ΠΡΑΚΤΙΚΑ ΤΗΣ ΑΚΑΔΗΜΙΑΣ ΑΘΗΝΩΝ

ΣΥΝΕΔΡΙΑ ΤΗΣ 28ΗΣ ΑΠΡΙΛΙΟΥ 1988

ΠΡΟΕΔΡΙΑ ΓΕΩΡΓΙΟΥ ΜΕΡΙΚΑ

ΑΣΤΡΟΝΟΜΙΑ.– **Sector Boundaries of the Heliospheric Current Sheet at 1 AU During the Last Solar Maximum,** *by V. P. Tritakis and H. Mavromichalaki**, διὰ τοῦ Ἀκαδημαϊκοῦ κ. *Ἰωάννου Ξανθάκη*.

ABSTRACT

Thirty eight cases of sector boundary passages of the heliospheric current sheet by the earth have been compiled by the interplanetary magnetic field data which have been collected by the ISEE-3 spacecraft.

The analysis of these data has shown that the (+, —) sector boundaries within the solar rotation have almost the same distribution with those collected in the maxima of the solar cycles No. 18, 19, 20. In contrast, the frequency distributions of the (—, +) sector boundaries collected during the last and the previous solar maxima are quite different.

The particular behaviour of the (—, +) sector boundaries in the last solar maximum epoch in relation to the previous maxima imply a longitudinal relocation of the heliospheric Current Sheet.

This effect has been probably induced by a solar activity reorganization which has been determined to take place in each 22-year solar cycle.

1. INTRODUCTION

The sector structure of the interplanetary magnetic field (IMF) is probably one of the most impressive discoveries of the satellite era. Nowadays it is widely admitted that the sector structure of the IMF is formulated by

* Β. Π. ΤΡΙΤΑΚΗ καὶ Ε. ΜΑΥΡΟΜΙΧΑΛΑΚΗ, **Ὁριακὲς ἐπιφάνειες τοῦ ἡλιοσφαιρικοῦ ρευματοφλοιοῦ κατὰ τὴν διάρκεια τοῦ τελευταίου μέγιστου τῆς ἡλιακῆς δραστηριότητος (1979-1980).**

a large-scale heliospheric current sheet (HCS), similar to a thick tangential discontinuity, which stays quasi-sinusoidally on both sides of the solar equator and corotates with the sun separating in this way the interplanetary medium in 2-4 sectors. The IMF direction within each sector is uniqly «away» from or «toward« to the sun while in successive sectors the field direction is opposite (Schultz, 1973; Wilcox et al. 1980a).

Intersections of the HCS with the earth's orbit on the ecliptic plane, which have been detected as abrupt changes of the IMF direction by 180° have been referred to as sector boundaries. Systematic investigation of the last twenty years have pointed out that sector boundaries of the HCS play an important role in geosciences and space physics because they have been found to correlate with several solar, interplanetary and atmospheric phenomena. At the beginning, the solar activity seems to control significantly the number of boundaries they appear per solar rotation as well as certain days of the rotation where the boundaries mainly prefer to occur.

A detailed analysis of observed and high-accuracy inferred IMF data covering the period 1957-1975 (cycles No. 19-20) have pointed out that a two-sector structure is prominent during the extrema of the solar cycles but a four-sector structure predominates during the intermediate years, especially in the descending branch of each 11-year cycle. In addition, sector boundaries seem to occur in selected days of the solar rotation. Actually in the epoches of the extrema (+, −) boundaries, namely boundaries where the IMF direction is away from and toward to the sun in front and behind of it respectively, occur mainly around the 11th day of the solar rotation while (−, +) boundaries prefer to concentrate in the two edges of the rotation. In contrast sector boundary occurences during the descending branch of the solar cycle is a rather complicated case though an average four sector structure is finally formed (Tritakis, 1979; Balthasar and Schüssler, 1983).

Relationships between sector boundaries and solar flares have been reported by Dittmer (1975) and Henning et al. (1985) while a close relation with the green coronal line intensity has been described by Antonucci (1974). Indications for sector boundary relations with atmospheric parameters have been mentioned by Shapiro (1976), Wilcox (1980b) and Tritakis (1984a) while Akasofu (1981) has described the coexistance of the HCS passage with major geomagnetic storms. Finally significant indications that the HCS affects seriously the low energy particles propagation in the interplanetary medium have been also announced (Svestka, 1968; Tritakis, 1984b).

