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Physical and Chemical Conditions in the Dust Formation Zone of IRC+10216

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Abstract. A mid-infrared high-resolution spectral survey of the source IRC+10216 (CW Leo) has been carried out between 11 and 14 μm. A large number of lines of C_2H_2 and HCN and their most abundant isotopologues, have been identified. Lines involving high-energy ro-vibrational levels allow an accurate derivation of the physical and chemical conditions in the innermost envelope. We have developed a radiative transfer model capable of fitting the observed lines satisfactorily. The fit of more than 200 ro-vibrational lines allowed us to get the kinetic, vibrational and rotational temperatures and the abundances of the C_2H_2 and HCN between 1 and 300 R_*.

Keywords. instrumentation: spectrographs — line: identification — line: profiles — radiative transfer — stars: AGB and post-AGB — stars: carbon — stars: mass loss — surveys — techniques: spectroscopic

1. Introduction

IRC+10216 is a carbon-rich AGB star surrounded by a circumstellar envelope (CSE) at $\simeq$180 pc from the Earth. The low stellar temperature, $\simeq$2300 K, and a high mass-loss rate of $\simeq 2\times10^{-5}$ $M_\odot$ yr^{-1} (Keady *et al.* 1988; Cernicharo *et al.* 1999), turn the CSE into an environment friendly to high molecular abundances. By now, 60 different molecular species have been detected, with CO the most abundant species with a fractional abundance of 8×10^{-4}, C_2H_2 with 8×10^{-5} and HCN with 4×10^{-5} (Keady & Ridgway 1993; Cernicharo *et al.* 1996). The dust grains, assumed to consist of amorphous graphite and refractory species (e.g., SiC), condense in two different shells at $\simeq$5 R_* and $\simeq 15-20$ R_* (Keady *et al.* 1988; this work). The acceleration, produced by the interaction between the dust and the stellar radiation and other phenomena, produces a complex velocity profile equal to 1–5 km s^{-1} ($1 \leqslant r/R_* \lesssim 5$), 11 km s^{-1} ($5 \lesssim r/R_* \lesssim 15-20$) and 14 km s^{-1} ($15-20 \lesssim r/R_*$) (Keady *et al.* 1988; Ridgway & Keady 1988; this work).

2. Observations, Detections and Results

The observations were obtained in 2002 December with the 3 m optimized infrared telescope IRTF in Hawaii and the TEXES spectrometer (Lacy *et al.* 2001), working between 5 and 25 μm with a power resolution $R\sim10^5$.

In the observed spectrum we have identified many lines corresponding to the R and Q branches of ro-vibrational transitions ν_5, $\nu_4+\nu_5-\nu_4$, $2\nu_5-\nu_5$, $2\nu_4+\nu_5-2\nu_4$, $\nu_4+2\nu_5-\nu_4+\nu_5$ and $3\nu_5-2\nu_5$ for C_2H_2, ν_2 and $2\nu_2-\nu_2$ for HCN and some of them for their isotopologues. Many lines remain still unidentified (see Figure 1).

