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STELLAR DYNAMO MODELS: FROM F TO K

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ABSTRACT We extend the two-dimensional solar dynamo models to stars of different spectral types. Dynamo action is restricted to the overshoot layer, and differential rotation is generated by the Reynolds stresses.

INTRODUCTION

Stellar dynamo theory has so far been unable to make firm predictions about the dependence of magnetic flux generation on rotation rate and spectral type. The main uncertainty results from our incomplete knowledge of the underlying physics. This has led to a number of *ad hoc* assumptions concerning differential rotation and turbulence physics. In order to make progress it is essential to base the dynamo model on self-consistent physics in which the basic drivers of stellar activity – differential rotation and cyclonic convection – result from a unique turbulence model. Rüdiger & Kitchatinov (1993) and Kitchatinov & Rüdiger (1993) have made important steps in this direction and have derived from a unique, albeit simple, turbulence model expressions for the full, anisotropic, alpha-tensor and the Reynolds stress tensor as a function of the inverse Rossby number, Ro^{-1}. Many previous models ignore the fact that even the sun must be considered a rapid rotator in the sense that $\mathrm{Ro}^{-1} \gg 1$.

With these expressions for the α-tensor, Rüdiger & Brandenburg (1993) constructed dynamo models for the solar convection zone. Various nonlinear effects, including magnetic buoyancy and α-quenching have been included. However, the distribution of the internal angular velocity has been adopted from helioseismology. This, of course, is not possible when constructing models of different spectral type or angular velocity. Thus, in the present paper we also solve for the differential rotation using the parameterization of the Reynolds

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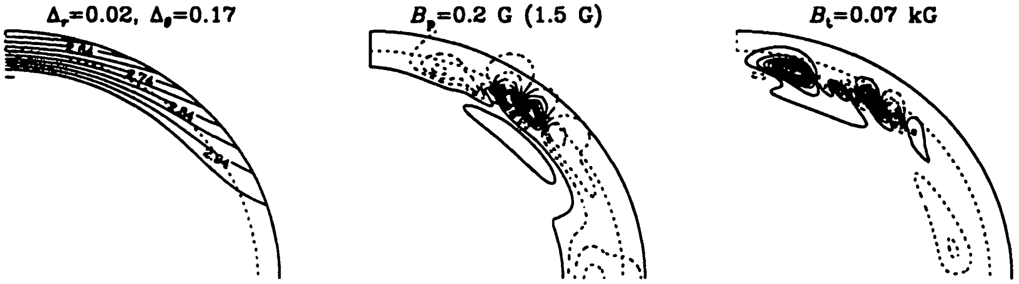

FIGURE I Contours of the angular velocity, poloidal field lines, and contours of the toroidal field (dashed contours refer to negative values) for a F-type model.

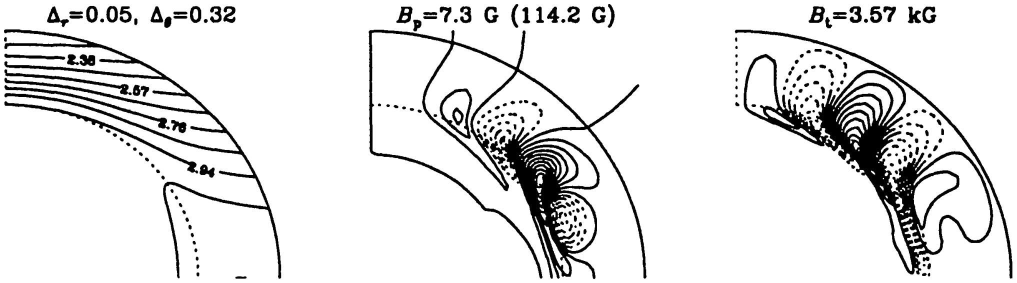

FIGURE II As Fig. I, but for a G-type model.

stress tensor given by Kitchatinov & Rüdiger (1993), which yields good results for the solar differential rotation (Küker et al. 1993). For the details of our model we refer to Brandenburg et al. (1992) and Rüdiger & Brandenburg (1993).

RESULTS

In Figs. I-III we present results for models corresponding to different spectral types, by using three different values for the inner fractional radius of the convection zone: $r_0/R = 0.5$, 0.7, and 0.92, corresponding approximately to K5, G5 and F2 dwarfs, respectively. In all cases we assume a rotation period of 25 days. The numbers in the figure characterize the resulting differential rotation, $\Delta_r \equiv (\Omega_{\rm eq} - \Omega_0)/\Omega_0$ and $\Delta_\theta \equiv (\Omega_{\rm eq} - \Omega_{\rm pole})/\Omega_0$, and the resulting average field strengths of the poloidal field at the surface ($B_{\rm p}$) and the toroidal field in the bulk of the convection zone ($B_{\rm t}$). The value in parenthesis quoted for the poloidal field gives the peak field strength at the surface.

By comparing the three figures we note that the number of toroidal field belts increases for earlier type stars. This arises because the magnetic field belts tend to have roughly similar ratios between radial and latitudinal dimensions. In an F-star the radial extent is relatively small, thus reducing the horizontal (latitudinal) wavelength of the flux belts. Multiple activity belts and a reduction

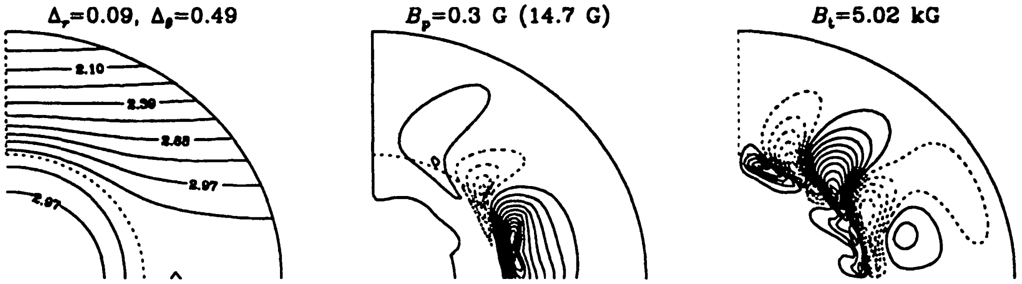

FIGURE III As Fig. I, but for a K-type model.

in cycle amplitudes are, in fact, observed in stars with shallow convection zones (Donahue & Baliunas 1993; Saar & Baliunas 1992). In our models, the strongest field generation also appears at higher latitudes in the F stars compared to the G and K stars. Furthermore, flux generation is a strong function of r_0 for a fixed Ω, consistent with the observed correlation between fB and Ro^{-1} (e.g., Saar 1991). For a more conclusive comparison a realistic dependence of convection zone parameters on spectral type is needed. Also, in our model of a G-star the average poloidal field strength (7 G) somewhat exceeds the solar value (1 – 2 G), as does (perhaps) B_t. These values are sensitive to the form of α-quenching which, however, is uncertain.

DISCUSSION

We feel that our models are now beginning to show some resemblance to the solar dynamo and so, by extension, hopefully to dynamos operating in stars of other spectral types. We have adopted a dynamo operating in the convective overshoot layer. Although this is the currently favored view, we are not completely convinced that this is the sole site of the solar dynamo; it is at least plausible that a 'distributed dynamo' operating in the bulk of the convection zone contributes to the dynamo action, with mean field being pumped down to the overshoot layer.

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