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OUTER ATMOSPHERES OF COOL STARS. XI. HIGH-DISPERSION *IUE* SPECTRA OF FIVE LATE-TYPE DWARFS AND GIANTS

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ABSTRACT

We present high-dispersion, far-ultraviolet (1150–2000 Å) spectra of five late-type dwarfs and giants obtained with the *International Ultraviolet Explorer*. The chromospheric ($T \lesssim 10^4$ K) emission lines in the giants tend to be about twice as broad as the corresponding features of the dwarf star spectra, suggesting a width-luminosity relation similar to the Wilson-Bappu effect for Ca II H and K. The Si III λ1892 and C III λ1909 intercombination lines formed in hotter layers ($T \approx 5 \times 10^4$ K) also broaden by a factor of 2 from the main-sequence stars to the evolved stars, and the permitted resonance doublets of C II (3×10^4 K), Si IV (6×10^4 K), and C IV (10^5 K) are as much as a factor of 4 broader in the giants than in the dwarfs. However, we find no evidence for asymmetric or shifted emission profiles that might indicate the presence of warm ($T \lesssim 10^5$ K) stellar winds. We conclude that broad C IV profiles, in particular, are typical of active chromosphere giant stars and are unlikely to be a unique signature of an extended, expanding warm wind. Since the resonance lines tend to be wider than the intersystem lines formed at similar temperatures in the chromosphere and in hotter layers, we conclude that opacity must be an important broadening enhancement mechanism in active chromosphere giant stars. Nevertheless, the intercombination line widths do indicate a general increase in the outer atmosphere Doppler motions from the dwarfs to the giants.

Application of the density sensitive line ratio C III λ1909/Si III λ1892 suggests that the outer atmosphere pressures ($T \approx 5 \times 10^4$ K) are similar in the active chromosphere subgiant λ And and the quiet chromosphere dwarfs, α Cen A and B. However, the pressures derived for the Capella secondary and β Dra are factors of 3 or more lower than the dwarfs, suggesting geometrically extended, low-density outer atmosphere structures qualitatively different from the high-pressure, compact structures typical of solar magnetic active regions.

Finally, we have isolated the He II λ1640 emission component from contaminant blends, and we find that the line strength is well correlated with soft X-ray fluxes of the sample stars, as predicted by photoionization-recombination models of the He II Bα formation.

Subject headings: stars: atmospheres — stars: chromospheres — stars: late-type — ultraviolet: spectra

I. INTRODUCTION

Prior to the *International Ultraviolet Explorer* (*IUE*) (Boggess *et al.* 1978), only the very brightest spectral features in a few late-type stars had been observed successfully at high dispersion in the 1150–2000 Å far ultraviolet (e.g., McClintock *et al.* 1975; Dupree 1975; Evans, Jordan, and Wilson 1975; Anderson and Weiler 1978). However, with the advent of *IUE*, high-dispersion profiles of numerous emission features in the ultraviolet spectra of many late-type stars have been obtained, including Capella (α Aur A [G6 III+F9 III]; Ayres and Linsky 1980); Procyon (α CMi [F5 IV–V]; Brown, Jordan, and Wilson 1979); Aldebaran (α Tau

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TABLE 1

OBSERVING LOG

Target Name	Spectral Type	Image Number	JD (mid-exposure) (2,444,000+)	Exposure Time (minutes)
α Centauri B......	(K1 V)	SWP 9036	378.043	340
α Centauri A	(G2 V)	SWP 5541	040.920	120
		SWP 5542	041.019	120
		SWP 6477	128.547	120
		SWP 6478	128.645	120
		SWP 6479	128.755	102
λ Andromedae ...	(G8 III–IV+)	SWP 9057	380.006	450
α Aurigae A	(G6 III+F9 III)[a]	SWP 8626	331.306	10
		SWP 8627	331.353	30
		SWP 8628	331.394	25
		SWP 8629	331.434	25
		SWP 8630	331.485	25
		SWP 8631	331.524	25
		SWP 8632	331.555	10
β Draconis	(G2 II)	SWP 5437	028.836	360

[a]Phase 0.52; spectrum is single-lined and dominated by secondary star (see Ayres and Linsky 1980).

[K5 III]; Brown and Jordan 1980); Atria (α TrA [K4 III]; Hartmann, Dupree, and Raymond 1981); and the short-period, RS Canum Venaticorum system HR 1099 ([K0 IV+G5 V]; Ayres and Linsky 1981).

