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## Upper Atmosphere Geophysics

REPORT UAG-5

# DATA ON SOLAR EVENT OF MAY 23, 1967 AND ITS GEOPHYSICAL EFFECTS

February 1969

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# DATA ON SOLAR EVENT OF MAY 23, 1967 AND ITS GEOPHYSICAL EFFECTS

## 1. INTRODUCTION AND SUMMARY OF GENERAL SOLAR CONDITIONS

by

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This report was inspired by the offer of a collection of reduced magnetic records for the May 25-26, 1967 geomagnetic storm by S.-I. Akasofu for publication in the IER-FB "Solar-Geophysical Data" reports. At approximately the same time we became aware of several papers in the literature concerned with the solar flare associated with this storm. Also at the September 1968 International Symposium on the Physics of the Magnetosphere in Washington, D. C., several papers were read presenting satellite data concerned with the period. Thus, it was decided that rather than publishing simple data tabulations or figures in the "Miscellaneous Section" of "Solar-Geophysical Data", we should compile an expanded data publication.

Some of the data published in "Solar-Geophysical Data" are repeated here, and other reports routinely sent to World Data Center A, Upper Atmosphere Geophysics, have been utilized. The significance of the report rests, however, in the expanded contributions of the many scientists who made this data collection possible. Since it has been impossible to circulate each person's contribution to each of the others, there will be some repetition, but from different viewpoints.

The data are grouped into 8 sections, with several contributors to most of them. In some cases the introductory text is supplied by the compiler.

It should be noted that it was not practical in this case to search out relevant data from all worldwide sources. Rather, we have requested cooperation from regular contributors to the World Data Center and from other sources which happened to come to our attention. It may be mentioned that the Pennsylvania State University, Radio Astronomy Observatory was unfortunately not in operation at the time of this flare and so is not represented in this report.

The cooperation of all contributors to this report as identified in detail in the various subsections is gratefully acknowledged.

### General Solar Conditions

Figure 1 shows the daily scout maps of solar phenomena on May 23, 1967, as reprinted from "Solar-Geophysical Data", IER-FB 275, issued July 1967.

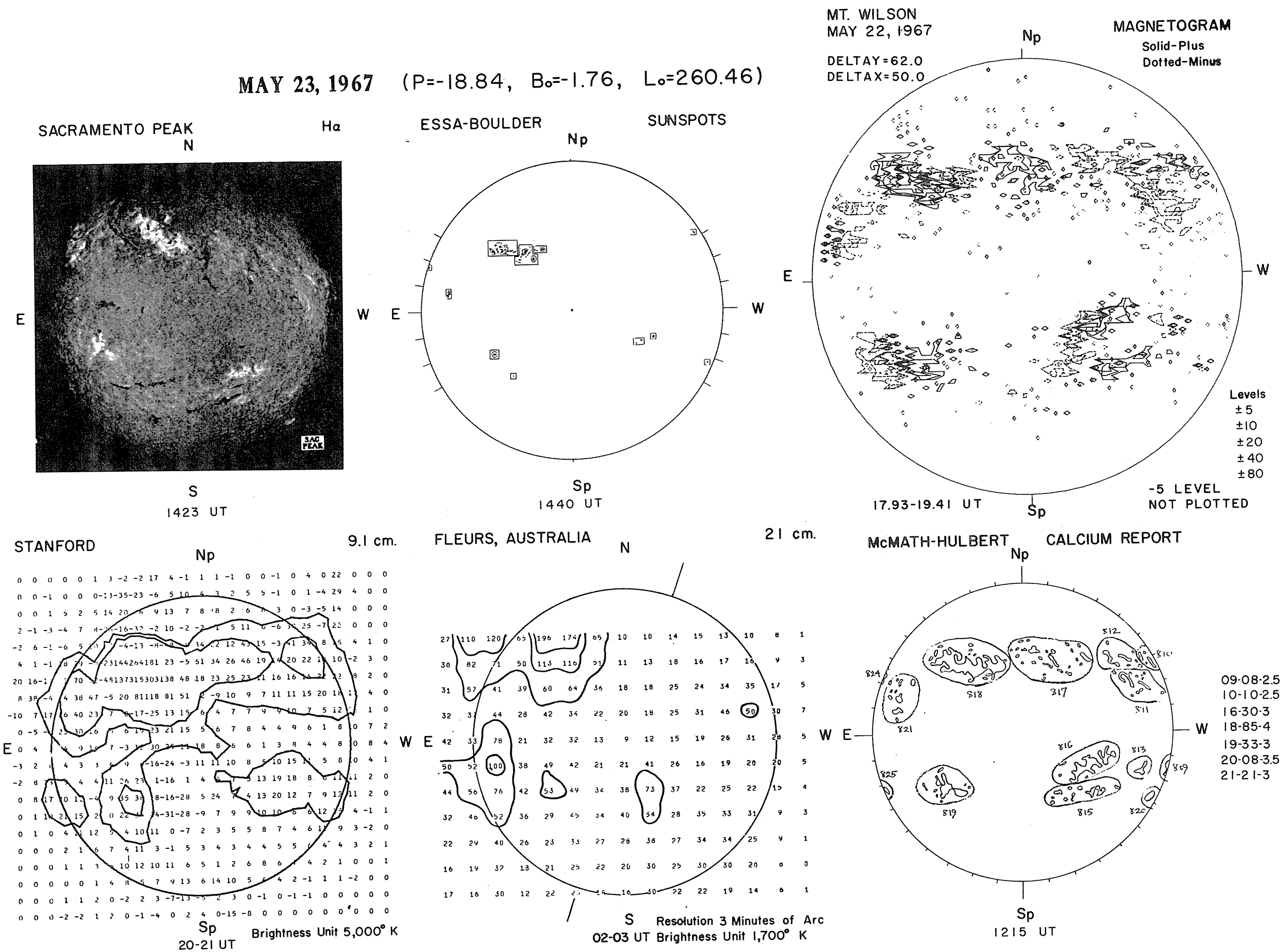



Fig. 1. General solar situation as depicted by Hα, sunspots, general solar magnetic field, 9.1 cm radiation, 21 cm radiation and calcium plages.

The final $R_z$ and 2800 MHz solar flux associated with the transit of the solar region are:

| May | $R_z$ | $S_A$ | May | $R_z$ | $S_A$ | May | $R_z$ | $S_A$ |
|---|---|---|---|---|---|---|---|---|
| 18 | 55 | 124.8 | 23 | 145 | 194.0* | 28 | 197 | 202.6 |
| 19 | 70 | 135.6* | 24 | 159 | 200.9 | 29 | 164 | 188.3 |
| 20 | 80 | 146.3 | 25 | 164 | 210.7 | 30 | 150 | 177.4 |
| 21 | 99 | 160.3* | 26 | 174 | 218.9* | 31 | 147 | 175.4 |
| 22 | 118 | 182.7 | 27 | 194 | 213.8 | June 1 | 138 | 174.6 |
| | | | | | | 2 | 118 | 158.0* |

* Adjusted for solar burst.

These are the highest daily values as yet reported for the current sunspot cycle. The histogram (Fig. 2) depicts these same values with several days either side in addition.

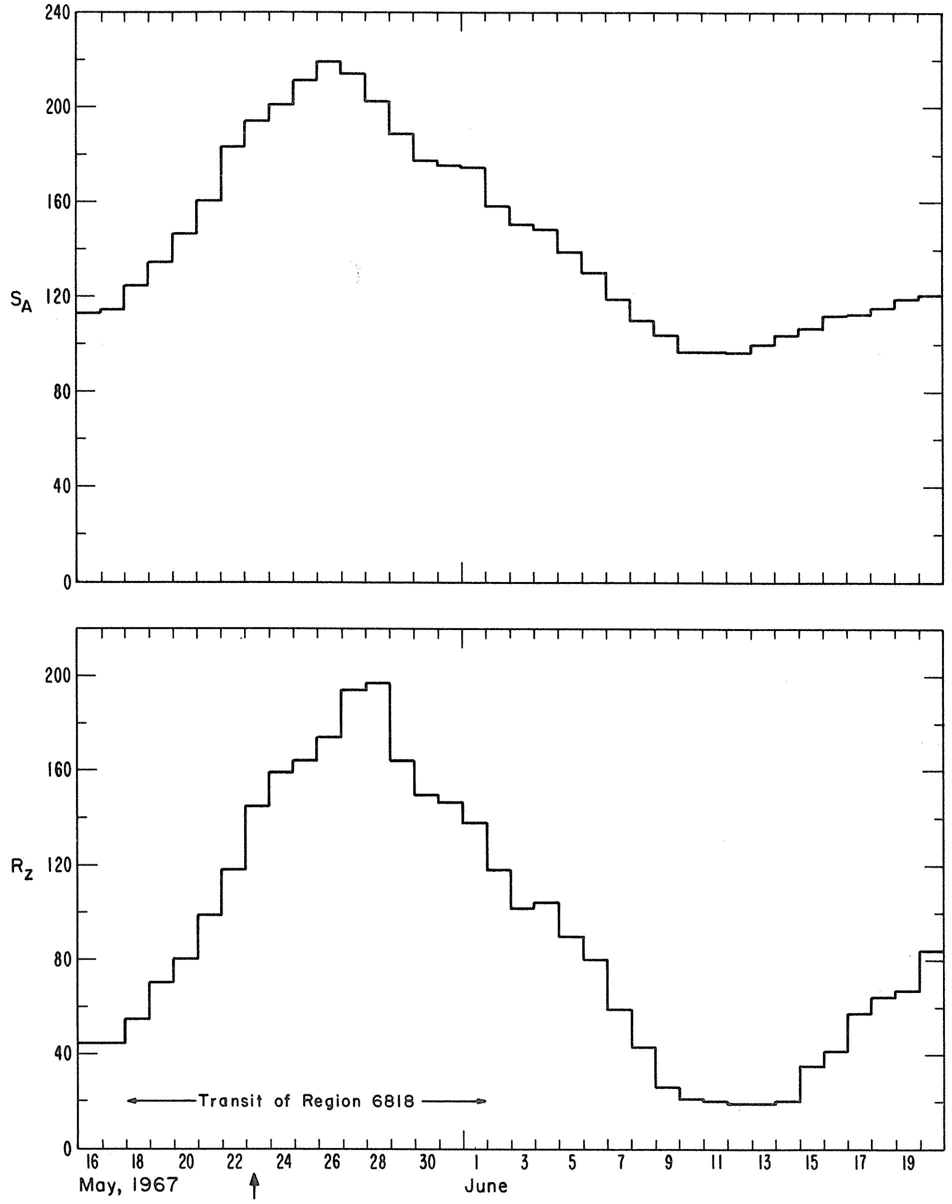



Fig. 2. Daily solar flux at 2800 MHz adjusted to 1 A.U., $S_A$, and relative sunspot numbers, $R_z$, May 16 - June 20, 1967.

## 2. THE SOLAR FLARE AND SUNSPOT REGION

"Visual and Photographic Observations of a White-light Flare on May 23, 1967"

by

H. L. DeMastus and R. R. Stover
Sacramento Peak Observatory, Sunspot, New Mexico

[The following paragraphs are adapted from the article as published in Publications of the Astronomical Society of the Pacific, 79, 615-621, December 1967, reprinted by permission of the editor.]

A large and concentrated region of sunspots of at least three separate groups located at latitude approximately N26 produced chromospheric flares of importance one or larger from May 18 through 29, 1967. On May 23 a series of three separate Hα flares occurred between 1803 and 2156 UT in the largest of these sunspot groups. The second and brightest flare in this sequence is of special interest. Both visual and photographic observations show parts of the flare structure visible in continuum light.

An importance 3 B+* flare began at 1834:40 UT in the western portion of the large penumbral region at N27 and E24. The flare rapidly developed into two approximately parallel bright ribbons by 1838 UT. Figure 1 (1840:50 UT) shows the flare at Hα ± 2 Å. Visual analysis of the Hα light curve indicates flare maximum occurred at 1844:00 UT ± 10 seconds. The recording flare videometer records indicate an integrated intensity maximum at 1844:30 ± 15 seconds. Sufficiently underexposed Hα pictures were also helpful in determining the maximum time of the Hα event.

Two patches of continuum brightening were observed visually between 1838 and 1845 UT by patrol observers with reported maximum intensity at approximately 1840 UT. Figure 2 shows the relative locations of the visually and photographically observed white-light enhancement with those of the bright filaments in Hα.

Patrol sunspot films show the first indication of continuum brightening at 1837:00 or 1837:30 UT with a rapid increase in radiation beginning at 1839:00 UT. Apparent maximum brightness occurred at 1840:00 (Figure 3). The last frame with any detectable white-light emission was at 1846:30 ± 30 seconds. Maximum white-light intensity apparently preceeded the Hα flare maximum by three to four minutes.

Microphotometer measurements of the two white-light patches made just prior to the increase in continuum intensity and at maximum continuum emission show a total intensity change of approximately 16 percent for the brighter patch and a change of approximately 12 percent for the fainter patch in the continuum around 5800 Å.

*At Sacramento Peak the total corrected area of this flare was measured at 12.42 square degrees, which is just into the importance three category (Imp 2 = 5.15 through 12.39 sq deg). The numerical importance of this most complex event - especially a borderline case - will depend to a great extent on such things as filter profile, image quality, time resolution, film emulsion characteristics and observer interpretation. This can explain reported importance differences for the event.

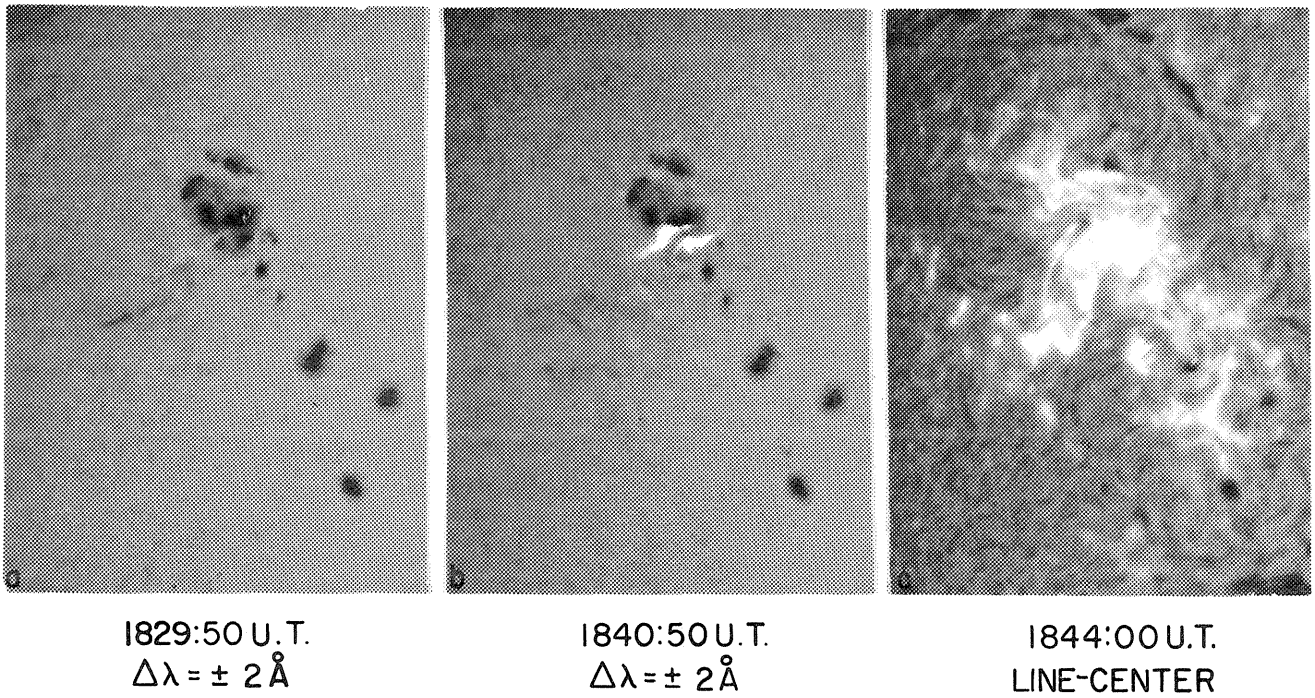



Fig. 1. Hα FLARE PATROL

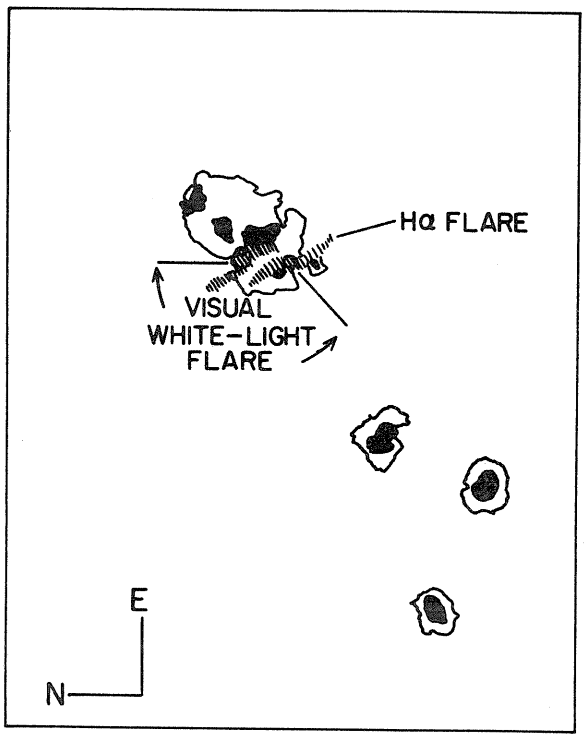
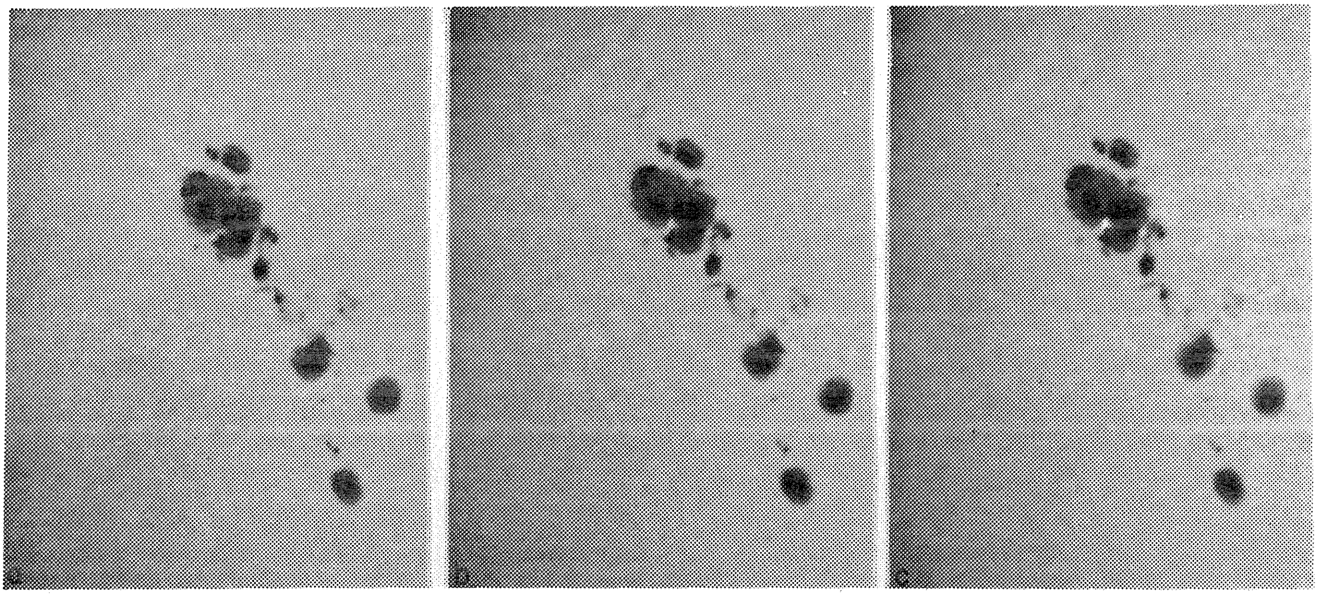



Fig. 2. Visual and Hα enhancements May 23, 1967



1838:00 U. T. 1839:00 U.T. 1840:00 U.T.

