OBSERVATIONS OF INTERSTELLAR MOLECULES WITH THE INTERNATIONAL ULTRAVIOLET EXPLORER

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The ultraviolet spectra of 25 early-type stars have been obtained with the International Ultraviolet Explorer observatory. Bands of the 4th-positive system of interstellar CO are seen towards 12 of these stars. Spectra of HD46223 have been examined for interstellar lines of CH, C_2, CH_2, OH, HCl, and H_2O.

INTRODUCTION

Electronic transitions of many simple interstellar molecules lie in the wavelength region λλ1150-3200 Å which is accessible to the spectrographs of the International Ultraviolet Explorer satellite (IUE). Measurements of the abundances of molecules in diffuse interstellar clouds permit tests of theories of molecule formation and, in some instances, provide diagnostic probes of physical conditions inside the clouds.

The design and performance of IUE have been described by Boggess *et al.* (1978a,b). Although the resolving power ($R \simeq 13000$) of IUE is smaller than that of the Princeton ultraviolet spectrometer on the *Copernicus* satellite, IUE can be used to observe more highly-reddened stars. The details of our survey of interstellar absorption lines are presented elsewhere (Black *et al.* 1979).

A SURVEY OF INTERSTELLAR CO

Ultraviolet absorption lines of interstellar CO have been observed previously by Smith and Stecher (1971), Snow (1975, 1977), Morton (1975), and Jenkins *et al.* (1973). Smith *et al.* (1978) analyzed *Copernicus* observations of CO in the ζ Oph cloud, and showed that the rotational excitation of CO is dominated by its interaction with the cosmic background radiation, indicating that the density is too low to thermalize the rotational populations at a kinetic temperature much greater than 3 K.

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As part of a survey of interstellar lines with IUE, the spectra of 25 O and B stars were examined for the presence of the 6-0 through 0-0 bands of the 4th-positive system ($A^1\Pi - X^1\Sigma$) of CO. Profiles of several of these bands in the spectrum of HD46223 are shown in Figure 1.

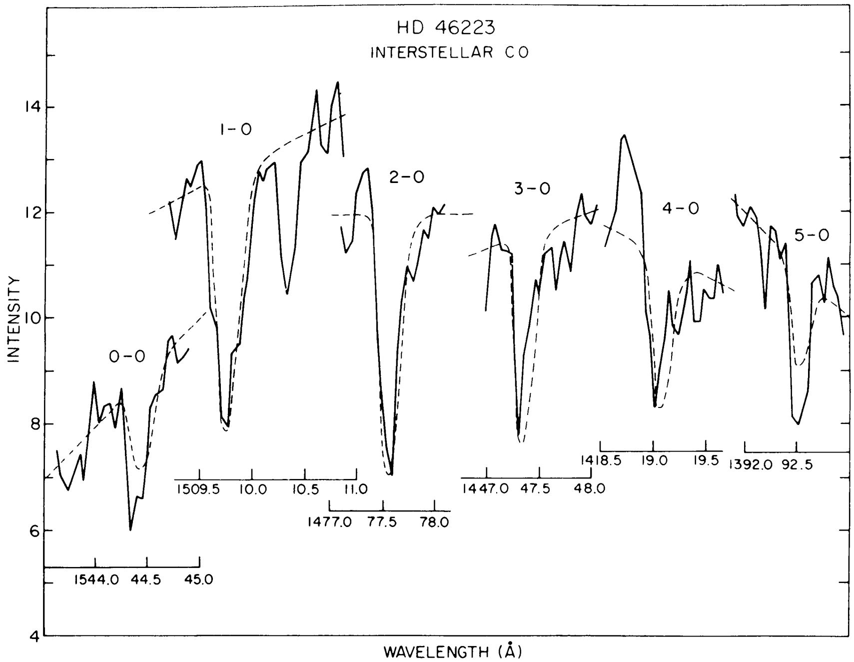

Figure 1. Profiles of CO bands in HD46223.