Here we extend the previous work by comparing high-dispersion far-ultraviolet spectra of two solar-like dwarfs (α Centauri A [G2 IV] and B [K1 V]), a subgiant of the long-period RS CVn class (λ And [G8 III–IV+?]), a normal giant (α Aur Ab [F9 III]), and a bright giant (β Dra [G2 II]). These five stars span a narrow range of effective temperature (5000–6000 K), but a factor of nearly 10^3 range in surface gravity. Consequently, comparisons among these spectra can test for *luminosity* effects in emission features from the chromospheres (6×10^3 K) and higher temperature layers of the stellar outer atmospheres analogous to the solar transition region (TR: $T\approx10^5$ K). An important question in such comparisons is whether the prominent far-ultraviolet emission lines broaden with increasing stellar luminosity in a manner analogous to the well-known width-luminosity correlation seen in the chromospheric cores of Ca II H and K (Wilson and Bappu 1957).

Furthermore, high-dispersion spectra are essential for (1) studying important diagnostic features, such as He II λ1640, that are blended at low dispersion (Brown and Jordan 1980); (2) determining accurate ratios of density sensitive lines, such as C III λ1909/Si III λ1892 (Doschek *et al.* 1978), that are superimposed on bright photospheric continua; (3) separating the individual emission contributions of binary stars whose orbital motions exceed the limiting 25 km s^{-1} FWHM resolution of the *IUE* echelle mode (Ayres and Linsky 1980, 1981); and (4) measuring line shape parameters—widths, central intensities, and velocity centroids—that are diagnostics for such atmospheric properties as radiative power outputs, turbulent motions, optical depths, macroscopic flows, and stellar winds (cf. Linsky 1980).

II. OBSERVATIONS

Table 1 lists the *IUE* images obtained from several observing programs. All of the targets were observed through the large aperture, with exposure times ranging from 10 minutes to 7 hours. The α Cen A spectrum is a sum of five individual exposures that were co-added to improve the signal-to-noise ratios of the fainter features. Typically α Cen A was positioned near one end of the large aperture to displace the stellar Lyα emission from the geocoronal feature. Some light was lost in several of these spectra; consequently, we normalized the fluxes of each exposure to those of image SWP 5542, for which we have confidence that α Cen A was entirely within the large aperture. The Capella spectrum is a composite of seven independent exposures that were taken sequentially during a single 8 hour observing shift (Ayres, Linsky, and Schiffer 1982).

The individual exposures were reduced as follows:

We adopted the Goddard standard intensity extractions for the gross and interorder spectra. For the prominent emission features in each echellogram, we determined the means and standard deviations of the interorder flux numbers in 100 pixel windows centered on the rest wavelengths of the lines, and then we recomputed the background levels, excluding any samples beyond $\pm1\ \sigma$ of the original means. We then subtracted the filtered mean background level from the gross spectrum and corrected the resulting net spectrum for the echelle blaze using order-dependent grating constants

TABLE 2

LINE-SHAPE PARAMETERS FOR PROMINENT EMISSION FEATURES

1.	Transition[a]	l_{bol}[b] (10^{-7} ergs cm^{-2} s^{-1} at Earth)	H I Lyα	O I 1305	O I 1306	C II 1336	Si IV 1394
2.	Rest wavelength (Å)[a]	...	1215.67	1304.86	1306.03	1335.71	1393.76
3.	s_{λ}^{-1} [10^{-14} ergs cm^{-2} s^{-1} (FN min^{-1})$^{-1}$]	...	8.3	4.7	4.7	4.7	5.3
4.	α Centauri B (K1 V)	...	...	−1.	−2.	−2.	+3.
		...	230:	25.	44.	52.	35.
		95	[40][c, d]	0.39±0.05	0.55±0.04	0.90±0.03	0.43±0.06
5.	α Centauri A (G2 V)	...	...	−2.	−2.	−3.	−1.
		...	220:	50.	47.	66.	61.
		270	[16][c]	0.25±0.03	0.30±0.02	0.55±0.03	0.30±0.02
6.	λ Andromedae (G8 III−IV+?)	...	...	−3.	−4.	+2.	+6.
		...	450:[c]	65.	49.	111.	67.
		10.6	[240],[c] [4.8×10^{-12}][e]	11.8±0.7	11.3±0.6	6.8±0.4	3.0±0.4
7.	α Aurigae (G6 III+F9 III)[f] ...	...	...	−1.	−9.	+17.	+6.
		...	420:[c]	93.	90.	192.	128.
		110	[170][c]	9.0±0.8	9.6±0.6	12.1±0.8	9.2±0.4
8.	β Draconis (G2 II)	...	...	+7.	+1.	...	+19.
		...	81[e]	118.	128.	...	152.
		24	3.9×10^{-12}[e]	4.4±1.2	6.0±1.2	[≲0.5]	2.2±0.5

NOTE.—In rows 4–8, the entries for each row, from top to bottom, are: V_L (km s^{-1}), FWHM (km s^{-1}), and f_L/l_{bol} (10^{-7}). Square brackets indicate direct numerical integrations; otherwise, values are from least-squares Gaussian fits. The uncertainties cited for the flux ratios are based on the RMS deviations of the fitted Gaussians from the measured profiles. Parentheses indicate continuum subtraction before Gaussian fitting: In cases of α Aur and β Dra, variations in FWHM up to ±20% and in f_L/l_{bol} up to ±50% are possible with different, reasonable choices of continuum level. Colons indicate uncertain values.

