Why Does the Sun Sometimes Look Like a Magnetic Monopole?

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SUIPR Report No. 469

May 1972

Office of Naval Research
Contract N00014-67-A-0112-0068

National Aeronautics and Space Administration
Grant NGR 05-020-559

and

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Abstract

For several months in early 1965 the sun appeared to have large-scale magnetic field directed outwards at nearly all latitudes and longitudes. Several independent observations that lead to this puzzling situation are discussed.

WHY DOES THE SUN SOMETIMES LOOK LIKE A MAGNETIC MONOPOLE?

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A puzzling situation exists in the observations of the sun's magnetic field during the first part of 1965. For three or four consecutive months the observations obtained with solar magnetographs show that the solar field was predominantly directed out of the sun at all solar latitudes. Although it is true that we only observe one hemisphere of the sun at a given time, the continuing predominant polarity of observations during several consecutive months makes it almost certain that the backside solar hemisphere had the same predominant polarity. These surprising observations with the solar magnetograph are at least partially validated by spacecraft observations of the polarity of the interplanetary magnetic field observed near the earth, which show during this same interval that the interplanetary field was very predominantly directed away from the sun.

This interval in the first part of 1965 is near the minimum of the sunspot cycle. The surprising magnetic observations mentioned above can be discussed with regard to some further information. Solar activity has been strongly associated with large-scale solar regions with field directed predominantly into the sun, while the observations mentioned above seem to show that just near solar minimum there is almost no field observed to be directed into the sun. A recent model of magnetic fields in the sunspot cycle, based on interplanetary field polarities inferred from geomagnetic observations during an interval of forty-five years, suggests that an interval of several months at sunspot minimum during which the solar field is very predominantly directed out of the sun may be a characteristic of each sunspot cycle. In the present note we will attempt to describe and develop these interesting circumstances.

Consider first the observations obtained with the solar magnetograph at Mount Wilson Observatory. Figure 1 shows synoptic charts[1] of the photospheric magnetic field during Bartels rotations 1800-1802, which cover the interval February 3, 1965 to April 24, 1965. Contours with dark shading represent field directed out of the sun and contours with light shading represent field directed into the sun. It is clear that at nearly all of the latitudes and longitudes shown in Figure 1, the observed solar field was predominantly directed out of the sun. The solar magnetograph observations during Bartels Rotation 1799 were similar to the situation shown in Figure 1. Thus for several consecutive months the observed solar field had a predominant outward polarity at the latitudes shown in Figure 1 (poleward of about 40^{o} or 50^{o} latitude the field contours are not shown in Figure 1, because of the projection effect). This is a very unusual situation, because the synoptic charts usually show approximate equality between areas of outward and of inward field polarity.

Upon looking at Figure 1 and considering Maxwell's equation $\nabla \cdot \underline{B} = 0$ (integrated over the solar surface), we might come to either of two conclusions. First, perhaps the polar regions of the sun for which the fields are not shown in Figure 1 had field directed predominantly inward to the sun. Second, perhaps during this interval of several months, the zero-level of the solar magnetograph at Mount Wilson was consistently in error by several gauss such as to bias the observations in the direction shown in Figure 1. We will examine each of these possibilities.

Figure 2 shows ten-day averages of the observed longitudinal component of the solar fields poleward of about 60° latitude during the years 1964, 1965 and 1966, obtained with the Mount Wilson solar magnetograph.[2] A letter N represents the average field magnitude in the northern polar region, and a letter S represents the average field magnitude in the southern polar region. The interval in early 1965 is shown with a bracket in Figure 2. During most of this interval the field in the northern polar region is nearly zero and the field in the southern polar region has field directed away from the sun with a magnitude of about 1/3 gauss. There is no indication in the observations shown in Figure 2 of the many magnetic field lines directed into the sun in the polar regions that would be needed to balance the predominantly outward directed field lines shown at the lower latitudes in Figure 1.

Observations obtained with the solar magnetograph at the Crimean Astrophysical Observatory appear to be consistent with the results shown in Figure 2. Severny[3] says "In the first half of the year 1965 (February - June) we observe the appearance at both poles of a field of the same outward* polarity". Severny goes on to observe that "At times, if we judge by the polar field, the sun acts as a 'monopole' of one sign". Thus, all of the available solar magnetograph observations

*We note that in this paper Severny[3] uses the convention that a negative sign represents field directed out of the sun.

consistently show that the sun's polar regions had field predominantly directed outward at both poles during this interval in early 1965.