Fig. 3. SUNSPOT PATROL CENTERED AT 5800 Å

"Description and Evaluation of the Major H$\alpha$ Flare, May 23, 1967"

by

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McMath-Hulbert Observatory
The University of Michigan

## INTRODUCTION

On May 23, 1967 between $\sim$1803 and 2300 UT a major solar flare occurred in the northeast quadrant of the sun. The event was observed totally or in part at Huancayo, Lockheed, Haleakala, Houston, San Miguel, Culgoora, and Sacramento Peak Observatories. It was cloudy at the McMath-Hulbert Observatory. The optical flare already has been described by DeMastus and Stover (1967).

The radio frequency, x-ray, ionospheric, and particle aspects of this flare were so great that special interest in the flare has developed and efforts have been made to bring together in one place all observations related to the event. As part of this program we at the McMath-Hulbert Observatory were asked to review the reports of all who were observing the sun at the time of the event in the manner of our "Reevaluation of Solar Flares, 1964-1966" (Dodson and Hedeman, 1968). In addition, the astronomers at Sacramento Peak Observatory were good enough to send us their film of the 1967 May 23rd flare with the suggestion that we attempt yet another evaluation of the complex solar circumstances on that day. We are most grateful to our colleagues at Sacramento Peak for the opportunity of looking at the primary record of this truly major flare. We hope the accompanying report will enable solar astronomers and geophysicists to visualize, at least in part, the sequence of phenomena in the exceedingly complex, and somewhat atypical, event that took place on May 23,1967.

We feel confident that different investigators examining the H$\alpha$ record of the sun from $\sim$1800 to 2300 UT on May 23, 1967 would have different opinions about the portions of the sun that should be considered as "flaring" at particular times. They probably also would differ in their interpretations of the event. Although these differences already are evident in the reports to World Data Centers from the individual observing stations, there is a certain gratifying accord in the total data. The reports indicate that the event was either one flare with three maxima, or possibly three separate flares since the flare spread to three different parts of the plage. At no time between 1803 and 2200 UT, however, did the intensity drop to preflare level. The reported areas for times at or near the respective intensity maxima range from those that are associated with the upper limits of importance 2 to the lower limits that lead to an evaluation of importance 3.

After studying carefully the H$\alpha$ record of the flare entrusted to us, we look upon the event as a single flare, but with three phases as well as three intensity maxima. Our estimates of the area of the flare (as seen by us on the Sacramento Peak film) at each of the intensity maxima tend to be greater than those reported by other observers. For each intensity maximum our measurement of the total flaring area, on the center of Hα records, exceeded the lower limit for a flare of importance 3, viz. 12 square degrees. For the second maximum 1844 UT we measured 18 square degrees. The assumption of a single flare with triple maxima can be expected to lead to reports of larger total areas at specific times than if the event had been considered to be three separate but partially concomitant flares. However, it also should be realized that in our measurements for the 1967 May 23rd flare, we were studying records with photographic properties different from those to which we are accustomed. Our evaluations based on the premise that the flare on 1967 May 23 between 1803 and 2300 UT was a single event are summarized below:

| | Start (UT) | Maximum (UT) | Area (Sq. Deg.) | Importance |
|---|---|---|---|---|
| Phase 1 | 1803 | ∿1817 | ∿12.5 | 3b |
| Phase 2 | ∿1835 | 1843 - 1845 | ∿18 | 3b |
| Phase 3 | ∿1932 | ∿1950 | ∿16 | 3b |

## DESCRIPTION OF THE FLARE

### Phase One

The flare-event began at 1803 UT with the brightening of the portions of the Hα plage marked (1) in Figure 1A. Between 1806 and 1812 UT flare emission increased markedly in intensity and spread northward along the east side of a long filament to isolated portions of the Hα plage. This development is crudely indicated by the numerals 1b in Figure 1A. The first phase of the flare reached a "bright" maximum intensity at ∿1817 UT. A diagram showing the location of flare emission for this maximum is given in Figure 2B. At this time flare emission was superposed upon two umbrae of R polarity and impinged upon an umbra of V polarity. Compare Figures 2A and B.

For the next ∿20 minutes the intensity of the flare diminished but still remained bright. During this interval a small, very narrow, dark, filament-like feature became more conspicuous on the eastern edge and near the southern foot of the long filament that entered the plage from the northwest. (The central numeral (1) in Figure 1A approximately marks the location of this small feature.) Within the accuracy with which the various records can be compared, the small filament appeared to lie between and to the north of the adjacent R and V umbrae within the large eastern penumbra. During phase one of the flare, this small dark filament was bordered by very narrow tracks of bright emission in the center of Hα pictures. In phase two, the two patches of white light emission and the two regions of wide Hα flare emission developed on either side of this little filament.

### Phase Two

The second phase of the flare can be said to have started at ∿1835 UT with increasing intensity in existing flare regions and with the development of new centers of flaring emission. During the rise to the second intensity maximum, and as reported by DeMastus and Stover (1967, "a flare wave was visible between $18^h37^m30^s$ and $18^h42^m30^s$ UT which traveled a distance of 0.3 solar radius beyond the flare region." Successive locations of manifestations of this rapidly expanding feature are shown in Figure 1B. The wave apparently moved northward

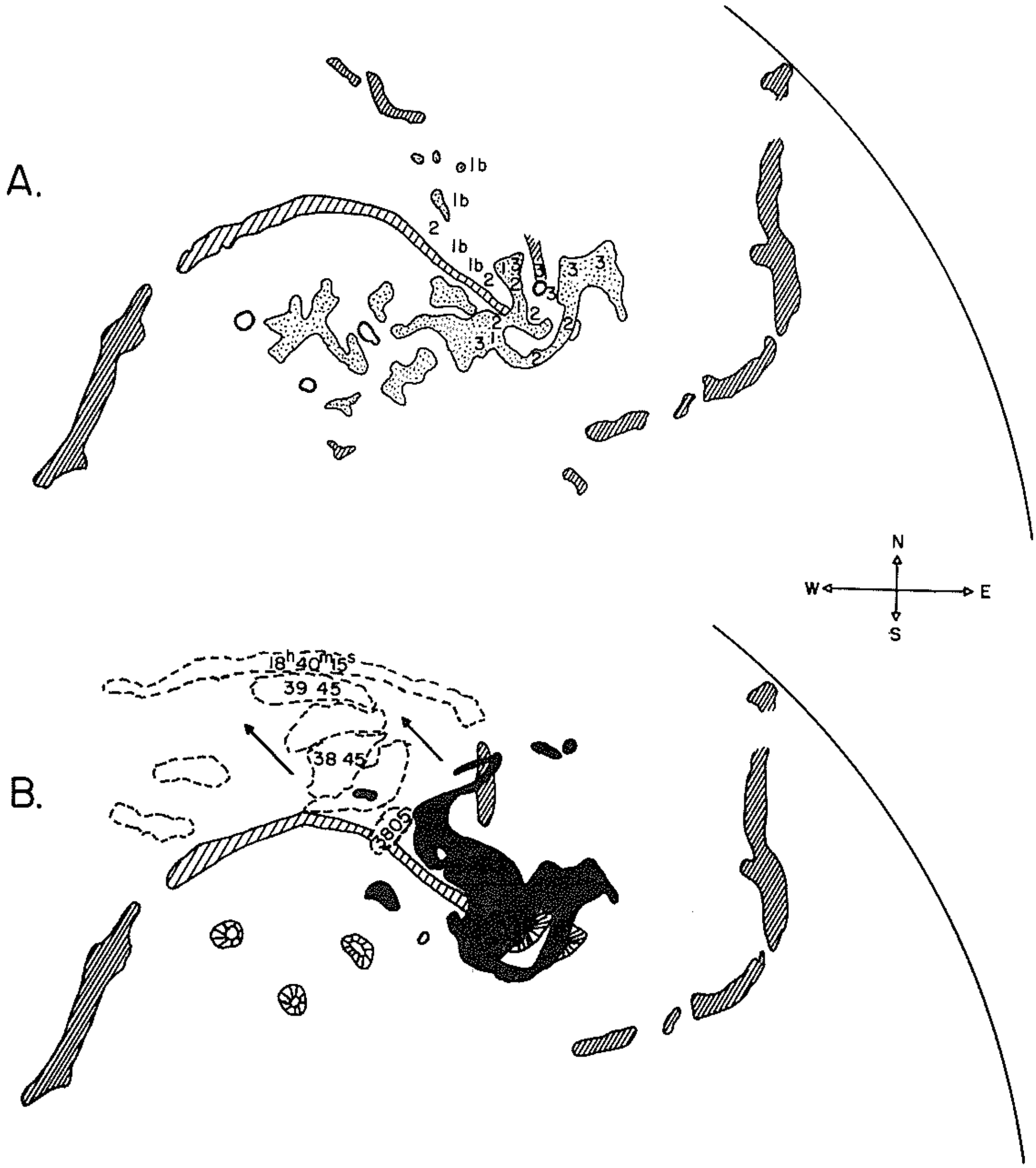


Fig. 1. A: Schematic presentation of Hα spectroheliogram on May 23, 1967 showing plage, filaments, spots, and general location of flare during three phases of event.

Hα plage - stippled
Filament - parallel, diagonal lines; denser lines indicate more conspicuous feature
Spot umbra - white
Flare location - numerals 1, 2, 3

B: Schematic presentation of composite location of Hα flare emission, and rapidly expanding flare-wave, May 23, 1967.

Filament - parallel diagonal lines; denser lines indicate more conspicuous feature
Flare emission - black
Spot - umbra, white; penumbra, radial lines
Expanding flare wave - dotted outline, 1838 - 1840 UT

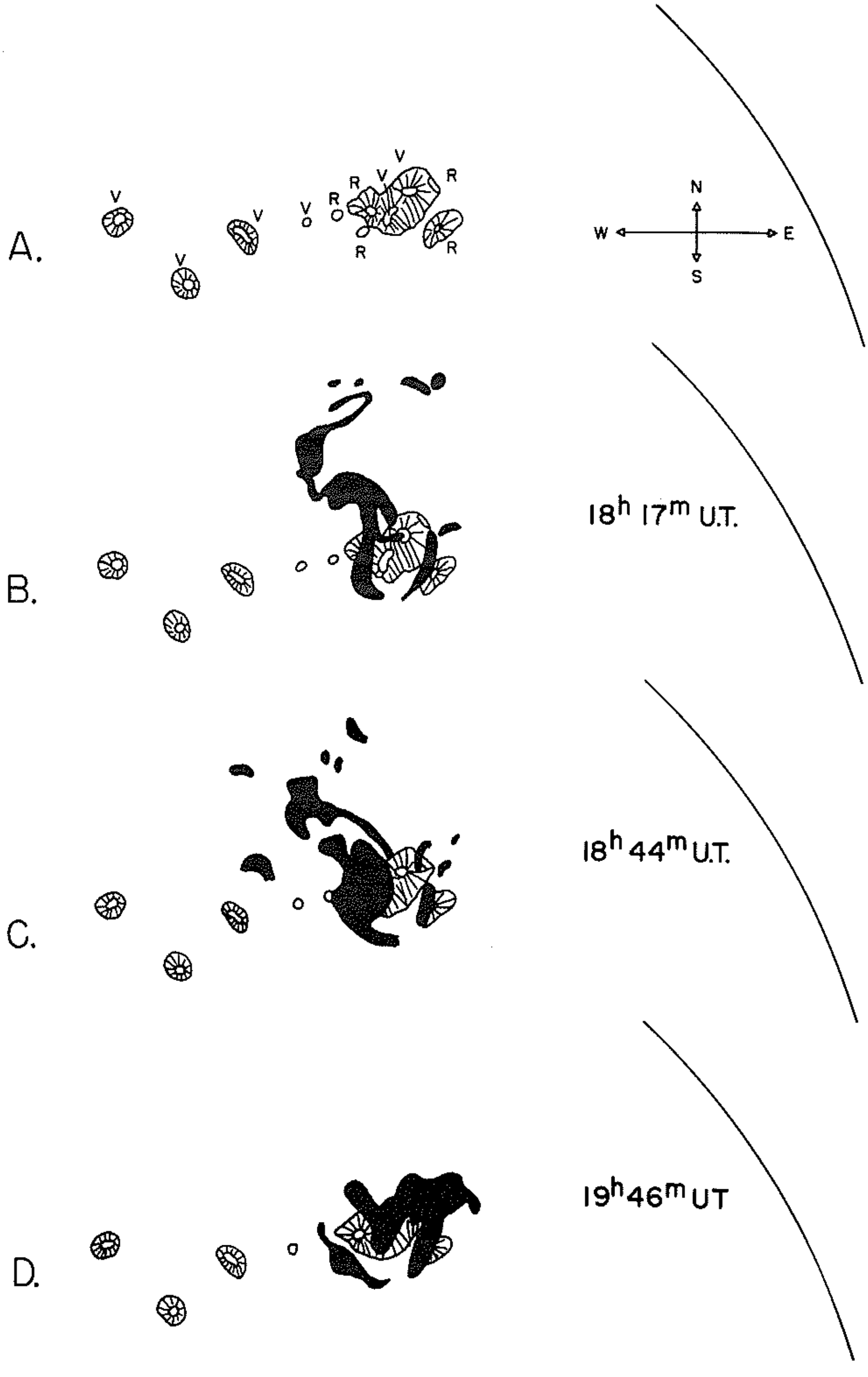


Fig. 2. A: Schematic presentation of sunspots near the flare, 1803 - 2300 UT, May 23, 1967.
Polarities, as measured by the McMath-Hulbert Observatory at ∿1300 UT are indicated by the letters R and V

B-D: Schematic presentation of Hα flare emission with respect to spots at the times of the three maxima.
Flare - black
Spots - umbra, white; penumbra, radial lines

or northwestward with a velocity of ∼1000 km/sec. The manifestations of this expanding feature both in and out of wavelength were in general accord with the description of the expanding feature given in the study of the 1966 August 28 flare by Dodson and Hedeman (1968). The limbward location of the 1967 May 23rd expanding feature made it less auspicious than the earlier event for detailed study. If one extrapolates the location of the flare-wave backward to the starting time of phase two of the flare, i.e., 1835 - 1836 UT, one passes close to the foot of the large filament and the regions that were to be the sites of the principal flare emission at ∼1844 UT, the time of maximum intensity of phase two. On 1967 May 23 as on 1966 August 28 the apparent shape and location of the rapidly expanding feature bore a certain kinship to the pattern of previously existing filaments. See Figure 1B.

Another event of great interest occurred during the rise to Hα maximum of phase two of this complex flare. According to visual observations obtained by McIntosh (1967) at Boulder and Stover and Flynn at Sacramento Peak, distinctly enhanced white light radiation could be seen from ∼1837 to ∼1846 UT. The patrol sunspot films at Sacramento Peak confirmed the observations. The white light emission apparently reached maximum intensity at ∼1840 UT, at least 3 or 4 minutes prior to Hα maximum. The white light emission is well shown in the frontispiece of Solar Physics for September 1968, in pictures submitted by J. W. Evans.

Maximum intensity of phase two of the 1967 May 23 flare was attained between 1843 and 1845 UT. Photographs showing the Hα flare at these times have been published by DeMastus and Stover (1967 see above). A diagram indicating the location of flare emission in the center of Hα at 1844 UT is shown in Figure 2C. The general regions of flare emission in phase two are identified by the numeral 2 in Figure 1A. By the time of maximum intensity in phase two, bright flare emission had extended southeastward until it completely covered the large umbra (V polarity) in the central part of the large penumbra. From 1845 to 1932 UT the intensity of the flare emission diminished markedly but continued to be of flare brightness.

## Phase Three

At 1932 UT new flare segments appeared and intensity increased in the easternmost extremities of the Hα plage. A third intensity maximum was attained at ∼1950 UT with the brightest parts of the flare extending across the two large umbrae of V polarity in the large penumbra, and across the two easternmost spots and umbrae of R polarity. See Figures 2A and D. The general locations of flare emission in phase three of the flare are indicated by the numeral 3 in Figure 1A. Flare emission was still present at 2156 UT when the Sacramento Peak film was interrupted. According to later coverage by Haleakala and Culgoora the flare was still in progress at 2300 UT.

## General Aspects

The foregoing description has attempted to point out that the unusual flare-events of 1967 May 23 appeared primarily as three impulses within a flare whose center of intensity migrated progressively from the northwestern to the southeastern parts of the Hα plage. The overall Hα flare appeared to advance slowly in a direction opposite to that of the rapidly moving flare wave of 1837 - 1842 UT. See Figure 1B. During all phases, flare emission covered major umbrae.

The area of the umbrae covered by flare emission was much greater in phases two and three than in phase one. See Figures 2A-D. A composite plot of the Hα flare at the three maxima, drawn in Figure 1B, shows that all of the umbrae in the eastern part of the center of activity were, at one phase or another, covered by flare emission.

The flare did not present an aspect in which one could see readily the two bright filaments that dominate so many major flares. Nevertheless this type of structure could be discerned in the location of the principal flare emission during the second and third phases of the flare.

At no time from 1803 UT to 2156 UT did the records seem to us to indicate the presence of loop-type prominences.

## IMPORTANCE EVALUATION OF THE FLARE

The complexity and unusual pattern of development of the 1967 May 23rd event increase the difficulties of classification according to guidelines appropriate to simple flares. Whether one describes the event as three separate flares, as at Sacramento Peak, or as one event with multiple maxima as at Haleakala, Lockheed, and in the foregoing description, is primarily a matter of choice, but the decision in this matter can affect the areas assigned to the events. The I.A.U. Quarterly Bulletin on Solar Activity summarizes the individual reports as three flares, each of importance 2. Our interpretation has been influenced in large measure by the continuity of flare emission and by the apparently steady migration of the center of flare intensity from northwest to southeast within the plage.

All stations which were conducting patrols at the time of the major aspects of the event reported the occurrence of a flare at least as great as 2b. We and Sacramento Peak Observatory are alone in assigning importance 3 to the flare.

In our judgment, the second maximum (1844 UT) was the brightest of the three, but without photometric data it is difficult to be certain. According to our measurements the area of regions which had brightened to flare intensity after the start of the event at 1803 UT and which were still bright at 1844 UT equaled ∿18 square degrees, well above the 12 square degrees which mark the lower limit for flares of importance 3. Note that this total area is greater than would have been assigned to any one of the component flares on the assumption of three separate events.

Not only do the numerical guides lead us to an evaluation "3b" for the flare on 1967 May 23rd from 1803 - >2300 UT, but our qualitative judgment of the event also places it among the "great" and unusual flares whose records we have seen. Although it was not a flare of exceptionally large area, it was very bright and was observed in white light. The unusually sustained progression of the flare across the plage led to three intensity maxima, with flare emission at all times located over and close to major spot umbrae. According to our evaluation of the observations, a great Hα flare of importance 3b took place between 1803 and 2300 UT on May 23, 1967.

We again express our appreciation to the Director and Staff of the Sacramento Peak Observatory for having sent us for study their excellent Hα film of the sun for May 23, 1967.

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Dodson, H. W. and E. R. Hedeman, "The Proton Flare of August 28, 1966," Solar Physics, 4, 229, 1968.

McIntosh, P. S., included in "White-Light Solar Flare and the May 25th Aurora," Sky and Telescope, 34, 57, 1967.

# "Sunspots Associated with the Proton Flare of 23 May 1967"

by

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The sunspots associated with the proton flare of 23 May 1967 formed a remarkable chain spanning 30 degrees of solar longitude centered near N23 latitude and 225° Carrington longitude. The amount of growth, proper motion, and rotation exhibited by the spots made this a truly outstanding region. The correlation of some of these rapid changes with both the time and the position of the proton flare point to a clear common cause.

The first appearance of this extremely active region was as a very small and simple bipolar region at east limb on 21 April 1967. This region evolved into a peculiar, magnetically complex region by 27 April by the formation of new plage and spots near the original spots. The region never grew beyond Brunner class D and area of 150 millionths of the solar hemisphere. A smaller, short-lived group formed on 27 April only 15 degrees west of the complex group and both sunspot regions had disappeared before west limb passage on 2 and 3 May.

