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A SEARCH FOR CHROMOSPHERIC EMISSION IN A-TYPE STARS USING THE GODDARD HIGH-RESOLUTION SPECTROGRAPH[1]

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ABSTRACT

We have used the Goddard High-Resolution Spectrograph on the *Hubble Space Telescope* to search for chromospheric emission in the ultraviolet C II 1335 Å lines of eight A-type stars. The $B-V$ colors of these stars range from 0.12 to 0.22. We have detected emission in the spectrum of the A7 V star Altair, but in no other star. We present tentative evidence that the emission from Altair is blueshifted by ~ 60 km s^{-1} or more with respect to the photospheric spectrum of this star. We interpret this as expansion and suggest that the base of the A star winds that we have proposed in earlier work may lie within the chromosphere. Together with *IUE* spectra, our observations indicate that in ordinary main-sequence stars the onset of convection zones capable of supporting detectable chromospheres occurs in the close vicinity of $B-V = 0.22$.

Subject headings: stars: activity — stars: chromospheres — stars: individual (α Aquilae) — ultraviolet: stars

1. INTRODUCTION

The basic source of energy for chromospheric heating is supplied by the convection zone. Consequently, stars with thin convection zones are not expected to have bright chromospheres or bright chromospheric emission. On the main sequence, the early F stars are typically strong sources of UV chromospheric emission lines (Wolff, Boesgaard, & Simon 1986; Walter & Linsky 1986). The strength of this emission appears, on the average, to diminish only slightly with decreasing $B-V$ color, up to the earliest detections made, at $B-V = 0.25$ in the C II 1335 Å lines (Simon & Landsman 1991), and at $B-V = 0.22$ in Lyα (Marilli et al. 1992; Landsman & Simon 1993).[2] The emission shows greater scatter in the hotter stars, which suggests a larger range in their chromospheric activity as compared to the early F stars.

Efforts to find chromospheric emission lines in *IUE* spectra of the early A stars have not produced any evidence for activity (Böhm-Vitense & Dettmann 1980; Freire Ferrero & Talavera 1984; Freire Ferrero 1986), other than in the pre–main-sequence Ae stars, which, because of accretion or deuterium burning, may be in a short-lived convective state (Palla & Stahler 1991). For the main-sequence and older stars of interest here, the observations suggest that the more conventional stellar chromosphere, and by implication the convection zone needed to sustain it, must vanish somewhere in the middle of the A stars. It is in the same range of effective temperatures and $B-V$ colors that theoretical calculations predict a steep decline in the dynamical power generated by convection (Bohn 1984; Gilliland 1986).

Given the importance of establishing the location where this change in stellar structure occurs, we have used the Goddard High-Resolution Spectrograph (GHRS) on the *Hubble Space Telescope* to survey the UV chromospheric emission of a representative group of A stars. Our observations cover the critical range in $B-V$ color not previously explored by *IUE*, from $B-V = 0.12$ to $B-V = 0.22$, and they do so at a much higher signal-to-noise than is achievable, even for bright stars, with that telescope. In this paper we present the initial results from our survey.

2. OBSERVATIONS

Table 1 lists the basic information about the eight stars we have observed and the individual exposures of those stars taken with the GHRS. In each case, we have used the large ($2'' \times 2''$) aperture and the intermediate resolution G160M grating, which provides a dispersion of ~ 0.072 Å per diode on the D2 Digicon detector. Each spectrum is centered on the C II 1334.53, 1335.71 Å lines (UV multiplet 1: $2s^2 1p\ ^2P^o – 2s2p^2\ ^2D$) and covers the wavelength range from 1317 to 1352 Å. A third line in the multiplet, located at 1335.66 Å, has a very small atomic transition probability and should always be of negligible strength. We have chosen to observe the C II lines because synthetic spectra based on model atmospheres predict far less line blending in the underlying A star photosphere at this wavelength than in regions surrounding other high-temperature chromospheric lines, for example, those of C IV near 1550 Å (see Simon & Landsman 1991).

