A Southern Hemisphere Ammonia Survey

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Abstract: A spectral line survey for interstellar NH_3 is being carried out using the 64-m telescopes at Parkes and Tidbinbilla. Both telescopes are equipped with K-band maser receivers yielding system temperatures below 100 K. The preliminary survey is being made with the Parkes antenna (beam = 1.35 arcmin), with follow-up mapping of the more interesting sources at Tidbinbilla (beam = 0.9 arcmin). The selected sources have in general been HII regions from the H_2CO surveys made at Parkes. Statistical results from initial observations of the (1,1), (2,2), and (3,3) lines in the preliminary survey are presented.

Introduction

Interstellar ammonia is one of the most useful molecules for probing the dense cores of molecular clouds. To a good approximation, the total NH_3 column density is given by summing the populations of the lowest energy levels in each rotational ladder, the metastable (K,K) states. The inversion-rotation doublet transitions corresponding to these states have hyperfine structure which can be resolved for most galactic molecular clouds. The intensity ratios of the hyperfine components allow the determination of the optical depth and excitation temperature for the transition. This allows the column densities in the metastable states to be determined.

Collisions (primarily with H_2 molecules) determine the relative populations of these states. When inserted in the Boltzmann relation these relative populations can be expressed in terms of the 'rotation' temperatures between the levels. These have been commonly adopted as the kinetic temperatures (e.g. Morris *et al.* 1983). However, Walmsley and Ungerechts (1983) have shown that such kinetic temperatures are often under-estimates and have proposed an improved kinetic temperature estimate based on a three-level approximation. Recently, Kuiper (1986) has shown how the three-level temperature estimate can be further improved.

The spins of its three hydrogen atoms separate ammonia into two forms: ortho (all spins parallel) and para. Ortho-ammonia has (K,K) metastable states with K always a multiple of three. Even in collisions, transitions between the ortho and para forms are rare; thus the populations of each form are indepentent, except on time scales greater than a million years (Cheung *et al.* 1969). Therefore, rotation temperatures determined between ortho and para forms may reflect conditions averaged over long time scales while temperatures determined within a single form refer to more recent conditions.

A great advantage of using ammonia in the study of interstellar clouds is that the closely spaced frequencies of several of the transitions can be observed simultaneously. This means that comparisons between such transitions are free from uncertainties due to relative variations of calibration, beam-width, atmospheric absorption, and pointing accuracy.

Observations and Results

Several years ago, using the 64-m radio telescopes at Parkes and the NASA-JPL Deep Space Tracking Station at Tidbinbilla, Australia, we initiated a collaborative program to study the physical conditions and NH_3 content in southern molecular clouds (see Dickinson *et al.* 1982). The first phase of this program at Parkes involves observations of the molecular clouds located primarily towards southern HII regions, molecular-line masers, and bright IR sources. A maser receiver was used with a bandwidth sufficient for simultaneous observations of the (1,1), (2,2), and (3,3) metastable transitions near 23.7 GHz. The system temperature was about 100 K during most of the observing. Only the inner, more precise surface (22-m radius) of the telescope was illuminated by the feed. This yielded an approximately circular beam with a half-intensity width of 81 arcsec. The spectra were obtained with the Parkes digital correlator, in three 10 MHz bands of 512, 256, and 256 channels centred on the (1,1), (2,2) and (3,3) transitions respectively. The corresponding velocity resolutions after Hann smoothing were 0.5, 1.0, and 1.0 km s^{-1}. Corrections were made for the variation of antenna gain with elevation. The intensity scale was calibrated by continuum observations of M87, adopting a point-source equivalent flux density of 20 Jy, and a beam brightness temperature (T_B)/flux density ratio of 0.36.

Observations of a particularly interesting object observed in this survey, G1. 6-0.025, were published separately by Gardner *et al.* (1985). Short reports of the survey and follow-on observations of the HH46 complex have been given by Peters *et al.* (1986) and Kuiper *et al.* (1986).

To date, approximately 70 objects (out of a target of about 100) have been observed. Ammonia has been detected in 70% of these. (The detection limit in peak brightness temperatures was roughly 0.2 K.) In general the observations were made towards continuum peaks of southern HII regions. Small maps of some of the objects were also made. All three transitions were detected in nearly every case. Fits were made to determine the central velocity, full width of half-maximum, and the peak antenna temperature.