Beginning on 18 May 1967 a series of sunspots appeared at east limb which formed a stream 30 degrees long when all had rotated onto the visible hemisphere. The evolution of these sunspots as recorded with the Sacramento Peak Observatory 6-inch white-light patrol telescope has been studied for a detailed relation with the proton flare. Figure 1 shows the growth and movements of the spots from 19 May until two days after the proton event.

The distribution of the magnetic polarities shown in Figure 2 indicates that the spots could be divided into four bipolar groupings, each with the normal arrangement expected for the northern hemisphere in cycle 20. Groups 1, 2, and 3 formed on the invisible hemisphere and group 4 formed on 20 May immediately south of the first three groups. Differential rotation caused group 4 to move westward with respect to the other spots during the disk passage. The growth and movement of the leader of group 4 very near the follower of group 1 and the leader of group 2 may be related to the occurrence of an importance 2 flare on the 21st near the location of these spots.

The sunspot evolution that is surely connected with the production of the proton flare on 23 May can be observed in the eastern, or following, end of the stream of spots. Group 3 formed near the following end of group 2 with its leading sunspot (spot A) at a higher latitude than its follower, contrary to the usual orientation of bipolar sunspot groups. From its appearance at east limb on 19 May to the time of the proton flare on 23 May this group steadily grew and merged with the follower of group 2 (spot C). Spots A and B formed a sunspot configuration that rotated counter-clockwise throughout the days shown in Figure 1. Their rotation and growth and merging with growing spot C combined to close the separation between B and C, creating a rapid buildup of magnetic field gradient between spots of opposite polarity.

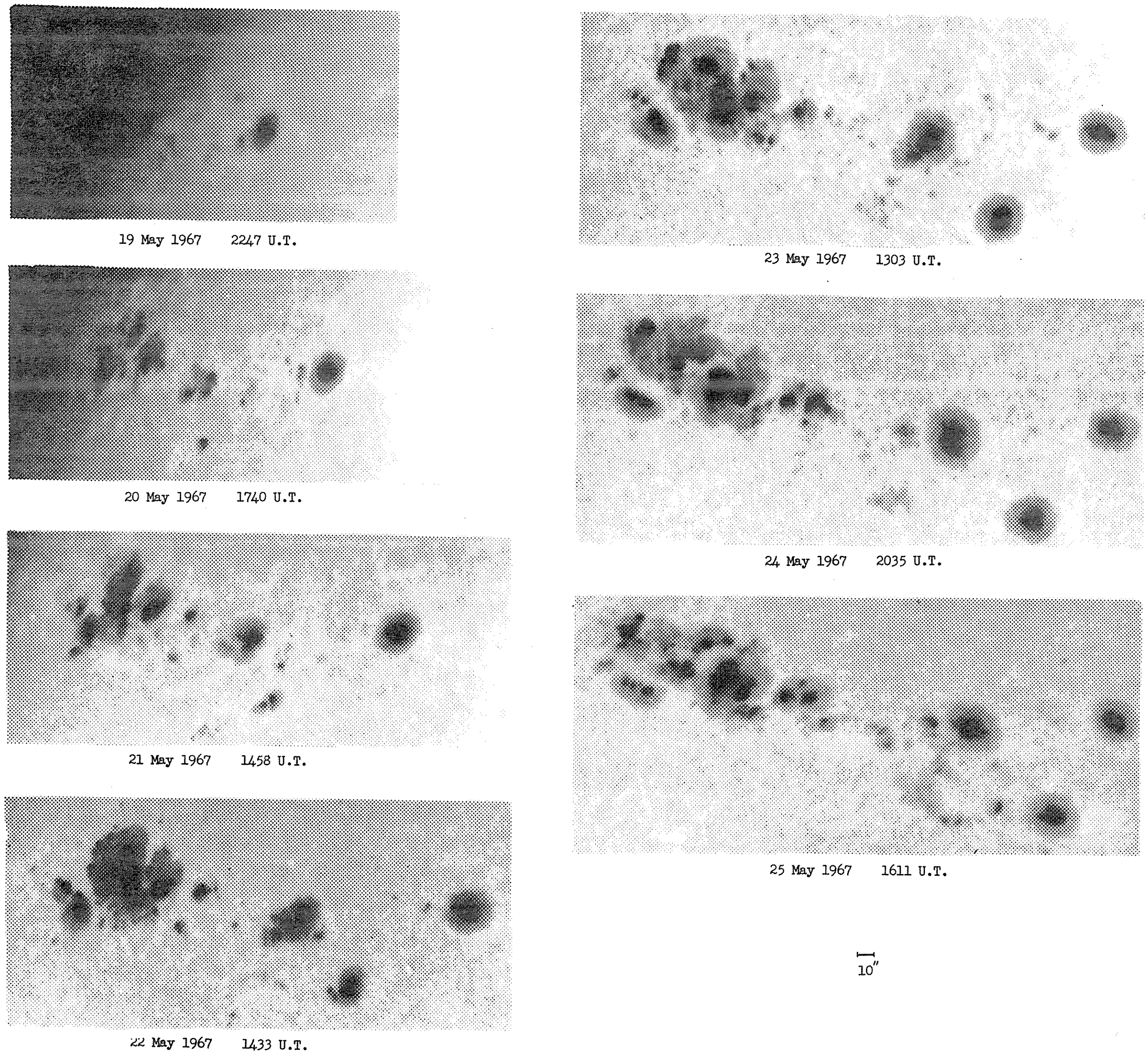


Fig. 1. Evolution of the series of spot groups from east limb to central meridian.

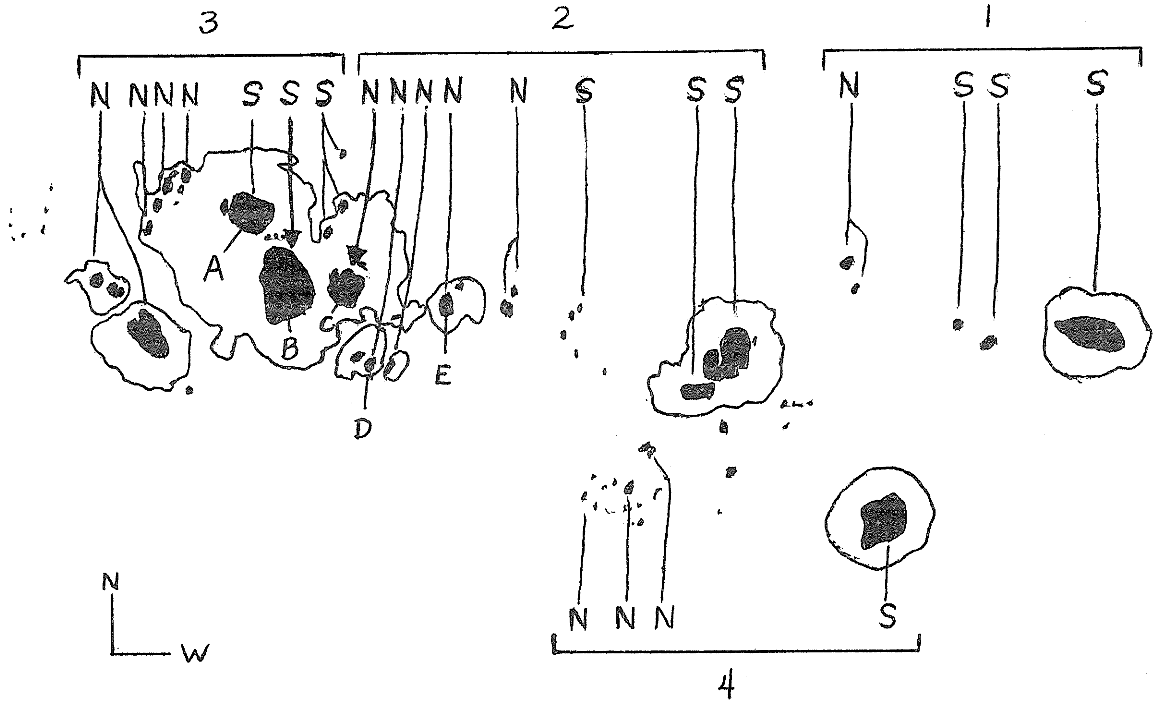


Fig. 2. Magnetic polarities measured at the Crimean Astrophysical Observatory on 21-25 May 1967 have been combined and placed on the sunspots as observed on 23 May. The polarities allow a division into four bipolar spot groupings.

Another rotating configuration was formed by spots D and E in the center of group 2, but their rotation was clockwise and their polarity was opposite to the A-B pair. The D-E rotation may have contributed to the increasing field gradient near B-C by bringing D close to B-C. It is of interest to note that D became involved in a common penumbra with B-C following the proton flare and that E exhibited rapid growth after the flare.

Many of the white-light patrol frames taken throughout 23 May were enlarged in order to follow in detail the white-light changes before, during and after the proton flare. Figure 3 presents the better-quality frames through this time, enlarged to draw attention to the gap between B-C, the strong spots of opposite polarity. The H-alpha and white-light emission reported by DeMastus and Stoyer (1967)lay directly over and adjacent to this gap. During the six hours preceding the flare the space between the spots gradually filled with darker material and spot B enlarged toward spot C decreasing the separation between them from 6 arc seconds to about 3 arc seconds at the moment of the maximum white-light emission from the flare. After the flare the separation increased to the pre-flare value of 6 arc seconds but the gap remained abnormally dark. Figure 4 presents the changes in separation in kilometers and shows a distinct acceleration in the rate of decrease just prior to the flare.

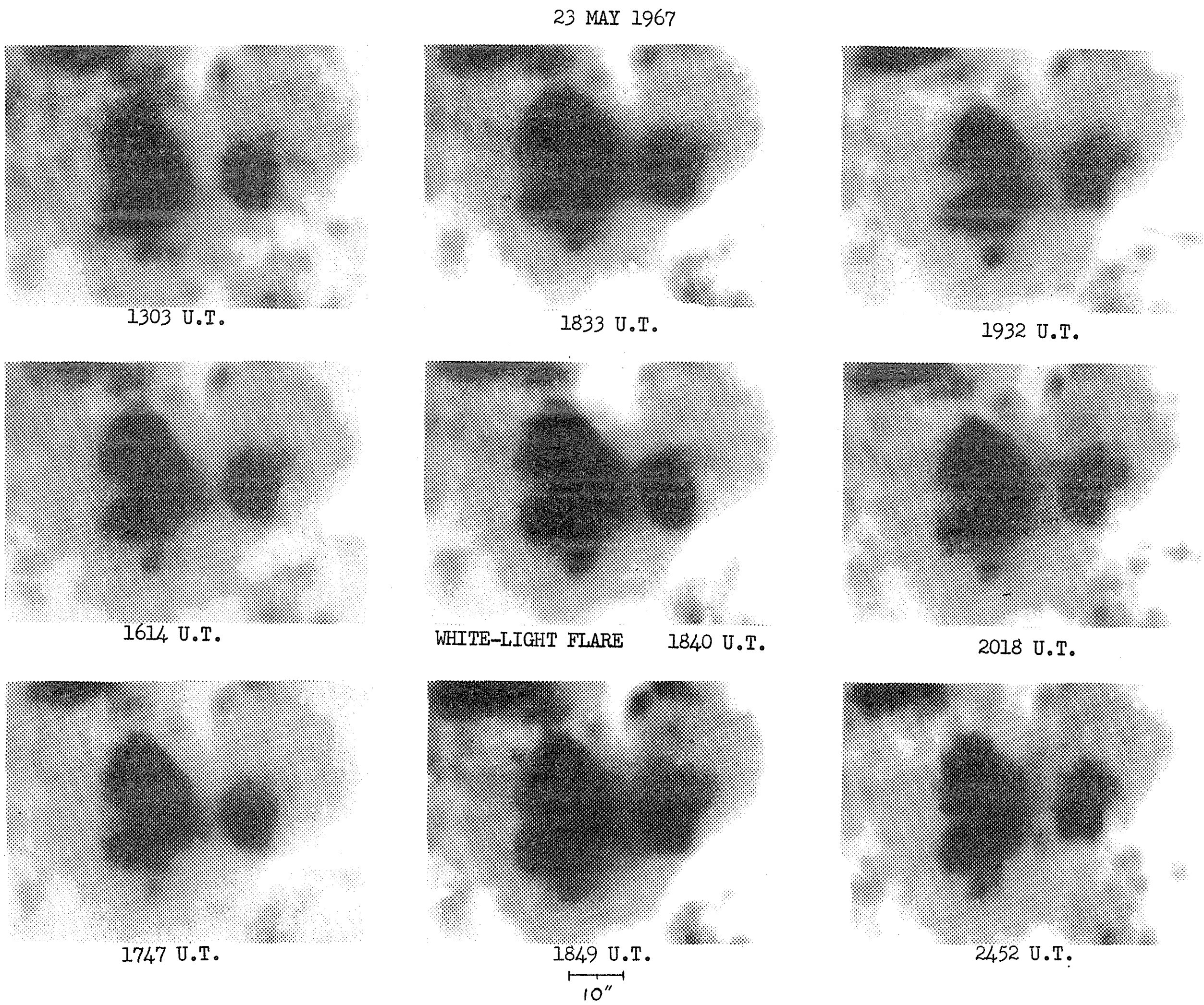


Fig. 3. Changes in the intensity and separation between spots of opposite polarity at the location of the proton flare.

An estimate of the magnitude of the magnetic field gradient between spots B and C can be made from the above separations and the field strengths measured at the Crimean Astrophysical Observatory. Early on the 23rd that station measured spot B as 2800 gauss and spot C as 2500 gauss. Since the spots were dark enough up to their edges to remain unexposed on the patrol films one might assume that the field strengths near the edges of these spots were little less than the centrally-measured values. Also the measured values might be lower limits to the actual values since any scattered light in the magnetograph would tend to lower the measured readings. Using a field-strength difference of 5000 gauss and the minimum observed separation at the time of the flare maximum, the magnetic field gradient estimate becomes approximately 2.5 gauss/km. This compares with a value of about 1 gauss/km measured by Severny 20 hours before the proton flare of 7 July 1966 (Svestka, 1968). Looking at Figure 4 one would conclude that the gradient in this case was also about 1 gauss/km until the hour of the flare, bringing these two observations into close agreement.

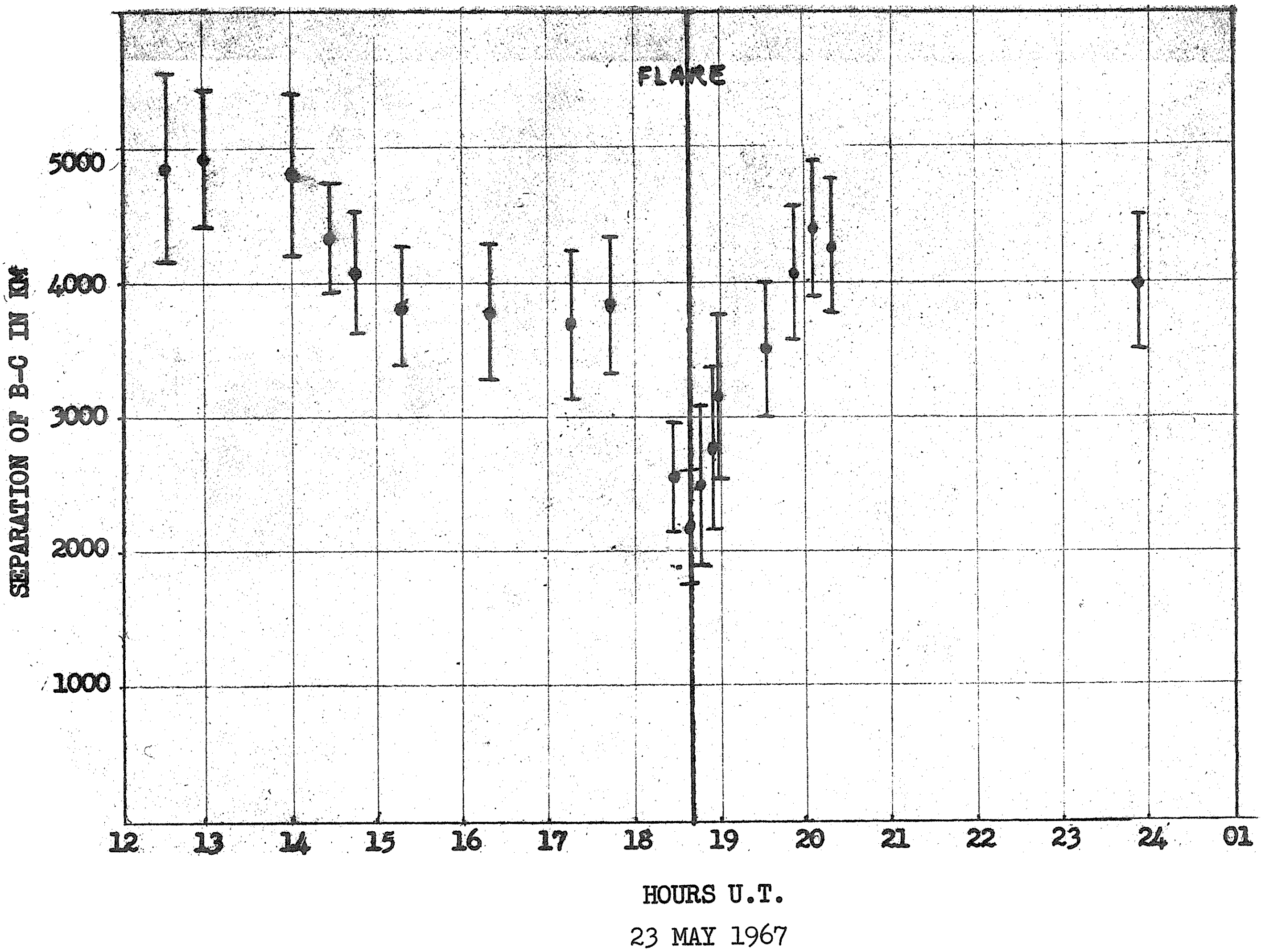


Fig. 4. Separation of spots B and C before, during and after the proton flare. The separation has been corrected for fore-shortening.

The abnormally dark penumbra between spots B and C has been noted previously only in the proton-flare sunspot groups of September, 1963 and July, 1966 (McIntosh and Sawyer, 1968). In these three cases the dark penumbra lay between strong spots of opposite polarity which were separated by less than 10 arc seconds. The time of formation of the dark penumbra relative to the time of the proton flares was different in each case.

The following sunspot changes occurred immediately after the 23 May 1967 proton flare: (a) growth of the NW portions of both spots B and C, (b) growth of penumbra south of spot C near one of the areas of white-light emission, and (c) formation of a light bridge between spot B and the strong spot north of B. The light bridge may be no more than the disappearance of penumbra as spot B continues its trend since the 22nd of separating from its northern companion. The growth of spots B and C result in an impression of rotation of the gap between them and may be the commencement of an apparent rotation of B-C about each other seen on 24 and 25 May in Figure 1.

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## 3. SOLAR RADIO BURSTS

"The Solar Radio Burst at 2700 and 2800 MHz"

by

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The burst is shown in the following figure combining the 2800 MHz data from the Algonquin Radio Observatory (A.R.O.) (45° 57'N, 78° 03'W) and the 2700 MHz data from the Dominion Radio Astrophysical Observatory (D.R.A.O.) at Penticton, B. C. (49° 19'N, 119° 37'W). The estimated error in the values is about ± 10%. The burst profiles are generally those of A.R.O. for 1300-2300 UT and those of D.R.A.O. for 1300-0130 UT. The bursts occurring in the common observing period are intercompared.

