HIGH DISPERSION IUE SPECTRA OF ACTIVE CHROMOSPHERE G AND K DWARFS

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ABSTRACT. We analyze IUE far ultraviolet echelle spectra of three active chromosphere dwarf stars: $\chi^1$ Orionis (G0 V), $\xi$ Boötes A (G8 V), and $\epsilon$ Eridani (K2 V), utilizing spectra of $\alpha$ Cen A (G2 V) and $\alpha$ Cen B (K1 V) as quiet chromosphere comparisons.

INTRODUCTION. The advent of IUE has permitted the beginnings of detailed far ultraviolet studies of nearby late-type dwarf stars similar to our Sun. Despite our inability to observe the surfaces of such stars directly, we can utilize the high dispersion capability of the IUE echelles to obtain surrogate information concerning the spatial organization of dwarf star chromospheres ($T \approx 6000$ K) and higher temperature layers analogous to the solar transition region ($T \approx 10^5$ K) and corona ($T \approx 10^6$ K). Such information is valuable for elucidating the surface magnetic properties of dwarf stars, since the high temperature plasma of the solar outer atmosphere is known to be intimately associated with compact, bipolar magnetic structures that are distributed inhomogeneously across the solar disk (Vaiana and Rosner 1978). Here, we report a spectroscopic comparison of five dwarf stars that span a wide range of chromospheric activity.

OBSERVATIONS. We have obtained IUE echelle spectra of five representative dwarf stars with SWP exposure times ranging from 120 minutes to 952 minutes, and LWR exposures of 1 to 60 minutes. The SWP and LWR images were reduced as outlined by Ayres (1982), incorporating the provisional echelle mode calibration of Cassatella, Ponz and Selvelli (1981). Line centroid velocities, integrated fluxes and FWHMs were determined by least squares Gaussian fits to the observed emission profiles. Each image was registered to the flux-weighted mean velocity of the strongest features.

Figure 1 compares profiles of the 2800 Å Mg II doublet in the active and quiet dwarfs. The ordinate of the figure is the monochromatic flux measured at Earth divided by the stellar bolometric flux, with units commensurate to the segmented velocity scale of the abscissa. The area under the doublet profiles is the fraction of the stellar bolometric luminosity provided by Mg II emission, which in turn is a measure of the chromospheric heating rate (e.g. Linsky and Ayres 1978).

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Provided by the NASA Astrophysics Data System
Note that the Mg II profiles of the active stars, aside from their obvious flux enhancement, tend to be narrower at the peaks but broader at the bases than those of the quiet chromosphere comparison stars, although the FWHMs are nearly the same. Such behavior is typical of Mg II and Ca II profiles in solar magnetic active regions (plages) and has been interpreted in the context of schematic chromosphere models by Ayres (1979).

Figure 2 depicts selected bright lines from the far ultraviolet spectra of the five dwarfs, plotted in the same way as Figure 1. In addition, crosshatching indicates saturated pixels (or reseau marks); "#$" symbols denote prominent particle radiation hits; and "@" or "sa" designates geocoronal Ly$\alpha$ emission.
ANALYSIS. Despite the order of magnitude increase in line emission strengths of the active dwarfs compared with the quiet chromosphere stars, the FWHMs of low excitation features like Si II $\lambda$1808 and high excitation features like C IV $\lambda$1548 are very similar between the two classes. In fact, the only feature that behaves anomalously with respect to both strength and width between the active and quiet dwarfs is the $\lambda$1640 Balmer $\alpha$ line of He II. (The utility of high dispersion observations is clear in this case, since the weak He II emission of the quiet dwarfs is blended partially with an Fe II feature of comparable or greater strength.) However, it is believed that the He II emission is produced largely by an XUV photoionization-recombination mechanism (e.g. Avrett, Vernazza and Linsky 1976). Consequently the He II intensity may be a proxy diagnostic for coronal radiation fields. To test this possibility, we have compared in the left hand panel of Figure 3 He II $\lambda$1640 flux ratios measured here to soft x-ray flux ratios derived from the detections reported by Golub et al. (1982), Walter et al. (1980), and Johnson (1981). The linear correlation of He II with soft x-rays is apparent. The power law plotted in the figure is the relationship predicted by Hartmann, Dupree and Raymond (1980) using a model based largely on solar considerations.

Although the "low excitation" He II emission appears to be simply proportional to the "high excitation" coronal x-ray flux, a similar purely linear relation does not hold between chromospheric and transition region emission. The right hand panel of Figure 3 compares C IV $\lambda$1548 flux ratios with those of the Mg II doublet. A power law slope of 1.5 appears to fit quite well, as might have been anticipated from the results reported in the low dispersion survey by Ayres, Marstad and Linsky (1981).

Finally, note that the range in Mg II flux ratios between the active and quiet dwarfs is only about 0.7 dex, while the range of soft x-ray flux ratios is nearly 2.5 dex. Chromospheric flux modulation periods available from Stimeets and Giles (1980) and Hallam and Wolff (1981) indicate a range in equatorial rotational velocities of 0.9 dex or more. Accordingly, the dependence of chromospheric emission on stellar rotation could be nearly linear for these stars (c.f. Skumanich 1972), while the x-ray rotation-activity connection
must be described by a steeper power law (e.g. Ayres and Linsky 1980). However, our results also are entirely consistent with a sharp break in the rotation-activity relation near $P \approx 10$ days, as proposed by Walter (1981), and discussed recently by Durney, Mihalas and Robinson (1981) in the context of mode switching by the stellar magnetic dynamo.

CONCLUSIONS. The ultraviolet spectra of active chromosphere dwarfs presented here are morphologically similar to chromospheric and transition region spectra of solar plages. The fact that the emission line FWHMs do not broaden substantially with increasing activity suggests that the major difference between active and quiet dwarfs occurs in the surface coverage of magnetic regions, rather than a gross physical change in the stellar "transition region" itself. In particular, if the emitting structures simply were becoming optically thicker in the active stars, rather than spatially more pervasive, we would expect opacity broadening to increase the FWHMs of lines like C IV $\lambda 1548$ which are strong enough in the Sun to begin to exhibit optical depth effects. In short, the active dwarfs probably are largely covered by solar-like plage. Accordingly, the solar analogy appears to be viable, at least in the narrow context of late-type dwarf stars of near-solar temperature. Finally, the comparatively shallow dependence of chromospheric emission on stellar rotation, but the rather steep x-ray rotation-activity relation suggests that the heating of the multi-million degree corona is far more sensitive to the details of the magnetic flux production and spatial organization mechanisms than is that of the underlying chromosphere.

We acknowledge support by NASA through grants NAG5-199, NAG5-82 and NGL-06-003-057 to the University of Colorado and NAG 5-146 to the University of Hawaii, and thank the staff of the IUE Observatory for their assistance in the acquisition and reduction of the stellar spectra reported here.

REFERENCES