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CARBON STAR PHOTOMETRY: CO AND 3.2 MICRON BANDS

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ABSTRACT

This paper reports filter photometry of CO band strengths at 2.36 μ (filter width = 0.18 μ) for 23 carbon stars. Present results are compared with CO depression of 10 stars observed in 1970 at 2.29 μ with a spectral scanner (spectral resolution = 0.0032 μ). Our CO index and the scanner index are linearly related, with a standard deviation of 0.04 mag. Each of the 23 carbon stars was also observed at the 3.2 μ band (filter width = 0.4 μ). The depression of this unidentified band increases with Na D line strength and C_2 absorption. The 3.2 μ band lacks rotational line structure, and it occurs at the CH stretch frequency common to all hydrocarbon molecules. Our results suggest a possible association between the 3.2 μ band and the C_2H radical.
Subject headings: infrared: spectra — stars: carbon

I. INTRODUCTION

Frogel and Hyland (1972) observed the CO indices of 28 carbon stars between 1969 September and 1970 April. They used a spectral scanner with a resolution of 32 Å and measured the depression of the (2, 0) CO band at 2.29 μ relative to the continuum. The purpose of our study is to report narrow-band filter measurements of CO depressions for 23 stars, 13 of which have no previous CO indices. Our CO depressions are measured relative to the mean of the fluxes through the K (2.2 μ) and L (3.5 μ) band filters. Filter photometry of carbon stars should be compared with scanner results cautiously because CN and C_2 absorptions in the K and L filters may create systematic differences between scanner and filter CO indices. The CO index of individual carbon stars may also vary with time, since Baumert (1972) reports that the CN indices of the carbon stars vary by 10 percent or more during a light cycle; he uses filters on CN bands between 0.79 and 1.08 μ.

A second goal of this study is to make measurements of the intense depression at 3.2 μ with the ICE band filter (so named in accordance with its original use). The dependence of the 3.2 μ depression on carbon star temperature and carbon class should be observed to aid in the identification of the carrier molecule (or molecules). Identification of the broad 3.2 μ band is difficult because low-resolution Fourier transform spectra of this depression show no rotational line structure (see Johnson and Mendez 1970).

II. OBSERVATIONS

Observations of the carbon stars were made with the KPNO photometer and 1.3 m telescope on 1974 September 20 and 21 (UT). Four filter measurements were made: K (2.2 μ) and L (3.5 μ) as continuum filters, plus the CO filter (central $\lambda = 2.36\ \mu$, half-width = 0.09 μ) and the ICE filter (central $\lambda = 3.2\ \mu$, half-width = 0.2 μ).

By interpolation between 2.2 μ and 3.5 μ the continuum levels at 2.36 μ and 3.2 μ were estimated according to

$$F(2.36\ \mu\ \text{cont.}) = 0.83[F(K) - F(L)] + F(L)\,,$$

$$F(3.2\ \mu\ \text{cont.}) = 0.48[F(K) - F(L)] + F(L)\,. \quad (1)$$

We define the CO and 3.2 μ depressions as follows:

$$\text{CO} = 2.5 \log\,[F(2.3\ \mu\ \text{cont.})/F(\text{CO})]\,,$$

$$\text{ICE}(3.2\ \mu) = 2.5 \log\,[F(3.2\ \mu\ \text{cont.})/F(3.2\ \mu)]\,. \quad (2)$$

From examination of medium-resolution spectrophotometry in this spectral region (our unpublished work), it appears that these indices are independent of CN blanketing to first order. This occurs because CN blanketing is fairly uniform through the 2.0 to 2.5 μ range and small in the 3.0 to 3.5 μ range.

The mean CO and ICE depressions for the two days for each of the 23 stars observed are given in Table 1, along with star name (arranged by increasing right ascension) and spectral class (Yamashita 1967, 1972). Observations of 18 stars made on both days indicate a standard deviation of 0.04 mag.

