

The quest for C₂N in space

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

G. W. Fuchs¹, U. Fuchs¹, T. F. Giesen¹, and F. Wyrowski²,

¹ I. Physikalisches Institut, Universität zu Köln, Zùlpicher Str. 77, 50937 Köln, Germany
e-mail: [fuchs;feldt]@ph1.uni-koeln.de

² Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany
e-mail: wyrowski@mpi.fr-bonn.mpg.de

Received 31 January 2004 / Accepted 29 June 2004

Abstract. An extensive search for the linear C₂N 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 C₂N 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 C₂N radical towards IRC+10216. Instead, a new upper limit $N_T = 3.8 \times 10^{-12} \text{ cm}^{-2}$ for the column density of C₂N 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 C₃N and C₅N were first observed by Guélin & Thaddeus (1977) and Guélin et al. (1998) in this source and at least C₃N has comparable column densities to molecules like HC₅N 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 ²Π electronic ground state would be poor candidates for interstellar detection. C₂N has a ²Π 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 ²Σ electronic ground state species C₃N and C₅N 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 C₂N was carried out by Mebel & Kaiser (2002) who found that the reactions forming CCN, CNC, and c-C₂N are strongly endothermic by 52.7, 59.0, and 99.6 kJ mol⁻¹, respectively. Hence, they concluded that C₂N 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 C₂N 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}) + C₂N (or CNC and cyclo-C₂N). Guelin & Cernicharo (1991) detected HCCN in the circumstellar envelope of IRC+10216 and also looked at frequencies corresponding to C₂N transitions. They reported a hint of a 0.03 K doublet coincident with the ²Π_{1/2} 13/2 → 11/2 transition of C₂N but could not give a conclusive positive result. Considering that the column density ratios $N_T(\text{HC}_3\text{N}/\text{C}_3\text{N})$ and $N_T(\text{HC}_5\text{N}/\text{C}_5\text{N})$ are of the order of 10 and assuming that this is also valid for $N_T(\text{HC}_2\text{N}/\text{C}_2\text{N})$ an astronomical search seemed to be challenging since the parent molecule HC₂N has already been observed towards IRC+10216 with a column density of $N_T = 1.2 \times 10^{13} \text{ cm}^{-2}$ (assuming a dipole moment of 3 D for HCCN). In addition, astro-chemical models by Millar et al. (2000) suggest the column density of C₂N to be $3.6 \times 10^{12} \text{ cm}^{-2}$.

2. Observations

Using the molecular constants of C₂N 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 C₂N¹ and searched for transitions towards the carbon star envelope IRC+10216 at position ((Eq 1950) RA 09:45:14.8

¹ The C₂N data are now available at the Cologne Database for Molecular Spectroscopy (www.cdms.de, see Müller et al. 2001).

Table 1. Observational parameters.

Receiver frequency (GHz)	$T_{\text{sys}}^{(a)}$ (K)	τ	Tot. integr. time (on/off) (min)	$\rho^{(b)}$	Telescope beam <i>HPBW</i> (")	1 σ (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) $T_A^* = \rho T_{\text{mb}}$.

Dec 13:30:40.0) close to the center of the star envelope². 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 C₂N. 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 $T_A^* = \rho T_{\text{mb}}$, see Table 2. Here, $\rho = B_{\text{eff}}/F_{\text{eff}}(\nu)$ 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 C₂N were examined. Four lines were found at or nearby C₂N 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 C₂N. The reason that we assign three of these lines to species other than C₂N³ is the fact that the λ -doublet components of the rotational transitions of C₂N, 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 C₂N transitions at 82 741 to 82 744 MHz and therefore

does not belong to CCN. Also other targeted C₂N 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 C₂N we used the CCN dipole moment $\mu = 0.425$ Debye calculated by Pd & Chandra (2001). The theoretical intensities of the C₂N 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 of⁴

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

with $\int T_{\text{mb}} dv$ 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 function⁵, 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 C₂N 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 C₂N has a rotational temperature of 15 K then $N_{\text{T}} \leq 3.5 \times 10^{12}$ cm⁻², if $T_{\text{rot}} = 50$ K then $N_{\text{T}} \leq 1.8 \times 10^{12}$ cm⁻² and for $T_{\text{rot}} = 100$ K we find $N_{\text{T}} \leq 2.3 \times 10^{12}$ cm⁻².

4. Discussion

The search for C₂N towards IRC+10216 lead to a negative result. If one assumes that C₂N is produced via photo-destruction of HC₂N 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 $T_{\text{rot}} = 12 \pm 4$ K. If we assume

² See for example the SiC₂ 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 C₂N radical $\alpha = 7.1$ and $\beta = 1.2$.

