FIRST DETECTION OF AMMONIA IN N 58

ABSTRACT

We report the detection of the first line emission of ammonia (NH$_3$) in the LISM toward N 58. A total of 28 K(A, A') transitions above 8.0 K(A, A') were observed with the VLA in the C, B, and A configurations, with corrections for the phase errors. The line center of the NH$_3$ gas is located at a distance of 9.4 kpc, consistent with the distance of N 58 determined from the optical spectrum. The NH$_3$ column density in the direction of N 58 is estimated to be $1 \times 10^{17}$ cm$^{-2}$, typical of the gas density in the CMZ. The NH$_3$ line is optically thin, and its linewidth is consistent with the optical linewidth of 58 km s$^{-1}$. The NH$_3$ emission is elongated along the line of sight, indicating that the gas is likely associated with the trailing edge of the interstellar cloud.

1. INTRODUCTION

First detection of ammonia in N 58

W3(OH) before each observing run (for fluxes see Mauersberger, Wilson, & Henkel (1988) and Ott et al. (1994)). Pointing was checked every 1.5 hours on the nearby continuum source 0856+71 and was found to be stable to within $5 \times 10^{-6}$. A linear baseline was removed from each spectrum and intensities were converted to a $T_{mb}$ scale. The summed spectra were smoothed to a velocity resolution of 16 km s$^{-1}$. We estimate the flux calibration of the final reduced spectra to be accurate within $\pm 20\%$ (10% error of the flux calibration and 10% uncertainty due to low-level baseline instabilities).

3. Results

The observed spectra of the ammonia lines are shown in Fig. 1. The (J,K) = (1,1)-(3,3) lines are detected with a S/N ratio better than 4. The (4,4) line is not detected. The (1,1) and (2,2) lines peak at $v_{\text{LSR}} = 100$ km s$^{-1}$ ($C_{100}$) and show a weaker component at $v_{\text{LSR}} = 160$ km s$^{-1}$ ($C_{160}$). Both velocity components are also detected in low- and mid-J CO emission lines (see e.g. Harris et al. (1991); Wild et al. (1992); Mao et al. (2000); Petitpas & Wilson (2000)). At 40$^\circ$ resolution the intensity of the low-J CO transitions from $C_{100}$ is stronger than that from $C_{160}$. To emphasize this point we show the line profile of the $^{12}$CO(J = 1 $\rightarrow$ 0) transition at 40$^\circ$ resolution in the top panel of Fig. 1.

Beam averaged column densities for individual inversion states were calculated using

$$N(J,K) = \frac{7.77 \times 10^{13} J(J+1)}{K^2} \int T_{mb} dv$$ (1)

(e.g. Henkel et al. (2000)). The column density $N$, the frequency $\nu$ and the integrated line intensity are in units of cm$^{-2}$, GHz and K km s$^{-1}$, respectively. Line parameters and column densities are summarized in Tab. 1. Note that this approximation assumes optically thin emission and the contribution of the 2.7K background to be negligible ($T_{mb} \gg 2.7K$). Following the analysis described by Henkel et al. (2000) the rotation temperature ($T_{rot}$) between levels J and J' can be determined from the slope of a linear fit in the rotation diagram (normalized column density vs. energy above the ground state expressed in E/k) by

$$T_{\text{rot}} = \frac{-\log(\epsilon)}{a} = \frac{-0.434}{a}$$ (2)

where $a$ is the slope of the linear fit.

The rotation diagram for the observed ammonia lines is shown in Fig. 2. The rotation temperature between the (1,1) and (2,2) inversion levels of para-ammonia is $T_{rot}$ = 29 K (thick solid line). The uncertainty, derived from the extrema of the slope including the (4,4) level as an upper limit, is $\pm 5$ K (dotted lines). The (J,K) = (3,3) line is not included in the fit because it belongs to ortho-ammonia, thus to a different ammonia species. Nevertheless, it nicely fits to the rotation temperature derived from the two lowest inversion levels of para-ammonia.

