New Perspectives on Solar Prominences, IAU Colloquium 167
ASP Conference Series, Vol. 150, 1998
David Webb, David Rust, and Brigitte Schmieder (eds.)

Magnetic Flux Transport and Formation of Filament Channels

A. A. van Ballegooijen

Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

N. P. Cartledge and E. R. Priest

Mathematical and Computational Sciences Department, University of St. Andrews, KY16 9SS Scotland, UK

Abstract. We present a model of the transport of photospheric and coronal magnetic fields with the aim of explaining the observed global pattern of dextral and sinistral filaments on the quiet sun. The model is based on the assumption that the axial field in a filament channel originates in the surrounding coronal arcade. The model predicts that switchbacks in the polarity inversion line have opposite chirality on the two arms of the switchback: the higher latitude "lead" arm has sinistral (dextral) orientation in the North (South), while the lower latitude "return" arm has dextral (sinistral) orientation. This is in conflict with prominence observations which show that the chirality is the same on the two arms of a switchback. The model predicts the wrong sign of the axial field in polar crown filaments. This suggests that axial field in quiescent filaments are not produced by differential rotation acting on the surrounding coronal arcades.

1. Diffusion Model

Measurements of magnetic fields in solar prominences (Leroy 1978, Leroy, Bommier and Sahal-Bréchot 1983, 1984, Bommier and Leroy 1998, these proceedings) and observations of Hα filaments on the solar disk (Martin, Marquette and Bilimoria 1992, Martin, Bilimoria and Tracadas 1994) show that the "axial" component of magnetic field (i.e., the component along the polarity inversion line) exhibits a large-scale organization: quiescent filaments in the northern hemisphere predominantly have *dextral* orientation (i.e., axial magnetic field pointing toward the right when viewed from the positive polarity side), while those in the southern hemisphere have *sinistral* orientation. In this paper we consider a model of the formation of filament channels which assumes that these axial fields are produced by differential rotation acting on the surrounding coronal arcades. Then the axial field in the filament channel should have the same sign as the axial field in the surrounding arcade.

The transport of radial magnetic field in the solar photosphere can be described in terms of a diffusion model (e.g., Leighton 1964, Sheeley et al. 1987).

https://doi.org/10.1017/S0252921100047710 Published online by Cambridge University Press

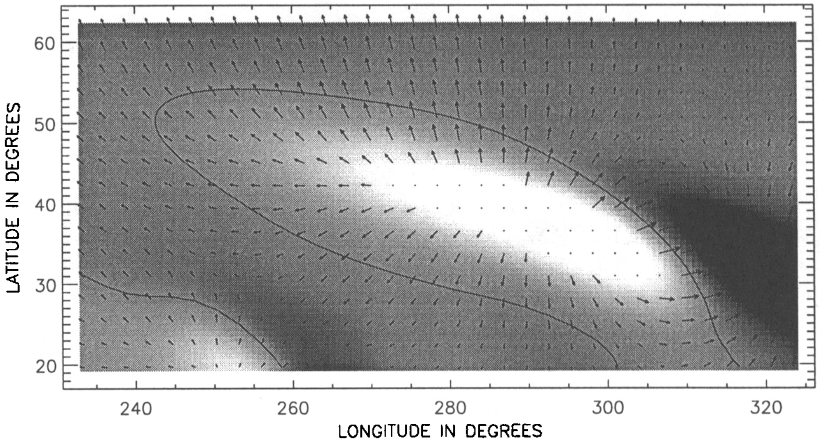

Figure 1. Magnetic field near a switchback in CR 1791. Grey levels indicate radial magnetic field in the photosphere ($|B_r| < 15$ Gauss); vectors indicate the horizontal magnetic field at $r = 1.1R_{\odot}$.

We extended this model to include not only the radial field at the photosphere but also the horizontal field, both in the photosphere and higher up in the corona (van Ballegooijen, Cartledge and Priest 1998). The model includes differential rotation, meridional flow and supergranular diffusion (photospheric diffusion constant $D = 450$ km$^2/s$). We assume that fluid motions in the corona are purely horizontal, and we artificially suppress the vertical diffusion of horizontal magnetic fields. The magnetic induction equation is solved numerically by decomposing the magnetic field into spherical harmonics ($l_max = 63$). For the initial conditions we use potential fields computed from synoptic magnetic field data obtained at NSO/Kitt Peak[1]. The magnetic field from one Carrington Rotation (CR) is evolved over a period of 27 days, and the result is compared with the observed field for the next rotation. Figure 1 shows the simulated magnetic field near a switchback in the polarity inversion line in CR 1971 (July 1987).

2. Analysis

We simulate the magnetic fields for four Carrington Rotations (CR 1791, 1816, 1849 and 1876) and deduce the orientation of the axial field over the polarity inversion lines. Figure 2 shows histograms of the predicted number of dextral and sinistral channels as a function of latitude (compare with Martin et al. 1994). We assume that filament channels form preferentially in locations where

[1]The NSO/Kitt Peak data used in this study are produced cooperatively by NSF, NASA/GSFC and NOAA/SEC.