The tabulated values as published in "Solar-Geophysical Data", IER-FB 274, June 1967 are as follows:

| | Type | Starting Time UT | Time of maximum UT | Duration minutes | Flux Density $10^{-22}$ $Wm^{-2}$ $Hz^{-1}$ Peak | Mean |
|---|---|---|---|---|---|---|
| Simple 2 | 3 | 1808 | 1809.5 | 3 | 27.0 | 17.0 |
| Post burst increase | 29 | 1811 | | 13 | 12.0 | 9.0 |
| Precursor | 28 | 1834.2 | | 1.3 | 3.4 | 3.4 |
| Great burst | 47 | 1835.5 | 1952 | 127.5 | 8000.0 | 1370.0 |
| | | 1835.5 | 1839 | 54.5 | 2300.0 | |
| | | 1930 | 1952 | 73 | 8000.0 | |
| Post burst increase | 30 | 2043 | | 95 | 30.0 | 11.0 |
| Simple 2 | 3 | 2044 | 2045.5 | 5 | 12.0 | 6.0 |
| Simple 2 | 3 | 2100 | 2111.7 | 6 | 11.0 | 5.5 |
| Simple 3 | 20 | 2237 | 2244 | 18 | 11.0 | 5.5 |

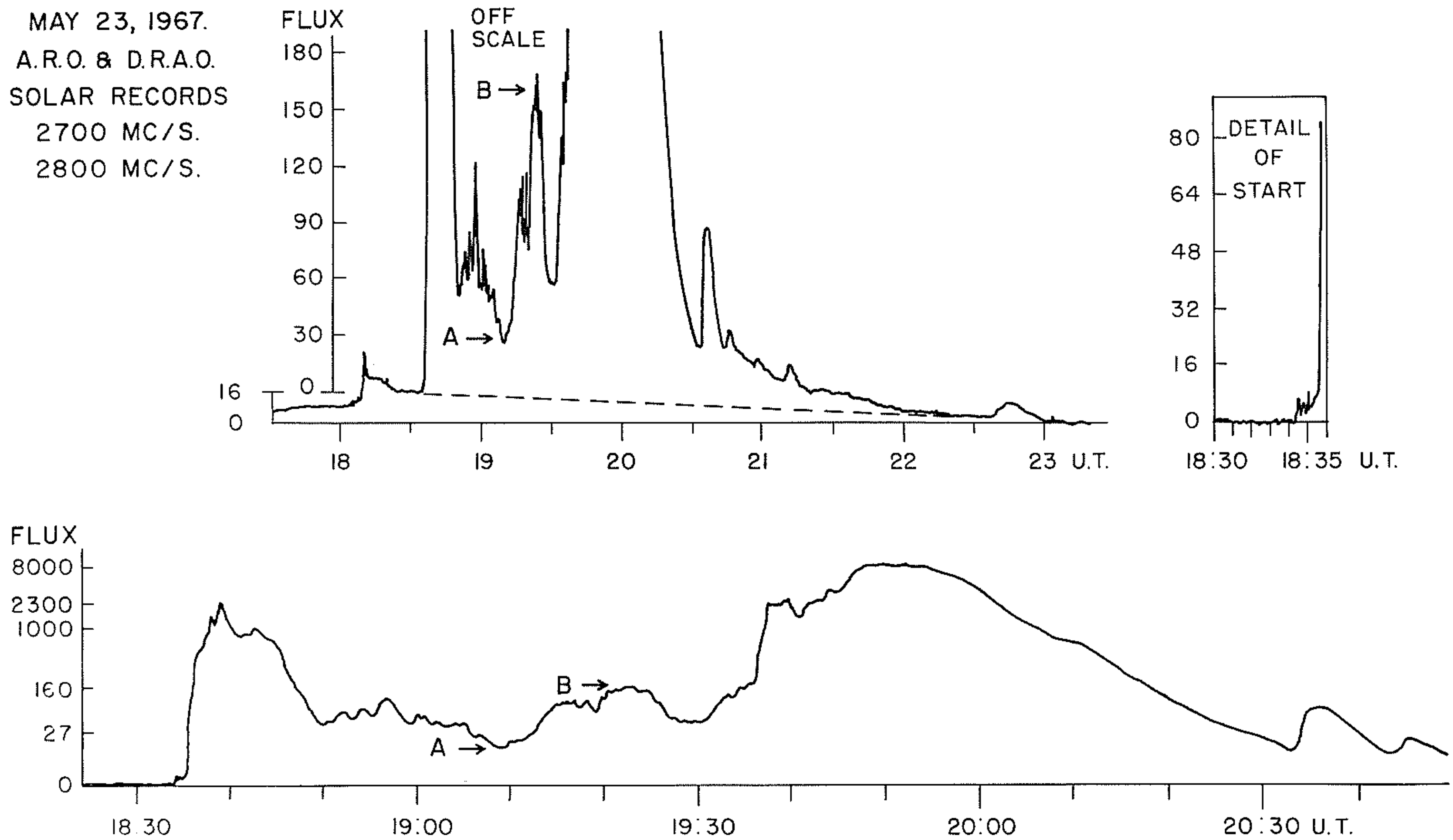



Fig. 1. Solar radio burst of May 23, 1967 at A.R.O. and D.R.A.O. Algonquin and Penticton

# "The Great Solar Radio Burst of May 23, 1967"

by

John P. Castelli and Jules Aarons
Air Force Cambridge Research Laboratories, Bedford, Massachusetts
and
Glen A. Michael
Air Weather Service, Ent AFB, Colorado

[An article with the above title was published in the Astrophysical Journal, 153, 267-273, July 1968. The authors have provided slightly revised versions of two of the figures from the paper. Figure 1 shows (a) the sweep frequency record from 1800 to 2400 UT and (b) on an expanded time scale the record from 1900 to 2000 UT. Figure 2 shows the records of five fixed frequencies from 1750 to 2050 UT (in the published paper the records begin at 1835 UT).

[According to the abstract of the paper, the solar burst was one of the largest ever recorded at the Sagamore Hill Observatory (AFCRL), Hamilton, Massachusetts. Using high-accuracy flux-density measurements at five frequencies ranging from 606 to 8800 MHz, its flux-density spectrum was compared with spectra of other flares observed in white light. It was found that along with most of the other white-light flares the burst displayed a U-type flux-density spectrum, i.e., high flux density in the meter and centimeter range and lower flux density in the decimeter range.]

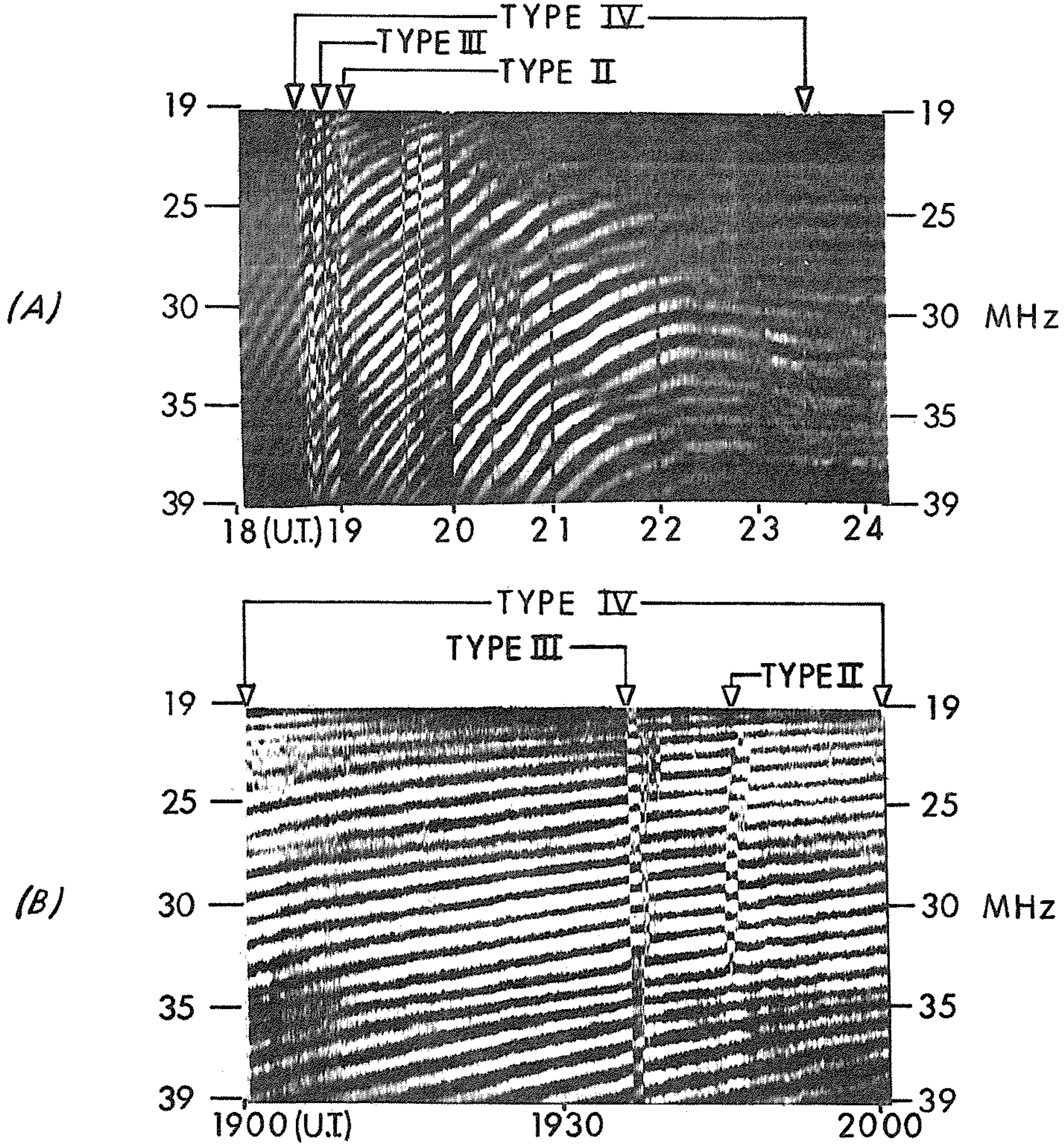
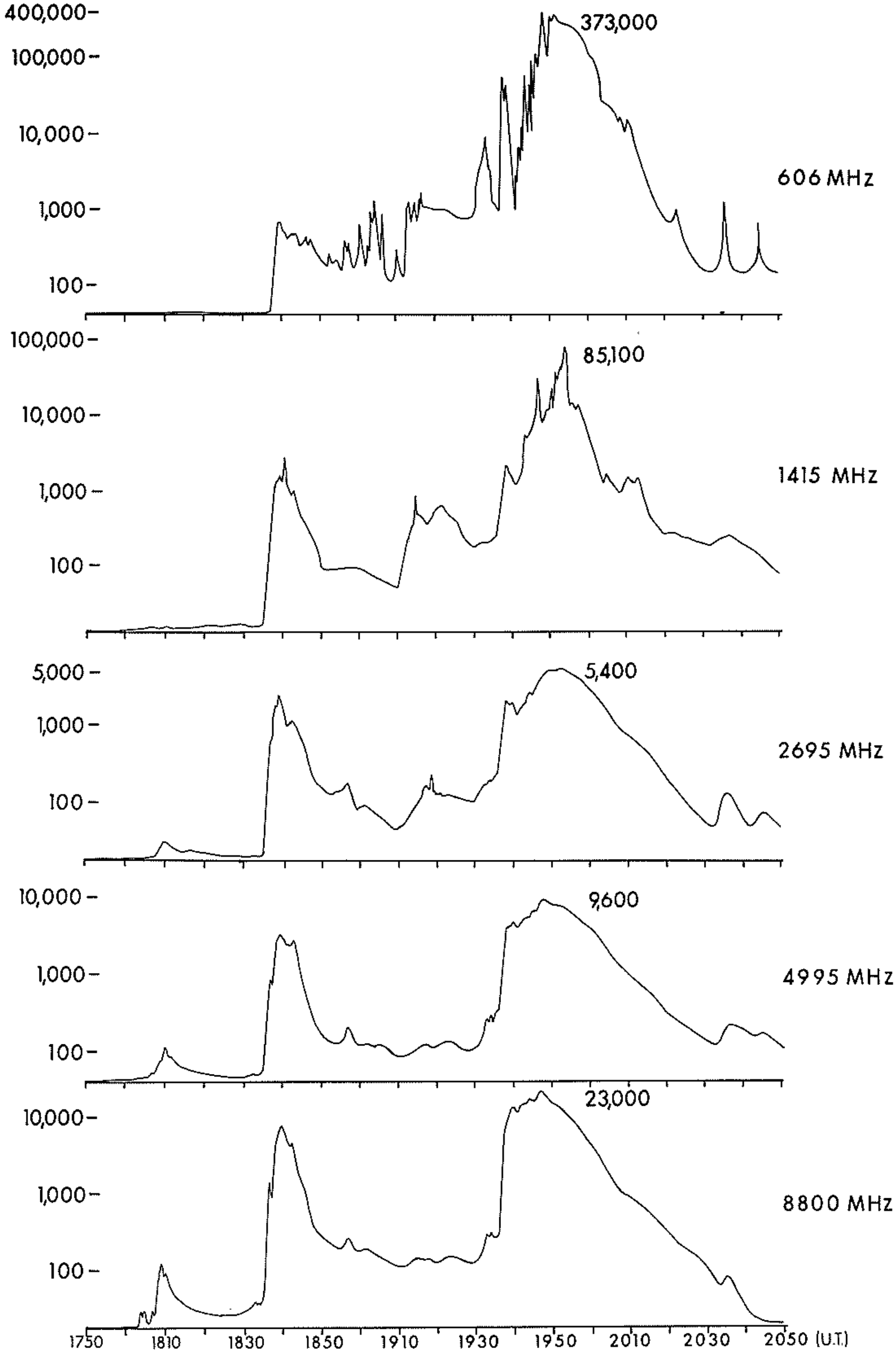



Fig. 1. Type II-IV spectra of the solar proton flare of 23 May, 1967
Sagamore Hill Radio Observatory (AFCRL) Hamilton, Mass.




(*CHART RECONSTRUCTED-FLUX VALUES PLOTTED AT INTERVALS OF ONE MINUTE OR LESS)
(FLUX DENSITY IN UNITS OF $10^{-22}$ $Wm^{-2}$ $Hz^{-1}$)

Fig. 2. Great radio burst* of the solar proton flare 23 May, 1967
Sagamore Hill Radio Observatory, Hamilton, Mass.

The scaled values from the Sagamore Hill Observatory as published in "Solar-Geophysical Data" IER-FB 274, June 1967 are given in the following table:

| Frequency | Type | Starting Time UT | Time of maximum UT | Duration minutes | Flux Density $10^{-22}$ $Wm^{-2}$ $Hz^{-1}$ Peak | Mean |
|---|---|---|---|---|---|---|
| 606 | Simple 3 | 1755.3 | 1813.8 | 32.9 | 2.9 | 1.0 |
| 8800 | Precursor | 1802.5 | 1809.6 | 32.5 | 130.8 | 21.8 |
| 4995 | Precursor | 1757 | 1809.6 | 38 | 108.8 | 28.0 |
| 2695 | Precursor | 1800 | 1809.7 | 35.5 | 33.4 | 2.5 |
| 1415 | Precursor | 1802.5 | 1829.5 | 33 | 7.6 | 2.5 |
| 8800 | Great burst | 1835 | 1839.7<br>1947 | 112 | 8,100.0<br>23,000.0 | 2,800.0<br>2,800.0 |
| 4995 | Great burst | 1835 | 1839.2<br>1948 | 110 | 3,400.0<br>9,600.0 | 2,000.0<br>2,000.0 |
| 2695 | Great burst | 1835.5 | 1839.1<br>1951.8 | 108.5 | 2,500.0<br>5,400.0 | 1,400.0<br>1,400.0 |
| 1415 | Great burst | 1835.5 | 1840.7<br>1954.1 | 129.5 | 2,000.0<br>28,000.0D | 1,100.0U<br>1,100.0U |
| 606 | Great burst | 1835.6 | 1839.5<br>1948.5 | 159.4 | 534.0<br>19,200.0D | 2,000.0U<br>2,000.0U |
| 8800 | Post burst increase | 2027 | 2027 | 138 | 109.0 | 54.5 |
| 4995 | Post burst increase | 2025 | 2025 | 140 | 78.4 | 39.2 |
| 2695 | Post burst increase | 2024 | 2024 | 141 | 72.0 | 24.0 |
| 1415 | Post burst increase | 2045 | 2045 | 133 | 45.2 | 20.0 |
| 606 | Post burst increase | 2115 | 2115 | 104.4 | 125.0 | 41.0 |

"The Solar Radio Burst at 184 MHz"

by

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Space Disturbances Laboratory
ESSA Research Laboratories, Boulder, Colorado

The large May 23, 1967 solar outburst at 184 MHz, as observed by ESSA at Boulder, Colorado is shown in Fig. 1. At this frequency the burst did not begin until Phase 2 of the solar flare as described by Helen W. Dodson and E. Ruth Hedeman on page 8 of this report. With the onset of Phase 3 of the flare the intensity of the solar burst at 184 MHz went off scale reaching a value $\geq 6480 \times 10^{-22}$ $Wm^{-2}$ $Hz^{-1}$. The initial phase of the burst lasting 13 minutes began at 1835 UT with the initial maximum near this time. The second and largest maximum was reached sometime after 1922 UT and before 2140 UT. A third distinctive maximum occurred after 2215 UT, between 2224 UT and 2253 UT. A noise storm continued until sunset.

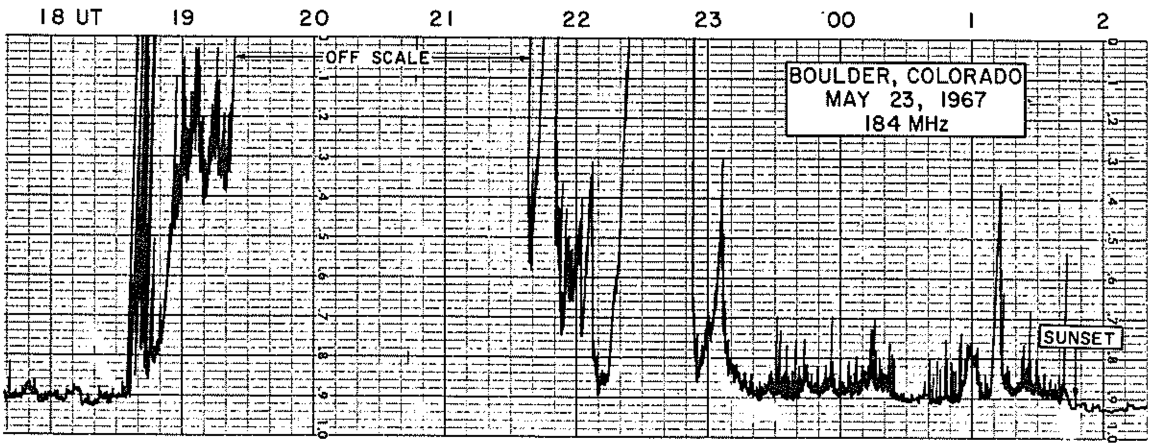



Fig. 1. Solar radio noise burst of May 23, 1967 on 184 MHz at Boulder, Colorado.

"Spectral Observations - Fort Davis, Texas"

Alan Maxwell has furnished the following figure of the dynamic spectrum of the solar radio outburst in the frequency range 10-580 MHz as recorded at the Harvard Radio Astronomy Station, Fort Davis, Texas.

