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MHD window on the sun

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Abstract. Our recent studies of rotation and magnetic field near the Sun's surface have indicated that the solar activity may be originating in interference of global torsional MHD oscillations in the Sun. Using theory of dynamics and solar system ephemerides we have shown that these oscillations may be caused by a latitude-dependent inertial torque which couples the Sun's internal MHD to the solar system dynamics.

Key words: sun: interior - sun : activity - sun: magnetic field - solar system dynamics

1. Introduction

Helioseismology has made great strides in its acoustic branch. Global oscillations in the gravity mode are yet to be positively identified on the Sun. It may appear preposterous to talk about the MHD helioseismology based on measurements of temporal frequencies. However the studies reviewed here indicate that global MHD modes may be existing on the Sun and it may be possible to use the information on their latitudinal structures, relative amplitudes and phases (besides frequencies) for studying the flows and magnetic fields inside the Sun. Here I review our studies in this direction.

2. Possible existence of MHD modes and their properties

2.1. Emergence of toroidal magnetic flux out of the Sun as a result of superposition of global MHD oscillations

Invoking the laws of magnetic induction across a meridional section bounded by radii at any two latitudes, we have shown (Gokhale & Javaraiah 1995) that superposition of global 'MHD oscillations' (with non-zero perturbations in toroidal magnetic field) will lead to emergence of toroidal magnetic flux (<u>'tmf'</u>) out of the Sun at a rate (per unit latitude interval per unit time)

$$Q(\vartheta,t)=\sum_{l}\sum_{n}q_{l,n}P_l(cos\vartheta)sin(2\pi\nu_{l,n}t+\varphi_{l,n})$$

so that the amplitudes $b_{l,n}$ and the phases $\varphi_{l,n}$ of the LF terms in the MHD oscillations can be determined from the amplitudes $q_{l,n}$ and phases $\varphi_{l,n}$ of the LF terms in $Q(\vartheta,t)$ if the latter is determined observationally.

2.2 Latitudinal structure, frequencies, amplitudes and phases

We estimated the 'observed' rate of emergence of 'tmf' ('$Q(\vartheta,t)$'), per unit latitude interval per unit time, using sunspot data during 1874-1976 and laws of sunspot polarities.

Legendre-Fourier (LF) analysis of this rate $Q(\vartheta,t)$ has yielded the following information about the global MHD modes whose superposition could have led to the emergence of the 'tmf' which produced the sunspot activity (Gokhale et al, 1992).

(i) Legendre orders : $l = 1,3,5,..29..$, (maximum power at $l = 5 and 7$), *i.e.* same as those given by magnetogram data (Stenflo & Vogel 1986),

(ii) Temporal frequencies : $\nu = \nu_*$, $3\nu_*$, $5\nu_*$, etc., where $\nu_* = 1/21.4 \quad (\pm 1/103)\, yr^{-1}$, (*independent of l*, suggesting that the oscillations may be 'forced'),

(iii) b_l and φ_l are approximately constant in time, but *do undergo small* variations (causing cycle-to- cycle variations).

2.3 The reality of the suggested global MHD modes

Superposition of the computed LF terms not only reproduces the 'shapes' and 'sizes' of individual sunspot cycles and the behaviour of <u>strong</u> fields ($\geq 10^3$ Gauss) in the low latitudes ($0^o - 30^o$) ('butterfly diagrams') *as expected*, <u>but also predicts</u> the following observed behaviour of the field in the <u>middle</u> ($30^o - 60^o$) and the <u>high</u> ($60^o - 90^o$) <u>latitudes</u> :

(i) Occurence of <u>'weak fields'</u> (< 10 gauss) in the <u>middle latitudes</u>, and their <u>poleward</u> migrations,

(ii) Occurence of moderately strong fields (10-100 gauss) in <u>high latitudes</u> and their <u>poleward</u> migrations and

(iii) Reversal of polar fields at the right phase in the cycle.

This fact suggests that the LF terms obtained from the sunspot data represent <u>real</u> global MHD oscillations on the sun.

2.4 *The 'torsional ' nature of the MHD oscillations*

Presence of torsional oscillations on the Sun related to solar cycle was pointed out by Howard and Labonte (1980). Fourier analysis of the variation of the coefficient 'B' in the differential rotation, determined from the Greenwich sunspot data 1874-1976 (Javaraiah & Gokhale 1995), shows existence of torsional oscillations (of even l) having the following periodicities common with those of the 'MHD' modes detemined from the sunspot (/magnetogram) data :

$$43.0 \pm 10, \qquad 18.3 \pm 2.0, \qquad 8.5 \pm 1.0, \qquad 3.9 \pm 0.15 \qquad yr.$$

The common frequencies and the even latitudinal parity suggests that the solar MHD oscillations which produce solar activity, may essentially be "torsional MHD oscillations" ("TMO"s).

3. The energetics

Correlations between the total measure of sunspot activity during a given cycle and the phase shifts of the dominant MHD terms during the previous one or two cycles show that the measure of solar activity also gives a measure of the energy 'lost' by the 'TMO's in the form of the 'tmf' that leaves the Sun (Gokhale & Javaraiah, 1995).

4. Possibility of existence of a suitable steady field

Modeling of the 'steady' parts of the Sun's internal magnetic field and rotation (Hiremath & Gokhale, 1994) has indicated that a poloidal field (possibly of primordial origin) could be threading through the whole Sun, (*and merging with the interstellar field at large distances*), which admits 'TMO's in the Sun with odd parity in B_φ (mainly $l \doteq 5$) . Observationally the existence of such a field can neither be proved, nor ruled out at present.

5. Excitation and Maintenance

Here we summarize our latest results regarding the excitation of torsional waves in the Sun which are related to solar magnetic activity cycle (Gokhale, Javaraiah & Vasundhara, 1995).

Using the law of conservation of angular momentum and the solar system ephemerides (Bretagnon & Simon 1986) we have recently shown that the Sun's spin angular momentum L_{spin} varies with rms magnitude $\sim 10^{46}\ gm \quad cm^2 \quad s^{-1}$ such that the mean angular velocity $< \omega >$ of the solar rotation varies with rms magnitude $\sim$ 4 nHz. This causes a latitude-dependent inertial torque T_{inert} in the Sun which is approximately equal to T_{spin}, the rate of change of L_{spin}. This T_{spin} varies with most of the fourier power distributed around the conjunction frequencies of planetary pairs as follows (in arbitrary unit) : $\sim$ 2.7 at ω_{JS}, $\sim$ 0.5 at ω_{JU} and ω_{JN} together, $\sim$ 0.03 at ω_{SU}, and $\sim$ 0.02 at ω_{SN}, where the each subscript represents the planetary pair indicated by the letters. The rms value of T_{spin} , and hence of T_{inert} , is $\sim 10^{39}$ dyne cm. This is strong enough to force global torsional MHD waves of similar frequencies in the Sun.

Observational support for this theory comes from the fact that the Fourier power in ('$Q(\vartheta,t)$') is also distributed mainly around the frequencies ω_{JS}, ω_{JU}, ω_{JN}, ω_{SU}, ω_{SN} and ω_{UN}, with most (but not all) of the power in ω_{JS}.

The rate of work done by the inertial torque T_{inert} and the total gravitational energy of the solar system are adequate to maintain the solar activity at the observed rate of $\sim 10^{30} - 10^{31}$ erg s^{-1} throughout the Sun's life on the main sequence.

6. Conclusion

The above studies can be considered as pointing to a small MHD window on the magnetic field and rotation inside the Sun.

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