A&A 426, 517–521 (2004)
DOI: 10.1051/0004-6361:20047177
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Astronomy & Astrophysics

The quest for C_2N in space

A search with the IRAM 30 m telescope towards IRC+10216

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Received 31 January 2004 / Accepted 29 June 2004

Abstract. An extensive search for the linear C_2N radical towards the circumstellar envelope IRC+10216 has been performed. Eight frequency bands of the rotational transitions J = 7/2–5/2 up to 13/2–11/2 and 17/2–15/2 up to 23/2–21/2 of the C_2N molecule including their λ-doubling components have been probed, using the IRAM 30 m telescope at Pico Veleta, Spain. However, there is no evidence for the existence of the C_2N radical towards IRC+10216. Instead, a new upper limit $N_T = 3.8 \times 10^{-12}$ cm^{-2} for the column density of C_2N was estimated. Additionally, at least ten yet unidentified lines have been found.

Key words. molecular processes – stars: AGB and post-AGB – stars: carbon – circumstellar matter

1. Introduction

The envelope of the carbon star CW Leo/IRC+10216 is well known for its rich chemistry. Already over 50 molecules have been detected in this source of which many are unsaturated carbon chains. Linear C_3N and C_5N were first observed by Guélin & Thaddeus (1977) and Guélin et al. (1998) in this source and at least C_3N has comparable column densities to molecules like HC_5N and HNC. Pauzat et al. (1991) discussed the feasibility of linear C_nN (n = 1–7) detection in space and concluded that due to the small dipole moments all C_nN members with a $^2\Pi$ electronic ground state would be poor candidates for interstellar detection. C_2N has a $^2\Pi$ electronic ground state and recent calculations by Pd & Chandra (2001) suggest a permanent electric dipole moment of ~0.425 D, which is small compared to the $^2\Sigma$ electronic ground state species C_3N and C_5N having dipole moments of 2.78 D (Botschwina et al. 1993) and 3.38 D (Botschwina 1996), respectively. Although the dipole moment of a molecule can be crucial for an astronomical detection it is also important to consider the abundance of the molecule which depends on the local environment in space. A study of the formation of C_2N was carried out by Mebel & Kaiser (2002) who found that the reactions forming CCN, CNC, and c-C_2N are strongly endothermic by 52.7, 59.0, and 99.6 kJ mol^{-1}, respectively. Hence, they concluded that C_2N cannot synthesize in cold molecular clouds where average translational temperatures are only 10–15 K. Instead, circumstellar envelopes, like IRC+10216, seem to represent ideal targets for C_2N because close to the photosphere of the central star temperatures can reach 4000 K and thus the reaction endothermicity can be overcome. In their model a neutral-neutral reaction between $C(^3P_j)$ and HCN forms a cyclic HCCN intermediate which can open up to form linear HCCN or react to $H(^2S_{1/2})$ + C_2N (or CNC and cyclo-C_2N). Guelin & Cernicharo (1991) detected HCCN in the circumstellar envelope of IRC+10216 and also looked at frequencies corresponding to C_2N transitions. They reported a hint of a 0.03 K doublet coincident with the $^2\Pi_{1/2}$ 13/2 → 11/2 transition of C_2N but could not give a conclusive positive result. Considering that the column density ratios $N_T(HC_3N/C_3N)$ and $N_T(HC_5N/C_5N)$ are of the order of 10 and assuming that this is also valid for $N_T(HC_2N/C_2N)$ an astronomical search seemed to be challenging since the parent molecule HC_2N has already been observed towards IRC+10216 with a column density of $N_T = 1.2 \times 10^{13}$ cm^{-2} (assuming a dipole moment of 3 D for HCCN). In addition, astro-chemical models by Millar et al. (2000) suggest the column density of C_2N to be 3.6×10^{12} cm^{-2}.

2. Observations

Using the molecular constants of C_2N derived by Ohshima & Endo (1995) which include their microwave data as well as the constants derived by Kakimoto & Kasuya (1982), we have recalculated the millimeter rotational spectrum of C_2N[1] and searched for transitions towards the carbon star envelope IRC+10216 at position ((Eq 1950) RA 09:45:14.8

[1] The C_2N data are now available at the Cologne Database for Molecular Spectroscopy (www.cdms.de, see Müller et al. 2001).

Article published by EDP Sciences and available at http://www.aanda.org or http://dx.doi.org/10.1051/0004-6361:20047177

Table 1. Observational parameters.