The values read from the records for the outburst as published in "Solar-Geophysical Data", IER-FB 277, September 1967, are tabulated below.

| | Decimetric band | | | Metric band | | | Dekametric band | | | Type |
|---|---|---|---|---|---|---|---|---|---|---|
| | Start UT | End UT | Int. | Start UT | End UT | Int. | Start UT | End UT | Int. | |
| May 23 | | | | 1620 | 1835 | 2 | | | | IC |
| | | | | 1742 | | 3 | 1742 | | 3 | IIIG |
| | | | | 1754 | 1811 | 2 | | | | IIIGG |
| | 1835 | 1838 | 2 | 1835 | 1838 | 3 | 1835 | 1838 | 2 | IIIGG |
| | 1838 | 1842 | 3 | 1838 | 1905 | 3 | 1846 | 1905 | 2 | II |
| | 1839 | 2252 | 3 | 1839 | 2320 | 3 | 1846 | 2300 | 2 | IV |
| | | | | | | | 1852 | 1900 | 2 | IIIGG,RD |
| | | | | 1937 | 1940 | 3 | 1937 | 1940 | 1 | IIIGG |
| | | | | 1937 | 2400 | 2 | | | | IC |

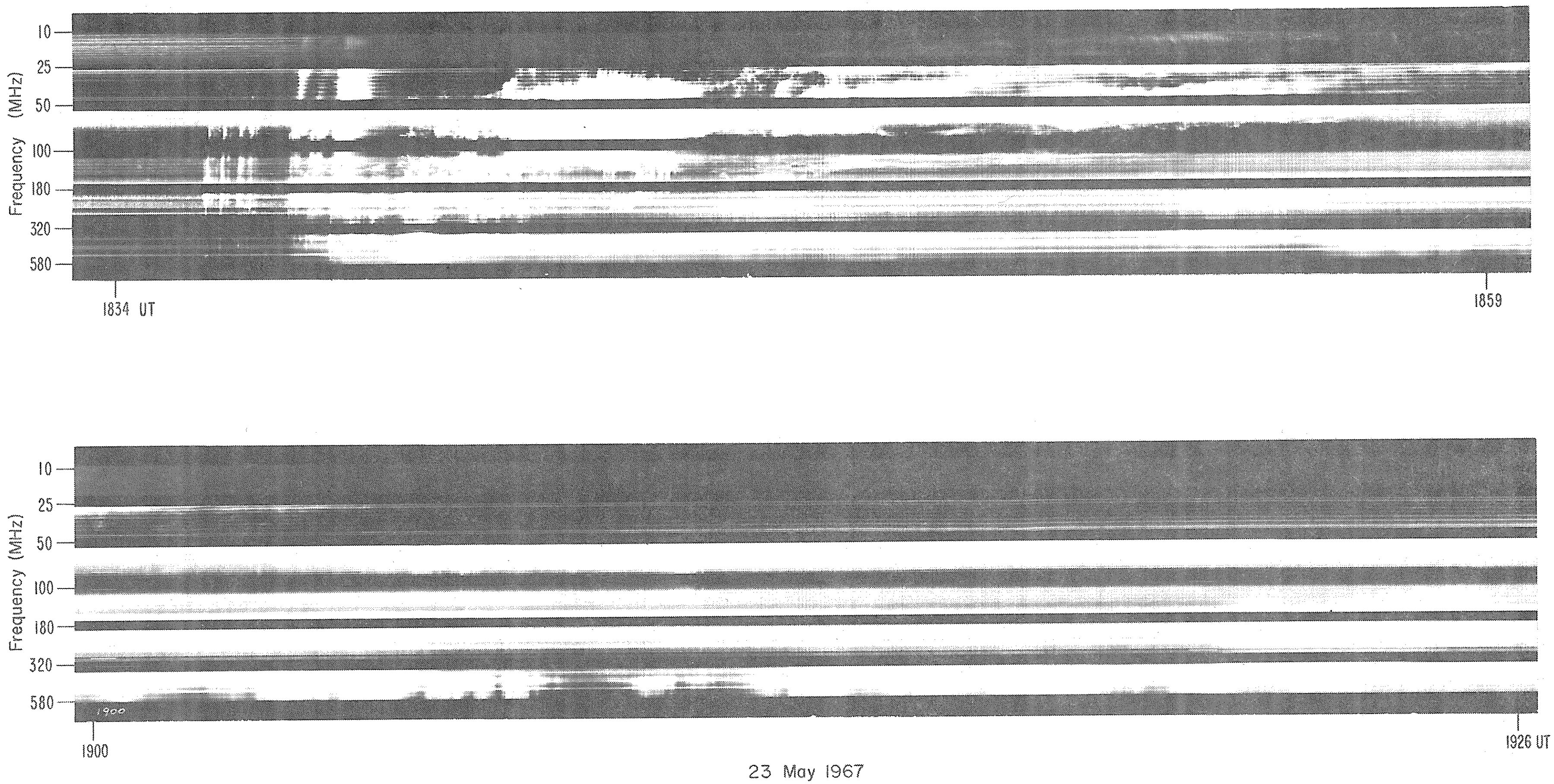



Fig. 1 Dynamic spectrum of solar radio outburst, 23 May 1967. Frequency range 10-580 MHz. Harvard Radio Astronomy Station, Fort Davis, Texas.

"The Solar Radio Event of 23 May 1967 at Dekameter Wavelengths"

by

George A. Dulk
Department of Astro-Geophysics
University of Colorado, Boulder, Colorado

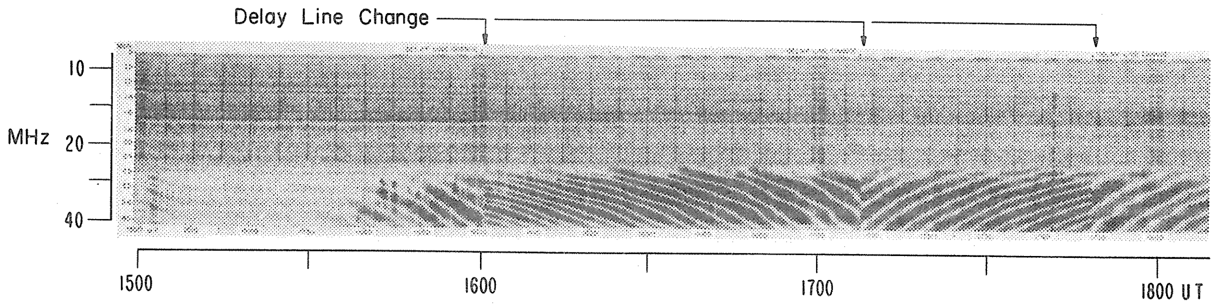
The low frequency radio spectrograph--interferometer of the University of Colorado (Lee and Warwick, 1964) recorded intense radio emission from the sun during the several flares of 23 May 1967. The major events occurred at $\approx$1835 UT and $\approx$1935 UT whereas the sun transited the Boulder meridian at 1900 UT; hence the solar zenith angle was about 20° during the events. For this reason, uncertainties due to absorption and to refraction effects are minimized.

A photograph of the spectrograph record is shown in Figure 1. The record is shown in four sections, each about three hours long. For most of the eleven hours shown, interference from ionospherically reflected radio stations obscures solar emission below about 26 MHz. Occasional strong Type III bursts are seen through the interference, and, thanks to the SWF from about 1837 to 2030, other types of solar emissions are visible down to about 11 MHz. Below 11 MHz, only interference is seen because solar emission was reflected from the topside of the earth's ionosphere.

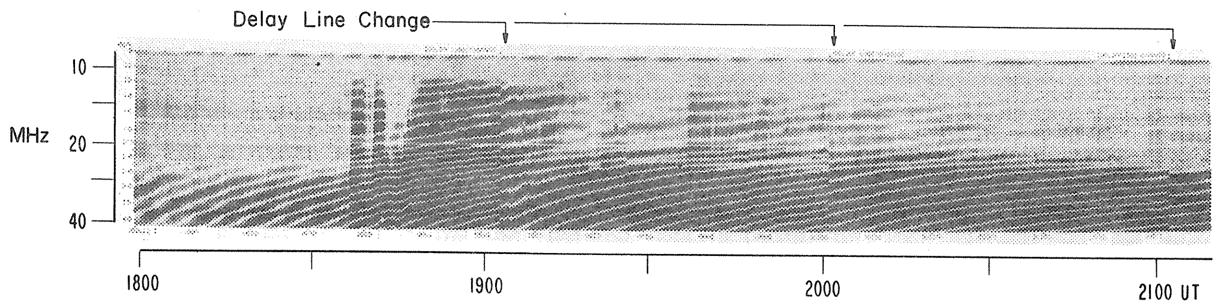
Table 1 is a chronology of the events of the spectrogram, together with associated x-ray, optical, and decimeter radio observations. Before 1500 UT, a few, weak Type III bursts are probably unrelated to the later, major events. (This section of the spectrogram is not shown.) A moderately intense group of Type III bursts is seen in Figure 1a at about 1502. These are noteworthy because they are trailed for about five minutes by a weaker continuum (possibly Type V), and because of their possible association with a subflare in McMath plage region 8818, the seat of the subsequent events. Another subflare occurred between 1525 and 1543; its relation to subsequent events is conjectural. Starting at about 1537, moderately strong Type IV emission spreads from 41 MHz to below the interference caused cutoff at 26 MHz and continues from then through the major flare at about 1830. No strong Type III or Type II bursts serve as the initiating event for the Type IV; this is unusual but not unprecedented (c.f. Skerjanec, Wightman and Warwick, 1964; Warwick, 1965). Only during the first few minutes of the emission, about 1543, 1545, and 1556, are intensity variations seen, probably Type III's which cover only part of our frequency range.

Subflares were reported at 1706 and 1745 in McMath plage region 8824 on the east limb, but no evidence of them is visible in the spectrogram.

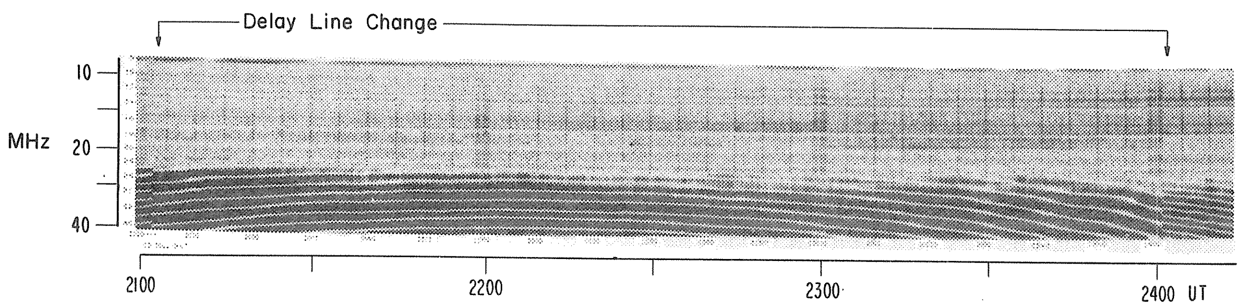
Another subflare in region 8818 was reported at 1740. This was probably the source of the short, very intense Type III burst seen in Figure 1a from 1741.9 to 1742.4 UT. The burst is sufficiently intense to be seen through the interference down to 12 MHz. No Type II is observed nor is the ongoing Type IV noticeably enhanced.



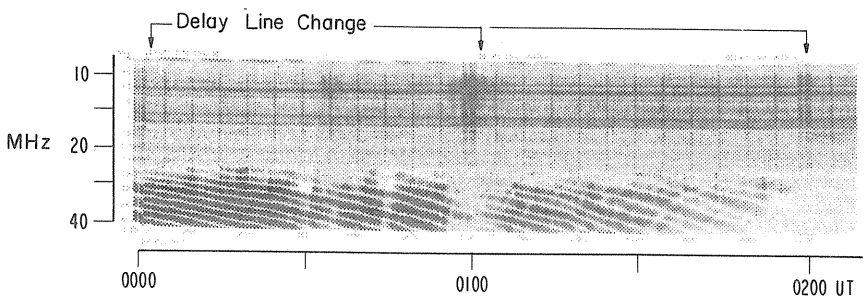

a. 23 May 1967




b. 23 May 1967




c. 23 May 1967




d. 24 May 1967

Fig. 1. Spectrograph record May 23-24, 1967 at University of Colorado

Table 1 - Chronology of Events

| Start | Max. | End | Type of Radiation | Intensity or Importance | Frequency Range | Location | Observatory and Reference | Remarks |
|---|---|---|---|---|---|---|---|---|
| 1100 | | 1500 | III's | 1 or 2 | 24 - 41 | | Boulder | ≈one per hour |
| 1501 | 1504 | 1522 | Hα | -F | | N29 E32 | Huancayo (1) | |
| 1502.2 | | 1503.9 | III | 2 | 28 - 41 | | Boulder | + continuum |
| 1525 | 1533 | 1543 | Hα | -N | | N26 E24 | Huancayo (1) | |
| 1537.0 | | 1900.0 | IV | 2 | 24 - 41 | | Boulder | |
| 1543.0 | | 1546.0 | III g | 3 | 28 - 38 | | Boulder | |
| 1706 | 1709 | 1714 | Hα | -N | | N23 E90 | Lockheed (1) | no dkm burst |
| 1720 | 1735 | 1745 | Hα | -F | | N23 E90 | Lockheed (1) | no dkm bursts |
| 1745 | 1754 | 1807 | Hα | -F | | N22 E90 | Lockheed (1) | no dkm bursts |
| 1740 | 1742 | 1753 | Hα | -N | | N24 E25 | Haleakala (1) | |
| 1741.9 | | 1742.4 | III | 3 | 12 - 41 | | Boulder | |
| 1759 | 1817 | 1834 | x-ray | 30 units | 2 - 12Å | | Expl. 33 (2) | |
| 1803 | 1814 | 2200 | Hα | 2B | | N31 E25 | Lockheed (1) | no dkm bursts |
| 1834 | 1846 | 1936 | x-ray | 600 units | 2 - 12Å | | Expl. 33 (2) | |
| 1834 | | 2130 | SWF | 3+ | | | Many (1) | |
| 1835 | 1844 | >1932 | Hα | 3B | | N28 E24 | Sac Peak (1) | |
| 1835 | 1840 | 1937 | cm & dm | ~1000 fu | 606-8800 | | AFCRL (3) | |
| 1837.1 | | 1840.7 | III | 3 | 11 - 41 | | Boulder | |
| 1839 | 1840 | 1844 | white light | | | | Sac Peak (4) | |
| 1841.2 | | 1843.4 | III | 3 | 11 - 41 | | Boulder | |
| 1843.4 | | 1900.0 | II | 3 | 11 - 41 | | Boulder | |
| 1900.0 | | 1936.0 | IV | 3 | 12 - 41 | | Boulder | |
| 1932 | 1947 | 2156 | Hα | 2B | | N28 E28 | Sac Peak (1) | |
| 1936 | 1953 | >2400 | x-ray | 300 units | 2 - 12Å | | Expl. 33 (2) | |
| 1936.6 | | 1940.7 | III | 3 | 11 - 41 | | Boulder | |
| 1937 | 1950 | 2040 | cm & dm | ~5000 fu | 606-8800 | | AFCRL (3) | |
| 1947.2 | | 1952.2 | II | 3 | 12 - 41 | | Boulder | |
| 1936.6 | | 2052.2 | IV | 3 | 12 - 41 | | Boulder | |
| 2052.2 | | 2400.0 | IV | 3 | 24 - 41 | | Boulder | |
| 2112 | 2113 | 2137 | Hα | 1N | | N66 E28 | Houston (1) | no dkm bursts |
| 2124 | 2125 | 2145 | Hα | -N | | N24 E18 | Houston (1) | no dkm bursts |
| 2400 | | >2600 | dkm cont. | 3 | 24 - 41 | | Boulder | |

References: (1) Solar-Geophysical Data, Feb. 67, June 67, July 67, Nov. 67; (2) Van Allen, 1968 (3) Castelli, Aarons, and Michael, 1968; (4) DeMastus and Stover, 1967.

The 2B flare starting at 1803 was anomalous in that it produced considerable x-ray emission (Van Allen, 1968) and meter wavelength radio emission (IAU Bull., 1967) but no dekameter radio bursts. Evidently its effects were confined to the chromosphere and low corona.

From 1750 through 1835, the fringe positions of the Type IV have peculiar steps. These are due to ground reflections or an instrumental defect. They complicate analysis of burst positions but do not affect determination of burst types.

The major flare of the day, reported 3B by the Sacramento Peak Observatory and 2B by most other observatories, started at 1834 or 1835 UT. It was accompanied by x-ray bursts (Van Allen, 1968), a strong SWF, some of the strongest centimeter and decimeter radio bursts ever recorded (Castelli, Aarons, and Michael, 1968) and it was visible in white light (DeMastus and Stover, 1968). The Boulder spectrograph recorded major Type III's from 1837.1 to 1840.7 UT and from 1841.2 to 1843.4 UT. These bursts were so intense (probably greater than $10^{-20}$ $Wm^{-2}$ $Hz^{-1}$) that they are visible through the interference down to the ionospheric cutoff at 11 MHz. The accompanying SWF is visible in Figure 1b as a decrease in interference level in the 8 to 24 MHz range. It is especially noticeable from about 1843 to 1850 UT, but careful inspection shows that individual ionospherically reflected radio stations, which ordinarily show up as short lines during each five minute calibration period, are largely absent from 1840 UT to about 2030 UT.

After the initial Type III bursts, a Type II burst begins at 1843 UT at 41 MHz. It drifts downward in frequency and at 12 MHz it begins at about 1849. At frequencies above 24 MHz the Type II can be distinguished from the Type IV by a shift of fringe position; thus the Type II emanates from a different location than the Type IV. Because of a few small Type III bursts, it is difficult to follow the onset of the II over the entire frequency range. Similarly, small Type III bursts complicate the appearance of the Type II harmonic and a possible second Type II at about 1854. The drift rate of the Type II burst from high to low frequency is unusually fast, requiring only six minutes to drift from 41 MHz to 12 MHz. This is about five times the usual Type II drift rate in this frequency range (Warwick, 1965). A disturbance velocity of >5000 km/sec is required if the radiation results from plasma oscillations and if the "radio model" of coronal electron density (Malitson and Erickson, 1966) is correct.

At some time during the Type III - Type II emissions, the Type IV increased in intensity by perhaps a factor of ten, from about $10^{-21}$ to about $10^{-20}$ $Wm^{-2}$ $Hz^{-1}$. It is visible through the interference to about 12 MHz. It fades somewhat, especially at low frequencies, until about 1936.

Another 2B flare began at 1932. It reached its maximum brightness at about 1947, and was accompanied by strong x-rays and decimeter radio emission. On Figure 1b we see the resulting Type III burst from 1936.6 to 1940 UT. Again, fringe shifts show that its origin is at a different location than the Type IV. A Type II burst occurs a few minutes later, drifting from 41 MHz at 1944 UT to 12 MHz at 1950 UT. The Type IV intensity increases at the time of the Type III burst; this is especially noticeable at frequencies lower than 20 MHz.

Type IV emission continues to be strong and is visible through the interference until about 2050 UT, when either decreased intensity of the Type IV or the increased interference level (caused by decreased station absorption as the ionosphere recovered to its normal state) causes it to fade. At frequencies higher than 26 MHz, Type IV emission continues for several hours (Figure 1c) and is remarkably free from contamination by Type III bursts. After 2400 UT, intensity variations begin to appear (Figure 1d) and the Type IV shows signs of changing to the dekametric continuum which commonly succeeds Type IV. After 0100 UT, 24 May, when the sun was setting behind the mountains to the west, the dekametric continuum is seen to be crossed by subordinate interferometer fringes caused by ground reflections of the waves into the antennas.

Weak dekametric continuum is visible on the records of the following day, after 1100 UT (local sunrise) on 24 May. This probably is a continuation of the coronal activity resulting from the flares of 23 May.

Analysis of burst positions during the events of 23 May has not yet been undertaken.

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I.A.U. Quart. Bull. Solar Activity, 1967 (Germany: Eidgenossische Sternwarte Zurich), No. 59.

Lee, R. H. and Warwick, J. W. 1964. Radio Sci. 68D, 807.

Malitson, H. H. and Erickson, W. C. 1966. Ap. J. 144, 337.

Skerjanec, R. E., Wightman, D. W. and Warwick, J. W. 1963. Info. Bull. of Solar Radio Obs., Utrecht, 13, 5.

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Van Allen, J. A. 1968. Ap. J. 152, L85.

## 4. SUDDEN IONOSPHERIC DISTURBANCES

"The 10-1030 Å Flux for the Flares of May 23, 1967, as Deduced from SFD Data: Preliminary Results"

by

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Space Disturbances Laboratory
ESSA Research Laboratories, Boulder, Colorado

Figure 1 shows some of the sudden frequency deviations (SFD) observed at Boulder on May 23, 1967. Figure 2 shows the flare enhancement of 10-1030 Å radiation deduced from SFD data. The first event shown, which started at about 1808 UT, was a moderate size SFD. There is nothing particularly special about this SFD, except perhaps that it had no distinct negative decay stage which implies that the 10-1030 Å radiation remained at a relatively high level after its initial fast increase.

