

**N66-11213**

(ACCESSION NUMBER)

(PAGES)

(NASA CR OR TMX OR AD NUMBER)

(THRU)

(CODE)

(CATEGORY)

**X-612-65-302****NASA TM X-55317**

# A QUASI-STATIONARY CO-ROTATING STRUCTURE IN THE INTERPLANETARY MEDIUM

BY

**JOHN M. WILCOX****NORMAN F. NESS**

GPO PRICE \$ \_\_\_\_\_

CFSTI PRICE(S) \$ \_\_\_\_\_

Hard copy (HC) 2.00Microfiche (MF) 50**JULY 1965**

ff 653 July 65



**GODDARD SPACE FLIGHT CENTER**  
**GREENBELT, MARYLAND**

Submitted to Journal of Geophysical Research

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John M. Wilcox

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## ABSTRACT

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A quasi-stationary co-rotating structure in the interplanetary magnetic field has been observed with the IMP-1 satellite during 3 solar rotations. The interplanetary field is directed predominantly away from the sun for  $2/7$  of a rotation, then toward the sun for  $2/7$  of a rotation, then away from the sun for  $2/7$  of a rotation, and finally toward the sun for  $1/7$  of a rotation. The interplanetary magnetic field magnitude and the solar wind velocity, density and flux are discussed with regard to this sector structure. As the structure rotates past the earth once every 27 days it influences geomagnetic activity and cosmic ray density. A recurring stream of protons of a few MeV energy is almost entirely contained within one sector. The solar source of the recurring geomagnetic storm of December 2, 1963 is associated with a ghost Unipolar Magnetic Region in the solar photosphere.

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## INTRODUCTION

A quasi-stationary co-rotating structure has been observed in the interplanetary magnetic field with the magnetometer experiment on the IMP-1 satellite. This satellite was launched November 27, 1963 and observed the interplanetary medium for 3 solar rotations thereafter. The satellite orbit was highly elliptical with the apogee being at 31.7 earth radii. The flux gate magnetometers gave a vector measurement of the magnetic field every 20 seconds with an accuracy of  $\pm 1/4 \gamma$  ( $1 \gamma = 10^{-5}$  gauss). Further details of this experiment have been published by Ness, et al. (1964).

An interplanetary magnetic field structure suggested by the magnetometer observations is shown in the inner part of Figure 1. The observed direction of the interplanetary field is on the average consistent with the Archimedian spiral picture predicted by Parker (1958), but the sense of the field (toward the sun or away from the sun) changes from time to time. For about 2/7 of the total circumference the field is directed away from the sun,

for the next  $2/7$  toward the sun, for the next  $2/7$  away from the sun, and for the last  $1/7$  the field is again toward the sun. The pattern co-rotates with the sun as was suggested by Ahluwalia and Dessler (1962). As the sectors shown in Figure 1 rotate past the earth, systematic changes can be observed in the interplanetary field magnitude, the solar wind velocity and density, the geomagnetic activity index  $K_p$ , and cosmic ray intensity. In the idealized situation shown in Figure 1 the solar wind plasma velocity is radial while the interplanetary field lines are twisted into Archimedian spirals.

#### METHOD OF ANALYSIS

The observed distribution of interplanetary magnetic field directions is shown in Figure 2 with the field being averaged every 5.46 minutes. The left hand side of the figure shows the component parallel to the ecliptic plane. An isotropic distribution of vectors would result in the dashed circle. It can be seen that the actual distribution is stretched out along directions predicted by the Archimedian spiral model. Figure 3 is similar to Figure 2 except that the average is taken over 3 hours. Some of the deviations about the streaming angle are thereby averaged out and the resultant distribution of direction is even more stretched out along the directions predicted by the spiral model. The directions labeled "positive" in Figure 4 represent an interplanetary field that is predominantly directed away from the sun, while the directions labeled "negative" represent an interplanetary field that is predominantly directed toward the sun. Each

3 hour period of time has been assigned a plus sign or minus sign depending upon the predominant direction of the interplanetary field within that interval. The validity of this description can be judged from Figures 4 and 5 which show that within a given 3 hour period the field direction is usually confined entirely to either the positive range of directions or the negative range of directions. Figure 4 is a sample of the interplanetary magnetic field data obtained on January 21 and 22, 1964. Of interest for the present considerations is the angle  $\phi$  which is defined to be zero in the earth-sun direction, as shown in Figure 2. The range of  $\phi$  labeled "positive" in Figure 2 is indicated in Figure 4 with a plus sign and the range of  $\phi$  labeled "negative" in Figure 2 is indicated in Figure 4 with a minus sign. It can be seen that the field direction remained within the positive interval (away from the sun) during each of the 3 hour intervals shown in Figure 4. Figure 5 is similar to Figure 4 and shows interplanetary field data obtained on January 7, 1964. During most of this interval the field is directed away from the sun, but near the end of the figure the field direction abruptly changes to being toward the sun. This represents a boundary between two sectors. The change of direction occurs between one 5.46 minutes point and the next; therefore the boundary between the sectors is very narrow. The sectors co-rotate with the sun and therefore have an azimuthal velocity at the distance of the earth of 440 km per second. Thus the upper limit of 5.46 minutes for a sector boundary to sweep past the earth represents an upper limit of about 148,000 km for the thickness of the sector boundary.

The plus and minus signs at the perimeter of Figure 1 are a representation of the direction of the interplanetary field in successive 3 hour intervals. The position of orbit number 1 is indicated and the other orbits follow along in a clockwise direction. For a period of about 1 day centered

about each perigee pass, the satellite is within the region influenced by the geomagnetic field so that interplanetary measurements cannot be made. The resulting gaps in the data can be seen in Figure 1. For the most part the sector structure indicated at the center of Figure 1 agrees very well with the observations at the perimeter of Figure 1; i.e. a sector with the arrow indicating interplanetary field directed predominantly away from the sun is occupied almost entirely by plus signs at the perimeter and similarly a sector with the arrow indicating field directed toward the sun is occupied almost entirely by minus signs at the perimeter. The first orbit represents an exception to the proposed sector structure. It could be a time at which the quasi-stationary structure was changing. In the second orbit the series of plus signs following the arrival of the storm of December 2, 1963 appears to be an exception to the sector structure, but this can be understood in terms of the solar wind velocity. At this time the average solar wind velocity (Lyon, et al., 1964) was about 470 km/sec, which would correspond to a transit time from the sun to the earth of  $3 \frac{3}{4}$  days with the assumption of a uniform radial solar wind velocity. The average solar wind velocity during the 3 solar rotations considered here was 315 km/sec, which would correspond to a transit time of  $5 \frac{1}{2}$  days. Thus the change of interplanetary field direction associated with the storm arrived too soon by about  $1 \frac{3}{4}$  days, which just corresponds to the number of plus signs indicated in the second orbit of Figure 1.

## CO-ROTATION

The evidence for the co-rotation of the sector structure will now be examined. Figure 6 shows an autocorrelation of the direction (toward or away from the sun) of the interplanetary magnetic field. This direction was described by a time series of plus or minus signs, as described above. When these data were first analysed in this manner it was noticed that most of the disagreement occurred within the first 8 days observed by the satellite. Therefore in order to try to examine a quasi-stationary condition the data of the first 8 days were excluded from the analysis shown in Figure 6, and in the subsequent analysis. The autocorrelation of the direction of the interplanetary magnetic field shows a prominent peak at about 27 days. This is evidence for co-rotation of the interplanetary magnetic field structure if the 27 day period is assumed to represent the synodic rotation period of the low latitude region of the sun. Also we have previously shown (Ness and Wilcox, 1964) that the interplanetary field is rooted in the photospheric magnetic field, and this also implies co-rotation. Since the structure of Figure 1 co-rotates with the sun its influence at the earth is not caused by the radial advance of a spherical front but rather by the rotational motion of the structure past the earth.

## LIMITATIONS

Before examining this structure and its influence in more detail we may note certain limitations. The observations cover only the short time of three rotations of the quiet sun, and thus cover a time that is small compared with the 11 year cycle of solar activity. They have a limited statistical weight in that there are only 4 of the large sectors with field



directed away from the sun and 3 of the large sectors with field directed toward the sun available for analysis. When we attribute physical reality to the sector structure shown in the center of Figure 1, we must assume a near coincidence in both period and phase between the co-rotation of the sector structure with the sun and the orbit of the IMP-1 satellite. The time required for a  $1/7$  sector to rotate past the earth is almost equal to the orbital period of the satellite. The phase relationship is such that usually when a sector boundary rotates past the earth the satellite is near perigee and therefore unable to observe the boundary. The possibilities inherent in this situation for creation of an artifact have been carefully examined with negative results at the present time. The fact that the sense of the interplanetary field remains the same throughout a  $2/7$  sector, and therefore during two successive orbits of the satellite, is a strong argument that the sector structure is not related to the orbital parameters of the satellite.

#### ANALYSIS OF SECTOR STRUCTURE

We now proceed to analyse the structure shown in Figure 1 in more detail, using the method of superposed epoch analysis. One of the  $2/7$  sectors rotates past the earth in  $2/7 \times 27$  days =  $7 \frac{3}{4}$  days. The abscissa in Figure 7 represents position within a  $2/7$  sector measured in days as the sector rotates past the earth. The sector boundary is defined as the position at which the sense of the direction of the interplanetary magnetic field changes. As can be seen from Figure 1 there is an uncertainty of several hours in the exact location of the sector boundaries. For purposes of the analysis it is assumed that the total circumference is divided up into three  $2/7$  intervals and one  $1/7$  interval.

The degree of approximation involved in this can be ascertained from Figure 1. Because of the uncertainty of several hours in the location of the boundary and also to provide some smoothing of the data, 24 hour average values of the interplanetary field magnitude have been used in this analysis. The numerical procedure provides interpolation at 3 hour intervals. The ordinate of Figure 7 represents the average value of the interplanetary field magnitude as measured at the same relative position within each of the  $2/7$  sectors. Thus structure that is organized with respect to the  $2/7$  sectors will tend to be reinforced, while other random effects will tend to be averaged out. Figure 7 shows that the average magnitude of the interplanetary field declines from greater than  $6 \gamma$  early in the sector to less than  $4 \gamma$  in the trailing portion of the sector. The results of the analysis for the sectors with field directed away from the sun and the sectors with fields directed toward the sun are shown separately in Figure 7.

