INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
CABLE: CENTRATOM - TELEX 460392-1

H4.SMR.203 - 8

" SPRING COLLEGE ON GEOMAGNETISM AND AERONOMY "

( 2 - 27 March 1987 )

" Sector structure interplanetary magnetic field and geomagnetic field changes at low latitudes "

presented by :

G.K. Rangarajan
Indian Institue of Geomagnetism
Dr. Nanabhoy Moos Road
Colaba
Bombay 400 005
India





# SECTOR STRUCTURE INTERPLANETARY MAGNETIC FIELD AND GEOMAGNETIC FIELD CHANGES AT LOW LATITUDES

G. K. Rangarajan

Indian Institute of Geomagnetism, Bombay

## Introduction

It is now well known that the supersonic solar wind drags with it the embedded solar magnetic field. Wilcox and Ness (1965) discovered that Interplanetary Magnetic Field (IMF) was a well-organised entity with the field direction predominantly toward or away from the Sun lasting for several days. This dominant direction is a large scale feature defining the sector structure of the IMF and is different from the small scale changes. The IMF orientation is best organised in the Geocentric Solar Equatorial (GSEQ) coordinate system in which the X axis is the Earth-Sun line, Z axis is parallel to the solar rotation axis and the Y axis completes the right-handed system. The angle of IMF measured from X axis should correspond to either 135° (away) or 315° (toward) as the IMF lies usually along the Archemedian spiral close to 1 AU . Explorer 33 and 35 data indicated that the predicted angle is the most frequent. The interaction of the IMF with the magnetosphere, however, is ordered better in the Geocentric Solar Magnetosphere (GSM) coordinate system. In GSM, the X axis is unaltered, but the Z axis lies in the plane containing X axis and the dipole axis of the earth, Y axis completing again the right handed system. The interaction, therefore, will have both Universal Time and seasonal dependence.

If spacecraft measurements are the only source of the IMF parameters, data gaps will exist whenever they are inside the magnetosphere. But if the IMF interaction with geomagnetic field could be used as a predictor, these data gaps can be easily filled. Almost simultaneously Svalgaard (1968) and Mansurov & Mansurova (1969) discovered that the diurnal variation of the vertical component in the polar cap region responded in a highly systematic manner to the polarity of IMF. Superposed on the normal variation, for a few hours near magnetic local noon, the Z variations showed deviations on either side of the mean depending on the IMF polarity. In an 'away' sector, the deviation is negative (positive) in the northern (southern) polar cap and vice-versa for the 'toward' sector. Close to the polar cap boundary, the H component reveals the signature. It has been shown (Kawasaki et al 1973) that the polar cap field is sensitive to IMF even at much shorter time scales (10-20 minutes). Subsequently, Friis-Christenten et al (1972) showed that the polar cap variation are better related to the azimuthal or East-West component (By) of IMF rather than the polarity (Bx) and that when the IMF is along the Archemedian spiral, azimuthal component in one direction, corresponds to a given polarity of IMF.

As surface magnetic field records date back sufficiently in time, the polarity of IMF could be inferred using H magnetograms of Godhavn from 1926 (Svalgaard 1972). The accuracy inference increased substantially when polar cap stations in either hemisphere are utilised ( ~80%) and is an adequate substitute for 'in situ' observations for statistical purposes (Russell et al 1975). Inferred polarity



of IMF is regularly published in prompt reports of "Solar Geophysical Data" and are extensively used.

The sector structure of the IMF, with its origin in the Sun, corotates with the Sun so that a sector boundary, separating the two polarities, sweeps past the earth every 27 days. When arranged in Bartels' solar rotation, the pattern of polarity reveals that it is either 2 sectors or 4 sectors per solar rotation. The rotation period changes with solar cycle. The sector structure has been related to the dipolar solar magnetic field and a predicted heliographic dependence of the dominant polarity observable by spacecraft has been confirmed (Rosenberg and Coleman 1969); (Wilcox and Scherrer 1972). The polar cap field changes relating to the orientation of IMF is brought out directly through the corresponding changes in the ionosphere. Several geophysical parameters in the high latitudes respond to the IMF polarity. At mid and low latitudes the effects of auroral electrojets are reduced while the magnetospheric ring current effects will begin to dominate. The physical mechanism relating IMF to low latitude field changes will thus be different and needs careful study for a unified view of the physical processes.

