Doppler Imaging of Ei Eridani

Albert Washuettl\textsuperscript{1}, Klaus G. Strassmeier\textsuperscript{1}, and Andrew Collier-Cameron\textsuperscript{2}

Abstract:
We present Doppler images of the rapidly rotating active close binary star Ei Eridani. Several Doppler images have been produced since 1984 making use of different versions of the Doppler imaging technique. They all show high-latitude spots surrounding or covering the rotational pole as well as some smaller spots on lower latitudes. The high-latitude/polar spot seems to be long-lived (at least a decade) but changes its shape on comparatively short timescales (of the order of one month). From time to time spots along the stellar equator also occur, but their lifetimes tend to be relatively short (weeks). Furthermore, long-term photometric observations revealed the existence of a magnetic cycle which has been estimated to be around 11 years.

We also present time-resolved Doppler images from EiEri obtained at McMath/NSO in fall 1996 during 70 consecutive nights. The final aim of this program is to investigate the spot evolution over the whole activity cycle.

1. The Active Binary Star Ei Eridani

Ei Eridani = HD 26337 (G5 IV, $P_{\text{rot}} = 1.945$ days, $V = 7.1$ mag) is a rapidly rotating ($v \sin i = 51$ km s\(^{-1}\)) active SB1 binary star. EiEri is a typical RS CVn star. RS CVn stars are close but detached binary systems that rotate synchronously due to tidal forces. The fast rotation is believed to be responsible for the high activity level found on these stars.

With its large rotational velocity and an intermediate inclination EiEri is an ideal candidate for Doppler imaging. This technique (see Rice 1996) allows the reconstruction of the surface spot distribution of rapidly rotating stars by using the relation between wavelength position across an absorption line and spatial position across the stellar disk.

However, the rotation period of 1.945 d makes it difficult to obtain spectral coverage for a complete rotation period, and ideally three weeks of observations are needed to provide a good phase coverage for a Doppler image of Ei Eridani.

The observations were obtained at Kitt Peak National Observatory (KPNO) with the coudé feed telescope during the period January 10 – 24, 1996, and at National Solar Observatory (NSO) with the McMath-Pierce telescope from November 1, 1996, to January 8, 1997.

\textsuperscript{1}Institute for Astronomy, University of Vienna, Austria
\textsuperscript{2}School of Physics and Astronomy, St. Andrews University, Scotland

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Table 1. Various parameters of Ei Eri

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Spectral type</td>
<td>G5 IV</td>
</tr>
<tr>
<td>$v \sin i$</td>
<td>51 km s$^{-1}$</td>
</tr>
<tr>
<td>Inclination $i$</td>
<td>46°</td>
</tr>
<tr>
<td>Rotation period</td>
<td>1.945 days</td>
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<tr>
<td>Orbital period</td>
<td>1.947227 days</td>
</tr>
<tr>
<td>Photospheric temperature</td>
<td>5500 K</td>
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<tr>
<td>Spot temperature</td>
<td>3600 K</td>
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2. Doppler Imaging of Ei Eridani

Doppler images of the 1984-87 period were presented by Hatzes & Vogt (1992), and Strassmeier et al. (1991) published Doppler images from 1987-88.

Here, we present Doppler images for Ei Eridani from January and November/December 1996. All maps were generated with the Doppler imaging code DOTS by Andrew Collier-Cameron (see Collier-Cameron 1997). A typical Doppler image of Ei Eri is shown in Figure 1a, the line profile variations are shown in Figure 2.

All images show a large asymmetric spot at the pole or at high latitudes with several appendages and occasionally equatorial spots. The polar spot is long-lived but exhibits significant changes in its size and shape, while the equatorial spots change on short timescales.

3. The Photometric Impact on the Doppler Images

What does photometry contribute to the surface map, and in particular to the quest for the polar spot? Introducing light curve fitting to the surface map reconstruction (with a weighting of 0.8 for spectroscopy) leads to a large low latitude spot that is not present at all in the spectroscopic data (Fig. 1b – as compared to Fig. 1a). Calculating a surface map from photometric data alone shows the same low-latitude feature and – as expected from photometry – no polar spot (Fig. 1c).