The solar wind plasma was observed on the IMP-1 satellite by a Faraday cup detector flown by the MIT group (Lyon, et al, 1964). The observations from this experiment of the solar wind velocity, density and flux have been analysed in a manner similar to that used in Figure 7 for the interplanetary field magnitude. Figure 8 shows the results for the solar wind velocity. The location of the peak at about 2 days is real, because the uncertainty in the location of the sector boundaries is only a few hours. However the upward excursion of the plus signs at about day 4 may well be an artifact related to the loss of data when the satellite is near perigee. After the peak of about 340 km/sec the solar wind velocity declines to a value less than 290 km/sec in the trailing portion of the sector. A similar analysis of the solar wind density is shown in Figure 9. After a peak early in the sector at greater than 12 protons/cc the density declines to about 6

protons/cc in the middle of the sector and then has a substantial rise in the trailing portion of the sector. Thus in the trailing portion of the sector the solar wind velocity is decreasing, while the solar wind density is increasing. The analysis of the solar wind flux is shown in Figure 10. Since the solar wind plasma is also well organized by the sector structure, this structure is a fundamental property of the interplanetary medium.

#### INFLUENCE ON GEOMAGNETIC ACTIVITY AND COSMIC RAYS

As the sector structure in the interplanetary medium rotates past the earth does it influence geomagnetic activity? The answer is shown in Figure 11 which is a similar analysis of the 24 hour sum of Kp. This index rises to a peak greater than 25 at about day 2 and then declines to a minimum less than 10 in the trailing portion of the sector. The change in the geomagnetic activity with respect to the sector structure shown in Figure 11 is similar to the variation of solar wind velocity shown in Figure 8. This is consistent with the result reported by Snyder, et al., (1963) from the Mariner II spacecraft that the solar wind velocity is linearly related to the 24 hour sum of Kp.

The change in time of the geomagnetic activity as a 2/7 sector rotates past the earth is shown in Figure 11 from a superposed epoch analysis. Figure 12 shows that an approximation to this can be observed as each individual sector rotates past the earth. Figure 12 shows the planetary magnetic 3 hour range indices (Central Radio Propagation Laboratory, 1964). The sector boundaries observed by IMP-1 have been added to this chart. Cases where the location of the boundary are uncertain due to the satellite being near perigee are indicated with cross-hatching.

It is difficult to assess the statistical significance of the limited data sample used in this analysis. However, it is useful in this regard to divide the data sample into two parts and to perform the same analysis on each. It can be seen in Figure 11 that the results for sectors with field away from the sun and for the sectors with field toward the sun are very similar. This gives a measure of the physical content of the results.

The influence of the rotating sector structure on the local cosmic ray intensity is shown by the analysis of the Deep River neutron monitor counting rate in Figure 13. The counting rate tends to increase throughout most of this sector. This is consistent with the viewpoint that galactic cosmic rays are excluded by kinks and irregularities in the interplanetary magnetic field. Early in the sector where the interplanetary field magnitude is largest the cosmic ray intensity is smallest and vice versa. Most of the decrease shown in the positive sectors in Figure 13 occurs in only one of the two positive sectors. The significance of this effect in such a limited data sample is not clear.

#### OUTER BOUNDARY OF SECTORS

Simpson and Fan (1965) have a detector on the IMP-1 satellite that responds to protons of a few MeV energy, and the counting rate of this detector is shown in Figure 14. Also shown in Figure 14 are the times of 3 recurrences of a  $2/7$  sector having field directed away from the sun. It can be seen that the recurrent proton stream detected by Simpson and Fan is almost entirely contained within this positive sector. This observation suggests that the interplanetary field lines in the positive sector do not join smoothly to interplanetary field lines that return to the sun in

adjacent negative sectors. If there were a smooth connection between the positive sector and the negative sectors the observed protons would have sufficient time to follow the field lines and thus should appear also in the adjacent negative sectors.

These remarks apply to the situation in the plane of the ecliptic. It is also clear that  $\text{div } B$  is not conserved in this plane. In 4/7 of the total circumference the field is directed away from the sun and in only 3/7 of the total circumference is the field directed toward the sun. Also the average magnitude of the field in the away sectors is about 10% higher than in the toward sectors, although the average solar wind velocity is the same in the two cases. Thus near the plane of the ecliptic there are more lines leaving the sun than return to the sun, and some of these lines must return to the sun at other latitudes. In this connection we can note that at this time the northern polar region had a large scale field directed into the sun, the southern polar region had a large scale field too small to be detected by the solar magnetograph and the lower latitudes have a complex pattern of Bipolar magnetic regions, unipolar magnetic regions and background fields. (Bumba and Howard, 1965a).

#### THE SOLAR SOURCE OF THE RECURRING GEOMAGNETIC STORM OF DECEMBER 2, 1963

Geomagnetic storms of moderate intensity often recur at intervals of about 27 days. Since this is the rotation period of low latitudes on the sun as seen from the earth, it has been assumed that some long-lived feature on the sun is responsible for these storms. Bartels (1932) called the solar source of recurring geomagnetic storms an M-region, and since that time there has been no general agreement in the literature as to the

exact nature of the source. The storm of December 2, 1963, whose position is indicated in Figure 1, was a member of a series of geomagnetic storms that had recurred at 27 day intervals for one and a half years. The following discussion compares the satellite observations with recent observations of photospheric magnetic field patterns by Bumba and Howard at the Mt. Wilson Observatory.

Soon after the solar magnetograph was placed in operation at Mt. Wilson H. W. and H. D. Babcock (1955) reported that one kind of feature in the photospheric field involves a considerable extent in latitude and in longitude in which the photospheric field is directed either into the sun or out of the sun. Simpson and the Babcocks (1955) suggested that these Unipolar Magnetic Regions (UMRs) might be the source of the recurring geomagnetic storms. Bumba and Howard (1965a) in a recent discussion of UMRs define them as having the polarity of the following portion of active regions in a given region. At the time of the IMP-I observations, in the northern solar hemisphere the leading portions of active regions had magnetic field directed out of the sun and the following portions had field directed into the sun, and thus a Unipolar Magnetic Region had field directed into the sun. Bumba and Howard (1965b) have recently discussed an additional feature in the photospheric magnetic field which they call a ghost UMR and which they define as follows: "Each UMR for which we have good magnetic observations has preceding it a region of leading polarity that is roughly the same as an UMR and sometimes nearly as large, but that has fields in the tail that are more than a factor of 2 weaker than the UMR." "There is only slight enhanced calcium emission to be seen accompanying these ghost Unipolar Magnetic Regions. Almost always during some part of the lifetime of the regions, a large quiescent prominence separates the UMR from the ghost UMR."

Figure 5 is a synoptic chart of the photospheric magnetic field (Bumba and Howard, 1964). The solid contours indicate field out of the sun and the dashed contours represent field into the sun. The large region with dashed contours in the upper right hand portion of Figure 5 is the continuation of a sequence of UMRs. The region with field out of the sun in the northern hemisphere in the middle of Figure 15 is a ghost UMR.

The observed interplanetary magnetic field at the beginning of the storm of December 2, 1963 is displayed on an expanded time scale in Figure 35 of Ness et al. (1964). One hour after the commencement of the storm a sector boundary rotated past the earth such that the direction of the interplanetary field changed from toward the sun to away from the sun, as shown in Figure 1. At this time the measured plasma velocity was about 470 km/sec (Lyon et al, 1964). With the assumption of a constant radial solar wind velocity this gives a transit time from the sun to the earth of  $3 \frac{3}{4}$  days. This transit time has been subtracted from the observed time at which the sector boundary rotated past the earth to define the beginning of the positive sector on the sun, as shown in Figure 15. The position on the sun of the end of this positive sector has been estimated in the same way. The cross-hatched area represents the uncertainty in the sector boundary associated with the presence of the satellite near perigee. Probable errors in the position of the sector boundaries caused by uncertainties in the measured solar wind velocity and by the assumption of constant radial solar wind velocity are not included. The various times of interest are summarized as follows: the storm commencement was 2117 UT on December 2, the sector boundary associated with the change from field toward the sun to field away from the sun rotated past the satellite at 22xx UT on December 2, the storm ended at 17xx UT on December 7, and the

positive sector ended between 12xx UT on December 12 and 03xx UT on December 13.

The positive sector whose boundary coincides (within 1 hour) with the commencement of the recurring geomagnetic storm thus appears to extrapolate back to the sun such as to include the ghost UMR. We therefore suggest that in this one case the ghost UMR is to be identified with Bartel's M-region. The weak magnetic fields of the ghost UMR might be such as to not interfere with the escape of solar wind plasma from the sun. The position and extent in heliographic longitude of the ghost UMR are consistent with the commencement time and duration of the recurring geomagnetic storm of December 2, 1963.

On the following solar rotation a small geomagnetic storm was recorded from 03xx UT on January 2, 1964 to 05xx UT on January 4. This storm is located in the first part of recurrence of the same positive 2/7 sector discussed above. Twenty-seven days after this some observatories reported a small storm. Due to bad weather at Mt. Wilson, photospheric magnetic field observations are not available at the 27 day and 54 day intervals after the storm of December 2.

This identification of an M-region would not be directly related to the presence of newly formed active regions on the sun. Since the UMR is often separated from the ghost UMR by a large quiescent prominence a statistical relationship between these prominences and recurring geomagnetic storms might be observed, but only when prominences associated with active regions have been excluded. The ghost UMR has only slightly enhanced calcium emission and therefore it would be very difficult to detect it by any means other than the solar magnetograph.



In view of the many years of controversy regarding the identification of M-regions it must be strongly emphasized that these comments apply to the observation associated with one recurring geomagnetic storm. Additional observations are required to determine the generality of these results.

#### SUMMARY

The IMP-1 satellite has observed a quasi-stationary co-rotating structure in the interplanetary medium during 3 solar rotations of the quiet sun. Since this structure can be observed in both the interplanetary magnetic field and the solar wind plasma it is a basic feature of the interplanetary medium. In the preceding portion of the sectors the interplanetary field magnitude, solar wind velocity, and geomagnetic activity tend to be large, and in the trailing portion of the sectors these quantities tend to be small. The density is large in the preceding and trailing portions of the sectors and is small in the middle of the sectors. Cosmic ray intensity is smaller in the preceding portion of the sector in which the interplanetary field magnitude is larger with conditions reversed in the trailing portions of the sector. The recurring protons of a few MeV energy observed by Simpson and Fan are fairly well contained within a single positive sector. This suggests that there is not a smooth connection between this positive sector and the adjacent negative sectors. In the ecliptic plane more magnetic flux is directed away from the sun than is directed toward the sun, so that some of this flux must return to the sun at other latitudes. The solar source of the recurring geomagnetic storm of December 2, 1963 is associated with a ghost unipolar magnetic region in the photosphere on the basis of magnetic field polarities and time relationships.