It is evident that the various correlations between sector boundaries and a great number of solar, interplanetary and atmospheric parameters underline the great importance of the whole HCS pattern for the geosciences and the space physics. Therefore the main intention of this report is to emphasize that the heliospheric current sheet behaviour during the last solar maximum is compatible to that of previous solar maxima. In addition we have the chance to elongate the sector boundary list with additional well defined cases contributing in this way to a more detailed study of the relations between the IMF and various geophysical phenomena.

2. DATA REDUCTION

Sector boundaries of the HCS have been detected by the data which have been collected by the ISEE-3 spacecraft from September 1978 to January 1980. This spacecraft was launched in August 1978 into a so far halo orbit around the so-called Langrange or libration point (L1) between the sun and the earth where the heliocentric motion of the spacecraft remains in dynamic equilibrium with the gravitational forces of the sun and the earth. In any case the spacecraft stays in front of the earth towards the sun which is an excellent position for observing travelling interplanetry phenomena in response to various events of the terrestrial environment.

Sector boundary passages of the HCS by the earth are mainly manifested by abrupt or gradual changes depending on the thickness of the boundary and the HCS inclination to the ecliptic of the longitudinal angle of the magnetic field vector by 180°. All measurements are referred to the orthogonal earth-centered GSE coordinates system that has its x-axis towards the Sun the z-axis towards the North ecliptic pole and the y-axis completes a right-handed system.

The predominant longitudinal angle of the magnetic field vector within positive or «away» and negative or «toward» magnetic sectors for the time under consideration was about 300° and 120° respectively.

The first Atlas of interplanetary sector structure has been edited by Svalgaard (1976) who has also introduced the basic rules of data reduction. According to his techniques he was starting by determing or inferring the sector polarity of each day. Field reversals manifested by a sector polarity change were classified as sector boundaries when the sector polarity was the same for at least four days before the reversal and it was remaining reversed for four days after the reversal. Large scale sector structure and finer scale filaments and reversals could be distinguished by this technique. Since a sector boundary occurence was detected on the basis of a daily IMF polarity determination it was obvious that the exact time of a boundary passage was undefinable. Moreover the use of data from deep space probes introduced errors in the definition of the day of a boundary passage. The reason was that data collected by deep space probes far from the earth should be corrected by timing so that to correspond to near-earth observations. This transformation has been made under the assumption that the solar wind velocity is uniform and radial fact which is rarely valid.

In our case, the ISEE-3 position on the Sun-earth line implies that a timing correction of the data is not necessary while sector boundaries detection at near-earth conditions is easy and trustful.

From detailed measurements of the IMF parameters, especially longitudinal and elevation angles of the IMF vector, for the last 140 days of 1978 (No, of day 226-365). We have tabulated fourteen sector boundary cases. On the other hand twenty four more cases have been collected for 1979 (table I). The nature of the IMF reversals which have been detected to connect with sector boundary passings vary greatly from one reversal to the next. In some cases a field reversal takes place within a minute whereas at other times the field direction changes gradually or in a turbulent way over many hours.

In our effort to define the time of a sector boundary passage we have entered in table I the universal time when the field reversal manifested by a 180^0 change of the longitudinal angle took place with a half an hour approximation. When the IMF is turbulent and the field reversal takes time the passing time entered in the table I expresses the gradual commencement of the field reversal.

TABLE I

Sector Boundary passages of the IMF from September 1978 to the end of 1979.

	DAY NO.	BARTELS DAY NO.	APPROX TIME U.T.	SIGN.
1978	226	27	20	+/—
	237	11	12	—/+
	255	2	20	+/—
	264	11	12	—/+
	267	14	16	+/—
	270	17	16	—/+
	282	2	21	+/—
	292	12	02	—/+
	311	4	20	+/—
	318	11	12	—/+
	328	21	20	+/—
	337	3	02	+/—
	349	15	02	—/+
	362	1	02	+/—
1979	12	16	22	—/+
	24	1	23	+/—
	42	19	04	—/+
	54	4	14.30	+/—
	69	19	23	—/+
	82	5	08	+/—
	99	22	12	—/+
	111	7	20	+/—
	125	21	16	—/+
	138	7	09	+/—
	157	26	10	—/+
	166	8	07	+/—
	184	26	04	—/+
	193	8	02	—/+
	210	25	08	—/+
	222	10	19	+/—
	237	25	21	—/+
	251	12	20	+/—
	264	25	03	—/+
	277	11	10	+/—
	280	14	20	—/+
	286	20	03	+/—
	293	27	05	—/+
	336	16	16	+/—

Data gaps exist between the days No. 305-330 and 337-365 of 1979.

