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MAIN-SEQUENCE B STARS WITH STRONG WINDS IN THE CORE OF NGC 6231

DERCK MASSA,[1] BLAIR D. SAVAGE,[1] AND JOSEPH P. CASSINELLI
Washburn Observatory, University of Wisconsin-Madison
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ABSTRACT

Low-dispersion *IUE* observations of 13 main sequence B0–2 stars in the Sco OB1 association are presented. Eleven of these are in the rich open cluster NGC 6231. Most of the NGC 6231 stars have strong UV resonance lines which are inconsistent with either their spectral types or the rest of their UV spectra. Consequently, these spectra lie outside the usual two-dimensional (temperature—luminosity) spectral grid. A high-dispersion *IUE* spectrum of one of the peculiar stars, CPD $-41°7719$, reveals an abnormally strong wind ($\dot{M} > 4 \times 10^{-9}$ $M_\odot$ yr^{-1}) with an unusual velocity law. Attributing all of the peculiar low-dispersion UV spectra to such winds, we present evidence that these winds *are not* related to either large rotational velocities or abnormally strong atmospheric magnetic fields. On the other hand, several of the OB supergiants in Sco OB1 are known to be chemically peculiar. This, in conjunction with theoretical considerations, leads us to conclude that an overabundance of carbon (and possibly other elements) by 3–5 times solar is responsible for the strong winds of the main-sequence B stars. Because the UV wind lines of these stars are unsaturated, they may be very sensitive to abundances, with their strengths scaling as abundance squared.

The spatial distribution of the peculiar stars in Sco OB1 is very localized, being confined to the core of NGC 6231. This suggests that the primordial cloud complex which formed the Sco OB1 stars was either not completely mixed or else developed a chemical inhomogeneity during the star forming process. In either case, the observations imply that composition gradients can exist within a given molecular cloud complex.

Subject headings: clusters: open — stars: abundances — stars: early-type — stars: winds — ultraviolet: spectra

I. INTRODUCTION

In contrast with the visual, the UV spectra of early main-sequence B stars are rich in strong metallic lines, especially those of C, Si, Fe, and Al. Therefore, the UV spectra of B0–2 V stars (B V's hereafter) provide an excellent data base to search for abundance differences from one star to another. However, the only high-resolution UV studies of B V's thus far have been restricted to stars in the solar neighborhood (Snow and Jenkins 1977; Kamp 1982; Underhill and Doazan 1982).

Even at optical wavelengths, high-resolution ($\lambda/\Delta\lambda \gtrsim 10^4$) spectral studies of normal B V's have focused on nearby objects (see Auer and Mihalas 1973; Kamp 1978; and references therein). Consequently, the only available large-scale survey data for distant B V spectral lines are MK spectral classifications and various measures of H I and He I line strengths. Quantative information about line strengths of other elements is lacking. This is not suprising since only He I and H I have strong lines in the visual spectra of B V's.

During year 5 of *IUE*, we obtained low-dispersion observations of B V's in a number of open clusters and associations. Our goal was to determine the UV extinction to these regions. In the process, we discovered that several of the B V's in one cluster, NGC 6231, have exceedingly strong C IV 1550 Å and Si IV 1400 Å features for their spectral types. This prompted us to obtain a high-resolution spectrum for one of these stars, CPD $-41°7719$, during year 6 of *IUE*. These observations are the basis of the current work.

In § II we present *IUE* spectra of B V's in Sco OB1 and compare them to observations of local B stars with similar spectral types. In § III we analyze the resonance line profiles of a high-dispersion spectrum of CPD $-41°7719$ and deduce that they result from a stellar wind with some unusual properties and a large mass loss rate for a B V. In § IV we examine some possible causes of such a wind and conclude that an overabundance of carbon is the most likely origin. We then discuss how the postulated abundance anomaly could originate and consider some implications of our results.

II. DATA AND RESULTS

In this section, we present both high- and low-dispersion *IUE* data for early main-sequence B stars (B V's) in Sco OB1. Table 1 lists some basic photometric and spectroscopic data for the stars that will be used as standards which are mainly from the Wu *et al.* (1983) *IUE* Spectral Atlas. Table 2 presents data for the program stars. Column (1) lists HD or CPD numbers, and column (2) gives the numbers assigned by Braes

TABLE 1

STANDARD STARS

HD/Name	Sp[a]	V	$B-V$	c_0[b]	β	$E(B-V)$	C[c]
υ Ori	B0 V	4.62	−0.26	−0.09	2.598	0.04	11.25
HD 31726 ...	B1 V	6.15	−0.21	0.05	2.634	0.05	11.25
HD 64802 ...	B2 V	5.49	−0.19	0.23	2.658	0.05	10.25
HD 63922 ...	B0 III	4.11	−0.18	−0.09	2.592	0.12	11.25
HD 91983 ...	B1 III	8.59	+0.05	−0.01	2.587	0.31	12.75
HD 51283 ...	B2 III	5.28	−0.19	0.15	2.589	0.05	10.25

[a] Spectral types, B, V photometry and $E(B-V)$'s are from the Wu *et al.* 1983 *IUE* Spectral Atlas except for HD 91983, whose data are from Turner *et al.* 1980.

[b] *uvby*-β data are from Crawford, Barnes, and Golson 1970, 1971*a*, *b* or Shobbrook 1980 and the c_0 data are derived as in Crawford *et al.* 1971.

[c] See Fig. 1.

[1] Guest Observer with the *International Ultraviolet Explorer* which is sponsored and operated by the National Aeronautics and Space Administration, the Science Research Council of the United Kingdom, and the European Space Agency.

TABLE 2

PROGRAM STARS

HD/CPD (1)	Braes (2)	Sp[a] (3)	Sp[b] (4)	V^c (5)	$B-V$ (6)	c_0 (7)	β (8)	$E(B-V)$ (9)	C^d (10)	UV Spectral Peculiarities (11)
326309	650	...	...	10.02[e]	0.24[e]	0.02	2.630	0.50	13.50	no
326330	672	B0.5 V	B1 V(n)	9.41	0.19	−0.05	2.615	0.45	16.00	yes
326332	674	B0.5 V	B1 III	9.70	0.24	−0.03	2.635	0.50	14.75	no
326364	703	B0 IV[f]	...	9.62	0.35	−0.12	2.605	0.65	17.00	no
−41°7711	930	B2:V:nn	B2:V:+B2:V:	9.80	0.17	0.07	2.614	0.41	17.25	no
−41°7719	934	B1 V	B1 V	9.47	0.13	−0.01	2.624	0.39	16.25	yes
−41°7724	937	B0.5 V	B0.5 V	9.50	0.14	−0.04	2.608	0.42	15.25	yes
−41°7727	939	B1 V	B0.5 V	9.44	0.15	0.01	2.627	0.43	15.50	yes
−41°7730	940	B1 V	B1 V	9.29	0.17	0.03	2.635	0.43	14.75	yes
−41°7736	943	B1 Vn	...	10.21	0.26	0.10	2.626	0.52	14.50	yes
−41°7743	946	B0.5 V	B0.5 V	9.76	0.25	−0.02	2.629	0.53	14.00	yes
−41°7753	948	B1 V	...	9.83	0.25	−0.02	2.612	0.51	13.50	no
... .	1017	B2 IV–V	...	10.64	0.23	0.16	2.649	0.47	13.25	yes

[a] Spectral types from either Schild, Hiltner, and Sanduleak 1969, Schild, Neugebauer, and Westphal 1971, or Garrison and Schild 1979.
[b] Spectral types from high-dispersion (39 Å mm^{-1}) data (Levato and Malaroda 1980).
[c] Mean photometric data are from the sources listed in note a.
[d] See Fig. 2.
[e] Photometry is from Houck 1956, transformed to the standard *B* and *V* systems as described by Bok, Bok, and Graham 1966.
[f] Spectral type from Houck 1956.

(1967). Columns (3)–(8) list visual data from different investigators. The intrinsic *ubvy*-β data are taken directly from Crawford *et al.* (1971). Column (9) gives the color excesses derived from the spectral types, column (10) lists the constants which are added to the spectra shown in Figure 2, and column (11) notes if the UV spectra are peculiar.