Let us examine the second possibility mentioned above, that during several consecutive months in this interval the Mount Wilson solar magnetograph had an error in the zero-level of several gauss such as to bias the observations and produce the predominant outward polarity shown in Figure 1. This appears to be unlikely for several reasons. We note that each day's observations were monitered in real time at Mount Wilson through the use of an X-Y plotter. During the considered interval almost every daily solar magnetogram showed field directed out of the sun in most areas. This surprising situation resulted in immediate attention to the optical and electronic components to try to detect an error in the zero-level. For several months these efforts were unsuccessful, and finally the "difficulty" mysteriously went away.

The solar observations with the solar magnetograph at the Crimean Astrophysical Observatory were in agreement with the Mount Wilson observations as described above. Thus if the Mount Wilson observations had an instrumental error of several gauss, then the Crimean observations would have had a similar instrumental error. Kotov and Stenflo[4] have shown that during the summer of 1968 simultaneous measurements of the polar magnetic fields made at the Crimea and at Mount Wilson were in good agreement.

A strong independent validation of at least some of the Mount Wilson observations shown in Figure 1 comes from observations made with spacecraft of the polarity of the interplanetary magnetic field near the earth. This interplanetary field polarity is usually very similar to the large-scale photospheric field polarity.[5,6] The observed interplanetary field was very predominantly directed away from the sun during the first part of 1965, that is, during most of Bartels Rotations 1799 through 1802. These spacecraft observations are represented by the bars drawn at the bottom of the synoptic charts in Figure 1, and are plotted four days later to allow for the transit time of the solar wind plasma that brings the magnetic lines from near the sun to the earth. (One of the clearest individual examples of the solar magnetic sector boundary structure inferred by Wilcox and Howard[7] can be seen in the narrow region near the start of rotation 1802 with field directed into the sun from 40° north to 40° south. The resulting narrow inward polarity interplanetary sector can be seen in the spacecraft observations. The fact that this inward polarity region shows so clearly in the solar magnetograph observations is some additional evidence against the presence of a large error in the instrumental zero-level at this time.)

A broader perspective on the spacecraft observations of predominant outward polarity can be gained by inspection of Figure 2 of Wilcox[8]. This figure shows that these four consecutive Bartels Rotations have the most concentrated predominantly outward polarity of any such interval that has been observed with spacecraft. Severny[3] has noted that "If the interplanetary field is a continuation of the solar field, which is indicated by the close connection between the data on the interplanetary field and the appearance on the sun of regions of heightened magnetism, then the fine structure of the interplanetary field is a reflection of the fine structure of the sun's general field and the preponderance of a field of one sign indicates a continuation into interplanetary space of the effect of the disruption of balance observable in the photosphere and chromosphere." Thus it appears that the predominant polarity situation existing in early 1965 cannot easily be dismissed as an instrumental effect.

Since the solar magnetograph actually measures the product of the line-of-sight components of the field and the brightness, the magnetograph observations of a predominantly outward polarity might be explained by postulating a configuration in which the inward field lines were concentrated in small dark filaments and therefore not properly measured by the magnetograph. The outward field lines would be postulated to be much more spread out and therefore fully measured by the magnetograph. (If such a situation were to obtain over the entire sun, it would be quite interesting in itself.) However, it appears to be very unlikely that any such configuration could cause the spacecraft magnetometers to miss any appreciable amount of inward polarity field.

The predominant outward polarity observed at the minimum of the sunspot cycle can be related to some other considerations. Solar activity has been strongly associated with large-scale solar regions of predominantly inward field polarity, so that the interval of predominantly outward field polarity just at the minimum of the activity cycle may have fundamental significance. Bumba[9] says "Again in the present cycle, as in the previous one, the concentrations of solar activity inevitably coincide with concentrations of negative polarity fields on the large scale" and also discusses the "close relation of the position of very large flares (flares with cosmic ray and PCA events) to the regularities in the internal structure of hugh features formed in inward polarity regions." Similar results have been discussed by Ambrož, et al.[10] It is important to note that the association of solar activity with inward polarity regions has been observed during at least two sunspot cycles and in both the northern and the southern solar hemispheres. If such an association existed in a single solar hemisphere during a single sunspot cycle, the association might be related to the dynamical differences between preceding and following magnetic regions and sunspots, but when activity remains associated with just the <u>inward</u> polarity through two sunspot cycles and in both solar hemispheres, then this association assumes a more fundamental importance.

