Surface Imaging of EI Eri

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Abstract: We present maps of the temperature distribution on the spotted RS CVn-type binary EI Eri (HD 26337), obtained by means of the surface imaging technique described in the Colloquium (Piskunov, 1991). Images were calculated for two separate lines for two epochs of observation. For one epoch we also calculated an image using a blend of several lines. The reliability of the maps is confirmed by comparing the simultaneous photometric observations with the light curves calculated from the temperature maps.

1. Observations

The spectroscopic observations for the present surface imaging study were obtained with the McMath solar telescope at Kitt Peak National Solar Observatory during two epochs. The data for "image 1" consists of spectra for eight different phases obtained between October 22 and November 21, 1988. The data for "image 2" consists of spectra for eleven different phases taken between November 27 and December 22, 1988. Simultaneous Johnson BV photometry was available from the 0.4 m Vanderbilt University APT. More information about the observations can be found in papers by Strassmeier (1990 and 1991). For image 1 and 2 the spectra of the lines Fe I λ6411.66 Å and Ca I λ6439.073 Å were used to produce separate temperature maps. In addition a blend of five lines, V I λ6430.50, Fe I λ6430.85, Ni I λ6432.02, Fe II λ6432.65 and Si I λ6433.46, was used to derive a third temperature map for image 2. The largest contribution to the main component of the blend Fe I λ6430 Å comes from the line Fe II λ6432 Å, without which it is impossible to produce the red part of the line profile.

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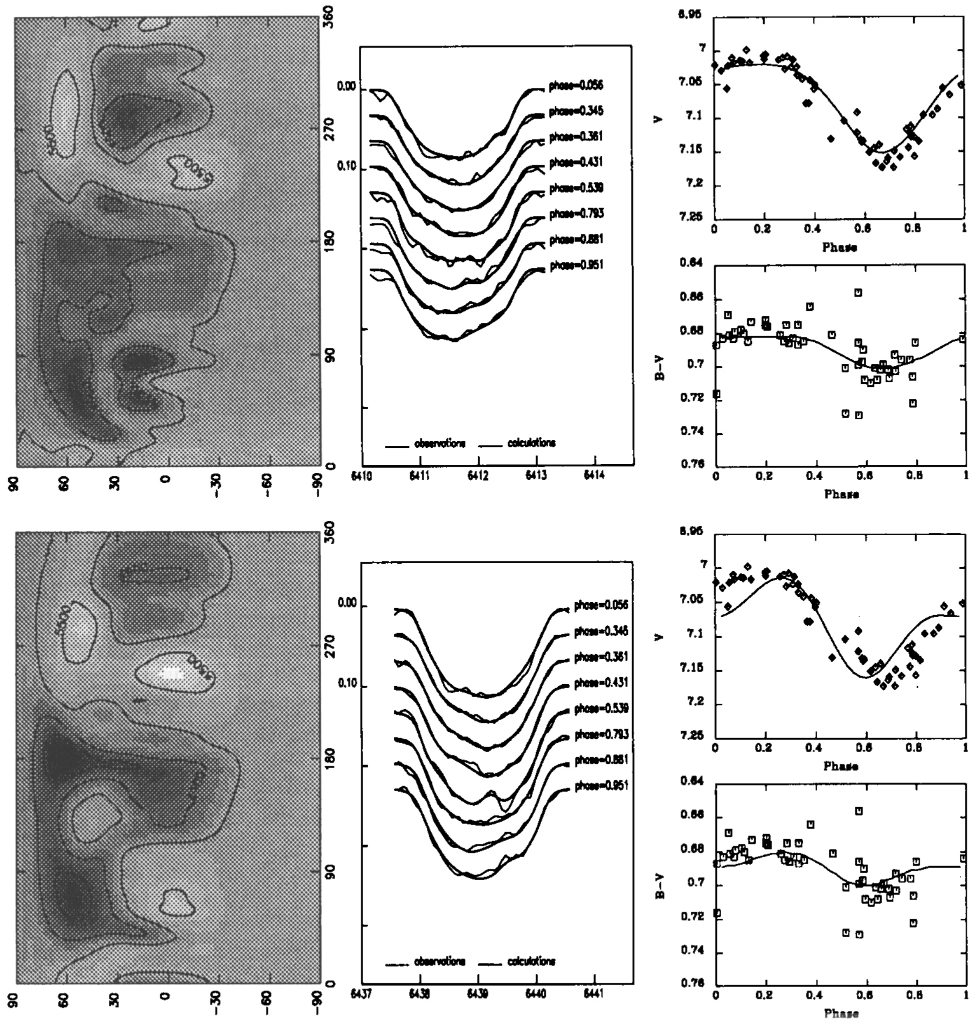

Fig. 1. Surface imaging solution of image 1 using the Fe I λ6411.66 Å line (upper row) and the Ca I λ6439.073 Å line (lower row). The solutions are presented by temperature maps in Mercator projection, comparison of observed spectra and line profile resolved by a numerical solution of the equation of radiation transfer, and comparison of the simulated V- and B-V -photometric curves (lines) and observations (squares). The grey shade scale for the temperature maps ranges from 4200 K (black) to 5700 K (white).