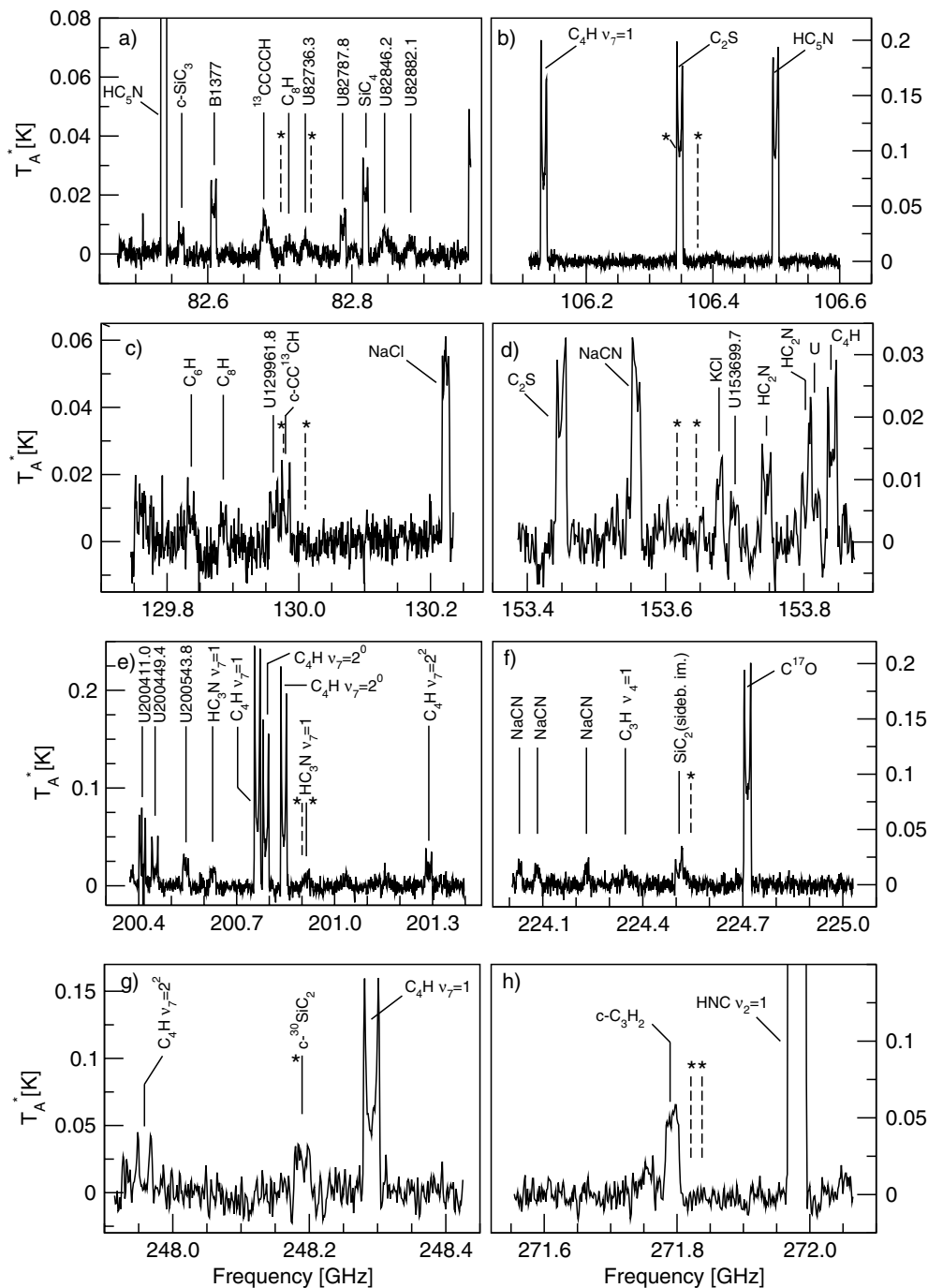


Fig. 1. Lines observed towards IRC+10216 with the IRAM 30 m telescope at a spectral resolution between 0.3 and 1.3 MHz. The frequency scale is computed for an LSR source velocity of -27 km s^{-1} and the ordinate is T_A^* , the effective antenna temperature above the atmosphere. The asterisks (★) mark the transition frequencies of C₂N.

the same physical conditions for C₂N as those for HCCN derived by Guélin & 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 ($T_{\text{rot}} = 12 \text{ K}$) = $3.8 \times 10^{12} \text{ cm}^{-2}$ ⁶. The previously published 3σ upper limit $N_T = 5 \times 10^{13} \text{ cm}^{-2}$ by Guélin & Cernicharo (1991) assumed a dipole moment

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

of 1.3 D for C₂N and therefore has to be corrected by $N_T(0.425 \text{ D}) \approx 10 \cdot N_T(1.3 \text{ D})$ 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 $3.8 \times 10^{12} \text{ cm}^{-2}$ 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).

