THE RELATIONSHIP BETWEEN RADIATIVE AND MAGNETIC FLUXES FOR THREE ACTIVE SOLAR-TYPE DWARFS

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ABSTRACT We present some preliminary results from our coordinated campaign of IUE and McMath Telescope magnetic field measurements of three active solar-type dwarf stars: 59 Vir, \(\xi\) Boo A, and HD 131511. We observed the three stars nearly every day from May 9 to May 25, 1993, covering between 1 and 3 rotations. We explore the functional and spatial relationship between magnetic and radiative fluxes.

The relationship between stellar coronal soft X-ray and chromospheric emissions is nonlinear (Ayres, Marstad, & Linsky 1981; Schrijver 1983), implying that the structure of the stellar active regions (AR) changes with activity level. If only the number of active regions were to change, linear relations should be observed. Understanding the physics of stellar activity requires knowledge of the relations between surface magnetic field strength \((B)\), magnetic filling factor \((f)\), and chromospheric and coronal radiative losses. Observations of the active K2 dwarf \(\xi\) Eri, show a weak correlation between \(f\) and Ca II H+K flux (Saar, Linsky, & Duncan 1986), as is also seen for the Sun. Simultaneous magnetic field and IUE observations of \(\xi\) Boo A show strong modulation of the UV transition region (TR) lines in phase with the magnetic flux (Saar et al. 1988). Despite incomplete phase coverage, these studies provide the first direct evidence for a correlation between stellar upper atmospheric heating and magnetic flux. Our new campaign is designed to confirm and extend these initial results.

The solar-type stars 59 Vir (G0 V; \(P_{\text{rot}} = 3.4\) d), \(\xi\) Boo A (G8 V; \(P_{\text{rot}} = 6.3\) d), and HD 131511 (K1 V; \(P_{\text{rot}} \approx 10\) d) were observed by the IUE (one SWP-LO and one LWP-HI image) nearly every day between May 9 and May 25, 1993, yielding temporal coverage of between 1 to 3 rotational periods each. Figure I shows the flux variations with time in the C IV and Mg II lines of 59 Vir.

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RADIATIVE AND MAGNETIC FLUXES

Significant variations are seen for all three stars but especially for 59 Vir, the only star which does not show rotationally modulated TR emission.

Magnetic field data were obtained with the NSO McMath echelle+CCD system and a 180 mm transfer lens, yielding $\lambda/\Delta\lambda = 125,000$ and $200 \leq S/N \leq 400$ in the 20Å interval centered near the Landé $g_{\text{eff}} = 2.5$ Fe I 6173 Å line.

Magnetic parameters were derived using an improved version of the Saar (1988) technique. We fit a spatially homogeneous, two-component model of the stellar surface to the observed flux $F = f F_m(B) + (1 - f) F_q(0)$, where we assume that $F_m(0) = F_q(0)$, i.e., the magnetic and quiet regions are identical except for the fields. The magnetic radiative transfer (RT) equations are solved in a Milne-Eddington atmosphere including magneto-optical effects and radial-tangential macroturbulence ($v_{\text{mac}}$), and disk-integrated (15 μm angles) to generate $F$. Collisional broadening is scaled from fits to solar lines. Lines and blends are separately modeled first assuming $B=0$. The resulting $v \sin i$ and $v_{\text{mac}}$ will tend to vary with $g_{\text{eff}}$ if $B \neq 0$. We extrapolate this correlation to $g_{\text{eff}} = 0$, and use the resulting $v \sin i$ and $v_{\text{mac}}$ values as first guesses to fit to the $g_{\text{eff}} = 2.5$ line at 6173 Å.

For this initial analysis, we have studied spectra taken at extremes in the total TR line fluxes (C IV+Si IV+N V+He II) for each star. We chose the 9 May and 13 May spectra as low and high state spectra for 59 Vir, 9 and 17+18 May spectra, respectively, for $\xi$ Boo A, and 13 and 19 May spectra for HD 131511. No $fB$ value was obtained for HD 131511 in the “low” state, and we estimate $fB < 100$ G. We find that the magnetically sensitive $g = 2.5$ line at 6173 Å is clearly broader when $F_{\text{CIV}}$ is high for each star. One notable feature of these new magnetic measurements is that $fB$ is a factor of $\approx 2$ smaller (primarily a change in $f$) than previous RT measurements which did not include disk-integration of the Stokes $I$ profiles.

In Fig. II we show the resulting correlation between the measured C IV and magnetic flux densities ($fB$), including solar data (Schrijver 1990) and data for some individual stars. Except for 59 Vir, which has enhanced C IV for its measured $fB$ values, the new data are in good agreement with the overall trend. If 59 Vir is excluded from the fit, we find $F_{\text{CIV}} \propto (fB)^{0.66\pm0.05}$, consistent with
FIGURE II  \( fB \) versus \( F_{\text{CIV}} \) for this paper (\( * \)), the quiet Sun and solar AR (\( \triangle \); Schrijver 1990), and some individual dwarf stars (\( + \)). Measurements of the Sun, 59 Vir, and \( \xi \) Boo A are connected.

Schrijver (1990). The slopes of the flux-flux variations for 59 Vir and \( \xi \) Boo A are somewhat less steep than this relation. It is unclear why the fastest rotator of the group, 59 Vir, should deviate, perhaps its TR heating is dominated by mechanisms (such as flares) other than direct magnetic wave heating. It is also possible that \( fB \) is underestimated, a tendency which is expected in early G stars (Solanki 1992; Saar, B"unte, & Solanki, these proceedings). Nevertheless, with the possible exception of 59 Vir, it appears that spatially integrated stars, different spatial averages of the same star, and resolved solar active regions all show similar relationships between TR line fluxes and \( fB \). This result has important implications for the structure and energy balance in the stellar outer atmosphere (e.g., Schrijver et al. 1989).

This research is supported by NASA IUE grants to the University of Colorado and CfA. We are indebted to P. Avellan and the NSO McMath team for support and obtaining many of the spectra analyzed here.

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