THE INFLUENCE OF SOLAR DIFFERENTIAL AND RIGID ROTATION ON THE INTERPLANETARY MAGNETIC FIELD

John M. Wilcox and Andrew S. Tanenbaum

Series 12, Issue 45
June 2, 1971

UNIVERSITY OF CALIFORNIA, BERKELEY

14

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Space Sciences Laboratory University of California Berkeley, California 94720	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

THE INFLUENCE OF SOLAR DIFFERENTIAL AND RIGID ROTATION ON THE INTERPLANETARY MAGNETIC FIELD

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report

5. AUTHOR(S) (Last name, first name, initial)

Wilcox, John M. and Tanenbaum, Andrew S.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 2, 1971	9	4

8a. CONTRACT OR GRANT NO. ONR Contract N00014-69-A-0200-1049 b. PROJECT NO. NR 021 109 c. NASA Grant NGL 05-003-230 d. NSF Grant GA-16765	9a. ORIGINATOR'S REPORT NUMBER(S) Series 12, Issue 45 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. AVAILABILITY/LIMITATION NOTICES

Qualified requesters may obtain copies of this report from DDC.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Nuclear Physics Branch Office of Naval Research Arlington, Virginia 22217

13. ABSTRACT

The large-scale photospheric magnetic field has been shown to have 1) a differential rotation pattern not too different from that observed by Newton and Nunn for sunspots, and 2) a rigid rotation pattern for the solar magnetic sector boundaries. Since the observed interplanetary magnetic field has been shown to be closely related to the photospheric magnetic field, it is of interest to search for these two rotation properties in the interplanetary field. An autocorrelation of the direction of the interplanetary field observed during the interval 1962-1968 shows 16 recurrent peaks at intervals of approximately 27 days, i.e. the lag of the autocorrelation extends from 0 to slightly more than 16 x 27 days. The rotation period associated with the first peak is about 27.3 days, and the periods associated with subsequent peaks show a monotonic decline to slightly less than 27.0 days, with the last few peaks showing a suggestion of a constant period. This result is interpreted in terms of photospheric field having differential and rigid rotation properties, and in terms of an assumed change through the sunspot cycle of the heliographic latitude of the source of the interplanetary magnetic field observed near the earth. (U)

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Interplanetary magnetic field						
Solar magnetic field						
Solar differential rotation						

DD FORM 1 JAN 64 1473 (BACK)

UNCLASSIFIED
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ONR Contract N0014-69-A-0200-1049, Project NR 021 109
NASA Grant NGL 05-003-230 and NSF Grant GA-16765

*Submitted to Journal of Geophysical Research

The Influence of Solar Differential and Rigid Rotation on the Interplanetary Magnetic Field

John M. Wilcox and Andrew S. Tanenbaum
Space Sciences Laboratory
University of California
Berkeley, California 94720

Abstract

The large-scale photospheric magnetic field has been shown to have 1) a differential rotation pattern not too different from that observed by Newton and Nunn for sunspots, and 2) a rigid rotation pattern for the solar magnetic sector boundaries. Since the observed interplanetary magnetic field has been shown to be closely related to the photospheric magnetic field, it is of interest to search for these two rotation properties in the interplanetary field. An autocorrelation of the direction of the interplanetary field observed during the interval 1962-1968 shows 16 recurrent peaks at intervals of approximately 27 days, i.e. the lag of the autocorrelation extends from 0 to slightly more than 16 x 27 days. The rotation period associated with the first peak is about 27.3 days, and the periods associated with subsequent peaks show a monotonic decline to slightly less than 27.0 days, with the last few peaks showing a suggestion of a constant period. This result is interpreted in terms of photospheric field having differential <u>and</u> rigid rotation properties, and in terms of an assumed change through the sunspot cycle of the heliographic latitude of the source of the interplanetary magnetic field observed near the earth.

The large-scale weak photospheric magnetic field has been shown to have a differential rotation pattern (Wilcox and Howard, 1970) that is similar to that observed for long-lived sunspots by Newton and Nunn (1951) near the solar equator, but away from the equatorial zone the field has a slightly shorter rotation period than the spots.

At the same time another analysis (Wilcox et al., 1970) has shown that this photospheric magnetic field has a sector pattern that rotates in an approximately rigid coordinate system with a synodic period near 27 days over a wide range of heliographic latitude. This solar magnetic sector pattern appears to be related to and a source of the observed interplanetary magnetic sector pattern (Wilcox and Ness, 1965).

