshapes are consistent and relative line intensities are approximately the same over the full extent of the maps. The line intensity ratio gives $T_{\text{rot}} \sim 140 \pm 30 \text{ K}$. The (5,5) and (7,7) spectra were taken with different spacings, but comparing interpolated spectra we obtain similar results. Accounting for the errors, which include noise and baseline uncertainties, the value of $T_{\text{rot}} \sim 140 \text{ K}$ from the emission line data is consistent with $T_{\text{rot}} \sim 160 \text{ K}$ from the absorption line data.

Taking an LTE population distribution with $T_{\text{rot}} = 140 \text{ K}$ and $\tau(1,1) = 1.4$ (see Table 3 and Sect. 4), we obtain a beam-averaged total NH_3 column density of 10^{16} cm^{-2} in the metastable inversion doublets. A combination of the (1,1) and (5,5) line data yields $T_{\text{rot}} \sim 110 \text{ K}$, a value significantly lower than the $\sim 140 \text{ K}$ obtained from the comparison of higher lines. This indicates that there are at least two kinetic temperature components in the cloud. The colder gas, with $T_{\text{rot}} \sim 30 \text{ K}$, has approximately the same column density as the warm component. T_{rot} is a lower limit to the kinetic temperature, T_{kin} . The relation between T_{rot} and T_{kin} does not depend strongly on $n(\text{H}_2)$ over a wide range of density values.

Over the entire extent of our maps (Figs. 4 and 5), the average linewidth is $\Delta v_{1/2} \sim 15 \text{ km s}^{-1}$. Taking the radius of the assumed spherical metastable emission region as $2'$ (5.5 pc), we obtain a virial mass of $3 \cdot 10^5 M_{\odot}$ and an average H_2 density of 10^4 cm^{-3} . This density is consistent with the values obtained from the metastable absorption lines (Sect. 5.1).

5.3. The non-metastable emission

The non-metastable emission is more spatially confined (Figs. 2 and 4) and there are fewer velocity components compared to the metastable lines. The -40 km s^{-1} feature is not seen in the $(J, K) = (2, 1)$ inversion transition. This is expected since T_{rot} is very low (see Sect. 5.2). The warm ($T_{\text{rot}} \sim 95 \text{ K}$; see Fig. 9) 0 km s^{-1} component is also not seen down to a 3 rms level of $T_{\text{MB}} = 0.14 \text{ K}$ in the (2,1) line. If collisions populate the (2,1) levels, a combination of metastable data and the rms upper limit for the (2,1) line leads to $n(\text{H}_2) \leq 10^5 \text{ cm}^{-3}$. Although the 85 km s^{-1} component is seen in all the observed metastable inversion lines, there is no corresponding non-metastable feature toward Sgr B2 (N). For collisional excitation, this leads to $n(\text{H}_2) < 10^6 \text{ cm}^{-3}$. It is likely that a strong infrared field is present (see Sect. 6.2). Then the density might be significantly lower. It is reasonable to assume that for the 85 km s^{-1} feature the situation is similar to that described for the $\sim 65 \text{ km s}^{-1}$ component (Sects. 5.1 and 5.2), with subthermal excitation for the metastable lines, densities of $\sim 10^4 \text{ cm}^{-3}$ and $T_{\text{rot}} \sim 160 \text{ K}$.

The 65 km s^{-1} emission of the (2,1) line is somewhat more extended than that seen in the (3,2) line. Both distributions are elongated NS. The (2,1) line has a deconvolved size of $50'' \times 120''$ ($\alpha \times \delta$), and a maximum line temperature $\sim 10''$ W of Sgr B2 (M). This positional offset has been checked repeatedly by interspersing line measurements with cross scans of the continuum peak of Sgr B2 (M); thus, this offset is to be consid-

Table 4. Source parameters of the 55 to 85 km s⁻¹ velocity components

Source	Radial Velocity	Angular Size ^{a)}	Rotational Temperature	Virial Mass	Local Density ^{b)}	Column Density		X(NH ₃)
	km s ⁻¹	(FWHP)	K	M _⊙	cm ⁻³	H ₂ ^{b)} cm ⁻²	NH ₃ cm ⁻²	
Sgr B2 (N)								
Core emission	~ 65	4''	150–300 ^{c)}	2 10 ³	2 10 ⁷	10 ²⁵	10 ^{21 d)}	10 ⁻⁴
85 km s ⁻¹ component	~ 85	120''	160	10 ⁵	4 10 ⁴	5 10 ²³	6 10 ^{15 e)}	10 ⁻⁸
Sgr B2 (M)								
Core Emission	~ 65	4''	180	2 10 ³	2 10 ⁷	10 ²⁵	< 5 10 ^{20 f)}	< 5 10 ⁻⁵
Core Absorption	~ 55	1.5''	160	3 10 ³	6 10 ⁷	10 ²⁵	5 10 ^{20 d)}	5 10 ⁻⁵
Non-Metastable Extended Emission	55–65	50'' × 120''	~100 (?)	7 10 ⁴	10 ⁵	10 ²⁴	–	–
Metastable Extended Emission ^{g)}	50–80	4'	140 ^{h)}	3 10 ⁵	10 ⁴	3 10 ²³	1 10 ^{16 e)}	8 10 ⁻⁸
	50–80	–	30	–	–	–	1 10 ^{16 e)}	–

a) Size estimates from VLA-maps (Vogel et al. 1987; Gaume & Claussen 1990) or from our data. The size of the non-metastable extended emission is determined from the (2,1) line; the size of the 'Metastable Extended Emission' is confined by the size of our maps and may thus be a lower limit.

b) Calculated from virial masses assuming spherical cloud geometry with constant density; these are cloud averaged (as opposed to beam averaged) values.

c) Lower (J, K) transitions yield higher rotational temperatures; see Sect. 5.3.

d) Calculated for thermalized gas ($T_{\text{ex}}=T_{\text{rot}}$) by explicitly summing the populations of all levels ($K = 0 \dots 15$, $J = 0 \dots 20$). The column densities are referred to the (7,6) value. The optical depth determined for this level appears to be particularly trustworthy (see Table 2).

e) Calculated only from metastable levels and $T_{\text{ex}} = 10$ K (subthermalized gas). Apparent optical depths from the absorption toward the peak positions were used.

f) A comparison of the Sgr B2 (M) 65 and 55 km s⁻¹ core emission components shows that the NH₃ abundance and column density are much lower in the 65 km s⁻¹ component. However, due to line blending direct estimates for the weaker component cannot be given.

g) Rotational temperature and gas density derived from the metastable absorption lines toward Sgr B2 (M) and (N) are consistent with those obtained from the metastable emission lines. The column density includes a cool ($T_{\text{rot}} \sim 30$ K) and a warm ($T_{\text{rot}} \sim 140$ K) component, each responsible for ~50% of the total value.

h) Average value for the warm component. For values toward peak positions (M) and (N) see Fig. 9.

ered very significant. According to Winnewisser et al. (1979) the presence of non-metastable line emission and metastable line absorption could imply population inversion in some of the non-metastable inversion doublets. However, our data and the VLA maps (Vogel et al. 1987; Gaume & Claussen 1990) show no evidence for maser emission.

We have determined the parameters referred to the 'Non-Metastable Extended Emission' (Table 4) from the (2,1) line parameters. T_{rot} must exceed 50 K to populate the (3,2) levels. We adopt 100 K, but note that this is a very uncertain value. For a linewidth of ~15 km s⁻¹ combined with a size of 77'' (the geometrical mean of α and δ sizes) we obtain a virial mass of 7 10⁴ M_⊙ and thus $n(\text{H}_2) \sim 10^5$ cm⁻³.

The source with strongest NH₃ emission from highly excited non-metastable inversion transitions is Sgr B2 (N). Here we obtain $T_{\text{rot}} \sim 300$ K for lower lying transitions (i.e. the (2,1), (3,2), and (4,3) transitions; see Fig. 9). Inversion lines from other, higher lying levels give $T_{\text{rot}} \sim 150$ K. This may be due to self absorption in the lower lying levels. For a thermalized gas with $T_{\text{rot}} \sim 150$, the column density of NH₃ is 10²¹ cm⁻². When a size of 4'' (Gaume & Claussen 1990) and linewidth of 10 km s⁻¹ are combined, the virial mass is ~2000 M_⊙, $n(\text{H}_2) \sim 2 \cdot 10^7$ cm⁻³, and the H₂ column density is ~10²⁵ cm⁻². The resulting NH₃/H₂ ratio $X(\text{NH}_3)$ is 10⁻⁴, an extremely large value. This implies that nearly all of the nitrogen is in NH₃. The H₂ column density is also very large. Note, however, that this is a source averaged, not a beam averaged value.