3. DISCUSSION

The entries of the table I concern to thirty eight sector boundary cases detected during 505 days of observations near the last solar maximum, namely from the day No. 226 of 1978 to the day No. 365 of 1979. Since the time of observation consists of 505:27≈18,7 Bartels rotations, there is an average of 38 sect. bound.: 18,7 Bart. rot.≈2 sec. bound/Bart. rot. which confirms previous conclusions that during the solar maxima a two-sector pattern predominates (Tritakis, 1979).

In the figure 1 the frequency distribution of the (+,—) and the (—,+) sector boundaries within various Bartels days is depicted. From this histogram it is evident some preference of the sector boundaries to occur in certain days of the Bartels rotation. Actually the highest peaks of the (+,—) boundary cases occur during the 11th and the 25th Bartels days (figure 1, low panel) whereas the most of the (—,+) boundary cases are concentrated between the 1st and the 8th Bartels days (figure 1, upper panel).

The particular behaviour of the sector boundaries to occur within selective days of the solar rotation formulating two sector structures has been also detected during the solar maxima of all the previous solar cycles where valid IMF data are available.

In the figure 2 we have presented the frequency distribution of sector boundary cases which have been occured during the maxima of the cycles No. 18, 19, 20, High and statistically significant peaks of (+,—) and (—,+) boundary cases are obvious in the 11th and 27th Bartels days of the low panel and around the 20th day of the upper panel, respectively.

Similar conclusions have been also derived from inferred IMF data which have been compiled during the solar cycles No. 16-17. Althought the quality of these data is rather low we could risk the implication that sector boundary occurences within selective Bartels days is consistent to a systematic phenomenon which extends over several solar cycles (Xanthakis et al. 1981).

From the figures 1 and 2 it is clear that the (+,—) boundary cases of the last solar maximum (figure 1, low panel) show the same more or less behaviour with the (+,—) boundaries they occured in the maxima of the three previous solar cycles (figure 2, low panel). In both cases the boundaries prefer to occur mainly during the 11th and between 25th-27th Bartels days. This is a strong evidence that both the (+,—) boundaries detected by the ISEE-3 spacecraft during the last solar maximum and those detected during the maxima of the cycles No. 18-20 belong to the same statistical population of data.

On the other hand a significant change of the (—, +) boundaries behaviour in the last solar maximum is evident in the figures 1 and 2. These boundaries during the maxima of the cycles No. 18-20 have preferred to occur mainly around the 20th Bartels day but during the last solar maximum this peak has shifted to the beginning of the solar rotation especially in the days 1^{st}-2^{d}, 4^{th}, 7^{th}-8^{th}.

This particular distribution of the (—, +) boundaries during the last solar maximum implies a longitudinal relocation of the HCS which could be interpreted by a solar activity redistribution between the solar hemispheres. Actually a solar activity transfer from the Northwest to the Southwest solar quarter has been detected since 1972 where a polarity inversion of the solar magnetic field took place and a new 22-year solar magnetic cycle started (Tritakis et al. 1986).

The establishment of the highest solar activity in the Southwest solar quarter during the current 22-year cycle (1971-1993) perhaps relates to the (—, +) boundary longitudinal relocation expressed by the shifting of the peak of the (—, +) cases from the end to the beginning of the solar rotation. In essence, the tendency of the sector boundaries to occur within selective days of the solar rotation implies a close correspondance between boundaries and «active» solar longitudes on which these boundaries are firmly rooted. In this case we can not talk about recurrency but about a kind of «solar memory» for preferred longitudes of activity extending probably over two 11-year cycles or one magnetic 22-year cycle (Balthasar and Schüssler, 1983).

