THE ASTROPHYSICAL JOURNAL, 324:490–500, 1988 January 1

ON THE VIOLET FLUX OF N TYPE CARBON STARS

DANNY R. FAULKNER,[1] R. KENT HONEYCUTT,[1] AND HOLLIS R. JOHNSON
Indiana University
Received 1986 August 11; accepted 1987 June 19

ABSTRACT

We present new six-color violet photometry of 26 carbon stars. These observations reveal the shape of the spectrum between 3400 Å and 4500 Å and provide a measurement of the violet flux deficiency. The strength of the 11.5 μm SiC emission feature was also measured using ground-based infrared spectrophotometry and the *IRAS* low-resolution spectral catalog. The lack of correlation between the 11.5 μm emission and the violet flux deficiency leads to the conclusion that SiC is not the predominant violet opacity source in N type carbon stars. The violet photometry presented here does not quantitatively agree with previous spectrophotometry that supported C_3 as the opacity source. Our observations alone do not rule out the C_3 opacity, but when they are combined with *IUE* data, the C_3 opacity appears less plausible.
Subject headings: opacities — spectrophotometry — stars: carbon

I. INTRODUCTION

Carbon stars are peculiar red giant stars whose spectra are characterized by bands of the carbon-containing molecules C_2, CN, CH, and HCN, in contrast to the spectra of K and M giants, where oxides such as TiO are the strongest features (cf. Alksne and Ikaunieks 1983). The spectral differences arise from an enhanced carbon (or decreased oxygen) abundance in carbon stars so that C/O > 1, whereas C/O < 1 in normal red giants (cf. Iben and Renzini 1983; Jaschek 1985; Querci 1986). Cooler (N type) carbon stars, except for the ^{13}C-rich carbon stars (Utsumi 1985), have also been contaminated by *s*-process elements. Iben (1974) was one of the first to suggest that carbon and *s*-process elements are convected to the surface during the dredge-up following thermal pulses during thin-shell He burning. It is now believed that carbon stars are double shell-source, asymptotic giant branch (AGB) stars possessing electron degenerate carbon-oxygen cores (cf. Iben and Renzini 1983; Iben 1984). Carbon and the neutron-rich elements are produced during the thermal pulse. The primary source of the neutrons is believed to be the $^{22}Ne(\alpha, n)^{25}Mg$ reaction in the more massive stars (Iben 1975*b*), while $^{13}C(\alpha, n)^{16}O$ is the neutron source in less massive stars (Scalo 1981; Iben 1984). The amount of carbon dredged up depends upon how much carbon is destroyed at the bottom of the convective envelope (Iben 1984). This latter quantity is crucially dependent upon the temperature at the base of the convective zone and the mixing length (Iben 1975*a*, 1976). Being AGB objects, carbon stars have appreciable winds (cf. Goldberg 1986; Dupree 1986) and are possible progenitors of some planetary nebulae (Iben and Renzini 1983), and thus they are important contributors to the enrichment of the interstellar medium. The present stellar evolution calculations are in qualitative agreement with observations (Scalo 1981; Iben 1982; Mould and Aaronson 1986), and it is hoped that further work will bring better quantitative agreement.

Many physical processes present in carbon stars such as winds, chromospheric heating, and grain formation cannot be completely understood until the outer atmosphere of these stars is deduced. One obstacle to this endeavor is the large violet flux deficiency which N type carbon stars suffer compared to other stars of similar temperature (Shane 1928). That is, the blue and violet flux in carbon stars appears to decrease more rapidly toward shorter wavelengths than does the flux in M giant stars or blackbodies. In fact, the violet flux deficiency is the characteristic feature distinguishing between the R and N type carbon stars. This flux deficiency is usually attributed to some atmospheric or circumstellar absorber, and the phenomenon is often referred to as "the violet opacity." If the violet absorber is largely atmospheric, the corresponding opacity must be included in computing a stellar atmosphere for these stars. Two suggested sources of this opacity have recently received observational support: SiC grains and C_3 molecules.

Walker (1976) found a correlation between the strength of the violet depression, as measured by the $(B-V)$ color, and the 4866 Å Merrill-Sanford band in 40 southern carbon stars. Because the Merrill-Stanford bands are due to SiC_2, the gaseous counterpart of SiC, Walker concluded that the violet opacity source is SiC grains, as had been suggested by Gilra (1973). However, it does not necessarily follow that the SiC_2 abundance is related to the presence of SiC grains; what is needed is a direct measurement of the grains themselves. An opportunity for this is provided by Gilra's prediction that the grains would reemit in a broad band centered at 11.5 μm, an emission feature detected in carbon stars by several investigators (Hackwell 1972; Treffers and Cohen 1974; Forrest, Gillett, and Stein 1975; Goebel *et al.* 1980; Little-Marenin and Wilton 1986). Because the observed wavelength and profile of the 11.5 μm emission agrees with the prediction of Gilra, most investigators believe that the 11.5 μm emission is indeed caused by SiC grains.

McKellar and Richardson (1955) suggested molecular C_3 as the opacity source, based upon the agreement of the laboratory spectrum of C_3 with the existing observations of carbon stars. Goebel *et al.* also identified C_3 in the infrared spectra of carbon stars. Bregman and Bregman (1978) (hereafter, B & B) noted that the C_3 opacity would have a maximum at 3900 Å, while the SiC opacity would continue to increase with shorter wavelength. Thus the behavior of the flux curves of carbon stars for

[1] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatory, operated by AURA, Inc., under contract to the National Science Foundation.

$\lambda < 3900$ Å is expected to be a discriminant between these two suggested opacity sources. B & B obtained spectrophotometry of eight carbon stars between 3200 and 6800 Å. Six warmer stars showed an increase in flux below 3900 Å, from which B & B concluded that the predominant opacity source in these stars is C_3. The two remaining cooler stars were undetectably faint below 4000 Å, and so B & B could not determine the opacity source for them, but a rough calculation of the absorbers' temperature produced an upper limit of 1660 K. Because this is close to the temperature 1650 K at which SiC can condense (Gilman 1969), B & B suggested that SiC may predominate in cooler carbon stars.

A few comments should be made about the physical location of the violet absorbers. Placing the violet absorbers in the photosphere causes a problem for the SiC opacity, because photospheres usually do not have regions where the temperature is cool enough for grains to form. Because circumstellar grains are common with many other stars, it would be tempting to place the SiC in a circumstellar shell. Furthermore, the temperatures inferred from the infrared observations, typically between 600 and 2500 K (Hackwell 1972; Treffers and Cohen 1974; Forrest, Gillett, and Stein 1975; Goebel *et al.* 1980; Little-Marenin and Wilton 1986), would most likely place the grains in a circumstellar shell. However, it has been known for some time (recently rediscussed by Querci *et al.* 1982) that the veiling of the CN violet lines with respect to the CN red lines (King and Swings 1945) and the veiling of atomic lines (Shajn and Struve 1947) show that the violet absorption is largely occurring in the photosphere. When discussing grain opacity sources, some authors have neglected a clear discussion of whether the grains are photospheric or circumstellar. As discussed above, some stars may contain photospheric temperatures near the condensation temperature of SiC, but it appears that many others are too warm to have photospheric grains. In either case it is not clear that photospheric grains would survive transport through the warmer chromospheres that have been shown to surround these stars (Johnson and O'Brien 1983; Johnson and Luttermoser 1987). Addressing the issue of whether the SiC could exist in the photosphere and survive passage through the chromosphere is not presently possible, for it requires rather complete models of the photosphere, chromosphere, and circumstellar shell. Indeed, to produce such models is the ultimate goal of our study. One could argue that the grains are both photospheric and circumstellar. Regardless of location, however, SiC grains must both absorb in the violet and emit in the infrared. We will not consider the location of the grains further, but we will assume along with Gilra (1973) that if SiC grains are the predominant violet absorbers, they are the same grains emitting at 11.5 μm, or (at worst) that the amounts of emitting and absorbing grains are correlated, even if physically separated.