Our results, although more complete, are in reasonable agreement with the conclusions of Vogel et al. (1987). For example, Vogel et al. find $\tau(7,6) = 48 \pm 10$, while we obtain 55 ± 5 (Table 2). The values of T_{rot} obtained from the VLA also agree with our estimates. There are however significant differences between the VLA and 100-m spectra and maps: the spatially compact (3,2) maximum, found with the 100-m, is 10'' W of the continuum sources, but there is no emission at this location in the VLA map; in addition, toward Sgr B2 (N), about 75% of the (3,2) peak flux density observed with the 100-m is not recorded by the VLA. This is all the more remarkable because the optical depths from the 100m and the VLA agree so well. Apparently, the measurements of Vogel et al. (1987) are biased toward very compact regions of intense NH₃ emission or absorption and discriminate against the lower surface brightness regions. Their non-detection of spatially extended (2,1) and (3,2) emission (their Fig. 5) indicates that there is little small scale clumping in this region.

If the $N(\text{H}_2)/A_v$ relation obtained for a medium with low extinction ($A_v < 20^m$; Frerking et al. 1982; Duvert et al. 1986) can be extrapolated to very high column densities, the visual extinction, A_v , is of order 10000^m. Since this implies that the molecular clump is optically thick in the IR range, the luminosity can be derived from the Stephan-Boltzmann relation. If the brightness temperature of the source is 150 K and the diameter is 0.16 pc, the compact molecular cloud core seen toward Sgr B2 (N) has a luminosity of ~ 5 10⁶ L_⊙. This is 50% of

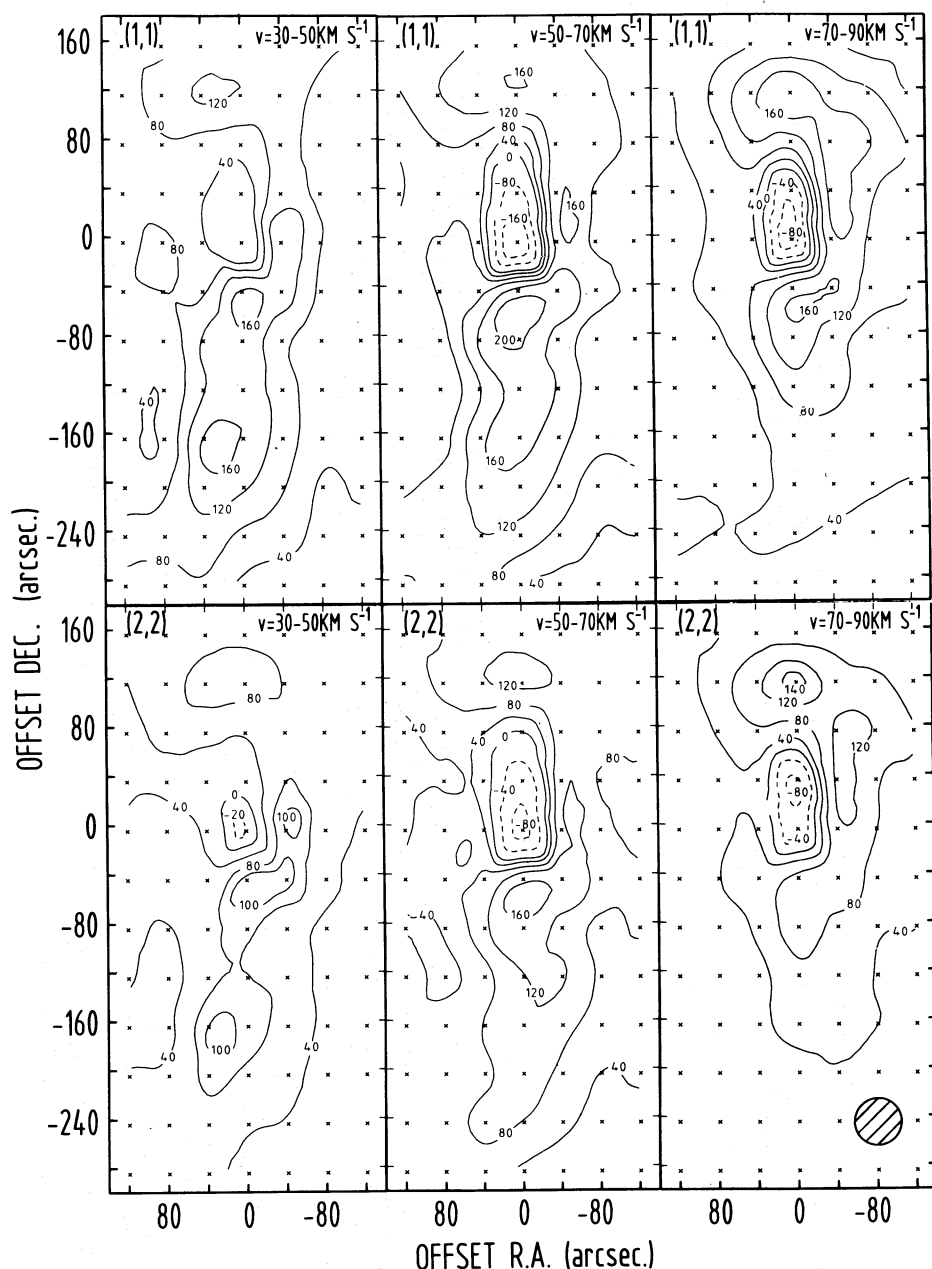


Fig. 4. Contour plots of integrated main beam brightness temperature at given velocity intervals for different transitions of NH_3 . Dashed contours indicate absorption; the contour units are K km s^{-1}

the value estimated by Thronson & Harper (1986) and could be considered as agreement; since the dust luminosity depends critically on the dust temperature.

Toward Sgr B2 (M), we find yet another source in highly excited non-metastable inversion transitions even up to the (6,3) and (8,7) levels. From the VLA map of Gaume & Claussen (1990), this emission, measured at $v_{\text{LSR}} \sim 65 \text{ km s}^{-1}$, originates from a $\sim 4''$ source located south of the ultracompact HII region F3. The source size, virial mass, H_2 density, H_2 column density, and rotational temperature of ammonia are similar to the corresponding parameters for the Sgr B2 (N) core. Since in hot cores, $T_{\text{rot}} \sim T_{\text{kin}}$ (see e. g. the discussion by Hermsen et al. 1988), this also implies similar infrared luminosities. However, the NH_3 column density and relative abundance $X(\text{NH}_3)$ are

definitely smaller. Due to blending with a 55 km s^{-1} absorption feature (see Sect. 5.4), only upper limits to the ammonia column density and relative abundance can be given in Table 4.

5.4. The non-metastable absorption toward Sgr B2 (M)

This component was first detected by Vogel et al. (1987). It is seen best in the more highly excited ($J \geq 6$) lines (Fig. 6), possibly because the absorption from lower transitions is mixed with emission from other, more extended regions. From the VLA maps of Gaume & Claussen (1990), this absorption arises from a compact molecular region toward the HII component F, a complex of 4 compact radio continuum sources; the ammonia absorbs F1–3. The source averaged continuum brightness temperature of the most extended source, F3, is 6500 K. From