Table 2. Observed lines.

Molecule	Transition	Obs. frequency ^a (MHz) ^b	Theor. freq ^c (MHz) ^b	Obs-calc (km s ⁻¹)	$\int T_{\text{mb}}d\nu$ (K km s ⁻¹) ^b
HC ₅ N	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 ₈ H ($\Pi_{3/2}$)	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 ₄ H $\nu_7 = 1$ ($\Pi_{3/2}$)	f 11.5–10.5	106 133.02(3)	106 133.37(9)	–0.99	4.15(19)
C ₂ S	$N_J = 8_9$ –7 ₈	106 347.55(3)	106 347.73(2)	–0.51	4.89(19)
HC ₃ N	40–39	106 498.78(3)	106 499.4(3)	–1.7	5.04(19)
C ₆ H	47–46	129 836.5(2)	129 836.13(7)	0.3	0.39(6)
C ₈ H ($\Pi_{1/2}$)	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 ₂ S	$N_J = 12_{11}$ –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 ₂ N	$N_J = 7_8$ –6 ₇	153 745.9(4)	153 746.21(1)	–0.7	0.43(9)
HC ₂ N	$N_J = 7_7$ –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 ₄ H, $\nu = 2^2$ ($\Delta_{3/2}$)	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 ₃ N $\nu_7 = 1$	22–21	200 625.8(25)	200 626.933(3)	–1.6	0.76(25)
C ₄ H $\nu_7 = 1$ ($\Pi_{3/2}$)	f 21.5–20.5	200 763.52(8)	200 763.92(3)	–0.6	6.34(25)
C ₄ H $\nu_7 = 2^0$	$N_J = 21_{21,5}$ –20 _{20,5}	200 789.1(1)	200 789.38(3)	–0.4	3.81(25)
C ₄ H $\nu_7 = 2^0$	$N_J = 21_{20,5}$ –20 _{19,5}	200 844.2(1)	200 844.80(3)	–0.9	4.82(51)
★ HC ₃ N $\nu_7 = 1$	22–21	200 914.8(137)	200 913.942(3)	1.3	0.51(51)
C ₄ H $\nu_7 = 2^2$ ($\Delta_{5/2}$)	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 ₃ H, $\nu_4 = 1$	$N_J = 10_{9,5}$ –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 ₄ H $\nu_7 = 2^2$ ($\Delta_{3/2}$)	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 ₄ H $\nu_7 = 1$ ($\Pi_{3/2}$)	f 26.5–25.5	248 291.37(7)	248 291.64(3)	–0.33	5.02(17)
c-C ₃ H 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 (1 σ).^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 C₂N 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.

References

- Botschwina, P. 1996, *Chem. Phys. Lett.*, 259, 627
Botschwina, P., Horn, M., Flugge, J., & Seeger, S. 1993, *J. Chem. Soc. Faraday Trans.*, 89, 2219
Cernicharo, J., Guélin, M., & Kahane, C. 2000, *A&AS*, 142, 181
Gensheimer, P., Likkell, L., & Snyder, L. 1995, *ApJ*, 439, 445
Guélin, M., & Cernicharo, J. 1991, *A&A*, 244, L21
Guélin, M., Neining, N., & Cernicharo, J. 1998, *A&A*, 335, L1
Guélin, M., & Thaddeus, P. 1977, *ApJ*, 212, L81
Kakimoto, M., & Kasuya, T. 1982, *J. Mol. Spectrosc.*, 94, 380
Kawaguchi, K., Kasai, Y., Ishikawa, S.-I., & Kaifu, N. 1995, *PASJ*, 47, 853
Mebel, A. M., & Kaiser, R. I. 2002, *ApJ*, 564, 787
Millar, T., Herbst, E., & Bettens, R. 2000, *MNRAS*, 316, 195
Müller, H., Thorwirth, S., Roth, D., & Winnewisser, G. 2001, *A&A*, 370, L49
Ohshima, Y., & Endo, Y. 1995, *J. Mol. Spectrosc.*, 172, 225
Pauzat, F., Ellinger, Y., & McLean, A. 1991, *ApJ*, 369, L13
Pd, R., & Chandra, P. 2001, *J. Chem. Phys.*, 114, 1589
Pickett, H., Poynter, R., Cohen, E., et al. 1998, *J. Quant. Spectrosc. Radiat. Transfer*, 60, 883
Turner, B. E. 1991, *ApJS*, 76, 617