Since the large-scale photospheric field has thus been shown to have both rigid and differential properties, and since this field has been shown to be a source of the interplanetary magnetic field (Ness and Wilcox, 1966), it is of interest to search for the possibility that the observed interplanetary magnetic field may show both rigid and differential rotation properties.

The method of analysis is similar to that employed with the photospheric magnetic field by Wilcox et al. (1970). An autocorrelation as a function of time lag is computed for the polarity of the interplanetary magnetic field observed by spacecraft from September 1962 to December 1968 (Wilcox and Colburn, 1970). For a time series of this length an autocorrelation can be computed with a range of lags from zero to $1\frac{1}{4}$ years without serious loss of statistical significance. Such an extended autocorrelation is schematically represented in the top curve of Figure 1, which is included to help explain the method of analysis. The nth recurrent maximum is at a lag of $n\tau_n$. (The lag corresponding to each peak is calculated using the position of the centroid.) A synodic rotation period τ_n can then be associated with the nth peak, as indicated in the lower portion of Figure 1. Features of the interplanetary magnetic pattern with a lifetime of a few solar rotations will dominate the rotation periods associated with the first few values of the recurrence number n, but by definition will have little effect on the rotation periods corresponding to large values of n, since only features whose lifetimes equal or exceed a time interval $n\tau_n$ can contribute to the rotation period corresponding to a recurrence number n.

The computed autocorrelation of the polarity of the observed interplanetary magnetic field is shown in Figure 2. The recurrent peaks selected for further analysis are indicated with vertical arrows. Figure 3 shows the synodic rotation period associated with each of the indicated recurring peaks in Figure 2. Figure 3 thus corresponds to the lower half of the schematic Figure 1.

At this point we may ask whether the peaks selected for the larger recurrence numbers are physically significant? For example, perhaps the peak to the left or the right of the peak indicated for n = 10 should have been selected to represent the 10th recurrence period. These peaks are at a lag approximately 13 days removed from the lag of the indicated peak. Then if one of them were chosen to represent the period corresponding to the 10th recurrence this period would be

$$\tau'_{10} \cong 270 \pm 13/10 \text{ days} = 27.0 \pm 1.3 \text{ days}.$$

Reference to Figure 3 shows that this change of approximately 1.3 days is very large compared with the fluctuations (approximately 0.05 days) of the periods corresponding to the chosen (indicated with arrow) peaks, and thus these selected peaks are significant.

A plausible interpretation of Figure 3 is the following. As shown by Wilcox and Colburn (1970, Figure 4) the synodic recurrence period of the interplanetary field has changed through the sunspot cycle, being near 27.0 days at sunspot minimum in 1964, increasing to about 28.0 days with the rise of solar activity in 1965 and then returning toward 27 days in subsequent years. A reasonable interpretation of this is that near solar minimum the heliographic latitude of the predominant source of the interplanetary field observed near the earth was at near-equatorial solar latitudes. With the rise of new sunspot cycle solar activity at latitudes near 25° the predominant latitude of the solar source of the interplanetary field may similarly have changed to about 25° (presumably in the northern solar latitudes, where most of the activity was concentrated) (Wilcox, 1965). Then in the succeeding years the predominant latitude of the solar source would tend to return nearer to the equator.

Thus the rotation period of the interplanetary magnetic field corresponding to the first recurrence in the present analysis may be an average of the variation of this quantity through the portion of the sunspot cycle from September 1962 to December 1968. We see in Figure 3 that there is an approximately monotonic decline of the rotation period of the interplanetary field from the first recurrence to about the 12th. By analogy with the results of Wilcox et al.(1970) for the analysis of a rigidly rotating pattern in the photospheric field, the last few recurrences in Figure 3 may correspond to a constant rotation period. We do not claim that this result is established by Figure 3, only that Figure 3 is consistent with the earlier analysis of the photospheric magnetic field. The solid straight line in Figure 3 is fit by eye to the data points, and the horizontal dashed line is drawn by analogy with the earlier photospheric field results.

By definition features in the interplanetary magnetic field that do not exist for at least a time of the order of one year cannot contribute to the last few recurrence points in Figure 3. Figure 3 is thus consistent with the presence of a rigidly rotating pattern in the interplanetary magnetic field with a period near 26.95 days. Although it is true that the presence of a rotation period independent of recurrence number for large values of the recurrence number is not independently established in Figure 3, it may be difficult to explain the nearly monotonic decline (which is well established) in Figure 3 for recurrences from the first to the twelveth by physical explanations other than the one given above.