2. Analysis technique

We used a surface imaging technique with Tikhonov regularisation (Piskunov 1991) to produce temperature maps of the two images. The tabulated local line profiles and continuum fluxes were calculated using four atmospheric models, $T_{\rm eff}=$ 4000, 4500, 5000 and 5500 K, with $\log g$ = 3.75 and solar element abundances (Bell

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et al. 1976). Local line and continuum fluxes were calculated for 40 points from the centre of the star disk to the limb. The microturbulent velocity was adjusted in such a way that the temperature of the unspotted surface was the same for the different temperature maps of the different lines and images. The damping parameter is important, effecting especially the line wings of the strong lines Fe I λ6430 Å and Ca I λ6439 Å.

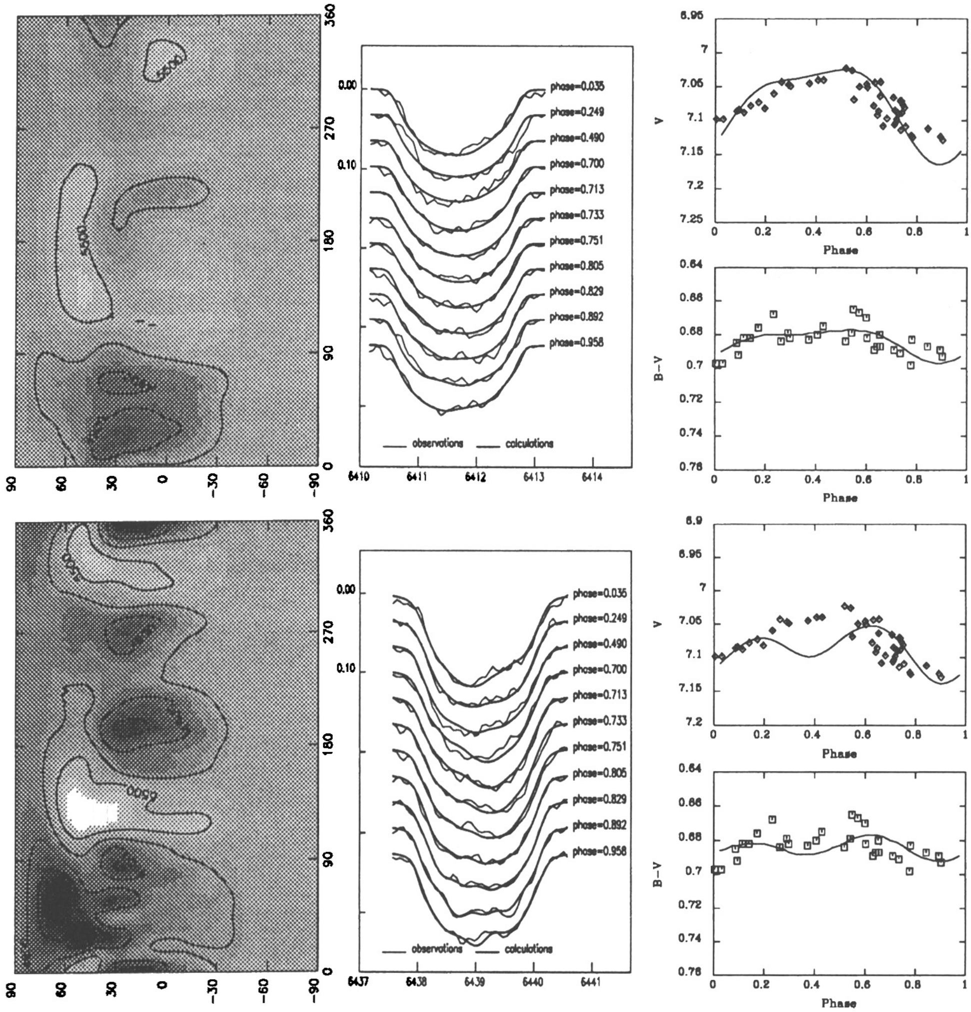

Fig. 2. Solution for image 2, using the Fe I λ6411.66 Å line (upper row) and the Ca I λ 6439.073 Å line (lower row), presented as temperature maps, line profiles and photometry. The grey-shade scale for the temperature maps is the same as in Fig. 1.

