UV CHROMOSPHERIC AND CIRCUMSTELLAR DIAGNOSTIC FEATURES AMONG F SUPERGIANT STARS

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INTRODUCTION

We undertook a survey of F supergiant stars to evaluate the extension of chromospheric and circumstellar (CS) characteristics commonly observed in the slightly cooler G, K and M supergiant spectra. In the optical regions, the usual diagnostic spectral features are swamped by the brighter photospheric light in F stars. Therefore, an ultraviolet survey was elected since UV features of Mg II and Fe II might persist in revealing outer atmosphere phenomena even among F supergiants. Our survey encompassed spectral types F0 to G0, and luminosity classes Ib, Ia and Ia-0.

PROFILE TYPES

Four generic types emerged from our limited survey -- two indicative of chromospheres, one strictly photospheric and one indicative of CS envelopes (Figure 1).

CHROMOSPHERIC PROFILES

Optical and UV observations of the Sun and other G, K and M stars have revealed that the emission cores of the Ca II "H&K" (3933,3968 Å), and Mg II "h&k" (2795,2802 Å) resonance lines are valuable indicators of the existence of and conditions in stellar chromospheres. Such lines are very optically thick at line center and collisionally coupled to the excitation temperature (T_e) in the stellar atmosphere to heights above the temperature minimum and into the chromospheric temperature rise [cf. Stencel et al. (1)].

Doubly reversed emission is seen in the F8 Ib and G0 Ib stars surveyed, including γ Cyg, α UMi and β Aqr. However, the F8 profiles are strikingly different from the G0 type, despite a very small difference in T_e. β Aqr shows a strong longward dominated emission with substantial CS absorption superposed on the shortward emission component. In contrast, γ Cyg and α UMi show far weaker doubly reversed central emission features. In γ Cyg it is difficult to be certain that the shortward emission component is not affected by CS absorption. Böhm-Vitense and Parsons have described γ Cyg as lacking in Mg II emission, suggesting to us that chromospheric or CS variability is at play, possibly as has been now seen for α Aqr (G2 Ib).

Among more luminous late F supergiants we find another Mg II profile type, characterized by δ CMa (F8 Ia), which shows strong shortward emission near line center, but no longward emission. This profile type is reminiscent of an inverse P Cygni profile and has been seen also in HD 96918 (G0 Ia-0) and ρ Cas (F8p Ia), where it is even more pronounced. To avoid the difficulties of invoking global chromospheric collapse (inverse of the standard P Cygni explanation), we could explain the appearance of such profiles by noting an excess longward absorption component, perhaps due to large scale downflows along the edges of giant cells (as seen in the solar network). This could obscure the longward emission and leave us with the observed inverse P Cygni profile. It is noteworthy that we find this chromospheric profile type only for stars of the highest intrinsic luminosity.

PHOTOSPHERIC PROFILES

As we look to F stars of warmer T_e, evidence in Mg II for chromospheric emission vanishes, presumably due to the increasing degree of ionization. For spectral types F0 to F5 we find repeatedly a smooth broad absorption feature with strongly damped line wings and a narrow Doppler core of essentially zero residual intensity. Examples of this include α Car (F0 Ib), ν Aql (F2 IB) and α Per (F5 Ib), all objects of comparable M_V. Among objects of greater intrinsic luminosity we find a hybrid profile -- strong damping line wings with a boxy, non-Doppler core. This boxy dark core is probably CS in origin and is seen in l^1 Sco (F2 Ia), HD 74180 (F2 Ia) and in 89 Her (F2 Ia), except that 89 Her also reveals a trace of longward emission next to the CS absorption at line center. Again we find a distinct luminosity difference in the Mg II profiles.

CIRCUMSTELLAR PROFILES

Finally we detected one object which may provide the link between strong mass-losing stars like α Cyg (A2 Ia) and β Aqr (G0 Ib) in having qualitatively similar Mg II profiles. α Lep (F0 Ib) was found to have a pair of strong CS components shifted by -1.24 and -1.73 Å from line center. No chromospheric emission is obvious, although strong interstellar absorption at line center could obscure this. This CS structure suggests a substantial envelope and extensive mass loss. Alternately, one might identify the region between CS and line center absorptions as due to emission, but rather arcane radiative transfer effects might be required to verify such a picture. Success in CS profile modeling of α CYG by Kunasz should help to clarify the meaning of the α Lep profile.

THE OUTER ATMOSPHERES OF F SUPERGIANTS

With the IUE observations of our survey, it is possible to make some general comments regarding the atmospheric structure of F supergiant stars.

DETECTION OF CHROMOSPHERES

We have obtained high dispersion Ca II K line spectra for many of the stars in our UV study and find in general that outer atmospheric structure is far more apparent in the Mg II k line than in Ca II K. Hence the necessity for UV observations in this area is now clear. Deep exposures of the Ca II K line center for δ CMa and α Lep revealed only photospheric absorption without a hint of the striking profile structure seen in Mg II k. This occurs because the abundances and ionizations are different, but the general lack of significant chromospheric emission in Ca II K and Mg II k places strong constraints on the geometric extent of chromospheres since radiative losses in these lines (dominant sinks for G, K and M chromospheres) are minimal. Either the losses are confined to resonance lines of higher ions (hot chromospheres) or the chromospheres are "thin." Additional far UV and EUV observations will clarify this matter.