This work was supported in part by the Office of Naval Research under Contract N00014-69-A-0200-1049, by the National Aeronautics and Space Administration under Grant NGL 05-003-230, and by the National Science Foundation under Grant GA-16765.

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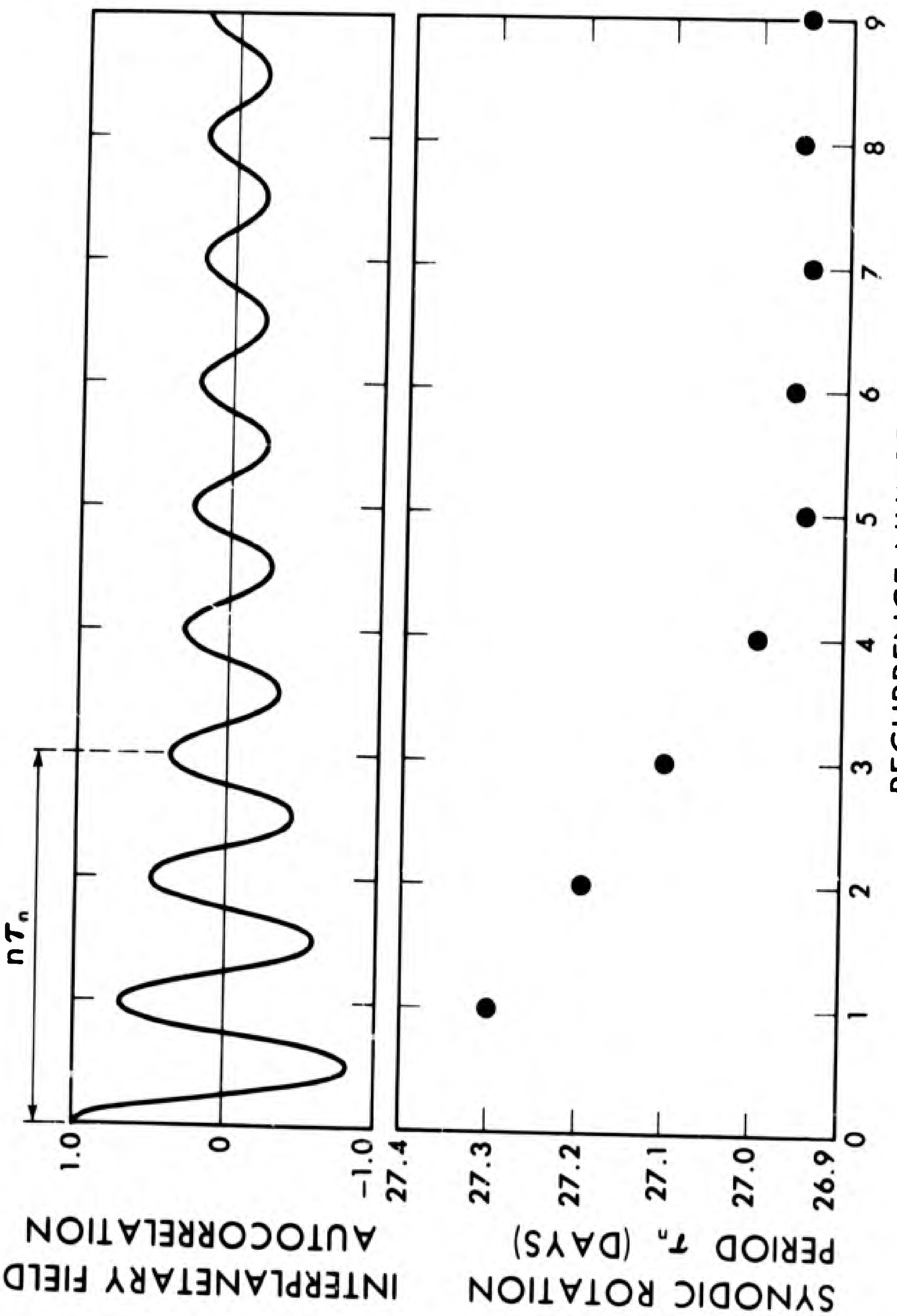
Figure Captions

Figure 1. Schematic drawing of the extended autocorrelation method used in this investigation. A synodic rotation period τ_n is associated with the lag $n\tau_n$ of a peak in the autocorrelation.