### Acknowledgements

One of us (J.M.W.) thanks R. Howard and V. Bumba for several informative discussions and the director of the Mt. Wilson observatory for guest investigator privileges at the observatory.

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## Figure Legends

Fig. 1. The + (away from the sun) and - (towards the sun) signs at the circumference of the figure indicate the direction of the measured interplanetary magnetic field during successive 3 hour intervals. A parenthesis around a + or - indicates a time during which the field direction has moved beyond the "allowed regions" shown in Figure 2 for a few hours in a smooth and continuous manner. The inner portion of the figure is a schematic representation of a sector structure of the interplanetary magnetic field that is suggested by these observations. The deviations about the average streaming angle that are actually present are not shown in this figure.

Fig. 2. Distribution of the measured interplanetary magnetic field direction in the plane of the ecliptic and normal to the ecliptic, averaged over 5.46 minute intervals. Both histograms show the field angular distribution per unit solid angle; the dashed circles would correspond to an isotropic distribution of the same number of vectors. The distribution is peaked in directions corresponding to the spiral streaming angle. The angular intervals in which the field is predominantly away from the sun and predominantly toward the sun are labeled positive and negative in this figure, and represented by + and - signs in Figure 1. The distribution normal to the ecliptic shows that the interplanetary field is predominantly parallel to the ecliptic rather than being perpendicular to it.

Fig. 3 Same as Figure 2, but averaged over 3 hour intervals.

Fig. 4. Interplanetary magnetic field data for January 21 and 22, 1964.  $F$  is the magnitude of the field in  $\gamma$ , and  $\phi$  and  $\theta$  are defined in Figure 2. The points are shown at 5.46 minute intervals. The range in  $\phi$  labeled "positive" in Figure 2 is shown with a + sign in this figure (field predominantly away from the sun), and the range in  $\phi$  labeled "negative" in Figure 2 is indicated with - signs (field predominantly toward the sun). The interplanetary field was directed predominantly away from the sun during the entire time interval covered by this figure. At the bottom of the figure the field variances in  $\gamma$  are shown for 3 mutually perpendicular axes. (Ness et.al., 1964)

Fig. 5. Interplanetary magnetic field data for January 7, 1964. The Ordinates are the same as in Figure 4. In most of this figure the interplanetary field is predominantly directed away from the sun. At 2220 UT a sector boundary rotates past the satellite and the field direction changes to being predominantly toward the sun. (Ness et.al., 1964)

Fig. 6. Autocorrelation of the observed direction of the interplanetary magnetic field. The large positive peak at about 27 days lag indicates that the interplanetary magnetic field structure co-rotates with the sun.

Fig. 7. Superposed epoch analysis of the magnitude of the interplanetary magnetic field as a function of position within the 2/7 sectors shown in Figure 1. The abscissa represents position within the sector, measured in days as the sector sweeps past the earth. The ordinate is the average magnitude at the same relative position within the sectors. The results are shown separately for the four sectors with field away from the sun, the three sectors with field toward the sun, and for all sectors.

Fig. 8. Superposed epoch analysis of the solar wind velocity as a function of position within the 2/7 sectors.

Fig. 9. Superposed epoch analysis of the solar wind density as a function of position within the 2/7 sectors.

Fig. 10. Superposed epoch analysis of the solar wind flux as a function of position within the 2/7 sectors.

Fig. 11. Superposed epoch analysis of the geomagnetic activity index 24 hour sum Kp as a function of position within the 2/7 sectors.

Fig. 12. Planetary magnetic 3 hour range indices Kp. The sector boundaries are indicated with vertical lines. The cross-hatched areas indicate uncertainties in the position of the sector boundaries caused by the position of the satellite near perigee. An approximation to the average shape shown in Figure 11 can be seen in each individual sector.

Fig. 13. Superposed epoch analysis of the Deep River neutron monitor counting rate as a function of position within the 2/7 sectors.

Fig. 14. Counting rate of the University of Chicago experiment on IMP-1 detecting protons of an energy of a few MeV. Three solar rotations are shown. The recurring stream of protons is for the most part contained within the positive sector. The cross-hatching indicates the uncertainty in the position of the sector boundary caused by the position of the satellite near perigee.

Fig. 15. Synoptic chart of photospheric magnetic fields for central meridian dates November 25, 1963 to December 11, 1963. This is a rectangular equal area projection. Solid lines represent positive polarity and dashed lines represent negative polarity. Isogauss lines are for 2, 4, 8, 12 and 25 gauss. The equator is drawn across the center. The extrapolated position of the positive sector is indicated as described in the text.