By using the transmission functions of B and V passbands and integrating the continuum flux distribution of the radiative transfer solution over the visible hemisphere in different phases, we calculated theoretical V, B, and B-V light curves

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for the temperature maps. We used an arbitrary zero point scaling in order to fit the curves to the observed magnitudes.

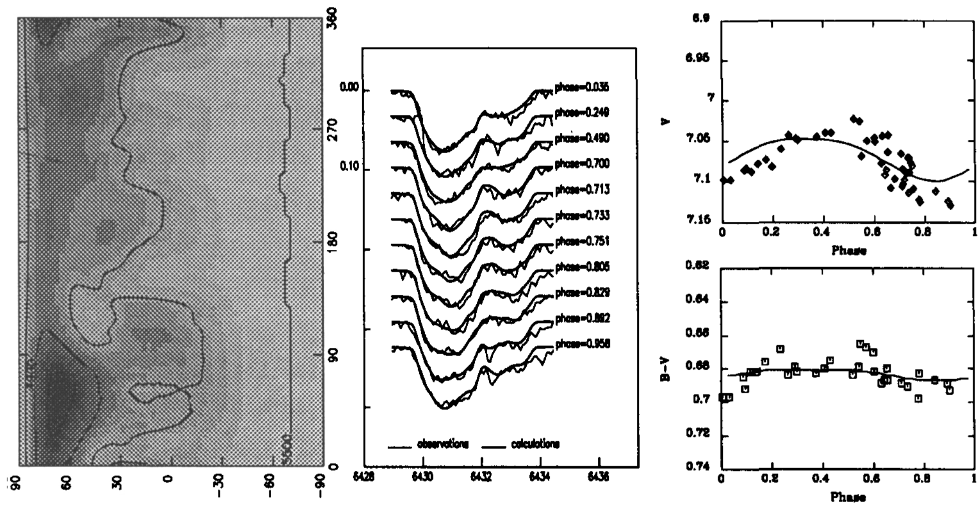

Fig. 3. Solution for image 2, using the λ6430 Å blend of lines, presented as temperature map, line profiles and photometry. The grey-shade scale for the temperature map is the same as in Fig. 1.

3. The images and conclusions

The temperature maps (Figs. 1–3) show large cool spots on both low and high latitudes. The spots are 500-1000 K cooler than the unspotted surface. The spot structure is somewhat similar to that derived for the FK Comae star HD 32918 by Piskunov *et al.* (1990). In addition, the maps show some smaller bright spots, with temperatures up to 500 K hotter than the unspotted surface. None of the temperature maps show large caps on the pole. This result differs significantly from those derived by two other groups (Vogt and Hatzes, Rice and Wehlau) using the same data set and presented by Strassmeier *et al.* (1991). The main difference between the present analysis and theirs is the direct calculation of the local line profiles in our analysis.

The overall fit of the calculated light curves to the observed photometry is quite satisfactory, giving the general variation with phase correctly. The light curves from the temperature maps produced by using the Fe I λ6411.66 Å line coincide better with the observations than those produced using the Ca I λ6439.073 Å line and the λ6430 Å blend. The cool regions have a tendency to be at higher latitudes for the strong Ca I line than for the weaker Fe I λ6411.66 Å line. Whether this results from the fact that the stronger line is formed in higher layers of the atmosphere

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or form inaccuracies in the line formation calculation, should be investigated. The differences in the temperature maps produced for the same image can also partly be explained by lack of data for some phases. This means that noise in spectra more easily may produce artificial features on the temperature maps. The overall pattern of the spots is, however, the same on temperature maps of the same image.

Simultaneous photometry thus provides very useful extra constraints for the inversion. This is especially important since some spectral line parameters, which significantly effect the line profile, are not well enough known for all lines.

The main difference between images 1 and 2 seems to be a shift in the longitude of the spot features. The same shift can be seen in the light curves. The difference in the light curves can be eliminated if the period is increased by about 0.01 days. This suggests that the differences can be due to the use of an inaccurate period rather than changes in the spot structure. Since one of the purposes of this work was to compare different surface imaging techniques we have used the same period (1.945 days) as the other groups analysing the same data (Strassmeier 1991, Strassmeier *et al.* 1991).

The use of the λ6430 Å blend of lines (Fig. 3) for surface imaging is especially interesting, since the five lines have different temperature behaviour. This puts extra constraints on the fitting procedure which means that noise in the spectra is not as easily interpreted as spot features. The use of a blend of lines instead of single lines, however, complicates especially the calculation of local line profiles. Even though the calculated line profile for the 6430 blend fits the observed line profile satisfactorily, the deviation from the observed profile is larger than that of the Fe I λ6411.66 Å or the Ca I λ6439.073 Å line.

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