## IMF polarity & Sq focus

Matsushita et al (1973) examined the relationship between sector structure and quiet geomagnetic field at about 40 stations for summer of 1965. They observed that IMF polarity has not only a clear influence on the currents over the polar region but also has a remarkable effect on mid latitude Sq currents and that sector structure effect is clearly exhibited in quiet day X component. An equatorward (poleward) shift of the Sq focus may occur for toward (away) sector. Matsushita (1975) confirmed these suggestions later using data over two longitudinal chains. He also suggested that IMF polarity could be inferred from mid-latitude geomagnetic field variations. Recently Butcher and Brown (1981) found that if the phase variability of Sq (H) is taken into account and the days are separated into normal and abnormal quiet days (AQDs) then the apparent focal movement occurs only on AQDs and only for IMF directed away from the Sun. This effect was seen both in summer and winter and is probably of magnetospheric origin. Shiraki (1977) has also reported influence of IMF on Sq (H) for station in the Japanese sector.

IMF polarity & low latitude geomagnetic field

Nishida (1966), from IMP 1 satellite observations of IMF over three solar rotations, found that at low latitudes the horizontal intensity was most depressed a day after the passage of a sector boundary indicative of the intensification of the equatorial ring current. First comprehensive analysis of the effect of IMF polarity on low latitude field was presented by Bhargava and Rangarajan (1975) who used the long series of Alibag (Dipole lat. 9.5° N) magnetic data and the inferred polarity (A/C index) of Svalgaard (1972) covering the period (1926-1972). They indicated significantly different response of the field dependent on the polarity of IMF and the local time. Correlation between A/C index and the field was significant up to 1958, but was absent after 1962. This aspect



of the A/C index invoked criticism by Russell & Rosenberg (1974), Russell et al (1975), Berthelier and Guerin (1975) who suggested that the correlation was an artifact of the inference based on Godhavn data. Using mostly satellite data supplemented occasionally by polar cap magnetic records, Svalgaard (1975) presented a revised atlas of A/C index for the period 1947-1975 and showed that the change in geomagnetic activity index, Am was different for the two epochs 1947-56 (pre-satellite era) and 1963-70 (satellite era) and suggested that the difference is real. Rangarajan (1977) using K-indices for 3 low latitude stations for two separate epochs showed that the response was larger in association with away/toward (+/-) boundary especially during conditions of low solar activity and that while the nature of response to a +/- boundary remained unaltered for the two epochs - pre-satellite and satellite era - that for -/+ boundary showed significant differences. Geomagnetic response for separate UT intervals showed that the effect due to different UT diurnal variation of activity on days of opposite polarity are manifested more clearly in post-boundary intervals or the leading parts of the sectors.

Kane (1971) used partial correlation technique for the influence of IMF on the range of quiet day diurnal variation at Trivandrum and Alibag and found that while $\Delta$H at Alibag was moderately correlated with Bx component of IMF, $\Delta$H at Trivandrum was not related to any interplanetary parameter. In another study, Kane (1975) showed that passage of well-defined sector boundaries does not affect equatorial Dst directly or in unambiguous fashion.

Rangarajan (1977) showed that mean daily range at low latitude was significantly larger following a sector boundary passage and that at Trivandrum and Sabhawala the magnitude of the departure was nearly same indicating the disturbance was essentially non-ionospheric. This result was confirmed from anaylsis of Kodaikanal data by Sastri (1979) who found no significant change when the data is corrected for equatorial Dst. Murthy (1979) using daily range of H at Kodaikanal in the vicinity of sector boundary found that the significant aspect is not only the increase following the passage but also the minimum before crossing with the response across the +/- boundary being distinctly larger. His results were thus in conformity with that of Shapiro (1974) and of Rangarajan (1977). A plausible explanation for the greater response in association with +/- sector boundary was given by Rangarajan and Arora (1980) who showed the length of the sector itself played a crucial role. While the geomagnetic field change associated with 'toward' or negative sectors was unaltered for short and long lived sectors, that for 'away' sector was significantly dependent on the length thus leading to reduced magnitude of the response for -/+ when sectors of different length are combined.