The undoubtful effect of sector boundary occurences namely HCS passages by the earth, in certain Bartels days deserves a further and detailed Study because it can lead to significant conclusions about the HCS configuration as well as to relations between the IMF and several geophysical phenomena.

ACKNOWLEDGMENTS

The author expresses his gratitude to Dr E. J. Smith as well as the cosmic ray group of the Space Research Laboratory at Utrecht, The Netherlands, especially Drs. Jan van Rooijen and Gerard Stevens, for providing ISEE-3 magnetometer data.

REFERENCES

1. Akasofu S. I., Sol. Phys. **71**, 175, 1981.
2. Antonucci E., Sol. Phys. **34**, 471, 1974.
3. Balthasar H., and Schüssler, Sol. Phys. **87**, **23**, 1983.
4. Dittmer, P. H., Sol. Phys. **41**, 227, 1975.
5. Henning H. M., Scherrer P. H., and Hoeksema J. T., CSSAASTRO-85-17, Stanford University (Preprint), 1985.
6. Schulz M., Astrophys. Space Sci. **24**, 371, 1973.
7. Shapiro R., J. Atmosp. Sci. **33**, 865, 1976.
8. Svalgaard L., SUIPR Report No. **648** Stanford University, 1976.
9. Svestka Z., Sol. Phys. **4**, 361, 1968.
10. Tritakis V., Sol. Phys. **63**, 207, 1979.
11. Tritakis V. J., Geophys. Res. **89**, 2609, 1984a.
12. Tritakis V., Adv. Space Res. **4**, 323, 1984b.
13. Tritakis V., Mavromichalaki H., and Petropoulos B., Sol. Phys. **115**, 367, 1988.
14. Wilcox J. M., Hoeksema J. T., and Scherrer P. H., Science, **209**, 603, 1980a.
15. Wilcox J. M., SUIPR No. **818**, Stanford University, 1980b.
16. Xanthakis J., Tritakis V., and Zerefos D. H., J. interdiscipl. Cycle Res. **12**, 205, 1981.

APPENDIX

The statistical significance of predominant distribution peaks has been extensively discussed in the section 4 of a previous paper (Tritakis, 1984). According to that analysis prominent distribution peaks which do not relate to any known physical mechanism must be checked under a more stringent criterion than a 2 or 3 sigma deviation. First, we assume as a «null» hypothesis continuum the mean μ given by the relation

$$\mu = N.p \qquad (1)$$

Where N is the sample size and p the probability of a certain case occuring in a specific bin.

The statictic associated with each bin of a distribution, on the basis of which the statistical significance of the deviation of a peak from the «null» continuum can be determined, is the ratio of the magnitude of the peak under consideration to the continuum. This ratio has been found to follow an

x^2/v distribution, where V the degrees of freedom of each bin given by the relation

$$V = \frac{2N - m/2}{m} \qquad (2)$$

Where m is the maximum lag in time units.

In case we want to test the significance of a prominent distribution peak at a 95% confidence limit, we check the ratio of the maximum peak to the continuum peak/cont. against a percentage against a percentage point of the x^2/v distribution, that is appropriately higher than the 95% confidence limit. If the desired percentage point for the test is Pt, then the appropriate percentage point Pd of the x^2/v distribution is given approximately by the relation

$$Pd = \frac{100m + Pt}{m+1} \qquad (3)$$

Thus, when we want to test the peaks of the figure 2 for Pt=95% our peaks must satisfy the Pd confidence limit in the x^2/v distribution which in our case is

$$Pd = \frac{27 \times 100 + 95}{28} = 99{,}82\%$$

The results of this test applied for the prominent peaks of the figure 2 have been tabulated in table II.

From this table it is clear that

$$\frac{\text{Peak}}{\text{Cont.}} > \frac{x^2}{v}$$

namely, both of the prominent peaks of the figure 2 are statistically significant, at least at a 0.05 confidence level.

TABLE II

Statistics evaluating the distribution peaks of the figure 2.

