LONG-TERM COHERENT PERIODICITIES IN THE MEAN MAGNETIC FIELD OF THE SUN

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To investigate periodic variations of the magnetic field of the Sun as a star (SMMF; see Severny, 1969) we have used the mean field measurements made in Crimea, Mt. Wilson, and Stanford observatories; in total $N = 5783$ daily values were available for the time interval 1968 - 1981. In essence, these data offer a unique possibility to study the Sun as a variable magnetic star (Scherrer et al., 1977).

To combine the three data sets into a single time series we corrected the original measurements of each observatory for the systematic calibration error applying correction factors determined via inter-comparison of the three individual power spectra:

$$a(\text{Cr.}) = 0.77, \quad a(\text{M.W.}) = 0.94, \quad a(\text{St.}) = 1.57.$$

Then the common harmonic amplitude (A) spectrum was computed with the use of a simple least-squares technique to find the Fourier coefficients.

The power spectrum of the SMMF (Figure 1) exhibits a set of discrete lines within the range of (synodic) periods 27 to 29 d. Along with 5 dominant peaks: $P = 26.95$, 27.18, 27.34, 27.87, and 28.15 ($\pm$ 0.08) d, there exist also several reliable peaks corresponding to fast rotating ($P = 26.35$ and 26.60 d) and slow rotating, higher-latitude structures (periods up to 30.00 d).

The signature of the discrete character of the SMMF spectrum is reinforced by the fact that almost all dominant peaks of the SMMF are well reproduced in the changes of the polarity of the interplanetary magnetic field (IMF, 1926 - 1981; in all 20332 daily values of the polarity (+ 1, - 1, or 0) were used in the analysis). The latter data were taken from Svalgaard (1972) and Mansurov et al. (1978) supplemented with new data now available from in situ measurements in space. A similar data set was used earlier by Svalgaard and Wilcox (1975) for the analysis of the long term evolution of the solar sector structure.

J. O. Stenflo (ed.), Solar and Magnetic Fields: Origins and Coronal Effects, 23–27.

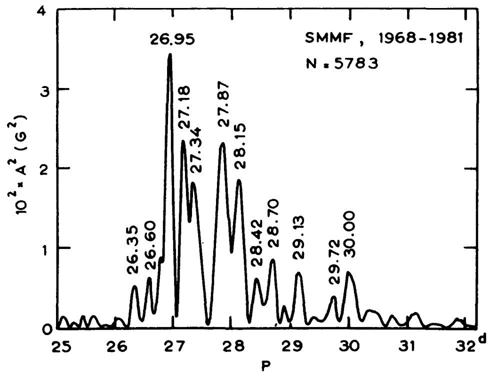

Figure 1. Power spectrum of the mean solar magnetic field.

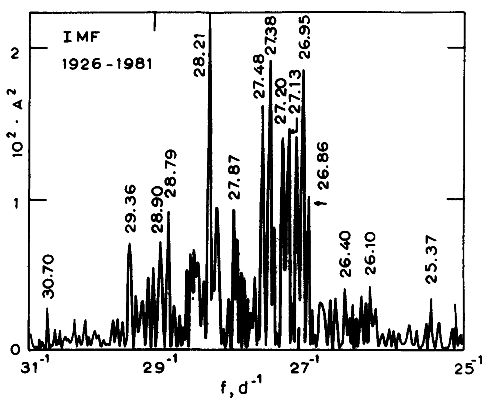

Figure 2. Power spectrum of the IMF polarity.

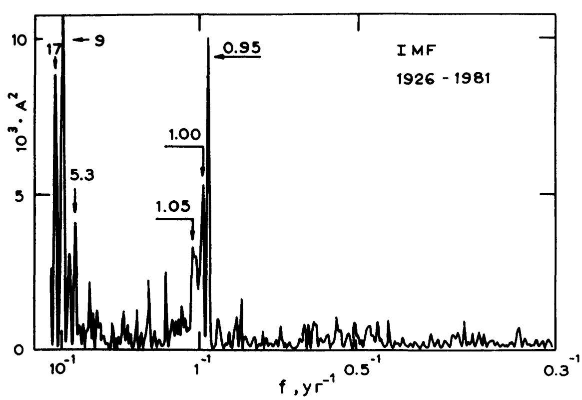

Figure 3. The low-frequency portion of the IMF spectrum.

https://doi.org/10.1017/S0074180900029685 Published online by Cambridge University Press

The complete spectrum of the IMF polarity was computed in 0.11 nanoHz steps from 1.17 to 463 nanoHz, i.e. from 25 d to 27 yr in periods. A small part of the spectrum is shown in Figure 2 where we find nearly the same dominant periods as in the case of the SMMF: 26.95, 27.20, 27.38, and 28.21 (± 0.01) d, with addition of a few more peaks caused by splitting and possible phase-amplitude modulation of the IMF.

The detailed analysis (Kotov and Levitsky, 1982) has shown that the discrete character of the SMMF and IMF spectra cannot be ascribed to a sampling effect or modulation by the 11 yr cycle. The high confidence level of all peaks dominating both spectra (the ratio $2A/\sigma \approx 7$ to 11) rules out also the statistics as explaining the origin of the discrete lines.