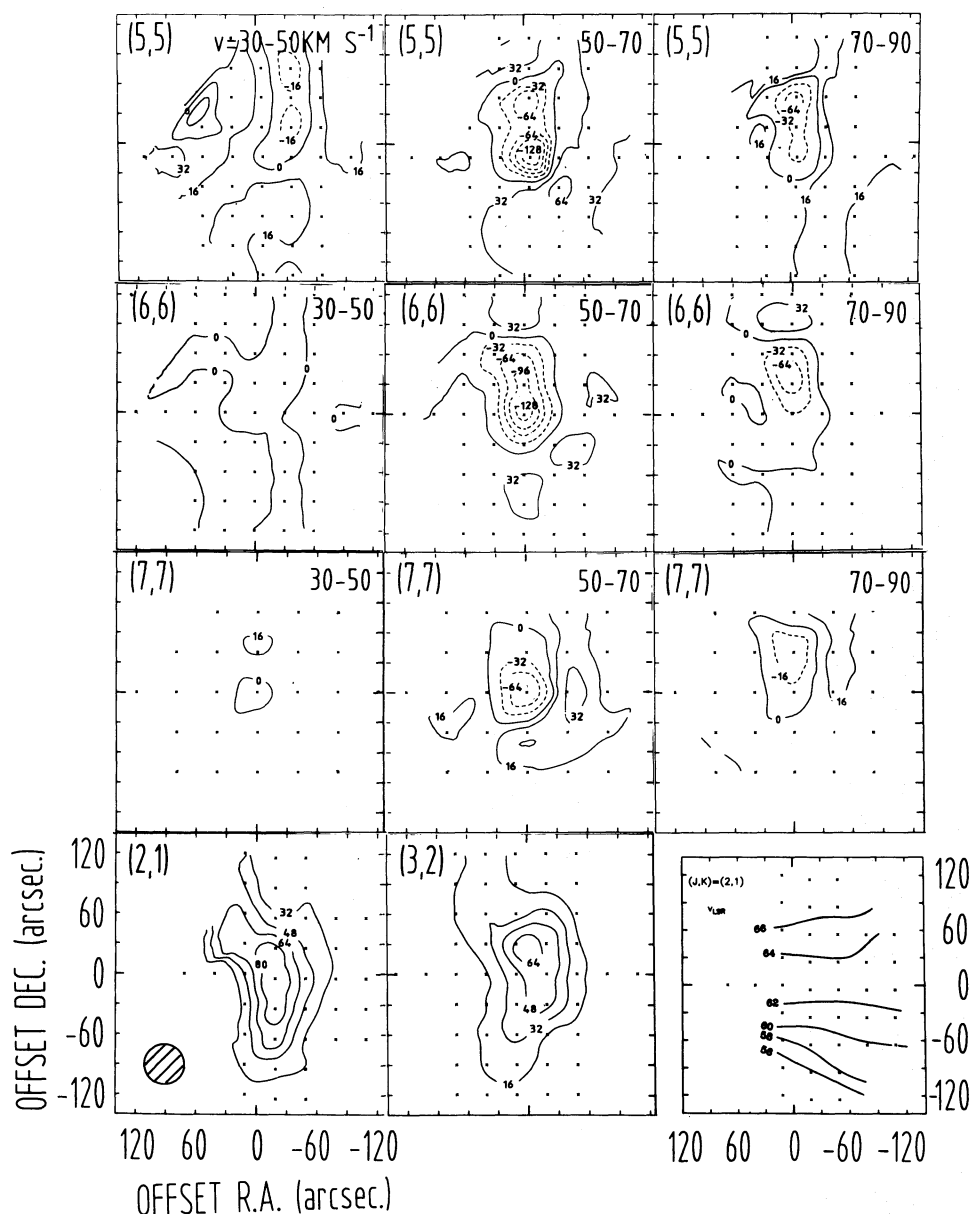


Fig. 5. Contour plots as in Fig. 4, for more highly excited NH_3 inversion transitions. The upper three rows are metastable lines from high lying energy levels (see Table 1). In the lowest row are plots of integrated intensity from the (2,1) and (3,2) non-metastable lines. We also show the distribution of the (2,1) line peak velocities

Appendix A2, absorption would be favored if the size of the NH_3 cloud is of the same order as the size of the background continuum source. From the VLA maps (Gaume & Claussen 1990) and our non-metastable data, the absorption arises from a high density $1.5''$ (0.06 pc) diameter region with $T_{\text{ex}} \sim T_{\text{rot}} \sim 160$ K. The values of T_{rot} are similar to that of the dense, compact emission cores described in Sect. 5.3. However, the cloud size is smaller, so that the infrared luminosity of this source is likely smaller than that of the other two cores. As for the Sgr B2 (N) core, NH_3 column density and relative abundance are higher than in other sources of this type.

6. Comparison with other data

6.1. NH_3 and other molecular species

Millimeter-wave line maps of HNCO , HC_3N , OCS , and SO with $\sim 15''$ resolution (Goldsmith et al. 1987b; see also Lis & Goldsmith 1991) allow detailed comparisons with our NH_3 data. The 65 km s^{-1} peaks of HNCO , OCS , and vibrationally excited HC_3N are located slightly west of Sgr B2 (N). An association with any of the 65 km s^{-1} NH_3 components mentioned in Sect. 5 is not obvious. The $\text{SO } 2_3 - 1_2$ distribution peaks near Sgr B2 (M) and is not extended to the south; some emission is associated with the ridge between Sgr B2 (M) and (N). The distributions of the spatially resolved metastable and non-metastable ammonia transitions are quite different. The regions traced in various molecular species differ, although the A co-

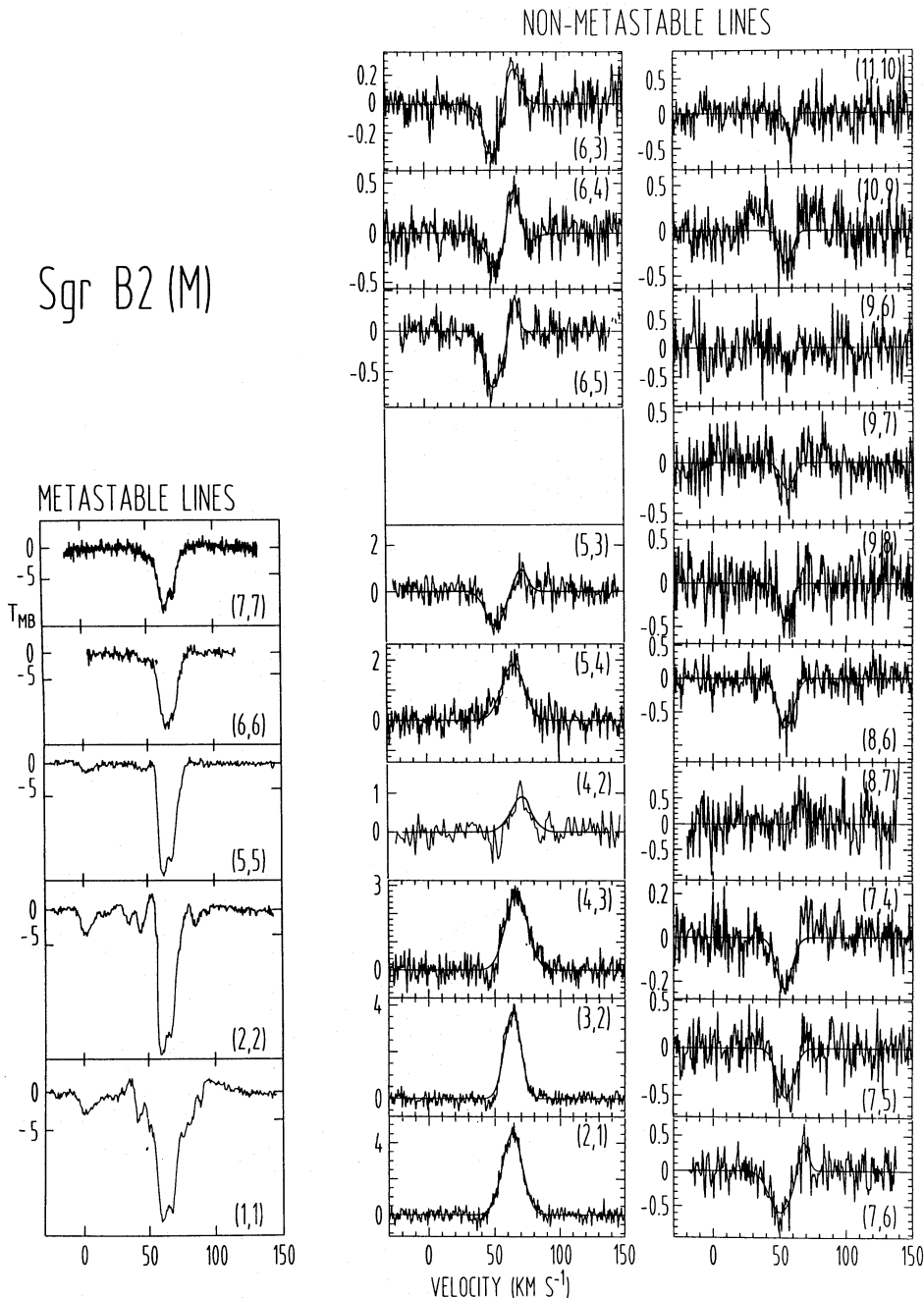


Fig. 6. A series of line profiles measured toward Sgr B2 (M). The metastable ($J = K$) transitions are shown in the left part of the picture; the non-metastable ($J > K$) lines are presented in the middle and right columns. Within the metastable and non-metastable transitions, the placing is determined by the energy levels from which the line arises. All metastable lines are seen in absorption. For the non-metastable lines, there is an absorption component at $v_{\text{LSR}} \sim 55 \text{ km s}^{-1}$ and an emission component at $v_{\text{LSR}} \sim 65 \text{ km s}^{-1}$. The latter cannot be seen at $J > 7$. The smooth curves are gaussian fits to the non-metastable profiles

efficients are similar. This indicates that the spatial differences must be due to a high degree of chemical differentiation.