The observations were made in the standard observing modes, as described in the GHRS Instrument Handbook (Duncan 1992). These procedures include taking four subexposures at different positions of the GHRS grating carousel in order to reduce the fixed pattern noise and granularity of the

[1] Based on observations with the NASA/ESA *Hubble Space Telescope*, which is operated by the Space Telescope Science Institute under NASA contract NAS5-26555 to the Association of Universities for Research in Astronomy, Inc.

[2] For low surface gravity stars, the earliest detections are at $B-V = 0.23$ for C II (Simon & Landsman 1991) and at $B-V = 0.19$ for Lyα (Marilli et al. 1992). These detections are quite weak and should be viewed as tentative only.

TABLE 1

GHRS OBSERVATIONS OF A STARS

Star	Spectral Type	$B-V$	$v \sin i$	V_{ism}	V_r	Date	Exposure Time (s)	SNR
δ Leo	A4 V	0.12	181	4	−20	1993 Apr 27	870	43
ω Oph	A7p	0.13	41	−22	3	1993 Feb 11	1523	46
ϵ Ser	A2m	0.15	37	−23	−9	1993 Mar 23	762	20
τ^3 Eri	A4 IV	0.16	144	19	−10	1993 Jun 16	898	33
15 Vul	A4 III	0.18	23	−22	−21	1993 Apr 7	1741	9
π Pav	A7p	0.22	20	−9	−16	1993 Feb 6	1523	7
α Aql	A7 V	0.22	242	−24	−26	1993 Apr 7	435	46
α Cep	A7 V	0.22	246	−11	−10	1993 Jan 19	1197	30

NOTE.—V_{ism} is the velocity (in km s^{-1}) of the interstellar line. V_r is the stellar radial velocity. SNR is the signal-to-noise ratio after averaging across three diodes and is computed for the continuum near 1335 Å.

detector, plus an additional substepping of each subexposure to produce four spectral samples per diode, so as not to undersample the spectrum. Each observation was preceded by a spectrum Y-balance, or SPYBAL, as a pseudo-wavelength calibration exposure. No major operational anomalies were encountered during the observations, except for an early termination of the τ^3 Eri exposure because of an unrelated commanding error to the spacecraft. (The data acquired for τ^3 Eri prior to this event do not appear to be compromised.)

We have used two independent methods to process and analyze the data: the first relies on software available in the STSDAS/GHRS package, running under IRAF; the second uses the 1993 April version of CALHRS, a suite of IDL programs that has been developed by the GHRS science team at the NASA/Goddard Space Flight Center and that has been kindly made available to us. We have compared the independently reduced spectra and found them to be in excellent agreement.

Figure 1 presents the GHRS spectra reduced with the IDL software. The plots have been smoothed with a three-diode running mean, yielding a spectral resolution of 0.216 Å. The prominent absorption feature to the left of center in each panel is the C I 1329 Å line (UV multiplet 4). C I absorption appears to be absent in the spectrum of the cool magnetic Ap star, ω Oph. From optical spectra, Roby & Lambert (1990) have derived a factor of 10 underabundance of carbon for this star, and a similar underabundance for the Am star ϵ Ser, whose GHRS spectrum shows substantial 1329 Å absorption. The C II lines, located closer to the center of the figure, also appear in absorption, except in the spectrum of α Aql (Altair), where emission clearly stands out above the continuum level, although displaced ∼160 km s^{-1} shortward of the expected wavelength. The sharper, blueward absorption in C II is the interstellar line; its location in each panel serves as a check on the fidelity of the wavelength scale. In cooler stars, including the Sun, the chromospheric C II lines appear prominently in emission, with a wide range in the relative strengths of the red and blue components, but with a flux ratio often close to 1 (e.g., Ayres, Jensen, & Engvold 1988; Lites, Shine, & Chipman 1978).