To further study the predominant violet opacity source, we recently obtained new observations, including violet photometry and infrared spectrophotometry, of more than two dozen carbon stars. Photometry between 3400 and 4500 Å provides a measure of the violet flux deficiency and the possibility of measuring a flux upturn below 3900 Å, as noted by B & B. The contribution of the SiC grains was determined by measuring the strength of the 11.5 μm emission feature. If SiC is the predominant violet opacity source, then following our assumption stated above, there should be a correlation between the violet flux deficiency and the excess 11.5 μm emission.

II. OBSERVATIONS

Program stars were selected according to their visibility from Kitt Peak, brightness, and previously published observations, especially those of B & B and from *IUE*. The program stars observed, as time and weather permitted, are listed in Table 1.

The violet photometry was obtained during a total of seven nights in 1985 February and 1985 September with the No. 2 0.9 m telescope at KPNO. A single-channel photometer was used with a bialkali photomultiplier tube cooled to $-10°$C. This tube offers the advantages of good ultraviolet response and very low red sensitivity. Six filters were selected to avoid large known stellar absorption features, to help ensure that the continuum was being sampled. The characteristics of these filters are listed in Table 2. Donald Hayes at KPNO kindly traced each filter for us to ensure that it was effectively blocked. These tracings show that each filter has at least 9 mag of red leak protection, while the low red sensitivity of the photomultiplier tube adds about 2.5 more magnitudes of red leak protection. This minimum protection against red leak should be adequate, since broad-band photometry shows that carbon stars typically are 8–10 mag brighter in the red than in the ultraviolet.

Integration times varied between 10 s and 10 minutes, depending upon the brightness of each star. We attempted to obtain at least 10,000 net counts for each observation, but this was not always feasible; an arbitrary upper limit of 10 minutes was adopted to permit a reasonable number of observations to be made. Measurements of the nearby sky were subtracted from the star measurements and instrumental magnitudes were formed in the usual fashion. To minimize the effects of extinction, each program star was observed near the meridian. On each night at least one standard star was observed at various air masses, from which separate extinction coefficients were determined for each night and each filter. Because the filters are so narrow, no transformation or extinction color terms were used.

Several spectrophotometric standard stars were also observed near the meridian each night. Calibrated fluxes of these standard stars (Barnes and Hayes 1984) were used to transform the instrumental magnitudes of the program stars into calibrated fluxes. The logarithms of these calibrated fluxes are presented in Table 1 and plotted in Figure 1, where the units are ergs cm^{-2} s^{-1} $Å^{-1}$. The errors, computed solely on the basis of shot noise, are shown in Table 1 in parentheses following the flux measurements. These errors are tabulated only when they exceed 1% and are plotted as error bars in Figure 1 only when their sizes exceed that of the dots. Subtraction of the sky measurement from the star measurement occasionally resulted in negative net counts, but by treating the shot noise formally it was sometimes possible to determine a positive upper limit to the net counts, and thus an upper limit to the flux. In some cases, however, even this procedure did not produce a positive upper limit, and so no upper limit on the flux could be set. Where only upper limits in the flux were obtained, they appear in parentheses in Table 1 with no listed errors and are indicated in Figure 1 by a bar. The fluxes presented here are consistent with published observations to within a few percent for the four carbon stars (BL Ori, U Hya, Y CVn, and V460 Cyg) for which Johnson, Mitchell, and Latham (1967) obtained intermediate band photometry.

Infrared spectrophotometry was obtained on two nights during 1985 March with the 1.3 m Kitt Peak telescope. The

TABLE 1

VIOLET FLUXES OF THE PROGRAM STARS

STAR	λ3410	λ3500	λ3676	λ3792	λ4090	λ4520
WZ Cas	$-14.20^{+0.06}_{-0.07}$	-14.22 ± 0.02	-14.10 ± 0.03	$-13.94^{+0.03}_{-0.04}$	-13.18 ± 0.01	-12.29
Z Psc	-13.68 ± 0.02	-13.69 ± 0.01	-13.52 ± 0.01	-13.47 ± 0.01	-12.72	-12.10
V Ari	-13.66 ± 0.02	-13.63 ± 0.01	-13.52 ± 0.01	-13.57 ± 0.02	-12.93 ± 0.01	-12.53 ± 0.01
HD 19557	-13.26 ± 0.01	-13.29	-13.17 ± 0.01	-13.29 ± 0.01	-12.52	-12.15 ± 0.01
U Cam	(-16.57)	$-15.32^{+0.20}_{-0.38}$	...	(-15.46)	-14.28 ± 0.05	-13.24 ± 0.01
UV Cam	-13.32 ± 0.01	-13.29 ± 0.01	-13.14 ± 0.01	-13.28 ± 0.01	-12.56	-12.20 ± 0.01
ST Cam	-15.63 ± 0.57	(-15.80)	$-15.04^{+0.14}_{-0.21}$	(-15.55)	-13.17 ± 0.01	-12.20
W Ori	$-14.91^{+0.20}_{-0.40}$	(-16.19)	$-15.27^{+0.19}_{-0.34}$	$-14.62^{+0.10}_{-0.14}$	-13.63 ± 0.01	-12.28
BL Ori	-13.24 ± 0.01	-13.28	-13.25	-13.13	-12.38	-11.68
UU Aur	-13.99 ± 0.03	-14.14 ± 0.01	-13.93 ± 0.01	-13.63 ± 0.01	-12.64 ± 0.01	-11.55
RY Mon	...	$-15.25^{+0.14}_{-0.20}$	$-15.33^{+0.23}_{-0.50}$	...	-14.69 ± 0.03	-13.45 ± 0.01
HD 59643	-12.95 ± 0.01	-13.00 ± 0.01	-13.12 ± 0.01	-12.98 ± 0.01	-12.77	-12.28
W CMi	$-14.15^{+0.04}_{-0.05}$	-14.11 ± 0.01	-14.05 ± 0.01	-13.90 ± 0.02	-13.39 ± 0.01	-12.72 ± 0.01
X Cnc	$-14.34^{+0.08}_{-0.10}$	$-14.90^{+0.08}_{-0.09}$	$-14.56^{+0.06}_{-0.07}$	-15.05 ± 0.31	-13.35 ± 0.01	-12.13
Y Hya	(-16.07)	(-15.88)	-15.44 ± 0.22	$-14.80^{+0.14}_{-0.20}$	-14.19 ± 0.01	-12.86
U Hya	$-14.11^{+0.04}_{-0.05}$	-14.21 ± 0.02	-13.82 ± 0.01	-13.52 ± 0.01	-12.50	-11.51
VY UMa	-13.46 ± 0.01	-13.41	-13.23	-13.08	-12.35	-11.55
SS Vir	$-14.81^{+0.17}_{-0.24}$	-14.88 ± 0.06	-14.00 ± 0.02	-14.17 ± 0.04	-13.84 ± 0.01	-12.82
Y CVn	$-14.99^{+0.22}_{-0.48}$	$-15.43^{+0.15}_{-0.24}$	$-14.97^{+0.09}_{-0.11}$	-14.26 ± 0.05	-12.85	-11.46
RY Dra	...	(-15.82)	(-15.82)	$-14.79^{+0.14}_{-0.21}$	-13.54 ± 0.01	-12.15
V1942 Sgr	-13.88 ± 0.05	-13.86 ± 0.02	-13.69 ± 0.02	-13.54 ± 0.02	-12.70 ± 0.01	-11.97
UX Dra	-13.26 ± 0.01	-13.33 ± 0.01	-13.23 ± 0.01	$-14.34^{+0.14}_{-0.22}$	-12.38	-11.71
RS Cyg	-13.86 ± 0.04	-13.96 ± 0.02	-13.85 ± 0.02	-13.77 ± 0.03	-13.11 ± 0.01	-12.41 ± 0.01
V460 Cyg	-13.91 ± 0.03	-13.89 ± 0.01	-13.75 ± 0.01	-13.56 ± 0.02	-12.59	-11.82
DG Cep	$-14.74^{+0.20}_{-0.31}$	$-14.86^{+0.08}_{-0.10}$	...	$-14.55^{+0.11}_{-0.15}$	-13.82 ± 0.01	-12.97 ± 0.01
TX Psc	-12.85 ± 0.01	-12.89 ± 0.01	-12.77 ± 0.01	-12.73 ± 0.01	-11.94	-11.29

