Cosmic Magnetic Fields:
From Planets, to Stars and Galaxies
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Turbulent effects in flux-transport solar dynamos

G. A. Guerrero[1], **E. M. de Gouveia Dal Pino**[1] **and M. Dikpati**[2]

[1]Department of Astronomy, IAG, University of Sao Paulo, Sao Paulo, SP, Brazil
email: guerrero,dalpino@astro.iag.usp.br

[2]High Altitude Observatory, National Center for Atmospheric Research
P.O. Box 3000, Boulder, Colorado, 80307, USA
email: dikpati@ucar.edu

Abstract. The effects of turbulent pumping and η-quenching on Babcock-Leighton dynamo models are explored separately. Turbulent pumping seems to be important to solve several reported problems in these dynamo models related to the magnetic flux transport and to the parity. On the other hand, the suppression of the magnetic diffusivity, η, could help in the formation of long-lived, small and intense structures of toroidal magnetic field.

Keywords. Sun: activity – Sun: magnetic fields

1. Introduction

It is generally believed that the Solar Cycle corresponds to a hydromagnetic dynamo process operating at some place within the Solar interior. Parker (1955) was the first to build a solar dynamo model, since then there has been important improvements in the observations, theory and simulations, but a definitive model for the solar dynamo is still missing.

Two processes are necessary to close the dynamo loop: the transformation of an initial poloidal field into a toroidal field, the so called Ω effect, which is due to a large scale shear, and the transformation of the toroidal field into a new poloidal field of opposite polarity, which is a less understood process that has been the subject of intense debate and research. Two main hypotheses have been formulated in order to explain the nature of this effect (usually denominated α effect): the turbulent and the Babcock-Leighton (BL) α effect.

In the second proposed mechanism above, the large scale poloidal field is formed from the emergence and decay of bipolar magnetic regions (BMR's) which contain a net dipole moment. The new dipolar field, formed at lower latitudes, is transported by meridional circulation to the higher latitudes in order to form the observed polar field. For the meridional flow to be important in the transport of magnetic flux, the advection time must dominate upon the diffusive time, for this reason these models are often called flux-transport dynamo models.

The flux-transport dynamo model has been relatively successful in reproducing the large scale features of the solar cycle Dikpati & Charbonneau (1999), however it presents several problems that have been widely discussed in the literature Brandenburg (2005). In this work, we discuss the inclusion of two turbulent effects in a BL dynamo model – the turbulent pumping and the η-quenching – and show that, under determined conditions, they can produce results which are in better agreement with the observations.

2. Turbulent pumping and η quenching

The turbulent pumping provides the transport of magnetic flux due to the presence of density and turbulence gradients in convectively unstable layers. It has several important effects. For dynamos operating at the convection zone and at the tachocline, we find that the pumping leads to a better distribution of toroidal fields inside the convection zone when compared to a model without pumping (left panel of Figure 1). It also increases the penetration of the toroidal field formed at the convection zone in the overshoot region, allowing further field amplification by the large radial shear in that region. The strongest fields at the top of the overshoot layer are located at latitudes below 30°, as can be seen in the right panel of Fig. 1. We find that the flux transport due to the pumping can be more important than the meridional circulation at providing the correct migration of the magnetic fields, in setting the correct period of the cycle and also at providing the appropriate parity of the magnetic fields. Models including a near-surface shear layer and turbulent pumping result in butterfly diagrams that are also in agreement with the observations (Guerrero & de Gouveia Dal Pino 2008).

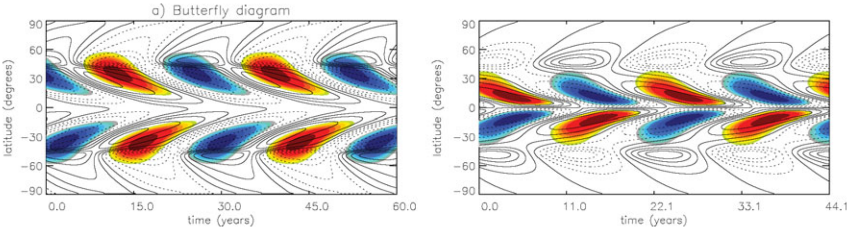

Figure 1. Butterfly diagram for models without and with turbulent pumping (left and right, respectively), the blue (red) contour scale represents positive (negative) toroidal field at the base of the convection zone, the solid (dotted) lines represent radial fields at the surface.

When the magnetic field is strong, the turbulence decreases and the turbulent diffusivity is suppressed. We have included this effect by adopting the following algebraic quenching function $\eta = \eta_T/(1+(\overline{\mathbf{B}}/B_q)^2)$ (Guerrero *et al.* 2009). We have found that, as soon as the magnetic field reaches the value B_q, the diffusivity can be strongly suppressed leading to the formation of long-lived small and intense magnetic structures. The magnitude of the maximum magnetic field can be twice as large as that of models without quenching, nevertheless these intense fields appear mainly at the center of the convection zone rather than at its base where it is usually believed to be produced. We find also that the larger the quenching efficiency the larger the period of the cycle, however for high values of η_T the models drift from the flux-transport regime to the diffusion regime.

Acknowledgements

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Carsten Denker (middle) chatting with H. Zinnecker (left) and Günther Rüdiger (right)

Elisabete de Gouveia dal Pino (right) talking to Federico Stasyszyn

Visit to the solar telescopes on Teide/Izana

The meeting place: Hotel Playa de la Arena