All but two of the program stars, HD 326309 and HD 326364, are within 4′ of HD 326329 which roughly defines the center of the luminous members of NGC 6231.

a) The Low-Dispersion Spectra

Figure 1 shows the low dispersion SWP data for the standards listed in Table 1. Figure 2 is a similar plot of the program stars. The spectra have not been corrected for interstellar extinction or H I Lyman-α absorption. The latter causes considerable spectral distortion over the interval 1180–1250 Å in the program stars. Table 3 is the *IUE* observing log for the program stars.

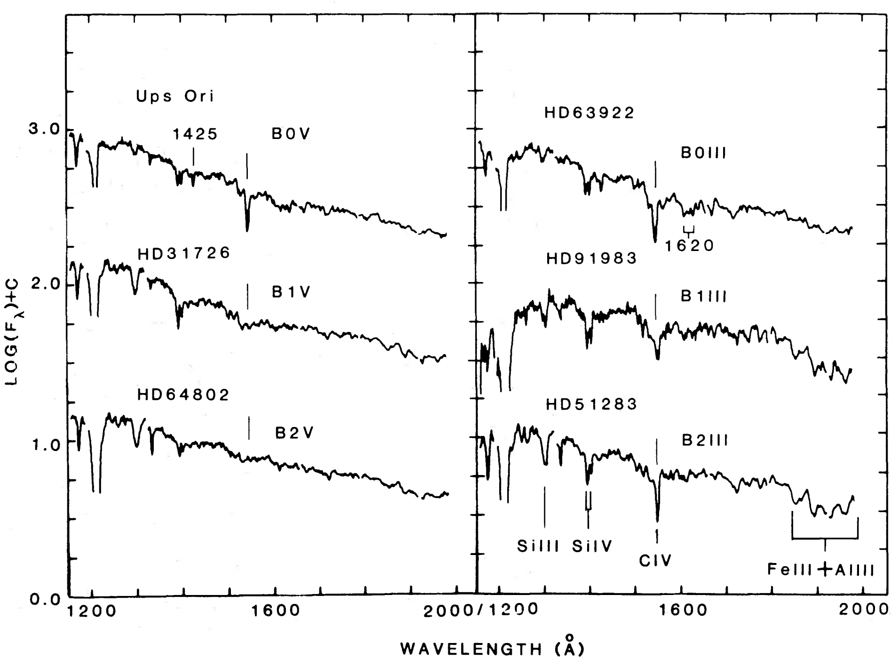

FIG. 1.—Low-dispersion *IUE* spectra for the standard stars. These are from the Wu *et al.* (1983) *IUE* Spectral Atlas except for HD 91983 because the spectrum of the Wu *et al.* B1 III standard was unavailable. Some of the major features are indicated. Notice that the minimum of the C IV line is always at 1550 Å for those spectra with strong C IV absorption. Although C III 1175 Å is well defined for the standards, it is usually poorly exposed in the spectra of reddened stars. The C II line at 1335 Å is contaminated by interstellar absorption in reddened stars. Constants, listed in Table 1, are added to the individual spectra for display purposes.

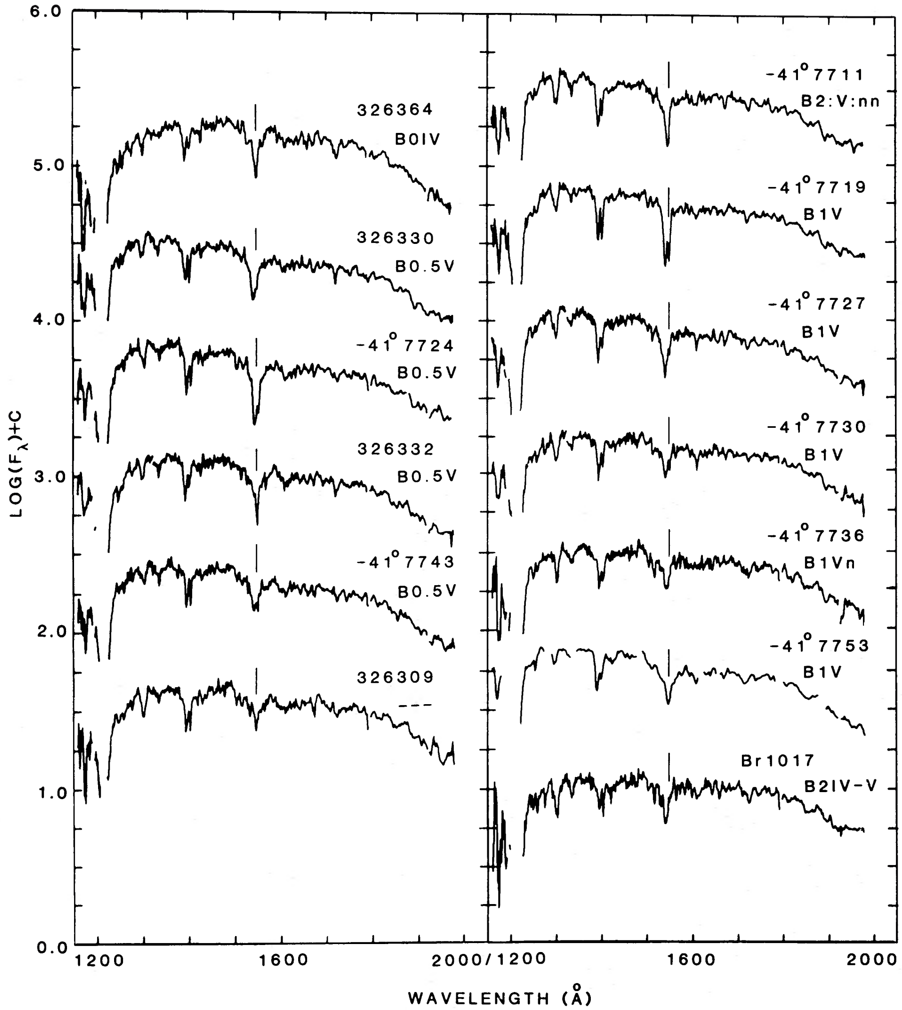

FIG. 2.—Low-dispersion spectra for the program stars. HD or CPD numbers and spectral types are shown, as is the normal position of C IV absorption. The spectrum of CPD −41°7753 was processed prior to 1980 November 3. As a result, it is sampled at half the frequency of the other spectra (Bohlin, Lindler, and Turnrose 1981). Constants, listed in Table 2, are added to the individual spectra for display purposes.

Classification of B0–2 class III–V stars by their low-dispersion *IUE* spectra is generally straightforward and unambiguous. The major useful classification features are the following: the 1300 Å feature due to five strong Si III lines (see § II*b*, Fig. 3) which strengthens for later types; the Si IV 1393.8, 1402.8 Å doublet which reaches maximum strength at B1 and strengthens with increasing luminosity; the 1425 Å feature due to several unidentified lines which are present only at B0–0.5; the C IV 1548.2, 1550.8 Å doublet which is unresolved and strengthens for earlier and more luminous types; the unidentified 1620 Å depression which increases with increasing luminosity for B0–0.5; the 1900 Å feature due to several lines mostly from Al III and Fe III and which strengthens with increasing luminosity at B1–2.

A cursory comparison of the spectra in Figures 1 and 2 reveals gross spectral differences between many of the Sco OB1 B stars and the standards. The spectra of HD 326309 and HD 326364 can be easily placed within the grid defined by the standards. Those of HD 326332, CPD −41°7711, and CPD −41°7753 have very strong C IV absorption but weak 1900 Å or 1620 Å features. However, because C IV absorption may obtain maximum strength for luminosities very near class V while the other luminosity sensitive features may not strengthen except for luminosities very near class III, we consider these spectra normal, indicating luminosities intermediate between class V and III. However, the remaining Sco OB1 stars have spectra which are not intermediate between the standards. The Si IV 1400 Å feature is usually too strong and the C IV 1550 Å feature is always too strong for the corresponding Si III 1300 Å blend or MK spectral type. Frequently, the C IV feature is very broad (HD 326330, CPD −41°7727, CPD −41°7743) and sometimes distinctly double with an extra component near 1540 Å (CPD −41°7719, CPD −41°7724). In some cases (CPD −41°7730, CPD −41°7736, Br 1017), the C IV feature occurs near 1540 Å instead of 1550 Å. Although absorption by interstellar ions can affect low-dispersion spectra, this does not seem to be the case here (see § II*b*).

