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Research Note

The abundance of nitric oxide in TMC 1

M. Gerin[1,2], **Y. Viala**[2,1], **F. Casoli**[1,2]

[1] Radioastronomie Millimétrique, URA336 du CNRS, ENS, 24 Rue Lhomond, F-75231 Paris cedex 05, France
[2] DEMIRM, URA336 du CNRS, Observatoire de Meudon, F-92195 Meudon cedex, France

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Abstract. We report the detection of nitric oxide, NO, in the dark cloud TMC1; the column density is 2.7 ±0.5 10^{14} cm^{-2} resulting in a fractional abundance relative to H_2 of [NO] = 2.7 10^{-8}, a factor 8 less than in L134N, a dark cloud where NO has been previously observed.

This large difference in abundance for a simple molecule is reproduced in two types of models of interstellar chemistry :

– models at steady state with different depletions factors for C, N and O;

– models with constant depletions but including mixing processes with largely different time scales. These two effects contribute probably to enhance the chemical differences between dark clouds, and throughout an individual cloud.

Key words: line: identification – interstellar medium: clouds – general – molecules – radio lines: molecular: interstellar

1. Introduction

The recent detection of nitric oxide in both dark and warm clouds (Mac Gonagle et al., 1990, Ziurys et al. 1991, Gerin et al., 1992) showed that NO is a fairly abundant interstellar molecule, one of the most or even the most abundant nitrogenated molecule so far detected at millimeter wavelengths. The chemistry is relatively simple since NO is formed and destroyed in the neutral-neutral reactions :

$$N + OH \longrightarrow NO + H \qquad [1]$$

$$N + NO \longrightarrow N_2 + O \qquad [2]$$

which initiate the whole nitrogen chemistry. Gerin et al. (1992) and Pauzat et al. (1992) have shown using both quantum mechanics calculations of reaction [1], and interstellar chemistry calculations, that this reaction proceeds with no activation barrier. The high abundance relative to H_2 observed towards the dark cloud L134N, 2 10^{-7}, is predicted by steady state chemical models of cold dense clouds (Viala 1986; Gerin et al. 1992; Pineau des Forêts, private communication). However nitric oxide remained undetected in the well known dark cloud TMC1, with an abundance upper limit of about half the value of L134N. We decided to reobserve NO in TMC1 in order to get better constraints on the chemical abundances in this cloud known to exhibit high abundances of hydrocarbons. We present our observations in section 2, and discuss the results in section 3.

2. Observations

They were carried out in April 1992 at the IRAM 30m telescope at Pico Veleta, Spain. We searched for the two main hyperfine components of the Π^+ and Π^- bands of nitric oxide, namely the (J, F) = (3/2, 5/2) – (3/2, 1/2) transitions at 150176.458 and 150546.464 MHz (Saleck et al., 1991) towards the cyanopolyyne position in TMC1, at $RA(1950)$ = $4^h38^{min}38.6^{sec}$, $DEC(1950)$ = 25°35′45", V_{LSR} = 5.7 kms^{-1}.

At this frequency the half-power beamsize of the telescope and the main beam efficiency are 17" and $\eta_{mb} = 0.6$ respectively. The receiver was a cooled SIS mixer with SSB temperature around 180 K SSB, resulting in a system temperature in the T_A^* scale of about 480 K. We will use throughout this paper the main beam temperature scale, $T_{mb} = T_A^*/\eta_{mb}$.

We used the 256 channels 100kHz filter-bank in splitted mode, i.e. each half was centered on the frequency of one hyperfine component. The velocity resolution was 0.2 kms^{-1}, the observing procedure was position-switching.

We observed a five points map centered on the cyanopolyyne position, with 7" step. The spectra were then combined together ignoring the information on position. Thus the final spatial resolution is somewhat larger than the HPBW, 17", in order to compare these data with 3mm data taken with the same telescope (HPBW = 23" at 110 GHz). The final spectra are shown on Fig 1. The integration time is approximatively two hours for each spectrum. With a r.m.s. noise level of 35 mK and maximum temperature of 90 mK, each line is seen at the 3σ level,

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Send offprint requests to: M. Gerin