instrument used was the closed-cycle cooled photometer (CCP) with the circular variable filter (CVF). The instrument automatically beam switches, and the observer is provided with an instrumental magnitude at each bandpass. The observations were made between 8.4 and 13.6 μm and included a terrestrial ozone band at 9.6 μm. Observations of Arcturus at several air masses showed that extinction was, as expected, a small effect, and was neglected. One of our Arcturus flux curves and the calibrated flux curve of Arcturus from the low-resolution spectral catalog from *IRAS* were used for calibration. The fluxes of the nine successfully observed stars are presented in Table 3,

TABLE 2

VIOLET FILTER CHARACTERISTICS

λ_E (Å)	FWHM (Å)
3410	90
3500	314
3676	130
3792	116
4090	168
4520	111

where the units are ergs cm^{-2} s^{-1} Å^{-1}. Because we were more concerned with the shape of the infrared flux curves than with the absolute flux levels, other researchers should be cautioned that our zero point of the flux curves may be in error.

Unfortunately, because of cloudy weather, some of the infrared observations were of lower quality, and these were rejected. To supplement our observations, we used the low-resolution spectrophotometry from the *IRAS* catalog. Because of the steepness of the flux curves, the 11.5 μm emission is not always readily apparent. Little-Marenin and Wilton (1986) noted that the continuum of these stars can usually be matched to the flux distribution of a 1000–2500 K blackbody in the 8–12 μm range. The flux curve of each program star found in the *IRAS* catalog was therefore divided by a 2500 K blackbody curve matched near 10 μm. This greatly flattened the flux curves and enhanced the appearance of the emission feature. A comparison of the Kitt Peak observations and the *IRAS* data for several stars is shown in Figure 2. This comparison shows that while the agreement is very good in some stars, others show systematic and/or random differences, some of which may arise from real variations of the star. The scatter in some of our curves appear to be greater than in the *IRAS* curves, but we would assess our errors to be less than 10%. Several of the KPNO stars were