For several of the fastest rotators, the absorption lines in Figure 1 are appreciably narrower than one would expect from the cataloged rotation speeds. The star τ^3 Eri, for example, has a $v \sin i$ of 144 km s^{-1}, but its line widths in the 1340–1350 Å region indicate a rotational broadening of ∼90 km s^{-1}. The shallow C II lines of α Cep are best fitted with $v \sin i \approx 105$ km s^{-1}, or less than half the nominal rotation rate of 246 km s^{-1}. This discrepancy in the UV line widths may be related to the "UV line narrowing effect" encountered among the rapidly rotating B stars. The effect has been discussed by Hutchings (1976) and Carpenter, Sletteback, & Sonneborn (1984), and is explained by rotational distortions of the star, which cause the local effective temperature and surface gravity of the star to vary with latitude. Highly temperature-sensitive lines such as those of C II should preferentially form in the hot polar regions, where the projected rotation rate is low. A similar

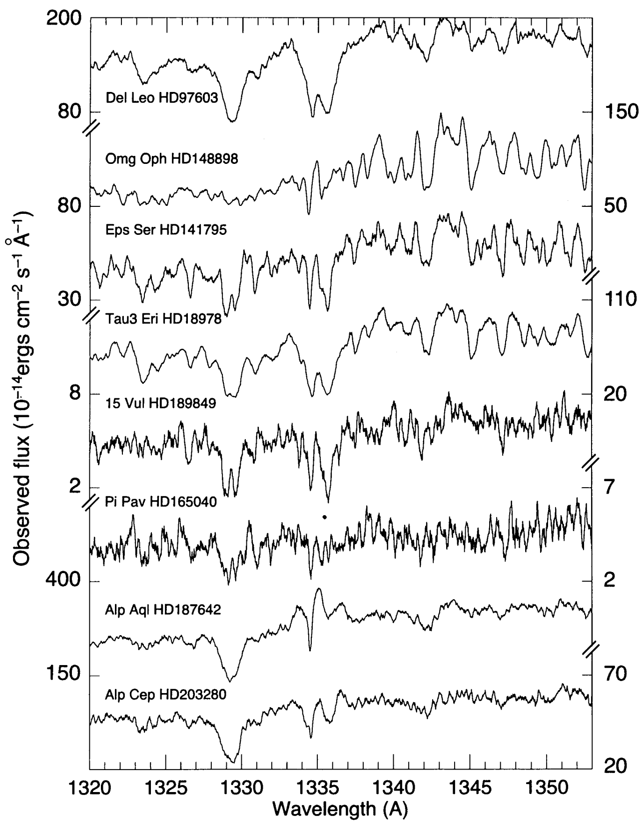

FIG. 1.—GHRS spectra of A stars. The spectra are arranged from top to bottom in the order of increasing $B-V$ color index. The observed flux scales for the individual spectra alternate from left to right, starting on the left with the top spectrum. The wavelength scale is heliocentric. The data have been smoothed with a three-diode running mean.

effect would be expected to lift the UV continuum brightness by an order of magnitude or more (Slettebak, Kuzma, & Collins 1980). However, in our GHRS spectra, and in longer-wavelength *IUE* spectra at 1900 Å, the UV fluxes of our two fastest rotators, Altair and α Cep, agree to within 25% with the spectral energy distributions predicted by nonrotating Kurucz (1993) models at the nominal $T_{\rm eff}$ of these two stars.

3. DISCUSSION

3.1. *The Chromospheric Flux of Altair*

The presence of C II emission in the GHRS spectrum of Altair is consistent with the detection of chromospheric Lyα in *IUE* spectra of this star (Catalano et al. 1991b; Landsman & Simon 1993). No chromospheric emission is evident to us in any of the other GHRS spectra, and in particular there appears to be none in the spectrum of α Cep, a star that is a near twin of Altair in terms of spectral class, photometric colors, and projected rotation speed. Landsman & Simon (1993) reported weak Lyα in low-dispersion *IUE* spectra of α Cep, at a flux level ~22 times weaker than that detected from Altair, and Catalano et al. (1991a) also claim a possible detection from a high-dispersion *IUE* spectrum. If C II emission is present in the spectrum of this star, veiling the photospheric line beneath, then the emission cannot be greatly Doppler shifted since the observed line is not noticeably asymmetric or displaced by more than 4 km s^{-1} from its expected position.