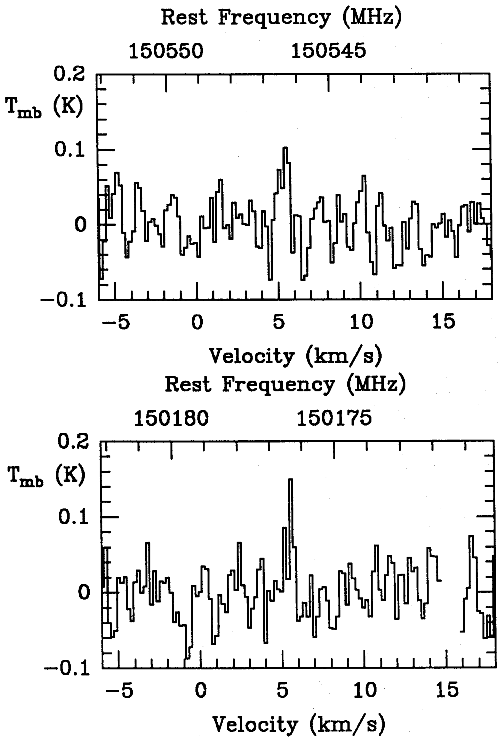

Fig. 1. Top: the $(J, F) = (3/2, 5/2) - (1/2, 3/2)$ Π^- line of nitric oxide at 150546.464 MHz towards TMC1. The temperature scale is T_{mb} in K, the lower scale is the LSR velocity, the upper scale the rest frequency in MHz. Bottom: the corresponding Π^+ line of nitric oxide at 150176.458 MHz

but the simultaneous detection of the Π^+ and Π^- lines secures the identification.

3. Results and discussion

3.1. Column density and abundance of nitric oxide

The spectra have been fitted by gaussian profiles. At the observed position in TMC1, the central velocity ranges between 5.7 kms^{-1} and 5.9 kms^{-1} for most species. The NO lines appear at the LSR velocity of 5.9 kms^{-1}, similar to that of ammonia lines (Olano et al., 1988).

To determine the column density of nitric oxide, we used the partition function and Einstein coefficients calculated by Gerin et al. (1992), assuming an excitation temperature of 10 K, similar to that of $C^{18}O$. At low temperature the partition function varies linearly with the excitation temperature, hence the total column density is also expected to scale linearly with T. The column densities in the upper level of each band are then $N_u(\Pi^+) = 2.7 \pm 0.3\ 10^{13}$ cm^{-2} and $N_u(\Pi^-) = 2.5 \pm 0.3\ 10^{13}$ cm^{-2}, resulting in a total column density of $N_{TOT}(NO) = 2.7 \pm 0.5\ 10^{14}$ cm^{-2}.

With a column density of molecular hydrogen of 10^{22} cm^{-2} at this position, the fractional abundance of NO is about $2.7\ 10^{-8}$ in TMC1, a factor eight lower than in L134N, a dark cloud of similar density and temperature.

3.2. Consequences for models of interstellar chemistry

Other molecules present large abundance difference between L134N and TMC1, with enhanced abundances of oxygenated molecules in the former cloud and of hydrocarbons in the latter. We present in Table 1 a comparison of the abundances of nitrogenated species. Relative to H_2, the decrease of the NO abundance is balanced by an enhanced abundance of HCN and HNC. Ammonia presents less variation, although it is slightly more abundant in L134N than in TMC1. Indeed, species involved in the reactions initiating the chemical scheme are expected to be more affected by variations in the physical conditions than molecules obtained after several reactions. Pineau des Forêts et al. (1991) have shown that the abundance of ammonia remains close to 10^{-8} when carbon, oxygen and nitrogen are largely depleted (by a common factor δ up to 1000), whereas the abundance of CO and N_2 decreases and that of NO presents a maximum for $\delta \simeq 10$. HCN and HNC behave in the same way as NH_3.

Table 1. Nitrogenated molecules in dark clouds

Molecule	TMC1	L134N	Ref
NO	2.7 (-8)	$\simeq$ 2.0 (-7)	(1)(2)
NH_3	$\simeq$ 4.0 (-8)	6 – 17 (-8)	(3)(4)
N_2H^+	5 (-10)	0.5 – 8 (-10)	(5)(4)
CN	$\simeq$ 3 (-8)	$\leq$ 1 (-9)	(6)
HCN	7.0 (-8)	3 – 8 (-9)	(7)(4)
HNC	10.0 (-8)	2 – 10 (-9)	(8)(4)
$HCNH^+$	1.9 (-9)	$\leq$ 4 (-9)	(7)
[NO]/[NH_3]	0.7	$\simeq$ 1.8	
[NO]/[N_2H^+]	50	200 – 390	
[NO]/[HNC]	$\simeq$ 0.3	20	

(1) This work, (2) Gerin et al. (1992), (3) Olano et al. (1988), (4) Swade 1989, (5) Irvine et al. (1987), (6) Crutcher et al. (1984), (7) Schike et al. (1991), (8) Irvine and Schloerb (1984).