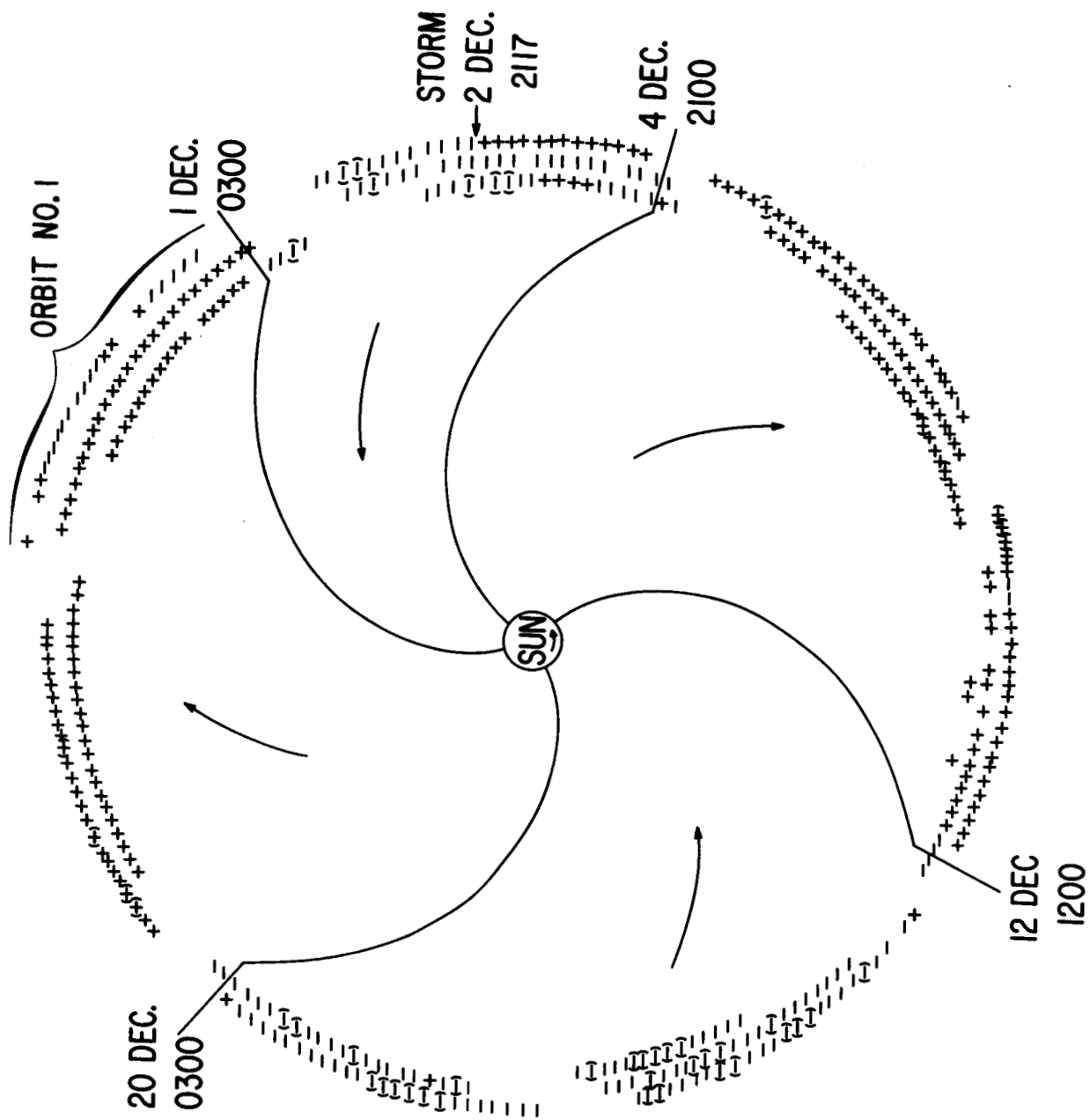
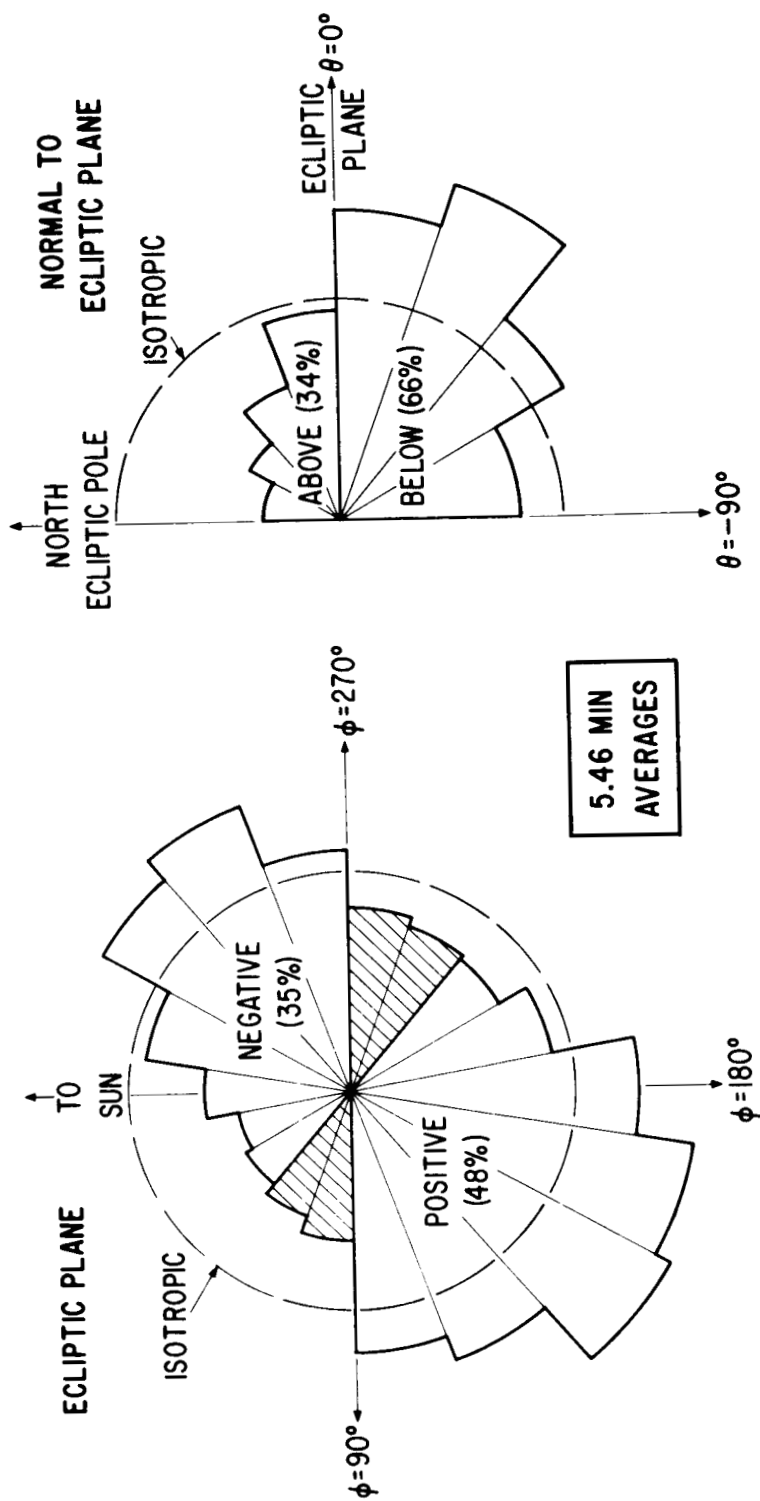
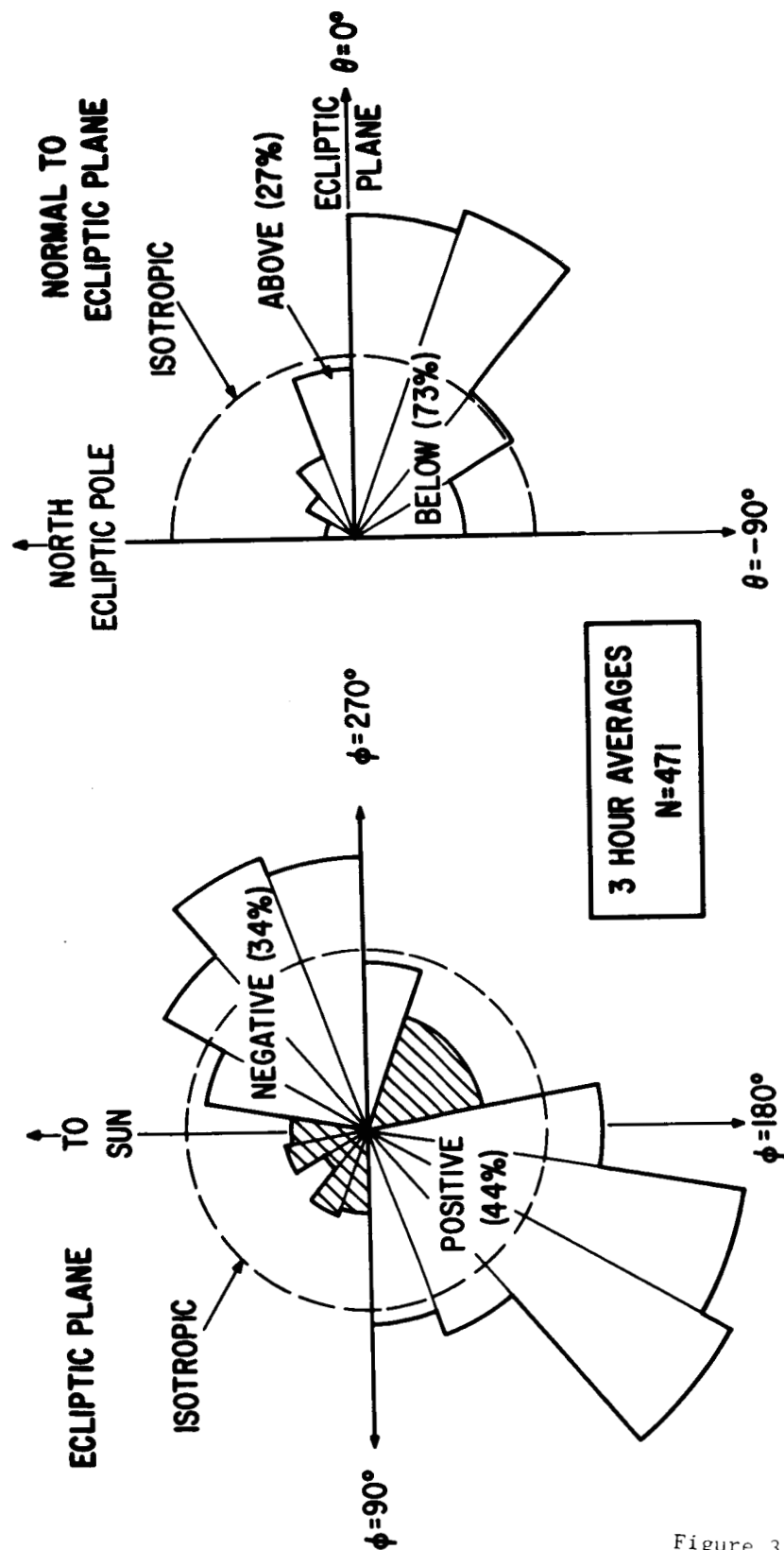


Figure 1



DISTRIBUTION OF INTERPLANETARY MAGNETIC FIELD DIRECTION

Figure 2



**DISTRIBUTION OF INTERPLANETARY MAGNETIC FIELD DIRECTION**

Figure 3

(15)