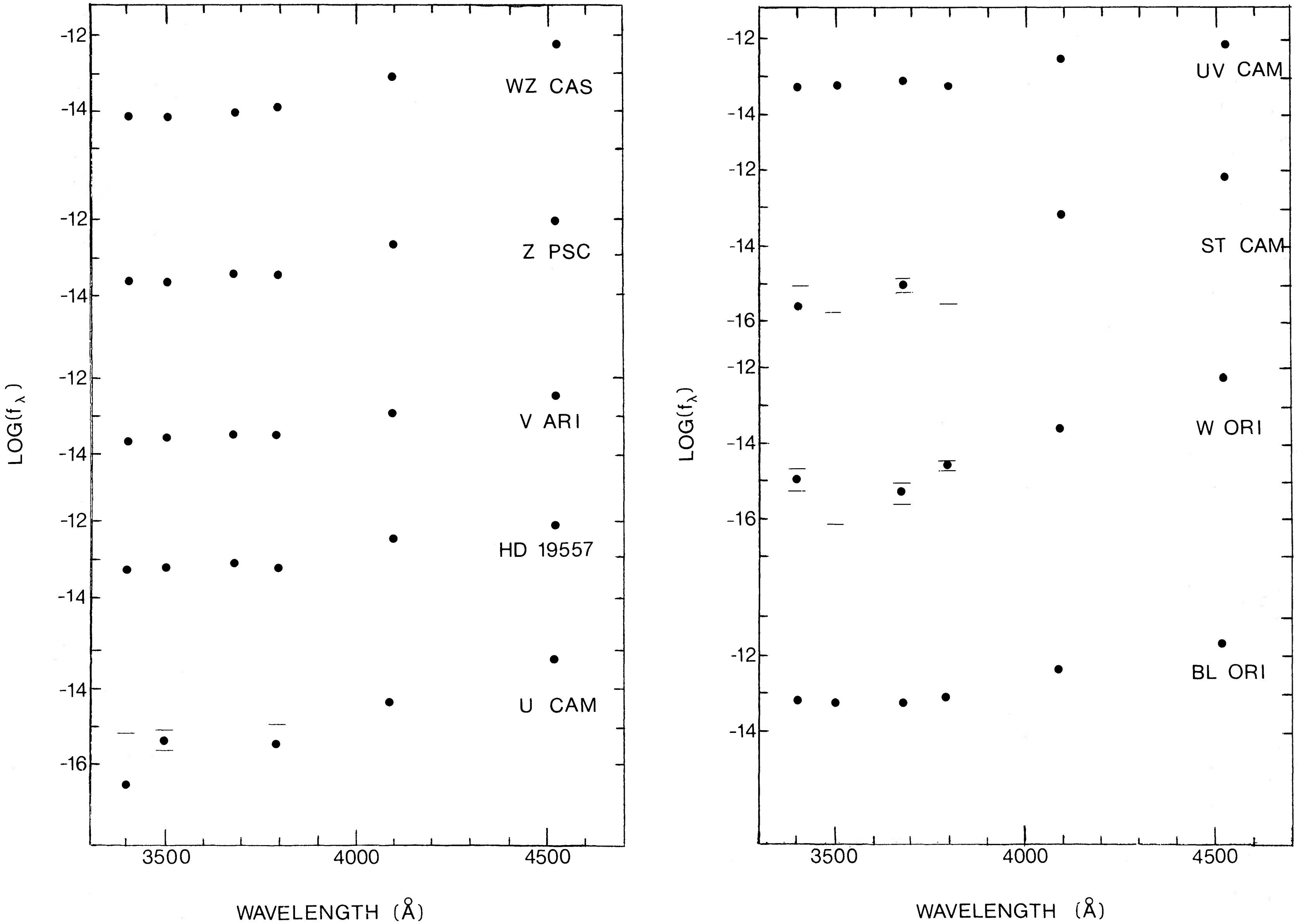
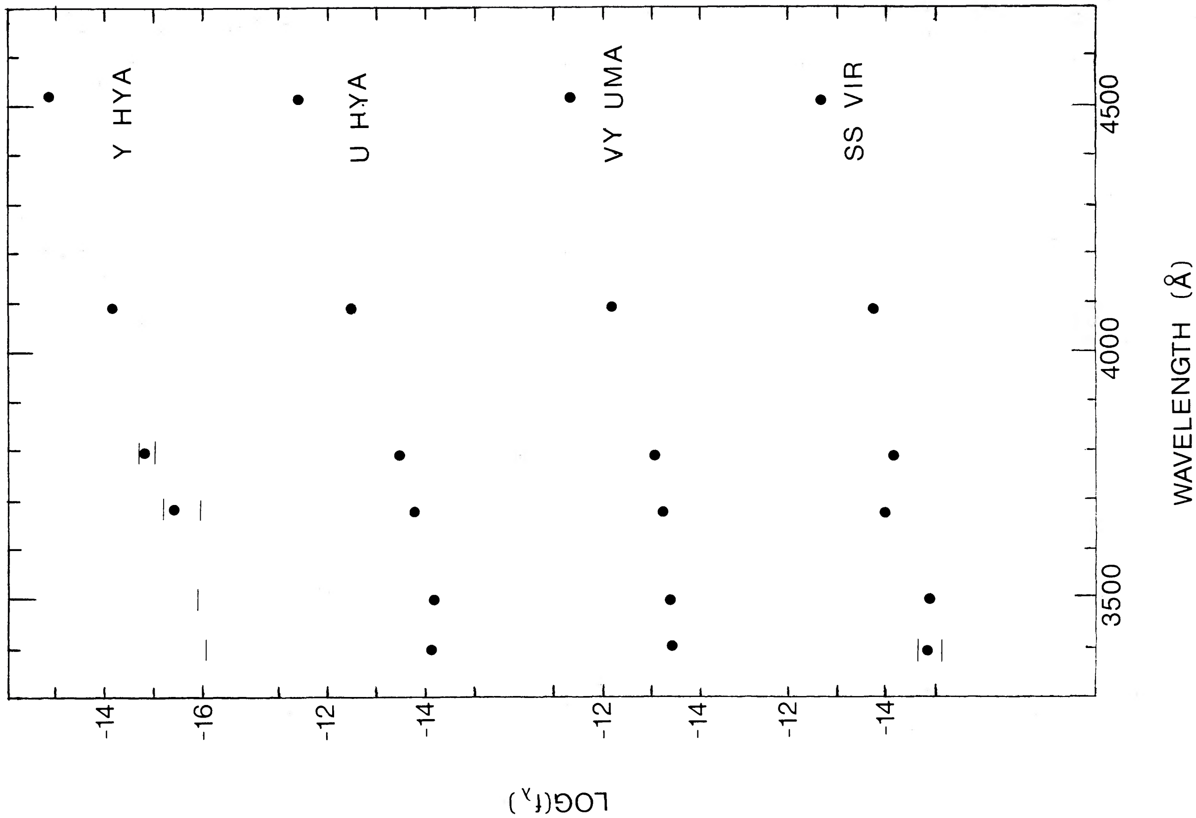
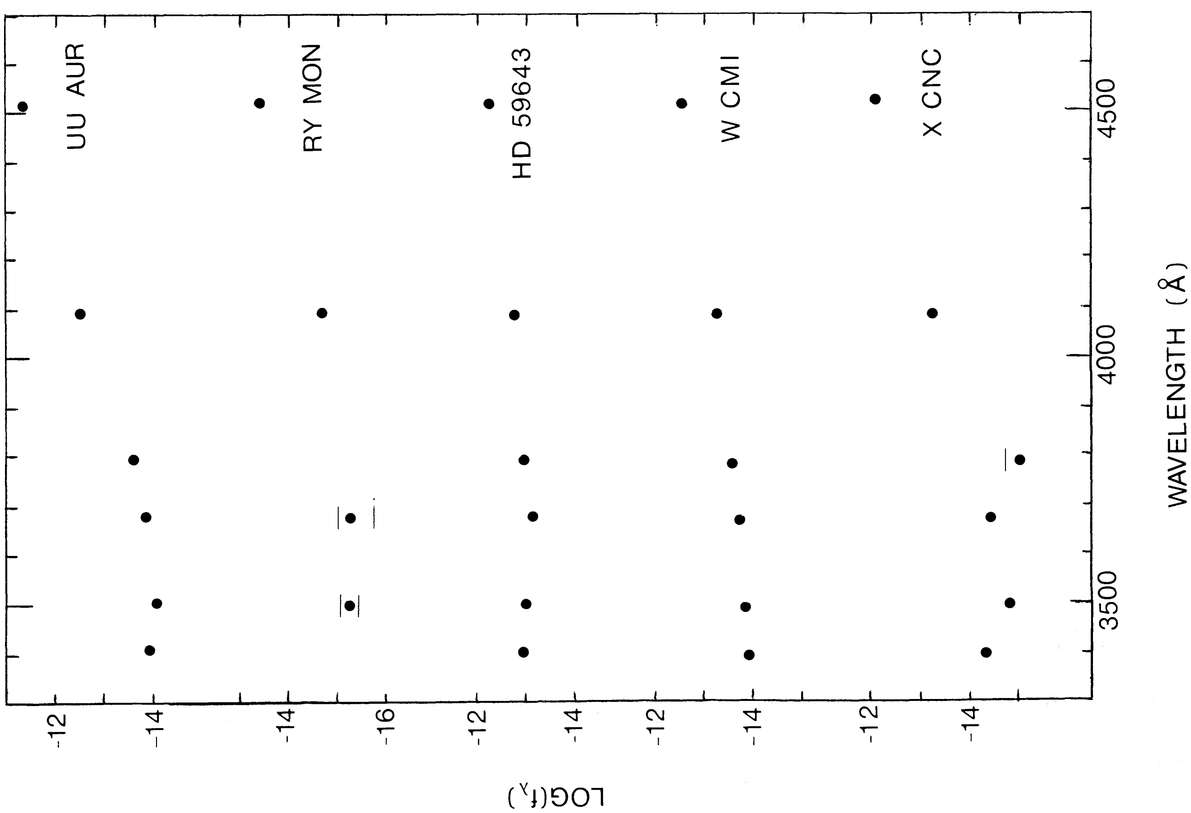


FIG. 1.—Calibrated violet photometry of the program stars


Y HYA
U HYA
VY UMA
SS VIR
WAVELENGTH (Å)
LOG(f_λ)


UU AUR
RY MON
HD 59643
W CMI
X CNC
WAVELENGTH (Å)
LOG(f_λ)