FAILURE OF THE WILSON-BAPPU EFFECTS

One of the aims of our survey was to determine the usefulness of the emission line width-to-luminosity correlation in use for the G-M stars in both the Ca II and Mg II lines [Wilson and Bappu (2), Weiler and Oegerle (3)]. In Table 1 we collect relevant information on our survey stars and present measured widths and infer M_V where possible. Inspection reveals that only the F8-G0 Ia-0 stars are even approximated in this way. We conclude that the Wilson-Bappu and Weiler-Oegerle correlations are probably not suitable for stars earlier than G0, because of significant physical differences in emission core formation as compared to cooler stars. We have already noted the striking difference between F8 and G0 Ib stars despite the small change in T_e. Some combinations of rotation, pulsation, evolution and magneto-acoustic effects makes the respective chromospheric signatures quite different. Whereas the wing emission lines of Ca II [Stencel (4)] are useful among F-M stars in evincing mass loss and indicating M_V, we found no comparable features in the Mg II line wings among F supergiants.

VELOCITY FIELDS

Where Mg II emission cores are seen, asymmetries can be interpreted as indicative of globally averaged motions. The near symmetric profiles of γ Cyg and α UMi suggest that inflow and outflow roughly cancel -- as they would in large scale convection-like motions. The inverse P Cygni profile of the F8 Ia-0 stars is more difficult to understand, but could arise from extensive network-like structures which are the sites of material downflow, vis-a-vis the Sun. A height dependent ionization transition could help accomplish this, i.e., hot (Mg III) matter wells up at the centers of large cells and cools (Mg II) as it begins its descent along the cell boundaries (the network). The alternative explanation for an inverse P Cygni profile, that of a collapsing envelope, might have its place in the evolutionary scenario for such volatile objects, but it is difficult to reconcile with other indicators for substantial stellar winds and mass loss, especially for ρ Cas.

Where CS core absorption is seen, assuming one can disentangle the interstellar component, the width and/or displacements from line center argue for significant stellar winds, mass loss and CS envelopes. As has been described by Lamers et al. (5) for α Cyg, stars like α Lep may provide additional evidence for the sporadic, non-continuous or "puffy" mass loss since we clearly detect a pair of outward moving shells.

FUTURE RESEARCH

With the limited time available for our survey, we did not have the opportunity to explore the SWP (1200-2000 Å) region of F supergiant spectra, nor the detailed comparison between Cepheid and non-Cepheid objects in this region of the HRD. Because of increasing continuum brightness, it will probably be difficult to clearly identify emission lines arising from any analog of the solar 'transition region' (TR: 100,000 to 250,000 K), or from cooler coronal hole outflow sites (CH: <25,000 K). Representative lines would include: TR -- N V 1240 Å, Si IV blend at 1400 Å and C IV 1550 Å; CH -- O I 1300 Å. Again, Böhm-Vitense and Parsons have surveyed similar stars and hopefully will describe their findings at this conference and elsewhere. A comprehensive survey would clarify the distribution of chromospheres, TR, coronae and CS material among the F supergiants.

We thank A. Boggess and his dedicated staff for assistance in obtaining and analyzing data under program LFBSW, as well as for contractual support. Mg II region spectral plots of stars mentioned herein will be available on request for a limited time from the first author.

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TABLE 1. - Comparison of Mg II k and Ca II K in F Supergiants

					Mg II k			Ca II K			
Star	Sp. Type	LWR#[a]	Exp.	M_v [b]	Profile	W_o [c]	$M_v(k)$ [d]	Profile	W_o [c]	$M_v(K)$ [e]	UV Fe II Emission?
α Car	F0 Ib	4703	3	-4.8	No em.	--	--	No obs.			No
α Lep	F0 Ib	5021	16	-4.5	CS&IS	1.2CS	--	No em.+CS	1.0a	--	No
ν Aql	F2 Ib	5015	70	-4.7	Wk.em?	--	--	No em.	0.9CS?	--	No
ι^1 Sco	F2 Ia	5046	25	-8.4	CS core	1.4CS	--	No em.	1.1CS?	--	No
HD 74180	F2 Ia	5043	60	-8.4	CS core	1.0CS	--	No. obs.			No
89 Her	F2 Ia	5047	100	-8.4	CS+em?	2.1CS	--	CS+w.e.*	2.2CS	--	Yes
α Per	F5 Ib	5018	14	-4.6	No em.	--	--	Wk. em.	1.5e?	-2.8	No
δ CMa	F8 Ia	5020	20	-7.5	Inv. P Cyg	2.3HW	-5.9	No em.	0.3core	--	Weak?
α UMi	F8 Ib	5017	15	-4.6	DR em.	1.8	+0.3	No em.	0.6core	--	No
γ Cyg	F8 Ib	5016	25	-4.6	DR em+CS?	2.3	-1.3	No em.+w.e.	0.6core	--	No
ρ Cas	F8p Ia	5014	447	-9:	Inv. P Cyg	2.1HW	-5.3	CS+w.e.	1.8CS	--	Yes
HD 96918	G0 Ia0	4702	75	-9:	Inv. P Cyg	2.9HW	-7.4	No obs.			Yes
β Aqr	G0 Ib	4446	18	-4.5	DR em.+CS	3.8	-4.6	Wk.em.	2.0	-4.7	No

[a] Large aperture, high dispersion; exposure time in minutes.