Receiver frequency (GHz)	T_{sys} [(a)] (K)	τ	Tot. integr. time (on/off) (min)	ρ [(b)]	Telescope beam *HPBW* (″)	1σ (rms) noise level (mK as T^*_A)	Band width (MHz)	Frequency resolution (MHz)
82.720	97	0.04	470	0.78	29	2	490	0.3
106.355	140	0.08	375	0.75	23	3	490	0.3
130.000	217	0.08	310	0.72	19	4	489	0.6
153.630	292	0.14	585	0.68	16	3	488	1.3
200.885	347	0.23	250	0.59	12	5	1023	1.0
224.519	393	0.29	331	0.54	11	5	1023	1.0
248.170	742	0.52	320	0.49	10	9	510	1.3
272.810	762	0.40	575	0.44	9	7	510	1.3

[(a)] Average system temperature.
[(b)] $T^*_A = \rho T_{mb}$.

Dec 13:30:40.0) close to the center of the star envelope[2]. The search was performed in September 2002 and July 2003 using the IRAM 30 m telescope at Pico Veleta, Spain. The observations focused on six 500 MHz and two 1 GHz broad frequency bands with their centers at 83 GHz, 106 GHz, 130 GHz, 154 GHz, 201 GHz, 224 GHz, 248 GHz, and 272 GHz, see Table 1, thus corresponding to the J = 7/2–5/2 up to 23/2–21/2 (except 15/2–13/2) rotational transitions of C_2N. Figure 1 shows all measured lines during this observation. The intensities are measured in T^*_A, the effective antenna temperature corrected for spillover losses and atmospheric attenuation, and are then converted to T_{mb} the main beam-averaged source brightness temperature by $T^*_A = \rho T_{mb}$, see Table 2. Here, $\rho = B_{eff}/F_{eff}(\nu)$ is the 30 m telescope beam efficiency, see Table 1. The typical line widths measured in this source are about 30 km s^{-1}. During the measurements the source had elevations between 40° and 70°. Depending on the frequency the integration time was between 4 and 9 3/4 h and for most of these bands the rms noise is 2–9 mK (in T^*_A temperature scale).

3. Data analysis

The Grenoble molecular line reduction software CLASS was used to fit the observed lines to a line profile corresponding to a shell-like emission region. The frequency scale is computed for a LSR source velocity of −27 km s^{-1}. Eight rotational transition frequencies of C_2N were examined. Four lines were found at or nearby C_2N transition frequencies, none of them have been seen before in any other survey of this source. However, these lines do not seem to belong to C_2N. The reason that we assign three of these lines to species other than C_2N[3] is the fact that the λ-doublet components of the rotational transitions of C_2N, which should be similar in intensity, are missing and that the measured intensities fit the expected intensities of the marked (⋆) species of Table 2. The remaining line at 82 736.4 MHz, although yet unidentified, is at least 5 MHz away from the calculated C_2N transitions at 82 741 to 82 744 MHz and therefore does not belong to CCN. Also other targeted C_2N lines were not detected and only upper limits for their intensities were obtained. For our calculations of the upper limit of the column density of C_2N we used the CCN dipole moment μ = 0.425 Debye calculated by Pd & Chandra (2001). The theoretical intensities of the C_2N transitions were calculated with the *dpfit* and *dpcat* program written by Herb Pickett. In the case of small optical depth the rotational temperature T_{rot} and the total molecular column density N_T [in cm^{-2}] can be determined by a least-square fit of[4]

$$\log_{10}\left(\eta \frac{\int T_{mb} d\nu}{\nu \mu^2 S}\right) = \log_{10}\left(\frac{N_T}{Q(T_{rot})}\right) - \frac{\log_{10}(e)\, E_u}{T_{rot}} \quad (1)$$

with $\int T_{mb} d\nu$ the line integral in (K km s^{-1}), μ in Debye, ν in MHz, S the line strength from Pickett et al. (1998, Eq. (2)), Q the partition function[5], E_u (in K) the energy of the upper level and $\eta = 1.669813 \times 10^{17}$ a factor to fit the units. We assumed a line width of 30 km s^{-1} and after baseline subtraction calculated the intensity by summing over various un-blended C_2N frequency positions. The large frequency range covered by these measurements allows an estimation of the upper limit for a variety of temperatures. We found that if C_2N has a rotational temperature of 15 K then $N_T \leq 3.5 \times 10^{12}$ cm^{-2}, if T_{rot} = 50 K then $N_T \leq 1.8 \times 10^{12}$ cm^{-2} and for T_{rot} = 100 K we find $N_T \leq 2.3 \times 10^{12}$ cm^{-2}.

