HIGH-RESOLUTION 3μm SPECTROSCOPY OF EXTREME CARBON STARS

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ABSTRACT. We have used the Cassegrain-focus Fourier Transform Spectrometer of the Canada-France-Hawaii Telescope to record high-resolution (0.03 cm^{-1}), high signal-to-noise ratio spectra of the extreme carbon stars IRC+10°216 and CIT6 in the 2850-3100 cm^{-1} region. Upper limits were obtained for the column densities of silicon nitride (2-0 band of the A-X system), ethylene (ν_{11} fundamental band at ν_0 = 2988.7 cm^{-1}), and ethane (ν_7 fundamental band at ν_0 = 2985.4 cm^{-1}).

RESULTS

1. Silicon Nitride (SiN)

In IRC+10°216, for a linewidth of 0.09 cm^{-1} and an assumed temperature of 175K [cf. SiH_4, Goldhaber and Betz (1984)], the absence of 0.5 percent absorption (S/N≈300) corresponds to a 3σ upper limit for the column density of SiN that is 7×10^{13} cm^{-2}. We have calculated the Franck-Condon factor to be 0.110 for the 2-0 band of the A-X system (Foster et al., 1985) and have used the r-centroid approximation to estimate the transition dipole matrix element = 0.768 D at $\bar{r}$ = 1.515 Å from ab-initio MRD-CI calculations by P. Bruna (private comm. 1985). The maximum populated level at T=175K is J=8.5 (for which the Honl-London factor was calculated to be 2.5). Recently, the possibility has been raised by Hirota (private comm. 1986) that the 3.3 μm band measured by Foster et al. is, in fact, the 1-0 band. This is not expected to alter our conclusions in any substantial way.

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2. Ethylene (C_2H_4)

In the 3.3 μm ν_{11} fundamental band the strongest single unobscured line is $^qP_0(14)$ or $13_{0,13}$-$14_{0,14}$ at 2964.14 cm^{-1}, for which the line absorption coefficient is 3.54×10^{-2} $torr^{-1}$ cm^{-1} at 295K (Pine 1980). Adopting 0.5 percent absorption as the minimum detectability and correcting for the linewidth of IRC+10°216 (0.09 cm^{-1}), $N(C_2H_4) \lesssim 6 \times 10^{16}$ cm^{-2}.

We have measured the absorption spectrum of the ν_{11} band of C_2H_4 at 300K and 0.09 cm^{-1} resolution using a BOMEM FTS in our lab to facilitate comparison with the CFHT spectra of IRC+10°216 and CIT6. This had enabled us to estimate the absorption coefficient of a strong blended feature at 2962.5 cm^{-1} (the strongest non-obscured feature in the ν_{11} band) to be 8.91×10^{-2} $torr^{-1}$ cm^{-1} at 300K. This leads to a slightly more stringent upper limit for $N(C_2H_4)$, namely $\lesssim 3 \times 10^{16}$ cm^{-2}.

C_2H_4 was reported to be present in the envelope of IRC+10°216 by Betz (1981) who used heterodyne spectroscopy with an N_2O laser to observe the 5_{15}-5_{05} and 1_{10}-0_{00} transitions of the ν_7 band (10.5 μm). At this wavelength the effective path length for absorption-line observations through the stellar envelope is longer than at 3.3 μm. A column density $N(C_2H_4) \sim 10^{16}$ cm^{-2} was reported. We have measured the absorption coefficients for the individual lines of C_2H_4 reported by Betz in our lab with a diode laser apparatus and with a BOMEM FTS rather than rely on the absorption coefficient of the entire band (Golike et al., 1956). This is necessary since the ν_7 band is Coriolis coupled to ν_{10}. The 5_{15}-5_{05} line at 951.7 cm^{-1} has α_{max} = 0.28 $torr^{-1}$ cm^{-1} and the 1_{10}-0_{00} line at 954.8 cm^{-1} has α_{max} = 0.18 $torr^{-1}$ cm^{-1} at 300K. Our revised column densities for the lines reported by Betz are thus ≈ 4 and 2×10^{16} cm^{-2}, respectively. Hence our non-detection of C_2H_4 in IRC+10°216 seemed somewhat surprising since our 3μm upper limits are comparable to the (corrected) column densities of Betz (1981). However, at this meeting Betz (1987) reported the likely detection of as many as 6 transitions of C_2H_4 (ν_7 band) consistent with a column density of $\approx 5 \times 10^{15}$ cm^{-2}.

3. Ethane (C_2H_6)

In the 3.3 μm ν_7 band of C_2H_6 the strongest unobscured rotationally assigned line is $^rQ_2(10)$ or 10_3-10_2 at 2993.460 cm^{-1}, for which the line absorption coefficient is 0.58 $torr^{-1}$ cm^{-1} (Pine and Lafferty 1982). Again, the non-detection of a 0.5 percent absorption line in IRC+10°216 leads to $N(C_2H_6) \lesssim 2 \times 10^{16}$ cm^{-2} at 300K, where we have adopted a linewidth of 0.09 cm^{-1} and corrected for the temperature used in Pine and Lafferty's experiment.

We have measured the absorption spectrum of the ν_7 band of C_2H_6 at 300K and 0.09 cm^{-1} resolution with a BOMEM FTS in our lab, to facilitate comparison with the CFHT spectra of IRC+10°216 and CIT6. This has enabled us to estimate the absorption coefficient of a strong

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blended feature at 2990.1 cm^{-1} (the strongest non-obscured feature in the ν_7 band) to be 1.09 $torr^{-1}$ cm^{-1} at 300K. This enables us to quote a much more stringent upper limit for $N(C_2H_6)$ in IRC+10°216, namely $\lesssim 4 \times 10^{15}$ cm^{-2}.

TABLE 1

UPPER LIMITS TO COLUMN DENSITIES OF MOLECULES IN CIRCUMSTELLAR ENVELOPES OF EXTREME CARBON STARS AT 3.3 MICRONS

STAR	MOLECULE	BAND	T (ASSUMED)	3-σ UPPER LIMITS TO COLUMN DENSITY N	NOTES
IRC+10°216	SiN	2-0, $A^2\Pi_i$-$X^2\Sigma^+$	175K	7×10^{13} cm^{-2}	1
	C_2H_4	ν_{11}	300	3×10^{16} for blend 6×10^{16} for $^qP_0(14)$	2
	C_2H_6	ν_7	300	4×10^{15} for blend 2×10^{16} for $^rQ_2(10)$	
CIT6	SiN	2-0, $A^2\Pi_i$-$X^2\Sigma^+$	175	4×10^{14} cm^{-2}	
	C_2H_4	ν_{11}	300	2×10^{17} for blend	
	C_2H_6	ν_7	300	2×10^{16} for blend	

NOTES:

1 $< 2.7 \times 10^{12}$ cm^{-2} (Ziurys et al., 1984), radio, N=2→1, 2.!3 arc beam.
2 $\approx 2\text{-}4 \times 10^{16}$ cm^{-2} (Betz 1981), 10.5 μm absorption (ν_7);
$\approx 5 \times 10^{15}$ cm^{-2} (Betz 1987), 10.5 μm absorption (ν_7).

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