Part If. Thermal Molecular Emission in Star Forming Regions

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Physical conditions in the NGC 6334 molecular cloud derived from non-LTE NH_3(J,K)=(1,1) transitions

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Abstract.
The high signal-to-noise ratio of the NH_3(J,K) = (1,1) spectra from NGC 6334 have allowed at a first time a detailed study of departures from LTE conditions in this molecular cloud. Differences in the line shapes have shown that the surveyed region is composed of at least three overlapped sources in different stages of star formation. Comparison between physical parameters of NGC 6334 derived from LTE and non-LTE conditions are presented and discussed here.

1. Introduction

NGC 6334 is considered a sequential star forming region associated to an extensive molecular cloud (Cheung et al. 1978; Moran & Rodríguez 1980). The northernmost portion of NGC 6334 is presumably the less evolved region and coincides with the strongest NH_3 source in the sky. Early NH_3(J,K) = (1,1) observations were used to determine the physical conditions of the gas, revealing velocity and line-width gradients across the region (Forster et al 1987; Kuiper et al. 1995) and density, kinetic temperature and NH_3 abundance were calculated assuming LTE conditions.

However, the NH_3(J,K) = (1,1) hyperfine spectra show clear signs of non-LTE conditions which reflect on differences in the intensities of the inner and outer satellite lines (see Figure 1, left panel). They are a consequence of non-thermal population in the hyperfine states, which could be induced by selective trapping in the hyperfine transitions of NH_3(J,K) = (2,1) $\rightarrow$ (1,1) (Matsakis et al. 1977). Since this mechanism is valid only when the line-widths of these transitions are between 0.3 and 0.6 km s^{-1}, it was necessary to assume that the clouds are formed by clumps, each one producing a narrow line spectrum.

Therefore, the observed spectrum would be the superposition of individual clump spectra.

Stutzki and Winnewisser (1985) made radiative transfer calculations in order to obtain the population of the NH_3 hyperfine states. They supposed spherical clumps, which are gravitationally stable, each one producing NH_3(J,K)=(1,1) spectrum with line-widths of 0.3 km s^{-1}. The model provided the intensity of each hyperfine level as a function of the NH_3 column density, H_2 density and kinetic temperature of the clumps. This model was used to determine the physical conditions in the molecular cloud.

2. Observations and results

The observations were made during July 1996 using the Itapetinga radio telescope[1], using the ON-OFF total-power technique. The receiver front-end consisted of a circularly polarized corrugated horn connected to a cooled HEMPT. An acusto-optical spectrometer was used in the back-end, with spectral resolution of 0.74 km s^{-1}. The angular resolution was 4.2′.

The NGC 6334 region was mapped in the NH_3(J,K) = (1,1) transition (Figure 1, right panel), covering 6′ in right ascension and 12′ in declination, with a spacing of 2′. The central position of the map [$\alpha(1950) = 17^h17^m32^s$ and $\delta(1950) = -35°42'$] was also observed in the NH_3(J,K) = (2,2) transition. The contributions from each source showed in Figure 1 were determined using the procedures described at Caproni et al. (2000).

We applied the results of Stutzki and Winnewisser (1985) to the sources NGC 6334 I(N)w and NGC 6334 I(N)e in order to calculate their physical parameters. The results are given in Table 1. We also calculated the physical parameters using LTE condition and the comparison between them and those estimated from non-LTE are shown in Table 2

Table 1. The physical parameters for I(N)w and I(N)e regions calculated in non-LTE conditions. The uncertainties are given in parenthesis.

	NGC 6334 I(N)w	NGC 6334 I(N)e
NH_3 column density (10^{15} cm^{-2})	2.3(0.8)	2.4(0.8)
H_2 density of each clump (10^7 cm^{-3})	1.8(0.4)	1.4(0.7)
Kinetic temperature of each clump (K)	24.0(0.8)	24.0(1.0)
Clump diameter (10^{-3} pc)	6.7(0.8)	7.5(1.7)
Clump mass ($M_\odot$)	0.21(0.03)	0.24(0.06)
Beam filling factor	0.33(0.03)	0.10(0.01)
Number of clumps per beam	36000(10000)	9000(4000)
Spatial density of clumps (pc^{-3})	$6000 \leq \zeta_{cl} \leq 33000$	720(360)
Collision time between clumps (10^6 years)	$0.4 \leq t_{coll} \leq 2.1$	23(15)

[1]Operated by CRAAE, Centro de Radio Astronomia e Aplicações Espaciais, São Paulo, Brazil

