Stellar Clusters and Associations
ASP Conference Series, Vol. 198, 2000
R. Pallavicini, G. Micela, and S. Sciortino, eds.

Can the magnetic topology of AB Doradus be explained by a potential field distribution ?

G.A.J. Hussain, M.M. Jardine, A. Collier Cameron, J.R. Barnes and

School of Physics and Astronomy, University of St Andrews, UK KY16 9SS

J.-F. Donati

Laboratoire d'Astrophysique, Observatoire Midi-Pyrénées, F–31400 Toulouse, France

Abstract.
We present potential magnetic field maps of the surface of the active K0 dwarf, AB Dor. Maps of the surface magnetic flux distributions of rapid rotators can be produced using the technique of Zeeman Doppler imaging (ZDI). Magnetic flux maps of active cool stars produced using ZDI show many features that have no solar counterpart. Currently, ZDI codes map only the simplest possible magnetic field distributions that will fit the observed data. It remains unclear how physically realistic these maps really are and this is what we are concerned with here.

We find that at low to mid latitudes there is a good correlation between the potential azimuthal field and that obtained from ZDI. However specific features visible in ZDI maps, such as the near unidirectional band of azimuthal flux, remain difficult to explain.

1. Introduction

Zeeman Doppler (ZD) maps of the active rapid rotator, AB Dor, obtained over three years show the presence of radial and azimuthal flux of similar strengths at both high and low latitudes. Strong azimuthal fields are also recovered on the active rapidly rotating stars, HR1099 (K1 IV) and LQ Hya (K0 V) (Donati 1999). There is no solar counterpart to many of these features and the cause of the strong azimuthal flux remains unclear. The technique of ZDI is subject to limitations and it is necessary to assess the reliability of these magnetic maps. We want to evaluate how physically realistic ZD maps really are.

2. Zeeman Doppler imaging

ZDI combines the principles of Doppler imaging with the Zeeman effect (Semel 1989). Doppler imaging allows velocity position in a rotationally broadened flux profile to be related to spatial position on the projected stellar disk. The Zeeman effect enables the size of the magnetic field to be evaluated. Within the weak field approximation, the local Stokes V profile scales linearly with magnetic field

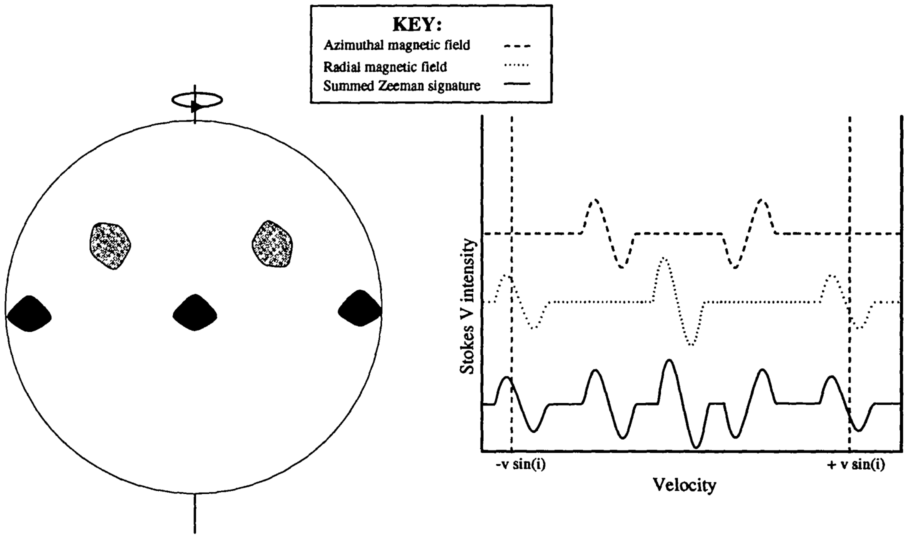

Figure 1. Schematic diagram showing the basic principles behind ZDI. The star shown here has magnetic regions of similar strengths but differing field orientations (radial field = black, azimuthal field = grey). The plot on the right shows how the summed Zeeman signature from the star depends on the field vector, the magnitude of the field and its position on the disk.