In half of the objects the optical depth in the (1,1) line was large enough (>0.5) to be accurately determined from the ratios of its hyperfine components. In another 25% the strengths of the satellite hyperfine lines were too small relative to the noise and only upper limits between 1.0 and 5.0 on the optical depth in the (1,1) line could be set. The hyperfine satellites in the (2,2) and (3,3) lines were weaker and consequently accurate optical depths were obtained less often. For the (2,2) transitions, optical depths could be determined for only 10% of the sources while in another 25% only upper limits of <5 were obtained. In the (3,3) line an accurate optical depth was only obtained for one object in our sample and in 10% the optical depth upper limit was <5.

Following Martin and Barrett (1978, equation 26), these results were used to infer the NH_3 column density in the metastable state corresponding to each line. The rotation temperatures between the (1,1) metastable state and the other two were calculated for those observations where the (1,1) optical depth could be determined. Excitation temperatures were also computed assuming a beam-filling factor of 1.0 for those lines with measurable optical depth (cf. Martin and Barrett, equations 24 and 23). Averages for the sources in the survey are given in Table 1. The lack of agreement between the excitation temperature and the rotation temperature can be removed if only a fraction of the beam is filled with ammonia.

Discussion

For the (1,1) transition there was a tendency for the inner pair and also the outer pair of satellite lines to differ slightly in intensity. This has been attributed to selective trapping in the far-IR $(2,1)\rightarrow(1,1)$ transition (Matsakis *et al.* 1977; Stutzki and Winnewisser 1985). Their model requires that the ammonia is composed of many small, high-density clumps of gas with narrower ($\sim$0.3 to 0.6 km s^{-1}) linewidths than the observed lines, which are an average of many clumps. The result of the trapping is always to reduce the intensity of the $1\rightarrow0$ and $2\rightarrow1$ satellites lines with respect to the $0\rightarrow1$ and $1\rightarrow2$ satellites, respectively (the order of the satellite transitions in terms of increasing velocity in the figures is $1\rightarrow0$, $1\rightarrow2$, $2\rightarrow1$ and $0\rightarrow1$). Where anomalies were observed, they were always in this sense.

The observed relation between the (1,1), (2,2) and (3,3) lines is not a simple one. In many sources the intensity of the (2,2) line is the smallest of the three, a non-LTE situation. It is not clear whether this can be explained by anomalous ortho-para abundance ratios, by different excitation conditions for the metastable states, or by the fact that the ortho and para species are not in equilibrium with each other. Walmsley and Ungerechts (1983) suggest that under certain conditions the (3,3) line may have inverted populations. This is supported by the fact that the (3,3) – (1,1) rotation temperature is usually larger than the (2,2) – (1,1) rotation temperature. (But note that a (3,3) – (1,1) rotation temperature calculation is not meaningful if the ortho and para species are not in equilibrium.) In addition, the (3,3) line is on average 60% wider than the (1,1) line. The upper limits on the optical depths would seem to rule out an explanation based on saturation effects. The most probable explanation for the differing linewidths is that the (1,1) and (3,3)

Table 1

Average Parameters for the Spectra in the Survey*

Parameters†	Average values All spectra		Sources with $H_2O/OH(e)$		Sources without $H_2O/OH(e)$	
Peak T_B (1,1)	2.07±0.21	(79)	1.75±0.25	(41)	0.95±0.11	(16)
(2,2)	1.41±0.15	(76)	1.23±0.18	(43)	0.60±0.09	(16)
(3,3)	1.31±0.16	(70)	1.27±0.21	(36)	0.48±0.09	(14)
FWHM (1,1)	3.54±0.15	(79)	3.70±0.18	(41)	4.20±0.41	(16)
(2,2)	4.49±0.32	(76)	4.91±0.53	(43)	4.81±0.56	(16)
(3,3)	5.95±0.31	(70)	6.54±0.39	(36)	5.35±0.87	(14)
N(NH3) (1,1)	5.9±0.5	(79)	5.9±0.6	(41)	3.7±0.7	(16)
(2,2)	6.5±0.6	(76)	5.7±0.6	(43)	3.8±0.8	(16)
(3,3)	9.2±1.0	(70)	9.5±1.3	(36)	3.0±0.7	(14)
Optical depth (1,1)	1.44±0.10	(44)	1.43±0.15	(27)	1.35±0.29	(6)
(2,2)	1.44±0.20	(8)	1.13±0.32	(4)		
FWHM(2,2)/FWHM(1,1)	1.21±0.06	(75)	1.27±0.10	(41)	1.22±0.12	(16)
FWHM(3,3)/FWHM(1,1)	1.64±0.09	(68)	1.73±0.11	(33)	1.30±0.12	(14)
T(2,2)/T(1,1)	0.70±0.03	(75)	0.76±0.04	(41)	0.65±0.06	(16)
T(3,3)/T(1,1)	0.67±0.05	(68)	0.77±0.07	(33)	0.58±0.11	(14)
T_{rot} (2,2-1,1)	24.0±1.6	(44)	24.8±2.4	(27)	20.7±1.9	(6)
(3,3-1,1)	30.4±1.1	(39)	33.0±1.8	(24)	24.6±1.6	(4)
T_{ex} (1,1)	6.6±0.5	(44)	5.7±0.5	(27)	4.6±0.4	(6)
(2,2)	6.9±1.9	(8)	9.0±3.6	(4)		
(1,1) Satellite ratios:						
$(2\rightarrow1)/(1\rightarrow2)$	0.88±0.03	(36)				
$(0\rightarrow1)/(1\rightarrow0)$	1.29±0.07	(34)				

