

## COVERED FIELDS

- Solar Wind and Heliosphere
- Solar Surface and Atmosphere
- Solar Interior
- Solar Activity
- Sun-Earth Connection
- Instruments, Methods and Techniques
- Solar-Stellar Connection
- Physical Foundations

## EDITORIAL BOARD

Sami Solanki (editor-in-chief)  
Jørgen Christensen-Dalsgaard  
Bernhard Fleck  
Eckart Marsch  
Robert Rosner  
Takashi Sakurai  
Karel Schrijver  
Manfred Schüssler  
Rainer Schwenn

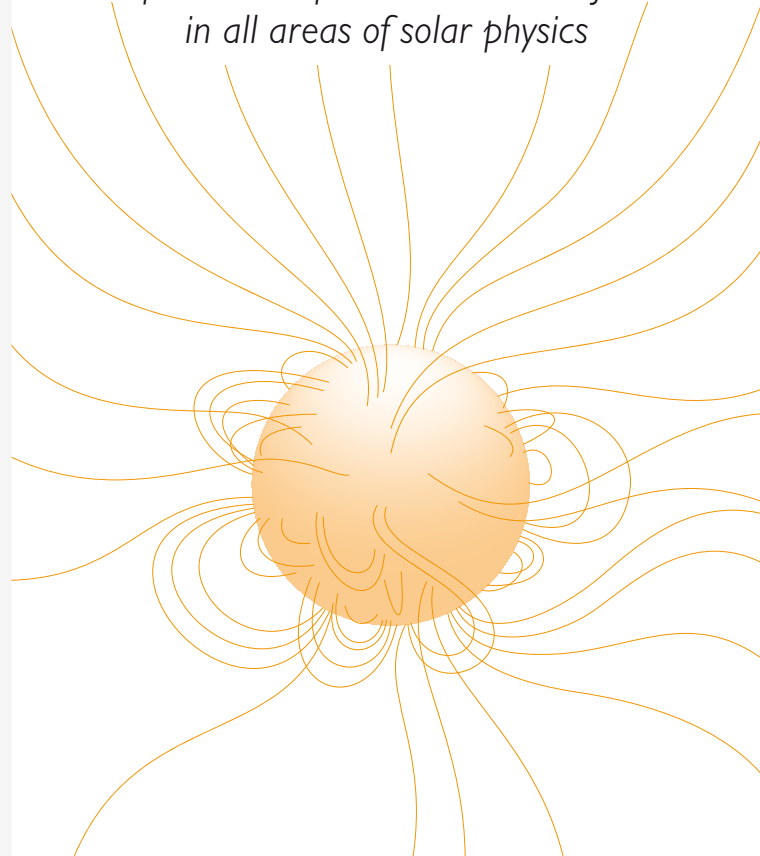
Published by the  
Max Planck Institute for Solar System Research  
Max-Planck-Straße 2 • 37191 Katlenburg-Lindau • Germany  
[info@solarphysics.livingreviews.org](mailto:info@solarphysics.livingreviews.org)



# LIVING REVIEWS

*in solar physics*

*an up-to-date open access review journal  
in all areas of solar physics*



Living Reviews in Solar Physics is an international open access online journal, which publishes review articles that summarise and evaluate the current state of research in all areas of solar and heliospheric physics.

Living Reviews articles, solicited from leading experts and subject to peer review, offer annotated insights into the key literature and online resources at or above graduate student level.

The unique concept and technology of Living Reviews allows authors to regularly revise their articles and keep them up-to-date with developments in the field. This is expressed by the word "Living" in the journal's title.

## ONLINE FEATURES

- reference tracking, revision tracking
- advanced navigation support for equations, images, footnotes
- support for additional material (movies or program code)
- download of various article formats and bibliographies
- online searchable reference database
- history of article updates and revisions

**Magnetic Fields in the Solar Convection Zone**  
by Yuhong Fan

**Abstract**

- 1 Introduction
- 2 Models and Computational Approaches
- 3 Equilibrium Conditions of Toroidal Magnetic Fields Stored at the Base of the Solar Convection Zone
- 4 Destabilization of a Toroidal Magnetic Field and Formation of Buoyant Flux Tubes
- 5 Dynamic Evolution of Emerging Flux Tubes in the Solar Convection Zone
- 6 Turbulent Pumping of a Magnetic Field in the Solar Convection Zone
- 7 Amplification of a Toroidal Magnetic Field by Conversion of Potential Energy
- 8 Flux Emergence at the Surface and Post-Emergence Evolution of Subsurface Fluxes
- 9 Summary
- 10 Acknowledgments

**References**

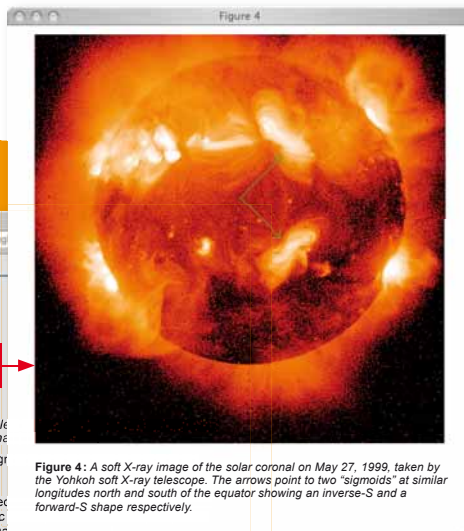
**Updates**

**Figures**

**View images in original size**

**Jump to next citation point**

**View references**



**Figure 4:** A soft X-ray image of the solar coronal on May 27, 1999, taken by the Yohkoh soft X-ray telescope. The arrows point to two "sigmoids" at similar longitudes north and south of the equator showing an inverse-S and a forward-S shape respectively.