Neglecting the spatially confined absorption components toward the ultracompact HII regions, the $\text{HC}_3\text{N } J=12-11$ transition from the vibrational ground state shows an extended ($> 90''$) north-south ridge similar to that seen in our 'metastable extended emission' component of NH_3 (see Table 4). For the ammonia gas we found two components, one with $T_{\text{rot}} \sim 140 \text{ K}$ and $n(\text{H}_2) \sim 10^4 \text{ cm}^{-3}$, the other with $T_{\text{rot}} \sim 30 \text{ K}$ and $n(\text{H}_2) < 10^6 \text{ cm}^{-3}$ (Sect. 5.2). The T_{rot} values determined from our NH_3 data are lower limits to the actual kinetic temperature. Lis & Goldsmith (1991) fitted their $\text{HC}_3\text{N } J=12-11/J=4-3$ line intensity ratios assuming optically thin emission and obtained

an 'approximate' T_{kin} value of ($\sim 30 \text{ K}$) by further assuming turbulent dissipation as the only heating mechanism. Solving the system of statistical equilibrium equations, they obtained $n(\text{H}_2) \sim 10^5 \text{ cm}^{-3}$. With density and temperature as free parameters, the observed HC_3N line temperature ratios allow a wide range of solutions with high density/low temperature and low density/high temperature at the extremes. Following the assumption of Lis & Goldsmith that the HC_3N lines are optically thin, we have also performed statistical equilibrium calculations to check whether solutions exist which are consistent with the parameters obtained for NH_3 . We find that for $(T_{\text{kin}}, n(\text{H}_2)) = (30 \text{ K}, 10^5 \text{ cm}^{-3})$ and $(150 \text{ K}, 10^4 \text{ cm}^{-3})$, the $\text{HC}_3\text{N } J=12-11/J=4-3$ line intensity ratio is approximately

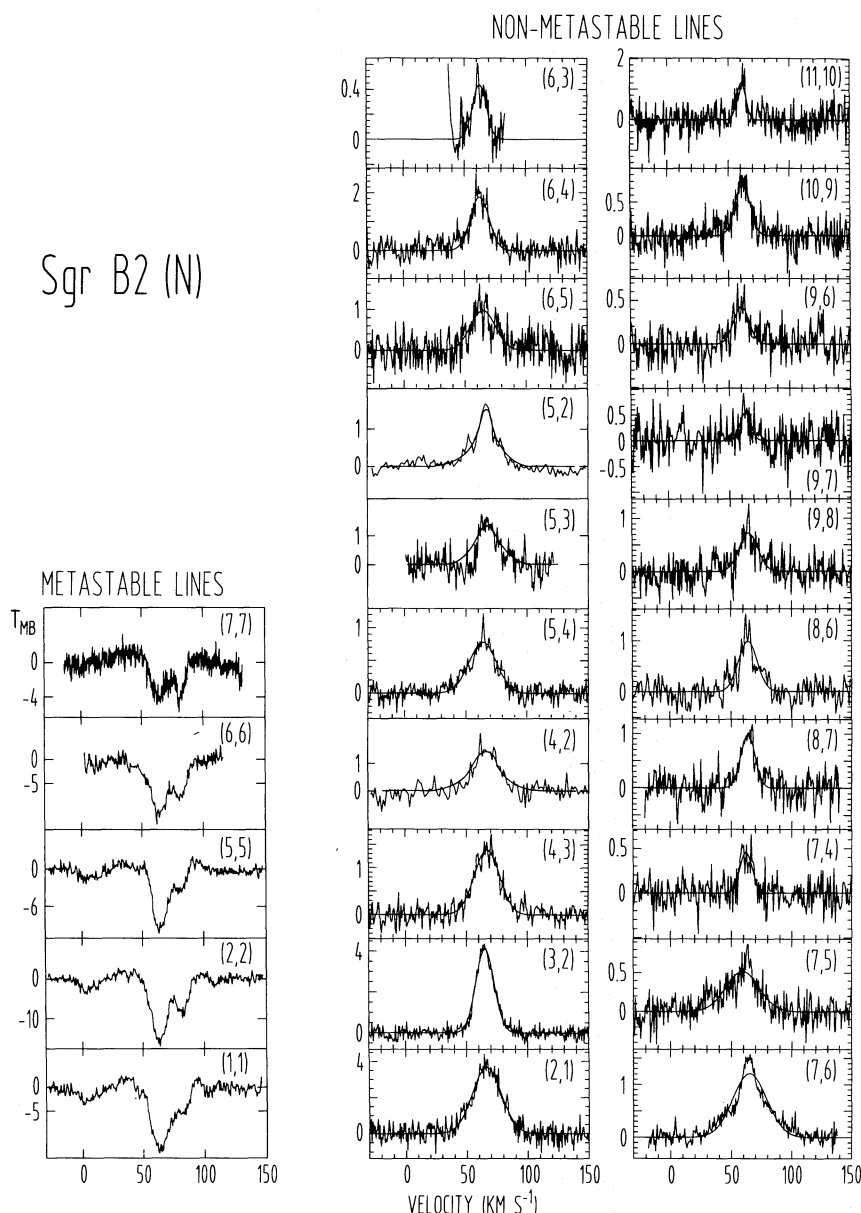


Fig. 7. A collection of spectra, as in Fig. 6, for Sgr B2 (N). The metastable lines are again seen in absorption, while all non-metastable lines are observed in emission. The smooth curves are gaussian fits to the non-metastable profiles

the same. It is thus likely that a significant part of the HC_3N emission originates from the warmer component giving rise to NH_3 emission in the higher excited metastable inversion lines. Then the metastable ammonia lines and the HC_3N emission originate from the same interstellar gas components which together have area filling factors of almost one (see Sect. 5.1 and 5.2).

Closer to the centers of Sgr B2 (M) and (N) densities are $\sim 10^5 \text{ cm}^{-3}$. High resolution maps from the BIMA array (L.E. Snyder, private communication) also indicate that most of the dense gas is located at the western side of the main centers of activity. This agrees with the distributions of the (2,1) and (3,2) non-metastable ammonia emission (Fig. 5).

The most complex molecules are concentrated in few arcsec regions toward Sgr B2 (N) and (M). H_2 densities of $\sim 10^{6-8} \text{ cm}^{-3}$, obtained from the NH_3 core components (see Ta-

ble 4) are consistent with those derived from other species (e.g. Martín-Pintado et al. 1990; Lis & Goldsmith 1990, 1991). Sutton et al. (1991) find that in most molecular species, column densities are larger toward Sgr B2 (M) than (N). For NH_3 , column densities appear to be similar toward the two sources. While only ammonia unambiguously traces the extended molecular material of high temperature, there is an impressive amount of data from various species all supporting the view that the Sgr B2 (M) and (N) cores are warm (e.g. Lis & Goldsmith 1991; Sutton et al. 1991).