To derive the true chromospheric C II flux of Altair, we must first estimate the strength of the underlying photospheric absorption line that has been filled in by chromospheric emission. For this purpose we may use either a model atmosphere calculation, taking into account that Altair is a possibly rotationally distorted star, or a spectral template. We take the latter approach. As our comparison star we choose α Cep, because (1) the weak Lyα flux of this star suggests it is relatively inactive, (2) there is no overt C II emission feature visible in our GHRS spectrum, which again suggests a weak level of activity, and (3) the fundamental parameters and appearance of the *IUE* spectrum of α Cep at wavelengths longward of 1600 Å very closely match those of Altair. Formally our approach yields only a lower limit to the chromospheric flux of Altair since there could be some filling in of the photospheric features of α Cep. Below we derive an a posteriori estimate of this chromospheric veiling.

According to Lindler (1993), GHRS spectra taken through the large aperture can have wavelength uncertainties of up 1.5 diodes (0.11 Å, or 24 km s^{-1}) due to centering errors and uncertainty in the calibration of the incidence angle offset. Therefore, as a first step, we test the accuracy of our wavelength scales using the interstellar line of C II. The rest wavelength of this line is 1334.53 Å. For each star observed, Table 1 lists the predicted centroid of the interstellar feature, given the bulk velocity of the local interstellar medium determined by Frisch & York (1991). Due to the multicomponent nature of the local interstellar medium, these velocities are probably limited to an accuracy ~10 km s^{-1} (Lallement & Bertin 1992). We expect the interstellar feature to appear in the spectra of Altair and α Cep at wavelengths of 1334.42 and 1334.49 Å, respectively. Our measurements place the line at 1334.39 Å for Altair and at 1334.49 Å for α Cep. Thus, only minor corrections are needed to the observed wavelength scales.

To adjust for the difference in radial velocity listed in Table 1, we shift the α Cep spectrum in wavelength by 16 km s^{-1}; we then scale the flux by a factor of 5.5 to match the continuum levels in the neighborhood of the C II lines; and finally we subtract the scaled flux at each wavelength from the flux observed for Altair. The resulting flux difference spectrum is shown in Figure 2. We note that that 16 km s^{-1} shift in wavelength brings the C I 1329 Å lines of the two stars into close alignment, as can be judged from the absence of an "S-wave"