1988ApJ...324..490F

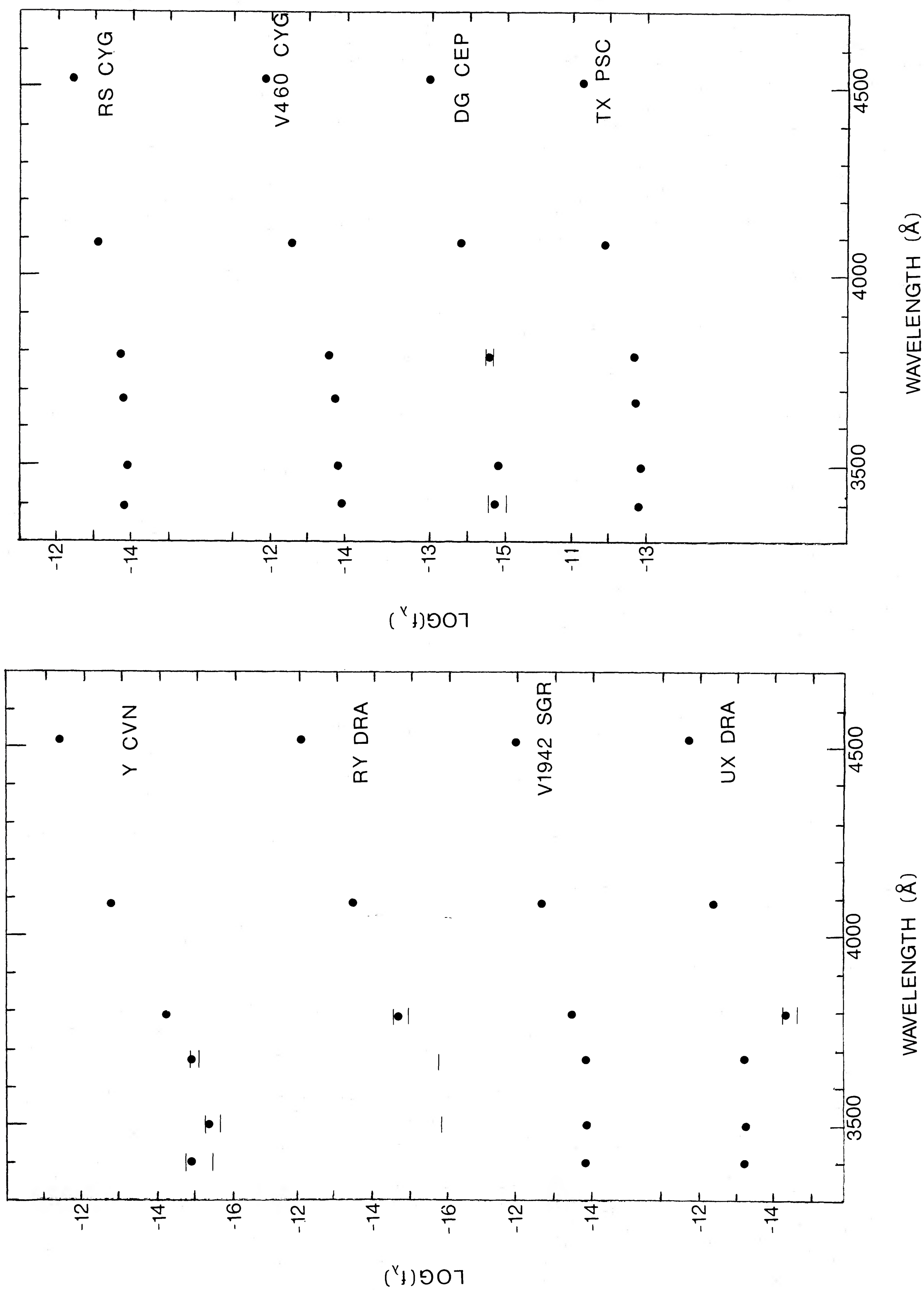


TABLE 3

KITT PEAK INFRARED FLUXES

λ	W Ori	BL Ori	UU Aur	RY Mon	X Cnc	Y Hya	U Hya	SS Vir	Y CVn
9.6	-11.365	-11.790	-11.246	-11.921	-11.251	-11.678	-11.208	-11.500	-11.011
9.8	-11.412	-11.873	-11.272	-11.824	-11.588	-11.674	-11.242	-11.474	-11.066
10.0	-11.420	-11.857	-11.314	-11.896	-11.629	-11.648	-11.231	-11.488	-11.092
10.2	-11.425	-11.914	-11.322	-11.910	-11.673	-11.670	-11.256	-11.500	-11.119
10.4	-11.441	-11.928	-11.322	-11.917	-11.704	-11.719	-11.256	-11.498	-11.150
10.6	-11.428	-11.955	-11.319	-11.924	-11.693	-11.742	-11.243	-11.489	-11.148
10.8	-11.391	-12.018	-11.297	-11.910	-11.718	-11.728	-11.245	-11.481	-11.145
11.0	-11.374	-12.020	-11.270	-11.870	-11.706	-11.730	-11.264	-11.487	-11.160
11.2	-11.429	-12.054	-11.321	-11.883	-11.730	-11.757	-11.285	-11.527	-11.164
11.4	-11.458	-12.068	-11.337	-11.928	-11.739	-11.770	-11.312	-11.559	-11.186
11.6	-11.474	-12.120	-11.310	-11.932	-11.779	-11.854	-11.379	-11.614	-11.231
11.8	-11.573	-12.160	-11.421	-12.027	-11.840	-11.879	-11.419	-11.670	-11.266
12.0	-11.620	-12.163	-11.478	-12.149	-11.876	-11.886	-11.453	-11.697	-11.302
12.2	-11.695	-12.246	-11.544	-12.361	-11.950	-11.967	-11.527	-11.790	-11.352
12.4	-11.733	-12.217	-11.573	-12.219	-11.994	-12.026	-11.595	-11.886	-11.389
12.6	-11.796	-12.283	-11.625	-12.413	-11.972	-12.042	-11.631	-11.866	-11.433
12.8	-11.836	-12.305	-11.662	-12.327	-12.097	-12.186	-11.701	-11.943	-11.480
13.0	-11.845	-12.280	-11.697	-12.376	-12.137	-12.244	-11.730	-11.921	-11.504
13.2	-11.873	-12.550	-11.706	-12.614	-12.190	-12.094	-11.742	-12.061	-11.521
13.4	-11.799	-12.471	-11.799	-13.302	-12.176	-12.393	-11.788	-12.301	-11.585
13.6	-12.110	-12.453	-11.686	-12.390	-12.474	-12.738	-12.317	-12.433	-11.928

observed more than once and showed repeatability to within a few percent.

III. DISCUSSION

As is apparent from Figure 1, the violet observations presented here do not agree in detail with those of B & B, in that no noticeable increase in flux occurs at shorter wavelengths. Jesse Bregman (1985, private communication) kindly provided some of their observations, and a comparison of the two sets of data for Y CVn is shown in Figure 3. Because the B & B observations are only relative fluxes, their curve was shifted vertically to match ours near 4500 Å. We note that the B & B curve drops more steeply toward shorter wavelengths, but rises again below 3900 Å, while our curve generally *levels out* below 3900 Å. The plots in Figure 1 show that this is the general tendency in most of the stars we observed. Our observations do show a small upturn below 3500 Å in about half of the stars. Several of these upturns are on the order of the errors, however, or they can be explained by slightly weaker discrete absorption near 3400 Å. It is also possible that because our spectral resolution is poorer, our bandpasses may have included absorption features that B & B were able to avoid. When our observations are accepted without these caveats, *we do not confirm the upturn found by B & B.*

Even though our flux curves do not reproduce the exact shape of the B & B flux curves, our observations do not necessarily contradict their conclusion. Indeed, the flattening displayed by the curves presented here argue for a decreasing opacity for $\lambda < 3900$ Å, because if an unusual opacity were not present, the flux curve at these wavelengths would rapidly drop below 3900 Å due to the steepness of the blackbody curve. This can be seen by dividing the flux curves by the flux of a star of similar temperature, one which does not suffer from violet opacity. To accomplish this, we chose to use the M6 star 30 Her, because it is bright, cool, nonvarying and also because it was similarly used by B & B. The resulting division by the flux of this star is displayed for several carbon stars in Figure 4. Notice that these normalized curves have a minimum near 3900 Å, indicating an opacity maximum there. However, recent observations with *IUE* at wavelengths shorter than 3400 Å may reveal that this modest recovery in the flux may not be sustained into the ultraviolet. Querci *et al.* (1982) compared continuum measurements from *IUE* spectra and optical spectra for several cool M stars and four carbon stars. The very long *IUE* spectra for the carbon stars revealed no signal below 3000 Å, resulting in only upper limits for their fluxes in the ultraviolet. Because these upper limits were orders of magnitude below the flux levels of similar temperature M stars, they concluded that the carbon stars suffered from a large flux depression below 3000 Å. Indeed, only for seven warmer carbon stars has it been possible to obtain *IUE* continuum measurements (Johnson and Luttermoser 1987), and they also show a flux depression in the ultraviolet. Figure 5 shows a comparison of our photometry, published spectrophotometry, and *IUE* continuum measurements for TX Psc. The *IUE* data show that the flux continues to decrease below 3000 Å. Notice that any modest flux recovery in the violet, even that flux upturn reported by B & B, is dwarfed by a dramatic decrease in flux in the ultraviolet.