6.2. Far infrared continuum maps

As shown in Fig. 5 and Sect. 5.3, a ridge of large H_2 density ($n(\text{H}_2) \sim 10^5 \text{ cm}^{-3}$), extending NS, peaks $\sim 10''$ west of the main continuum sources. A hint of this structure may be present

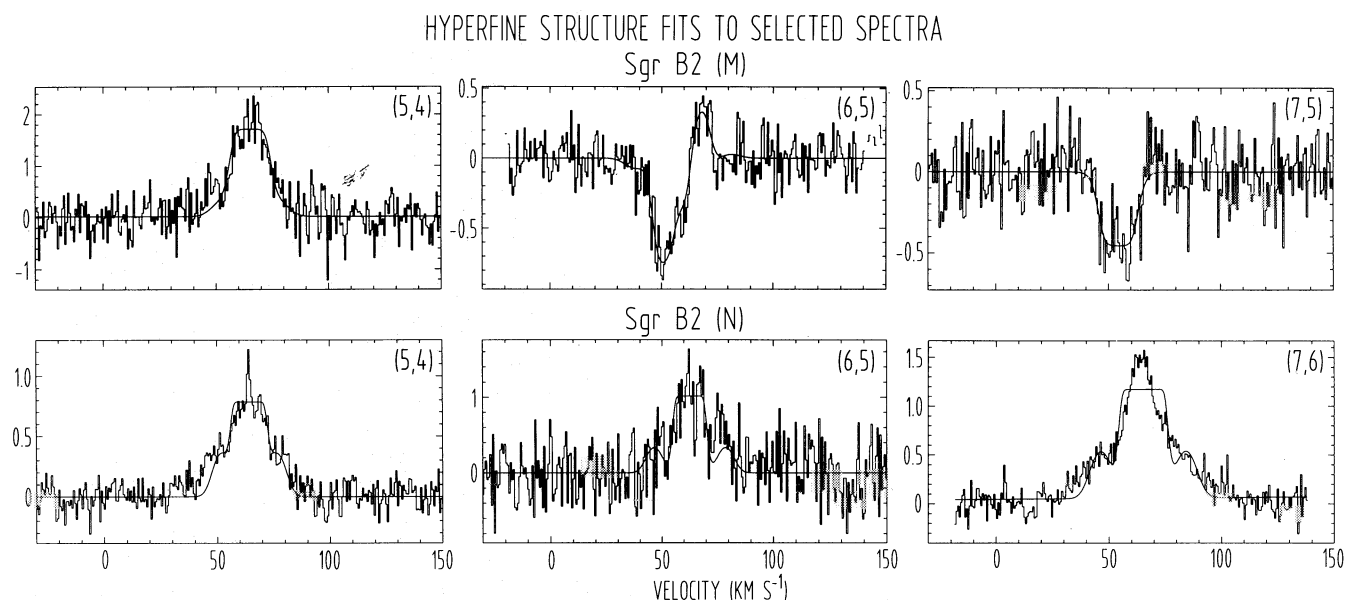


Fig. 8. A comparison of least squares hyperfine fits to selected NH_3 profiles. The effects of saturation are evident in all fits of profiles in Sgr B2 (N) and in the fits to the (5,4) emission line and the (7,5) absorption line in Sgr B2 (M). Note that the complex profile of the (6,5) line in Sgr B2 (M) is matched very well by the fit. All fit results are listed in Table 2

in the far infrared maps of Goldsmith et al. (1990). The dust temperatures (~ 50 K) are much lower than T_{rot} determined from our NH_3 data. At $n(\text{H}_2) > 10^6 \text{ cm}^{-3}$ gas and dust temperatures are coupled. Thus the compact warm ammonia sources associated with Sgr B2 (M) and (N) should also be detectable as hot infrared sources. However the extended envelope surrounding the Sgr B2 core (see Sect. 7), blocks the hot compact dust components from our view. Goldsmith et al. (1990) find that this envelope becomes optically thick at $\lambda \sim 100 \mu\text{m}$. A comparison of the far infrared fluxes is consistent with Sgr B2 (N) having a larger dust column density than Sgr B2 (M). According to Goldsmith et al. (1990), the dust radiation from Sgr B2 (N) becomes optically thick at $\lambda \sim 800 \mu\text{m}$. This is consistent with our results from NH_3 , as well as those from most other molecular species (see Sect. 6.1).

6.3. The heating of the gas

Vogel et al. (1987) estimate that the HII regions can provide the heat input required to warm the NH_3 to 170 K. This applies only to the molecular gas very close to the HII regions. Another heating scheme is required for the extended, warm NH_3 component. In the (6,6) line, emission is found at offsets larger than $1.5'$ (3.5 pc) from the HII regions. To heat dust and gas to 100 K over this distance requires $\sim 10^2$ times the observed infrared luminosity. Clearly another heating mechanism is needed. Also, since $n(\text{H}_2) < 10^5 \text{ cm}^{-3}$, the dust and gas temperatures need not be equal; observationally, the dust is indeed much colder (see Sect. 6.2). Alternatively, the gas could be heated by (1) the conversion of rotational motions into turbulence (Fleck 1981; Wilson et al. 1982; Mauersberger et al. 1986), (2) a large flux of low energy cosmic rays (Güsten et al. 1981) or (3) a mag-

netic ion-slip process (Scalo 1977). In molecular clouds close to Sgr A, Genzel et al. (1984) have favored UV heating by stars via photo-ejection of electrons from grains. Given that NH_3 is dissociated by 4 eV photons, such a process would lead to the destruction of the molecules, rather than the heating needed (see also Mauersberger et al. (1986) for discussing T_{rot} values in other molecular clouds near the galactic center).

6.4. Hot core properties

The criterion used to identify hot cores such as Orion KL is the presence of a large number of NH_3 inversion lines with high opacity and rotational temperature. In the galactic disk, the estimated lifetime of compact HII regions is about a factor of ten larger than that of NH_3 hot cores, from the data in Churchwell (1990) and Brown et al. (1988). One would expect that this is also the ratio of compact HII regions and hot NH_3 cores; this ratio is also found to be so for the Sgr B2 region, although the environment is very different. Since NH_3 data allow a determination of parameters like size, mass, temperature, and density, it is of interest to compare the main properties of the individual objects known to date. Virial equilibrium is assumed to obtain the parameters given in Table 5.

So far the number of known sources is small (see Cesaroni et al. 1992 for additional candidates) and many of them have not yet been thoroughly investigated. Rotational temperatures, densities, and cloud sizes are similar. The relative NH_3 abundance, $X(\text{NH}_3)$, is enhanced over 'normal' values, $\sim 10^{-7}$, supporting the contention by Pauls et al. (1983) and Walmsley et al. (1987) that most of the NH_3 is evaporated from dust grain mantles. Sgr B2 (M), (N) are much more massive than the other cores: two other cores at a similar distance from the sun, W 51-

Table 5. Ammonia hot core properties^{a)}

Source	<i>D</i> kpc	NH ₃ ^{b)}	<i>v</i> _{LSR} km s ⁻¹	<i>M</i> M _⊙	Size pc	<i>n</i> (H ₂) cm ⁻³	<i>T</i> _{rot} K	<i>N</i> (NH ₃) cm ⁻²	<i>X</i> (NH ₃)	Ref.
W3 (OH)	2.2	A	-44.5		0.010	10 ^{8.2}	95	10 ^{16.7}		1,2
W3 (H ₂ O)	2.2	E	-47.5		0.030	> 10 ^{5.0}	<i>E</i> /1.8 k ^c			2
Ori-KL	0.5	E	5.5	4	0.025	10 ^{7.0}	160	10 ^{18.1}	10 ^{-5.8}	3
S6	0.5	E	8.0							1
Sgr B2 (M)	8.5	A	55.0	3000	0.060	10 ^{7.8}	160	10 ^{20.7}	10 ^{-4.3}	4
Sgr B2 (M)	8.5	E	65.0	2000	0.160	10 ^{7.3}	180	< 10 ^{20.7}	< 10 ^{-4.3}	4
Sgr B2 (N)	8.5	E	65.0	2000	0.160	10 ^{7.3}	155	10 ^{21.0}	10 ^{-4.0}	4
W 31c	6.0	A	-0.7	25	0.026	10 ^{7.7}	120	10 ^{18.3}	10 ^{-6.3}	1,5
G 34.3+0.2	3.7	E	59.0	170	0.040	10 ^{8.0}	225	10 ^{18.5}	10 ^{-6.4}	6
W 49/1	10.4	A	12.5							1
W 51-IRS2	7.8	E	60.5	160	0.024	10 ^{7.7}	310	10 ^{19.3}	10 ^{-5.2}	7
W 51 e1/e2	7.8	E	58.5	<5000	<0.200	>10 ^{7.4}	240			1
W 75 S	3.0	E	-2.6	<200	<0.130	>10 ^{6.6}	200			1
NGC 7538	3.0	A	-60.0	20	0.017	10 ^{8.2}	200	10 ⁻⁴	10 ^{-5.5}	1,5,8

a) Only sources with detected (7,7) lines are included; for a number of promising candidates where the (6,6), the (7,7) and non-metastable lines have not yet been measured, see Cesaroni et al. (1992).

b) Emission (E), Absorption (A)

c) Valid for $E/k \leq 940$ K.

d) The values given are based on data up to the (5,5) inversion line; emission from higher excited levels are not yet published. References: (1) Mauersberger et al. (1986); (2) Mauersberger et al. (1988); (3) Hermsen et al. (1988); (4) This paper; (5) Wilson et al. (1983); (6) Henkel et al. (1988); (7) Mauersberger et al. (1987); (8) Henkel et al. (1984); some of the parameters have been updated to achieve internal consistency.

