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The emergence and growth of the flux transport dynamo model of the sunspot cycle

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The flux transport dynamo model is the currently favoured theoretical model to explain the origin of the 11-year sunspot cycle.

Sunspot observations suggest the existence of a strong toroidal magnetic field underneath the Sun's surface. The basic idea of dynamo theory is that the poloidal and toroidal components of the magnetic field sustain each other through a feedback loop, giving rise to oscillations under some circumstances. The observational data of sunspots and the polar magnetic field of the Sun indeed show oscillations of this kind. It has been realized since the beginnings of MHD research that differential rotation can stretch out a poloidal field to produce a toroidal field. How the poloidal field gets generated back from the toroidal field remained a more contentious issue.

During the last few decades, helioseismology has mapped the angular velocity of the Sun, showing the existence of strong shear at the bottom of the solar convection zone. The toroidal field is expected to be produced there and then rises through the convection zone to produce bipolar sunspots at the solar surface, having a tilt caused by the Coriolis force[1]. The currently accepted mechanism for the generation of the poloidal field is the Babcock-Leighton mechanism in which the poloidal field arises from the decay of tilted bipolar sunspot pairs.

From the mid-1960s there has been evidence for a meridional circulation of the Sun which is poleward near the surface. Theoretical considerations suggested an equatorward return flow of this meridional circulation at the bottom of the convection zone, which is now confirmed by helioseismology. Such a meridional circulation is found to play a crucial role in the new type of solar dynamo model known as the flux transport dynamo model, of which the foundational paper was due to Choudhuri, Schüssler & Dikpati[2]. This model has three main ingredients: (i) the generation of the toroidal field by differential rotation, (ii) the generation of poloidal field by the Babcock-Leighton mechanism, and (iii) the transport of magnetic fluxes by the meridional circulation. Our group developed a code for solving this problem based on mean field equations[3]. This model has been very successful in explaining various periodic features of the 11-year sunspot cycle.

The sunspot cycle is only approximately periodic. Within the last few years, the flux transport dynamo model has been used for studying the irregularities of the sunspot cycle. Assuming that the fluctuation in the Babcock-Leighton mechanism is the primary source of irregularities, Choudhuri, Chatterjee & Jiang[4] developed a method for predicting future sunspot cycles. Their prediction of cycle 24 turned out to be the first successful dynamo-based prediction of a sunspot cycle. The fluctuation in the meridional circulation has now been identified as the second source of irregularities in the sunspot cycle. Combining these two kinds of fluctuations, it has been possible to model extreme events like the grand minima when sunspots may not appear for several cycles[5].

The periodic variation of the meridional circulation with the sunspot cycle has now been explained as arising out of the Lorentz force feedback of the dynamo-generated magnetic field[6].

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