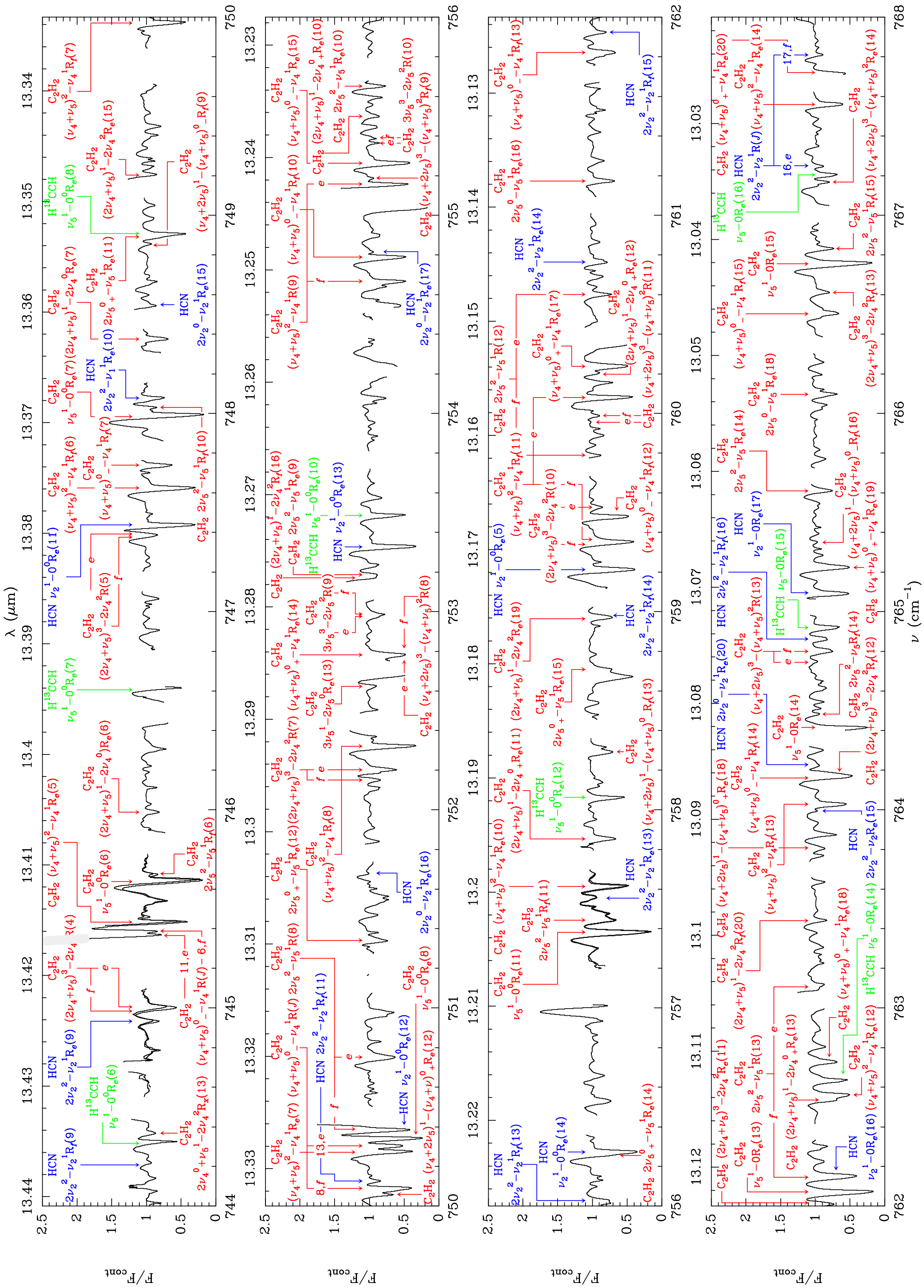

Figure 1. The 744 to 768 cm^{-1} spectrum observed toward IRC+10216.

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The main results derived through the fitting of the lines show that the abundances of C_2H_2 and HCN reach their maxima in the middle region (between the two dust formation shells) and keep their values nearly constant as the kinetic chemistry models predict and the outer CSE observations suggest. The derived C_2H_2 abundances suggest a possible condensation of this species onto the dust grains beyond the first dust formation shell, explaining the last acceleration process at $15-20$ R_*. The vibrational levels of C_2H_2 and HCN are out of LTE, supporting the existence of a radiative pumping mechanism in the middle region related to the near-IR radiation field (Cernicharo *et al.* 1999). The deviations from LTE depend on the molecule, being very different for C_2H_2 and HCN because of their own radiative selection rules (e.g., C_2H_2 $\nu_4\,(\pi_g) \rightarrow \mathrm{G.S.}(\sigma_g^+)$ is forbidden). While most of the vibrational levels of C_2H_2 are at LTE only in the innermost envelope, two of the three studied vibrational transitions of HCN present a marked non-LTE behavior, even near the star. The rotational levels seem to follow the LTE condition for $J \lesssim 20$ for C_2H_2 with good accuracy except for few lines which present non-thermal populations, probably produced by overlaps with other lines.

We derive the following velocity profile, v_e, kinetic temperature, T_K, and C_2H_2 and HCN abundances, $x\,(C_2H_2)$, x(HCN):

$$v_e\,(\mathrm{km/s}) = \left\{\begin{array}{rr} 5, & 1 \leqslant r/R_* < 5.2 \\ 11, & 5.2 \leqslant r/R_* < 21.2 \\ 14.5, & 21.2 \leqslant r/R_* < 300 \end{array}\right\}$$

$$T_K = \left\{\begin{array}{lr} 2330\left(\frac{1}{r}\right)^{0.58}, & 1 \leqslant r/R_* < 5.2 \\ 900\left(\frac{5.2}{r}\right)^{0.58}, & 5.2 \leqslant r/R_* < 21.2 \\ 400\left(\frac{21.2}{r}\right)^{1.00}, & 21.2 \leqslant r/R_* < 300 \end{array}\right\}$$

$$x\,(C_2H_2,\,\mathrm{HCN}) = \left\{\begin{array}{llr} 7.5\times10^{-6}, & 2.5\times10^{-5}, & 1 \leqslant r/R_* < 5.2 \\ 8.0\times10^{-5}, & 4.9\times10^{-5}, & 5.2 \leqslant r/R_* < 21.2 \\ 8.0\times10^{-5}, & 4.9\times10^{-5}, & 21.2 \leqslant r/R_* < 300 \end{array}\right\}$$

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References

Cernicharo, J., *et al.* 1996, *A&A* 315, L201
Cernicharo, J., *et al.* 1999, *Ap. J.* 526, L41
Keady, J.J., Hall, D.N.B., & Ridgway, S.T. 1988, *Ap. J.* 326, 832
Keady, J.J. & Ridgway, S.T. 1993, *Ap. J.* 406, 199
Lacy, J.H., Richter, M.J., Greathouse, T.K., Jafee, D.T., & Zhu, Q. 2001, *PASP* 144, 153
Ridgway, S.T. & Keady, J.J. 1988, *Ap. J.* 326, 843

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