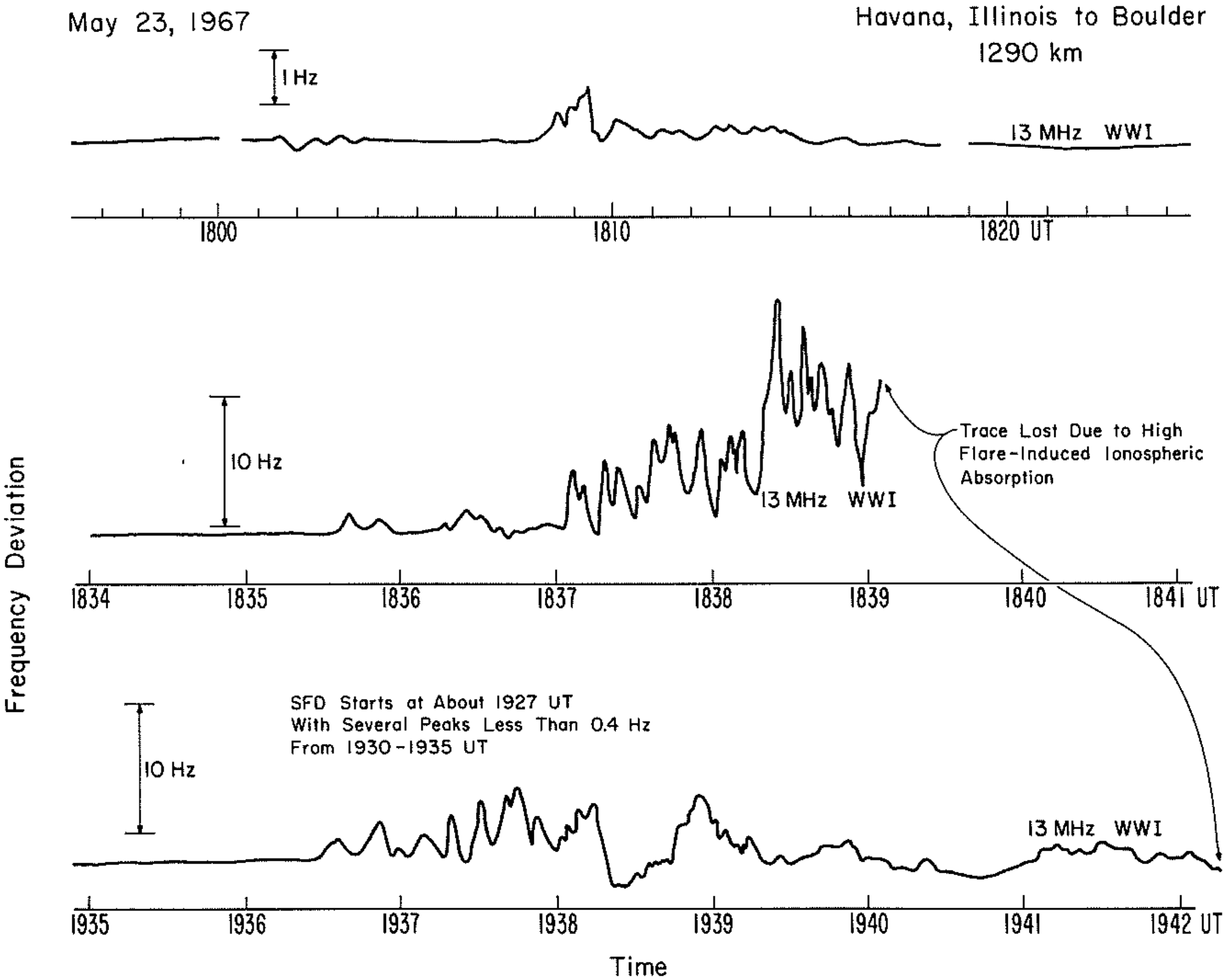


Figure 1. Boulder SFD observations. The small frequency deviation at 1802 UT is a type not associated with solar flare X-ray or EUV radiation.

The second SFD, which started at about 1835.5 UT, was very large, as large or larger than the SFD's for the proton flares of July 7, 1966 and August 28, 1966, and the SFD of 1924 UT, May 21, 1967. See Table 1. Unfortunately our SFD data were lost after 1839.1 UT due to the very high flare-induced absorption of radio waves reflected from the ionosphere so the peak of the event was probably missed. This second SFD seems to consist of a chain of bursts with rise times of about 5 sec, much like the SFD of the July 7, 1966 proton flare.

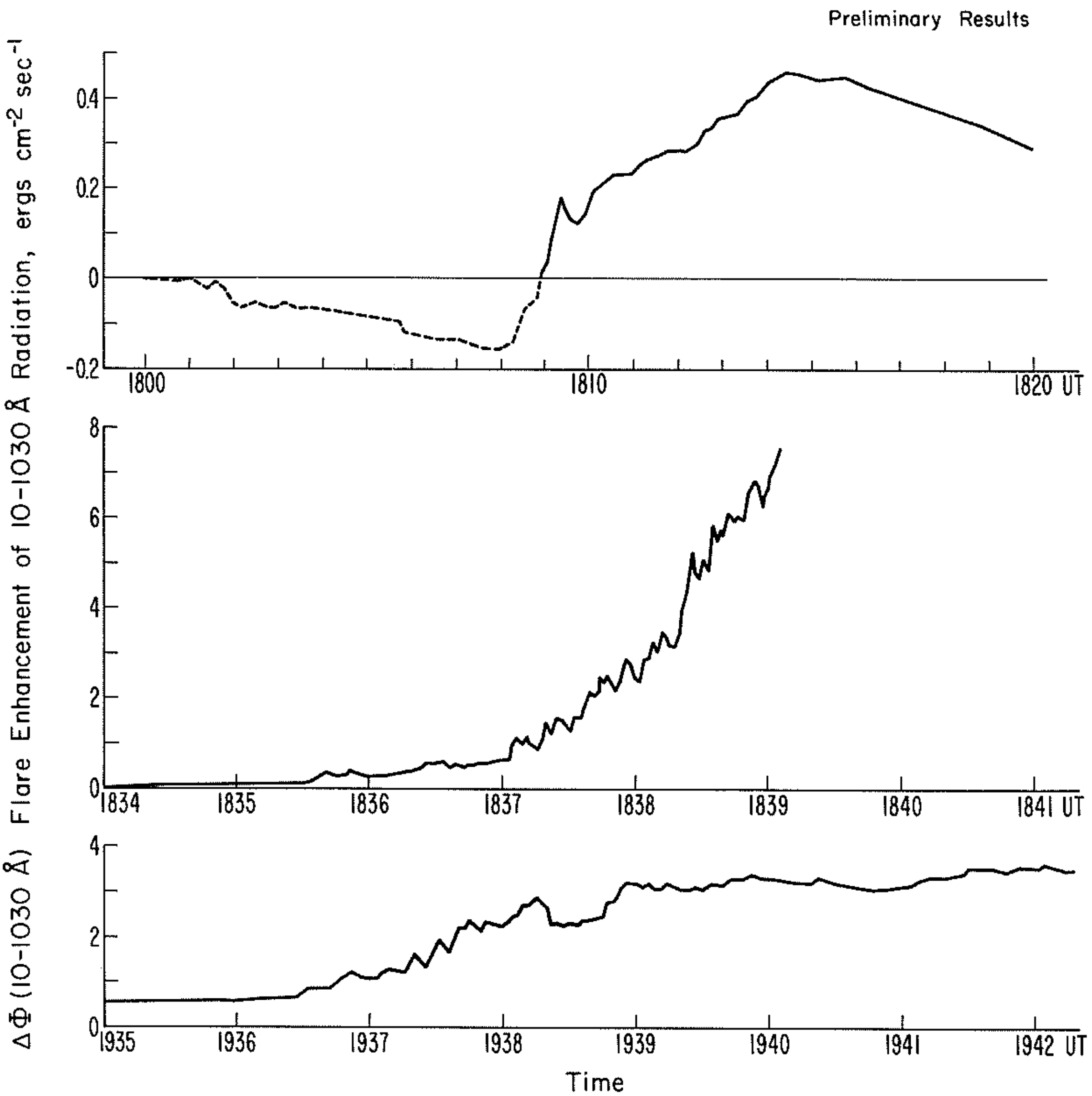


Figure 2. Time dependence of the flare enhancements of 10-1030 Å radiation deduced from SFD data. The top trace is dashed from 1800-1809 UT because the apparent decrease in flux from 1800-1808 UT is probably not real but rather the result of ionospheric irregularities disturbing the SFD data.

Table 1. 10-1030 Å Flare Enhancements Deduced from SFD's

| | Date | Approx. Time UT | Approximate* $\Delta\Phi_{max}$ (10-1030 Å) ergs $cm^{-2}$ $sec^{-1}$ above the earth's atmosphere | $\int_0^{\text{end of flare}} \Delta\Phi(10\text{-}1030\ \text{Å})dt$** ergs $cm^{-2}$ above the earth's atmosphere |
|---|---|---|---|---|
| | July 7, 1966 | 0027 | 5.3 | $8 \times 10^3$ |
| | August 28, 1966 | 1527 | 8.7 | $8 \times 10^3$ |
| Preliminary Results | May 21, 1967 | 1924 | 2.8 | $\sim 2 \times 10^3$ |
| Preliminary Results | May 23, 1967 | 1810 | 0.5 | $\sim 3 \times 10^2$ |
| Preliminary Results | May 23, 1967 | 1838 | $\geq 7.6$ | $\geq 1.2 \times 10^4$ |
| Preliminary Results | May 23, 1967 | 1942 | $\geq 3.6$ | $\geq 3 \times 10^3$ |

*Accurate to within a factor of 4.
**Accurate to about a factor of 10.

The third SFD was about half as large as the second event, but was still a fairly large event. Again our SFD traces were lost at 1942.3 UT due to the high flare-induced ionospheric absorption, so the peak of the event may have been missed. This event also appears to consist of a chain of smaller fast bursts. This third event occurred before the second one was completed. The combined three overlapping events constitute the largest group of SFD's or the largest enhancement of 10-1030 Å radiation observed by SFD's since routine observations commenced at Boulder in October 1960.

The E and F region effects and the corresponding ionizing radiation of the May 21 and May 23, 1967 flares observed by satellite Faraday-rotation total electron-density measurements and incoherent backscatter observations have been thoroughly studied and reported by Garriott, et al (1967, 1969).

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# "Ionospheric Effects Associated with the Solar Flares of May 23, 1967"

by

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A facility was developed at the Space Disturbances Laboratory at Boulder, Colorado, as part of project HANDS* to acquire and process data from a large number of geophysical experiments, using an on-line digital computer (Jean, 1965). In this system, data are sampled 10 times per second, smoothed with a ten second time constant and recorded continuously from each data channel at the rate of one point each 5 secs. World time is recorded to a resolution of 1 millisec from a standard rubidium oscillator synchronized to the NBS standard oscillator at Boulder, Colorado. The data shown in this report consist of the phase and amplitude of VLF, LF and HF radio waves and variations in the geomagnetic field. Data from selected channels were machine plotted on a common time scale to reveal small but simultaneous variations which may occur in different data channels. Colocated sensors offer the advantages of having similar time responses, signal-to-noise, and solar zenith angles (as well as accurate world time) and can provide dependable times of start and maximum of the SID effects and thus, clarify the chronology of ionospheric disturbances accompanying solar flares.

Three SID's were observed on May 23 starting at approximately 1800, 1835 and 1935 UT. The phase perturbations in the 100 kHz Loran C signals received at Boulder, Colorado, from Nantucket, Massachusetts; Cape Fear, North Carolina; and Jupiter Inlet, Florida, are shown in the top three traces in Figure 1. Phase in degrees is plotted from 1700 to 2100 UT with the direction of a phase advance being downwards, corresponding to a lowering in the ionospheric reflection height. This convention is followed in all of the LF and VLF phase data. Traces 4 through 6 (from the top) of Figure 1 indicate variations in the phase of the 24 kHz signal received at Boulder, Colorado, from Panama, Canal Zone, of the 21.4 kHz signal received from Annapolis, Maryland, and of the 18.6 kHz signal received from Seattle, Washington. The bottom trace represents the horizontal component of the geomagnetic field.

The observable onsets for the first SID in Figure 1 do not all occur at the same time. The earliest starting time (1800 UT) is observed in the 100 kHz signals received from North Carolina and Florida and in the 24 kHz signal received from Panama, Canal Zone. These signals exhibit variations in phase of about 7°/min from 1800 to 1807 UT. At 1807 UT the rate of change of phase increased to about 25°/min. The earliest starting time of the disturbance in the 21.4 kHz signal from Annapolis, Maryland, the 18.6 kHz signal from Seattle, Washington, and in the horizontal component of the geomagnetic field is about 1807 UT.

The top three traces of Figure 2 show the amplitudes in dB of the 100 kHz Loran C signals received from Massachusetts, North Carolina and Florida. Note

* High Altitude Nuclear Detection Studies, sponsored by ARPA.

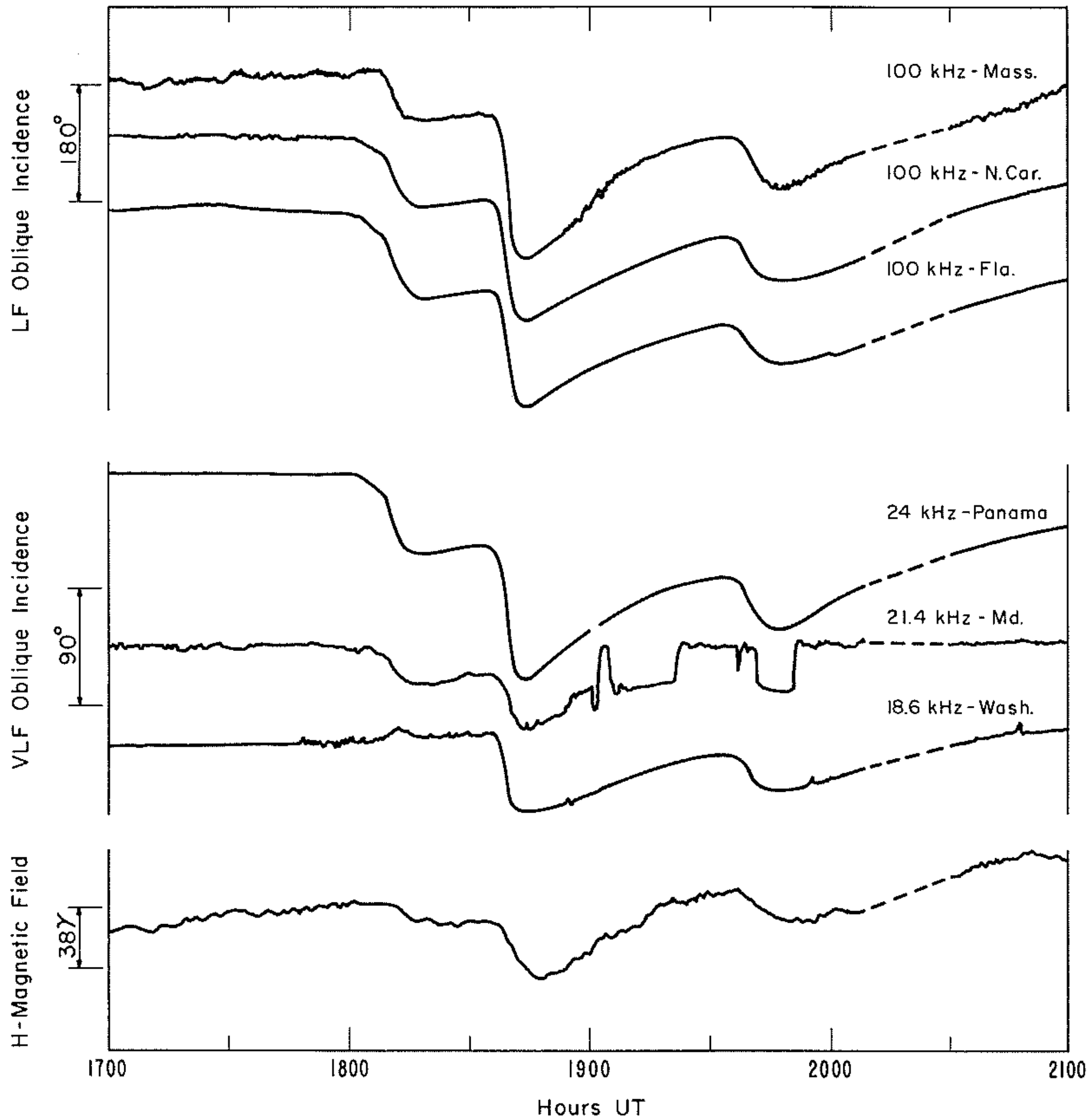


Fig. 1. Observations at Boulder, Colorado, during solar flares of May 23, 1967: phase of 100-kHz Loran C signals; phase of VLF signals; horizontal component of geomagnetic field. (In this and following figures, the dashed portions indicate missing data.)

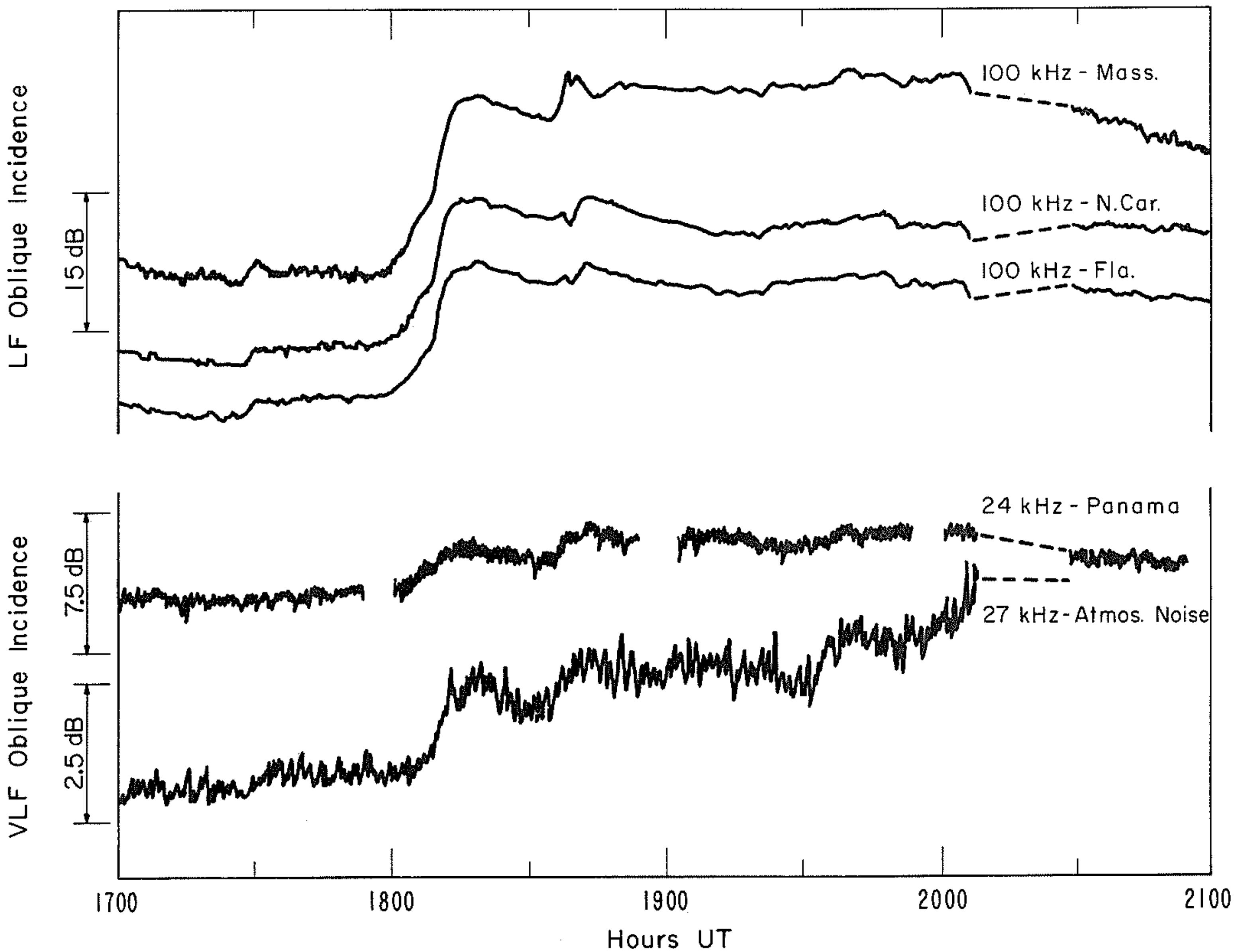


Fig. 2. Observations at Boulder, Colorado during solar flares of May 23, 1967; amplitude of 100-kHz Loran C signals; amplitude of VLF signals. Missing sections of the 24-kHz signal indicate transmitter off periods.

that the starting time of the disturbances in these records is approximately 1800 UT, followed by a more rapidly increasing disturbance starting at 1807 UT, as observed in the corresponding phase records of Figure 1.