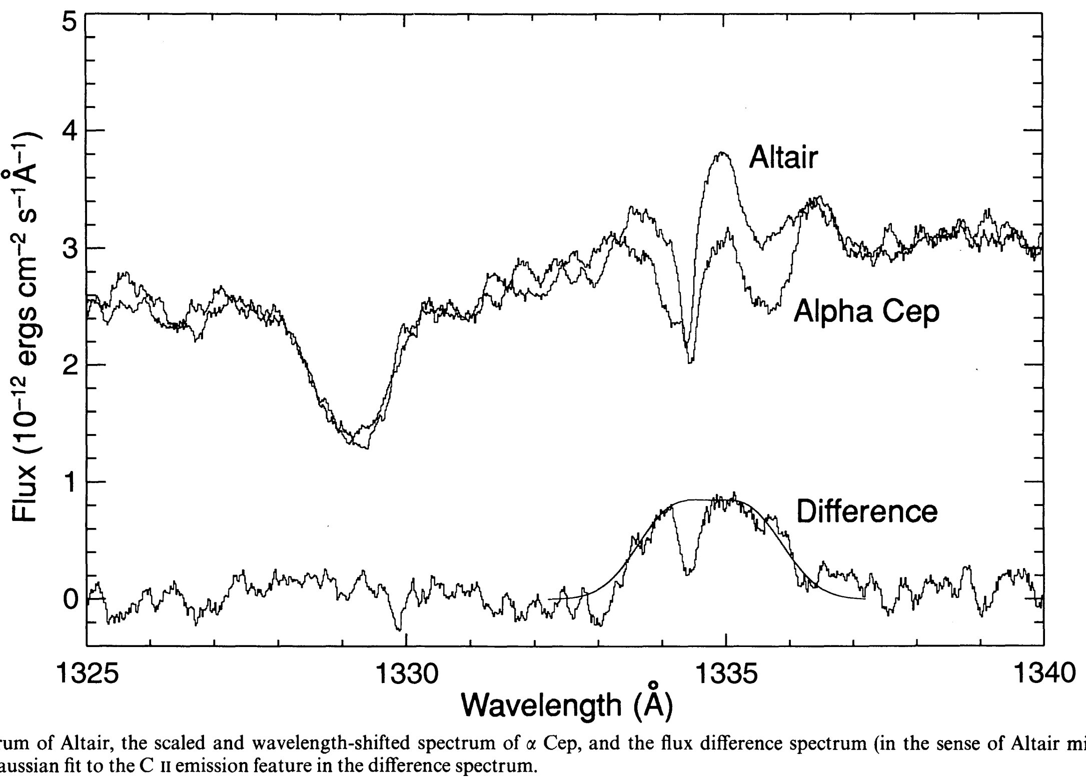

FIG. 2.—Spectrum of Altair, the scaled and wavelength-shifted spectrum of α Cep, and the flux difference spectrum (in the sense of Altair minus α Cep). Also plotted is a two-Gaussian fit to the C II emission feature in the difference spectrum.

in the flux difference curve (formally, the centroids of Gaussian fits to the profiles line up to within 1.5 km s^{-1}), while the flux scaling factor we use is only slightly larger than the factor of 4.7 difference in the brightness of these two stars at visible wavelengths. The effective temperature of α Cep, derived from Strömgren photometry, is $\sim$100 K cooler than that of Altair, and so a slightly larger flux scaling factor is to be expected in the UV.

The chromospheric emission feature that we derive for Altair is quite broad, having a full width at its base of 2.8 Å (= 625 km s^{-1}). A similarly large width of $\sim$4 Å is seen in the Lyα emission feature of this star (Catalano et al. 1991b). After removing the residual interstellar absorption, which remains because of imperfect cancellation in the subtraction process, we derive an integrated C II emission flux of $1.7(\pm 0.1) \times 10^{-12}$ ergs cm^{-2} s^{-1}. Stated as a fraction of the stellar bolometric flux, this value corresponds to a normalized C II line flux of $R(\text{C II}) = 1.4 \times 10^{-7}$, which is comparable to the quiet Sun flux of $\sim 1 \times 10^{-7}$. Altair and the Sun are thus quite similar in terms of their global chromospheric activity levels. However, Altair emits more than 30 times less energy in coronal X-rays than the quiet Sun, producing a normalized X-ray flux of only $R(\text{X-rays}) \approx 3 \times 10^{-8}$ (Schmitt et al. 1985) as compared to the solar value of 1×10^{-6}, and indeed it emits only one-third as much as a solar coronal hole.

We now derive an estimate of the chromospheric filling-in of the α Cep spectrum and the corollary adjustment to the chromospheric flux for Altair. Our estimate is based on the assumption that the chromospheric C II emission strengths of the two stars scale with their Lyα fluxes, in the ratio of 22:1. This assumption may be questioned, but we nevertheless carry the exercise through for completeness. Taking into account the factor of 5.5 used to scale the spectrum of α Cep to that of Altair, it is a simple matter to show[3] that chromospheric emission fills in 41% of the intrinsic photospheric C II line of α Cep, and that the measured chromospheric flux of Altair must be increased by the factor $22/(22 - 5.5) = 1.33$ to a value of 2.3×10^{-12} ergs cm^{-2} s^{-1}. In this case, the equivalent width that we infer for the photospheric line of α Cep, 500 mÅ, is reasonably consistent with the larger absorption equivalent widths of 600–1200 mÅ that we measure for the hotter stars shown in Figure 1.

3.2. *The Expanding Chromosphere of Altair*

Previous work with *IUE* has shown that the UV emission lines of stars are often Doppler shifted with respect to their photospheric lines, indicating large-scale motions in the chromosphere (Ayres et al. 1988). A similar measurement can be made of Altair's C II emission feature, which takes advantage of the high accuracy of the GHRS wavelength scale. However, in earlier work the C II lines analyzed for radial velocity shifts were resolved, whereas in the spectrum of Altair the lines appear totally blended (which we attribute to the much faster rotation of this star). Ultimately, to interpret such a feature, a detailed radiative transfer model will be required for the chromosphere of Altair, which should include the effects of a moving atmosphere, but as yet no models of this kind are available for A stars. Therefore, for the purposes of exploration here, we have taken a more simplistic approach and experimented with a variety of fitting functions to match the overall shape of the (unresolved) C II doublet; we have then appealed to *IUE* observations of other stars in order to determine the rest wavelength and Doppler shift for the centroid of the feature.