We must now decide which UV lines are peculiar, i.e., do these stars have normal Fe III + Al III or 1620 Å features and anomalously strong resonance lines or do they have normal resonance lines and anomalously weak luminosity sensitive features. We adopt the first description for the following three reasons. First, the MK classifications of the stars suggest that they are normal main-sequence stars. Second, the stars with

TABLE 3

IUE OBSERVING LOG

Name	*IUE* Image Nos.	Aperture	Exposure Time (s)
HD 326309	SWP 17134, 17895	L, L	470, 560
	LWR 14132	L	390
HD 326330	SWP 16593	L+S	200+350
	LWR 12829	L+S	120+1000
HD 326332	SWP 19381	L	400
	LWR 15417	L	260
HD 326364	SWP 17133, 17892	L, L	440, 450
	LWR 13423, 14129	L, L	290, 360
CPD −41°7711	SWP 16606	L+S	400 + 600
	LWR 12846	L+S	250+1700
CPD −41°7719	SWP 16595	L+S	330+550
	LWR 12831	L+S	190+1400
CPD −41°7724	SWP 17897	L	300
	LWR 15415	L	190
CPD −41°7727	SWP 19382	L	350
	LWR 15418	L	190
CPD −41°7730	SWP 19380	L	350
	LWR 15416	L	190
CPD −41°7736	SWP 17131, 17894	L, L	560, 630
	LWR 13421, 14131	L, L	350, 525
CPD −41°7743	SWP 17907, 17909	L, L	600, 390
	LWR 14139, 15439	L, L	285, 300
CPD −41°7754	SWP 2762	L	720
	LWR 2464	L+S	600+600
Braes 1017	SWP 17129, 17893	L, L	1000, 1140
	LWR 13419, 13420 14130	L, L, L	350, 700, 1050

peculiar UV spectra lie on the main sequence of NGC 6231 in both MK type versus V_0 and c_0 versus β diagrams (Garrison and Schild 1979; Shobbrook 1983). Third, in most cases the resonance line profiles are peculiar for any spectral or class seen in the Wu *et al.* atlas. We conclude, therefore, that we are dealing with a group of stars that are on or near the main sequence but which have abnormally strong resonance-line absorption.

b) The High-Dispersion Spectra

i) *The Stellar Spectrum*

Motivated by the low-dispersion results, we obtained a high-dispersion SWP spectrum of CPD −41°7719 (*IUE* image sequence number SWP 19396). The low-dispersion spectrum of this star (Fig. 2) shows two distinct absorption components near C IV—one at the usual 1550 Å position and the other at 1540 Å.

Figure 3 shows portions of the high-dispersion spectrum of CPD −41°7719 along with the normal B0.7 V (Walborn 1972) star 40 Per for comparison. Aside from their resonance lines, the two spectra are very similar. The isolated narrow lines, such as the Si III 1300 Å multiplet and Si III 1417 Å, are slightly more broadened by rotation in CPD −41°7719 than in 40 Per ($v \sin i = 60$ km s^{-1}; Slettebak and Howard 1951). A $v \sin i$ of about 150 km s^{-1} was determined for CPD −41°7719 by comparing its Si III profiles to those of other early B stars at our disposal.

The resonance lines of 40 Per show some effects of mass loss. Although the asymmetry of its C IV doublet near line center is due to several strong Fe III absorption lines in the region, it may have a weak violet wing extending shortward of 1540 Å. Its Si IV 1400 Å doublet also appears to be affected by a wind. The maximum between the doublet occurs slightly closer to the violet line than in later B stars. Because the violet component has an oscillator strength twice that of the red component, the implication is that the red wing of the violet line is partially filled in by emission from a wind and that violet wing of the red line is affected by absorption in a wind. Together, these effects shift the position of the interdoublet maximum to shorter wavelengths.

The obvious difference between the two spectra in Figure 3 is the strength of the resonance doublets of Si IV, C IV, and Al III. These are clearly stronger and more asymmetric in CPD −41°7719. Furthermore, the red component of the C IV doublet drops to about 0.1 residual intensity. Although the core of the 1548.2 Å component is contaminated by a cosmic-ray hit, its uncontaminated wings suggest a similar structure. The feature which appeared near 1540 Å in the low-dispersion spectrum is now clearly revealed as a broad absorption trough with a sharp edge near 1537 Å. Neither star has N V 1240 Å absorption.

ii) *The Interstellar Spectrum*

The interstellar (IS) spectrum of CPD −41°7719 also deserves comment. The IS O I and Si II lines near 1300 Å are not unusually broad or shifted. These lines are already saturated in stars like ζ Pup (Morton 1978) whose color excess is less than 0.05 mag. As a result, the IS contribution of O I and Si II to the low-dispersion Si III 1300 Å blend in the Sco OB1 stars (Fig. 2) should not be significantly larger than in the lightly reddened standards shown in Figure 1.

It is difficult to determine the IS contribution to Si IV, C IV, and Al III in a star with strong photospheric lines like CPD −41°7719. Therefore, we measured the IS absorption due to these ions in a high-dispersion spectrum of the O7f star HD 152248 obtained from the *IUE* data bank. HD 152248 is in the core of NGC 6231. Its C IV and Si IV resonance lines have classical P Cygni profiles with emission filling in the line