IMF polarity and daily and seasonal variation

The classical UT variation of geomagnetic activity changes phase with the season (McIntosh 1959). They are antiphase during the two solstices and during equinoxes it is semi-diurnal and with reduced magnitude. Averaged over all seasons the UT



variations are very small. When days are separated according to polarity, however, it is seen that the daily variations has opposite phase for opposite polarity and when difference between variations of activity for two polarities is computed, one can isolate variations critically dependent on sector polarity while averaging the variation for nearly equal number of days for either polarity will provide component independent of sector polarity (Svalgaard 1976). Russell and McPherron (1973) suggested that the semi-annual variation in geomagnetic activity was due to superposition of two annual waves one with April maximum for toward polarity and other for away polarity with October maximum. They suggested that the enhanced activity is due to an effective southward component of IMF in GSM system in corresponding equinoxes when By is transferred from GSEQ system. It is assumed that when IMF has northward Bz, there is no interaction with magnetosphere. Berthelier (1976) studied 'am' index of activity for its annual and diurnal variation properties as a function of IMF polarity. Bhargava and Rangarajan (1977) classified Ap index occurrence from quietest (Ap = 0) to most disturbed (Ap > 50) as a function of IMF polarity and demonstrated the existence of both the components of annual variation - one dependent on and the other independent of IMF polarity. Recently Oksman & Kataja (1981) studied the IMF influence on the seasonal change in Dst and showed that toward polarity was associated with spring minimum and away-polarity was associated with autumn minimum. Both exhibit an asymmetry between solstices. They concluded that solar-magnetosphere coordinate system may not be adequate for describing the interaction between IMF and magnetosphere during disturbed periods.

For low latitude field Nayar (1978) Nayar & Revathy (1979) utilizing the data from Alibag showed that the By influence changes as a function of time of the universal day and season in close accordance with the expectations of Russell-McPherron model and Svalgaard. Rangarajan (1979) using data of several low latitude stations between equator and Sq-focus showed that By effect at low latitudes is through non-ionospheric sources and that the effect has a local time dependence, especially for By+.

Bhargava and Rangarajan (1978) compared the polarity dependent and independent components of the seasonal change at Trivandrum and Alibag and showed that the polarity dependent component was in phase at both stations and exhibited nearly same dependence on the degree of magnetic activity, whereas polarity independent component was nearly antiphase and differed in magnitude.

## Long-term changes in IMF and geomagnetic activity

It is fairly well accepted that the solar wind stretches the solar dipole magnetic field forming a warped annular sheet in the heliomagnetic equator which intersects the ecliptic plane in four corotating arcs giving an apparent sector structure (Schulz 1973). The spiral sector structure has also been related to the magnetic structures on the photosphere of the sun. As the solar dipole magnetic field is known to undergo a 22-year (Hale or solar-magnetic) cycle, it was expected that the sector-related effects also show similar 'Hale' cycle effect. Svalgaard and Wilcox (1976) defined a 'Hale' sector boundary as that half of the sector boundary in the photosphere in which the change of polarity is the same as the change of polarity for the preceding to the following spot in a bipolar sunspot group. They found that above the 'Hale' boundary coronal green line has maximum brightness and above the non-Hale boundary it was minimum. The photosphere magnetic field was also much stronger above the 'Hale' boundary. Using this concept of 'Hale' boundary Nayar (1979) showed that the index Ap of magnetic-activity shows a sharp increase compared to that around non-Hale boundary when data for solar cycles 18, 19 and 20 were combined. Nayar (1981) also showed that the solar wind velocity and number density also exhibited such features. Lundstedt et al (1981) computed the Ap variations around Hale and no-Hale boundaries separately for 3 solar cycles to show that the increase across a Hale boundary was not always true and attributed the results derived by Nayar (1979) to the fact that the southward component of Bz was the responsible agent. Rangarajan and Nayar (1979) computed the response of low latitude field changes related to sector-boundary passage for 3 solar cycles separately for vernal and autumnal equinoxes and showed that 'Hale' part of the sector boundary has no enhanced response in the low latitude field.



Long-term temporal variation of geomagnetic response to IMF was studied by Arora and Rangarajan (1981) who showed that -/+ boundary was associated with variability in the magnitude of field response whereas +/- boundary was unaltered. The temporal evolution of the response during equinoxes for boundaries considered favourable in Russell-McPherron model exhibits a 22-year modulation.