4. Discussion

The search for C_2N towards IRC+10216 lead to a negative result. If one assumes that C_2N is produced via photodestruction of HC_2N the physical conditions and the region in which both species are detected should be similar. Guelin & Cernicharo (1991) detected HCCN towards IRC+10216 using the IRAM 30 m telescope. They found that this molecule is essentially present in the outer envelope and has a rotational temperature of T_{rot} = 12 ± 4 K. If we assume

[2] See for example the SiC_2 mapping of IRC+10216 by Gensheimer et al. (1995).

[3] These are the lines at 129 980.48 MHz, 200 914.8 MHz, and 248 190.2 MHz.

[4] The formula was derived using Eq. (1) from Turner (1991).

[5] The partition function for a temperature T has been calculated by $Q(T) = \alpha \cdot T^{\beta}$, where α and β are determined by the $Q(T_i)$ values given by the Pickett program. For the C_2N radical α = 7.1 and β = 1.2 .

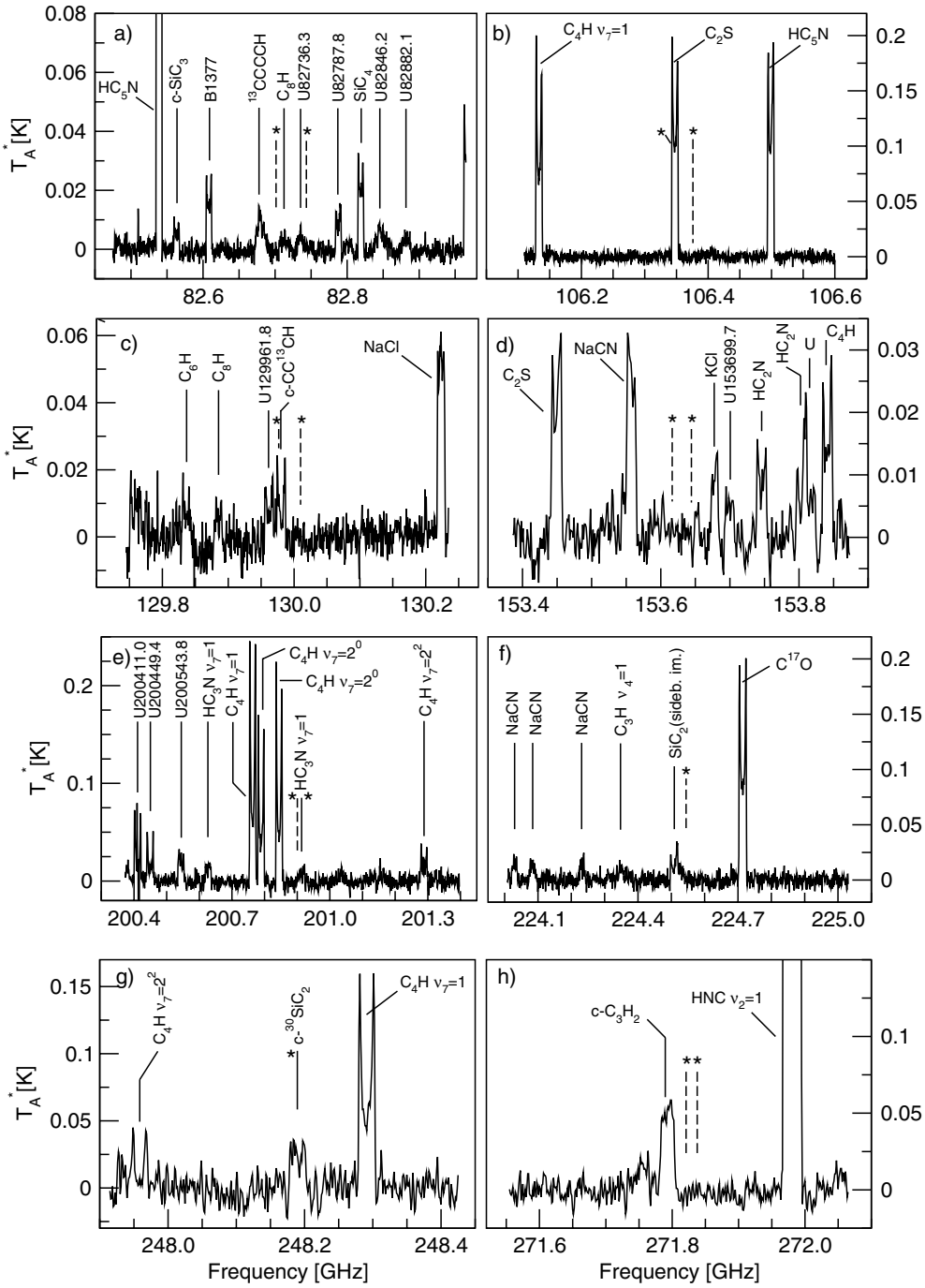

Fig. 1. Lines observed towards IRC+10216 with the IRAM 30 m telescope at a spectral resolution between 0.3 and 1.3 MHz. The frequency scale is computed for an LSR source velocity of −27 km s^{-1} and the ordinate is T_A^*, the effective antenna temperature above the atmosphere. The asterisks (⋆) mark the transition frequencies of C_2N.

the same physical conditions for C_2N as those for HCCN derived by Guelin & Cernicharo (1991), i.e. same rotational temperature and a spatial molecular distribution mainly in the outer shell so that almost no beam dilution has to be considered, we get an upper limit of N_T (T_{rot} = 12 K) = 3.8×10^{12} cm^{-2} [6]. The previously published 3σ upper limit $N_T = 5 \times 10^{13}$ cm^{-2} by Guelin & Cernicharo (1991) assumed a dipole moment of 1.3 D for C_2N and therefore has to be corrected by $N_T(0.425\ \mathrm{D}) \approx 10 \cdot N_T(1.3\ \mathrm{D})$ to be comparable with our new values. Due to the long integration time our measurements have a significantly lower noise than those of Guélin & Cernicharo and reveal many new lines even in frequency regions which have already been covered by line surveys (e.g. Cernicharo et al. 2000). Therefore the upper limit of 3.8×10^{12} cm^{-2} presented here is the most accurate value yet available. This value is of the same order of magnitude as the expected column density predicted by Millar et al. (2000).

[6] Taking the temperature uncertainty ±4 K into account we get N_T = $3.5–5.6 \times 10^{12}$ cm^{-2}.

Table 2. Observed lines.