[a] Kelly and Palumbo (1973).

[b] See Ayres, Marstad, and Linsky (1981).

[c] No correction for interstellar absorption or geocoronal emission.

[d] Saturated pixels included in fits.

[e] Estimated geocoronal contribution (in ergs cm^{-2} s^{-1} for f_L).

[f] The composite spectrum is dominated by the secondary star (see Ayres and Linsky 1980).

[g] A strong particle radiation hit was removed from the center of this feature before the line shape parameters were determined.

based on a least-squares fit to the optimum ripple parameters proposed by Beeckmans and Penston (1979). Next, we divided the ripple-corrected net spectrum by the exposure time and multiplied by monochromatic inverse sensitivity factors (see Table 2) appropriate to emission-line sources observed at high dispersion (Cassatella, Ponz, and Selvelli 1981). Finally, we registered the stellar velocity scales to the mean velocity obtained from least-squares Gaussian fits to prominent emission features within each image, assuming that, to first order, any systematic wavelength errors in the *IUE* echellograms are velocity-like (Leckrone 1980).

The Capella spectra were obtained at orbital phase 0.52 (velocity crossing) when the spectrum is single-lined. Since most of the flux in chromospheric and higher temperature emission lines is from the rapidly rotating F-type secondary (Ayres and Linsky 1980), the composite spectrum at phase 0.52 is representative of the Capella secondary (F9 III) rather than the primary (G6 III).

The λ Andromedae system is viewed nearly pole-on, and the spectrum is single-lined at all orbital phases, at least to the 25 km s^{-1} resolution limit of *IUE*. However, high-dispersion ground-based studies of Ca II H and K suggest that the spectroscopic primary (G8 III–IV) is the major source of chromospheric emission from the system (Baliunas and Dupree 1979). Accordingly, we presume that the far-ultraviolet emission in chromospheric and higher temperature species is characteristic of the λ And primary rather than the unseen secondary.

The calibrated emission-line spectra are illustrated in Figure 1. The flux ordinate in the figure is the ratio of the monochromatic flux measured at the Earth, f, to the stellar bolometric luminosity, l_{bol}, also measured in flux units at the Earth (see Ayres, Marstad, and Linsky 1981). The flux ratios, f/l_{bol}, provide a convenient, and distance-independent, way to compare stars of very different surface areas. The figure ordinate is expressed in units of inverse km s^{-1} commensurate with the segmented velocity scale adopted for the abscissa. Con-

TABLE 2—*Continued*

C IV 1548	C IV 1551	He II 1640	Fe II 1640	Si II 1808	Si III 1892	C III 1909	C I 1994	Soft X-rays[b]
1548.19	1550.77	1640.40	1640.15	1808.01	1892.03	1908.73	1993.62	0.1−4 keV
7.1	7.1	5.4	5.4	3.2	2.9	2.8	2.6	...
+4.	−1.	−8.	−6.	0.	0.	+1:	+1.	...
54.	54.	29.	37.	35.	46.	40:	34.	...
0.97±0.08	0.44±0.05	0.19±0.01	0.25±0.02	1.80±0.20[d]	(0.59±0.02)	(0.09±0.02:)	(0.40±0.01)	14
0.	0.	...	+6.	+8.	−4.	...	+1.	...
58.	45.	...	44.	33.	33.	...	29.	...
0.68±0.01	0.33±0.03	[≲0.05]	(0.12±0.01)	(0.75±0.03)	(0.22±0.01)	([≲0.2])	(0.48±0.03)	2
−6.	+2.	+4.	...	0.	−7.	+6.	−3.	...
124.	120.	69.	...	55.	84.	68.	33.	...
13.5±1.2	5.8±0.8	14.7±0.8	...	(7.2±0.1)	(4.8±0.3)	(1.0±0.1)	(2.6±0.2)	260
−3.	+4.	+5.	...	−1.	−3.	0.	−10.	...
174.	163.	115.	...	57.	81.	63.	47.	...
(23.2±1.1)	(12.6±1.3)	(6.8±0.6)	...	(5.4±0.4)	(17.7±0.3)	(5.6±0.7)	(2.2±0.2)	150
−2.	+49:	+10.	...	−2.	+5.[g]	−5.	−7.	...
171.	223:	121.	...	109.	87.[g]	66.	47.	...
4.6±0.9	3.2±0.9:	2.1±0.2	...	(1.4±0.2)	(5.2±0.3)[g]	(2.7±0.1)	(1.5±0.1)	30

sequently, the area under each emission feature is the fraction of the radiative output of the star that is provided by that line, f_L/l_{bol}.