strength and magnetic sensitivity of the line. The size of the magnetic field can then be evaluated from the size of the signature (Semel 1989). However, the size of the signature also depends on the brightness of the region (as the flux contribution from areas of low surface brightness such as starspots is suppressed). As Stokes V profiles are used, only the line-of-sight component of the surface field vector can be mapped. Fig. 1 illustrates how azimuthal signatures are reversed when they cross the centre of the projected stellar disk. By observing a series of line profiles taken over a full rotation cycle it is possible to distinguish between the signatures of different magnetic field vectors. The radial maps obtained may underestimate the true amount of surface flux as radial fields are expected to be strongest in the centre of starspots (using the solar analogy) where the flux contribution is suppressed. It is thus important to evaluate if the radial and azimuthal maps obtained are mutually consistent.

3. Potential field (PF) extrapolation

ZD radial maps are used to compute the azimuthal flux distribution expected if the field is potential. These predicted azimuthal maps are then compared with the ZD azimuthal map to test whether the distribution recovered using ZDI approximates a potential field. While the field may not be potential on small scales, this approximation should be valid on a global scale.

The magnetic field, **B**, is defined such that $\mathbf{B}=-\nabla\Psi$ and $\nabla \mathrm{x} \mathbf{B}=0$ (where Ψ is a flux function). We impose the condition that the field is purely radial at the