	Molecule	Transition	Obs. frequency[a] (MHz)[b]	Theor. freq[c] (MHz)[b]	Obs-calc (km s^{-1})	$\int T_{\rm mb} {\rm d}\nu$ (K km s^{-1})[b]
	HC_5N	31–30	82 538.840(3)	82 539.3(1)	−0.7	12.14(4)
	c-SiC_3	$7_{2,5}$–$6_{2,4}$	82 563.3(11)	82 563.525(5)	−1.0	0.23(32)
	B1377[d]	30–29	82 608.1(4)			0.65(32)
	^{13}CCCH	$N_J = 9_{9,5}$–$8_{8,5}$	82 679.8(101)	82 680.9−82 688.4		0.55(42)
	C_8H ($\Pi_{3/2}$)	e/f 69.5–68.5	82 712.4(30)	82 713.4−82 716.1		0.18(37)
⋆	U82736.3		82 736.3(3)			0.17(3)
	U82787.8		82 787.8(6)			0.37(32)
	SiC_4	27–26	82 819.02(3)	82 819.118(4)	−0.34	0.82(3)
	U82846.2		82 846.2(34)			0.42(51)
	U82882.1		82 882.1(30)			0.23(37)
	C_4H $\nu_7 = 1$ ($\Pi_{3/2}$)	f 11.5–10.5	106 133.02(3)	106 133.37(9)	−0.99	4.15(19)
	C_2S	$N_J = 8_9$–7_8	106 347.55(3)	106 347.73(2)	−0.51	4.89(19)
	HC_5N	40–39	106 498.78(3)	106 499.4(3)	−1.7	5.04(19)
	C_6H	47–46	129 836.5(2)	129 836.13(7)	0.3	0.39(6)
	C_8H ($\Pi_{1/2}$)	e/f 110.5–109.5	129 884.6(3)	129 885.7−129 889.7		0.29(6)
	U129961.8		129 961.8(1)			0.45(6)
⋆	c-CC^{13}CH	$3_{1,3}$–$2_{1,2}$	129 980.48(6)	129 982.7−129 984.6		0.48(3)
	NaCl	10–9	130 223.43(3)	130 223.64(5)	−0.76	1.87(3)
	C_2S	$N_J = 12_{11}$–11_{10}	153 449.12(6)	153 449.77(1)	−1.27	0.98(9)
	NaCN	$10_{0,10}$–$9_{0,9}$	153 556.7(5)	153 557.9(1)	−2.2	1.13(9)
	KCl	20–19	153 677.9(5)	153 677.5(1)	0.7	0.29(9)
	U153699.7		153 699.7(9)			0.20(9)
	HC_2N	$N_J = 7_8$–6_7	153 745.9(4)	153 746.21(1)	−0.7	0.43(9)
	HC_2N	$N_J = 7_7$–6_6	153 803.000[e]	153 804.03(2)	−2.00	0.46(12)
	U153816.0		153 816.000[e]			0.43(12)
	C_4H, $\nu = 2^2$ ($\Delta_{3/2}$)	15.5–14.5	153 841.1(2)	153 841.57(6)	−0.9	0.75(9)
	U200411.0		200 411.000[e]			1.35(13)
	U200449.4		200 449.4(4)			1.14(23)
	U200543.8		200 543.8(9)			1.02(51)
	HC_3N $\nu_7 = 1$	22–21	200 625.8(25)	200 626.933(3)	−1.6	0.76(25)
	C_4H $\nu_7 = 1$ ($\Pi_{3/2}$)	f 21.5–20.5	200 763.52(8)	200 763.92(3)	−0.6	6.34(25)
	C_4H $\nu_7 = 2^0$	$N_J = 21_{21.5}$–$20_{20.5}$	200 789.1(1)	200 789.38(3)	−0.4	3.81(25)