To obtain an objective measure of the violet flux deficiency, a blackbody curve of 3000 K was fitted to the observed flux at 4520 Å. The observed flux was interpolated at 100 Å intervals, and the difference between this curve and the blackbody curve was integrated between 3400 Å and 4500 Å by summing over 100 Å bins. An integrated violet flux deficiency, F^v (in units of ergs cm^{-2} s^{-1}), for each star is tabulated in Table 4. The strength of the 11.5 μm emission was also measured. The flattened infrared curves discussed above permitted selection of continuum points on either side of the emission feature. These continuum values were interpolated across the emission feature, and the difference between the flux and continuum was summed in short wavelength intervals, where $\Delta\lambda$ is the difference in wavelength between adjacent observations. Values of the integrated flux, F^{IR} (again in ergs cm^{-2} s^{-1}), for both the Kitt Peak and *IRAS* curves, are also tabulated in Table 4, along with the ratios F^{IR}/F^v.

Regardless of their location, if SiC grains were the dominant violet opacity source, and the radiation absorbed were reemitted at 11.5 μm, F^v and F^{IR} would be correlated, and thus their

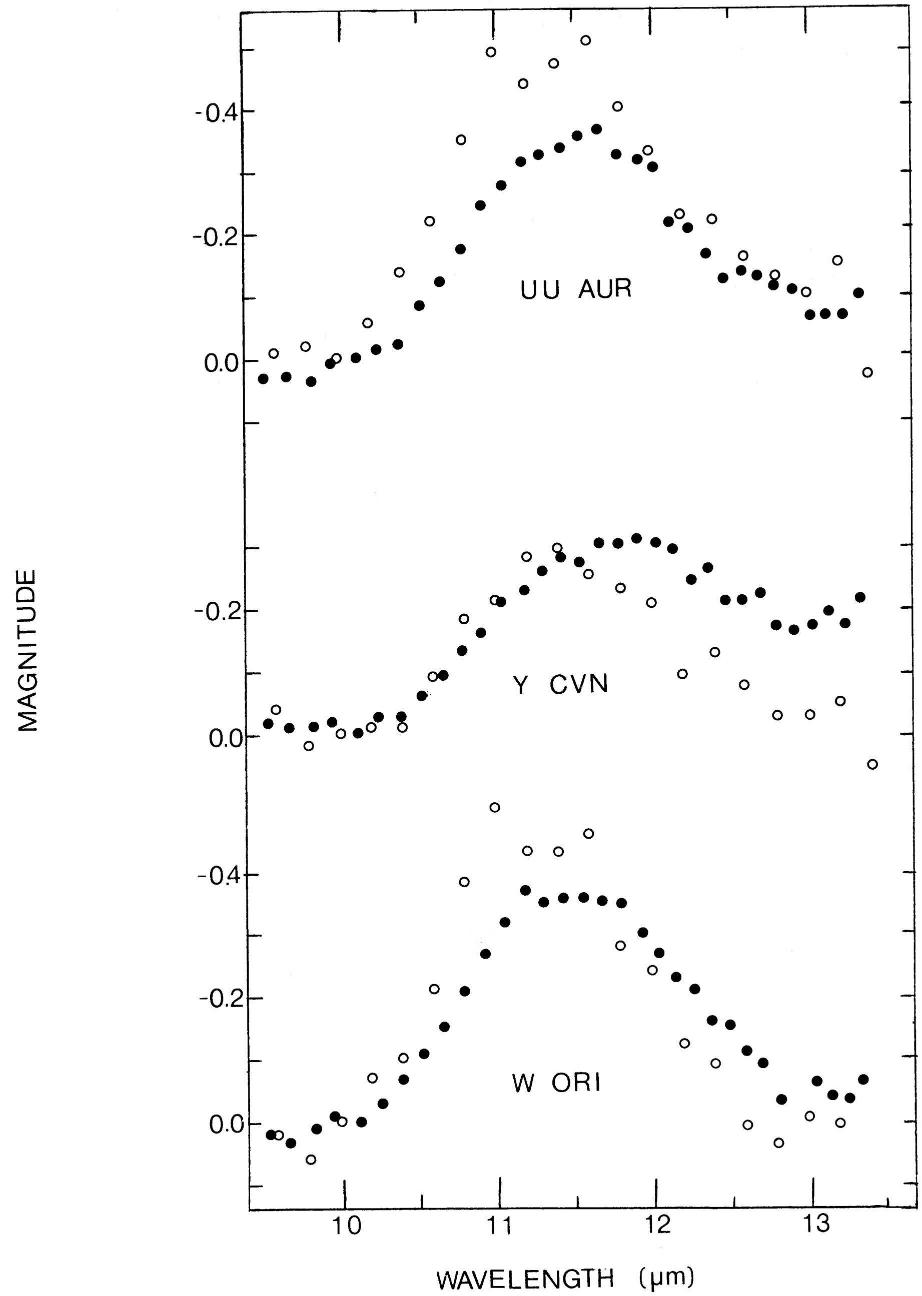


FIG. 2.—A comparison of the *IRAS* low-resolution spectra (*dots*) and our Kitt Peak infrared spectra (*open circles*) for three stars. Each curve has been divided by a 2500 K blackbody.

ratio would be nearly constant. Table 4 shows, however, that F^{IR}/F^{v} varies by a factor of several thousand even for our limited sample of stars. Furthermore, the values of $F^{IR}/F^{v} > 1.0$ demonstrate that, for at least some stars, the 11.5 μm emission is largely powered by absorption *outside* the violet part of the spectrum. This is particularly true of U Cam, for which F^{IR}/F^{v} is nearly 80. This suggests that SiC is a relatively minor violet absorber, especially in the stars that have F^{v}/F^{IR} of order unity or less, unless the absorption begins at wavelengths longer than 4250. Å. Further correlation checks were made between the 11.5 μm emission and other measurements of violet opacity, such as $(B-V)$ color and the gradient of the flux curves presented above. No correlations were discovered. *We conclude that SiC is not the dominant violet opacity source.*

IV. CONCLUSIONS

(1) The violet photometry presented here, although it does not agree quantitatively with some previous spectrophotometry, may be reconciled with C_3 being the violet opacity source. However, *IUE* spectra show that the flux continues to decrease dramatically toward shorter wavelengths in the ultraviolet. Therefore, though C_3 may be an important opacity source longward of 3500 Å, there is still a continuing flux deficiency in

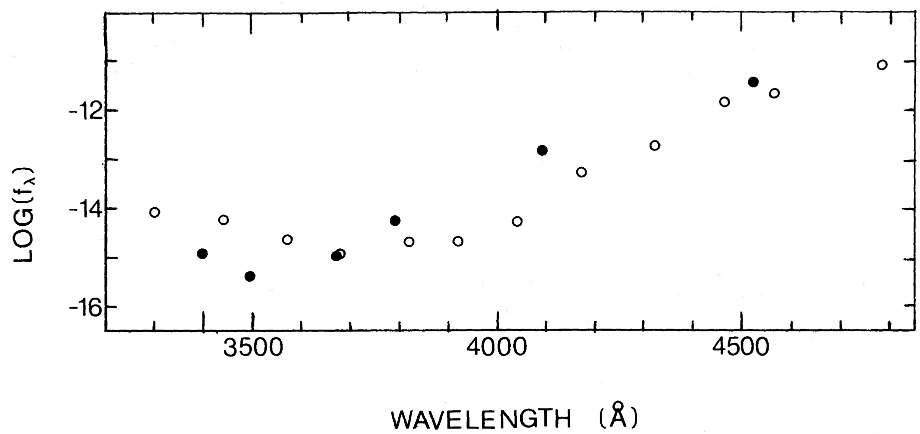


FIG. 3.—Y CVn: Our violet photometry (*dots*) compared to the spectrophotometry of Bregman and Bregman (*open circles*). The Bregmans' observations were shifted vertically to match our fluxes near 4500 Å.