IRS2 and W 31 c, have masses <10% of those of the 65 km s⁻¹ Sgr B2 cores. Also, their NH₃ column densities are small compared with those of the Sgr B2 (N) and the 55 km s⁻¹ Sgr B2 (M) cores. Clearly, the number of sources is not yet sufficient for firm conclusions. It would be worthwhile to improve the mass estimates of the W 51 e1/e2, the W 49, and other distant cores to check whether Sgr B2 (M) and (N) are truly exceptional. If they turn out to be as outstanding as they appear according to Table 5, this may be explained in terms of the high densities and temperatures encountered in all galactic center clouds (see e.g. Hüttemeister et al., submitted). This could have far reaching consequences for our understanding of massive star formation.

7. A model of the Sgr B2 region

The molecular line, infrared and radio continuum data provide detailed information on the morphology of the Sgr B2 complex (see also the summary of Goldsmith et al. 1990). In the following, we compare this information with our NH₃ data. A molecular envelope of size 45 pc, the largest in the galaxy (Scoville et al. 1975) contains most of the $\sim 10^6$ M_⊙ of interstellar gas.

In this low density gas ($\sim 10^4$ cm⁻³), only metastable NH₃ levels are populated. This gas component absorbs the thermal continuum sources associated with the embedded young massive stars. Based on the NH₃ metastable line data and an analysis of the HC₃N spectra presented by Lis & Goldsmith (1991), we favor the *coexistence* of extended cold and warm ($T_{\text{kin}} > 30, 140$ K) gas components, while previous results for other molecules (see Scoville et al. 1975) were interpreted as arising from cool ($T_{\text{kin}} \sim 20$ K) molecular material absorbing a

warmer background. The T_{rot} values determined from our NH₃ data are *lower* limits to the actual kinetic temperature. NH₃ spectra obtained with lower angular resolution (Morris et al. 1973) suggest that this gas is widespread.

From C¹⁸O data, Lis & Goldsmith (1989) derived a relation for $n(\text{H}_2)$ outside a radius $r_0 = 0.75$ pc (18''). Densities of order 10⁴ cm⁻³ are expected at radii of a few pc (> 30'' to > 100''). This is consistent with the extent of our 'metastable extended emission' gas (Table 4). The high volume filling factor obtained for NH₃ (see Sects. 5.1 and 5.2) and also for HC₃N (Sect. 6.1) is consistent with the assumption that the HC₃N lines are optically thin. The scenario also agrees with the fact that all known molecular clouds near the galactic center have substantial amounts of both cool and warm ($T_{\text{kin}} > 100$ K) gas (e.g. Scoville et al. 1975; Mauersberger et al. 1986).

In addition, Churchwell et al. (1986) studied an HNC emission peak 90'' north of Sgr B2(M). They argued that the HNC is excited by far infrared (FIR) radiation, but does not require very large densities. Thus, the HNC peak may be due to an excitation effect.

Many spectral line searches have concentrated on the OH maser center at Sgr B2(S), shown in Fig. 1. Sgr B2(S) is not an exceptional ammonia source, but one of the few objects showing H₂CO masers (Gardner et al. 1986).

Closer to Sgr B2 (M) and (N) densities are $\sim 10^5$ cm⁻³. As for the less dense component, the gas and dust temperatures are decoupled and the dust is cold (e.g. Cox & Laureis 1989). Most of this gas is located in a ridge $\sim 10''$ west of Sgr B2 (M) and (N).

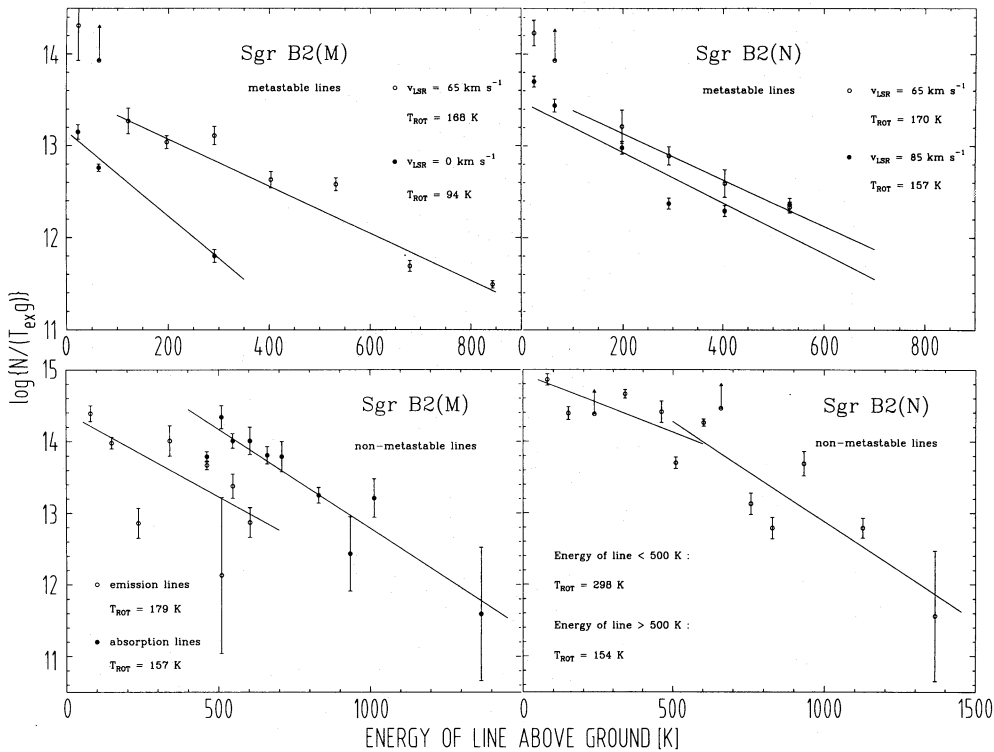


Fig. 9. Plots of least-squares fits to normalized column density in a given NH_3 energy level against energy above the molecular ground state. The values of rotational temperatures are inversely proportional to the slopes of the fitted lines. The metastable absorption line data are shown in panel a) (Sgr B2 (M)) and b) (Sgr B2 (N)), while the non-metastable data are shown in c) (Sgr B2 (M)) and d) (Sgr B2 (N)). The RMS errors in the determinations of T_{rot} are of order 20%

Four molecular hotspots are observed inside the envelope. These are aligned NS within $45''$; they are regions of recent or ongoing massive star formation. Each of the two major groups of ultracompact HII regions, Sgr B2 (M) and (N), contains at least one massive Ori-KL like hot core. Sutton et al. (1991) find molecular transitions of highest excitation in Sgr B2 (N).

With $n(\text{H}_2) > 10^6 \text{ cm}^{-3}$ dust and gas temperatures are coupled and have a common $T_{\text{kin}} > 100 \text{ K}$. Since the number of ultracompact HII regions is at least an order of magnitude larger than the number of hot cores, the molecular regions may be extremely shortlived. This is consistent with the estimated ratio between the lifetime of a hot core ($\sim 10^4 \text{ yr}$; e.g. Brown et al. 1988) and that of an ultracompact HII region ($\sim 10^5 \text{ yr}$; e.g. Churchwell 1990). It may be that these clouds' lifetime is determined by the evaporation of dust grain mantles.

From their data, Vogel et al. (1987) concluded that Sgr B2 (N) must be a very young source, while the Sgr B2 (M) region is more evolved. This interpretation is based (1) on the presence of an ultracompact HII region and a molecular outflow associated with Sgr B2 (M) but not with Sgr B2 (N) and (2) on a smaller mass of the Sgr B2 (M) core suggesting a more advanced stage of cloud dispersal. Both arguments are not supported by more recent data. In Sgr B2 (M), Gaume & Claussen (1990) report that the NH_3 emission arises from a rotating disk or torus, but not the outflow. We find two dense compact cores, one with an extremely high, the other with a lower NH_3 relative abundance. The non-metastable NH_3 emission from the Sgr B2 (N) core is closely associated with a group of four ultracompact HII regions, K1, K2, K3, and K5. (Gaume & Claussen 1990). These may contain several molecular components with an uncertain

morphology. Since the Sgr B2 (M) cores are as massive as the Sgr B2 (N) core (Table 4), the cloud dispersal scenario is less likely. We conclude that there is no compelling evidence for an age difference between the two Sgr B2 (M) region relative to the Sgr B2 (N) core. Comparing our data for the three compact cores, the 65 km s^{-1} Sgr B2 (M) core has a lower relative NH_3 abundance than the 55 km s^{-1} and the Sgr B2 (N) cores. Whether this is due to an earlier or later stage of evolution, a different chemical composition of the evaporated dust grain mantles or a lower luminosity of the newly formed stars remains a matter of speculation.