Table 2. Results of steady state models

(δO, δN)	(10,1)	(10,3)	(30,3)	(3,3)
NO	7.8 (-8)	1.1 (-7)	5.6 (-8)	1.2 (-7)
NH_3	1.0 (-7)	5.8 (-8)	5.4 (-8)	7.6 (-8)
N_2H^+	52 (-9)	20 (-9)	11 (-9)	68 (-9)
CN	4.8 (-7)	2.4 (-7)	5.2 (-6)	1.7 (-8)
HCN*	6.2 (-7)	4.2 (-7)	6.2 (-6)	1.2 (-7)
$HCNH^+$	24 (-9)	22 (-9)	2.4 (-9)	34 (-9)
[NO]/[NH_3]	0.75	1.9	1.0	1.6
[NO]/[N_2H^+]	150	560	500	180
[NO]/[HCN]*	0.12	0.27	0.01	1.1

Depletions factors are given as (δO, δN) with respect to solar sytem values. Depletions δM for metals and sulfur are 10^3, except for the last model where $\delta M = 10^4$, the hydrogen density is 10^4 cm^{-3}, the temperature 10K.
* In this model HCN represents HCN + HNC.

Since neutral and ionized carbon play a key role in chemical reactions networks, forming hydrocarbons and destroying oxygenated molecules, the overabundance of hydrocarbons in TMC1 may be the consequence of an overabundance of carbon compared to oxygen.

Using the model of Viala (1986), with reactions rates modified according to recent measurements as indicated in Gerin et al. (1992), we have run steady state models with varying depletions factors for O and N, assuming a depletion factor of 10 for C and 1000 for sulfur and metals. Some results are given in Table 2 for the nitrogenated molecules tabulated in Table 1. Even though the absolute values of the observed abundance are not well reproduced by the models, the abundance ratios follow the observed trend. A TMC1 like model is obtained for $\delta N = 1$, $\delta O = 10$, while a L134N like model corresponds to $\delta N = 3$, $\delta O = 3$. As remarked by Gerin et al. (1992), these steady-state models overproduce cyanides (HCN, CN) by a factor larger than 10 for L134N; this explains the low predicted values of the [NO]/[HCN] abundance ratio.

These steady-state models rely on an oversimplified description of dark clouds. In particular, the description of the cloud as a plane-parallel slab of constant density and temperature contrasts with the inhomogeneous structure visible on CO maps. To take into account the influence of the bulk motions of the gas (e.g. turbulent motions) on the chemical abundances, Chièze et al. (1991) have investigated the response of the chemistry to variations in the mixing time and shrinking time of a cloud, composed of a dense core and a diffuse envelope. Neutral and ionized carbon from the cloud envelope are brought into the cloud core with a characteristic time scale, the mixing time, ranging from 0.1 to 1 Myrs. The cloud is also allowed to contract with a shrinking time varying in the same interval. The chemical composition of the dense core is sensitive to these mixing processes. On mixing time scales smaller than the time necessary to reach chemical equilibrium ($\simeq 10^6$ years), large amounts of neutral and ionized carbon are cycled from the envelope into the core resulting in large abundances of hydrocarbons and low abundances of oxygenated molecules other than CO. Chemical abundances typical of "early state" of models may thus be maintained for more than 1 Myr, the necessary input of carbon being provided by the mixing processes. NO is predicted at an abundance level of about $3\ 10^{-8}$, in agreement with our measurement in TMC1. On the contrary, large mixing time scales (1 Myr) have little influence on the chemical abundances since they correspond to near equilibrium chemistry. Atomic nitrogen is converted into N_2, NO, NH_3 with a corresponding decrease of the abundance of CN, HCN and HNC; the predicted abundance of nitric oxide, $2.4\ 10^{-7}$, remains close to the measured value in L134N, $2\ 10^{-7}$ (Gerin et al.,1992). As noted by Chièze et al. (1991), the chemical differences between L134N and TMC1 are rather well reproduced by their models, with no need of different elemental depletions.

4. Conclusion

We have detected nitric oxide, NO, in the dark cloud TMC1 with a column density of $2.7\ 10^{14}$ cm^{-2}, corresponding to an abundance of [NO] = $2.7\ 10^{-8}$. The abundance difference between TMC1 and L134N, a factor eight, may be explained by different O, C and N depletion factors. It is also in agreement with the prediction of chemical model including mixing processes. More observations are required to test these models, but the present chemical inhomogeneities for very simple molecules is a good argument for the need of combining chemical and hydrodynamic models of interstellar clouds.

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