Our initial step was to make a least-squares fit to the flux difference spectrum, using a pair of Gaussians constrained to have a separation of 1.18 Å, the same as the distance between the two major lines in the C II multiplet. For this calculation we used the CURVEFIT program in the IDL system library. In the rest frame of the star, that is, following a correction for the -26 km s^{-1} radial velocity of Altair, the emission components were found to be blueshifted by -81 ± 9 km s^{-1}. The red emission component was computed to be $\sim$50% broader and stronger than the blue component, which is well within the bounds of behavior observed in C II spectra of solar-type stars. The reduced χ^2 of the solution is 0.93. The range of uncertainty in the Doppler shift corresponds to the 68% confidence level (i.e., for 1 σ) and was estimated in accordance with the prescription of Lampton, Margon, & Bowyer (1976) for the case of a single interesting parameter (the wavelength shift).

To assess the effects of rotation, we also computed the fits with rotationally broadened pairs of Gaussians, but we ignored possible limb brightening or limb broadening in the C II lines (Lites et al. 1978, p. 335). For the nominal rotation parameter of Altair, $v \sin i = 242$ km s^{-1}, the feature we computed had either too strong a central peak or broad wings that extended beyond the edges of the observed emission profile (even taking into account the low signal-to-noise and uncertainty in the data there). A much more acceptable fit was achieved for broadening parameters corresponding to $v \sin i < 242$ km s^{-1}. Figure 2 shows a best fit for $v \sin i = 120$ km s^{-1} and a Doppler shift of -55 km s^{-1}. Ignoring the interstellar feature, the fit in this case is very reasonable. Such a low broadening parameter may be a further example of the "UV line narrowing effect" mentioned earlier, in which the chromosphere of Altair is confined to the slowly rotating, high-latitude regions of the star.

In a variation upon this approach, we have tried to estimate the centroid velocity of a rotationally blended C II multiplet, which we extract from a pair of well-exposed high-dispersion *IUE* spectra of the G0 V star, χ^1 Orionis (image numbers SWP 22224 and SWP 22244). According to Ayres et al. (1988), after correcting for the radial velocity of this star plus small shifts in the *IUE* echelle format due to temperature fluctuations and miscentering of the target, the C II emission lines in these two spectra are blueshifted by 4.5 km s^{-1} with respect to the lower excitation UV lines. The latter are themselves redshifted by almost the same amount with respect to their laboratory wavelengths, so that the C II lines are at nearly their laboratory wavelengths. Our own measurements confirm this to be true. We determine the flux-weighted centroid of the multiplet to be at 1335.12 $\pm$ 0.01 Å. If we then broaden the χ^1 Ori spectrum to the 242 km s^{-1} $v \sin i$ of Altair, or to the smaller 120 km s^{-1} UV broadening cited above, then the convolved feature has a small central spike upon a $\sim$3.4 Å wide bell-shaped base, as well as a small asymmetry due to very slightly more flux on the red side than the blue. However, the centroid of the multiplet remains virtually fixed for each rotation parameter adopted and can be placed with considerable certainty at a wavelength of 1335.13 ($+0.02$, -0.01) Å.

Given this result, we expect to find the chromospheric emission of Altair centered on 1335.02 Å (after correcting for $V_r =$

[3] Let f_{aql}, f_{cep} be the true chromospheric fluxes of Altair and α Cep, respectively, and f_{obs} ($= 1.7 \times 10^{-12}$ ergs cm^{-2} s^{-1}) the Altair flux measured from the GHRS spectra, as described above. By assumption, $f_{aql} = f_{obs} + 5.5 f_{cep} \equiv 22 f_{cep}$. Hence, $f_{cep} = f_{obs}/(22 - 5.5) = 0.10 \times 10^{-12}$ and $f_{aql} = 22 f_{obs}/(22 - 5.5) = 2.3 \times 10^{-12}$.

