Temperature Surface Imaging as a Tracer for Stellar Magnetic Fields

K.G. Strassmeier

Astrophysical Institute Potsdam (AIP), D-14482 Potsdam, Germany

J.B. Rice

Department of Physics, Brandon University, Brandon R7A 6A9, Canada

T. Granzer, M. Weber

Astrophysical Institute Potsdam (AIP), D-14482 Potsdam, Germany

Abstract. Sunspots are well-known proxies for the breakthrough of magnetic lines of force through the solar surface. Their relative temperature, their geometry, and their kinematics are all tracers of the underlying magnetic flux tubes. To first order, we expect that the small-scale changes of stellar photospheric structure are due to changes induced by the magnetic field itself, due to dynamo action or local reconnection, and that the large-scale changes are due to global velocity fields like differential rotation and meridional circulation. We present a brief overview of our recent Doppler images and flux-tube models and discuss some observational evidence for the existence of surface velocity fields on active giants.

1. Introduction: a starspot gallery

Within the past years, we used our line-profile inversion code TEMPMAP to obtain Doppler images from strips of high-resolution spectra with many different spectral lines and applied it to many different types of stellar objects. Fig. 1 is a comparison of all our temperature maps obtained with TEMPMAP. It includes giants as well as dwarfs and pre-main-sequence objects, single stars as well as close binaries (for more details we refer to www.aip.de/groups/activity). It appears that there is no striking change of the surface temperature morphology for stars with rotation periods between 1.5 days (upper left corner) and 24 days (lower right corner). Polar spots as well as equatorial spots are recovered unrelated to the stellar rotational period. Doppler images of even more rapidly-rotating ZAMS stars, e.g. for AB Dor with a rotation period of 0.5 days, confirm this picture. Since this would be a most perplexing result and would contradict all previous models of flux-tube emergence that were based on the geometry of transition-region αΩ or α² dynamos. At the moment, we conclude that we probably can not directly compare these images due to the large diversity of the
Figure 1. Summary of temperature Doppler images (black is cool, white is hot) obtained with TEMPMap. The images are arranged by increasing rotation period from the upper left corner to the lower right corner.
internal stellar structure. One way out of this dilemma is to observe stars in open clusters with well defined ages.

2. Surface velocity fields?

Cross correlations between consecutive Doppler images can be used to detect and quantify spot changes on the stellar surface. HR 1099 (Strassmeier & Bartus 2000) and HD 218153 (Weber & Strassmeier 2001) are examples of (sub)giant RS CVn star with longitudinal as well as latitudinal changes. Whether these changes are systematic and due to a combination of differential rotation and meridional circulation, or were just of short duration due to e.g. magnetic reconnections, remains undetermined at the moment. In any case, it fuels evidence that the position of magnetic flux tubes could significantly evolve after their initial emerging position.

3. Flux-tube models

Parallel to our observational effort, we apply the well-known thin flux-tube approximation to model the ascent of magnetic flux from the overshoot region to the surface (Granzer et al. 2000). Two distinct scenarios of flux-tube evolution are considered. Firstly, the emergence of a flux tube for stars with relatively large cores. The main part of the flux tube remains anchored inside the overshoot layer during its entire lifetime. The path of the emerging part is determined by the interplay of the Coriolis and the buoyancy force. The magnetic tension can lift the anchored part of the flux tube only marginally towards the rotational axes ("pole slip"). Secondly, the emergence path for stars with extremely small cores. The pole slip is so pronounced that the entire flux-tube ring detaches from the overshoot layer. Only buoyancy forces govern its future ascent. A symmetric density distribution inside the flux tube leads to a vertical rise (instability modes with wave number $m=0$), while $m=1$ modes are deflected to the equator.

A flux tube in an initial stable mechanic equilibrium inside the overshoot region is exposed to a small (undulatory) disturbance which eventually grows and leaks out of the overshoot region into the convective envelope. Here, the superadiabatic stratification amplifies the growth of the disturbance which evolves into a (single) rising loop. The simulation must cease as the thin flux tube approximation breaks down due to the vast drop of the pressure scale height near the surface layers. In all studied cases, the flux tube-summits reach, however, an elevation of approximately 0.98 \( R_\star \). The straight extension to the surface of these end-points of the simulation are considered the emergence latitude of a star spot; twelve individual flux tubes with different equilibrium latitudes inside the overshoot layer (5° to 60°) are combined to yield the spot probability function, SPF, a normalized measure of probability of starspot formation as a function of latitude. Example SPF s are shown in Fig. 2, right panel (the models are shown in Fig. 2, left panel). Gray areas indicate the regions of spot formation, the probability rising as the appropriate area widens.

Amongst other drawbacks of this approach is the breakdown of this approximation in close-to-surface layers which prohibits any model-based predictions on post-emergence development of the star spots. One can merely argue that
Figure 2. **Left.** HR diagram of stars with masses of 0.6, 0.8, 1, 1.3 and 1.6 M☉. A 8.3 Myr isochrone is displayed as a dashed line. For comparison, recent tracks of D’Antona & Mazzitelli (2000) are included (dotted lines).

**Right.** A hypothetic stellar cluster, age 8.3 Myr. Masses of 0.6, 0.8, 1.0, 1.3, and 1.6 M☉ are shown. Note not only the strong increase in spot latitudes as one moves to higher rotational rates, but also the rather prominent increase of latitude with decreasing mass for any fixed rotation rate.

Meridional flows may transport magnetic flux to the poles, than backing this assumptions with actual simulations. Velocity fields below the surface layers can be taken into account, but for all stars other than our Sun our knowledge is very limited.

**References**

D’Antona, F., & Mazzitelli, I. 2000, wwwastro.phast.umass.edu/data/tracks.html