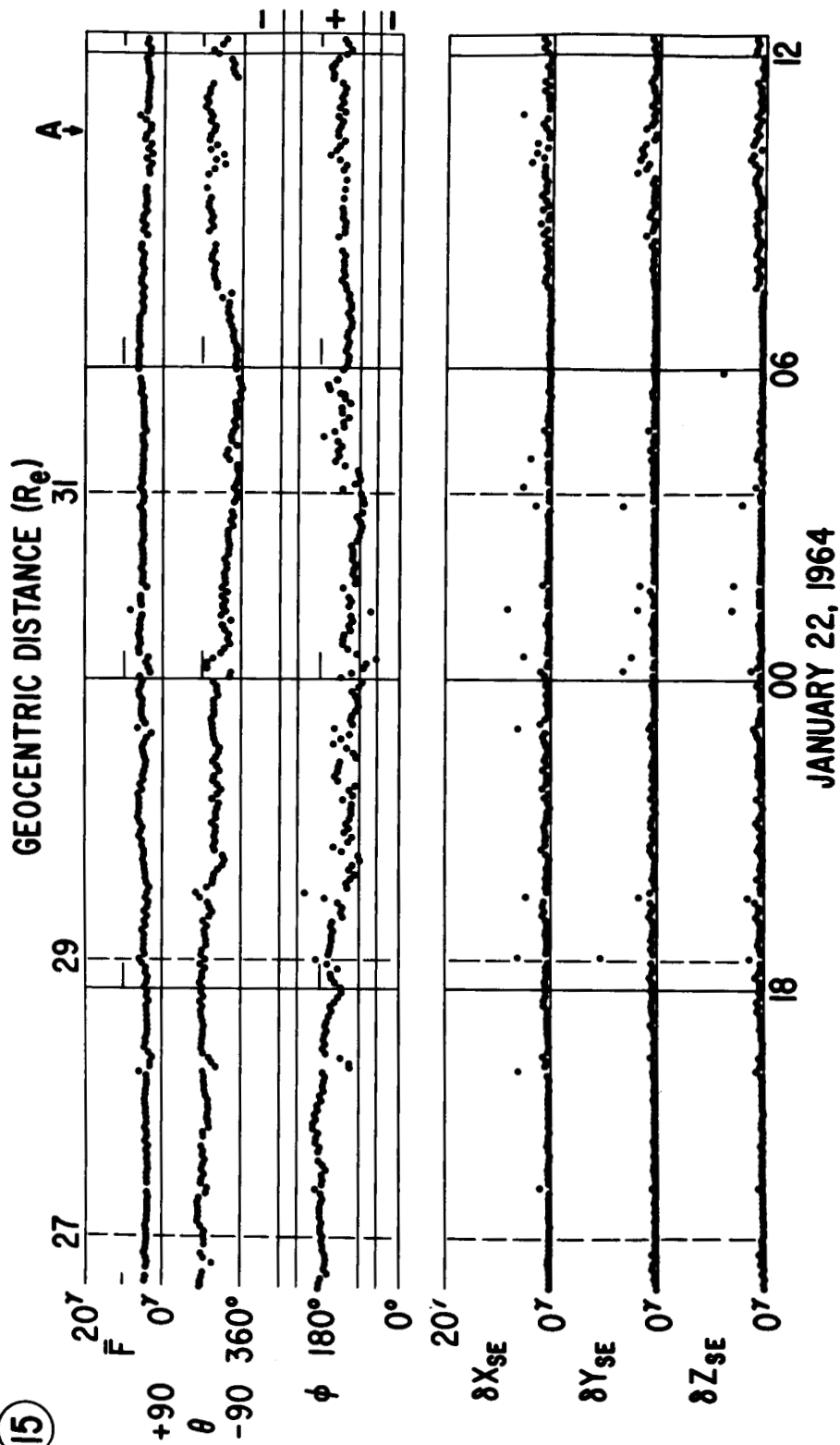


Figure 4

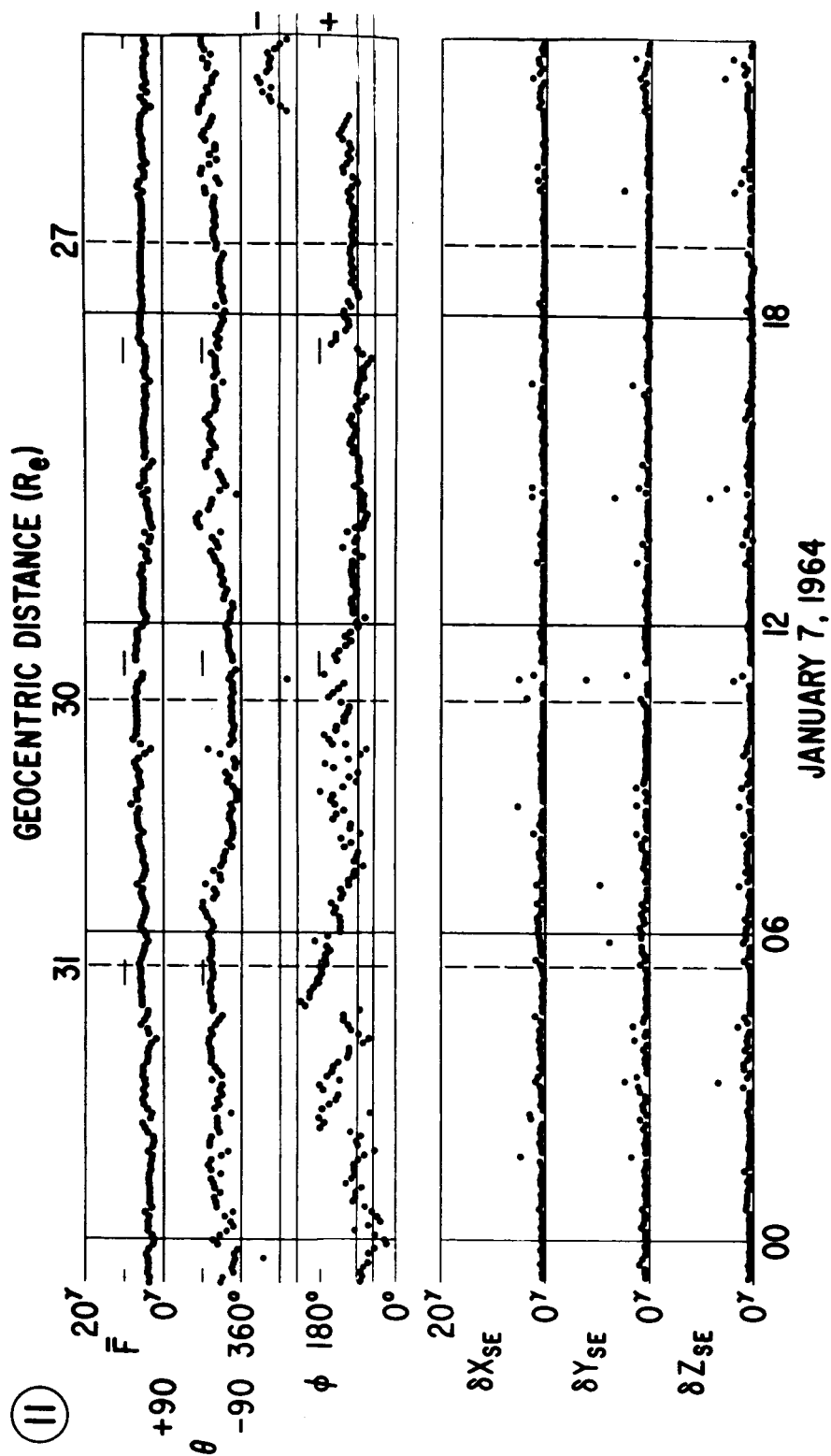


Figure 5

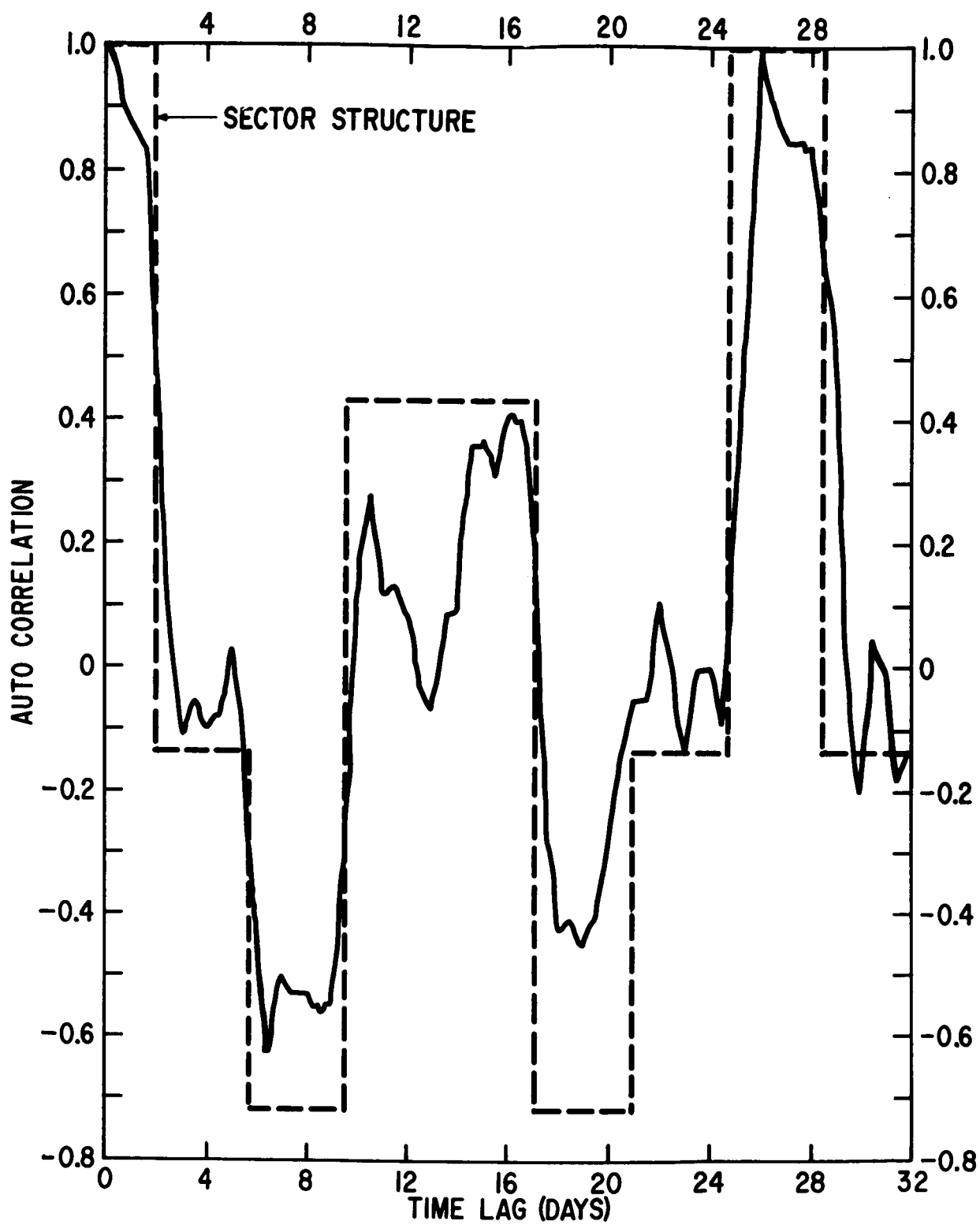


Figure 6