8. Conclusions

Toward the Sgr B2 complex, $40''$ resolution maps and single spectra of highly excited NH_3 inversion lines have been used to deduce physical conditions. For the -40 km s^{-1} component toward Sgr B2 (M) we find $T_{\text{kin}} \sim 20 \text{ K}$. This absorption is probably due to a foreground cloud associated with the 3 kpc arm.

The main results directly related to the Sgr B2 complex are as follows:

- (1) All clouds in Sgr B2 contain gas with $T_{\text{kin}} \geq 100 \text{ K}$.
- (2) Metastable inversion lines up to 850 K above the molecular ground state are observed in *absorption* toward the continuum sources Sgr B2 (M) and (N). Our maps show that the associated metastable line *emission* is extended. Thus the excitation temperature must be less than the main beam brightness temperature of the most intense background source, 21 K . This can occur if the H_2 density is $\sim 10^4 \text{ cm}^{-3}$ in the region in front of Sgr B2. There must be at least two gas components with different T_{kin} but similar NH_3 column densities. Non-metastable

levels are not populated in this region. From virial estimates and the assumption that only metastable levels are populated, the $[\text{NH}_3]/[\text{H}_2]$ abundance ratio is $\sim 10^{-7}$. Only emission from HC_3N in the ground vibrational state appears to arise from the same components.

(3) The non-metastable line emission is extended, ($\alpha \times \delta$) $\sim 50'' \times 120''$ in the (2,1) line, and is centered $10''$ west of the continuum sources. The distribution of the non-metastable emission is more compact, and definitely different from that of the metastable lines. From estimates based on the virial theorem, the H_2 density in this region is $\sim 10^5 \text{ cm}^{-3}$. This implies large variations in the excitation conditions in different parts of the complex.

(4) Associated with the ultracompact HII regions in Sgr B2 (M) and (N) are three compact, dense cores. The $n(\text{H}_2)$ and $X(\text{NH}_3)$ are similar to Orion KL, but with virial masses of a few $10^3 M_\odot$, these are the most massive hot cores. Particularly outstanding are, with NH_3 column densities of order 10^{21} cm^{-2} , the 55 km s^{-1} core observed in absorption toward Sgr B2 (M) and the 65 km s^{-1} emission core of Sgr B2 (N). For the core regions the H_2 densities imply LTE excitation conditions, so that T_{dust} and T_{kin} are coupled. The $X(\text{NH}_3)$ values are also larger than in other sources of this type, indicating that much of the gas phase N is in NH_3 and further supporting the model predicting evaporation of NH_3 -rich dust grain mantles due to heating by newly formed massive stars. The $X(\text{NH}_3)$ value for the 65 km s^{-1} core of Sgr B2 (M) is lower but it is not clear whether this is an age effect or whether it is caused by a different dust grain mantle composition or by lower luminosities of the newly formed stars. The relative number of detected sources indicates that the lifetime of a hot core is only 10% of the typical lifetime of an UC-HII region.

Appendix

A1. The excitation of the ammonia molecule

In Table 6, we give the separation of the main and satellite components, and the relative intensities of the quadrupole hyperfine splitting of NH_3 for the lines observed. Because of the large linewidths in Sgr B2, the magnetic splitting ($\Delta v_{1/2} < 0.2 \text{ km s}^{-1}$) cannot be resolved, and we have not accounted for this effect.

The NH_3 populations (for an energy level diagram, see e.g. Hermsen et al. 1988) are described by two temperatures: (1) the excitation temperature T_{ex} which characterizes the population across a (J, K) inversion doublet and (2) the rotational temperature T_{rot} , which characterizes the populations of energy levels with different (J, K) . The populations of metastable inversion levels are determined by collisions, which are characterized by T_{kin} . The spontaneous decay rate across an inversion level is $\sim 10^{-6} \text{ s}^{-1}$, so that $T_{\text{ex}} \ll T_{\text{kin}}$ at H_2 densities $< 5 \times 10^3 \text{ cm}^{-3}$. We show a plot of T_{ex} as a function of H_2 density in Fig. 10. As can be seen, the value of T_{ex} increases nearly monotonically with $n(\text{H}_2)$.

Table 6. Parameters of the quadrupole hyperfine satellites for selected inversion transitions of NH_3 .

Transition (J,K)	Distance		rel. intensity	
	inner Sat. km s^{-1}	outer Sat. km s^{-1}	Satellites	Main Component
(2,1)	8.5	13.1	0.051 ^a	0.796
(3,2)	no quadrupole splitting			
(4,3)	6.5	8.1	0.016	0.935
(5,4)	11.3	13.6	0.011	0.956
(6,5)	14.9	17.4	0.0078	0.9686
(6,4)	3.0	3.5	0.0078	0.9686
(6,3)	7.6	8.9	0.0078	0.9686
(7,6)	17.6	20.2	0.0059	0.9764
(7,5)	7.2	8.2	0.0059	0.9764
(7,4)	3.1	3.5	0.0059	0.9764
(8,7)	19.7	22.2	0.0046	0.9816
(8,6)	10.6	12.0	0.0046	0.9816
(9,8)	21.1	23.6	0.0037	0.9853
(9,7)	13.5	15.1	0.0037	0.9853
(9,6)	5.0	5.5	0.0037	0.9853
(10,9)	22.2	24.4	0.0030	0.9879
(10,8)	15.9	17.5	0.0030	0.9879
(11,10)	22.9	25.0	0.0025	0.9899
(12,11)	23.2	25.2	0.0021	0.9915

a) Only in this case, the results for the inner and outer components vary slightly: the calculations yield a relative intensity of 0.050 and 0.052 for the inner and outer satellites, respectively.

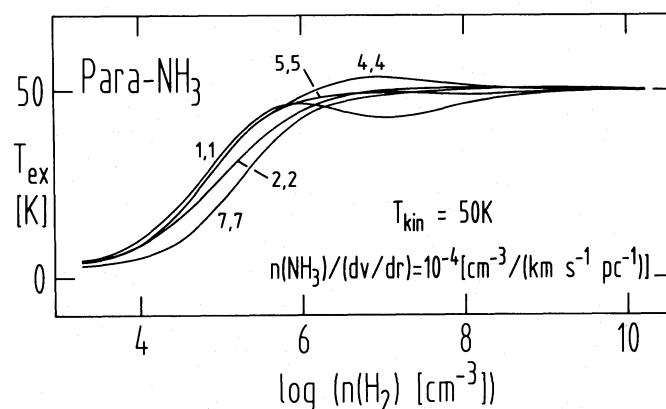


Fig. 10. Excitation temperature across metastable doublets as a function of H_2 density (para lines); taken from Schilke (1989)

Since the metastable populations can only be exchanged by collisions, there is a direct relation between T_{rot} and T_{kin} . The correlation between T_{rot} and T_{kin} is given by Walmsley & Ungerechts (1983) and, making use of improved collision rates, by Danby et al. (1988). $T_{\text{rot}} < T_{\text{kin}}$, but there is a monotonic relation. Calculations with an intense IR field give the same result. Thus, the extended metastable line emission gives a good lower limit to T_{kin} .

For non-metastable levels, the situation is quite different. This is because the level population can decay rapidly via allowed rotational ($\Delta J = 1$) transitions. The decay rate is $\sim 1 \text{ s}^{-1}$.

Thus, in the absence of optical depth effects, non-metastable lines require extreme excitation conditions. One requires either H_2 densities of 10^9 cm^{-3} or intense IR fields caused by radiation from dust grains. Clearly, the metastable and non-metastable levels require very different excitation conditions. Because of the extreme conditions needed for the non-metastable levels, it is not surprising that these are found in only a small region. A comparison of non-metastable levels to obtain T_{kin} is much more uncertain than in the case of metastable

A2. The influence of beam filling factors and source geometry

Here we give a comprehensive account of the influence of telescope beam size and source geometry on the observed line intensities. Basic line properties (i.e. the appearance of the line in emission or absorption) depend critically on these factors.