In addition to the analysis of the integrated line intensities we have decomposed the (J,K) = (1,1) and (2,2) spectra into two Gaussian components with fixed center velocities of $v_{\text{LSR}} = 100$ km s$^{-1}$ ($C_{100}$) and 160 km s$^{-1}$ ($C_{160}$). The Gaussian decomposition is shown together with the observed line profile in the two top panels of Fig. 1. A separate analysis of the rotation temperatures between the (1,1) and (2,2) inversion levels for both components yields $T_{rot,100} = 24^{+12}_{-6}$ K and $T_{rot,160} = 31^{+22}_{-10}$ K for $C_{100}$ and $C_{160}$, respectively. For the errors we have assumed 30% uncertainty from the Gaussian decomposition. Note that the observed upper limit for the (J,K) = (4,4) line intensity is still consistent with the shallow slope derived for the emission arising from the 160 km s$^{-1}$ component ($C_{160}$).

4. Discussion

4.1. The NH$_3$ emitting volume

High-resolution rotation CO observations show that the emission at $v_{\text{LSR}} \approx 100$ km s$^{-1}$ is mainly associated with the SW molecular lobe. The emission at $v_{\text{LSR}} \approx 160$ km s$^{-1}$ arises from regions closer to the nucleus, i.e. from the central molecular peak and the inner CO outflow region. Thus $C_{160}$ covers the regions of the western mid infrared peak close to the central molecular peak (Telesco & Gezari (1992)), and the region where an expanding molecular superbubble was identified (Weiβ et al. (1999)). Therefore $C_{160}$ represents a more active region than the outer molecular lobe itself. An overlay of the two regions at high spatial resolution ($\approx 2''$) as observed in the $^{13}$CO(J = 2 $\rightarrow$ 1) transition (Weiβ et al. (2001)) is shown in Fig. 3.

4.2. Comparison with temperature determinations from other line observations

Radiative transfer calculations (e.g. Walmsley & Ungerechts (1983)) of NH$_3$ show that rotation temperatures determined from meta-stable levels only reflect the kinetic gas temperature for low ($T < 15$K) temperatures. For larger temperatures the rotation temperature largely underestimates the kinetic gas temperature due to depopulation mechanisms. Correcting our results for these effects, our mean rotation temperature of 29 K corresponds to a mean kinetic temperature of $T_{k,\text{kin}} \approx 60$ K. Using the Gaussian decomposition we find $T_{k,\text{kin}} \approx 45$ K for the temperature in the SW molecular lobe ($C_{100}$), and $T_{k,\text{kin}} \approx 80$ K for the regions closer to the nucleus ($C_{160}$). These values are in good agreement with recent high-resolution kinetic temperature estimates using radiative transfer calculations based on CO observations by Weiβ et al. (2001)). They derive $T_{k,\text{kin}} \approx 55$ K for the SW molecular lobe, and an average of $T_{k,\text{kin}} \approx 110$ K over the region which corresponds to $C_{160}$ in our study. The simultaneous observations of two [C$^1$] fine structure lines towards the SW lobe allowed Sztuzki et al. (1997) to derive a lower limit for the kinetic temperature of the [C$^1$] emitting gas in $C_{100}$ of 50 K which is consistent with the temperature derived above from the NH$_3$ lines. Similar values ($T_{k,\text{kin}} = 50$ K) have been found by Seaquist & Frayer (2000) using HCO$^+$ and HCN emission lines. Note, however, that the uncertainty of the kinetic temperature estimates from the Gaussian decomposition of the NH$_3$ spectra is quite large. Nevertheless, the results are in line with the general picture that the kinetic temperature rises from the outer parts of the SW molecular lobe towards the active regions closer to the nucleus of M82. In comparison with rotation temperatures determined from NH$_3$ in IC342 ($T_{rot} \approx 50$ K; Martin & Ho (1986)) and Maffei 2 ($T_{rot} \approx 85$ K; Henkel et al. (2000)) the values
determined here for M 82 are very low. Thus the temperature of the dense molecular gas in M 82 is obviously much lower than in other galaxies with large nuclear concentrations of molecular gas. This explains the apparent underabundance of molecules like SiO, CH$_3$OH, HCN, and CH$_3$CN in M 82 which only form in a dense and warmer environment (see e.g. Mauensberger & Henkel (1993)).