-26 km s^{-1}). Various least-squares fits to the C II spectrum shown in Figure 2 all consistently yield a centroid wavelength of 1334.77 $\pm$ 0.02 Å (and a reduced $\chi^2 \approx 0.5$ for the fit). This result differs by -0.25 ± 0.02 Å or -55 ± 4 km s^{-1} from the expected position in the rest frame of the star. To within the combined 3 σ formal errors (plus the uncertainty arising from the presence of the residual interstellar absorption feature in Figure 2), the velocity we derive here is entirely consistent with our earlier estimates. We therefore suggest that our GHRS observations offer the first tentative indication ever for large-scale motions in the atmosphere of a normal A star. We choose to interpret this as chromospheric expansion; the alternative is that we are observing the upward leg of a global circulation pattern. Elsewhere we have suggested (Simon & Drake 1989, 1993; Simon & Landsman 1991) that A stars might be losing mass via coronal winds, which deplete the corona of material and reduce its X-ray brightness. The possibility now exists that these winds originate much deeper in the atmosphere within the C II–forming region at the top of the chromosphere.

Very high signal-to-noise spectra of the Hα line of Altair (Lanz & Catala 1992), upon reexamination, also appear to show an asymmetry in the line core, which may be related to the outflow we believe we have now observed in C II. No mention was made of this feature by Lanz & Catala, who may have ascribed it to telluric absorption lines. The Lyα profile of Altair described by Catalano et al. (1991a, b) appears to be fairly symmetric, but the effects of expansion most likely would be undetectable in the low signal-to-noise spectra available from *IUE* except for a very massive wind. Ayres et al. (1993) have recently described an asymmetry in high signal-to-noise Lyα spectra of Capella, from which they derive a mass-loss rate of the order 10^{-10} $M_\odot$ yr^{-1}, assuming a moderate temperature wind. Upper limits on the mass-loss rate of Altair estimated from Hα (Lanz & Catala 1992) and from sensitive radio continuum observations (Brown et al. 1990) fall below 10^{-10} $M_\odot$ yr^{-1}, while upper limits on other, selected A stars are as low as a few $\times 10^{-11}$ $M_\odot$ yr^{-1} (Wonnacott & Kellett 1993). Thus, for the wind losses in an A star like Altair to be detectable in Lyα will require a much improved signal-to-noise. We think this should be attainable in future observations with the GHRS, not only for Altair but for other stars with evidence of C II emission in *IUE* spectra.

3.3. *Chromospheric Activity along the Main Sequence*

For luminosity class IV or V stars, the earliest detection of C II emission recorded in *IUE* spectra is at $B-V = 0.23$ (Simon & Landsman 1991), while the earliest possible detection in Lyα comes at $B-V = 0.19$ (Marilli et al. 1992). If the stars we have observed with the GHRS are representative of normal A-type stars, then present indications are that the onset/disappearance of convection zones sufficient to generate chromospheres in main-sequence stars occurs in the vicinity of $B-V = 0.22$, while intense chromospheres make their first appearance somewhat later, near $B-V = 0.25$ (Simon & Landsman 1991). This juncture is in the middle rather than along the red side of the so-called A star gap near $B-V = 0.3$ (Böhm-Vitense & Canterna 1974), where former studies tended to place the onset of convection (Böhm-Vitense & Dettmann 1980; Wolff et al. 1986). A further implication of our result is that the mechanical energy fluxes generated by stellar convection must fall off more steeply with increasing T_{eff} than theoretical calculations currently predict.

Our detection of C II emission in the spectrum of Altair, and its apparent absence—or at least its relatively much weaker strength, by at least a factor of 4 in normalized flux—in the spectrum of α Cep, is consistent with our earlier findings from low-dispersion *IUE* spectra of a wide spread in activity among the late A and early F stars of any given color at $B-V < 0.3$, and the lack of any correlation of this activity with rotation. Those earlier results, and the ones reported here, lend support to the possibility first raised by Böhm-Vitense (1982, and references therein) that some A stars are able to suppress the onset of convection, and thereby remain purely radiative, while others are not, and thus turn convective. The reason for this dichotomy in convective properties has not yet been found.

