HIGH DISPERSION FAR ULTRAVIOLET SPECTRA OF COOL STARS

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ABSTRACT

We discuss recent far UV high dispersion spectra of two cool supergiant stars, Beta Dra (G2 Ib) and Alpha Ori (M2 Iab), which are examined in the context of current questions regarding stellar chromospheres, coronae and mass loss. These stars show very different outer atmosphere structure. Beta Dra has a geometrically thin transition region with bright emission lines of $10^5$ K plasma that are red-shifted, indicating downflow in magnetic flux tubes. By contrast, Alpha Ori has a cool extended chromosphere and circumstellar envelope with large mass loss.

I. THE IMPORTANCE OF FAR UV HIGH DISPERSION SPECTRA

Unsolved problems concerning the winds of late-type stars include the geometry of the regions in which the flow occurs, the flow velocities, wind generation mechanisms, and mass loss rates. The cool supergiants are interesting in this regard, because some of these stars, the so-called "hybrids" possess both hot plasma comparable to the solar transition region (TR), and cooler outflowing gas at substantial terminal velocities (cf. Hartmann et al. 1980). Although these data might imply a continuous variation in outer atmospheric properties between late type stars of decreasing surface gravity, there is also considerable evidence that a discontinuous change occurs, separating the solar-like stars with hot, multi-million degree coronae and apparently small mass loss rates, from the noncoronal red giants and supergiants (see the invited papers by Dupree and Linsky in this volume, and references therein).

High resolution spectra of far ultraviolet emission lines in cool stars can provide key information in solving some of these problems. Such spectra which can be obtained only for the brightest cool stars with the IUE, permit measurements of spectral line shape parameters. These can be used to infer properties of the emitting plasma, such as the electron density, emitting volume and flow velocities.

II. THE OBSERVATIONS

These data were obtained with the IUE in its echelle mode of operation, as an international collaboration involving the Universities of Colorado, Oxford, and Oslo. For each spectrum, two or three consecutive eight hour shifts of IUE time were used to obtain the lengthy exposures. In some instances, the frequently noisy US2 shift was particularly quiet, permitting a 1273 min (21.2 hour) exposure of Beta Dra (SWP 15293).

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In addition to the spectra of Beta Dra and Alpha Ori that are discussed below, we also obtained useful exposures of Beta Cet (K3 III, 795 minutes, SWP 14786) and 56 Peg (K0 IIp + wd, 1040 minutes, SWP 15283). Beta Cet is the coolest giant known to emit soft X-rays, and Eriksson et al. (1982) have computed a model chromosphere/TR that successfully matches the observed line profiles. 56 Peg is an interacting binary which has been analyzed by Schindler et al. (1982) in the context of "barium" binaries that contain cool giants and white dwarfs.

III. BETA DRACONIS

Beta Dra (HD 159181) is a G2 Ib star that lies in the Cepheid instability strip. Our 1273 minute echelle mode exposure (SWP 15293) shows emission features from a wide range of temperatures, from O I and Si II (8000 K) to C IV, Si IV and N V (150,000 K). Narrow intercombination lines of C I, O I, O III, Si III and C III were also detected. A photospheric continuum, appropriate for the 5700 K effective temperature, rises steeply toward the longwave end of the spectrum.

We have measured the line shape parameters for the emission features with a least-squares gaussian fitting procedure that yields line centroids, FWHM, and integrated fluxes. Using a flux-weighted average of the narrowest chromospheric lines to determine the stellar velocity scale, we find that the high temperature resonance lines are red-shifted by \( +20 \pm 4 \text{ km s}^{-1} \), suggesting systematic downflows in the TR gas relative to the chromosphere in Beta Dra (see Fig. 1). This result is similar to that seen in solar transition region lines, where the emission lines are formed in downflowing gas in closed magnetic flux loops. Accordingly, the portions of the Beta Dra transition region that are bright in C IV and N V do not likely participate in any wind expansion, but instead should be formed in the infalling component of a circulation pattern.