* Numbers in parentheses are the number of spectra in the corresponding average.

† Temperatures are in K; FWHM in km s^{-1}; N in 10^{14} cm^{-2}.

emissions come from slightly different parts of the molecular cloud. On average the (2,2) line is 20% wider than the (1,1) line an effect which persists when account is taken of the different optical depths of the two lines.

The average values of the ammonia line parameters for the sources associated with H_2O or OH masers differ from the average values for sources with no known association. To show this, the objects in the survey were divided into two groups: those sources that Whiteoak (1983) lists as having H_2O masers or OH emission and those listed that do not have either. The distinction between masers and non-masers is blurred by such factors as beamwidth, sensitivity and time-variability. The average parameters for the spectra in these two groups are given in Table 1, columns 3 and 4, respectively. (Except for the well-known H_2O masers in Orion BN, W33, W44, NGC 2264, and NGC 6334, those objects that were observed for NH_3 but were not listed by Whiteoak were omitted from columns 3 and 4. The maser sources have peak antenna temperatures and column densities in the (1,1) line that are more than 50% larger than the non-masers, and in the (2,2) and (3,3) lines they are 2-3 times larger. The average intensity in the (3,3) line is the same as that in the (2,2) line for the masers, whereas it is smaller for the non-masers. The rotation temperatures for the masers also tend to be larger. The same is true for the ratio of linewidths of the (3,3) and the (1,1) lines. This division according to the presence of OH emission or H_2O masers may tend to pick objects with more compact structure, greater star formation activity, or higher kinetic temperature. One might also expect this to be reflected in 2 cm or 6 cm H_2CO optical depths (Forster and Boland 1982). However, based on the single-dish H_2CO observations of Gardner and Whiteoak (1984), no difference between the 2 cm optical depth, 6 cm optical depth, or their ratio was found between the two groups.

Figures 1-3 show some typical spectra with the fitted profiles; all are associated with H_2O/OH masers. For G12.8-0.2 (Fig. 1), the dashed line on the (1,1) spectrum shows a fit with optical depth of 0.8. The (1,1) and (2,2) widths are equal in this object but the (3,3) is 1.8 times broader. Note also that the (2,2) line is the weakest of the three. The source G344.2-0.6 (Fig. 2) shows significant optical depth (2.7) in the (1,1) line. Upper limits of <1.5 and <3.5 can be set for the (2,2) and (3,3) lines. The (1,1)