In the upper panel of Figure 1, the β Dra Lyα profile is wholly geocoronal since β Dra is at a considerable distance and the intrinsic stellar Lyα emission is strongly attenuated by interstellar H I absorption. However, we have not applied a reddening correction to the β Dra spectrum owing to the difficulty in establishing a reliable value for $E(B-V)$. A comparison of standard color-color relations (Johnson 1966) with the measured $(B-V)$ and $(V-R)$ indices for β Dra (Johnson *et al.* 1966) suggests that $E(B-V)$ is as large as 0.1 mag. Because interstellar reddening affects the far-ultraviolet fluxes to a greater extent than $l_{bol}=l_{bol}[V,(V-R)]$, we potentially have *underestimated* the f/l_{bol} spectrum by as much as a factor of 2 (based on the mean reddening relation proposed by Savage and Mathis 1979). However, because we are studying stellar emission lines of ions that are abundant in the interstellar medium itself, the fluxes of features such as C II λ1336, Si IV λ1394, and C IV λ1548 may be underestimated by a larger factor.

Listed in Table 2 are values of the velocity centroid (V_L), width (FWHM), and flux ratio (f_L/l_{bol}) determined by least-squares Gaussian fits to the observed line profiles. The flux uncertainties cited in the table are a 1 σ measure of how well the observed profiles are reproduced by the least-squares Gaussians. The corresponding uncertainties in the line velocity centroids and FWHMs are difficult to assess with our technique, but they should be small ($\lesssim 10$ km s^{-1}) for the well-exposed emission features in regions of negligible background continuum. However, for features that are superposed on bright photospheric continua, variations in FWHM of up to 20% and in f_L/l_{bol} of up to 50% are possible with different, reasonable choices for the background continuum level.

III. DISCUSSION AND CONCLUSIONS

a) Comparison of Flux Ratios

The far-ultraviolet flux ratios of the three giant stars (λ And, α Aur Ab, and β Dra) are considerably larger than those of the solar-like dwarfs of the α Centauri system or the Sun itself. The $f_{\text{C IV}}/l_{bol}$ ratios, for example, are factors of 5–20 larger in the three giants than in the two dwarfs. Among the giants, β Dra and α Aur Ab are comparatively young ($\lesssim 3\times10^8$ yr), since their locations in the H-R diagram indicate that they have evolved from massive progenitors ($M>2.5\ M_\odot$). In addition, α Aur Ab and λ And are members of spectroscopic binaries ($P=104$ days, 21 days, respectively). Furthermore, λ And is a modest rotator ($V_{rot}\approx 7$ km s^{-1}; Vaughan *et al.* 1981), whereas α Aur Ab is a fast rotator ($V_{rot}\lesssim 40$ km s^{-1}) for its spectral type (Ayres and Linsky 1980). All of these characteristics—youth, membership in a close binary, and fast rotation—have been associated with chromospheric activity in late-type stars (e.g., Zwaan 1981). In fact, the first two characteristics simply may be consequences of the third. In