It therefore appears that the mean field tends to be surprisingly stable at definite periods of solar rotation retaining the phase-coherency over 14 to 56 yr irrespective of the phase of the 11 yr cycle. This suggests a significant stratification of the long-lived magnetic structures in the solar atmosphere; the picture resembles the latitude stratification clearly seen, e.g., in the Jovian atmosphere. This solar discrete pattern might be directly related to the alternating latitude zones of slow and fast rotation found recently in Doppler measurements by LaBonte and Howard (1982). The mechanism involved to ensure the long-term phase-coherency of the field at some favourable latitudes seems to be a challenging problem for the theory of the solar magnetic field generation and evolution.

In the lower frequency portion of the IMF spectrum (Figure 3) the strongest peaks correspond to the triplet 0.95, 1.00, 1.05 (± 0.01) yr, which is produced mainly by the Rosenberg and Coleman's (1969) effect in the predominant IMF polarity, and 9 (± 0.4) and 17 (± 1) yr. The nature of the two latter peaks is not yet known due to their poor statistical significance.

The power spectrum of the SMMF (not shown here) computed for the period range 0.1 to 6 yr has the highest peak at exactly 1.00 (± 0.02) yr. The superposed epoch plot of the SMMF strength (H) for this period (Figure 4) indicates a remarkable annual modulation with an amplitude of about 0.1 G ($2A/\sigma \approx 6.5$). It was shown previously (Kotov et al., 1981) that this annual wave can be explained neither by instrumental effects and data processing nor by the annual change of the Earth's heliographic latitude. We suppose that some asymmetry of the Sun's global magnetic field in inertial space (with respect to the stars) might be responsible for the appearance of this variation as observed from the Earth orbiting the Sun.

The authors gratefully acknowledge valuable discussions with A.B. Severny and would like to thank also R. Howard, J.M. Wilcox, and

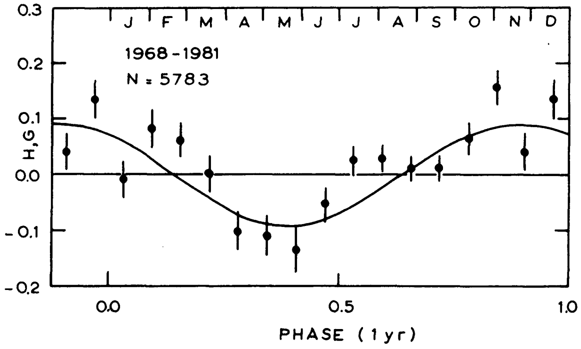

Figure 4. The annual variation of the SMMF. The solid line is the best fitted sinusoid; the vertical bars show double rms errors (± σ). The phase is defined to be 0 at 0 UT on 1968 January 1.

P.H. Scherrer for useful comments and for communicating to us their observations of the SMMF prior to publication.

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DISCUSSION

LIVINGSTON: No doubt all of us view a solar periodicity of one year with suspicion. Recently, however, other evidence of annual periods have been found in the full disk Ca K data, namely in the Wilson-Bappu parameter and in the equivalent widths of photospheric lines. Also P. Simon, Meudon, has pointed out that the quiet sun component of the 10 cm radio flux can exhibit a one year period. So it may be that we are discovering here a new component of solar variability.

KUKLIN: I have a comment on the interpretation of the discrete spectrum of the oscillations. One can show that a triplet near 27.2 days may be explained as an amplitude-frequency modulation of the basic harmonic by an oscillation with 9 yr period, and a doublet near 28.3 days may be explained as a frequency modulation with 17.6 yr period. Therefore in the first case the background fields rotating rigidly change during the 11 yr cycle, and in the second case the magnetic fields of active regions are modulated during a magnetic cycle (Hale cycle).

KOTOV: The influence of long-term modulations by 9–22 yr cycles on the 27–29 day variations seems to be a rather complicated problem. For instance, if we attempt to ascribe several discrete lines to a certain phase-amplitude modulation, the question arises why there are no other discrete lines which would be produced by the modulation. In addition, the existence of almost the same discrete lines in the spectrum of the solar mean field data covering only 14 yr does not favour this explanation. However, I agree that there may be other reasonable sources of the spectral pattern observed, besides the latitude-zone hypothesis.

FOING: (1) Can the described data of the solar and interplanetary magnetic fields be used to derive a quantitative topology of the field from the sun to earth? (2) Why is the one year period privileged? Is there an offset in period due to the proper motion of the field lines rooted in the sun's surface?

KOTOV: (1) There is a good correlation between the sector structures observed in the SMMF and IMF polarity patterns. The topology of the heliospheric current sheet and, therefore, of the sector structure, computed on the basis of the observed photospheric field, agrees well with the IMF polarity observed at Earth, during about 80% of the days (cf. papers by Severny, Wilcox, and many others). (2) I think that the nature of an annual variation in the SMMF is still open to discussion. The effect of possible proper motion of the field lines in the photosphere, if any, is perhaps rather small and within the error of the period determination. The exact value of the period in the SMMF is (1.00 ± 0.02) yr.

https://doi.org/10.1017/S0074180900029685 Published online by Cambridge University Press