The above considerations are further illuminated by Svalgaard's[11] recent model of the sunspot cycle. Svalgaard used interplanetary magnetic field polarities inferred[12] from forty-five years of polar geomagnetic observations. This method has been validated by Friis-Christensen, et al.[13] Portions of five sunspot cycles were available for the analysis. It appears that each of these sunspot cycles ended with an interval of a few months of predominantly outward field polarity. One such interval in early 1965 has been discussed above. In July, August and September, 1954, Svalgaard has inferred that the interplanetary field polarity was almost completely outward. Thomson[14] examined the solar diurnal variation of cosmic rays at the 1954 solar minimum, and says "It has generally been assumed that the away and the toward magnetic flux near the ecliptic plane is roughly in balance. We would like to suggest that this was probably not the case in the period July-September 1954 and that at that time the field was predominantly in one direction." Thus two very different methods of analysis have each suggested that a very unusual situation existed in July-September of 1954. Each strongly validates the other.

It is clear that the final word on the interesting situation described in this note remains to be said. It seems very likely that the resolution of this puzzle will be quite interesting.

This work was supported in part by the Office of Naval Research under Contract N00014-67-A-0112-0068, by the National Aeronautics and Space Administration under Grant NGR 05-020-559, and by the National Science Foundation under Grant GA-31138.

References

1. R. Howard, V. Bumba, and S. F. Smith, Carnegie Institution of Washington Publication 626 (1967).
2. R. Howard, "Polar Magnetic Fields of the Sun: 1960-1971", submitted to Solar Physics, 1972.
3. A. B. Severny, Iz. Krim. Ast. Obs. 38, 3 (1968).
4. V. A. Kotov and J. O. Stenflo, Solar Physics 15, 265 (1970).
5. A. Severny, J. M. Wilcox, P. H. Scherrer, and D. S. Colburn, Solar Physics 15, 3 (1970).
6. J. M. Wilcox, Space Science Reviews 8, 258 (1968).
7. J. M. Wilcox and R. Howard, Solar Physics 5, 564 (1968).
8. J. M. Wilcox, Comments on Astrophysics and Space Physics 3, 133 (1971).
9. V. Bumba, Proceedings of the Conference on the Solar Wind, Asilomar, California, March 1971, to be published.
10. P. Ambrož, V. Bumba, R. Howard, and J. Sýkora, in "Solar Magnetic Fields," (R. Howard, Ed.) p. 696, D. Reidel Publishing Company, Dordrecht-Holland, 1971.
11. L. Svalgaard, "Interplanetary Sector Structure during 4 Solar Cycles," Solar Physics Division Meeting, American Astronomical Society, University of Maryland, College Park, Maryland, April 4-6, 1972, to be submitted to Solar Physics.
12. L. Svalgaard, Danish Meteorological Institute Geophysical Papers R-6, (1968).
13. E. Friis-Christensen, K. Lassen, J. M. Wilcox, W. Gonzalez, and D. S. Colburn, Nature Physical Science 233, 48 (1971).
14. D. M. Thomson, Planetary and Space Science 19, 1169 (1971).

Figure Captions

Figure 1. Synoptic charts of the photospheric magnetic fields observed with the solar magnetograph at Mount Wilson Observatory. The dark contours represent field directed out of the sun and the light contours represent field directed into the sun. The first three contour levels are about 6, 10 and 16 gauss. The charts are equal-area projections of the solar surface obtained with a square aperture 23 arc-seconds on a side. The bars at the bottom of the charts represent the polarity of the interplanetary magnetic field near the earth observed with spacecraft, and are plotted four days later to allow for the transit time of solar wind plasma from near the sun to the earth (after Howard, et al.[1]).

Figure 2. Ten-day averages of the polar fields observed above about 60^{o} latitude on the sun. A letter N represents the average field observed in the northern polar region, and a letter S represents the average field observed in the southern polar region. The ordinates are in gauss, with a positive sign representing outward field polarity (after Howard[2]).