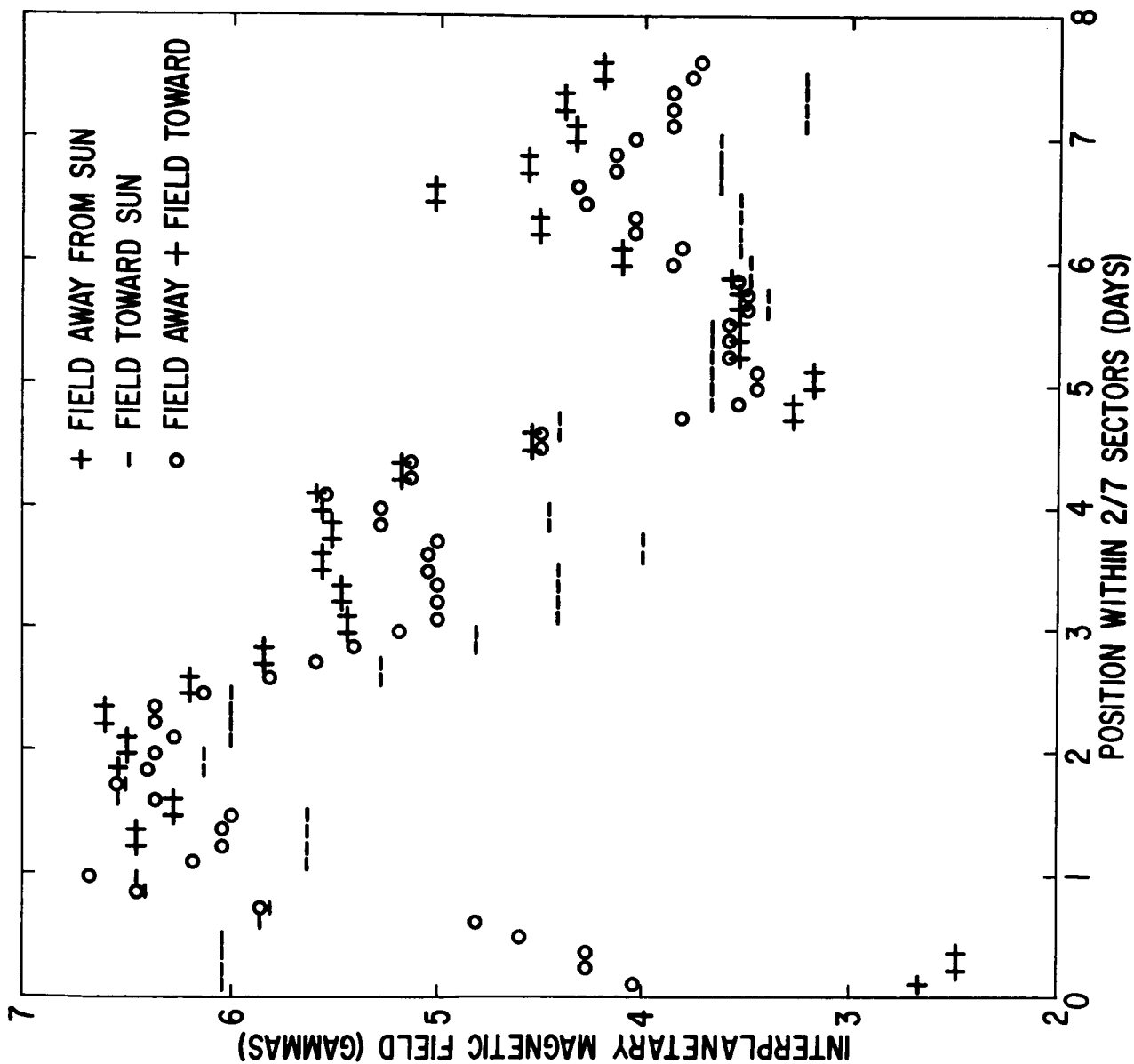


Figure 7

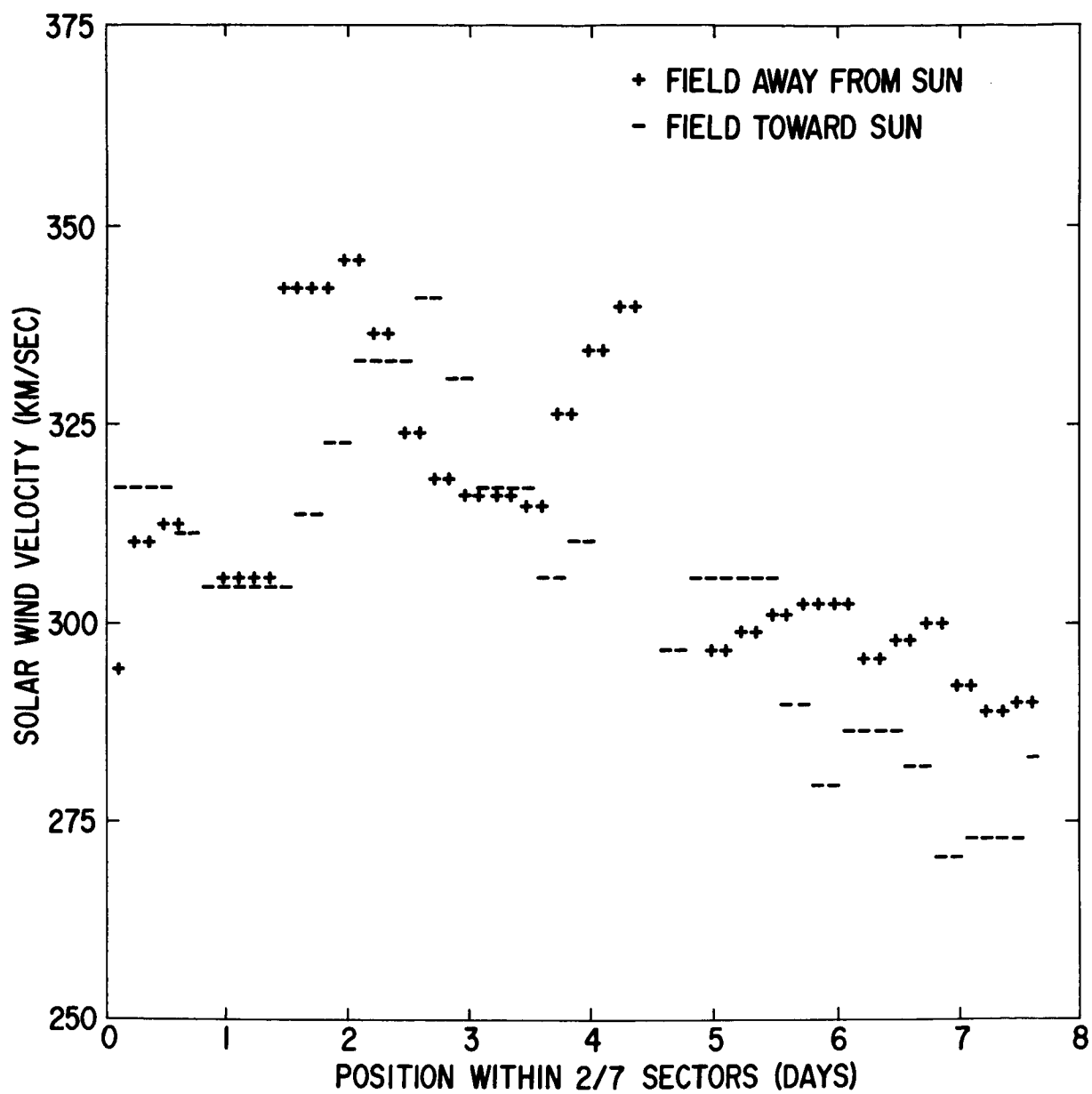


Figure 8



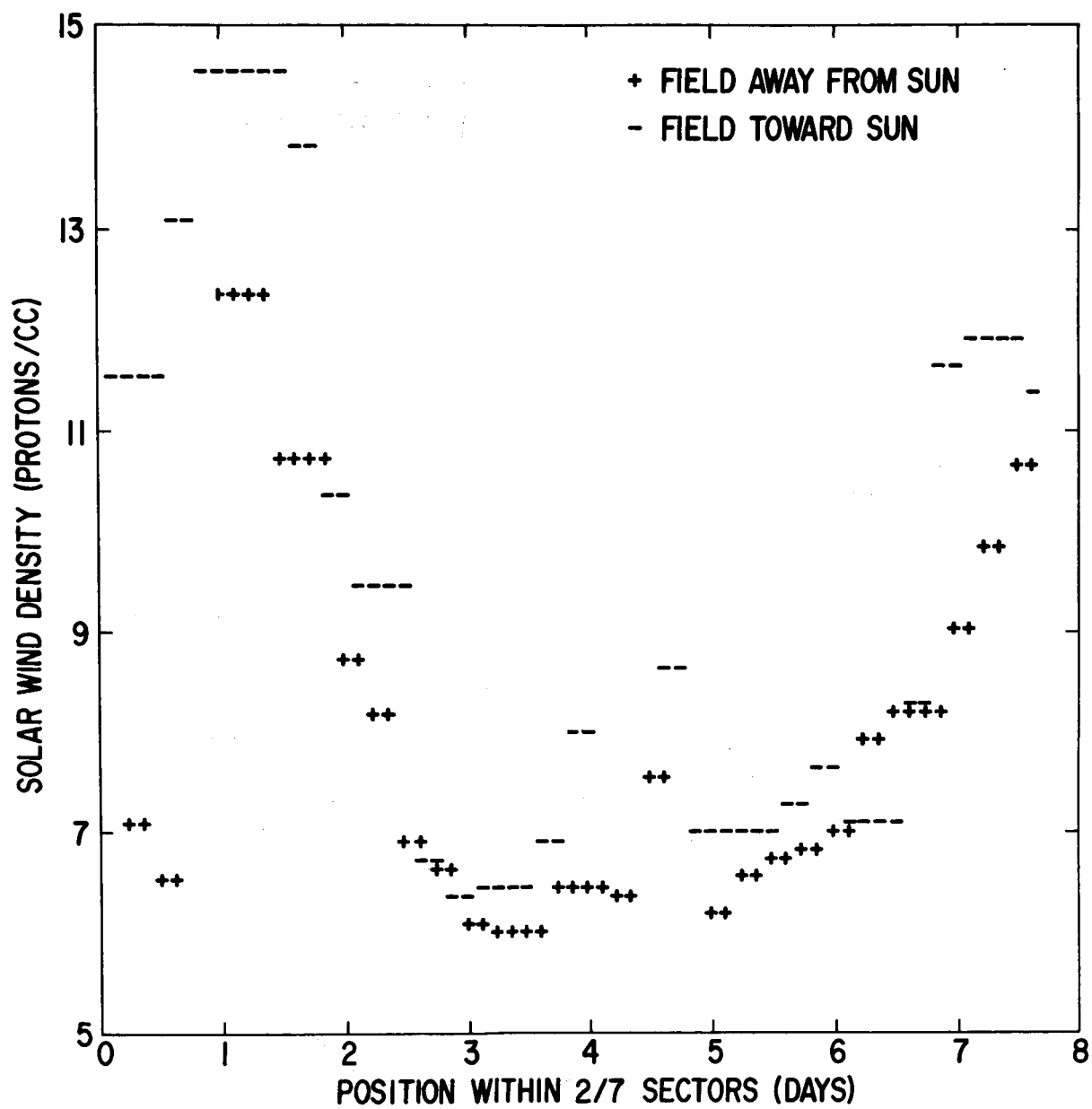


Figure 9

