MEASUREMENTS OF STARSPOT AREA AND TEMPERATURE ON FIVE ACTIVE, EVOLVED STARS

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INTRODUCTION

Using the absorption bands of TiO near 7055 Å and 8860 Å, we have measured starspot areas and temperatures on five single-lined active stars: the RS CVn stars II Peg, EI Eri, V1762 Cyg, and σ Gem; and the FK Comae star V1794 Cyg. Because these two TiO bands have different temperature sensitivities, the ratio of their strengths measures the starspot temperature, while the absolute band strengths are a function of starspot area. Where possible, we have used contemporaneous photometry to refine our estimate of the non-spotted photospheric temperature. We find that the spot filling factors (f_S) we observe range from below our detection threshold ($\approx 8\%$) to 56% of the visible hemisphere.

For each active star, we use spectra of inactive G and K stars to model the unspotted photosphere and spectra of M stars to model the starspots. For the M giant comparison stars, we derive a relationship between $T_{\rm eff}$ and the strength of each molecular band (Neff, O'Neal, & Saar 1995; O'Neal, Saar, & Neff 1995). These relations were used to compute band depths for model spectra with a variety of spot and non-spot temperature and f_S values.

Echelle spectroscopy allows the simultaneous observation of many molecular bands and other indicators of stellar activity. We present the first results from our analysis of echelle spectra.

OBSERVATIONS AND RESULTS

The one-dimensional spectra were obtained at the National Solar Observatory's McMath-Pierce telescope. These $\lambda/\Delta\lambda \approx 14,000$, high S/N (200–400) spectra with a range of ≈ 200 Å are centered on the TiO bands beginning at 7055 Å (the γ(0,0) system) and on the band at 8860 Å (the strongest of the δ(0,0) system). The echelle spectra ($\lambda/\Delta\lambda \approx 15,000$, wavelength range $\approx$ 3800–9000 Å) were obtained with the Fiber Optic Echelle Spectrograph at Kitt Peak.

Table 1 lists the properties of our five target stars along with the results of our starspot measurements. $V(f_S = 0)$ is the magnitude that a star would have if it were completely unspotted, compared to $V_{\rm min}$, the brightest V magnitude ever observed for the star. Min. f_S and Max. f_S are the smallest and largest spot filling factors we observed.

TABLE I Properties of Active Stars

	EI Eri	V1794 Cyg	σ Gem	V1762 Cyg	II Peg
Spectral Type	G5 IV	G5 III	K1 III	K1 III-IV	K2 IV-V
$P_{\rm rot}$ (days)	1.945	3.337484	19.60447	28.5895	6.72442
T_Q (K)	5600	5350	4500	4550	4800
T_S (K)	3700	3800	3850	3450	3500
Min. f_S	0.15	0.16	0.14	...	0.43
Max. f_S	0.38	0.37	0.33	0.24	0.56
$V_{\rm min}$	6.96	7.16	4.14	5.74	7.2
$V(f_S = 0)$	...	6.9	4.14	5.75	6.8

PRELIMINARY ANALYSIS OF ECHELLE SPECTRA

In addition to the 7100 Å and 8860 Å bands, spectra of cool stars display many other bands of TiO and other molecules that may be strong enough to detect in spectra of heavily spotted stars. To be a useful temperature diagnostic, a band must be strong enough to be detectable against the brighter non-spotted photosphere, but not yet saturated. None of the molecular bands are strong enough to use to study starspots with $T_S > 4000$ K. Thus far, we have modeled the order containing the 6650 Å set of TiO bands as well as the 7055 Å and 8860 Å orders in II Peg and EI Eri.

We observed II Peg with the FOE from 1995 January 19 to 23, and from the three TiO band head regions, we find $T_S \approx 3550$ K, $T_Q \approx 4900$ K, and f_S from 22 to 27%. Fitting the 7055 Å band with a 3950 K spot proxy, we find $20\% \leq f_S \leq 28\%$; a 3650 K spot proxy reduces this to $9\% \leq f_S \leq 17\%$. The 6650 Å band requires the cooler spot proxy and yields f_S values a few percent higher than implied by the fit to the 7055 Å bands. We also measured emission strengths in Hα, Ca II H and K, and the Ca II IRT for both stars, but found no correlation with the f_S values.

DISCUSSION

We plan to extend our investigations in three ways. First, by observing in the infrared H and K bands, we will be able to measure smaller f_S values, since at longer wavelengths the spots become substantially brighter relative to the unspotted photosphere than they are in the visible. Second, by obtaining better phase coverage and using, *e.g.*, a maximum-entropy inversion method, we should be able to determine a physical area starspot coverage. Finally, our analysis can provide a useful additional constraint in Doppler imaging studies; since Doppler imaging is much better at determining the distributions of inhomogeneities on a stellar surface than their temperatures, T_S could be provided by molecular spectroscopy.

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