If the telescope beam is small compared to the cloud size, which is small compared to the size of the background source, the observed line temperature, T_L , of a transition $1-0$ at a frequency ν_{10} is given by

$$T_L = \frac{1}{\eta_B} T_A^* = \frac{c^2}{2k\nu_{10}^2} [B_\nu(T_{\text{ex}}) - B_\nu(T_C)](1 - e^{-\tau}) \quad (1)$$

where T_A^* is the antenna temperature, η_B the beam efficiency, $B_\nu(T)$ Planck's function, T_{ex} the excitation temperature characterizing the molecular cloud and T_C the temperature of a continuum source. In all following considerations, we assume $T_C, T_{\text{ex}} \gg 2.7 \text{ K}$, that is, we will neglect the presence of the constant microwave background radiation. By inserting $B_\nu(T) = 2\nu_{10}^2 k / c^2 T$ (the Rayleigh-Jeans approximation), Eq. 2 becomes

$$T_L = (T_{\text{ex}} - T_C)(1 - e^{-\tau}) \quad (2)$$

Now, we will relax the assumptions about filling factors for both the molecular and the continuum source. Figure 11 shows a molecular cloud of the size Ω_{cl} and a continuum source (Ω_C) only partially filling the telescope beam (Ω_B). The continuum source is situated behind the cloud and partially covered by it.

In this general case, one has:

$$T_L = \underbrace{f_{\text{cl}} T_{\text{ex}} (1 - e^{-\tau})}_{\text{emission}} - \underbrace{f_o f_C T_C (1 - e^{-\tau})}_{\text{absorption}} = (f_{\text{cl}} T_{\text{ex}} - f_o f_C T_C)(1 - e^{-\tau}) \quad (3)$$

Here, f_{cl} and f_C are the beam filling factors of the molecular cloud and the continuum source, respectively, and f_o denotes the fraction of the continuum source covered by the cloud. Obviously, the relation $0 \leq f_{\text{cl}}, f_C, f_o \leq 1$ has to be fulfilled. If both the sources and the beam are gaussian shaped, f_{cl} and f_C are given by

$$f_{\text{source}} = \frac{\Omega_{\text{source}}^2}{\Omega_{\text{source}}^2 + \Omega_B^2}, \quad (4)$$

where Ω_{source} and Ω_B denote the solid angles covered by the source (Ω_{cl} or Ω_C) and the beam, respectively. The influence of

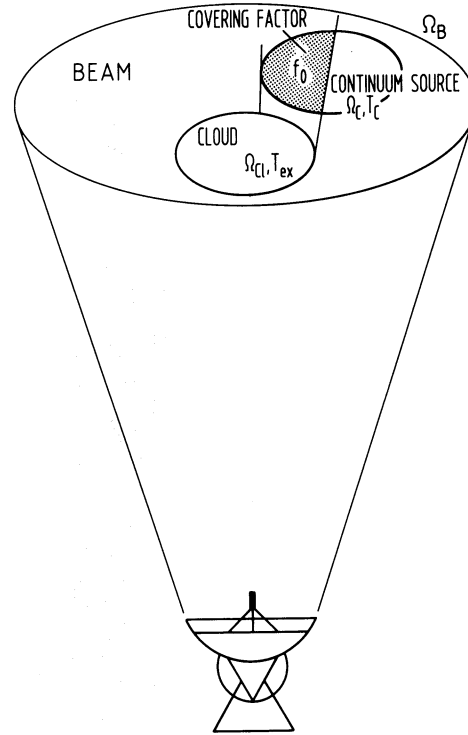


Fig. 11. Source geometry

the different factors becomes more obvious when one considers special cases of Eq. 4.

a) Optical Depth

For an optically thin line, Eq. 4 becomes

$$T_L = (f_{\text{cl}} T_{\text{ex}} - f_o f_C T_C) \tau \quad (5)$$

while for an optically thick line one has

$$T_L = f_{\text{cl}} T_{\text{ex}} - f_o f_C T_C \quad (6)$$

b) Degree to which the continuum source is covered

If the continuum source is not covered by the cloud, is in front of the cloud or if there is no continuum source, one has $f_o = 0$ and T_L simply becomes:

$$T_L = f_{\text{cl}} T_{\text{ex}} (1 - e^{-\tau}) \quad (7)$$

The line will always appear in emission. This case is realized for the extended metastable emission seen in our maps away from the peak positions of Sgr B2 and – most probably – for the highly excited non-metastable emission toward Sgr B2 (N).

If, on the other hand, the continuum source is completely covered by the cloud ($f_o = 1$), one has

$$T_L = (f_{\text{cl}} T_{\text{ex}} - f_C T_C)(1 - e^{-\tau}) \quad (8)$$

and the probability of absorption dominating emission is largest.

c) Source sizes

c1) In the simplest case possible, both the molecular cloud and the continuum source are significantly larger than the telescope beam ($\Omega_{\text{cl}}, \Omega_C \gg \Omega_B$). All filling factors approach unity ($f_{\text{cl}}, f_C, f_o \rightarrow 1$) and we recover Eq. 3.

If absorption lines are observed and there is reason to assume $T_{\text{ex}} \ll T_C$, it is possible to calculate optical depths from the ratio of the observed line temperatures and the continuum temperature by using

$$\tau \equiv \tau_{\text{app}} = -\ln\left(1 - \frac{|T_L|}{T_C}\right) \quad (9)$$

If $f_C < 1$, T_C has to be replaced by T_{MB}^C (see c2). This method works best if the optical depths are fairly low. In case of high τ , T_L/T_C will be very close to unity. Then the exact value of τ becomes fairly uncertain.

We have applied this procedure to the metastable absorption lines seen toward the peak positions of Sgr B2 (see Table 3). It can be used in cases where a fit to HF-satellites becomes impossible due to complex lineshapes, and it provides an independent check on the fit results if both methods are applicable.

c2) If the molecular cloud is larger than the beam, but the continuum source is smaller ($\Omega_{\text{cl}} \gg \Omega_B > \Omega_C \Rightarrow f_{\text{cl}} = 1, f_o = 1$), equation Eq. 4 becomes

$$T_L = (T_{\text{ex}} - T_{\text{MB}}^C)(1 - e^{-\tau}) \quad (10)$$

with the main beam continuum brightness temperature defined as $T_{\text{MB}}^C \equiv f_C T_C$. Emission is very likely now. Absorption requires $T_{\text{ex}} < T_{\text{MB}}^C$. Given the small values of $T_{\text{MB}}^C \sim 20$ K and $T_{\text{rot}} \sim 170$ K for the 65 km s^{-1} component toward Sgr B2 (M), this indicates subthermally excited inversion doublets. However, T_{ex} exceeds T_{MB}^C in case of the lower excitation, non-metastable lines seen over an extended region that appear in emission toward both peak sources.

c3) If the beam size is larger than both Ω_C and Ω_{cl} , without further assumptions we get the general case as described by Eq. 4. Assuming, however, $\Omega_{\text{cl}} = \Omega_C$ and (for simplicity) $f_o = 1$, resulting in $f_{\text{cl}} = f_o f_C = f$, Eq. 4 becomes

$$T_L = f(T_{\text{ex}} - T_C)(1 - e^{-\tau}) \quad (11)$$

Now, absorption is quite likely even for quasi-thermally excited lines, since for the compact HII regions T_C can be of order ~ 2000 K. This situation probably describes the absorption observed toward Sgr B2 (M) in the non-metastable lines at $\sim 55 \text{ km s}^{-1}$.

c4) Finally, Ω_{cl} may be smaller than both Ω_C and Ω_B . To within the noise, this probably does not occur for Sgr B2 and is discussed here for completeness only. One gets

$$0 \leq f_o \leq \frac{f_{\text{cl}}}{f_C} \quad (12)$$

and if $f_o = f_{\text{cl}}/f_C$, that is, if the molecular cloud is completely in front of the larger continuum source, Eq. 4 becomes:

$$T_L = f_{\text{cl}}(T_{\text{ex}} - T_C)(1 - e^{-\tau}) \quad (13)$$

Of course, all combinations between a) and b)/c) are possible. To complicate matters further, sometimes there will be several molecular clumps with different properties and geometries

present in the beam. For the $v_{\text{LSR}} \sim 65 \text{ km s}^{-1}$ ‘main’ component, this is the case. Mapping shows that the metastable region is very extended, and the non-metastable more compact. With the absorption at $v_{\text{LSR}} \sim 55 \text{ km s}^{-1}$, we are more fortunate, since the velocity shift relative to the main component greatly aids in clearing up ambiguities.

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