The two bottom traces of Figure 2 represent the amplitudes of the 24 kHz signal received from Panama, Canal Zone, and in the 27 kHz atmospheric noise received from an omnidirectional antenna. The 24 kHz signal resumed transmission at 1800 UT following a 5 minute off the air period, and the disturbance associated with the solar flare appears to start at approximately that time. The 27 kHz atmospheric noise trace contains short-term fluctuations of about 1 dB peak-to-peak, which tend to conceal a portion of the early onset of the SEA. The earliest identifiable onset is approximately 1807 UT in this record at which time the phase coherent radio signals exhibited more rapid variations.

It is of interest to note that the magnitudes of the VLF and LF phase disturbances for the three SID at 1800, 1835 and 1935 UT are in the approximate ratios of 1, 3 and 1; while the amplitude enhancements are in the ratios of 1, 0.2 and 0.1, or smaller. These data indicate that: 1) solar radiation capable of affecting oblique incidence VLF and LF propagation, started at 1800 UT and changed spectral and temporal character at 1807 UT; 2) some of the radio signals did not evidence changes until about 1807 UT when the solar X-radiation was more strongly enhanced, which could be due to the reflection heights of the signals or a poorer signal-to-noise ratio for these signals; 3) the LF radio onsets accompanying the three solar flares indicate a reduced detection sensitivity on a time scale of tens of minutes following the first X-ray event.

Some characteristics of these SID records including times of start and times and amplitudes of maximum variations, are listed in Tables 1, 2 and 3. These tables also contain approximate phase-height changes, h, for the VLF and LF signals. The calculations for the long path VLF signals use Wait's formulation (1959), while the calculations for the LF and short path VLF signals use the simple geometric (mirror reflection) formulation. No phase-height changes are shown for the Seattle to Boulder path, since the intermediate length of this path (1595 km) invalidates the above-mentioned formulations. These calculations are meant to be used as simple indicators of the magnitudes of the ionospheric disturbances. A more detailed analysis, e.g., Wait's exponential-conductivity formulation (Wait, 1959, and Wait and Spies, 1964) should be used to study the structure of the disturbed electon density profiles.

TABLE 1

MAY 23, 1967 - FLARE I

VLF EXPERIMENTS

| Source | Path (km) | Phase Advance Start(UT) | Max(UT) | Δφ | Δh(km) | Amp. Change Start(UT) | Max(UT) | ΔA(dB) |
|---|---|---|---|---|---|---|---|---|
| Seattle, Wash. 18.6 kHz | 1595 | 1804 | 1812 | -10° | | Obscured by keying pattern. | | |
| Ft. Collins, Colo. 20 kHz | 60 | ----------OFF AIR---------- | | | | | | |
| Annapolis, Md. 21.4 kHz | 2466 | 1803 | 1815 | +29° | -4.1 | Obscured by keying pattern. | | |
| Panama, C.Z. 24 kHz | 4270 | 1800 | 1818 | +59° | -4.6 | --- | 1817 | +2.2 |
| Oahu, Hawaii 23.4 kHz | 5370 | ----------OFF AIR---------- | | | | | | |
| Oahu, Hawaii 13.6 kHz | 5370 | 1803 | 1818 | +80° | -5.7 | ----indefinite---- | | ≈ -1. |
| Atmospheric Noise 27 kHz | ---- | ---- | ---- | --- | | 1807 | 1819 | +1.5 |

LF EXPERIMENTS

| Source | Path (km) | Phase Advance Start(UT) | Max(UT) | Δφ | Δh(km) | Amp. Change Start(UT) | Max(UT) | ΔA(dB) |
|---|---|---|---|---|---|---|---|---|
| Annapolis, Md. 88kHz | 2466 | ----------OFF AIR---------- | | | | | | |
| Cape Fear, N.C. 100 kHz(pulse) | 2509 | 1800 | 1819 | +104° | -2.9 | 1800 | 1817 | +15 |
| Jupiter, Fla. 100 kHz(pulse) | 2732 | 1803 | 1819 | +108° | -3.1 | 1759 | 1819 | +14 |
| Nantucket, Mass. 100 kHz(pulse) | 2962 | 1807 | 1819 | +72° | -2.0 | 1800 | 1819 | +15 |

HF EXPERIMENTS

| Source | Path (km) | Doppler Shift (Hz) Start(UT) | Max(UT) | Doppler(Hz) | Amp. Change Start(UT) | Max(UT) | ΔA(dB) |
|---|---|---|---|---|---|---|---|
| Erie, Colo. 2.1 MHz | 20 | ----------NO SIGNAL RECEIVED---------- | | | | | |
| Erie, Colo. 4.047 MHz | 20 | ----NO EFFECT---- | | | 1800 | 1820 | ≈ -14. |
| Long Branch, Ill. 8.9 MHz | 1290 | Indef. | 1809 | 1.5 | 1800 | 1812 | <-3.5 |
| Long Branch, Ill. 13.0 MHz | 1290 | 1809 | 1809 | 1.2 | 1800 | 1820 | -3.5 |

OTHER EXPERIMENTS

| Measurement | Effect |
|---|---|
| Hor. Comp. of Magnetic Field | Amplitude decrease of 12.75γ<br>Start: 1809 Max: 1819 |
| 30-MHz Riometer (Cosmic Noise Absorption) | Burst followed by 4-dB absorption.<br>Start: 1800, Max: 1820 |
| 3-cm Solar Noise | Burst of 50 units (see text) at 1807. Max: 1810 |
| 184-MHz Solar Noise | No change in noise level recorded. |

TABLE 2

MAY 23, 1967 - FLARE II

VLF EXPERIMENTS

| Source | Path (km) | Phase Advance Start(UT) | Max(UT) | Δφ | Δh(km) | Amp. Change Start(UT) | Max(UT) | ΔA(dB) |
|---|---|---|---|---|---|---|---|---|
| Seattle, Wash. 18.6 kHz | 1595 | 1836 | 1842 | +54° | | Obscured by keying pattern. | | |
| Annapolis, Md. 21.4 kHz | 2466 | 1835 | 1842 | +43° | -6.1 | ----------See Text---------- | | |
| Panama, C.Z. 24 kHz | 4270 | 1835 | 1844 | +104° | -8.1 | 1835 | 1844 | +1.5 |
| Oahu, Hawaii 13.6 kHz | 5370 | 1835 | 1844 | +160° | -11.4 | 1835 | 1840 | -3.4 |
| Atmospheric Noise 27 kHz | ---- | ---- | ---- | --- | | 1835 | 1843 | +0.7 |

LF EXPERIMENTS

| Source | Path (km) | Phase Advance Start(UT) | Max(UT) | Δφ | Δh(km) | Amp. Change Start(UT) | Max(UT) | ΔA(dB) |
|---|---|---|---|---|---|---|---|---|
| Cape Fear, N.C. 100 kHz(pulse) | 2509 | 1833 | 1845 | +185° | -5.2 | 1835 | 1843 | +3.0 |
| Jupiter, Fla. 100 kHz(pulse) | 2732 | 1835 | 1843 | +180° | -5.1 | 1835 | 1843 | +2.0 |
| Nantucket, Mass. 100 kHz(pulse) | 2962 | 1835 | 1843 | 216° | -6.1 | 1835 | 1840 | +4.0 |

HF EXPERIMENTS

| Source | Path (km) | Doppler Shift (Hz) Start(UT) | Max(UT) | Doppler(Hz) | Amp. Change Start(UT) | Max(UT) | ΔA(dB) |
|---|---|---|---|---|---|---|---|
| Erie, Colo. 2.1 MHz | 20 | ------------------------NO SIGNAL RECEIVED------------------------ | | | | | |
| Erie, Colo. 4.047 MHz | 20 | -----------NO EFFECT------------ | | | 1833 | 1835 | -4.0 |
| Long Branch, Ill. 8.9 MHz | 1290 | 1835 | 1835 | 1.7 | 1835 | 1838 | Fade out |
| Long Branch, Ill. 13.0 MHz | 1290 | 1835 | 1835 | 3.0 | 1836 | 1838 | Fade out |

OTHER EXPERIMENTS

| Measurement | Effect |
|---|---|
| Hor. Comp. of Magnetic Field | Amplitude decrease of 37.5γ<br>Start: 1836, Max: 1847 |
| 30-MHz Riometer (Cosmic Noise Absorption) | Burst at 1835 saturating equipment at 1838. |
| 3-cm Solar Noise | Large burst at 1835, saturating equipment at 1000-unit level at 1839. |
| 184-MHz Solar Noise | Large burst at 1834. |

TABLE 3

MAY 23, 1967 - FLARE III

VLF EXPERIMENTS

| Source | Path (km) | Phase Advance Start(UT) | Max(UT) | Δφ | Δh(km) | Amp. Change Start(UT) | Max(UT) | ΔA(dB) |
|---|---|---|---|---|---|---|---|---|
| Seattle, Wash. 18.6 kHz | 1595 | 1935 | 1945 | +24° | | Obscured by keying pattern. | | |
| Annapolis, Md. 21.4 kHz | 2466 | ---------------------------SEE TEXT------------------- ----------- | | | | | | |
| Panama, C.Z. 24 kHz | 4270 | 1936 | 1948 | +39° | -3.0 | -----Indefinite----- | | ≤+1. |
| Oahu, Hawaii 13.6 kHz | 5370 | 1936 | 1948 | +54° | -3.8 | -----Indefinite----- | | -2. |
| Atmospheric Noise 27 kHz | ---- | ---- | ---- | --- | | 1934 | 1948 | +.7 |

LF EXPERIMENTS

| Source | Path (km) | Phase Advance Start(UT) | Max(UT) | Δφ | Δh(km) | Amp. Change Start(UT) | Max(UT) | ΔA(dB) |
|---|---|---|---|---|---|---|---|---|
| Cape Fear, N.C. 100 kHz(pulse) | 2509 | 1934 | 1948 | +72° | -2.0 | -----Indefinite----- | | +1. |
| Jupiter, Fla. 100 kHz(071se) | 2732 | 1934 | 1948 | +63° | -1.8 | -----Negligible Effect----- | | |
| Nantucket, Mass. 100 kHz(pulse) | 2962 | 1937 | 1948 | +90° | -2.5 | -----Negligible Effect----- | | |

HF EXPERIMENTS

| Source | (km) | Start(UT) | Max(UT) | Doppler(Hz) | Start(UT) | Max(UT) | ΔA(dB) |
|---|---|---|---|---|---|---|---|
| Erie, Colo. 2.1 MHz | 20 | -------------------------NO SIGNAL RECEIVED------------------------- | | | | | |
| Erie, Colo. 4.047 MHz | 20 | ------------NO EFFECT------------ | | | 1930 | 1940 | -3.0 |
| Long Branch, Ill. 8.9 MHz | 1290 | -------------------SIGNAL ABSORBED AFTER 1838---------------------- | | | | | |
| Long Branch, Ill. 13.0 MHz | 1290 | -------------------SIGNAL ABSORBED AFTER 1838---------------------- | | | | | |

OTHER EXPERIMENTS

| Measurement | Effect |
|---|---|
| Hor. Comp. of Magnetic Field | Decrease of 19.5γ between 1937 and 1948 |
| 30-MHz Riometer | Equipment saturated after 1838. |
| 3-cm Solar Noise | Large burst at 1936, saturating equipment at 1000-unit (see text) level at 1936. |
| 184-MHz Solar Noise | Very large burst at 1936. |

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# 5. SOLAR X-RAYS AND SOLAR COSMIC RAYS

## "X-ray conditions on the 23rd of May 1967"

by

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Satellite 1965-93 Å was at an aspect angle of 4° for the period of the 23rd of May 1967. During the time of interest of 1800-2200 UT only two passes were obtained. During both of these passes the satellite x-ray detectors were heavily saturated. The first pass occurred from 1941-1951 and during this time the detectors were in much heavier saturation than during the later pass of 2137-2144. Preceding the period of interest continuous data was received from 1612-1654 UT. This 42 minute period of continuous data shows no major change in any of flux levels. The 8-20 Å flux is at a level of $4.4 \times 10^{-2}$ ergs $cm^{-2}$ $sec^{-1}$. This level is much higher than that which had been seen earlier in the day and it is surprising that the background level is constant at this value. The maximum value which can be read by the satellite while at this aspect angle is $5 \times 10^{-2}$ ergs $cm^{-2}$ $sec^{-1}$.

The 0-8 Å flux also is constant and also is much higher than that observed previously. It is up by a factor of 6 over the level seen an hour and a half earlier. The level observed is about $4.2 \times 10^{-3}$ ergs $cm^{-2}$ $sec^{-1}$. This is about a factor of 3 below the maximum observable level.

The 0-3 Å flux shows a decrease from about $7 \times 10^{-5}$ to $5 \times 10^{-5}$ during the interval of 1612-1645. The rest of the time this detector is affected by particles. The saturation level for this detector at this particular aspect angle is $1.6 \times 10^{-4}$.

From the above levels during the interval of 1600-1700 UT it can be seen that the sun was outputting a very high level of x-rays just prior to the interval of interest of 1800-2200 UT. Thus, a small flare on top of this high level would result in saturation and a large event, as was observed optically, would result in a very heavy saturation and probably would keep the satellite saturated for some time. The peak x-ray levels which were outputted by the event can only be very roughly estimated as probably being a factor of 5 above the saturation levels of each of these detectors.

The Lyman-alpha and calcium fluoride detectors show no visible signs of increase during this period. However, from the August 28th flare it has been found that in order to see an increase one has to be looking at the data at precisely the right time. And we did not have coverage of the sun at the time of the start and rise of the Hα flare.

# "Solar X-ray Flares on May 23, 1967"

by

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University of Iowa, Iowa City, Iowa

[Permission has been received from Prof. Van Allen to reprint his article in the Astrophysical Journal, 152, L85-86, May 1968.]

The soft X-ray flux from a sequence of three solar flares on May 23, 1967, was observed with a mica-window, neon-filled Geiger tube on satellite Explorer 33. The apparatus and technique have been described elsewhere (Van Allen 1967; Van Allen and Ness 1967). During this period detector GM3 was pointed continuously at the Sun with an angle of 2° between the axis of the detector and the spacecraft-Sun line. Hence, the geometric obliquity factor f(a) = 1.05. The accumulated counts from the detector during a 25.565-sec period were read out each 163.616 sec and assigned to the midtime of the accumulated sample. Each rate was corrected for dead time using the preflight calibration curve and converted to an absolute flux F(2-12 Å) at 1 a.u. as previously described (Van Allen 1967). A plot of these values for the period 1700 UT, May 23, to 0130 UT, May 24, 1967, is given in Figure 1. The uncertainty in the absolute values is estimated to be ≤50 per cent throughout.

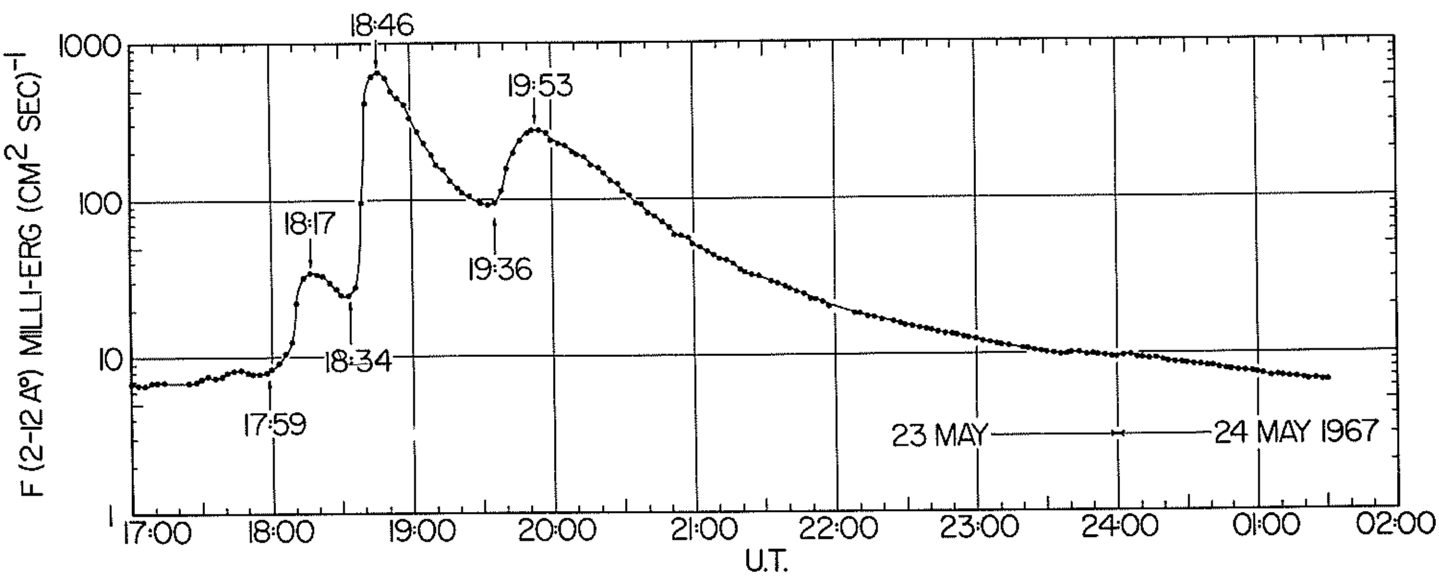


Fig. 1. Absolute solar X-ray flux as a function of time for the period 1700 UT, May 23, to 0130 UT, May 24, 1967, as observed with Explorer 33.

The ambient flux from the whole disk of the quiet Sun before and after the three flares was $7 \times 10^{-3}$ erg cm$^{-2}$ sec$^{-1}$. The maximum value F(2-12 Å) = 0.65 erg cm$^{-2}$ sec$^{-1}$ occurred at 1846 UT. I have been unable to find any report of an X-ray flare of this great a flux reported heretofore, though I have observed comparable maximum values, also during May 1967, as follows: 0.18 at 1927 UT, May 21; 0.28 at 1952 UT, May 23; and 0.32 at 0551 UT, May 28.

On the grounds of time coincidence with terrestrial optical observations (De Mastus and Stover 1967; Solar-Geophysical Data 1967), the three X-ray flares of May 23 are attributed to McMath plage region 8818 at N27 E25 on the solar disk.

This work is supported in part by NASA/GSFC contract NAS5-9076.

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["Observations of Energetic X-Rays and Solar Cosmic Rays Associated with the 23 May 1967 Solar Flare Event"

by

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[This full paper is to be published in "Solar Physics". Permission has been received to preprint portions of it together with four of the figures. The editors have excerpted and adapted the discussion which particularly refers to the figures.]

Figure 1 shows the x-ray and microwave observations for the present event. Here the one minute average pulsing rates of the OGO-III ion chamber during the period 1730-2200 UT on 23 May 1967 are plotted against time. Also shown in Figure 1 are the published 2-12 Å x-ray observations of Van Allen (1968), the radio observations of Castelli et al., (1967) at 606, 2695 and 8800 MHz, and the 2800 MHz measurements at Ottawa (Solar Geophysical Data, June 1967). At the beginning of the time interval in Figure 1 (1730 UT) the OGO-III chamber was sampling the particles from an earlier solar flare event which produced a chamber rate of ∿70 norm. pulses $sec^{-1} \times 10^3$, whereas the background due to galactic cosmic rays was ∿50 norm. pulses $sec^{-1} \times 10^3$. Three peaks, attributed to solar x-rays in the 10-50 keV range, occurred with onset times at ≈ 1808, 1832 and 1931 UT. Henceforth for brevity these three x-ray bursts are called burst numbers 1, 2 and 3 respectively. Each energetic x-ray burst had a rapid onset and a relatively slow decay. The burst number 2, which began at ∿1832 UT was the largest of the three bursts reaching a maximum flux value of $\sim 2.9 \times 10^{-3}$ ergs $cm^{-2}sec^{-1}$ above 20 keV at ∿1841 UT. The 2-12 Å x-ray intensity also showed three peaks corresponding to the energetic x-ray burst numbers 1, 2 and 3. However, the soft x-ray peaks are considerably flatter than the energetic x-ray peaks. This is apparently caused by the relatively slow rise and decay characteristics of the soft x-rays.