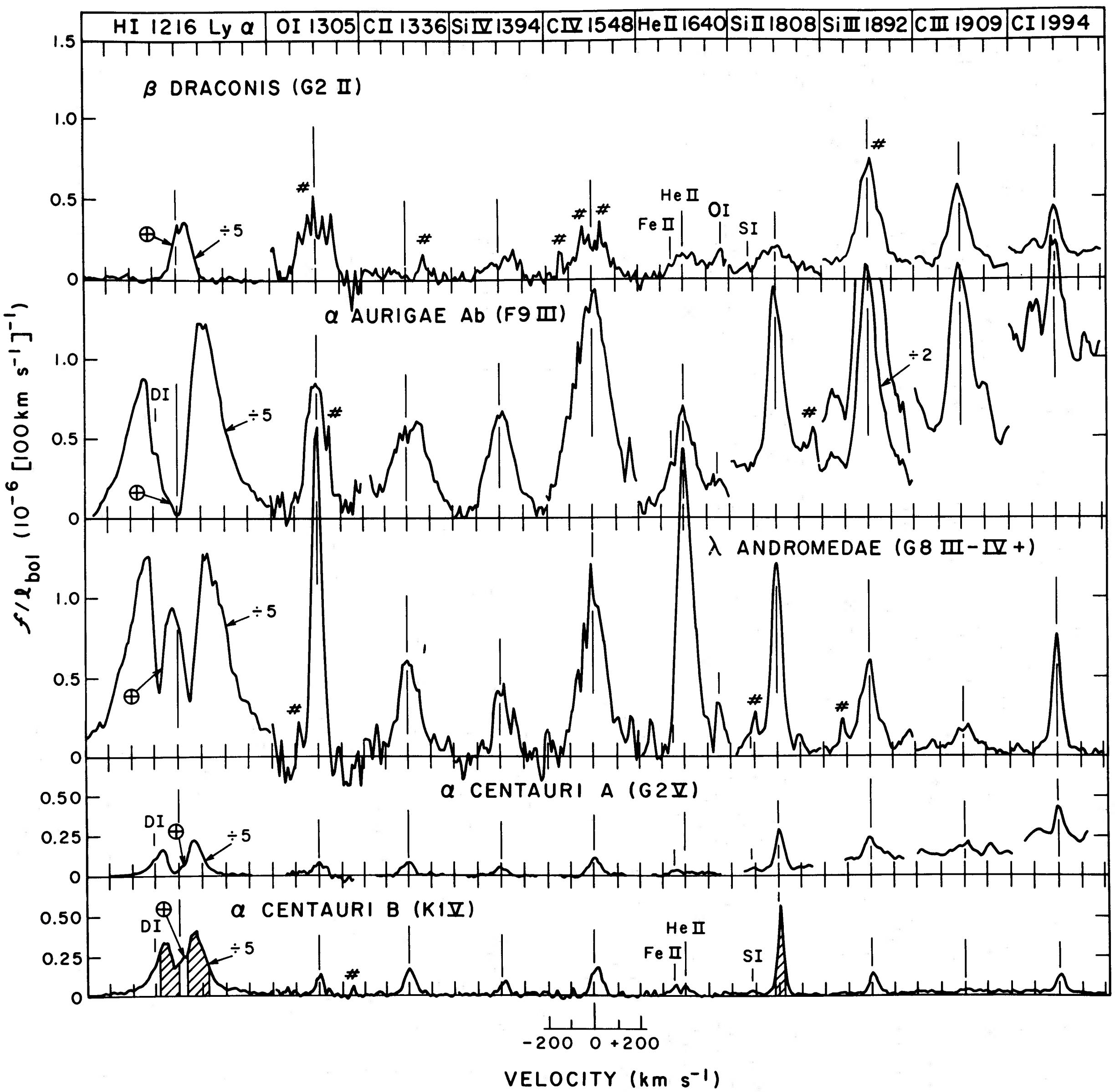

FIG. 1.—Comparison of prominent emission features in the far UV spectra of representative late-type dwarfs and giants. The stars are arranged from bottom to top in a sequence of increasing bolometric luminosity. The abscissa is a segmented velocity scale normalized in each case to the mean velocity of the well-exposed emission features. The ordinate is a monochromatic flux ratio with units commensurate to the abscissa scale. Note that the H I Lyα features have been reduced by a factor of 5. Prominent particle radiation hits are marked with "#" symbols (Note: in the case of β Dra Si III λ1892, the hit has been removed); geocoronal contributions to the stellar Lyα emission are denoted by "⊕" symbols; regions of the line profiles that were saturated in the original exposures are indicated by cross-hatching; and spectral substructures in the vicinities of H I Lyα, He II λ1640, and Si II λ1808 are identified explicitly.

particular, young stars tend to be faster rotators than old stars (Kraft 1967), and stars in close binary systems generally are fast rotators owing to rotational-orbital synchronism (Bopp and Fekel 1977). The origin of the rotation-activity connection likely is related to the close association between magnetic activity and chromosphere-corona emission seen in the particularly well-studied case of the Sun (Vaiana and Rosner 1978), since fast-rotating stars probably generate considerably more magnetic flux than slow rotators (Parker 1970).

In contrast, the α Centauri dwarfs exhibit comparatively weak far-ultraviolet emission levels. The ultraviolet flux ratios of α Cen B are similar to those of the Sun at the peak of the solar activity cycle, whereas the α Cen A flux ratios are similar to those of the Sun at minimum activity (Ayres, Marstad, and Linsky 1981).

The similarity between the emission levels of the α Centauri dwarfs and the Sun is plausible because the nearby system is thought to be as old as or somewhat older than the Sun (Flannery and Ayres 1978) and the α Cen stars likely rotate as slowly as the Sun (Hallam and Wolff 1981). However, α Cen B is nearly a factor of 2 brighter (in $f_L/l_{\rm bol}$ units) than α Cen A in high-temperature emission lines such as C II and C IV, and a factor of 7 brighter than the primary in the soft X-ray band (Ayres *et al.* 1981; Golub *et al.* 1981). Nevertheless, the difference in far-ultraviolet emission levels between the α Centauri dwarfs is much smaller than that between the Capella primary and secondary (Ayres and Linsky 1980). In the first case we likely are sampling variations in magnetic activity levels of similarly rotating stars of different spectral type, or stars in different phases of solar-like activity cycles. In the second case, the contrast in magnetic activity levels likely results from a large contrast in rotation rates between two stars of otherwise similar properties.