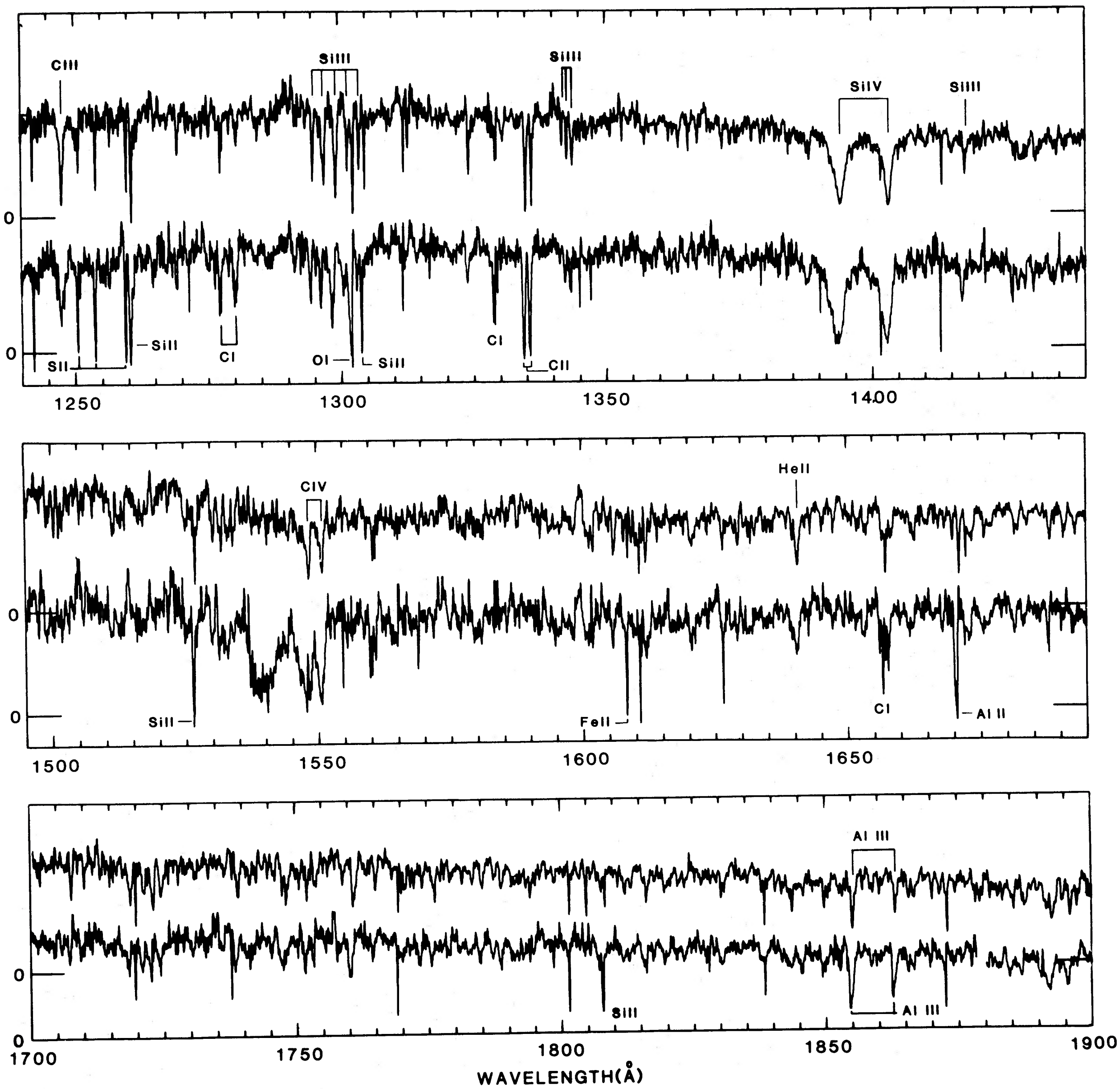

FIG. 3.—High-dispersion *IUE* spectra of the NGC 6231 B1 V star CPD −41°7719 (*bottom*) compared with one for the normal B0.7 V star 40 Per (*top*). Both spectra have been smoothed by a 0.1 Å FWHM Gaussian filter. A few stellar features are indicated above the spectra and some interstellar lines are identified below them. Fe III lines are not indicated because there are so many of them that identifications would make the figure unduly cluttered. The core of the 1548.2 Å component of the C IV doublet in CPD −41°7719 is contaminated by a cosmic-ray hit.

centers and photospheric Al III should not be present in an O7 star. Consequently, there is little problem separating its IS and stellar features. The equivalent widths of the C IV 1548.20, 1550.77 Å doublet are about 120 and 60 mÅ, and those of the Si IV 1393.76, 1402.77 Å doublet are about 100 and 50 mÅ. In each case, the residual intensity is always more than 50%. These results suggest that the IS contribution to the strong C IV and Si IV profiles in the CPD −41°7719 spectrum should be insignificant. On the other hand, the equivalent widths of the Al III 1854.72, 1862.80 Å doublet are about 220 and 110 mÅ. Because this amounts to about one-third of the total Al III equivalent width in CPD −41°7719, we consider this doublet too contaminated by absorption from IS gas to be analyzed further.

III. ANALYSIS

The feature at 1540 Å appears to be a P Cygni absorption trough due to C IV in a wind. Its bluest extent implies a velocity of about 2,300 km s^{-1} which is similar to the terminal velocity of the B0 V star τ Sco (Lamers and Rogerson 1978) and its shape resembles a P Cygni absorption profile, having a gradual increase in absorption with decreasing wavelength terminated by a sharp cutoff at the shortest wavelength. In addition, because the Si IV and C IV profiles near rest velocity are asymmetric and very strong, it is clear that CPD −41°7719 has an abnormally strong wind for a B1 V. Therefore, it seems natural to connect the feature at 1540 Å with this wind. We assume, therefore, that the absorption trough at 1540 Å is a P Cygni feature due to C IV and analyze it as such.

The model for doublet formation developed by Olson (1982) is used to fit the observations. This model is based upon the standard assumptions that the wind is spherically symmetric and has a monotonic velocity law. Lucy (1983) has described the effects of a nonmonotonic velocity law. However, because Olson's model gives an adequate fit to the observations, there is no justification for the additional complexity of a nonmonotonic velocity law in our case.

It is possible to anticipate the quantitative results with a qualitative analysis of the observed C IV profile. The first thing to notice is that although considerable wind absorption is apparent, there is little, if any, evidence of emission at wavelengths longward of 1550.77 Å. Within the bounds of the standard models, the only way to suppress such emission is to occult the emitting gas by the star. This means that the C IV ions must be confined to a very thin layer near the stellar surface. Furthermore, because the absorption occurs at large velocity, the wind must reach high velocity very near the stellar surface. This structure implies that a very steep velocity law will be required to explain the observations.

Model profiles for the C IV and Si IV doublets are shown in Figure 4. Details of the fitting proceedure and the physical parameters implied by the model are given in the Appendix. The fits are considered quite good given the simplicity of the model. Mass loss rate information is discussed in § IV*c*. The point we wish to stress is that it is possible to produce accurate facsimiles of the observed profiles by assuming that they originate in a stellar wind with reasonable physical properties.

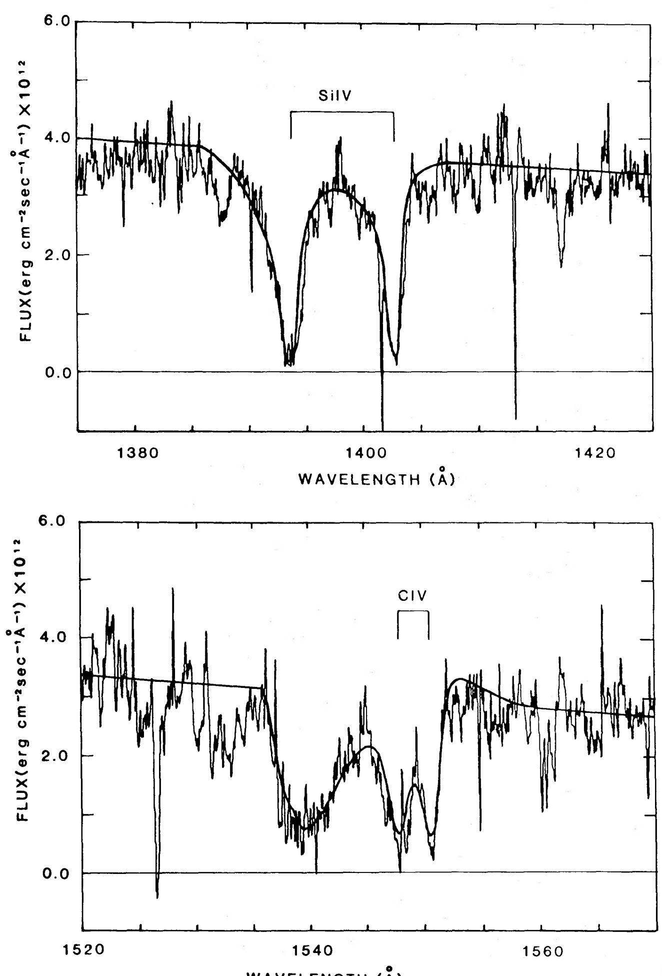

FIG. 4.—Fits from Olson's (1982) model for doublet formation in a stellar wind to the Si IV and C IV doublets of CPD −41°7719. The model fit implies a mass loss rate of *at least* 4×10^{-9} $M_{\odot}$ yr^{-1} with a terminal velocity of 2,300 km s^{-1} (see Appendix).

IV. DISCUSSION

Throughout this discussion, we assume that the peculiar C IV profile in the spectrum of CPD −41°7719 is due to an enhanced stellar wind. We also assume that the other Sco OB1 B V's with peculiar low-resolution UV spectra (see Table 2) also have abnormally large mass loss rates for their spectral types.

We begin the discussion with a summary of some results from a study of the UV continua of luminous OB stars in clusters by Massa and Savage (1984) and present a spatial plot of the B V's in NGC 6231. We then examine what physical mechanisms could explain the observations, emphasizing chemical abundances as the most likely candidate. Finally, we discuss how enrichments of certain atomic species might occur in a very localized region of space.

a) Spatial Distribution of Peculiar Stars in NGC 6231

Massa and Savage (1984) have studied the UV continua of luminous OB stars in clusters. Their approach uses the B V's in a cluster to determine the form and variability of the UV extinction to each cluster and then employs the resulting extinction curve to deredden the luminous cluster members—provided the reddening is well behaved. The following result from their work has a direct bearing on the current discussion. The shapes of the UV extinction curves derived from the NGC 6231 B V's have a dispersion which can be completely attributed to random errors. The curve shapes do not depend on whether or not the stars used to derive them have the spectral peculiarities described in § II. This result implies that the physical agent affecting the line spectra of the B V's is not modifying their continuous energy distributions, otherwise they would produce different curves.