However, generating a fake light curve from the purely spectroscopic surface image in Fig. 1a and reconstructing a surface image with this fake light curve (instead of the observed light curve) shows the same low-latitude feature (Fig. 1d)! This means that the purely spectroscopic surface map sufficiently explains the photometric fit, while the photometric fit does not coincide with any feature in the more constrained line profiles. The photometric fit itself, which cannot “make use” of a polar feature, is not able to explain the spot distribution as seen in the line profiles. Another hint for the existence of a polar spot!
Figure 1.  

a) Doppler image of El Eri from January 1996 (Ca I 6439Å); b) the same as a) but including photometry; c) For this reconstruction we used the photometric data alone and set the weighting for spectroscopy (beta) to 0; d) Same as c), but here we used the fake light curve generated from a) instead of the observed light curve. As we can see the purely spectroscopic surface map sufficiently explains the photometric fit, while the photometric fit does not coincide with any feature in the more constrained line profiles. This is another hint for the existence of the polar spot!
Figure 2. Line profile variations in the Ca I 6439 Å line. Observations are indicated by dots, the solid line are the theoretical profiles from the spot model. Notice the permanently filled-in line cores, due presumably to a polar spot. The corresponding surface map is shown in Fig. 1a.
4. Time-Resolved Doppler images

Previous Doppler images showed variations in the low-latitude spots and the shape of the polar spot but left us uncertain about the timescales.

In November/December 1996 we obtained 70 nights of observations at the NSO/McMath telescope. This allows us to produce a timeseries of Doppler images. It turns out that variations in low-latitudinal spot coverage occur on timescales shorter than three weeks. (Three weeks of data are combined for one Doppler image.) Therefore a larger number of images were produced with a spectral overlap between three images each to allow for the rapid variations. The results are shown in Figure 3a–g. The first image represents week 1 – 3, the second week 2 – 4 and so forth. Most low-latitude features come and go too quickly to be detected again in the next Doppler image without spectral overlap. In rare cases we find a subtle hint for a polewards drift (see the equatorial feature at $350^\circ$ in image a).

The polar spot is stable and confirms the image from January 1996 (Fig. 1a).

5. The Quest for the Polar Spot

Large cool polar spots are a common but doubted phenomenon on RS CVn stars. Critics pointed out that Doppler imaging is based on periodic variations in spectral line profiles, while a polar spot just causes a flat-bottomed “filled-in” line profile shape (see Fig. 2). However, if the flat-bottomed spectral line profiles are due to a stellar atmospheric effect rather than the presence of a cool polar spot, then it would show up as a time-independent symmetric effect (as for example a circular polar cap or equatorial ring). The opposite is true for Ei Eri.

Furthermore, four different Doppler imaging codes yield a polar spot for Ei Eridani — even with different reconstruction methods using Maximum Entropy Method, Tikhonov regularisation, and Trial & Error (Strassmeier et al. 1991; Washüttl et al. 1997).

More facts in favour of a polar spot:

- We do not see a large polar spot on all RS CVn stars (e.g., $\sigma$ Gem, Hatzes 1993).

- Some RS CVn stars do show a polar spot at a particular time and none at some other time (e.g., LQ Hya, Saar et al. 1994; Strassmeier et al. 1993).

- RS CVn stars show an inclination dependence of the line core flattening in a way that low inclination stars have the most flattened line cores (Hatzes et al. 1996). This cannot be explained satisfactorily by any uniform atmospheric effect.

This altogether makes it necessary for the successful formulation of a dynamo theory to explain polar spots on rapidly rotating stars.
Figure 3. (a) – (d)
Figure 3. continued, (e) – (g) Doppler images of EI Eri from November/December 1996 (Ca I 6439 Å). (a) Observations from week 1 – 3 were used for this map. (b) Observations from week 2 – 4 and so forth, so there is a spectral overlap between three images each. As seen here, most low-latitude features come and go too quickly to be detected again in the next Doppler image without spectral overlap. The polar spot remains stable.
6. Covering a Whole Activity Cycle

Long-term photometric observations of El Eri suggest the existence of a magnetic cycle which has been estimated to be around 11 years (see Fig. 4, Strassmeier et al. 1997).

It is not yet clear how far stellar cycles resemble the solar cycle. After each solar 11-year cycle the polarity of the magnetic field changes. If such a polarity inversion is indeed present for stars such as El Eri we would expect it to change the morphology of the polar spot which might decay and reemerge as a new cycle begins. Indeed such long-term variations were found by Vogt & Hatzes (1996) in the polar spot of the very similar RS CVn star HR 1099.

It is the final aim of this program to investigate the spot evolution over the whole activity cycle.

6.1. World Wide Web

For more and future information have a look at

http://www.ast.univie.ac.at/∼wasi/research/ELEridani.html

References

Figure 4. Long-term photometric observations of El Eri (Strassmeier et al. 1997). It shows the existence of a magnetic cycle of about 11 years. We are looking out for a periodicity in the area of the polar spot connected to this magnetic cycle.