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Why coronal mass ejections are necessary for the dynamo

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Abstract. Large scale dynamo-generated fields are a combination of interlocked poloidal and toroidal fields. Such fields possess magnetic helicity that needs to be regenerated and destroyed during each cycle. A number of numerical experiments now suggests that stars may do this by shedding magnetic helicity. In addition to plain bulk motions, a favorite mechanism involves magnetic helicity flux along lines of constant rotation. We also know that the sun does shed the required amount of magnetic helicity mostly in the form of coronal mass ejections. Solar-like stars without cycles do not face such strong constraints imposed by magnetic helicity evolution and may not display coronal activity to that same extent. I discuss the evidence leading to this line of argument. In particular, I discuss simulations showing the generation of strong mean toroidal fields provided the outer boundary condition is left open so as to allow magnetic helicity to escape. Control experiments with closed boundaries do not produce strong mean fields.

Keywords. Hydrodynamics – (magnetohydrodynamics:) MHD – turbulence – Sun: coronal mass ejections (CMEs) – Sun: magnetic fields – stars: magnetic fields – stars: mass loss

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All known large scale dynamos ($\alpha\Omega$, shear–current, and α^2 dynamos) produce magnetic helicity, which reacts back on the dynamo. As a consequence, the mean field saturates at a low value, $\overline{\mathbf{B}}^2 \ll B_{\rm eq}^2 \equiv \langle\mu_0\rho\mathbf{u}^2\rangle$. By allowing for magnetic helicity fluxes out of the domain, the large scale field is able to saturate at equipartition field strength (Fig. 1). The results of simulations are qualitatively, and in some cases also quantitatively, well reproduced by mean field models where the effect of magnetic helicity fluxes enters into the dynamical feedback formula for the magnetic alpha effect (even when there is no kinetic alpha effect!). For closed boundary conditions, the field saturates at much lower strength and no large scale field is being produced.

Contributions to the magnetic helicity flux include the shear-driven Vishniac-Cho (2001) flux, which can be written in the form $\overline{\mathbf{F}} \propto (\overline{\mathsf{S}}\,\overline{\mathbf{B}}) \times \overline{\mathbf{B}}$, where $\overline{\mathsf{S}}$ is the strain rate of the mean flow (Subramanian & Brandenburg 2006), and an advectively driven flux (Shukurov et al. 2006) of the form $\overline{\mathbf{F}} \propto \alpha_{\rm M}\overline{\mathbf{U}}$, where $\alpha_{\rm M}$ is the magnetic α effect. The former is the one operating predominantly in the simulations (Fig. 2).

A connection between dynamo-generated magnetic helicity fluxes and coronal activity was first predicted by Blackman & Field (2002). There are at present no direct simulations of turbulent dynamos that also include the relevant physics behind coronal mass ejections. On the other hand, the observed magnetic helicity fluxes from coronal mass ejections (Berger & Ruzmaikin 2000) of around $10^{46}{\rm Mx}^2$ per cycle agrees with what is predicted from simulations (Brandenburg & Sandin 2004).

References

Berger, M. A., & Ruzmaikin, A. 2000, *JGR* 105, 10481.
Blackman, E. G., & Field, G. B. 2000, *MNRAS* 318, 724.

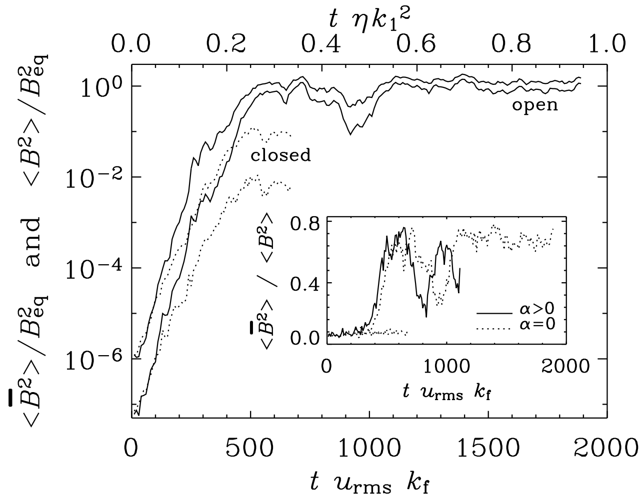

Figure 1. Evolution of the energies of the total field $\langle \mathbf{B}^2 \rangle$ and of the mean field $\langle \overline{\mathbf{B}}^2 \rangle$, in units of B_{eq}^2, for runs with non-helical forcing and open or closed boundaries; see the solid and dotted lines, respectively. The inset shows a comparison of the ratio $\langle \overline{\mathbf{B}}^2 \rangle / \langle \mathbf{B}^2 \rangle$ for nonhelical ($\alpha = 0$) and helical ($\alpha > 0$) runs. For the nonhelical case the run with closed boundaries is also shown (dotted line near $\langle \overline{\mathbf{B}}^2 \rangle / \langle \mathbf{B}^2 \rangle \approx 0.07$). Adapted from Brandenburg (2005).

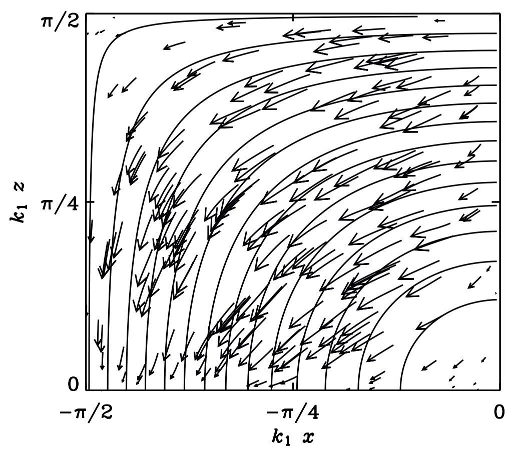

Figure 2. Vectors of the Vishniac & Cho flux together with contours of the mean flow which also coincide with the streamlines of the mean vorticity field. The orientation of the vectors indicates that negative current helicity leaves the system at the outer surface at $x = 0$. The equator corresponds to $z = 0$. Note that the vectors indicate positive flux, so vectors pointing away from the outer surface correspond to negative helicity leaving the sun in the northern hemisphere. Adapted from Brandenburg et al. (2005).

Brandenburg, A. 2005, *ApJ* 625, 539.
Brandenburg, A., & Sandin, C. 2004, *A&A* 427, 13.
Brandenburg, A., Haugen, N. E. L., Käpylä, P. J., & Sandin, C. 2005, *AN* 326, 174.
Shukurov, A., Sokoloff, D., Subramanian, K., & Brandenburg, A. 2006, *A&A* 448, L33.
Subramanian, K., & Brandenburg, A. 2006, *ApJ* 648, L71.
Vishniac, E. T., & Cho, J. 2001, *ApJ* 550, 752.