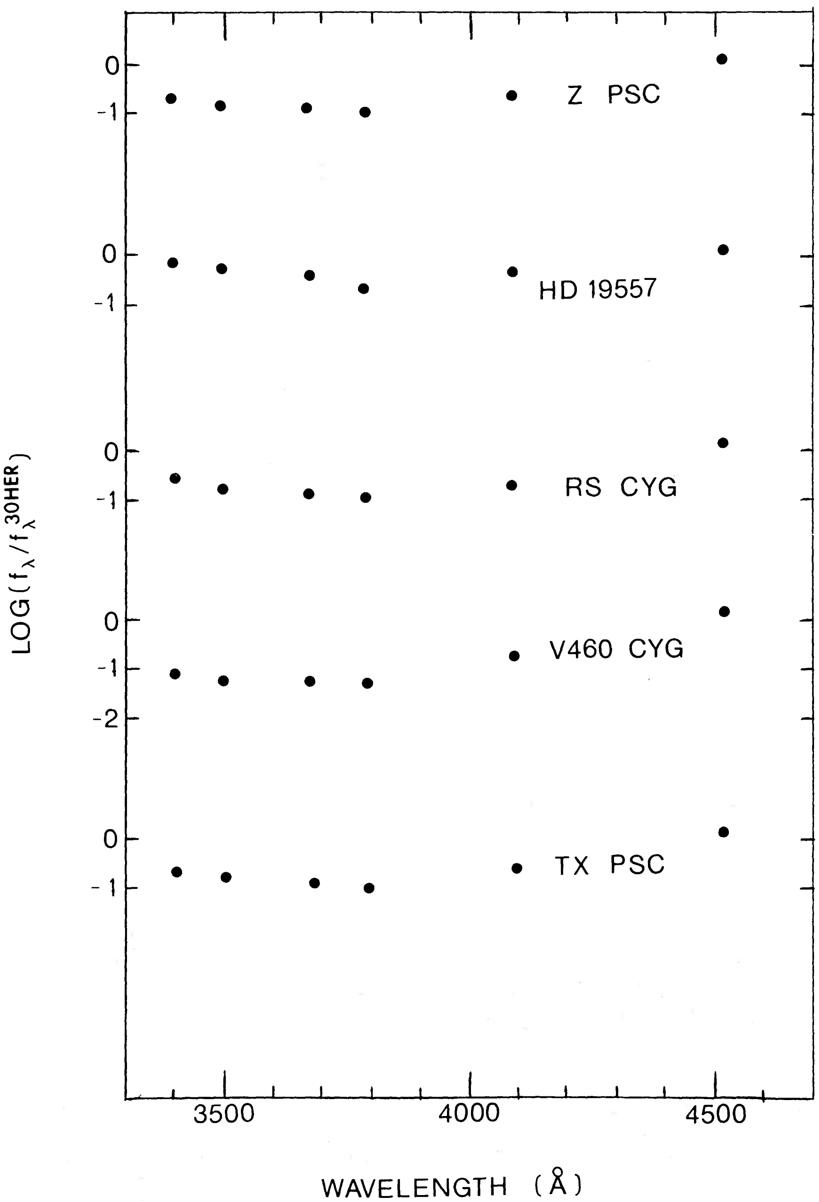


FIG. 4.—The violet fluxes of five stars divided by the flux of 30 Her. Each curve is normalized at 4520 Å.

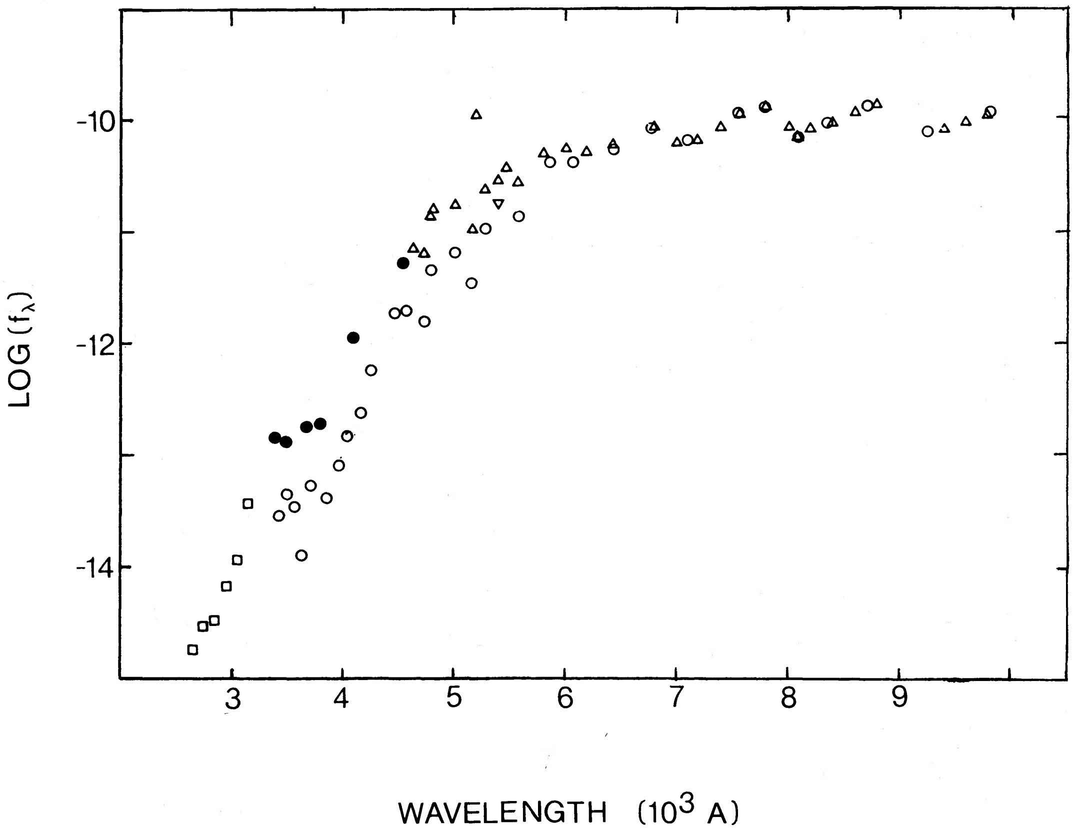


FIG. 5.—A comparison of calibrated spectrophotometry of TX Psc. The dots represent our violet data, the open squares represent fluxes from *IUE* spectra, the open circles represent the spectra of Fay and Honeycutt (1972), and the triangles represent a flux curve of Cochran (1980).

the ultraviolet, possibly requiring an additional source of opacity. (2) The infrared observations permit direct measurement of emission from the SiC grains. There is no correlation between the flux emitted by SiC grains at 11.5 μm and the flux absorbed in the violet region, leading us to reject SiC grains as the predominant violet opacity source. To attempt to circumvent this conclusion by arguing that the SiC grains absorbing in the violet are not the same SiC grains that are emitting in the infrared, or are physically located in different atmospheric layers or regions, seems untenable simply because of the thermodynamic relation between absorptivity and emmissivity. Also, the hypothesis clearly stated in the literature is that SiC grains in a circumstellar envelope absorb violet radiation and reemit infrared radiation. This, we have shown, is not generally true. (3) We therefore conclude that the two commonly suggested violet opacity sources—C_3 molecules and SiC grains—are inadequate as presented. (4) We emphasize that at least some of opacity is in the photosphere.