Figure 2	N	μ	ν	x^2/v	Peak / Cont.
Low Panel	92	3,4	6,3	3,17	3,24
Upper Panel	97	3,6	6,7	2,76	2,78

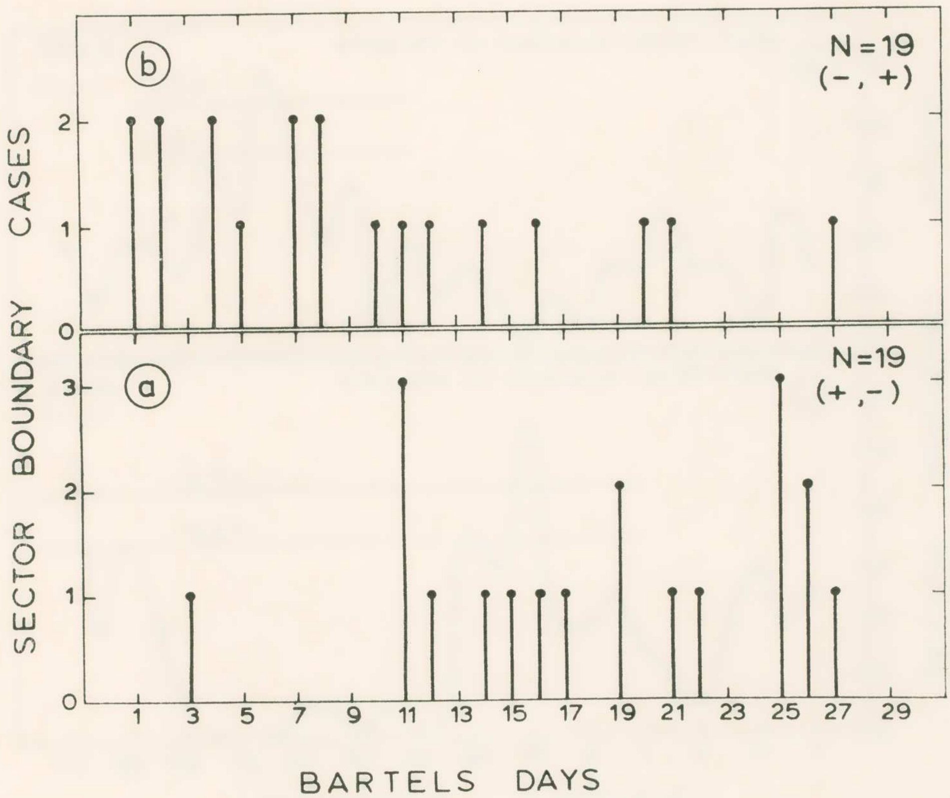

Figure 1. Frequency distribution within Bartels rotation of the (+, —) (low panel) and the (—, +) (upper panel) sector boundary passages detected by the ISEE-3 spacecraft from September 1978 to the end of 1979.