4.3. NH$_3$ abundance

Using eq. A15 of Ungerechts, Walmsley, & Winnewisser ((1986)) we have estimated a total beam-averaged NH$_3$ column density of \( N({\text{NH}}_3) \approx 1 \times 10^{13} \text{ cm}^{-2} \). The beam-averaged H$_2$ column density was estimated to be \( N({\text{H}}_2) \approx 1.9 \times 10^{12} \text{ cm}^{-2} \) using the CO spectrum shown in Fig. 1 and a conversion factor of \( X({\text{CO}}) = 5 \times 10^{18} \text{ cm}^{-2} (\text{K km s}^{-1})^{-1} \), which corresponds to the average value of the conversion factors derived by Weiß et al. ((2001)) in the region covered by 100–180 km s$^{-1}$ emission. This yields a relative abundance of ammonia of \( X({\text{NH}}_3) \approx 5 \times 10^{-10} \), which is an extremely low value. In nearby dark clouds the fractional NH$_3$ abundance is of order \( X({\text{NH}}_3) \approx 10^{-7} \) (e.g. Benson & Myers (1983)) and in hot cores NH$_3$ is even more abundant \( X({\text{NH}}_3) \approx 10^{-5} \) (e.g. Mauensberger, Henkel & Wilson (1987)). In a recent work on Maffei 2 Henkel et al. ((2000)) found \( X({\text{NH}}_3) \approx 10^{-8} \).

A closer look at the \((J,K) = (1,1)\) and \(^{12}\)CO \((J = 1 \rightarrow 0)\) spectra displayed in Fig. 1 (top) reveals another interesting aspect regarding the spatial variation of the NH$_3$ abundance: the line temperature ratio \( T({\text{NH}}_3(1,1))/T(^{12}\text{CO}(J=1\rightarrow 0)) \) decreases with increasing velocity for \( v_{lsr} > 100 \text{ km s}^{-1} \). The solid-body rotation in the inner part of M 82 allows one to associate velocities lower than the systemic velocity of \( v_{lsr} \approx 230 \text{ km s}^{-1} \) with a specific distance from the nucleus (e.g. Neininger et al. (1998)). Therefore, \( T({\text{NH}}_3(1,1)) \) per velocity interval traces the ammonia column density in a region much smaller than the spatial resolution, while \( T(^{12}\text{CO}(J = 1 \rightarrow 0)) \) traces the H$_2$ column density. Note that conversion from \(^{12}\text{CO} \) to \( Y({\text{H}}_2) \) changes across the major axis of M 82 and therefore for each velocity interval (Weiß et al. (2001)). Fig. 4 shows a histogram with \( Y({\text{H}}_2) \) versus radial velocity and galactocentric radius, accounting for variations of \( X({\text{CO}}) \) as determined by Weiß et al. ((2001)). The NH$_3$ abundance is found to decrease towards the center of M 82. We believe that this finding reflects a real change of the ammonia abundance, because a constant NH$_3$ abundance would imply that \( X({\text{CO}}) \) changes by a factor of more than 40 on a linear scale of 300 pc which is not consistent with radiative transfer models. Due to its low energy threshold for photodissociation (\( \approx 4.1 \text{ eV}, \) Suto & Lee (1983)), NH$_3$ should be destroyed rapidly in PDRs (Günster & Fiebig (1988)). This process should be even more efficient when the bulk of the gas is distributed in a diffuse phase with low H$_2$ column densities as it seems to be true for the central regions in M 82 (Mao et al. (2000), Weiß et al. (2001)). In such an environment shielding against the UV radiation is ineffective which leads to low NH$_3$ abundances towards the central star forming regions. Note, that NH$_3$ abundances are not always small in a warm environment. Efficient release of NH$_3$ into the gas phase by evaporation of dust grain mantles is known to occur in galactic ‘hot cores’. This process, however, becomes efficient at slightly higher temperatures than those obtained by us for NH$_3$ in Sect. 4.2.

We therefore interpret the abundance gradient as a result of ammonia being almost completely dissociated in the harsh environment close to M 82’s nucleus, whereas it can still partially survive, with low abundance, in the cooler, denser, and thus better shielded, clouds of the SW lobe.