## Lunar variations and IMF

Rao and Arora (1977) suggested that as the magnetospheric tail extends beyond the lunar orbit, the sector polarity of IMF may have a lunar component in earth's magnetic field. Using data of four Indian stations Alibag, Kodaikanal, Annamalainagar and Trivandrum and separating the days according to IMF polarity they computed L variations for a period of high solar activity (1958-61) and found that for away polarity, there was no equatorial enhancement in contrast to 'toward' polarity which showed considerable enhancement at Trivandrum relative to Alibag. To check whether this feature was solar-activity dependent, the exercise was repeated for other groups of year 1962-65, 1966-69 and 1970-73. The resulting pattern was complex, sometimes opposite to that for 1958-61 group; for e.g. 1966-69 Trivandrum showed larger variations for 'away' days. This was again indicative of some longer-period modulation of the IMF response. Using Huancayo H data for the period 1926-1961 divided into groups according to low and high solar activity Rao and Arora (1980) found that toward polarity have larger associated L variation in odd cycles during high solar activity and less L during even cycles. During low solar activity, the response was not consistent or significant. They inferred from these results a quasi-stationary solar-magnetic cycle in the response of L to IMF polarity.



## Geomagnetic bays & IMF

Burch (1973) investigated the sector structure dependence of auroral zone positive and negative bay activity (respective measures AU and AL). The seasonal variation in AU was similar for both sectors. During passage of 'toward' sectors AL peaked between spring equinox and summer solstice and for 'away' sectors AL peaked between fall equinox and winter. At low latitudes geomagnetic bays occur close to local midnight as large positive excursions. The occurrence frequency of low latitude positive bays at Trivandrum and Alibag as a function of IMF polarity was considered by Bhargava and Rangarajan (1977) who found that there is a large winter to summer decrease of bay activity for 'away' sector and the seasonal variation was dominantly semi-annual. For 'toward' sectors, the seasonal change in occurrence was fairly consistent with Russell-McPherron hypothesis of enhanced activity in April (October) for toward (away) sectors. As a function of local time, there exists a small time difference in peak occurrence of bays at equatorial station. Sastri (1979) examined the correlation between amplitude and rise-time of bays at Kodaikanal in relation to IMF polarity and found that the CC was larger for away sectors to conclude that IMF influences not only the occurrence (seasonal and nocturnal) pattern but also the characteristics of positive bays.

## Magnetic pulsations & IMF

With the availability of satellite observations of IMF relationships between magnetic pulsations

(PC1 to PC5, Pi1 and Pi2) have been extensively studied. Period and amplitudes pf PC2, PC3 & PC4 depend on the IMF magnitude ((Vero and Hollo 1977). Association of PC5 with magnitude and direction of IMF vector was inferred by Gogatischwilli (1976). Rao and Rangarajan (1977) studied the effect of passage of sector boundary on pulsational activity as recorded at Chettupal observatory near Hyderabad in the period range PC3 to PC5 and Pi1-Pi2. Some of the main results of their analysis were

1) maximum pulsational activity was in post-passage period except for PC4.
2) Occurrence of PC3 was more frequent compared to PC5 near the boundary.
3) There is a clear difference in response of pulsational activity of PC4 category dependent on the type of boundary.

IMF influence on equatorial ionospheric features have also been studied extensively in recent times but this topic is considered outside the scope of the present review and, therefore, not incorporated.

An elaborate bibliography of important papers and Indian contributions to this field is appended.

## Acknowledgement

I am grateful to Prof B.N. Bhargava who was responsible for triggering my interest in this exciting branch and to Prof R.G. Rastogi who has given all encouragement for continuing my research efforts in the field and to all my co-authors and colleagues at the Institute who have, without murmur, contributed to several useful discussions.