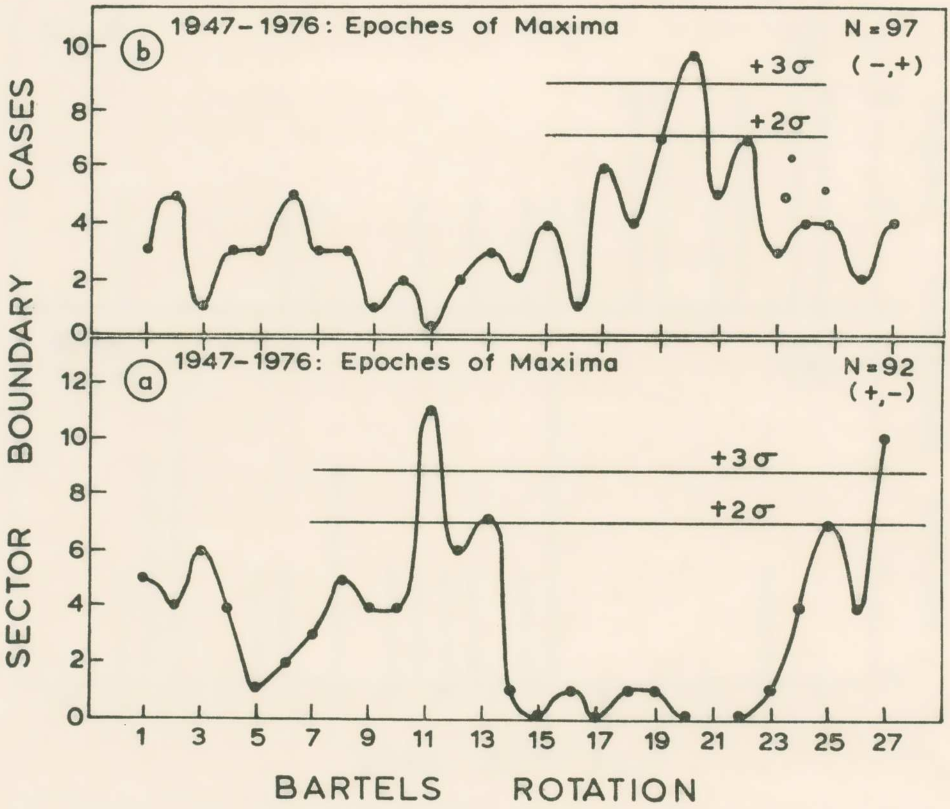

Figure 2. Frequency distribution within Bartels rotation of the (+, —) (low panel) and the —,+) (upper panel) sector boundary passages detected in the epoches of maxima of the solar cycles No. 18-20 (1944-1976). The statistical confidence levels 0.05 (2σ) and 0.01 (3σ) have been defined in both panels of this figure.

ΠΕΡΙΛΗΨΗ

Ὁριακὲς ἐπιφάνειες τοῦ ἡλιοσφαιρικοῦ ρευματοφλοιοῦ κατὰ τὴν διάρκεια τοῦ τελευταίου μέγιστου τῆς ἡλιακῆς δραστηριότητος (1979-1980).

Στὴν μελέτη αὐτὴ παρουσιάζονται τριάντα ὀχτὼ περιπτώσεις ὁριακῶν ἐπιφανειῶν τοῦ ἡλιοσφαιρικοῦ ρευματοφλοιοῦ ποὺ ἀνιχνεύτηκαν ἀπὸ τὸν δορυφόρο ISEE-3 στὸ σημεῖο Langange L1, δηλαδὴ στὸ σημεῖο ἰσορροπίας μεταξὺ ἡλίου-γῆς, ἀπὸ τὸν Σεπτέμβριο 1978 ἕως καὶ τὸν Ἰανουάριο 1980.

Ἡ μελέτη τῶν παρατηρήσεων αὐτῶν ἔδειξε ὅτι οἱ ὁριακὲς ἐπιφάνειες (—,+) ἔχουν τὴν τάση νὰ παρουσιάζονται κατὰ τὶς πρῶτες ἡμέρες τῆς ἡλιακῆς περιστροφῆς Bartels, ἐνῶ οἱ ὁριακὲς ἐπιφάνειες (+,—) παρουσιάζονται σὲ ἐπιλεγμένες ἡμέρες τῆς ἡλιακῆς περιστροφῆς ὅπως ἡ 11η, ἡ 19η καὶ ἡ 25-26. Ἐπιπλέον ἡ κατανομὴ συχνότητος τῶν ὁριακῶν ἐπιφανειῶν (+,—) εἶναι περίπου ὅμοια μὲ ἐκείνη ποὺ παρατηρήθηκε στὶς ἐποχὲς τῶν μεγίστων τῶν ἡλιακῶν κύκλων No. 18, 19, 20, ἐνῶ ἡ κατανομὴ συχνότητος τῶν ἐπιφανειῶν (—,+) διαφέρει σημαντικὰ ἐκείνης τῶν μεγίστων τῶν προηγουμένων κύκλων.

Ἡ ἰδιόρρυθμη αὐτὴ συμπεριφορὰ τῶν ὁριακῶν ἐπιφανειῶν (—,+) ποὺ παρατηρήθηκε στὸ ἡλιακὸ μέγιστο 1979-1980 ὀφείλεται πιθανότατα σὲ ἀναδιάταξη τοῦ ἡλιοσφαιρικοῦ ρευματοφλοιοῦ κατὰ μῆκος τοῦ ἡλιακοῦ ἰσημερινοῦ, πράγμα ποὺ εἶναι πολὺ πιθανὸ νὰ ὀφείλεται σὲ ἀναδιάταξη τῆς ἡλιακῆς δραστηριότητος.

Τέτοιες ἀναδιατάξεις φαίνεται ὅτι πραγματοποιοῦνται κατὰ τὴν ἔναρξη κάθε μαγνητικοῦ ἡλιακοῦ κύκλου 22 ἐτῶν.