One perplexing difficulty we had is that much published spectrophotometry is not calibrated, making comparison of observations at different epochs impossible. It is suggested that further observations consists of calibrated spectrophotometry and narrow and intermediate band photometry as presented here.

TABLE 4

COMPARISON OF INTEGRATED VIOLET FLUX DEFICIENCIES WITH INTEGRATED 11.5 μm EMISSION

Star	F^v	F^{IRAS}	F^{IRAS}/F^v	F^{KPIR}	F^{KPIR}/F^v
U Cam	1.7×10^{-11}	1.3×10^{-9}	78.	...	...
ST Cam	1.8×10^{-10}	2.0×10^{-10}	1.1	...	...
W Ori	1.6×10^{-10}	1.2×10^{-9}	7.6	1.3×10^{-9}	8.1
UU Aur	8.2×10^{-10}	1.1×10^{-9}	1.3	1.5×10^{-9}	1.8
RY Mon	...	6.4×10^{-10}	...	...	...
X Cnc	2.2×10^{-10}	3.5×10^{-12}	0.016	...	...
Y Hya	4.2×10^{-11}	...	...	5.1×10^{-10}	12.
U Hya	8.6×10^{-10}	...	...	2.3×10^{-9}	...
VY UMa	...	1.8×10^{-13}	...	...	...
SS Vir	3.8×10^{-11}	1.4×10^{-10}	3.7	1.1×10^{-9}	29.
Y CVn	1.1×10^{-9}	5.9×10^{-10}	0.55	1.2×10^{-9}	1.1
RY Dra	2.2×10^{-10}	1.0×10^{-10}	0.46	...	...
V460 Cyg	3.8×10^{-10}	6.8×10^{-11}	0.18	...	...

We thank Don Hayes and Dick Joyce for assistance in making the observations. We also thank Paula Jentgens for typing the many revisions of this paper. This research was partially supported by NSF grant AST 82-05800 and by the Wrubel Computing Center of Indiana University, and that support is gratefully acknowledged.

REFERENCES

Alksne, Z. K., and Ikaunieks, Ya. Ya. 1983, *Carbon Stars*, transl. J. H. Baumert (Tucson: Pachart).
Barnes, J. V., and Hayes, D. S. 1984, *Kitt Peak IRS Standard Star Manual.*
Bregman, J. D., and Bregman, J. N. 1978, *Ap. J. (Letters)*, **222**, L41 (B & B).
Cochran, A. L. 1980, *Univ. Texas Pub. Astr.*, No. 16.
Dupree, A. 1986, *Ann. Rev. Astr. Ap.*, **24**, 377.
Fay, T., and Honeycutt, R. K. 1972, *A.J.*, **77**, 29.
Forrest, W. J., Gillett, F. C., and Stein, W. A. 1975, *Ap. J.*, **195**, 423.
Gilman, R. C. 1969, *Ap. J. (Letters)*, **155**, L185.
Gilra, D. P. 1973, in *IAU Symposium 52, Interstellar Dust and Related Topics*, ed. J. M. Greenberg and H. C. van de Hulst (Dordrecht: Reidel), p. 517.
Goebel, J. H., *et al.* 1980, *Ap. J.*, **235**, 104.
Goldberg, L. 1986, in *The M, S, and C Stars*, NASA-CNRS series on *Non-Thermal Phenomenon in Stellar Atmospheres*, ed. H. R. Johnson and F. Querci, NASA-SP in press.
Hackwell, J. A. 1972, *Astr. Ap.*, **21**, 239.
Iben, I. 1974, *Bull. A.A.S.*, **6**, 316.
———. 1975*a*, *Ap. J.*, **196**, 525.
———. 1975*b*, *Ap. J.*, **196**, 549.
———. 1976, *Ap. J.*, **208**, 165.
———. 1982, *Ap. J.*, **260**, 821.
———. 1984, in *IAU Symposium 105, Observational Tests of the Stellar Evolution Theory*, ed. A. Maeder and A. Renzini (Dordrecht: Reidel), p. 3.
Iben, I., and Renzini, A. 1983, *Ann. Rev. Astr. Ap.*, **22**, 271.
Jaschek, C. 1985, in *Cool Stars With Excesses of Heavy Elements*, ed. M. Jaschek and P. C. Keenan (Dordrecht: Reidel), p. 333.
Johnson, H. L., Mitchell, R. I., and Latham, A. S. 1967, *Comm. Lunar and Planetary Lab.*, **6**, 85.
Johnson, H. R., Baumert, J. H., Querci, F., and Querci, M. 1986, *Ap. J.*, **311**, 960.
Johnson, H. R., and O'Brien, G. T. 1983, *Ap. J.*, **265**, 952.
Johnson, H. R., and Luttermoser, D. G. 1987, *Ap. J.*, **317**, 329.
King, A. S., and Swings, P. 1945, *Ap. J.*, **101**, 6.
Little-Marenin, I., and Wilton, C. 1986, *Fourth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun*, in press.
McKellar, A., and Richardson, F. H. 1955, *Mem. Soc. Roy. Sci. Liège*, **15**, 526.
Mould, J., and Aaronson, M. 1986, *Ap. J.*, **303**, 10.
Querci, F. 1986, in *The M, S, and C Stars*, NASA-CNRS series on *Non-Thermal Phenomena in Stellar Atmospheres*, ed. H. R. Johnson and F. Querci, (NASA-SP) in press.
Querci, F., Querci, M., Wing, R. F., Cassatella, A., and Heck, A. 1982, *Astr. Ap.*, **111**, 120.
Scalo, J. M. 1981, in *Physical Processes in Red Giants*, ed. I. Iben and A. Renzini (Dordrecht: Reidel), p. 77.
Shajn, G., and Struve, O. 1947, *Ap. J.*, **106**, 86.
Shane, C. D. 1928, *Lick Obs. Bull.*, **13**, 123.
Treffers, R., and Cohen, M. 1974, *Ap. J.*, **188**, 545.
Utsumi, K. 1985, in *Cool Stars with Excesses of Heavy Elements*, ed. M. Jaschek and P. C. Keenan (Dordrecht: Reidel), p. 243.
Walker, A. R. 1976, *M.N.R.A.S.*, **174**, 609.

Danny R. Faulkner: Physics Dept., University of South Carolina-Lancaster, Lancaster, SC 29720

R. Kent Honeycutt and Hollis R. Johnson: Department of Astronomy, Swain Hall West 319, Indiana University, Bloomington, IN 47405

Note added in proof.—Recently, Orlati (*Ap. J.*, **317**, 819 [1987]) also concluded, from a study of the Balmer decrement in a few carbon-rich mira variable stars, that the source of the violet opacity was not grains and probably not molecules, but was located fairly deeply in the photosphere.