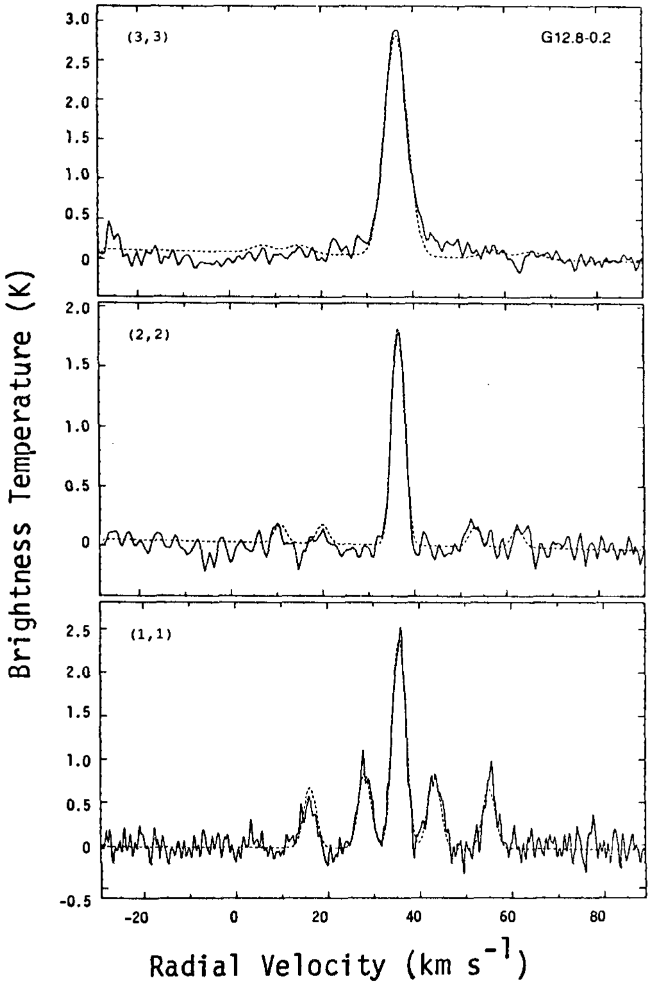

Figure 1—The three NH_3 spectra observed for G12.8-0.2 (W33). The broken lines (in all figures) show the fitted profiles.

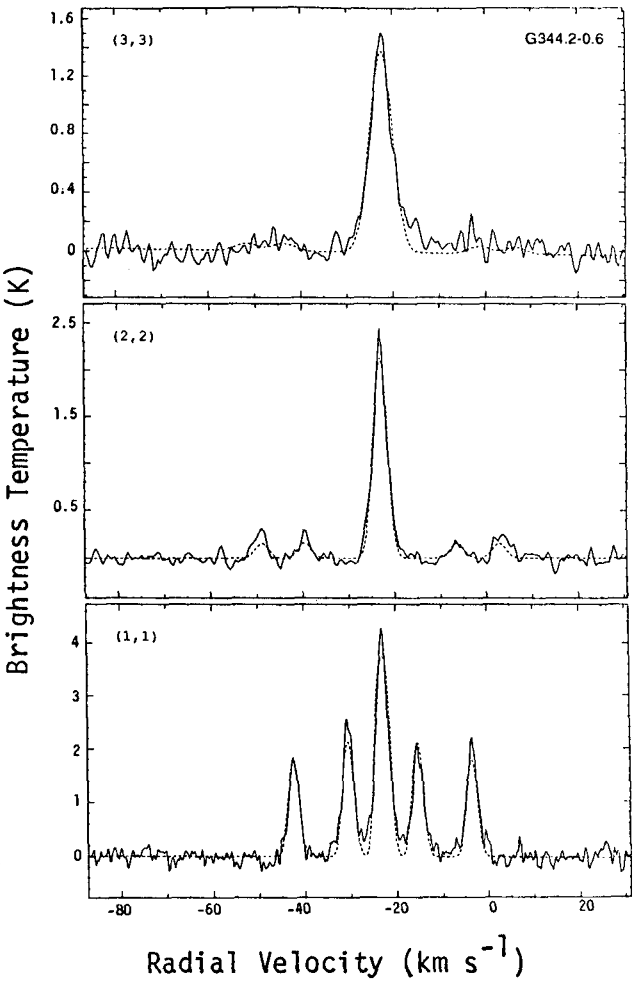

Figure 2—The three NH_3 spectra observed for G344.2-0.6.