[b] Data from Patterson and Neff, 1979 Astrophys. J. Suppl. 41, 215.

[c] Emission base width ($\Delta\lambda_{k\ 1}$), half width (HW) or CS absorption width, in Å.

[d] $M_v(k) = -15.15 \log W_o(\mathrm{km/sec}) + 34\overset{m}{.}93$.

[e] $M_v(K) = -15.0 \log W\ (\mathrm{km/sec}) + 28\overset{m}{.}0$.

*Wing emission lines, cf. Stencel 1977 Astrophys. J. 215, 176.

Mg II Profile Types in F Supergiant Stars

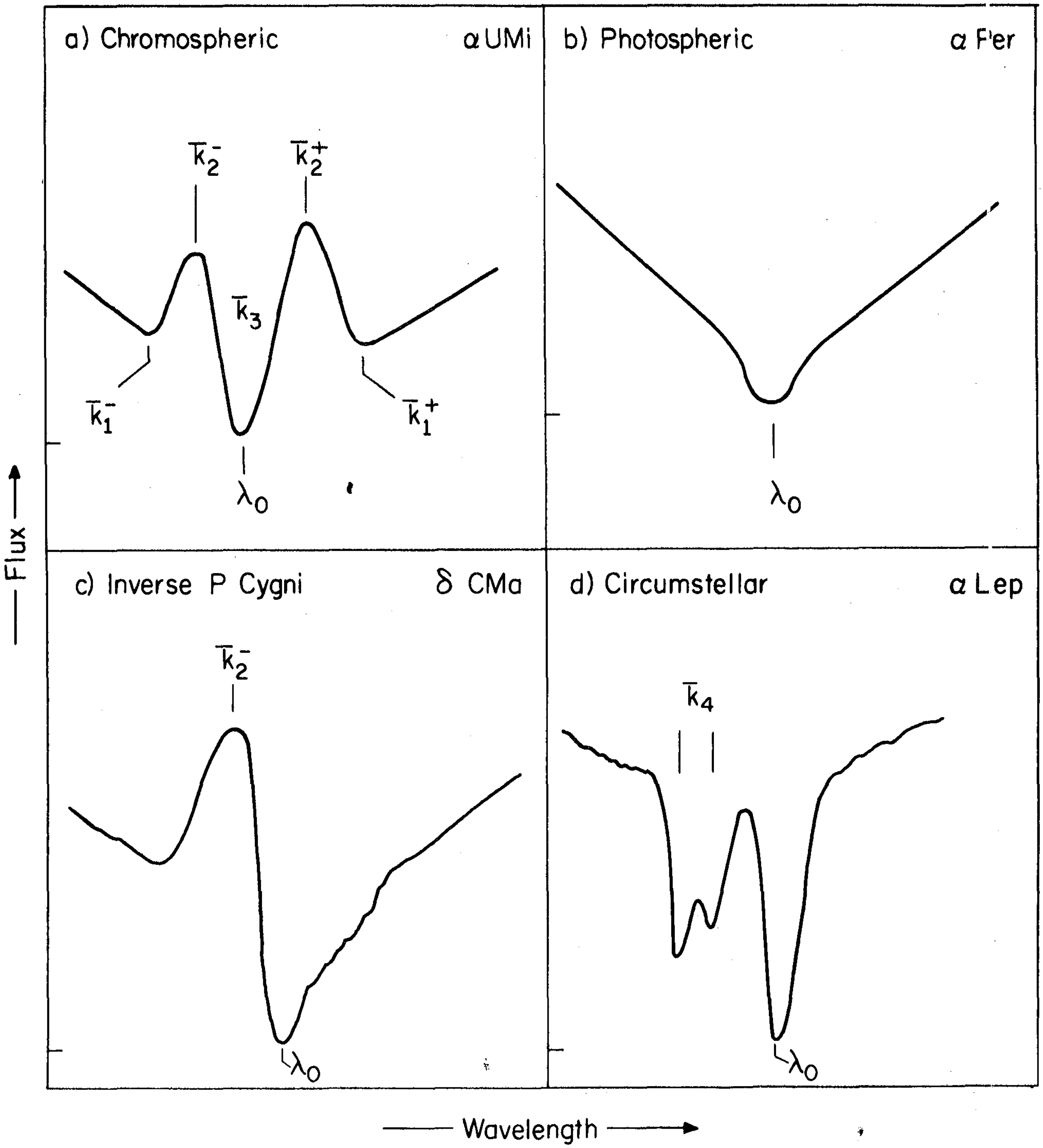

Figure 1