Figure 5 shows the distribution on the sky of the B stars observed at low dispersion with *IUE*. The open triangles denote B V's with normal UV line spectra and filled triangles those with strong C IV absorption (see Table 2). A projected distance of 1 pc is also shown for a distance modulus of 11.5 mag (Crawford *et al.* 1971). The apparently normal B V's HD 326309 and HD 326364 are off the figure to the north and southwest, respectively. The figure is centered on HD 326329 which is the centroid of the bright cluster members. The centroid of all the cluster members lies to the northwest of this (Seggewis 1968) and is denoted by a cross. The concentration of peculiar stars in a small region of space is very striking.

b) Possible Causes of the Spectral Peculiarities

The spectra presented in Figures 2 and 3 do not fit into the usual effective temperature-surface gravity (or inferred mass and age) grid of normal stellar spectra. Consequently, other physical mechanisms must be invoked to account for their appearance. Three obvious candidates are magnetic fields, stellar rotation, and chemical composition. The following discussion presents observational evidence which might indicate abnormalities in these parameters.

Magnetic Fields.—Strong magnetic fields are known to affect the visual spectra of B V's by producing specific pecu-

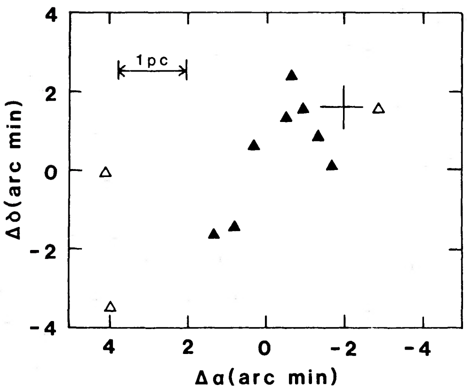

FIG. 5.—Distribution on the sky of the NGC 6231 B stars observed in low dispersion with *IUE*. The figure is centered on HD 326329 which roughly defines the centroid of the O and early B stars in the cluster. The cross denotes the cluster centroid determined from star counts. The open triangles represent main-sequence B stars with normal UV line spectra (this includes HD 326309 and HD 326364 which are beyond the boundaries of the figure; HD 326309 is 23′, 13 pc, to the north and HD 326364 is 32′, 19 pc, to the southwest) and the filled triangles those with peculiar UV line spectra. A clustering of the peculiar stars is apparent.

liarities. They are thought to be responsible for the helium strong spectra in early B V's and certain Bp spectra in late main-sequence B stars (Vauclair and Vauclair 1982). However, the spectra of the early B V's in NGC 6231 appear normal even at relatively high dispersion (Levato and Malaroda 1980). Furthermore, the investigation by Garrison and Schild (1979) was specifically designed to detect late Bp stars in NGC 6231 and they found only two peculiar stars (one helium weak star and one marginally peculiar silicon star) in a sample of eight B5–9.5 stars. Since only the silicon star would normally be associated with the presence of a strong atmospheric magnetic field, the incidence of magnetic stars in NGC 6231 is not extraordinary. As a result of these observations, a magnetic origin of the peculiar B V spectra is not considered likely.

Rotation.—Although no detailed rotational velocity study has been carried out for NGC 6231, $v \sin i$'s for some of the cluster O stars were measured by Conti and Ebbets (1977). These stars have typical rotation rates, as does CPD −41°7719 (see § II). In addition, the cluster contains only one known Be star (HD 326327; Levato and Malaroda 1980) and all of the program stars have normal β photometric indices for their spectral types (Crawford *et al.* 1971), indicating an absence of emission at Hβ. Since there is evidence that early B V's with rotational velocities greater than about 320 km s^{-1} become Be stars at some time (Massa 1975), it seems unlikely that the cluster members have unusually large rotational velocities. Thus, large rotation rates do not seem to be responsible for the observed spectral peculiarities.

Chemical Composition.—An overabundance of carbon would provide a straightforward explanation of the strong C IV resonance lines of the NGC 6231 B V's (both in the wind and near the rest velocity where there appears to be an abnormally strong photospheric contribution). In fact, Walborn (1976) lists seven chemically peculiar luminous OB stars in Sco OB1 and has noted a tendency for them to cluster near NGC 6231. Of these seven stars, five are moderately nitrogen deficient and two are strongly overabundant in carbon. Two stars in Walborn's sample are within the boundaries of Figure 5. These are the OC9.5 Iab star HD 152249 and the moderately nitrogen-deficient B0.5 Ia star HD 152234.

In contrast to luminous OB stars, Baschek and Scholz (1974) have shown that abundance anomalies larger than a factor of 3 in the atmospheres of main-sequence or giant early B and late O stars can escape detection by MK classification. Consequently, an abundance anomaly of this magnitude does not conflict with the normal MK classifications of the program stars. More recently, Lennon and Dufton (1983) have performed a quantitative analysis of 21 B V's near NGC 6231 and found a mean nitrogen deficiency in this sample. Unfortunately, only one of their stars, HD 326332, lies within the boundaries of Figure 5. This star was also observed with *IUE*, and its UV line spectrum appears normal (see Table 1). It should be noted that Lennon and Dufton also found a mean carbon overabundance in their sample which they attributed to observational error, and that Walborn (1976) has pointed out that a nitrogen defficiency is frequently accompanied by a carbon enhancement.

c) Consequences of Abundance Anomalies

We have already noted that an enhancement of carbon may explain the peculiar spectra of the NGC 6231 B V stars. Hutchings (1984) reviews how abundances less than solar might account for the weak wind lines observed in some supergiants in the Magellanic Clouds. In this section, we discuss some details of how abundances larger than solar might affect the winds of early B V's. In particular, we would like some idea of how large an abundance difference is implied by the C IV spectra of CPD −41°7719 and 40 Per and why CPD −41°7719 has such a rapidly accelerating wind. Abbott (1982) has demonstrated that for a radiatively driven wind, the mass loss rate, $\dot{M}$, scales as $(z/z_\odot)^{0.94}$, where z is the metal abundance. Thus, larger $\dot{M}$'s are expected for stars with larger metal abundances. For CPD −41°7719, the factor $z/z_\odot$ pertains mainly to the carbon abundance. This is because Abbott has shown that the line force for an early B star with an unsaturated, rapidly accelerating winds, such as CPD −41°7719, is dominated by carbon ions.

Abundance anomalies affect the observed spectrum of a wind line by changing the radial optical depth of the wind, $\tau_{\rm rad}$, which determines the character of the absorption caused by the wind (Castor and Lamers 1978). If we make the dubious assumption that the ion fraction in a wind does not differ for stars with different abundances, then $\tau_{\rm rad}$ is proportional to $A_E \dot{M}\ (vr^2 dv/dr)^{-1}$, where A_E is the atomic abundance of the element relative to hydrogen (see eq. [A2]). Thus, the optical depth of a line due to an overabundant element has a nearly $(z/z_\odot)^2$ dependence, while one due to an element with normal abundance has a nearly linear $z/z_\odot$ dependence due solely to the enhanced mass loss rate. With these results as a guide, we scaled the model used to fit the C IV profile of CPD −41°7719 by reducing the value of K in equation (A3) by a factor a^2 and the model photospheric profile by $a^{1/2}$ (this assumes that the C IV photospheric lines are on the damping portion of the curve of growth). Models with a between 3 and 5 bracket the C IV profile of 40 Per. Similarly, a reduction of K used to fit CPD −41°7719's Si IV line by 3 or more reduce the effect of the wind to less than 10% of the input residual intensity. This is a reasonable representation for 40 Per's Si IV profile which is only slightly affected by its wind (§ II*b*). Thus, abundance ratios for the two stars of about 3–5 for carbon and 1 for silicon are consistent with the observations. Other abundance differences may be present, but our approach only allows us to analyze elements with wind lines.