b) *Doppler Shifts and Profile Asymmetries*

There are no significant systematic Doppler shifts between the high-temperature emission lines, such as Si IV and C IV, compared with the lower temperature chromospheric lines, such as O I, C I, and Si II. Furthermore, the chromospheric Mg II *h* and *k* emission profiles are all comparatively symmetric, indicating little or no cool circumstellar material (Basri and Linsky 1979). We find, therefore, no evidence for the presence of discernible macroscopic flows or strong winds in any of the sample stars, at least not of the type common among yellow and red supergiants (Mullan and Stencel 1980*a*, *b*; Hartmann, Dupree, and Raymond 1981).

c) *The Lyα Wilson-Bappu Effect*

The outer edges of the stellar Lyα emission profiles, beyond the interstellar and geocoronal dominated cores, are considerably wider in the giants—λ And and α Aur Ab—than in the dwarfs. (As previously noted, interstellar absorption prevents observation of the β Dra Lyα profile.) The broadening of the chromospheric Lyα emission FWHM with increasing stellar luminosity is analogous to the well-known width-luminosity correlations exhibited by Ca II H and K (Wilson and Bappu 1957) and Mg II *h* and *k* (Moos *et al.* 1974; Evans, Jordan, and Wilson 1975; Weiler and Oegerle 1979). However, the correlation between the Lyα width and stellar luminosity is only approximate. For example, the Capella secondary is probably a magnitude more luminous in $M_{\rm bol}$ than λ And, yet the Lyα emission FWHM of the F giant is narrower. Furthermore, the α Cen secondary appears to have a broader Lyα profile than the optically more luminous primary.

Wilson (1957), Goldberg (1957), Hoyle and Wilson (1958), and Kraft (1959), among others, have argued that the increase in the Ca II emission core FWHMs with increasing stellar luminosity is produced by a general increase in the small-scale turbulent motions in stellar chromospheres with decreasing surface gravity, namely $V_D \sim L_{\rm bol}^{1/6}$. However, the widths of the Lyα emission profiles in the dwarfs and the giants greatly exceed those of other optically thick chromospheric emission lines. Furthermore, in each star Lyα is as much as an order of magnitude wider than the empirical upper limit to the chromospheric nonthermal broadening velocity indicated by the narrowest feature, the C I λ1994 intersystem line, which is thought to be optically thin ($\tau \lesssim 1$) in the solar chromosphere (Jordan 1967). (Note, the H I *thermal* Doppler width for $T \approx 2 \times 10^4$ K is only about 18 km s^{-1}.) Indeed, the C I λ1994 width is the *same* in α Cen A, α Cen B, and λ And, despite the large difference in Lyα emission widths. Finally, the β Dra C I width is at most only about twice as large as that of α Cen B (for an instrumental FWHM $\approx$ 25 km s^{-1}), compared with the factor of at least 5 expected from the purely Doppler interpretation of the Wilson-Bappu relations. Since the influence of the Doppler-dominated portion of the profile function for a strong resonance line does not extend beyond about three Doppler widths from line center (e.g., Mihalas 1978), we conclude that the outer edges of the Lyα emission, beyond the interstellar absorption core, are formed in the radiation-damping dominated Lorentzian wings of the profile function. Accordingly, the broadening of the Lyα emission core with increasing stellar luminosity suggests a systematic increase in the optical thickness of the chromosphere with decreasing surface gravity (Ayres 1979). Nevertheless, the mildly increasing Doppler motions with increasing luminosity indicated by C I λ1994 likely play an important role in the broadening of the other optically thick emission features of the chromosphere, such as the O I and Si II triplets, and perhaps have some influence on the Lyα wings through the mechanism of Doppler-redistribution (e.g., Basri 1979). If so, the origins of the Wilson-Bappu relations for Lyα, Ca II K and Mg II *k* likely are more subtle than the simple mechanisms proposed in previous work (e.g., Ayres 1979).

d) *Broadening of the High-Temperature Emission Lines*

Like Lyα, the high-temperature resonance lines—C II λ1336, Si IV λ1394, and C IV λ1548—broaden with increasing stellar luminosity, although the Si IV feature is always narrower than the C II or C IV features. Furthermore, the widths of the permitted transitions generally exceed those of the intersystem lines—Si III λ1892 and C III λ1909—that are formed at similar temperatures. These results set constraints on possible broadening mechanisms for the high-temperature species.

