SIMULTANEOUS SPOT & CHROMOSPHERE MAPS OF FK COMAE

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ABSTRACT Maps of the local $T_{\text{eff}}$ and chromospheric intensity (from He I D3) from a surface imaging analysis of 51 echelle spectra of FK Comae show a complex relationship between spots and activity.

INTRODUCTION, OBSERVATIONS AND ANALYSIS

FK Comae is a single, extremely active (Bopp & Stencel 1981), rapidly rotating ($v \sin i \approx 160$ km s$^{-1}$) G giant which is likely a recently coalesced binary (McCarthy & Ramsey 1984). It is thus an ideal laboratory for studying the relationships between surface structures and activity on very active stars. Such investigations have yielded mixed results in the RS CVn variables (e.g., Strassmeier 1992). In this paper we invert timeseries of absorption lines and the He I D3 line to yield local $T_{\text{eff}}$ and chromospheric maps for FK Comae.

The 51 optical spectra were taken over eight nights in 1989 at KPNO with the Penn St. Fiber Optic Echelle and an RCA CCD. The setup used yielded 34 orders per spectrum (nearly complete coverage for 380 nm $\leq \lambda \leq 900$ nm) at a resolution of $\lambda/\Delta \lambda = 12,000$ (see Huenemoerder et al. 1993 = HRBN).

We selected line complexes near 634 and 640 nm for Doppler imaging. Since the high $v \sin i$ guaranteed that all lines were blended, we used an inversion (with Tikhonov regularization) capable of synthesizing multiple lines (Strassmeier et al. 1991). A total of 75 lines were calculated. The exceptional phase coverage partly compensates for the relatively low “information-to-noise” ratio ($150 \leq S/N \leq 300$, but line depths were $\leq 7\%$). The mean $T_{\text{eff}}$ derived is 5400 K, close to that found by photometry, with only low contrast spots ($\Delta T \approx 350K$) required for a good fit. An inclination of $i = 75^\circ$ gave the best results. Spectrum fits and the resulting $T_{\text{eff}}$ map are shown in Fig. 1. As photometry was not used as an additional constraint in these preliminary maps, the relative $T_{\text{eff}}$ values are subject to systematic error. The mean longitude of the spot agrees well with the photometric models of HRBN, though the latitude is lower by $\approx 30^\circ$.

The He I D3 line (587.6 nm) is formed in the chromosphere of cool stars (no photospheric component) but the precise mechanism is debated (e.g., Garcia
López et al. 1993). D3 is seen in emission at the solar limb except beneath coronal holes (Zirin 1975). In FK Comae it appears as a variable absorption line with emission wings at velocities \( v > v \sin i \) (HRBN), implying a spatially extended chromosphere. We modeled the D3 feature with a simple "pseudo-optical depth" model, in which the line has a Voigt absorption profile \( \Delta \lambda_{Dep} = 0.35\text{Å} \) and \( \Delta \lambda_{Lor} = 0.25\text{Å} \) against the disk and is in emission off the limb. The D3 strength \( (I_{D3}) \) is scaled according to the path length through the extended D3 absorbing/ emitting shell, whose thickness we find is \( \approx 0.25R_{\ast} \). We set the maximum D3 absorption depth to 0.6 and used the Tikhonov regularization to solve the inverse problem and map \( I_{D3} \) (related to the D3 column density) across the stellar disk+shell (Fig. II, which also shows sample profile fits).

**DISCUSSION**

Figures I and II represent the first ever high-resolution simultaneous maps of \( T_{\text{eff}} \) and chromospheric activity (but see also Strassmeier, these proc.). The D3 chromosphere is fairly uniform - only about a factor of 3 in \( I_{D3} \) separates the weakest and strongest D3 features in Fig. II. This is not unexpected, considering FK Comae's "saturated" magnetic activity (Vilhu 1984). The strongest \( I_{D3} \) seems uncorrelated with spot position; \( I_{D3} \) in spots is average to low. Though at first this might seem counter-intuitive, D3 may be concentrated in plage regions which are mostly outside of the darkest spotted areas. This scenario has also been proposed to explain the typical lack of strong phase correlation between UV emission and photometry in RS CVn's (Strassmeier 1992). Alternately, the lack of correlation may be due to a peculiarity of He I D3 formation itself: as activity increases, the line first appears as a stronger and stronger absorption
line, but once activity reaches very high levels (chromospheric column densities are sufficiently large), the line eventually fills in and reverses into emission (in KM dwarfs; Vilhu et al. 1989). This behavior is similar to e.g., Hα (though without that line’s photospheric component). In this scenario, \( I_{D3} \) is weaker in the spotted areas because increased activity has begun to fill in the D3 absorption. Support for this idea can be found by plotting the D3 absorption eq. width vs. Hα emission equivalent width, which shows a peak in D3 absorption for smaller values of \( \dot{W}(H\alpha) \) and a steady decline as activity increases. A more quantitative analysis of the spot-chromosphere connection will require a realistic calculation of the He I D3 line in a chromospheric model atmosphere appropriate to FK Comae to convert \( I_{D3} \) into column densities.

We thank NOAO for observing time. This research is supported by NASA grants NAGW-112 and NAGW-3422.

REFERENCES