**Figure 4:** A soft X-ray image of the solar coronal on May 27, 1999, taken by the Yohkoh soft X-ray telescope. The arrows point to two "sigmoids" at similar longitudes north and south of the equator showing an inverse-S and a forward-S shape respectively.

This hemispheric preference of the sign of the active region field line twist and the direction of X-ray sign cycle (see Pevtsov *et al.*, 2001).

The cyclic large scale magnetic field of the Sun with a period of 22 years is believed to be sustained polarity law of solar active regions indicates the presence of a large scale subsurface toroidal magnetic mechanism. In the past decade, the picture of how and where the large scale solar dynamo operates has in part to new knowledge from helioseismology regarding the solar internal rotation profile (see Deluca and Gilman, 1991; Gilman, 2000). Evidence now points to the tachocline, the thin shear layer at the base of the solar convection zone, where solar rotation changes from the latitudinal differential rotation of the solar convective envelope to the nearly solid-body rotation of the radiative interior, as the site for the generation and amplification of the large scale toroidal magnetic field (see Charbonneau and MacGregor, 1997; Dikpati and Charbonneau, 1999; Dikpati and Gilman, 2001). Furthermore, with its stable (weakly) subadiabatic stratification, the thin overshoot region in the upper part of the tachocline layer (Gilman, 2000) allows storage of strong toroidal magnetic fields against their magnetic buoyancy for time scales comparable to the solar cycle period (Parker, 1975; 1979; van Ballegoijen, 1982; Moreno-Insertis *et al.*, 1992; Fan and Fisher, 1996; Moreno-Insertis *et al.*, 2002; Kempel, 2003). Thus with toroidal magnetic fields being generated and stored in the tachocline layer at the base of the solar convection zone, these fields need to traverse the entire convection zone before they can emerge at the photosphere to form the observed solar active regions.

High resolution observations have shown that magnetic fields on the solar photosphere are in a fibril state, i.e. in the form of discrete flux tubes of high field strength (in equipartition with the thermal pressure) having a hierarchy of cross-sectional sizes that range from sunspots of active regions down to below the limit of observational resolution (see Zwaan, 1987; Stenflo, 1989; Dominguez Cerdeña *et al.*, 2003; Khomenko *et al.*, 2003; Socas-Navarro and Sánchez Almeida, 2003). It is thus likely that the subsurface magnetic fields in the solar convection zone are also concentrated into discrete flux tubes. One mechanism that can concentrate magnetic flux in a turbulent conducting fluid, such as the solar convection zone, into high field strength flux tubes is the process known as "flux expulsion", i.e. magnetic fields are expelled from the interior of convecting cells into the boundaries. This process has been studied by MHD simulations of the interaction between convection and magnetic fields (see Galloway and Weiss, 1981; Nordlund *et al.*, 1992). In particular, the 3D simulations of magnetic fields in convecting flows by Nordlund *et al.* (1992) show the formation of strong discrete flux tubes in the vicinity of strong downdrafts. In addition, Parker (1984) put forth an interesting argument that supports the fibril form of magnetic fields in the solar convection zone. He points out that although the magnetic energy is increased by the compression from a continuum field into the fibril state, the total energy of the convection zone (thermal + gravitational + magnetic) is reduced by the fibril state of the magnetic field by avoiding the magnetic inhibition of convective overturning. Assuming an idealized polytropic atmosphere, he was able to derive the filling factor of the magnetic fields that corresponds to the minimum total energy state of the atmosphere. By applying an appropriate polytropic index for the solar convection zone, he computed the filling factor which yielded fibril magnetic fields of about  $1 - 5 \%$ , roughly in agreement with the observed fibril fields at the solar surface.

**References**

- Gilman, P.A., 2000. "Fluid Dynamics and MHD of the Solar Convection Zone and Tachocline: Current Understanding and Unsolved Problems - (Invited Review)", *Solar Phys.*, **192**, 27-48. Related online version (cited on 01 February 2007): <http://adsabs.harvard.edu/abs/2000SoPh..192...27G> [<http://dx.doi.org/10.1007/BF02731913>]
- Gilman, P.A., Charbonneau, P., 1999. "Creation of Twist at the Core-Convection Zone Interface", in *Magnetic Helicity in Space and Laboratory Plasmas*, (Eds.) Brown, M.R., Canfield, R.C., Pevtsov, A.A., vol. 111 of Geophysical Monograph Series, pp. 75-82, American Geophysical Union, Washington, U.S.A. Related online version (cited on 01 February 2007): <http://adsabs.harvard.edu/abs/1999msl.conf...75G>

Crosslink to first citation point

Online Search Interface

Living Reviews  
Reference Database