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REFERENCES

Ayres, T. R., Brown, A., Gayley, K. G., & Linsky, J. L. 1993, ApJ, 402, 710
Ayres, T. R., Jensen, E., & Engvold, O. 1988, ApJS, 66, 51
Böhm-Vitense, E. 1982, ApJ, 255, 191
Böhm-Vitense, E., & Canterna, R. 1974, ApJ, 194, 629
Böhm-Vitense, E., & Dettmann, T. 1980, ApJ, 236, 560
Bohn, H. U. 1984, A&A, 136, 338
Brown, A., Veale, A., Judge, P., Bookbinder, J. A., & Hubeny, I. 1990, ApJ, 361, 220
Carpenter, K. G., Slettebak, A., & Sonneborn, G. 1984, ApJ, 286, 741
Catalano, S., Gouttebroze, P., Marilli, E., & Freire Ferrero, R. 1991a, in IAU Colloq. 130, The Sun and Cool Stars: Activity, Magnetism, and Dynamos, ed. I. Tuominen (New York: Springer), 466
Catalano, S., Marilli, E., Freire Ferrero, R., & Gouttebroze, P. 1991b, A&A, 250, 573
Duncan, D. K. 1992, Hubble Space Telescope Goddard High Resolution Spectrograph Instrument Handbook, version 3.0 (Baltimore: Space Telescope Science Institute)
Freire Ferrero, R. 1986, A&A, 159, 209
Freire Ferrero, R., & Talavera, A. 1984, Proc. 4th European *IUE* Conf., ed. E. Rolfe & B. Battrick (ESA SP-218), 207
Frisch, P. C., & York, D. G. 1991, in Extreme Ultraviolet Astronomy, ed. R. Malina & S. Bowyer (New York: Pergamon), 322
Gilliland, R. L. 1986, ApJ, 300, 339
Hutchings, J. B. 1976, PASP, 88, 5
Kurucz, R. L. 1993, in Peculiar Versus Normal Phenomena in A-Type and Related Stars, ed. M. M. Dworetsky, F. Castelli, & R. Faraggiana (ASP Conf. Series 44), 87
Lallement, R., & Bertin, P. 1992, A&A, 266, 479
Lampton, M., Margon, B., & Bowyer, S. 1976, ApJ, 208, 177
Landsman, W., & Simon, T. 1993, ApJ, 408, 305
Lanz, T., & Catala, C. 1992, A&A, 257, 663
Lindler, D. J. 1993, BAAS, 25, 831
Lites, B. W., Shine, R. A., & Chipman, E. G. 1978, ApJ, 222, 333
Marilli, E., Catalano, S., Freire Ferrero, R., Gouttebroze, P., Bruhweiler, F. C., & Talavera, A. 1992, in Cool Stars, Stellar Systems, and the Sun, ed. M. S. Giampapa & J. A. Bookbinder (ASP Conf. Ser. 26), 178
Palla, F., & Stahler, S. W. 1991, ApJ, 375, 288
Roby, S. W., & Lambert, D. L. 1990, ApJS, 73, 67
Schmitt, J. H. M. M., Golub, L., Harnden, F. R., Jr., Maxson, C. W., Rosner, R., & Vaiana, G. S. 1985, ApJ, 290, 307
Simon, T., & Drake, S. A. 1989, ApJ, 346, 303
———. 1993, AJ, 106, 1660
Simon, T., & Landsman, W. 1991, ApJ, 380, 200
Slettebak, A., Kuzma, T. J., & Collins, G. W., II. 1980, ApJ, 242, 171
Walter, F. M., & Linsky, J. L. 1986, in Lecture Notes in Physics, Vol. 254, Cool Stars, Stellar Systems, and the Sun, ed. J. L. Linsky & R. Stencel (Berlin: Springer), 50
Wolff, S. C., Boesgaard, A. M., & Simon, T. 1986, ApJ, 310, 260
Wonnacott, D., & Kellett, B. J. 1993, in White Dwarfs: Advances in Observation and Theory, ed. M. A. Barstow (Dordrecht: Kluwer), 185