## Bibliography (Indian contribution)

Rengarajan G K With

1. B N Bhargava, Low latitude field variations related to IMF polarity, Planet. Space Sci. 1975, 23, 929
2. B N Bhargava, Seasonal variations in positive bays at Alibag, Trivandrum and Valentia, Planet. Space Sci., 1977, 25, 161.
3. B N Bhargava, Seasonal variations of Ap with increasing magnitude, J. Geomag. Geoelec. 1977, 29, 1.
4. B N Bhargava, Seasonal variation of polarity dependent and independent components at low & equatorial latitudes, J. Geomag. Geoelec. 1978, 30, 211.
5. D R K Rao, Magnetic pulsations Pc3-Pc4-Pc5 & Pi2 low latitudes, IUGG, 1977, at Seattle, USA
6. S R P Nayar, Polarity dependence over 3 solar cycles of low latitude H field, Indian J Radio Space Phys., 1979, 8, 393
7. B R Arora, Low latitude field variations for different lengths of sectors, J. Geomag. Geoelec. 1980, 33, 709.
8. B R Arora, Temporal change in response of Ap to sector boundary, J. Geophys. Res, 1981, 86, 3369.
9. B R Arora, Solar wind streams, sector boundary passage and low latitude field, Indian J. Radio Space Phys., 1981, 10, 54.
10. G K Rangarajan, Daily variation and range at low latitudes, Planet. Space Sci. 1977, 25, 1183.

11. G K Rangarajan, K-indices of Alibag, Honolulu and San Juan and sector boundary passage, Planet. Space Sci. 1977, 25, 465.

12. G K Rangarajan, Comparison of Kn, Ks, Kp and Alibag K, Indian J Radio Space Phys., 1980 9, 73.

13. G K Rangarajan, IMF control of diurnal variations of the low latitude field, J. Geomag. Geoelec. 1981 (in press)

14. G K Rangarajan, N-S asymmetry in the IMF response, Proc. International Magnetosphere Study, Japan, 1979.

15. S R P Nayar, IMF By, Bz and low latitude diurnal and seasonal variation, Proc. Indian Academy of Sciences, 1978, 87A, 139

16. S R P Nayar and Revathy, Extension of above, J. Geomag. Geoelec. 1979, 31, 67

17. S R P Nayar, SSC and sector boundary, Space Sci. Symposium, B.H.U., 1980.

18. S R P Nayar, Hale boundary and Ap, Planet. Space Sci. 1979, 27, 1033.

19. Kane R P, SD and IMF parameters, J. Geophys. Res. 1971, 76, 8199.

20. Kane R P, Day to day variability and IMF, Nature, 1971, 232, 21.

21. Kane R P, Indices of activity and IMF parameters, J. atmos. terr. Phys. 1972, 34, 1941.

22. Kane R P, Evolution of DS and IMF parameter, Proc. Indian Acad. Sci, 1974, 80, 124.

23. Kane R P, Electrojet strength and IMF, Indian J. Radio Space Phys., 1975, 4, 132.



24. Kane R P, Dst variations associated with sectors, Proc. Indian Acad. Sci, 1975, 81A, 253.

25. Bhargava B N and Sastri N S, CEJ and IMF polarity dependence, J. Geomag. Geoelec. 1979, 31, 97

26. Rao D R K and Arora B R, Lunar influence at low latitudes associated with IMF, J. Geomag. Geoelec. 1977, 29, 137.

27. Arora B R, Sastri N S and Rao D R K, 22-Yr modulation of IMF lunar effects, J. Geomag. Geoelec. 1980, 32, 389.

28. Murty B S, Daily range in H at low latitude and sector boundary, Indian J. Radio Space Phys, 1979, 8, 398.

29. Sastry, J H, Daily variation at equatorial region and IMF, Current Science, 1979, 48, 896.

30. Sastry J H, Amplitude and rise time of bays and IMF, Current Science, 1979, 48, 248.

31. Sastri, N S, Bhargava B N and Arora B A, Counter-electrojet occurrence and polarity of IMF, Indian J. Radio Space Phys, 1981, 10, 109.

32. Nayar, S R P and Revathy P, Cause of geomagnetic activity at Hale boundary, Planet Space Sci., 1982, 30, 519.

## Bibliography (Review articles)


Wilcox J M, The interplanetary magnetic field, solar origin and terrestrial effect, Space Sci. Rev. 8, 258, 1968.

Kovalevsky J V, The interplanetary medium, Sp. Sci. Rev. 12, 137, 1971.

Schatten K H, Large scale properties of IMF, Rev. Geophys. 9, 773, 1971.

Wilcox J M, Inferring the IMF by observing the polar geomagnetic field, Rev. Geophys. 10, 1003, 1972.