2000ASPC..198..463H

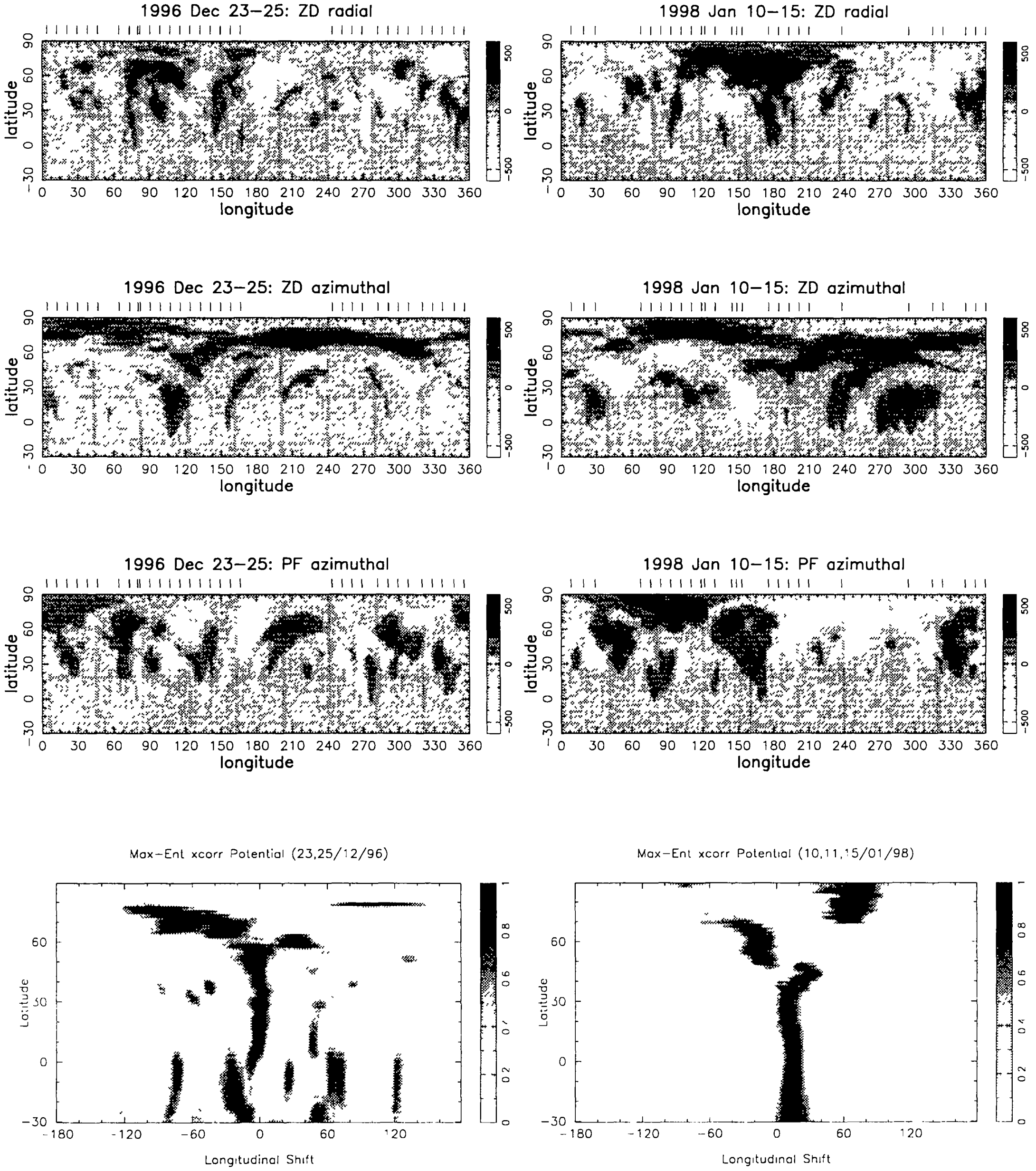

Figure 2. The input (ZD) radial maps, observed (ZD) azimuthal maps and predicted (PF) azimuthal maps are shown in rows 1, 2 and 3 respectively. Greyscales code for magnetic flux in Gauss. The bottom row shows cross-correlation functions (ccfs) computing the agreement between observed and predicted azimuthal maps at each latitude. Greyscales code for the strength of the ccf peak. The ccfs have been normalised to the peak value at each latitude.

height of $5R_*$. At the surface, the radial field, B_r, and azimuthal field, B_ϕ, can be expressed in terms of spherical harmonics (van Ballegooijen et al. 1998):

$$B_r = -\sum_{l=1}^{N}\sum_{m=-l}^{l}[la_{lm} - (l+1)b_{lm}]P_{lm}(\theta)e^{im\phi} \tag{1}$$

$$B_\phi = -\sum_{l=1}^{N}\sum_{m=-l}^{l}[a_{lm} + b_{lm}]\frac{P_{lm}(\theta)}{\sin\theta}ime^{im\phi} \tag{2}$$

Here P_{lm} are the associated Legendre functions.

4. Results and discussion

The ZD radial maps, observed (ZD) and predicted (PF) azimuthal maps are plotted in Fig. 2. The ZD maps were produced by Donati et al. (1999) and Donati et al. (*in preparation*). In order to quantify the agreement between the observed and predicted maps, constant latitude slices from the predicted and observed azimuthal maps are cross-correlated. The cross-correlation functions (ccfs) show good agreement up to 60° latitude (see Fig. 2). The PF maps consistently fail to reconstruct the unidirectional band of azimuthal field near the pole.

Hence, while the radial and azimuthal maps obtained using ZDI are mutually consistent in the low to mid-latitudes, the PF model breaks down near the poles. The origin of the unidirectional band of azimuthal field near the pole remains a puzzle. The presence of a polar spot may have led to much of the radial field being suppressed in this area, thus affecting the extrapolation. Alternatively, the field may open near the poles, leading to the field being sheared and non-potential. These results are discussed in more detail by Jardine et al. (1999).

In this study the ZD radial maps are used as the starting points for PF extrapolations. However, ZDI only models for the simplest possible flux distribution that can fit the circularly polarised data. In order to account for any biases it is necessary to fit circularly polarised data directly by combining ZDI principles with PF assumptions. Using this approach we hope to obtain more physically realistic surface flux distributions for rapid rotators.

References

Donati, J.-F. 1999, MNRAS, 302, 457

Donati, J.-F., Collier Cameron, A., Hussain, G.A.J. and Semel, M. 1999, MNRAS, 302, 437

Jardine, M.M., Barnes, J.R., Donati, J.-F. and Collier Cameron, A. 1999, MNRAS, 305, L35

Semel, M. 1989, A&A, 225, 456

van Ballegooijen, A.A., Cartledge, N.P. and Priest, E.R. 1998, ApJ , 501, 866