Figure 2. Autocorrelation of the interplanetary magnetic field direction versus lag (September 1962 - December 1968). The recurrent peaks selected for further analysis are indicated w th arrows.

Figure 3. Rotation period of the interplanetary magnetic field as a function of recurrence number, as determined from the indicated peaks in Figure 2.



INTERPLANETARY FIELD AUTOCORRELATION
1.0
0
−1.0
$n\tau_n$
SYNODIC ROTATION PERIOD τ_n (DAYS)
27.4
27.3
27.2
27.1
27.0
26.9
0
1
2
3
4
5
6
7
8
9
RECURRENCE NUMBER n

Figure 1

AUTOCORRELATION OF POLARITY OF INTERPLANETARY MAGNETIC FIELD

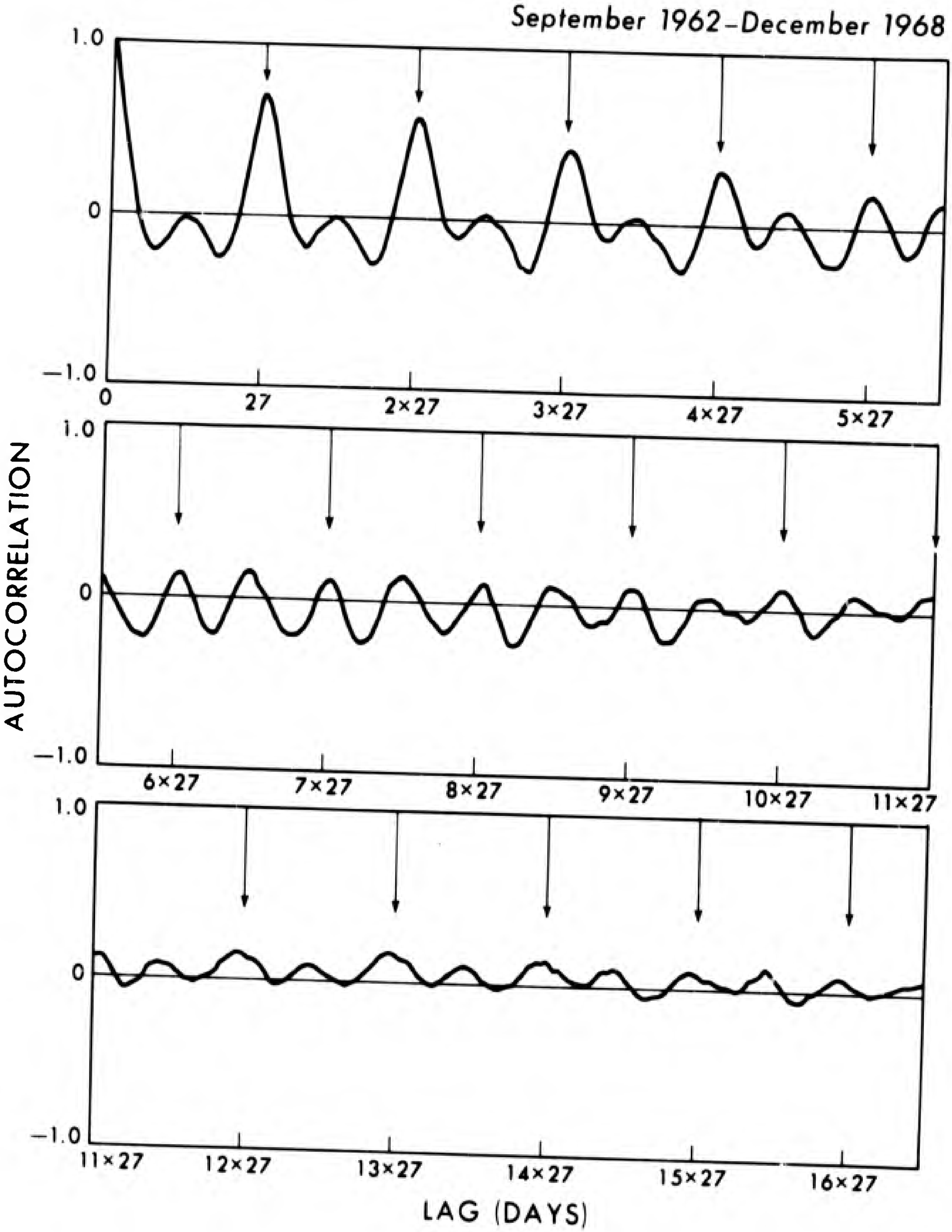


Figure 2

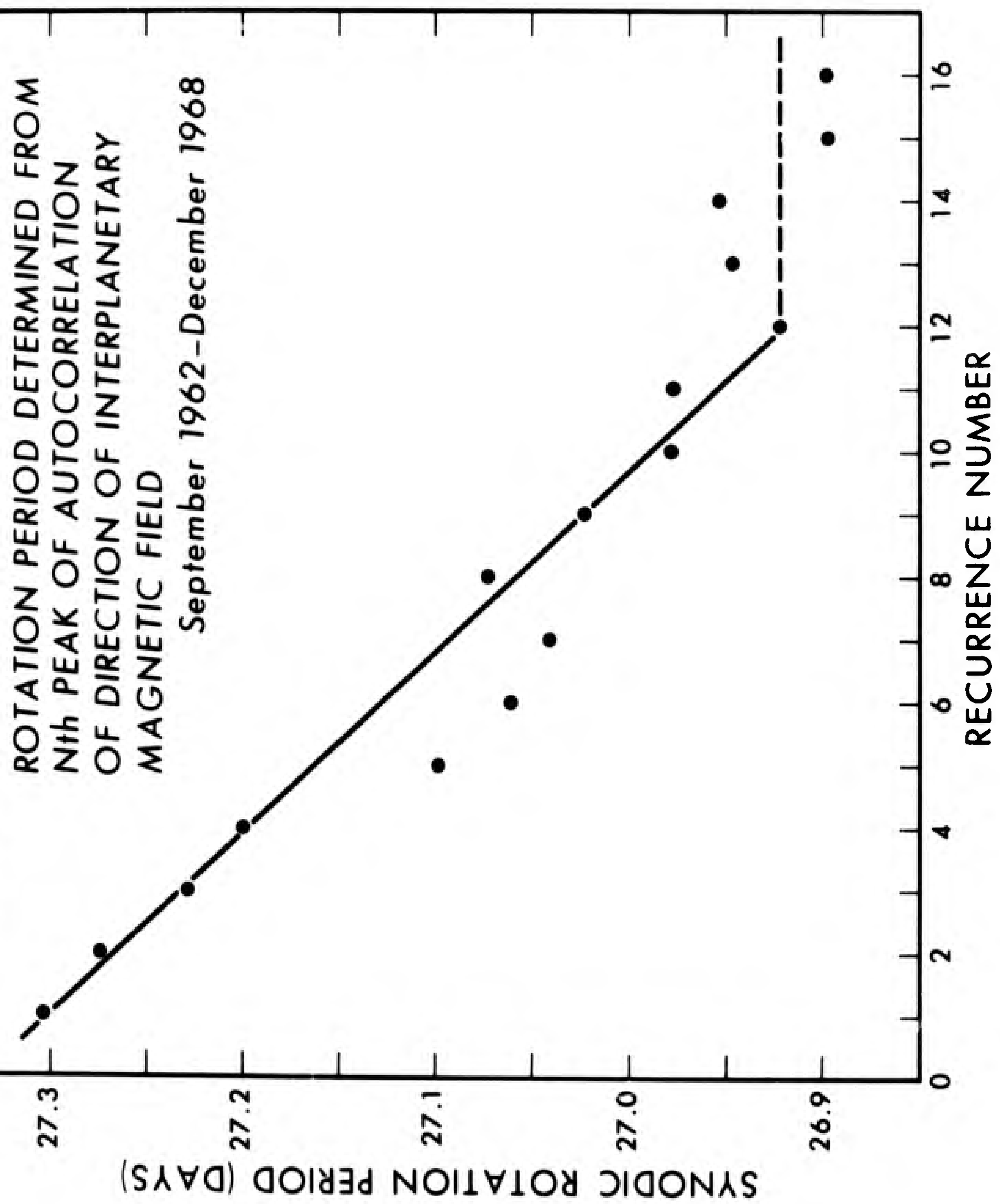

ROTATION PERIOD DETERMINED FROM
Nth PEAK OF AUTOCORRELATION
OF DIRECTION OF INTERPLANETARY
MAGNETIC FIELD
September 1962–December 1968
SYNODIC ROTATION PERIOD (DAYS)
27.3
27.2
27.1
27.0
26.9
RECURRENCE NUMBER
0
2
4
6
8
10
12
14
16

Figure 3