i) *Warm Wind Expansion?*

Hartmann, Dupree, and Raymond (1981) have proposed that the inferred large width (FWHM = 150–200 km s^{-1}) of C IV λ1548 in the K giant α TrA is produced by the spherically-symmetric expansion of an extended, warm ($T \approx 10^5$ K) stellar wind. If that mechanism is applicable to the yellow giants we have observed, the flow structure of the warm winds must be considerably different from that proposed for α TrA. In particular, the surface fluxes of C IV are greatly enhanced compared with α TrA, indicating more massive winds, yet no prominent blueshifted circumstellar absorption features appear either at low velocities ($V \lesssim 100$ km s^{-1}) in Mg II *h* and *k* or at higher velocities ($V \gtrsim 200$ km s^{-1}) in Lyα. The low-velocity absorption components in Mg II *h* and *k* are quite pronounced in α TrA, as well as in α Aqr (G2 Ib) and β Aqr (G0 Ib), and are thought to be produced far from the stellar surface where the wind has attained its terminal velocity and the plasma has cooled to Mg^+ temperatures (Hartmann, Dupree, and Raymond 1981).

We suspect, instead, that the broad C IV profiles of the yellow giants in our sample are related to properties of magnetic active region structures dominated by closed-field configurations (i.e., loops), and have little or nothing to do with any wind characteristics (which should be more representative of open-field regions analogous to solar coronal holes). Until unambiguous supporting evidence to the contrary becomes available, we conclude that broad C IV profiles, in particular, should not be taken as a unique signature of an expanding, warm wind.

ii) *Permitted Lines: Opacity Broadening*

Since the intercombination lines of Si III and C III are narrower than the permitted transitions that are formed at similar temperatures, nonthermal broadening cannot be responsible, exclusively, for the enhanced widths of the permitted lines. Instead, line *opacity* may be important in explaining the excess broadening. In particular, the FWHM of an optically thick emission line having a line-center optical depth of τ_L is a factor of $1.2\,(\ln \tau_L + 0.37)^{1/2}$ broader than an optically thin line formed under the same conditions of temperature and nonthermal motions. Unfortunately, owing to uncertainties in the surface filling fraction of the emitting structures and their internal gas pressures, we cannot estimate optical depths for these lines directly. We can, however, estimate optical depths indirectly according to the behavior of the semipermitted lines, which likely are optically thin.

iii) *Intersystem Lines: Nonthermal Doppler Broadening*

We find that the Si III λ1892 and C III λ1909 intersystem lines are systematically a factor of about 2 broader in the giants than in the dwarfs. Consequently, the nonthermal broadening in the transition regions of the giants likely is a factor of 2 larger than that of the dwarf stars. In the giant stars the widths of the C II λ1336 and C IV λ1548 resonance lines are another factor of 2 larger than the C III and Si III intersystem lines. Since the expression $1.2(\ln \tau_L + 0.37)^{1/2}$ indicates a factor of 2 width increase between the optically thin limit and $\tau_L = 10$, we believe that the difference in FWHM between the resonance and intersystem lines in the giants can be explained simply if $\tau_L \approx 10$ for the resonance lines and $\tau_L \ll 1$ for the intersystem lines.

iv) *Rotational Broadening*

Finally, rotational broadening could play an important role in enhancing the widths of high-temperature lines in the active chromosphere giants, particularly if the emitting structures, perhaps magnetic loops (Vaiana and Rosner 1978), extend significantly above the stellar surface and corotate with the photosphere. Rotational effects may, in fact, explain some of the line shape differences between the Capella secondary and the λ And primary. These stars have similar f_L/l_{bol} ratios in most of their lines, but the former is a rapid rotator ($V \sin i \approx 30$ km s^{-1}; Ayres and Linsky 1980), while the latter is viewed nearly pole-on and consequently exhibits virtually no rotational broadening (e.g., Baliunas and Dupree 1979).

e) *Pressures Estimated from Density Sensitive Line Ratios*

Because the geometry and mean pressures of the transition region structures on stars play important roles in energy balance arguments, we use measured values of the C III λ1909/Si III λ1892 line ratio to estimate mean electron densities. Unfortunately, this density sensitive line ratio is subject to serious uncertainties in direct derivations of plasma pressures (cf. Baliunas and Butler 1980). Nevertheless, the use of the C III/Si III density diagnostic in a *differential* comparison may be somewhat more reliable than the direct applications. Furthermore, the C III/Si III ratio is virtually the only density diagnostic that is accessible with good sensitivity in the *IUE* far-ultraviolet, and the method is, to first order, independent of the fraction of the stellar surface that is covered by active regions.