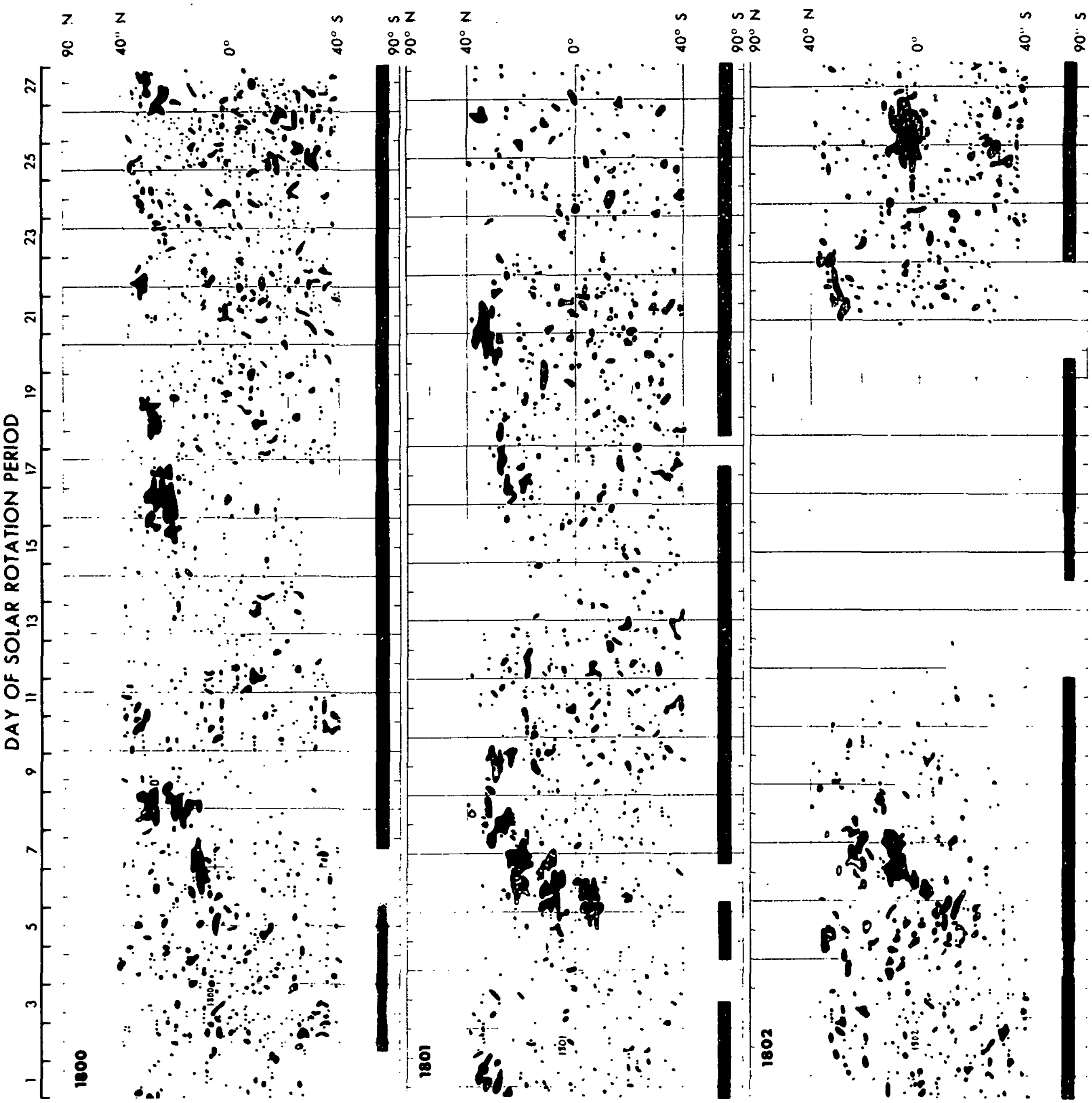
DAY OF SOLAR ROTATION PERIOD
1
3
5
7
9
11
13
15
17
19
21
23
25
27
1800
1801
1802
90° N
40° N
0°
40° S
90° S