We should emphasize, however, that any difference in chemical composition between two stars can have profound effects on their wind structures, making a simple scaling of models inadequate. For example, the form of $v(r)$, and thus dv/dr, may be expected to respond to changes in the driving force which, in turn, is affected by abundances. Indeed, if a wind does not contain an ion with at least one optically thick line, then no supersonic solution to the wind equations is possible (Abbott 1980). A comparison of the winds of CPD $-41°7719$ and τ Sco may be relevent to this point. The mass loss rate derived for CPD $-41°7719$ is $>4 \times 10^{-9}\ M_\odot\ \mathrm{yr}^{-1}$ (see Appendix) which is larger than any of the B0–5 class III–V stars (with or without emission lines) studied by Snow (1982). This rate is, however, similar to that of the B0 V star τ Sco (Lamers and Rogerson 1978; Hamann 1981) which also appears to have an abnormally strong wind (Walborn and Panek 1984). Although these stars are both class V and have similar mass loss rates, their winds seem to have entirely different structures. For example, the velocity law adopted for CPD $-41°7719$ reaches 90% of its terminal velocity at $r/R_* = 1.09$ as opposed to 5.2 (Lamers and Rogerson) or 2.3 (Hamann) for models of τ Sco. One reason for this might be the strong photospheric C IV resonance lines in CPD $-41°7719$ coupled with the fact that carbon ions are thought to be the dominant source of the radiative driving force in its wind. This should result in a strong increase in the line force with distance from the photosphere as more photospheric flux becomes available to accelerate the wind once the absorption wavelength of the wind material is shifted away from the deep photospheric lines. Such a positive radial gradient in the line force can result in a very steep velocity law (Abbott 1980). In contrast, the wind of τ Sco shows absorption from *several* high stages of ionization such as N V and O VI. Since these ionic lines have only weak photospheric components, considerable radiative force is available to the wind material at low velocity. This causes the radiative force to be uniformly distributed throughout the wind resulting in a less steeply increasing velocity law. Until more is known about how the ionization structure of stellar winds is produced, it is impossible to comment on how τ_{rad} might be affected by the chemical composition of a wind. The preceding arguments lead us to believe that a carbon overabundance of 3–5 provides a reasonable explanation for the differences in the UV spectra of CPD $-41°7719$ and 40 Per.

The line spectra of main-sequence O stars are relatively insensitive to abundance effects. Consequently, Walborn's (1976) spectral criteria for abundance anomalies are most sensitive for evolved late-type O stars. Furthermore, because the C IV wind lines are saturated in most early or evolved O stars, they are insensitive to the mass loss rate (Lucy 1971). This makes a comparative analysis of the sort applied to CPD $-41°7719$ and 40 Per impossible.

d) Origin of the Abundance Peculiarities

Until now, abundance anomalies in massive stars have been easily detected only in evolved late O and early B stars (Walborn 1976). Inferences about the initial abundances of such stars are complicated by the fact, as Walborn points out, that their atmospheres may be contaminated by the products of nuclear burning. For B V's, however, atmospheric composition anomalies are probably a direct result of their initial composition (except for the He strong stars; see Vauclair and Vauclair 1982). It seems reasonable, therefore, to explain the concentration of peculiar B V's in NGC 6231 in terms of the material which formed them. NGC 6231 is located closer to the galactic center than the Sun and a galactic abundance gradient for carbon is expected although its determination by the analysis of visual emission lines from H II regions is very difficult (Peimbert 1979). Abundance determinations from the UV spectra of H II regions are potentially more reliable, but very few results are presently available (Dufour, Shields, and Talbot 1982). More recently, Dufour (1984) finds that the carbon abundance tends to scale as the square of the oxygen abundance. Thus, if we use Peimbert's result, $d \log (\mathrm{O/H})/dr = 0.09$ kpc^{-1}, and take 10 and 8 kpc for the galactocentric radii of the Sun and NGC 6231 respectively, then the ambient carbon abundance near Sco OB1 should be roughly twice solar. By the arguments of the previous section, an abundance of about 3–5 times solar is needed to produce the strong winds of the NGC 6231 B V's. Thus, it seems that a local enhancement of carbon of about 2 in the core of NGC 6231 is required to explain the observations.

It has been proposed that concentrations of chemically peculiar early type stars may be indicative of global chemical anomalies in the parent cloud (see, for example, Walborn 1976; Lennon and Dufton 1983). If the peculiarities of the stars shown in Figure 5 are indeed due to composition anomalies, then the concentrated space distribution of these stars within NGC 6231 can be interpreted as evidence that chemical differences can occur in stars which probably formed out of the same molecular cloud complex. This leads us to speculate that an abundance stratification process of some type occurred within the primordial cloud either before or during the star formation process and that there is no need to postulate a global abundance anomaly.

There are several potential origins for local abundance inhomogeneities within a region of ongoing star formation (Edmunds 1977). The overall appearance of Sco OB1 suggests that it is such a region. It consists of an elongated OB association stretching about 2° along the galactic plane with the rich open cluster NGC 6231 located near the southern end (Bok, Bok, and Graham 1966). Furthermore, Talbot (1974) discusses how a metal-rich environment can initiate rapid star formation because of the enhanced cooling rates caused by the metals. Thus, there may have been ample opportunity for an abundance enhancement to develop within Sco OB1 and for this, in turn, to commence the formation of a metal-rich cluster of stars, i.e., NGC 6231.

Although it is difficult to imagine how the WC star HD 152270 could affect the atmospheres of the cluster B stars, its presence in the core of NGC 6231 suggests another possibility. Suppose that a previous generation of star formation in the region contained a WC star. Could this star have enriched the material which formed the present stars? If we take 5.8×10^{-3} as the mass fraction for carbon prior to enrichment (this is 2 times solar—see above), and let the WC star be composed of 25% carbon and 75% He by mass, then 2.5% of the total mass which formed the present stars must have been processed by the WC star to produce 4 times the solar carbon abundance. To determine how much processed mass is required, we must estimate the mass of the gas which formed the peculiar stars. There are approximately 175 $M_\odot$ of B1 and earlier stars within the core of NGC 6231 defined by Garrison and Schild (1979) which roughly corresponds to the region occupied by the peculiar stars. We assume that the cluster had an initial mass function similar to other rich clusters discussed by Herbst and Miller (1982), and we use Yorke's (1979) scheme to account for protostellar ejecta from stars with $M \geq 9\ M_\odot$. This calculation implies that the peculiar stars were formed from a cloud of $\sim 750\ M_\odot$ which contained about 20 $M_\odot$ of WC processed material. If the WC had a $\dot{M} \approx 5 \times 10^{-5}\ M_\odot\ \mathrm{yr}^{-1}$ (Barlow 1982), then a WC lifetime of 4×10^5 yr and an initial WC mass considerably larger than 20 $M_\odot$ are required. These numbers press the limits of plausibility especially since they require that none of the WC ejecta escaped the star forming region.

The current data do not warrent further speculation. Instead, the most pressing issues are to verify our interpretation of the BV spectra in terms of abundance anomalies by independent means and to determine if the BV's in the core of NGC 6231 constitute a unique anomaly or if they are typical of stars within a certain class of open clusters.

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APPENDIX

This appendix contains the details of how we arrived at the line profile fits shown in Figure 4. Since the conventional family of velocity laws is not used, we begin with an explanation of why these laws are inadequate for our purposes and discuss some properties of a more suitable family of laws. Next, the choice of parameterization for the radial optical depth of the wind is justified and, finally, the adopted model is given and a few of its physical implications are discussed.

a) Choice of Fitting Functions, $w(x)$, $\tau_{\rm rad}$

The most frequently used parameterization of the velocity law is $w(x) = (1 - w_0)[1 - (1/x)]^\beta$, where $x = r/R_*$, $w = v/v_\infty$ is the normalized velocity, w_0 is $w(x = 1)$, and β is a free parameter (e.g., Castor and Lamers 1979). As discussed in § III, the observations dictate that the wind must attain a high velocity very near the star. However, for $\beta = 0.5$ (the most steeply increasing velocity law normally used) w is only 0.71 at $x = 2.0$. Since sizable red emission results from material at radii of 1.5 R_* or larger, one is forced to assume that the maximum observed absorption velocity corresponds to $w \approx 0.7$ and that C IV is absent at higher velocities. In this case, the full terminal velocity must be $\sim 1/0.7$ times the maximum observed absorption velocity, 2,300 km s^{-1}, or $\sim 3{,}200$ km s^{-1}.

Although there is no reason to reject such a large terminal velocity, it seems difficult to accept that a B1 V has a terminal velocity that is typical of an early O star (Garmany *et al.* 1981; see, however, Abbott 1978). If, on the other hand, we adjust β so that the maximum absorption velocity occurs at $x = 2.0$ and the terminal velocity is $< 2{,}500$ km s^{-1}, then β must be < 0.12. For such small values of β the velocity law has an enormous gradient very near the stellar surface which results in numerical problems in the program that calculates the profiles. Furthermore, the acceleration of the wind at $x = 1.0$ is infinite for $\beta \leq 0.5$, indicating that such models are probably unphysical. The conventional velocity law with $\beta \leq 0.5$ also has adverse effects on $\tau_{\rm rad}$ discussed below. For these reasons, a different analytical expression for $w(x)$ was sought.