Burch J L, Observation of interactions between interplanetary and geomagnetic field, Rev Geophys. 12, 363, 1974.

Nishida A, Interplanetary field effect on the magnetosphere, Sp. Sci. Rev. 17, 353, 1975.

Crooker N U, Solar wind magnetosphere coupling: Geomag. activity and solar wind structure for IMF and geomag. activity, Rev Geophys, 13, 956, 1975.

Dobrowolny M and Moreno G, Latitudinal structure of solar wind and IMF, Sp. Sci. Rev. 18, 685, 1976.

Burlaga L F, Solar wind stream, Sp. Sci. Rev., 17, 327, 1975.

Marcia Neugebauer, Large scale and solar cycle variation of the solar wind, Sp. Sci. Rev. 17, 221, 1975.

Feldstein Ya I, Polar region and IMF, Sp. Sci. Rev. 18, 777, 1976.

Matsushita S, IMFP effects on equatorial geomagnetic field and ionosphere - a review JATP, 39, 1207, 1977.




## Bibliography (General)


1) Wilcox J M and Ness N F, J Geophys. Res., 70, 5793, 1965, First reported observation on sector structure of IMF.

2) Wilcox J M and Colburn D S
J Geophys Res 74, 2388, 1969
J Geophys Res 75, 6366, 1970
J Geophys Res 77, 751, 1972
Geomagnetic activity increases across sector boundary during all phases of solar activity - minimum, rise to maximum and maximum solar activity.

3) Svalgaard L, Geophys Papers, Danish Met. Inst. R-9, 1968, J Geophys Res 77, 4027, 1972
Inference of polarity from polar cap station data.

4) Friis-Christensen E, Lassen K, Wilhjelm J, Wilcox J M, Gonzalez W and Colburn D S
J Geophys Res 77, 3371, 1972.
showing that azimuthal (By) component is the relevant parameter governing polar cap-IMF relationship.

5) Russell C T, Burton R K and McPherron R L, J Geophys Res 80, 1349, 1975
Berthelier A and Guerin C, J Geophys Res 80, 4390, 1975.
Criticism of Svalgaard's A/C index and accuracy of inference.

6) Rosenberg R L and Coleman P J Jr., J Geophys Res 74, 5611, 1969.
Wilcox J M and Scherrer P S, J Geophys Res 77, 5385, 1972.
Annual wave in dominant polarity of IMF and solar magnetic cycle changes in IMF.

7) Matsushita S, Tarpley J D and Campbell W H, Radio Sci 8, 963, 1973
Matsushita S, J Geophys Res 80, 4751, 1975.
Butcher E L and Brown G M, Geophys J R A S, 63, 783, 1981.
Shiraki M, Memoin Kakioka Mag. Obs. 17, 1&2, 1977
IMF polarity effects at low and mid-latitudes and on Sq focus and abnormal quiet days.

8) Svalgaard L, J Geophys Res 81, 5182, 1976
Berthelier A, C L Acad. Sc. Paris 280, 195, 1975
Diurnal and Annual variation of geomagnetic activity related to IMF polarity

9) Shapiro R, J Geophys Res 79, 289, 1974
shows greater response for +/- boundary

10) Russell C T and McPherron R L, J Geophys Res 78, 92, 1973
Proposes a model for semi-annual variation in geomagnetic activity related to IMF

11) Svalgaard L and Wilcox J M, Solar Phys 49, 177, 1976

12) Schulz M, Astrophys Space Sci., 24, 371, 1973
Concept of sector structure due to warped neutral sheet of solar dipole magnetic field in equatorial plane intersected by the ecliptic plane.

13) Nishida A, Rep. Ionos. Space Res. Japan, 20, 36, 1966
Ring current intensification following boundary passage

14) Gogatishvili L, Ya M, Geomagn. & Aeron. 16, 225, 1976.
Pulsation & IMF.



Akasofu S I, Energy coupling between solar wind and magnetosphere, Sp. Sci. Rev. 28, 121, 1981.

Svalgaard L, An atlas of interplanetary sector structure 1957-1974, SUIPR Rep. 629, Inst. for plasma phys. Stanford Univ., Stanford, Calif. 1975.
Interplanetary sector polarity 1947-1956 SUIPR Rep. 648, 1976.