Figure 1

10-DAY AVERAGES OF POLAR FIELDS

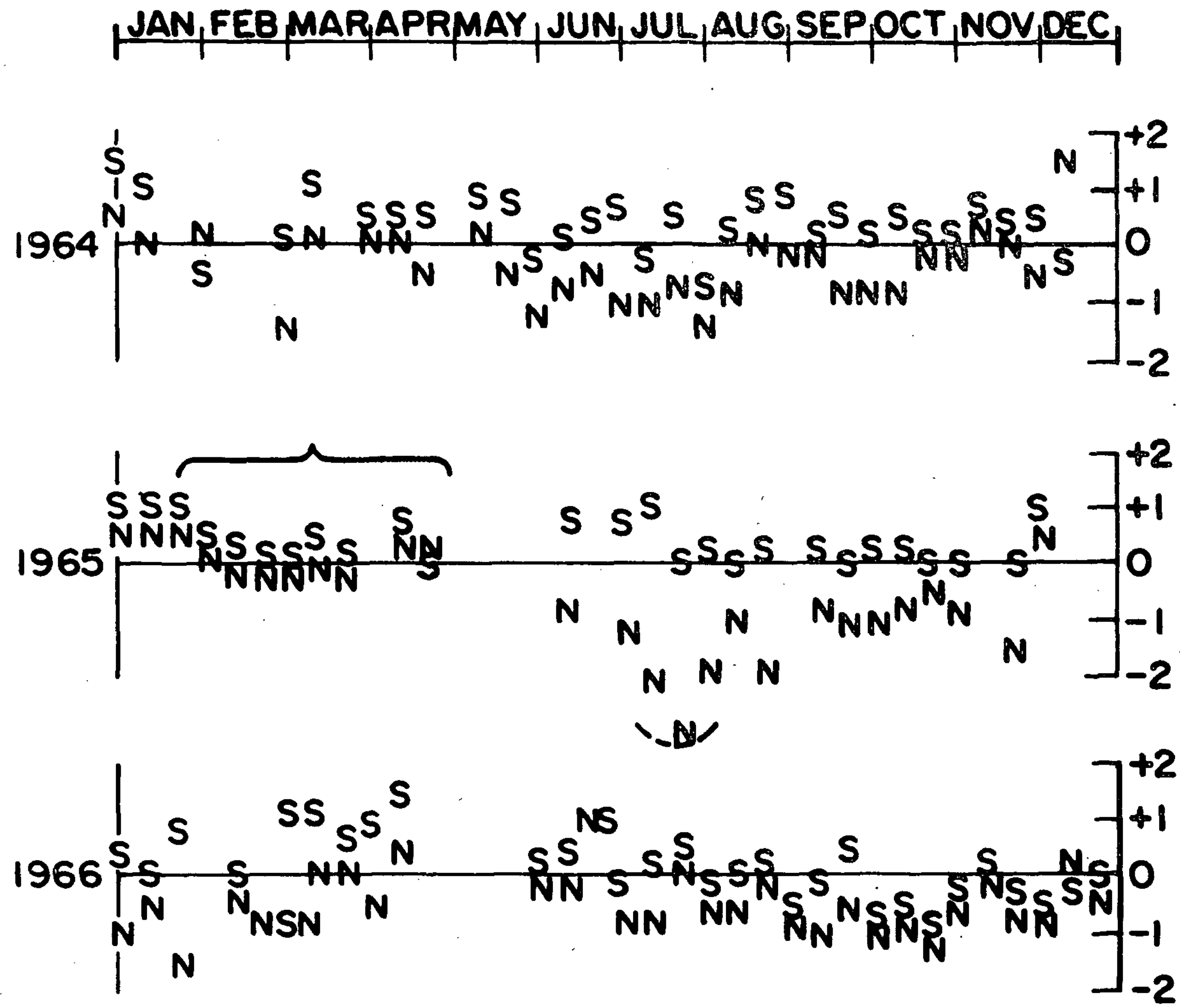

Figure 2

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) Institute for Plasma Research Stanford University Stanford, California 94305	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

WHY DOES THE SUN SOMETIMES LOOK LIKE A MAGNETIC MONOPOLE?

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

Scientific Interim

5. AUTHOR(S) (First name, middle initial, last name)

John M. Wilcox

6. REPORT DATE 11 May 1972	7a. TOTAL NO. OF PAGES 14	7b. NO. OF REFS 14

8a. CONTRACT OR GRANT NO N00014-67-A-0112-0068 b. PROJECT NO. NR 323-003 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) SUIPR Report No. 469 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES TECH, OTHER	12. SPONSORING MILITARY ACTIVITY Office of Naval Research 800 North Quincy Street Arlington, Virginia 22217

13. ABSTRACT

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
SOLAR MAGNETIC FIELD						