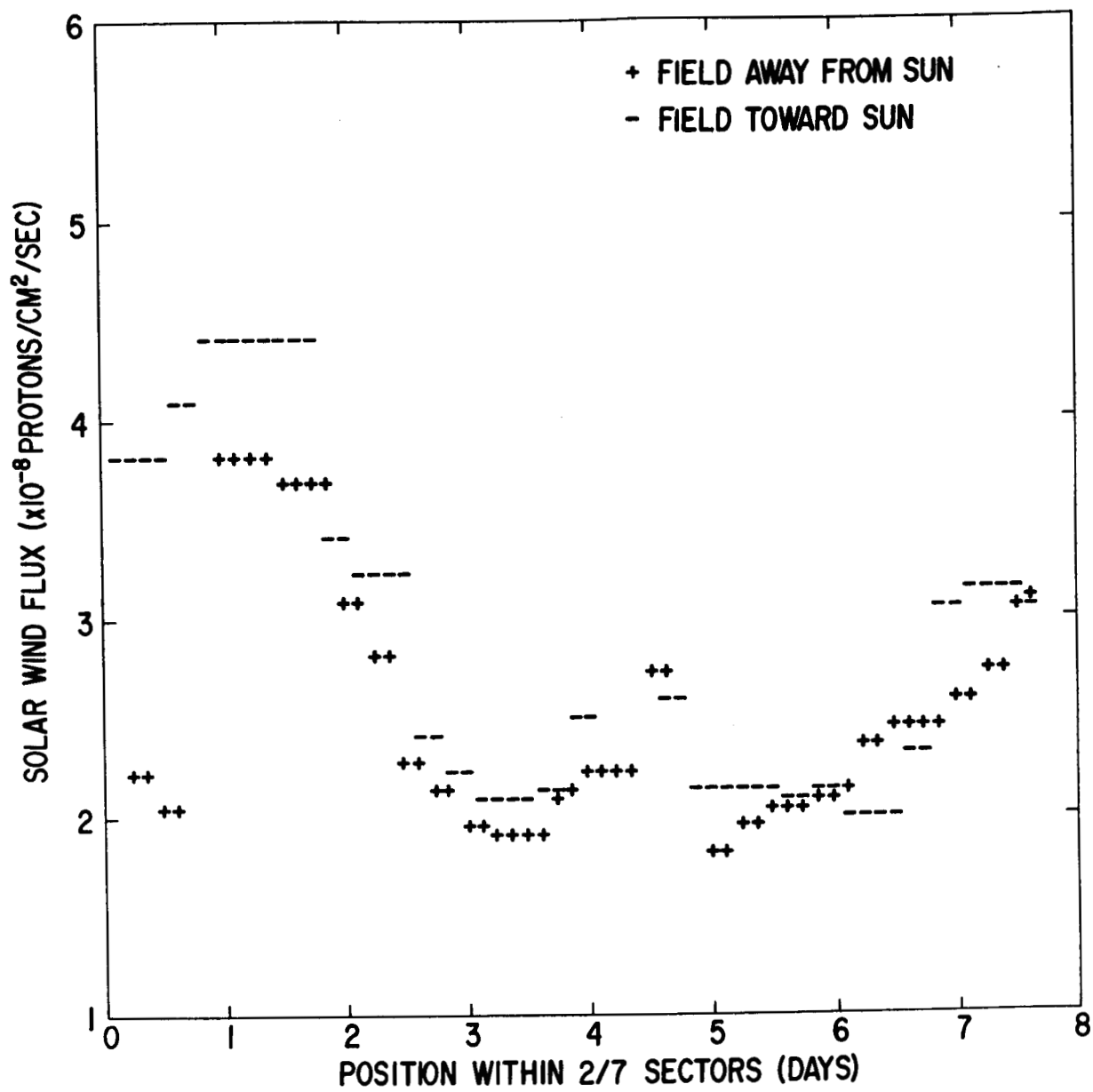


Figure 10

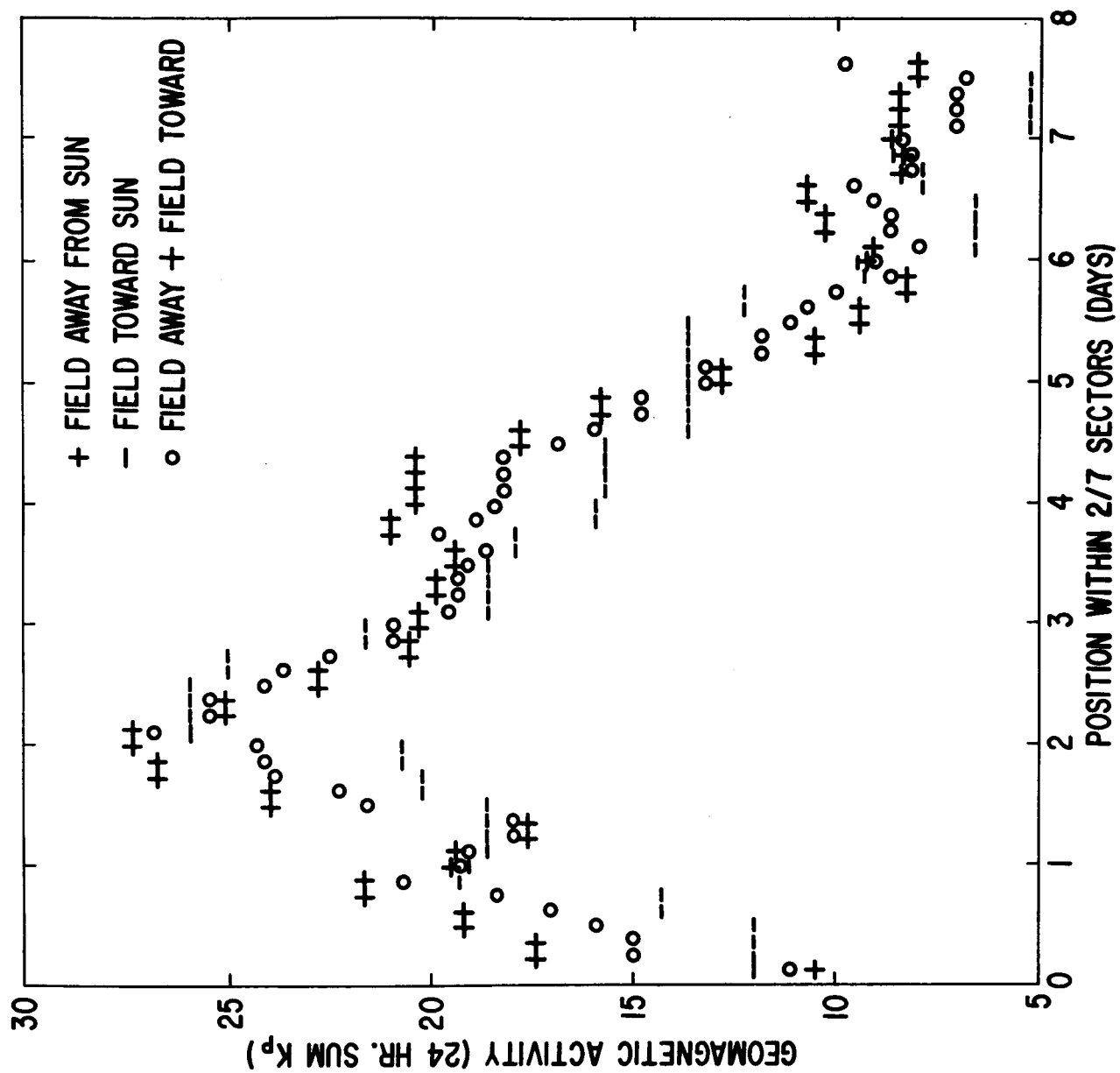


Figure 11

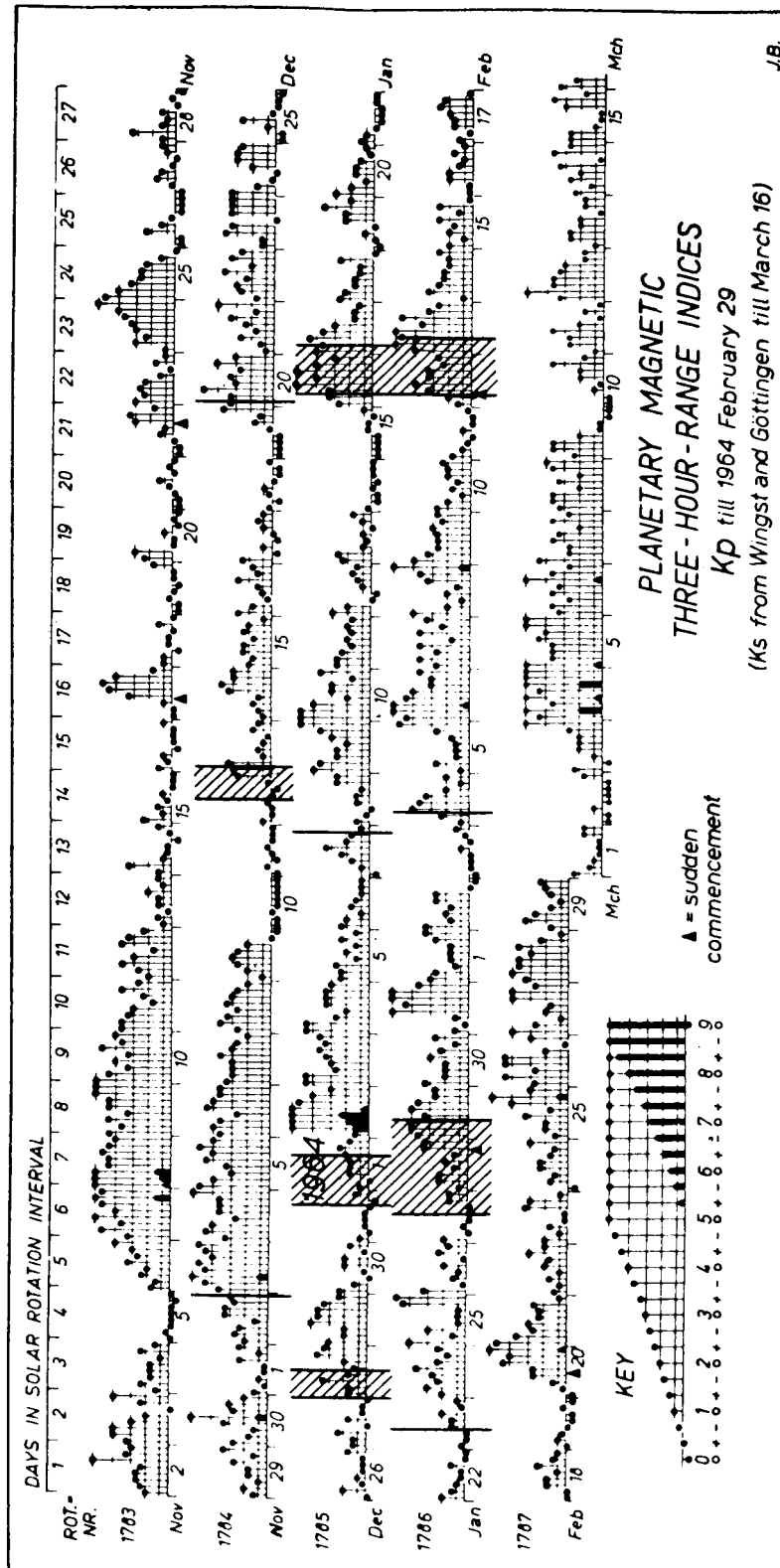


Figure 12