Despite some uncertainties associated with defining local continuum levels in several of the spectra, it is possible to extract reliable values, or upper limits, of the C III/Si III ratio for four of our sample stars. The C III/Si III ratios fall into two groups: (1) α Cen B and λ And, for which the ratio is $\lesssim 0.2$; and (2) α Aur Ab and β Dra, for which the ratio is > 0.3. Solar calculations suggest, for a fixed differential emission measure distribution, that decreasing C III/Si III ratio corresponds to increasing plasma density near 5×10^4 K (Doschek *et al.* 1978; Raymond and Doyle 1981). It is clear from Figure 1 and Table 2 that ratios of the permitted hot lines (C II, Si IV, and C IV) are not grossly different between the active giants and the quiet dwarfs. Consequently, the differential emission measures (cf. Doschek *et al.* 1978) likely are similar enough that the line ratio technique will provide a useful guide to any significant pressure differences between the two groups of stars. Accordingly, densities in typical transition region structures of λ And probably are similar to those of the quiet chromosphere dwarf α Cen B, whereas the Capella secondary and β Draconis probably have lower densities in their TR structures. The line emissivity calculations of Raymond and Doyle (1981), which include charge-exchange reactions, indicate that the gas pressure near $T \approx 5 \times 10^4$ K scales inversely as a moderate power of the C III/Si III intensity ratio, $P_{TR} \sim R^{-1.4}$. Accordingly, ratios of the C III and Si III fluxes in Table 2 suggest that the transition region pressures of the Capella secondary and β Dra are perhaps a factor of 3 and 6, respectively, lower than those of α Cen B, while the TR pressure of λ And is perhaps less than a factor of 2 smaller than that of α Cen B.

Finally, note that the Si III and C III intersystem lines are not important sources of radiative cooling, compared with the C II, Si IV, and C IV resonance lines, in the dwarfs and λ And, but are major contributors to the far-ultraviolet emission, and presumably therefore to the TR structure cooling, of α Aur Ab and β Dra. Furthermore, semipermitted lines of N IV (λ1487), O III (λ1666), and N III (λ1752) are strong in low dispersion spectra of the yellow giant and bright giant, but not the dwarfs (Ayres and Linsky 1980; Basri, Linsky, and Eriksson 1981). The prominence of the intersystem lines relative to the permitted transitions formed at similar temperatures is further evidence that TR densities are significantly lower in the Capella secondary and β Dra compared with the less luminous members of our sample.

The pressure, opacity, and radiative cooling differences between the active giants and the quiet dwarfs suggest that the emitting structures on the former are considerably different from the high-pressure, compact structures typical of solar magnetic active regions, and presumably those of other dwarf stars as well (Withbroe and Noyes 1977). Such differences may have important implications for extensions of solar analog models, scaled magnetic loops for example (Golub *et al.* 1981), to stars of very different surface gravity.

f) The Excitation of He II *λ1640*

Zirin (1975), Avrett, Vernazza, and Linsky (1976), and Schindler *et al.* (1981) have argued that the He II λ1640 Balmer α emission in the Sun is produced mainly through recombination following photoionization of helium ions by coronal XUV radiation. Consequently, the He II λ1640 emission strength should be an indirect measure of coronal radiation fields (Hartmann, Dupree, and Raymond 1980). SWP echelle spectra are required to determine the stellar He II fluxes accurately, because the He II feature is blended with Fe II λ1640 and O I λ1641 (Brown and Jordan 1980) at low dispersion. Although our sample is limited, we do find a correlation of He II flux with coronal soft X-ray emission (see Table 2). For example, α Cen B is brighter than α Cen A in soft X-rays, and the He II emission of the secondary is discernible clearly, whereas that of the primary is not. Furthermore, β Dra, α Aur Ab and λ And define a sequence of increasing He II *and* increasing soft X-ray intensity (in f_L/l_{bol} units), with a power-law slope of order unity. Note, however, that α Cen A and B are consistent with the relation,

$$f_x/l_{bol} \approx 50 f_{He\,II}/l_{bol},$$

proposed by Hartmann, Dupree, and Raymond (1980), while for the giants,

$$f_x/l_{bol} \approx 20 f_{He\,II}/l_{bol}$$

appears to be more appropriate. This difference suggests that the XUV excitation of He II is more efficient in the giant stars. One possible explanation is that the lower electron densities in the giants produce less radiative recombination of He^+ into neutrals, and consequently a larger equilibrium concentration of He^+ would be available in the chromospheres of the giant stars for subsequent photoionization-recombination. (Note, the chromospheric population of He^+ is itself produced by XUV photoionization of neutral helium [e.g., Schindler *et al.* 1981].)

g) Concluding Remarks

Our interpretations, above, are only the initial steps in a continuing effort to understand the chromospheres and coronae of late-type stars by means of high-dispersion, far-ultraviolet spectroscopy. In this regard, we urge a parallel effort to develop, more fully, numerical simulations of outer atmosphere structure, so that questions concerning the geometry, mean density and energy balance of stellar outer atmospheres can be pursued well beyond the largely empirical arguments presented here.

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