MEASUREMENTS OF STARSPOT AREA AND TEMPERATURE ON II PEGASI

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ABSTRACT
We are developing an empirical spectral synthesis technique that will yield independent measurements of starspot area and temperature. We have tested this technique on a series of spectra of the single-lined spectroscopic binary II Pegasi (HD 224085). II Peg is an RS CVn star from which evidence for magnetic activity has been observed in many wavelength bands.

OBSERVATIONS
Our sample of target stars consists of active, late-type stars of the RS CVn and BY Dra types. Our grid of M giant and dwarf spot comparison stars covers $T_{\text{eff}} = 3000$ to 3850 K, while the grid of G and K quiet comparison stars covers $T_{\text{eff}} = 4300$ to 5600 K. The data were obtained at the National Solar Observatory’s McMath-Pierce telescope. They consist of 617 moderate-resolution ($\lambda/\Delta\lambda \approx 14,000$), high S/N (200–400) spectra with a range of approximately 200Å centered on the TiO bands beginning at 7055 Å and on the band at 8860Å. The observations of II Peg we describe here are a small subset of our target star observations and were obtained during a single rotation period in October 1989.

METHOD
The 7100Å TiO bands first become evident at about spectral type K5, while the 8860Å band first appears around spectral type M1. Previous studies of TiO bands on II Peg (e.g., Ramsey & Nations 1980 and Huenemoerder, Ramsey, & Buzasi 1989) have found phase dependent variations in the band strengths, and generally a spot equivalent spectral type of M5 to M6. However, they observed only one TiO band (8860Å), so it was impossible to untangle the effect of increasing spot coverage with that of decreasing spot temperature. In this study, we use spectra of the 7055Å and 8860Å TiO bands to measure independently the area and the temperature of starspots. The different temperature
sensitivity of the bands permits an estimate of both the area (from the absolute band strengths) and temperature (from the ratio of band strengths) of starspots. Spectra of M stars serve as models for the spots, while spectra of inactive G and K stars model the quiet regions. We model the normalized spectrum from a spotted star \( F_{\text{total}} \) as the weighted sum of \( F_{\text{spot}} \) and \( F_{\text{quiet}} \), the normalized spectra of standard stars with \( T_{\text{eff}} = T_{\text{spot}} \) and \( T_{\text{eff}} = T_{\text{quiet}} \), respectively. The model is given by \( F_{\text{total}} = \frac{AR_sF_g+(1-A)F_\lambda}{AR_s+[1-A]} \), where \( A \) is the total fractional projected area of spots on the observed hemisphere, and \( R_\lambda \) is the continuum surface flux ratio between the spots and the photosphere. We also define band depth indices for each spectrum as the difference in normalized continuum level blueward and redward of the 7055Å and 8860Å bandheads. The depths measured in the comparison spectra were used to compute band depths for model spectra with a variety of spot and quiet temperatures and filling factors, and those were compared with the depths of the observed spectra.

![Graph showing spot filling factor as function of phase.](image)

**FIGURE I** Spot filling factor as function of phase.

**RESULTS**

A plot of spot filling factor vs. rotational phase for II Peg is given in Figure I. The small regions of spectrum we observed are insufficient to determine the quiet temperature; the derived area and the temperature of starspots depend on the quiet temperature. Assuming \( T_{\text{quiet}} = 4700 \) K, the spot filling factor varied from 41% to 52% during our observations. Figure II shows spectra of a quiet comparison star and a spot comparison star in the 7100Å region, along with an observed spectrum of II Peg and the artificial spectrum as constructed from a weighted sum of the two comparison spectra.

Spectra of M giants are better models for the starspots than are spectra of M dwarfs. Model spectra computed with M dwarf comparison stars were able to
match neither the band depth ratio observed on II Peg nor the absolute depths of the 8860Å band. M giants exhibit substantially deeper TiO bands for a given effective temperature than do M dwarfs.

DISCUSSION AND CONCLUSIONS

With spectroscopic observations of II Peg covering 0.75 of a rotational period, we have placed essentially independent constraints on the temperature and filling factor of its starspots. We determine the temperature of the spotted regions to be $3350 \pm 200$ K and the projected starspot coverage to vary from 41% to 52% as the star rotates. The spot filling factor must be adjusted slightly if the temperature of the quiet regions is different from 4700 K.

The variations in spot filling factor that we observed are roughly correlated with the photometric variability observed by Doyle et al. (1992) in August 1989, with spot maximum corresponding to photometric minimum and vice-versa. They observed a 0.45 magnitude V band variation.

REFERENCES