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STEADY AND FLUCTUATING PARTS OF SUN'S INTERNAL MAGNETIC FIELD

M. H. GOKHALE and K. M. HIREMATH
Indian Institute of Astrophysics, Bangalore 560 034, India

ABSTRACT We have modeled the 'steady' part of sun's internal poloidal magnetic field in the form of a central dipole and a central hexapole with strengths $(0.6\pm0.1)B_oR_o^3$ and $(0.16\pm0.05)B_oR_o^5$ embedded in an asymptotically uniform field B_o. A small deviation from isorotation seems to indicate: (i) a slow build-up of toroidal field near the base of the convection zone and (ii) presence of torsional MHD perturbations in the outer radiative core, with latitudinal structure and time scales which may be similar to those of solar activity.

1. INTRODUCTION

In this paper we determine a likely configuration of an axi-symmetric poloidal magnetic field that can remain in a 'steady' state with the helio-seismologically determined internal rotation of the sun.

According to Cowling's theorem, the resistive and the inductive terms of this steady part of the real field must vanish separately. Thus the steady part of the internal field must be in isorotation (Ferraro 1937) with the steady part of the rotation of the plasma. This requires existence of functional relation between the 'observed' rotation rate $\Omega(\mathbf{r})$ at a point $\mathbf{r}$ and the flux function $\phi(\mathbf{r})$ of the 'steady' poloidal field.

2. METHOD

The relation between the rotation velocity $\Omega(r,\vartheta)$ and the magnetic flux due to the internal and external sources is assumed to be linear, so that :

$$\Omega(r,\vartheta)=\Omega_o+\Omega_1x^2\sin^2\vartheta+\Omega_2[(2\mu_1x^{-1}+4\mu_3x^{-3}+\ldots)\sin^2\vartheta + (-5\mu_3x^{-3}+\ldots)\sin^4\vartheta+\ldots] \quad (1)$$

where x is the distance from the center in the unit of the solar radius R_0, ϑ is the co-latitude, $\Omega_o, \Omega_1, \Omega_2$ are constants and μ_ℓ, ℓ=1,3,5,...are the strengths of the multipoles, in the standard expansion of the magnetic potential, in units of $B_o R_O^{\ell+2}$ where B_o is the asymptotically uniform field at large distances. Isorotation requires $\Omega_1 = \Omega_2$.

3. THE DATA USED

We use the rotation data from the internal rotation $\Omega(\mathbf{r})$,given by Christensen-Dalsgaard and Schou (1988). We determine the coefficients $\Omega_o, \Omega_1, \mu_1, \mu_3$, etc., by obtaining least square fits for successive combinations of terms in equation (1) using the data points in convective envelope (CE),outer radiative core (ORC) and combination of these data ('ORC+CE').

4. RESULTS AND CONCLUSION

The least squre fit to the 'observed' $\Omega(r,\vartheta)$ in 'CE' yields:

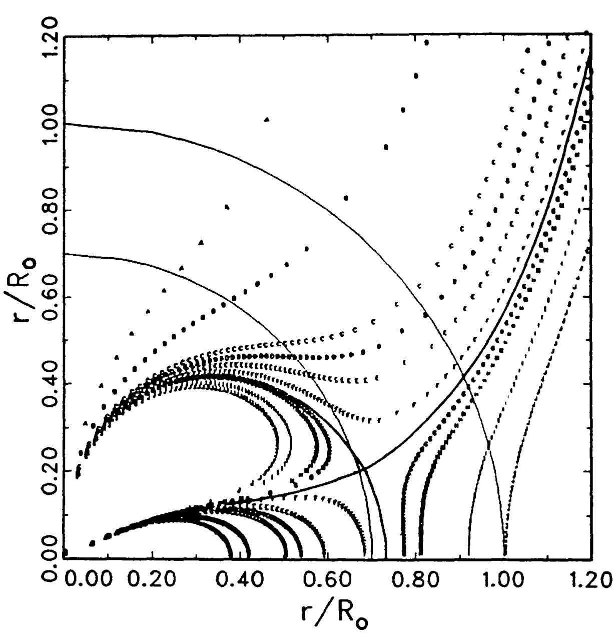

Fig. 1. Structure of the 'steady ' part of the poloidal field given by μ_1=0.6 and μ_3=0.16 in one quadrant of a meridian plane. The field lines A,...,J correspond to various flux values from 0.5 to 2.1 units. The continuous lines represent branches of the separatrix : ϕ = 1.84 units.

Ω_o=326±12 nHz/unit flux, Ω_1=Ω_2= 68±11 nHz/unit flux, μ_1=0.6±0.1 and μ_3=0.16±0.05 . The strength B_o cannot be determined from this fit itself, but can be independently estimated to be in the range of 10^{-4} - 1G.

The resulting field structure is shown in Fig. 1. Field directions will be relative to that of B_o which is presently unknown. Outer part of the structure will be deformed by several processes. The field structure also contains a separatrix. Revolution of its branch running pole-wards near the center, and along the inner boundary of 'CE' in low latitudes, gives the critical surface S_* , which rotates with angular velocity Ω_* =430 nHz. Inside S_* the rotation is 'rigid', with $\Omega(r,\vartheta) \approx \Omega_*$. However the fit in 'ORC+CE' indicates that near S_* it can be approximated by equation (1) with Ω_2=75 nHz/unit flux. The 'non-isorotation' due to the difference ~ 7 nHz/unit flux between Ω_1 and Ω_2 gives a time scale ~ 10^5 - 10^9 year for 'winding' of the poloidal field into a toroidal field B_T ~ 10^6G near S_* . The fit in 'ORC+CE' also yields a small μ_5, implying presence of time dependent torsional MHD perturbations, in ORC, with dominant term ℓ = 5. For these perturbations the non-isorotation near S_* yields 'periods' in the range ~ 1-100 year depending upon the ratio of perturbations in the toroidal and poloidal fields. It is known that in solar magnetic cycle the dominant term is ℓ = 5 (Gokhale, et. al 1992 ; Stenflo, J.O. 1988).

On long time scales, the field may also provide outward transport of angular momentum and magnetic flux.

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