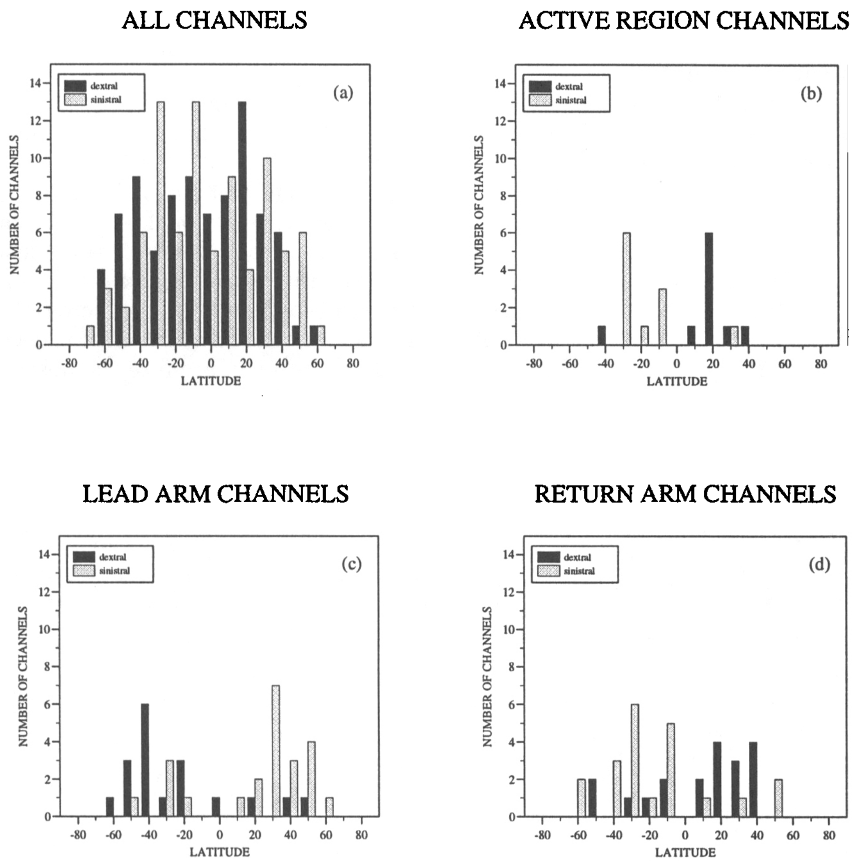

Figure 2. Histograms of predicted number of filament channels.

some magnetic shear is already present in the surrounding arcade, so we define a "channel" as a region where the computed magnetic field is sheared over a substantial section along the polarity inversion line (minimum length $0.15R_\odot$; minimum shear angle 30°). Note that there is no clear hemispheric pattern: the model predicts that dextral and sinistral channels occur in about equal numbers in each hemisphere (see Figure 2a). The subset of channels located within relatively young active regions (Figure 2b) are mostly dextral in the north and sinistral in the south, which is due to differential rotation acting on initially north-south oriented polarity inversion lines in these regions. Figures 2c and 2d show the latitude distribution of channels located on the "lead" and "return" arms of switchbacks. The lead arms are predicted to have sinistral (dextral) channels in the north (south), and the same is true for the polar crowns. This is due to differential rotation acting on coronal arcades overlying nearly east-west oriented polarity inversion lines (van Ballegooijen and Martens 1990). The return arms of switchbacks have dextral (sinistral) channels in the north (south), which can be traced to the influence of the polar magnetic field. Hence, the chirality of the field is predicted to be different on the two arms of a switchback, as shown in Figure 1. Since the lead arms occur at higher latitude than the return arms, there is a slight excess of sinistral (dextral) channels in the north (south) above latitudes of 40° (see Figure 2a).

Filaments are known to occur on both "lead" and "return" arms of switchbacks. Therefore, on the basis of the present model one would expect to find a mixture of both dextral and sinistral channels in each hemisphere. This is in conflict with observations which show a clear preference for dextral channels in the north and sinistral channels in the south (see Bommier and Leroy 1997, Martin et al. 1994). We conclude that the present model (filament axial field originating in the surrounding coronal arcade) does not reproduce the observed global patterns of dextral and sinistral channels on the quiet sun. However, the flux transport model may be successful in describing the build-up of magnetic shear in coronal arcades.

It has been proposed that the axial field in filament channels originates in the solar convection zone: differential rotation acting on subsurface fields can produce the correct sign of the axial field (e.g., Priest, van Ballegooijen and MacKay 1996). However, there is as yet no direct observational evidence for the emergence of such axial fields through the photosphere. Therefore, the origin of the observed global patterns is still unclear.

Acknowledgments. This work was supported by the UK Particle Physics and Astronomy Research Council and by the National Science Foundation under grant ATM-9596070 to the Solar Physics Research Corporation.

References

Leighton, R. B. 1964, ApJ, 140, 1547

Leroy, J. L. 1978, A&A, 64, 247

Leroy, J. L., Bommier, V. and Sahal-Bréchot, S. 1983, Solar Phys., 83, 135

Leroy, J. L., Bommier, V. and Sahal-Bréchot, S. 1984, A&A, 131, 33

Martin, S. F., Bilimoria, R. and Tracadas, P. W. 1994, in Solar Surface Magnetism, (eds.) R. J. Rutten and C. J. Schrijver, Dordrecht: Kluwer, p. 303

Martin, S. F., Marquette, B. and Bilimoria, R. 1992, in The Solar Cycle, (ed.) K. Harvey, ASP Conf. Ser. Vol. 27, San Francisco, p. 53

Priest, E. R., van Ballegooijen, A. A. and MacKay, D.H. 1996, ApJ, 460, 530

Sheeley, N. R., Jr., Nash, A. G. and Wang, Y.-M. 1987, ApJ, 319, 481

van Ballegooijen, A. A., Cartledge, N. P. and Priest, E. R. 1998, ApJ, submitted

van Ballegooijen, A. A. and Martens, P. C. H. 1990, ApJ, 361, 283