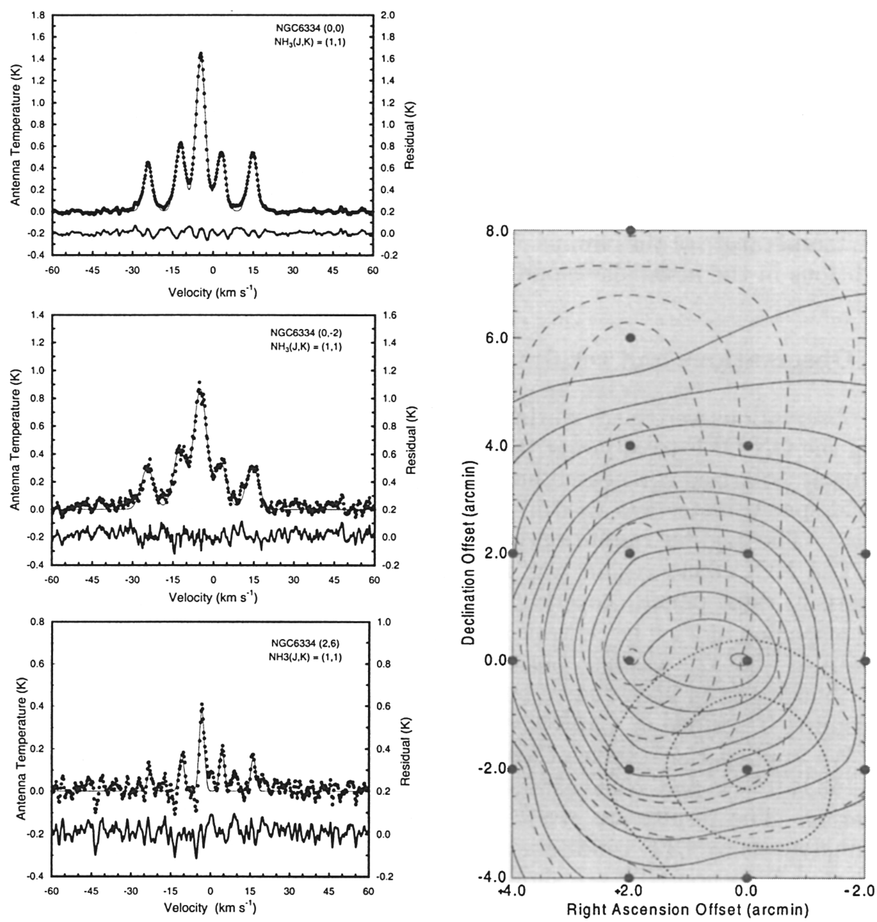

Figure 1. (*left panel*): NH_3(J,K) = (1,1) spectrum from the positions $(\Delta\alpha, \Delta\delta) = (0',0')$, $(0',-2')$ and $(2',6')$. It is also shown the Gaussian fittings and the residuals from them. (*right panel*): The superposition of the contribution of the three sources: NGC 6334 I (dotted lines), I(N)w (solid lines) and I(N)e (dashed lines). The contours are given in antenna temperature, starting at 0.1 and ending at 1.3 K (with spacing of 0.1 K). The gray points mark the observed positions.

Table 2. Comparison between the physical parameters for I(N)w, calculated in LTE and non-LTE conditions.

	LTE	non-LTE
Kinetic temperature of each clump (K)	44(8)	24.0(0.8)
Beam filling factor	0.88(0.10)	0.33(0.03)
Mean H_2 density (10^4 cm^{-3})	12(5)	$0.5 \le n \le 1.6$
NH_3 column density (10^{15} cm^{-2})	2.5(0.1)	2.3(0.8)
NH_3 abundance (10^{-9})	3.3(1.7)	6.2(2.3)

3. Conclusions

The whole area of NGC 6334 which was surveyed in this work exhibits non-LTE behaviour. Using the results from Stutzki and Winnewisser (1985), we calculated the physical parameters of NGC 6334 I(N)w and I(N)e. In spite of its relative simplicity, this numerical model was the only one developed quantitatively up to now. Besides, the existence of clumps seems to be reasonable if we consider the scenarios of star formation which are against the collapse of the molecular cloud as a whole. Considering the volume density of clumps, we believe that I(N)e is an stage of evolution earlier than I(N)w. Both regions will probably form in the future star clusters similar to that observed in IR by Tapia et al. (1996), possibly by collision between the clumps. Except for the NH_3 column density and NH_3 abundance, which depend basically on the line intensities of the NH_3(J,K) = (1,1) spectrum, the other parameters presented large discrepancies when calculated assuming LTE and non-LTE conditions.

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