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Magnetic flux transport and the lifetimes of spots on active cool stars

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Abstract. We present results of numerical simulations of magnetic flux transport on the surfaces of cool stars with radii of 1 $R_\odot$ and 3.3 $R_\odot$. The effects of differential rotation and the tilt angle on the lifetimes of stellar bipolar magnetic regions are discussed. The existence of long-lasting polar spots can be explained by high-latitude persistent emergence of bipolar regions.

1 Introduction

It is evident from studies of Zeeman-Doppler imaging of rapidly rotating cool stars that starspots are magnetic structures. We have applied the magnetic flux transport model, which works reasonably for the transport of magnetic fields on the Sun (Wang et al. 1989; Dikpati & Choudhuri 1995; van Ballegooijen et al. 1998; Mackay et al. 2002; Baumann et al. 2004) to understand the effects of large-scale surface flows on the lifetimes of starspots.

2 The model

The surface flux transport model for purely radial magnetic fields with horizontal and radial diffusion is used (Baumann et al. 2004, 2006). The horizontal and radial turbulent diffusivities are taken as $\eta_h = 600\ \mathrm{km^2\,s^{-1}}$ and $\eta_r = 100\ \mathrm{km^2\,s^{-1}}$, respectively. The observed differential rotation profiles of the Sun (Snodgrass 1983), AB Dor and HR 1099 (Donati et al. 2003) as well as the solar surface meridional flow profile (Hathaway 1996) are used. A starspot pair is represented by a bipolar magnetic region (hereafter BMR) emerged with a tilt angle $\alpha = 0.5\lambda_0$ between the bipole axis and the local latitudinal circle, where λ_0 is the emergence latitude. The area covered by the starspot is defined by the region with the field strength above a certain threshold level (for details, see Işık et al. 2007).

3 The effects of large-scale flows on starspot lifetimes

Figure 1 shows the evolution of three BMRs that emerged at different latitudes. The strongest rotational shear is at mid-latitudes. It leads to shorter lifetimes owing to a faster reduction of the characteristic length scales of the BMR, which leads to faster diffusion. Near the equator, local shear is less pronounced and this results in slightly longer lifetimes. At high latitudes, although the local shear rate is higher than in the equatorial regions, the lifetime is relatively

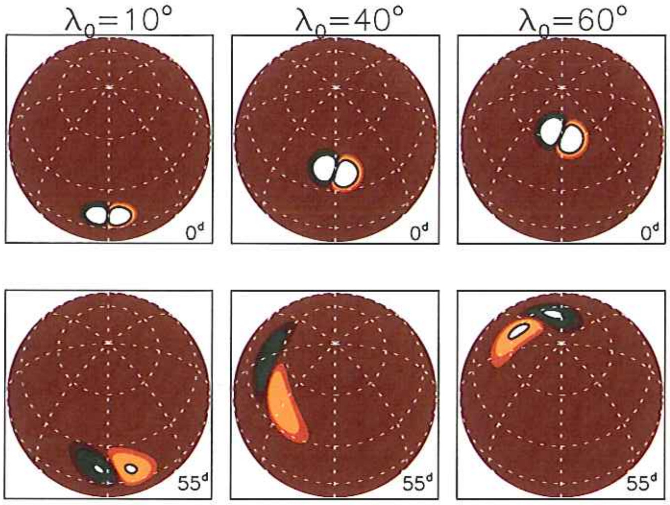

Figure 1. Evolution of BMRs with different emergence latitudes, with initial tilt angles $\alpha = 0.5\lambda_0$, and with solar surface shear (shown with respect to the rest frame of the equator). The top panels indicate the initial states, and the bottom panels show the states after 55 days. The field strength above a threshold level (14%) is indicated by white regions enclosed by a thick black contour. Contours for 4% and 2% of the initial peak strength are filled with shades of gray for each polarity.

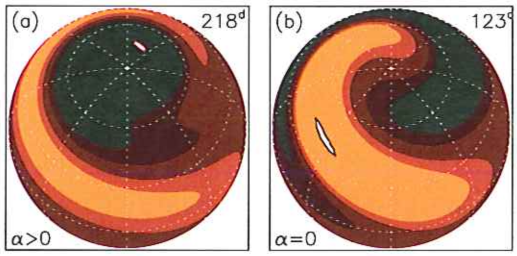

Figure 2. Two large BMRs with (a) and without (b) an initial tilt angle ($\alpha = 0.5\lambda_0$), at times shortly before their peak strength falls below the threshold.

long. The reasons are, firstly, that the poleward meridional flow decelerates with increasing latitude, and secondly, that the meridional flow advects the BMR to regions with weaker shear. Both effects prolong the lifetimes of high-latitude starspots. A BMR covering 12% of the stellar surface, emerging at $\lambda_0 = 40°$ with a tilt angle $\alpha = 20°$ may live as long as 7 months, because it develops into a roughly circular polar cap (Figure 2a). Polar caps require an initial tilt of the BMR (Figure 2b), because otherwise the enhanced flux cancellation leads to a relatively short lifetime.

In the case of (sub)giant stars, lifetimes increase as proportional to the square of the stellar radius. When a BMR, which covers about 0.8% of the stellar surface, emerges at 70° latitude, it lives for about 2 years. Emergence of additional BMRs at mid- to high latitudes, can lead to the formation of polar spots which live for many years. For instance, random emergence of 6 BMRs, each covering 3% of the stellar surface, during 1.4 years, leads to a lifetime increase of an already existing polar cap from 3 years to 10 years (Işık et al. 2007).

References

Baumann, I., Schmitt, D., Schüssler, M., & Solanki, S. K. 2004, A&A, 426, 1075
Baumann, I., Schmitt, D., & Schüssler, M. 2006, A&A, 446, 307
Donati, J.-F., Collier-Cameron, & Petit, P. 2003, MNRAS, 345, 1187
Dikpati, M. & Choudhuri, A. R. 1995, Sol. Phys., 161, 9
Hathaway, D. H. 1996, ApJ, 460, 1027
Işık, E., Schüssler, M., & Solanki, S. K. 2007, A&A, in press
Mackay, D. H., Priest, E. R., & Lockwood, M. 2002, Sol. Phys., 209, 287
Snodgrass, H. B. 1983, ApJ, 270, 288
van Ballegooijen, A. A., Cartledge, N. P., & Priest, E. R. 1998, ApJ, 501, 866
Wang, Y.-M., Nash, A. G., & Sheeley, N. R. 1989, ApJ, 347, 529