Our CO observations are compared with those of Frogel and Hyland (1972) in Figure 1 for 10 carbon stars observed in common. The regression line between the two sets of observations is

$$\text{CO(Frogel)} = 0.16 + 0.41 \times \text{CO(this paper)}\,. \quad (3)$$

TABLE 1

MEASUREMENTS WITH CO AND ICE FILTERS

Star Name	Spectral Type	CO Index	ICE Index
AQ And.....	C5, 4‡	0.00	+0.10
HD 19557....	C4, 5‡	+0.02	−0.31
U Cam......	C5, 4‡	+0.01	−0.01
UV Cam.....	C4, 4J	+0.03	−0.31
ST Cam......	C5, 4	+0 05	−0.09
R Lep.......	C7, 4e	−0.01	+0.25
W Ori.......	C5, 4	0.00	−0.08
Y Tau.......	C6, 4	−0.03	−0.12
TU Gem*....	C6, 4	+0.10	+0.10
FU Mon.....	C8, OJ	+0.18	−0.08
BL Ori*......	C6, 3	+0.15	−0.08
UU Aur*....	C6, 4	+0.09	+0.04
HD 47396†...	Cpec	−0.06	+0.07
RV Mon*....	C4, 4‡	+0.08	+0.01
W CMa*.....	C6, 3	+0.13	−0.05
16 Ser†......	KO(Ba II)	+0.08	+0.09
R CrB†......	Hd §	−0.23	−0.58
V CrB†......	C6, 2e	−0.09	−0.10
T Lyr†.......	C6, 5J‡	+0.01	+0.24
UX Dra.....	C7, 3	+0.27	+0.25
V Cyg.......	C6, 4e	−0.20	−0.33
TX Psc......	C7, 2	+0.14	+0.03
WZ Cas......	C9, 2JLi	+0.27	+0.20

* Observed on 1974 Sept. 20 only.

† Observed on 1974 Sept. 21 only.

‡ Yamashita (1972) C_2 intensity = 5 in at least one C_2 band or Yamashita (1966) C_2 intensity 9 or 10.

§ Hydrogen deficient.

The standard deviation of a single star from the regression line on the x-axis (our axis) is 0.04 mag. The correlation coefficient is 0.9 and its confidence is 94 percent. The departure of U Cam from the regression line by 2 standard deviations may not be significant, but our measurements made on both nights do agree to 0.02 mag.

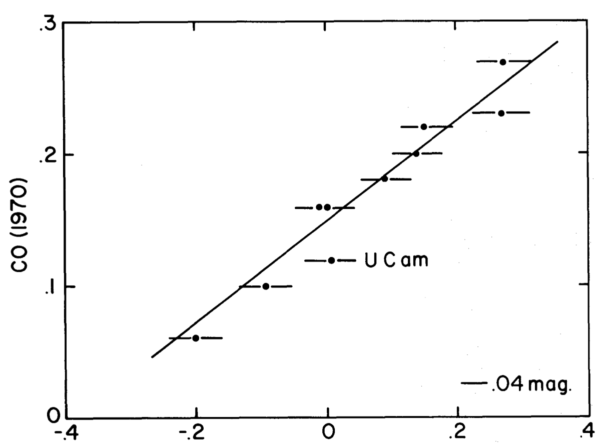

FIG. 1.—Comparison of the CO scanner indices of Frogel and the broad-band filter indices of this paper. Deepest CO bands have largest positive numbers. Measurements compared were made 4 years apart using very different techniques and spectral resolution (see text for details).

Frogel and Hyland (1972) expressed their CO depressions as log [F(cont.)/F(CO)] (compare our eq. 1). Equation 3 indicates that we find the same relative CO band strengths for these stars as Frogel and Hyland, with the possible exception of U Cam. The apparent agreement of the CO measurements is surprising because the K and L magnitudes of these carbon stars vary by at least several tenths of a magnitude and these changes are either irregular or semiregular with time. The CN indices of Baumert (1972) also vary with time by 10 percent or more on a time scale of months.

Observations with the ICE filter are compared with the Na D line and C_2 observations of Yamashita (1967, 1972) and Faÿ *et al.* (1974) in Figure 2. Carbon stars with C_2 band intensities 3 or 4 do fall on a regression line (10 such stars)

$$\text{Yamashita (Na D)} = 6.2 + 0.70 \times \text{ICE}\,. \quad (4)$$

The correlation coefficient is 0.9 (94 percent confidence) and the standard deviation from the ICE axis is 0.05 mag. The C_2 strong carbon stars have Yamashita (1972) C_2 index = 5 in at least one band, or Yamashita (1967) C_2 index = 9 or 10. Note that these C_2 rich carbon stars, e.g. T Lyr, have deeper ICE depressions for their Na D class than normal carbon stars. The C_2 poor carbon stars, e.g. WZ cas, have systematically weaker ICE bands for their Na D class. Yamashita (1972) demonstrates that the Na D index is temperature-sensitive, and hence we conclude that our ICE index is also, except that ICE also increases with C_2 strength. The peculiar star V Cyg departs from these trends (See Faÿ *et al.* 1974).