Because we would like a simple velocity law which is as closely related to the conventional one as possible, we decided to retain the usual functional form but to change the scale, i.e., let $w(x) = w_0 + (1 - w_0)\{1 - [1/u(x)]\}$, where $u(x) = \gamma x + \delta$. The condition that $w(x = 1) = w_0$ demands that $\delta = 1 - \gamma$. Thus, the adopted parameterization of the velocity law has the form

$$w = w_0 + (1 - w_0)\{1 - 1/[\gamma(x - 1) + 1]\} . \qquad \text{(A1)}$$

Unlike the conventional law, the corresponding acceleration, $w dw/dx = \gamma w(1 - w)^2/(1 - w_0)$, is well defined for all $0 < \gamma < \infty$ and $w_0 \leq w \leq 1$. Since any $w < 1$ can be attained at any $x > 1$ by a suitable choice of γ, this law has the desired flexibility.

The function which determines the nature of the short wavelength absorption in an unsaturated wind line is the radial optical depth of the wind, $\tau_{\rm rad}$. Castor and Lamers (1979) approximate $\tau_{\rm rad}$ with a variety of monotonic functions. However, the shape of the absorption observed in CPD $-41°7719$ indicates that $\tau_{\rm rad}$ has a minimum somewhere near $w = 0.5$ because the observed profile nearly reaches the continuum at $c\Delta\lambda/\lambda = -v_\infty/2$. Although it is possible to introduce additional parameters into $\tau_{\rm rad}$ which could fix the position and width of a minimum, additional parameterization seems unwarranted. Instead, we use the physical expression for $\tau_{\rm rad}$,

$$\tau_{\rm rad} = \frac{\pi e^2}{mc} \lambda_0 f \frac{\dot{M} A_E g_i}{4\pi \mu m_{\rm H}} \left(r^2 v \frac{dv}{dr}\right)^{-1} , \qquad \text{(A2)}$$

where $\dot{M}$ is the mass loss rate, A_E is the atomic abundance of the element relative to hydrogen, g_i is the ion fraction of ion i relative to its element, and μ is the mean molecular weight (Olson 1982). Simple parameterizations of g_i can easily produce minima in $\tau_{\rm rad}$ which result from the interplay of g_i, w, and dw/dx in equation (A2). Figure 6 shows the structure of $\tau_{\rm rad}$ for w given by equation (A1) ($w_0 = 0.01$, $\gamma = 100$) and $g_i \propto w^1$, w^0, and w^{-1}. This figure shows that a minimum in $\tau_{\rm rad}$ can develop and become quite pronounced. In contrast to the velocity law given by equation (A1), the conventional law, $w = w_0 + (1 - w_0)[1 - (1/x)]^\beta$, cannot produce a minimum in $\tau_{\rm rad}$ if $\beta < 0.5$ and $g_i \propto w^\alpha$. Thus, rather complicated functional forms of g_i must be introduced to produce a minimum in $\tau_{\rm rad}$ if the conventional velocity law is used. In any case, considerable red emission results if a reasonable terminal velocity is assumed as discussed above.

In deriving a fit for the observed profiles, we constrained the range of possible models to those producing emission less than 15% of the continuum redward of the C IV doublet. The model shown in Figure 4 has 14% emission and indicates that too much more emission would conflict with the observations. Since little is known about how the ionization structure of a wind is produced, a very simple form of g_i is assumed with g_i = constant for $1 \leq x \leq x_{\rm max}$ and $g_i = 0$ otherwise. The limiting value of x supresses excessive long wavelength emission. It also eliminates sharp absorption cores at $c\Delta\lambda/\lambda = -v_\infty$ which

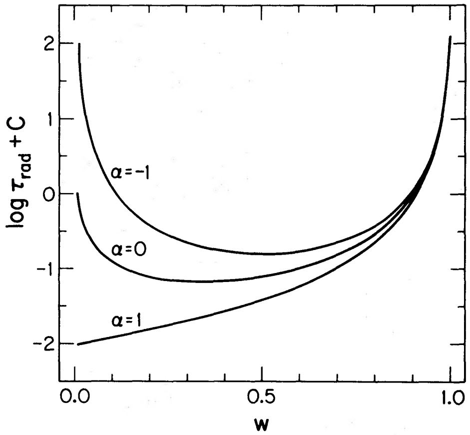

FIG. 6.—Plot of log $\{g(w)/g(1)[x^2 w\ dw/dx]^{-1}\}$ vs w over the interval $0.01 \leq w \leq 1$, where $w = v/v_\infty$, $x = r/R_*$, and $g(w)$ is the fraction of an element in the relevant ionization stage. The ordinate is proportional to the radial optical depth of the wind given by equation (A2). By parameterizing $g(w)/g(1)$ as w^α, α determines the run of ionization fraction in the wind. The curves shown demonstrate how the form of τ_{rad} differs for different values of α when $w(x)$ is given by equation (A1) with $\gamma = 100$ and $w_0 = 0.01$.

arise because dw/dx becomes very small near $w = 1$ causing τ_{rad} to become very large. Thus, the parameterization of τ_{rad} used here is

$$\tau_{rad} = \begin{cases} K(x^2 w dw/dx)^{-1} & 1 \leq x \leq x_{max} \\ 0 & x_{max} < x\,, \end{cases} \quad \text{(A3)}$$

where the model parameter K can be related to the physical parameters $\dot{M} g_i A_E$ by equation (A2).

The free parameters of the model are K and x_{max} in equation (A3) and γ in equation (A1) ($w_0 = 0.01$ was used in all models). We concentrated on fitting the C IV profile since it obviously constrains the models more than the Si IV profile. Because we have no example of a strong C IV profile that is uncontaminated by wind absorption, the photospheric C IV doublet was approximated by two Gaussians with full widths at half-maxima of 2.0 Å and central depths equal to 5% of the continuum. This parameterization reproduces the red wing of the 1550.77 Å doublet fairly well but probably underestimates the 1548.20 Å component because of its larger oscillator strength. For the Si IV photospheric profile we used a smoothed version of the *IUE* data for the B0.7 V star 40 Per. This doublet does not appear to be too strongly affected by a wind and matches the red wings of the CPD −41°7719 profile fairly well.

b) Discussion of the Fits

The model C IV profile shown in Figure 4 has $K = 2.2$ and 1.1 for the blue and red components, respectively; $x_{max} = 1.6$; $\gamma = 100$; and $v_\infty = 2{,}300$ km s^{-1}. The overall quality of the fit is considered good although there are some noticeable discrepancies near line center and on the violet wing of 1548.20 Å. Inadequacies of the fit in these regions are expected for the following reasons. Near line center, the Sobolev approximation is invalid and rotational effects introduce additional complications not accounted for by the models for $|c\Delta\lambda/\lambda v_\infty| < v_{rot} \sin i/v_\infty \approx 0.1$. Since, as discussed above, the photospheric absorption of the 1548.20 Å doublet was probably underestimated, the fact that the model predicts too much flux in this region is not surprising.

The Si IV profile was fitted using the same velocity law adopted for the C IV fit. The parameters for τ_{rad} are $x_{max} = 1.02$ and $K = 2.00$ and 1.00 for the blue and red doublets, respectively. The overall fit is considered quite good except near line center which, again, might be expected.

c) Physical Implications

Lamers and Rogerson (1978) demonstrate how the model results can be used to determine the mass loss rate as a function of velocity by equating the radiative force per unit mass to the acceleration at each velocity. This approach should be reliable for B stars if all the wind lines in the Balmer continuum are taken into account because these furnish the vast majority of the driving force for B star winds. Since the *IUE* data do not cover the entire Balmer continuum, only a lower limit for $\dot{M}$ can be obtained by assuming that all the radiative force at high velocity is furnished by the C IV doublet. This may be a reasonably good approximation since carbon is probably the main source of radiative force (§ IV*c*). Furthermore, two of the resonance lines expected to be present but which are inaccessible to *IUE* (C III 977 Å and N III 989.8, 991.6 Å) are from ions with ionization potentials similar to Si IV. Thus, their ionic distributions are expected to be similar to Si IV which is not a major opacity source at high velocity. However, the lack of data for O VI 1031.9, 1037.6 Å presents a real source of uncertainty in the mass loss estimate. Although its ionic distribution should be similar to N V which is not present, oxygen is more than 7 times as abundant. In addition, oxygen and carbon abundance anomalies are frequently linked (Walborn 1976). Because the ionization state of the wind seems to increase with x, x_{max}(Si IV) < x_{max}(C IV), the O VI doublet could conceivably make a sizable contribution to the line force at high velocity.