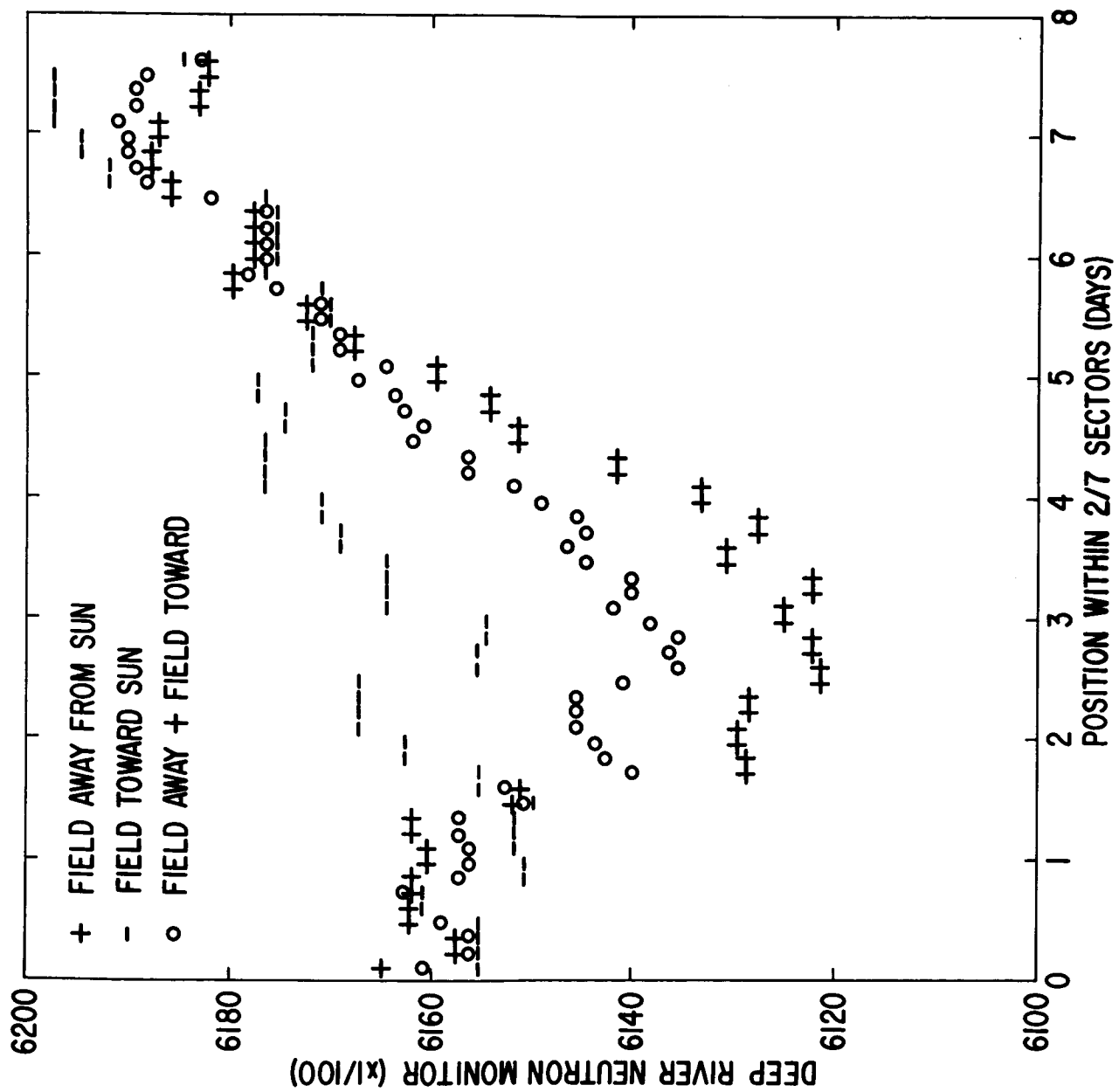


Figure 13

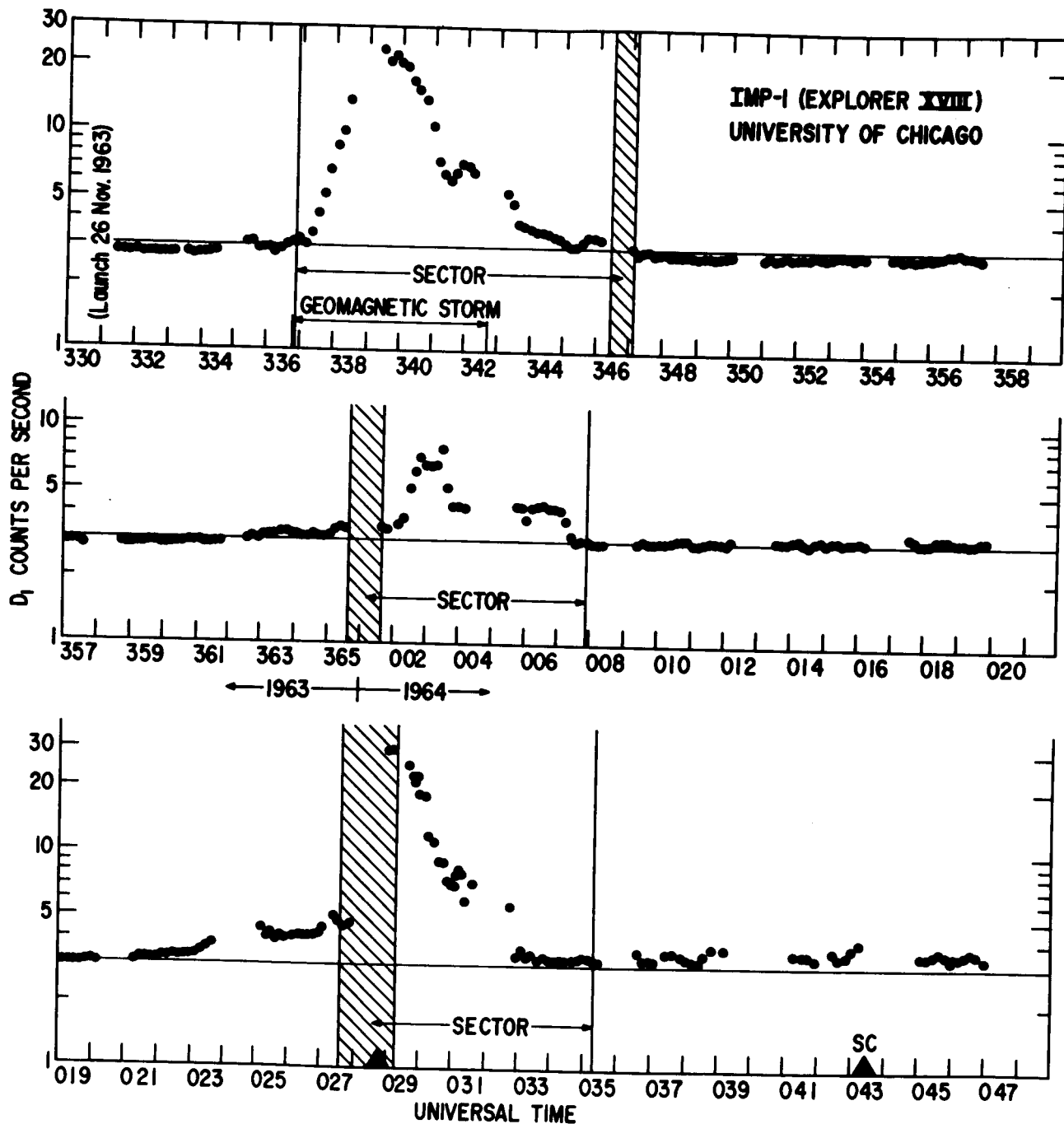


Figure 14

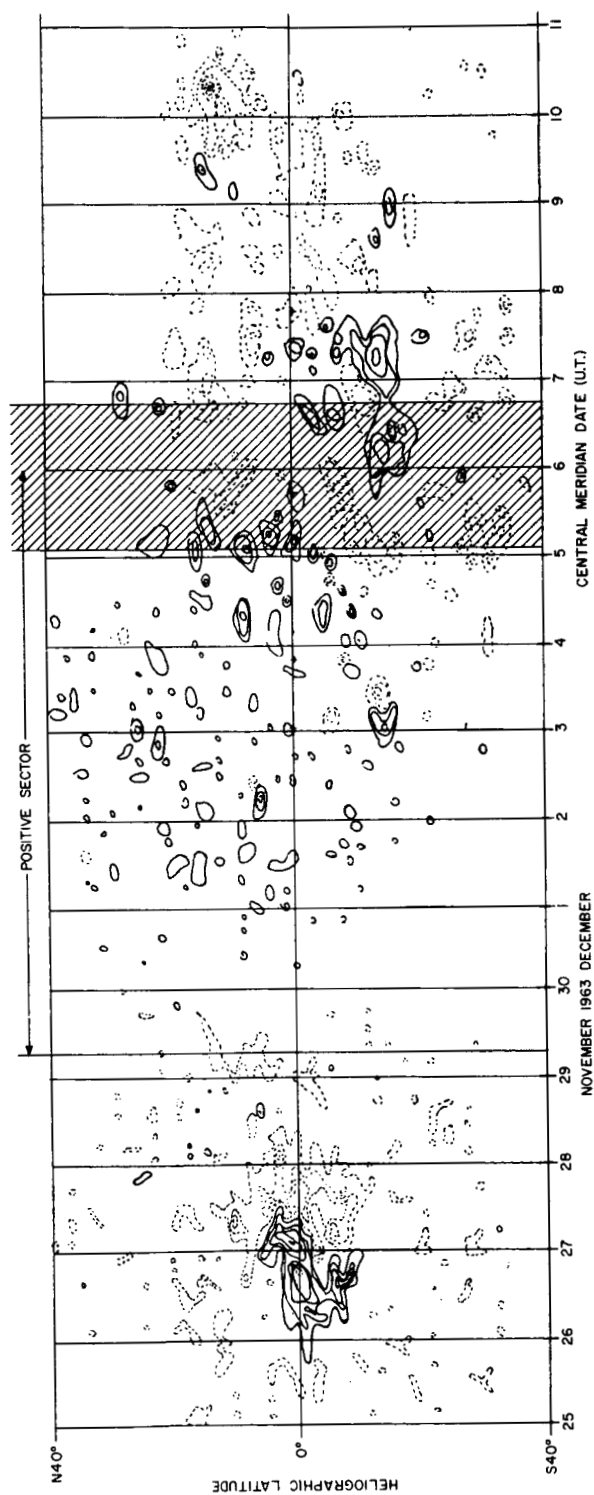


Figure 15