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References

Fig. 1.—NH$_3$ spectra towards the SW part of M82 ($\alpha_{2000} = 00^h54^m45.06^s$, $\delta_{2000} = 69^\circ40'41''.2$). The velocity resolution is 16 km s$^{-1}$ for each spectrum. The high-resolution spectrum in the top panel shows the $^{12}$CO ($J=1\rightarrow0$) emission line at the same position and spatial resolution (40$''$) scaled by 1/370. For the fits to the (1,1) and (2,2) lines see Sect. 3.
Fig. 2.— Rotation diagram of metastable ammonia transitions towards the SW molecular lobe in M82. The filled squares show the normalized column densities determined from the integrated line intensities. The thick solid line (denoted by ‘total’) corresponds to a linear fit to the \((J,K) = (1,1)\) and \((2,2)\) lines for these values. The dotted lines correspond to the linear fits with the lowest and highest slope, which are still consistent with the data including the upper limit for the \((J,K) = (4,4)\) line. The open squares and the stars show the normalized column densities determined from a Gaussian decomposition of the \((J,K) = (1,1)\) and \((2,2)\) spectra into the velocity components \(C_{100}\) and \(C_{150}\). Note that for display purpose the values for \(C_{100}\) and \(C_{150}\) have been shifted by \(-0.2\) and \(-0.8\) on the \(y\)-axis scale, respectively. The thin solid lines correspond to linear fits to these data points.

Fig. 3.— High-spatial resolution \(^{12}\text{CO}(J = 2 \rightarrow 1)\) data integrated over \(v_{lsr} = 130 - 190\ km\ s^{-1}\) \((C_{150},\ contours)\) juxtaposed on \(^{12}\text{CO}(J = 2 \rightarrow 1)\) data integrated over \(v_{lsr} = 80 - 120\ km\ s^{-1}\) \((C_{100},\ greyscale)\). The 40" beam size of the Effelsberg telescope is indicated by the circle.
FIG. 4.— NH₃ abundance relative to H₂ per velocity interval. The upper axis denotes the distance of the emission region from the nucleus of M82 assuming pure solid body rotation and a velocity gradient of 0.7 km s⁻¹ pc⁻¹.
Table 1

Parameters of the ammonia lines towards the SW molecular lobe of M 82. Column 2 to 6 correspond to the line parameters of the entire line profiles derived from a visual inspection. Columns 7 and 8 give the column densities for the (1,1) and (2,2) transitions derived from a gaussian decomposition of the spectra.

<table>
<thead>
<tr>
<th>Transition (J,K)</th>
<th>$T_{mb}$ (mK)</th>
<th>$\int T_{mb}dV$ (K km s$^{-1}$)</th>
<th>$V_{LSR}$ (kms$^{-1}$)</th>
<th>$\Delta V_{1/2}$ (kms$^{-1}$)</th>
<th>$N(J,K)$ (10$^{12}$ cm$^{-2}$)</th>
<th>$N(J,K)$$_{100}$ (10$^{12}$ cm$^{-2}$)</th>
<th>$N(J,K)$$_{100}$ (10$^{12}$ cm$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1,1)</td>
<td>6.9 ± 0.8</td>
<td>0.61 ± 0.16</td>
<td>97 ± 16</td>
<td>94 ± 11</td>
<td>4.0 ± 1.1</td>
<td>2.2 ± 0.8</td>
<td>1.8 ± 0.6</td>
</tr>
<tr>
<td>(2,2)</td>
<td>4.3 ± 0.9</td>
<td>0.36 ± 0.11</td>
<td>105 ± 16</td>
<td>80 ± 10</td>
<td>1.8 ± 0.5</td>
<td>0.9 ± 0.3</td>
<td>1.0 ± 0.3</td>
</tr>
<tr>
<td>(3,3)</td>
<td>3.5 ± 0.7</td>
<td>0.14 ± 0.06</td>
<td>95 ± 10</td>
<td>47 ± 20</td>
<td>0.6 ± 0.26</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>(4,4)</td>
<td>&lt; 2.1 (3σ)</td>
<td>&lt; 0.1</td>
<td>--</td>
<td>--</td>
<td>&lt; 0.4</td>
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