Because the high temperature resonance lines probably do not participate in any wind expansion, their widths can be interpreted to be due to local Doppler motions. This concept is supported by the narrower intercombination lines of O III, Si III, C III that are formed at comparable temperatures. Furthermore, the lines of O I and Si II are of sufficient breadth as to be opacity broadened, and we propose this may also be the case in the high temperature lines.

As shown in Fig. 1c, a comparison of the surface flux ratios between Beta Dra and G2 V solar-like star Alpha Cen A (Ayres et al. 1982), indicates increasing relative emission measure with increasing temperature of formation. To estimate the geometrical thickness of the Beta Dra transition region, we derive the emission measure distribution by multiplying the solar distribution by the surface flux ratios in Fig. 1c and estimate \( n_e = 2 \times 10^{10} \text{ cm}^{-3} \) at \( T = 5 \times 10^4 \text{ K} \) using four density sensitive line ratios. From these data we conclude that the transition region is geometrically thin like the Sun even if the emitting regions cover only a small fraction of the stellar surface. The corona, on the other hand, would be 0.01 stellar radii thick if the X-ray emission is uniform across the surface or perhaps extended if the emission is only from small regions.

Beta Dra is a close neighbor in the H-R diagram to the so-called "hybrid" stars Alpha Aqr (G2 Ib) and Beta Aqr (G0 Ib). Unlike the hybrids, Beta Dra
exhibits soft X-ray emission and lacks circumstellar absorption features. These data combined with the previous analysis lead us to suspect a discontinuous change in the outer atmospheric properties between solar like and nonsolar like stars, in the sense first argued by Linsky and Haisch (1979). There is sufficient indication to further hypothesize that magnetic topology is the controlling factor (see Mullan and Stencil, this volume).

IV. ALPHA ORIONIS

Alpha Ori (HD 39801) is the brightest M2 Iab supergiant visible from Earth. Consistent with its lack of soft X-ray emission ($f_X/f_{bol}$ less than $3 \times 10^{-9}$), our 930 minute echelle mode exposure (SWP 14775) lacks any trace of high temperature lines associated with transition regions. The observed emission can be identified with O I, S I, Si II and Fe II. Comparison of high and low dispersion spectra of Alpha Ori indicates that bright low dispersion emission features which are not seen in high dispersion may in many cases be diffuse atomic or molecular bands, such as 1541Å CO emission (Ayres et al. 1981). In high dispersion, the lines of S I appear doubly reversed, suggesting very high opacity. The total lack of the O I 1300Å and S I 1295Å fluorescent lines also argues for considerable circumstellar absorption. This level of absorption is consistent with the arguments for an extended cool chromosphere surrounding such noncoronal giants and supergiants (cf. Stencil 1982).

An interesting result of this exposure, not detected in previous shorter echelle mode observations, is the appearance of the Fe II (UV 191) multiplet in emission near 1785 Å. These lines are seen prominently in emission in the spectra of the late type supergiant eclipsing binaries like Zeta Aur, 32 Cyg and WW Cep. In those cases the continuum of the hot dwarf companion can populate the 10 eV upper state via Fe II UV9 lines near 1270Å (see Stalio and Selvelli 1981). However, such pumping seemingly should not occur for Alpha Ori given its lack of a hot companion or high temperature material in its outer atmosphere. The high excitation Fe II emission may represent a preferred deexcitation channel for Fe II excited by free electrons or multiply scattered Lyman photons in the vast chromosphere of Betelgeuse.

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Fig. 1. The top panel shows emission line centroid velocities for emission lines in Beta Dra, with symbol size proportional to flux. The open circles are intercombination lines, filled circles are resonance lines and the square is He II 1640 Å. The middle panel shows the FWHM of these features. The bottom panel shows a comparison of surface fluxes of lines in the spectra of Beta Dra and Alpha Cen A. For each line the corresponding volume emission measures should be proportional to the surface fluxes.