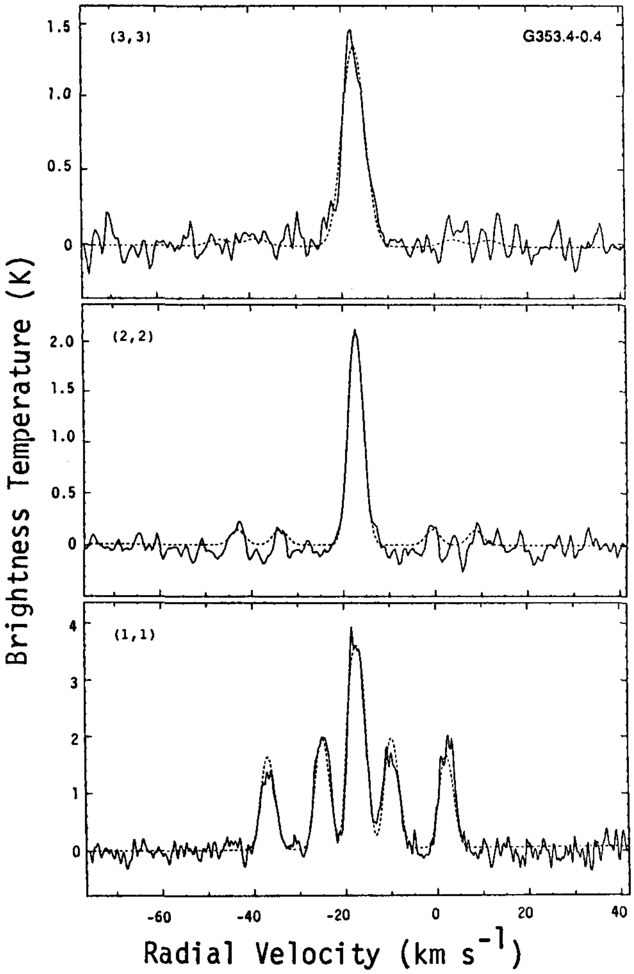

Figure 3—The three NH_3 spectra observed for G353.4-0.4.

satellites show a small deviation from their equilibrium ratios. Furthermore the (1,1) satellites (which are not appreciably broadened by the optical depth) are 1.4 times narrower than the (2,2) line and 2.2 times narrower than the (3,3) line. One explanation for this is that the source is a combination of a turbulent high-temperature core and a cooler envelope. Thus the higher excitation transitions originate in a different region from the (1,1) line. The third object, G353.4-0.4 (Fig. 3), is another example where the (1,1) hyperfine satellites suggest deviations from equilibrium ratios.

Conclusions

These results show that more work must be done in order to understand the conditions in the molecular clouds that give rise to the ammonia lines. Further observations will be made to establish how the relations between the ammonia lines change with position in the cloud and to extend the survey to other classes of objects. Observations of other ortho-ammonia lines are also needed to determine how ortho-ammonia differs from para-ammonia. Finally, comparisons of these results will be made with those obtained from other molecules.

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Cheung, A. C., Rank, D. M., Townes, C. H., Knowles, S. H. and Sullivan, W. T., 1969, *Astrophys. J.*, **157**, L13.

Dickinson, D. F., Gulkis, S., Klein, M. J., Kuiper, T. B. H., Batty, M., Gardner, F. F., Jauncey, D. L. and Whiteoak, J. B., 1982, *Astron. J.*, **87**, 1202.

Forster, J. R. and Boland, W., 1982, *Astron. Astrophys.*, **114**, 109.

Gardner, F. F. and Whiteoak, J. B., 1984, *Mon. Not. R. Astron. Soc.*, **210**, 23.

Gardner, F. F., Whiteoak, J. B., Forster, J. R., Peters, W. L. and Kuiper, T. B. H., 1985, *Proc. Astron. Soc. Aust.*, **6**, 176.

Kuiper, T. B. H., 1986, *Astron. Astrophys.* (in press).

Kuiper, T. B. H., Peters, W. L., Gardner, F. F. and Whiteoak, J. B., 1986, in *Star-Forming Regions* (Proc. IAU Symp. No. 115, held Tokyo) (eds. M. Peimbert and J. Jugaku), Reidel, Dordrecht.

Martin, R. N. and Barrett, A. H., 1978, *Astrophys. J. Suppl. Ser.*, **36**, 1.

Matsakis, D. N., Brandshaft, D., Chui, M. F., Cheung, A. C., Yngvesson, K. S., Cardiasmenos, A. G., Shanley, J. F. and Ho, P. T. P., 1977, *Astrophys. J.*, **214**, L67.

Morris, M., Polish, N., Zuckerman, B. and Kaifu, N., 1983, *Astron. J.*, **88**, 1228.

Peters, W. L., Forster, J. R., Gardner, F. F., Whiteoak, J. B. and Kuiper, T. B. H., 1986, in *Star-Forming Regions* (Proc. IAU Symp. No. 115 held Tokyo) (eds. M. Peimbert and J. Jugaku), Reidel, Dordrecht.

Stutzki, J., and Winnewisser, G., 1985, *Astron. Astrophys.*, **144**, 13.

Walmsley, C. M. and Ungerechts, H., 1983, *Astron. Astrophys.*, **122**, 164.

Whiteoak, J. B., 1983, in *Surveys of the Southern Galaxy* (eds. W. Burton and F. Israel), p. 31, Reidel, Dordrecht.

Instrumental

The Parkes Radio Telescope—1986

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Abstract: The Parkes radio telescope was commissioned in 1961, with an anticipated operational life of 15 years. Twenty-five years later the telescope has been refurbished with the aim of extending its life yet another decade or two. A major undertaking has been the complete replacement of the drive and