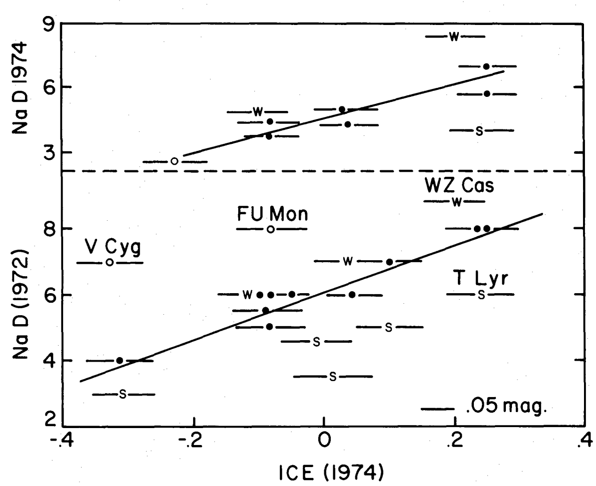

FIG. 2.—Comparison of two types of Na D indices (Yamashita 1972; Faÿ *et al.* 1974) with the ICE filter indices of this paper. We conclude that ICE depressions increase with D line strength and carbon abundance. Symbols: S, Yamashita C_2 rich (index = 9, 10 in 1966 or 5 in one band in 1972); ●, C_2 normal; W, C_2 weak (index = 2). FU Mon has C_2 index = 0.

III. DISCUSSION

The spectra of Johnson and Mendez (1970) indicate that the 3.2 μ band is too strong in most carbon stars to be affected by interstellar ice, and they do not identify the carrier of the band. The carrier must be some molecule(s) in the atmosphere of the star that has (have) the following characteristics: (1) little rotational line structure at carbon star temperatures, (2) temperature and C_2 sensitivity, (3) a vibrational frequency close to that of the CH stretch band, and (4) a large column abundance in some carbon stars.

Many polyatomic hydrocarbons have bands in this region. For example, C_2H_2 (tentatively identified in the spectra of TX Psc and Y CVn by Hirai 1974) has several bands near 3.1 μ. But from a comparison of laboratory spectra (Bell and Nielson 1950) with observed spectra (Johnson and Mendez 1970) it appears that C_2H_2 cannot be the dominant opacity.

One abundant molecule that fulfills the conditions completely is C_2H. The laboratory spectrum of C_2H is unknown, but like all other hydrocarbons it must show a strong CH stretch fundamental band between 3.1 and 3.4 μ. The radical C_2H is an asymmetric top; therefore its rotational line structure will have at least 10 times greater line density per unit frequency interval than linear hydrocarbons like HCN, C_2H_2, and CH. The close spacing of C_2H lines (0.1 cm^{-1} or less) makes any resolution of rotational structure unlikely at the temperatures and probable microturbulent velocities of carbon star atmospheres. This is due to the high population of the excited rotational levels. Morris and Wyller (1967) show the sensitivity of C_2H to temperature; it is also correlated with C_2 abundance. It is also significant that calculations of molecular dissociation equilibria for possible cool carbon star conditions (Greene 1972) predict a C_2H abundance 10^2 or 10^3 times greater than the C_2H_2 abundance.

The column density of C_2H is sufficient to produce the observed ice absorptions in the coolest stars. Johnson *et al.* (1975) compute the column density, X, of C_2H at 1 μ in the range $10^{19} > X > 10^{17}$ for carbon star atmospheres with $\log g = 0$ and $2500 < T_{\rm eff} < 3000$ K. Their column densities might yield an optical depth τ at 3.2 μ, $\tau = KX > 0.1$, provided the opacity, K, of C_2H at 3.2 μ is 10^{-18} cm^2 per molecule or higher. The laboratory spectrum of C_2H should be measured at 3 μ, particularly the opacity or f-value of its CH stretch band. Such a measurement may well affect the computation of future model atmospheres of cool carbon stars and the computation of their C, N, and O isotopic abundances from observed molecular line strengths. Such abundance determinations are critical tests of theories of stellar evolution and nucleosynthesis.

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