	C_4H $\nu_7 = 2^0$	$N_J = 21_{20.5}$–$20_{19.5}$	200 844.2(1)	200 844.80(3)	−0.9	4.82(51)
⋆	HC_3N $\nu_7 = 1$	22–21	200 914.8(137)	200 913.942(3)	1.3	0.51(51)
	C_4H $\nu_7 = 2^2$ ($\Delta_{5/2}$)	20.5–19.5	201 288.4(1)	201 288.37(3)	0.0	0.94(8)
	NaCN	$14_{1,13}$–$13_{1,12}$	224 029.9(3)	224 030.7(3)	−1.1	0.57(7)
	NaCN	$14_{2,12}$–$13_{2,11}$	224 083.5(11)	224 082.7(4)	1.3	0.59(7)
	NaCN	$15_{1,15}$–$14_{1,14}$	224 232.8(7)	224 232.2(4)	0.8	0.47(22)
	C_3H, $\nu_4 = 1$	$N_J = 10_{9.5}$–$9_{8.5}$	224 355.1(12)	224 354.2(2)	1.2	0.47(22)
	SiC_2 (sideband im.)		224 508.770[e]	232 534.067(6)		
	C^{17}O	2–1	224 713.81(3)	224 714.385(3)	−0.50	6.34(7)
	C_4H $\nu_7 = 2^2$ ($\Delta_{3/2}$)	25.5–24.5	247 958.1(4)	247 959.54(3)	−1.8	0.99(25)
⋆	c-$^{30}SiC_2$	$11_{2,10}$–$10_{2,9}$	248 190.2(6)	248 188.9(33)	1.6	1.48(25)
	C_4H $\nu_7 = 1$ ($\Pi_{3/2}$)	f 26.5–25.5	248 291.37(7)	248 291.64(3)	−0.33	5.02(17)
	c-C_3H_2	$22_{15,8}$–$22_{14,9}$	271 793.0(2)	271 795.23(5)	−2.5	2.74(10)
	HNC $\nu_2 = 0$	$J_l = 3_{0e}$–2_{0e}	271 980.40(3)	271 981.14(2)	−0.82	75.80(76)

Notes:

[a] Rest frequencies (assuming a source LSR velocity of –27 km s^{-1}) in IRC+10216.

[b] The numbers in parenthesis are the estimated uncertainties (1σ).

[c] Frequencies are taken from Müller et al. (2001), Pickett et al. (1998) and the Lovas catalog.

[d] B1377 denotes an un-identified species with the rotational constant of 1376.869 MHz as it appears in Kawaguchi et al. (1995).

[e] Manually fitted.

⋆ Denotes a partial overlap or blend of a line with a C_2N transition frequency within a ±15 km s^{-1} linewidth tolerance.

Acknowledgements. We thank J. Cernicharo for his helpful comments and suggestions on the manuscript. We also are grateful to the IRAM 30 m staff for their hospitality and assistance. This work was supported by the *Deutsche Forschungsgemeinschaft, DFG* project number SFB 494 and IRAM.

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