Since the sharp cutoff of τ_{rad} in the model is probably somewhat schematic, we compute the mass loss due to C IV 1548.20 Å at $w = 0.98$ ($x = 1.49$). Since only a lower limit for $\dot{M}$ can be found, we neglect the forces due to the red doublet and gravity which are about the same magnitude and in opposite directions (see Lamers and Rogerson 1978). With these assumptions and the model parameters previously quoted we obtain $\dot{M} \geq 4.0 \times 10^{-9}\ M_\odot$ yr^{-1}, where we have assumed $R_* = 5\ R_\odot$ and $F_\nu = 2.5 \times 10^{-3}$ cgs for the continuum flux near 1550 Å for a 25,000 K log $g = 4.0$ atmosphere (Kurucz 1979).

Given a lower limit for $\dot{M}$, it is possible to estimate upper limits for the ion fractions from equation (A2). The results are g(C IV) $\leq 0.2\ (A_E/A_\odot)^{-1}$ and g(Si IV) $\leq 0.7\ (A_E/A_\odot)^{-1}$, where the factors $A_E/A_\odot$ have been retained to account for abundance enhancements which are probably ≈ 3. Assuming that N V has the same ionic distribution as C IV, an upper limit on g(N V) can be obtained by assuming $K \leq 0.10$ for the blue component since the effects of the wind are less than 10% of the input residual intensity for this value of K. This gives g(N V) $\leq 0.2\,(A_E/A_\odot)^{-1}$. While these results do not contain any obvious contradictions, observations of more lines, especially C III 977 Å and O VI 1031.9, 1037.6 Å, would be necessary to construct a coherent model of CPD −41°7719's wind.

In spite of the uncertainties in the empirical model, two results do seem well established. First, a very steeply increasing velocity law is needed to explain CPD −41°7719's C IV profile. Second, CPD −41°7719 has a much higher mass loss rate than is normally associated with stars of its spectral type.

REFERENCES

Abbott, D. C. 1978, *Ap. J.*, **225**, 893.
———. 1980, *Ap. J.*, **242**, 1183.
———. 1982, *Ap. J.*, **259**, 282.
Auer, L. H., and Mihalas, D. 1973, *Ap. J. Suppl.*, **25**, 433.
Barlow, M. J. 1982, in *IAU Symposium 99, Wolf-Rayet Stars: Observations, Physics, Evolution*, ed. C. de Loore and A. J. Willis (Dordrecht: Reidel), p. 149.
Baschek, B., and Scholz, M. 1974, *Astr. Ap.*, **30**, 395.
Bohlin, R. C., Lindler, D. J., and Turnrose, B. E. 1981, in *IUE NASA Newsletter*, No. 12, p. 9.
Bok, B. J., Bok, P. F., and Graham, J. A. 1966, *M.N.R.A.S.*, **131**, 247.
Braes, L. L. E. 1967, *Bull. Astr. Inst. Netherlands Suppl.*, **2**, 1.
Castor, J. I., and Lamers, H. J. G. L. M. 1978, *Ap. J. Suppl.*, **39**, 481.
Conti, P. S., and Ebbets, D. C. 1977, *Ap. J.*, **213**, 438.
Crawford, D. L., Barnes, J. V., and Golson, J. C. 1970, *A.J.*, **75**, 624.
———. 1971*a*, *A.J.*, **76**, 621.
———. 1971*b*, *A.J.*, **76**, 1058.
Crawford, D. L., Barnes, J. V., Hill, G. and Perry, C. I. 1971, *A.J.*, **76**, 1048.
Dufour, R. J. 1984, in *Future of Ultraviolet Astronomy Based on Six Years of IUE Research*, in preparation.
Dufour, R. J., Shields, G. A., and Talbot, R. J. 1982, *Ap. J.*, **252**, 461.
Edmunds, M. G. 1977, in *IAU Colloquium 45, Chemical and Dynamical Evolution of our Galaxy*, ed. E. Basinsha-Grzesik and M. Mayor (Geneva: Geneva Observatory), p. 67.
Garmany, C. D., Olson, G. L., Conti, P. S., and Van Steenberg, M. E. 1981, *Ap. J.*, **250**, 660.
Garrison, R. F., and Schild, R. E. 1979, *A.J.*, **84**, 1020.
Harmann, W.-R. 1981, *Astr. Ap.*, **100**, 169.
Herbst, W., and Miller, D. P. 1982, *A.J.*, **87**, 1478.
Houck, T. E. 1956, Ph.D. thesis, University of Wisconsin.
Hutchings, J. B. 1984, in *Future of Ultraviolet Astronomy Based on Six Years of IUE Research*, in preparation.
Kamp, L. W. 1978, *Ap. J. Suppl.*, **36**, 143.
———. 1982, *Ap. J. Suppl.*, **48**, 415.
Kurucz, R. 1979, *Ap. J. Suppl.*, **40**, 1.
Lamers, H. J. G. L. M., and Rogerson, J. B. 1978, *Astr. Ap.*, **66**, 417.
Lennon, D. J., and Dufton, P. L. 1983, *M.N.R.A.S.*, **203**, 433.
Levato, H., and Malaroda, S. 1980, *Pub. A.S.P.*, **92**, 323.
Lucy, L. B. 1971, *Ap. J.*, **163**, 95.
———. 1983, *Ap. J.*, **274**, 372.
Massa, D. 1975, *Pub. A.S.P.*, **87**, 777.
Massa, D., and Savage, B. D. 1984, in preparation.
Morton, D. C. 1978, *Ap. J.*, **222**, 863.
Olson, G. L. 1982, *Ap. J.*, **255**, 267.
Peimbert, M. 1979 in, *IAU Symposium 84, The Large-Scale Structure of the Galaxy*, ed. W. B. Burton (Dordrecht: Reidel), p. 307.
Schild, R. E., Hiltner, W. A., and Sanduleak, N. 1969, *Ap. J.*, **156**, 609.
Schild, R. E., Neugebauer, G. and Westphal, J. A. 1971, *A.J.*, **76**, 237.
Seggewis, W. 1968, *Veroff. Astr. Inst. Bonn*, No. 79, p. 1.
Shobbrook, R. R. 1980, *M.N.R.A.S.*, **192**, 821.
———. 1983, *M.N.R.A.S.*, **205**, 1229.
Slettebak, A., and Howard, R. T. 1951, *Ap. J.*, **121**, 102.
Snow, T. P. 1982, *Ap. J.* (*Letters*), **253**, L39.
Snow, T. P., and Jenkins, E. B. 1977, *Ap. J. Suppl.*, **33**, 269.
Talbot, R. J. 1974, *Ap. J.*, **189**, 209.
Turner, D. G., Grieve, G. R., Herbst, W., and Harris, W. E. 1980, *A.J.*, **85**, 1193.
Underhill, A., and Doazan, V. 1982, *B Stars With and Without Emission Lines* (NASA SP-456).
Vauclair, S., and Vauclair, G. 1982, *Ann. Rev. Astr. Ap.*, **20**, 37.
Walborn, N. R. 1972, *Ap. J.*, **77**, 312.
———. 1976, *Ap. J.*, **205**, 419.
Walborn, N. R., and Panek, R. J. 1984, **286**, 717.
Wu, C.-C., *et al.* 1983, in *IUE NASA Newsletter*, No. 22, p. 1.
Yorke, H. W. 1979, *Astr. Ap.*, **80**, 308.

Joseph P. Cassinelli, Derck Massa, and Blair D. Savage: Washburn Observatory, University of Wisconsin-Madison, 475 North Charter Street, Madison, WI 53706