The bands cannot be resolved with IUE, and the observed band profiles must be compared with theoretical profiles which have been convolved with the instrumental response in order to extract column densities from the data. The widths and central depths of the band profiles are sensitive to the rotational excitation temperature, T_{rot}, and to the Doppler parameter, b, as well as to column density, N(CO). The dashed curves in Figure 1 represent theoretical profiles calculated for b=5 km s^{-1}, T_{rot}=7.5 K, and N(CO)=1.9×10^{14} cm^{-2}. This value of b is an upper limit determined from a preliminary curve-of-growth analysis of lines of C I, Mg I, and S I, so that the corresponding value of N(CO) must be considered a lower limit. The other observations of CO in our sample are all consistent with $T_{rot} < 10$ K. Effective curves of growth have been computed by integrating theoretical band profiles for the conditions T_{rot}=3 K and b=2 km s^{-1}. Column densities estimated from the equivalent widths and these curves of growth are presented in Table 1 together with the HD catalogue number and color excess, E(B-V), of the star, the equivalent width of the 1-0 band, W_{1-0}, and the number of bands, n, upon which the estimate is based.

Table 1. Observations of Interstellar CO

HD	E(B-V)	W_{1-0} mÅ	N(CO) cm^{-2}	n
23180	0.30	57±8	1.5 +14	6
30614	0.34	19±10	3.9 +13	3
36879	0.54	40±9	1.2 +14	4
41117	0.45	80±13	2.1 +14	4
46223	0.54	104±6	5.5 +14	6
147933	0.42	48±9	1.5 +14	6
148937	0.66	89±12	5.0 +14	5
149404	0.74	91±7	6.1 +14	6
151804	0.38	36±6	5.5 +13	3
152424	0.70	66±9	3.5 +14	5
209975	0.39	35±8	1.2 +14	5
213087	0.62	63±14	7.5 +14	5

Upper limits ranging from $1\text{-}5\times10^{13}$ cm^{-2} can be placed upon the estimated N(CO) for 13 other stars. Noteworthy limits include $N(CO) < 1.5\times10^{13}$ cm^{-2} and $N(CO) < 7.5\times10^{12}$ cm^{-2} towards 20 Tau and 23 Tau, respectively: these are stars in the Pleiades whose visible spectra show unusually strong lines of interstellar CH^+ and CH. Although the estimated column densities in Table 1 are of limited quantitative significance individually, they do show a tendency to correlate with E(B-V) according to

$$N(CO) \simeq 5\times10^{12} \exp(7\ E(B-V))\ \ cm^{-2} \quad .$$

This differs considerably from the results of studies of millimeter-wavelength rotational lines of CO in dark clouds in which the column densities of CO are found to be much larger and to be directly proportional to the amount of extinction (Tucker *et al.* 1976, Dickman 1978).

SEARCHES FOR OTHER MOLECULES

Four exposures at long wavelengths (2000-3200 Å) and five exposures at short wavelengths (1150-2100 Å) of HD46223 provide the data of highest signal/noise ratio in our survey. The combined spectra have been searched for molecular lines of C_2 (C-X), CH (C-X, D-X, E-X, F-X, and G-X), CH_2 ($\tilde{B}$-$\tilde{X}$ and $\tilde{C}$-$\tilde{X}$), H_2O ($\tilde{C}$-$\tilde{X}$), HCl (C-X), and OH (C-X). With the exception of CH, no other species are detected. An interstellar line appears near 1370 Å in HD23408, 23480, 46223, 149404, and 152424. Using the 1347.240 Å line of Cl I to adjust for radial velocity shifts, we find a rest position for the new line of λ=1369.58±.05 Å and $\tilde{\nu}$=73015±2 cm^{-1}. It is tempting to identify this feature with a line of the G(3d)-X system of CH (cf. Herzberg and Johns 1969). Further laboratory studies of this system are needed in order to resolve its complex structure and to establish its identification in interstellar absorption.

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DISCUSSION FOLLOWING BLACK

Vanden Bout: Are the CO spectra averages of several exposures?

Black: There are repeated exposures for about half the stars in our sample.

Glassgold: How do your column densities compare with those determined by Copernicus for the same thickness (A_V)?

Black: The column densities in Table 1 tend to be smaller than Copernicus results for similar A_V, but the arbitrary selection of b and T_{rot} in the analysis probably causes underestimated column densities.

W. Watson: What are the current and future prospects for detecting CH_2?

Black: The ultraviolet bands of CH_2 are quite diffuse, and may be difficult to distinguish from stellar features. Strong features appear in HD46223 near 1415 Å, but they are probably stellar. Our data will be analyzed further by differencing techniques to eliminate some of the confusion with stellar lines.