In general, there is excellent correlation between the microwave and energetic x-ray intensity. The microwave time-intensity profile also showed three peaks corresponding within 9 minutes to the three x-ray bursts. However, the largest microwave burst did not correspond to the largest x-ray burst. The largest microwave burst started at ∿1930 UT and reached its peak value at ∿1947 UT corresponding approximately to the maximum in the x-ray burst number 3. Castelli et al. (1967) have described this radio burst as one of the largest four bursts ever recorded in the 3 cm region and the largest burst in the decimeter region.

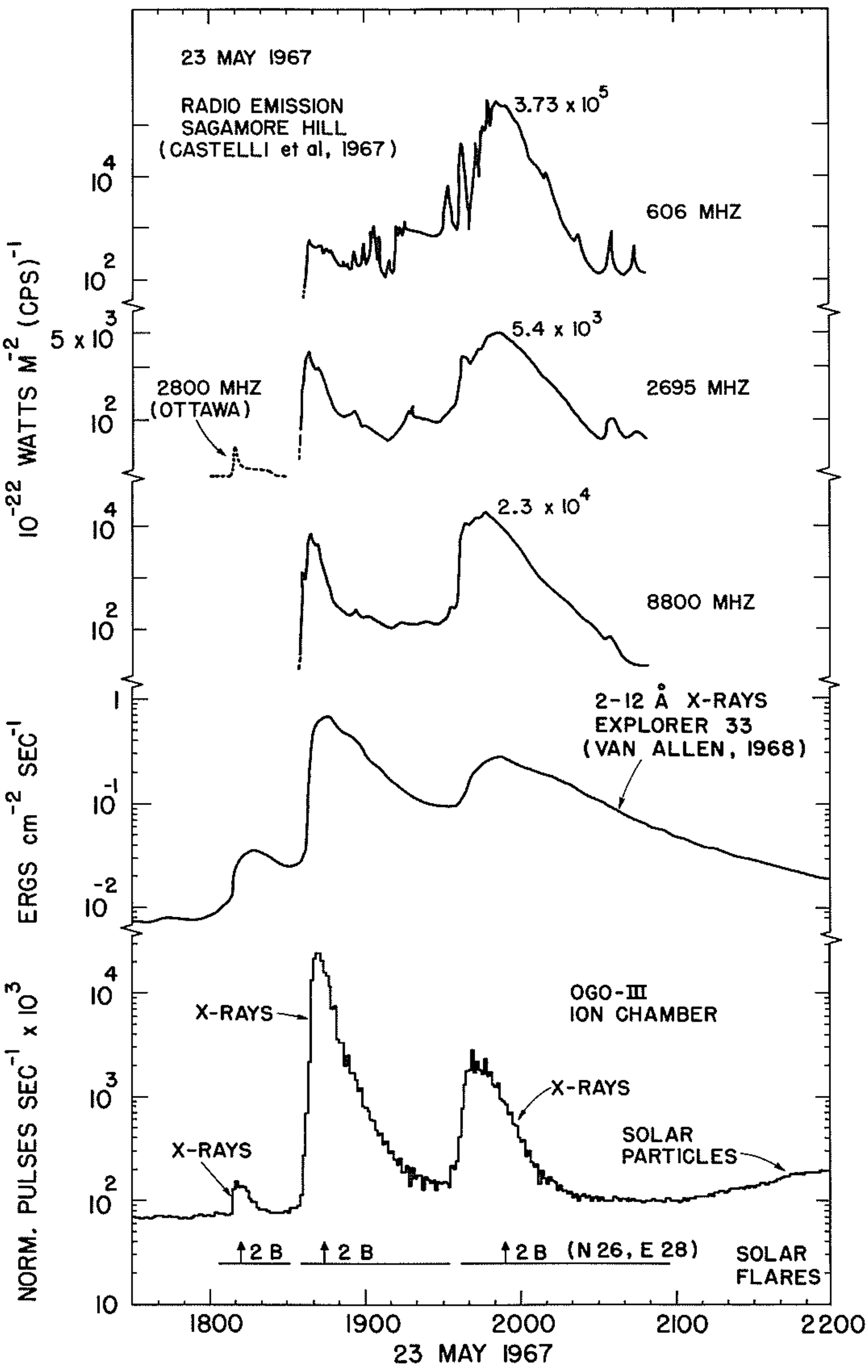


Fig. 1. One minute average pulsing rates of the OGO-III ion chamber during the period 1730-2200 UT on 23 May 1967. Also shown are the 2-12 Å x-ray observations by Van Allen (1968) and the radio observations of Castelli et al., (1967) at 606, 2695 and 8800 MHz.

The flare corresponding to the x-ray burst number 2 was visible in white light (Sky and Telescope, 1967). The maximum of the white light emission occurred at ∿1840 UT nearly coincident with the peak in the corresponding x-ray burst. The Hα maximum for this flare occurred at ∿1844 UT (Sky and Telescope, 1967).

SWF events of importance 3 and 3+ started within about one minute of the onset of the energetic x-ray burst numbers 1 and 2, respectively. The second event lasted until 2230 UT and could have been a combination of the SWF events associated with the x-ray burst numbers 2 and 3. The present measurements are thus consistent with our earlier observation that a very good correlation exists between the occurrence of large SID events (importance ≥ 3) and energetic x-ray bursts (Arnoldy et al., 1968b).

Higher time resolution profile (10 second averages) of the energetic x-ray burst number 2 is shown in Figure 2. Here the satellite roll effect (roll period ∿105 seconds) on the uni-directional beam of solar x-rays incident on the chamber is clearly evident. This roll modulation is almost certainly produced by the various portions of the spacecraft eclipsing the sun once each roll period. In all the three x-ray bursts, apart from this roll modulation superposed on the smooth envelope of the burst, there is no indication of any appreciable fluctuations in the x-ray intensity.

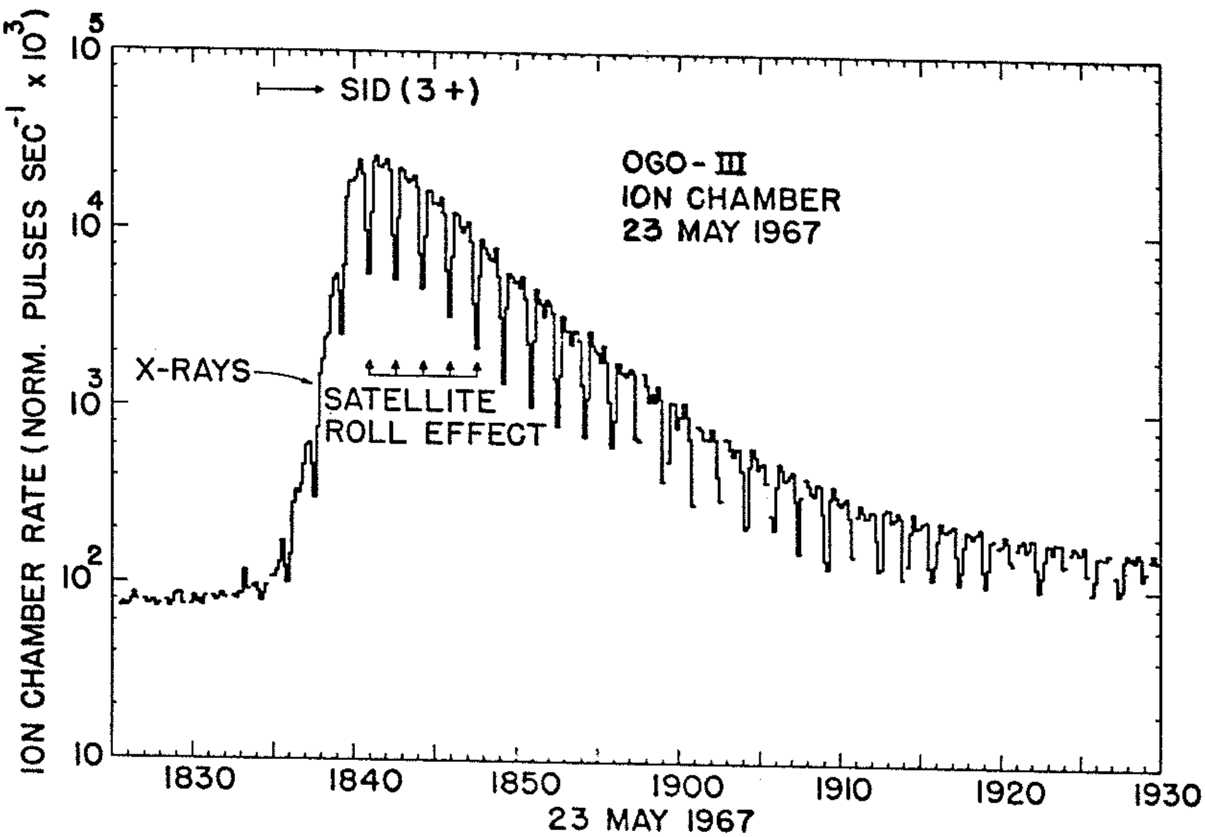


Fig. 2. Ten second average pulsing rates of the OGO-III ion chamber during the period 1825-1930 UT on May 23. In the text this x-ray burst is called burst number 2. Notice the satellite roll effect on the solar x-ray beam.

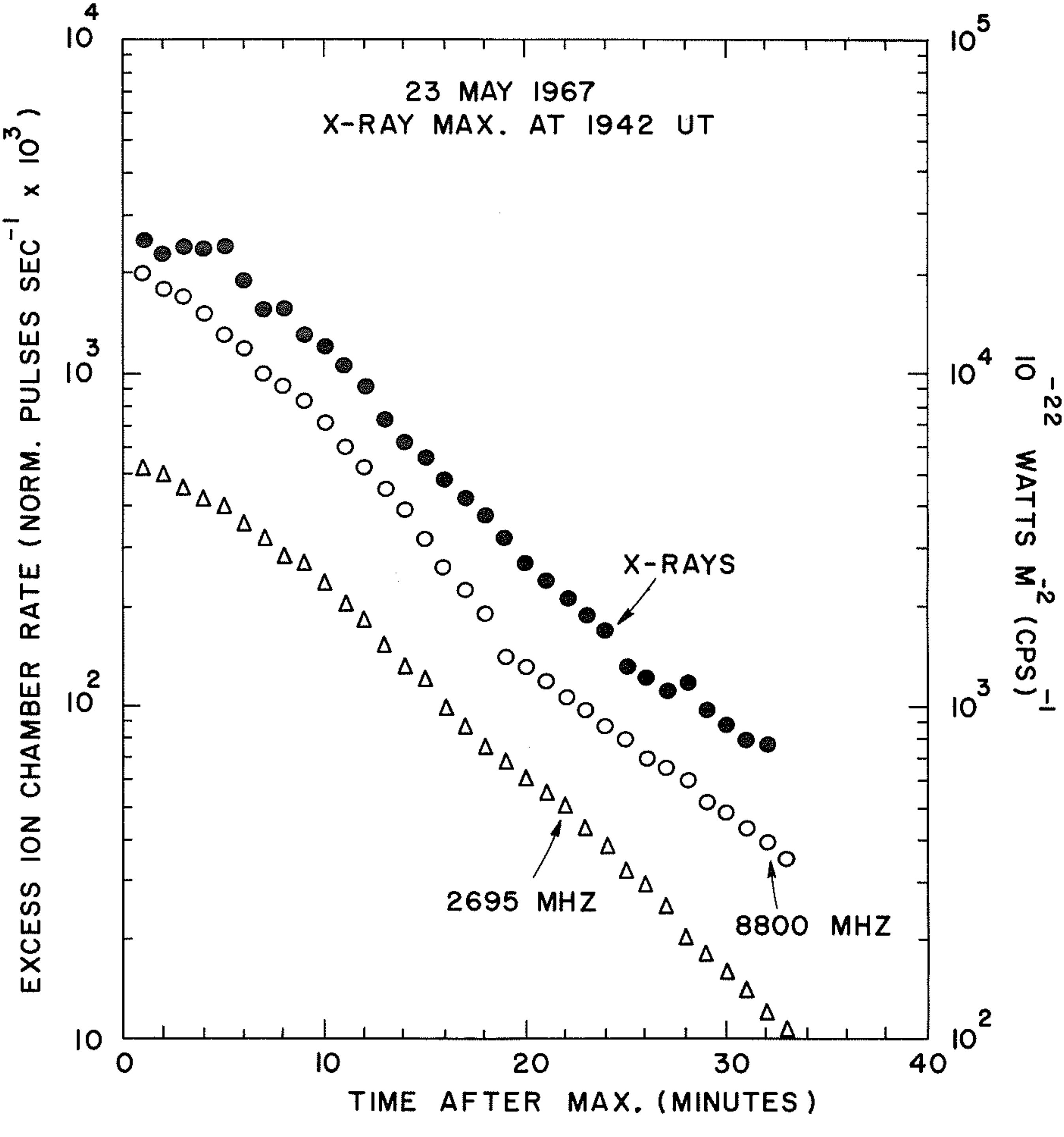


Fig. 3. Decay characteristics of the x-ray burst number 3 and the corresponding radio burst at 2695 and 8800 MHz. In each case the time of maximum intensity is taken as the "0" time.

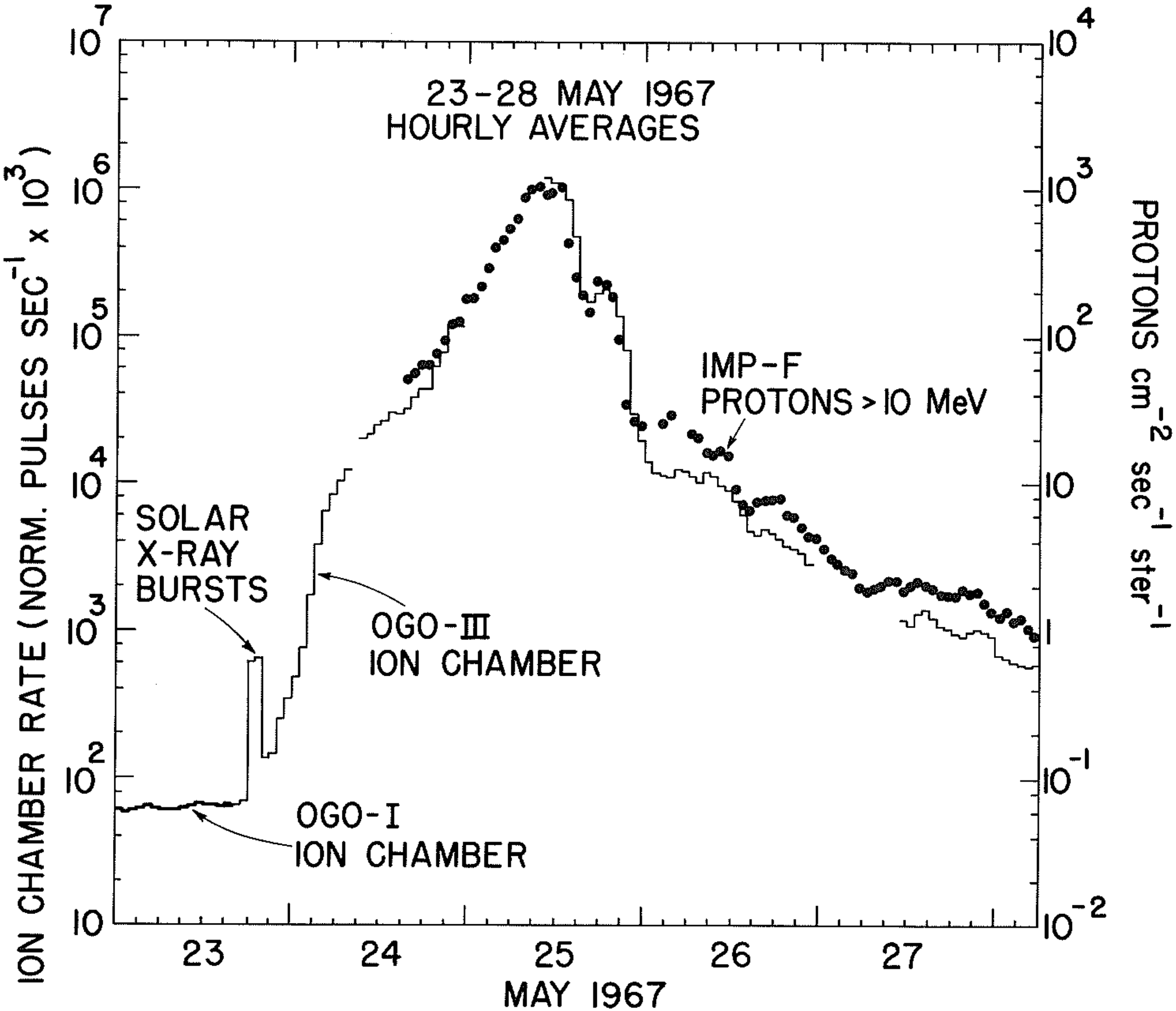


Fig. 4. One hour average pulsing rates of the OGO-III ion chamber during the period 23-27 May 1967 showing the solar particle event that followed the 23 May 1967 solar x-ray bursts. Also shown are the hourly average rates of the IMP-F Solar proton Monitor (Bostrom et al., 1968a).

The decay characteristics of the x-ray burst number 3 are shown in Figure 3. The x-ray data used in this figure are obtained after correcting for the satellite roll modulation and then subtracting the background chamber rate of ∿70 norm. pulses $sec^{-1}$x $10^3$. From Figure 3 it can be seen that in the case of burst number 3 the decay of the x-ray intensity was very nearly exponential with a time constant of about 8 minutes. The corresponding microwave burst also decayed in a similar manner. However, the situation is quite complex in the case of burst number 2, particularly for the radio flux. It is important to note that the similarity of the decay characteristics of the ion chamber rate and the microwave emission seen in many solar flare events is a specific characteristic of the range of x-ray energies (10-50 keV) to which the OGO chamber is most sensitive. For example, the case of the burst number 3, the decay time constant for the 2-12 Å x-rays is ∿43 minutes which is about 5 times the decay time constant for the energetic x-rays.

The solar particle event following the 23 May 1967 solar x-ray bursts has been widely studied. (Lindgren, 1968; Bostrom et al., 1968; Gardner et al., 1968; Singer et al., 1968). Figure 4 shows the time intensity profile of the OGO ion chamber rate during this event. In this figure the hourly average rates of the OGO ion chambers are plotted against time for the period 0000 UT on 23 May 1967 - 0600 UT on 28 May 1967. Also shown in the figure is the hourly average flux of protons with energy >10 MeV measured by the IMP-F Solar Proton Monitor (Bostrom et al., 1968a).

A detailed analysis of the response of the OGO chamber to solar cosmic rays is reported elsewhere (Kane et al., 1968). This analysis shows that for a steep spectrum or a large proton to α-particle ratio in the solar cosmic rays, as is often the case, the chamber responds predominantly to protons >12 MeV and a nearly linear relationship exists between the OGO chamber rate and the flux of protons >12 MeV. Therefore the close absolute agreement between the OGO-III chamber and the IMP-F proton monitor seen in Figure 4 is to be expected.

One minute averages of the OGO-III ion chamber rate show that the maximum intensity was reached at ≃1003 UT on 25 May 1967. The peak chamber rate was equivalent to a dosage of ≃24 R/hour behind the 0.22 g $cm^{-2}$ thick aluminum wall of the chamber. It may be pointed out that this dosage was considerably smaller than the maximum dosage (≃60 R/hour) measured during the 2 September 1966 event which is the largest solar particle event observed so far by the OGO-I and OGO-III satellites.

Examination of Figure 1 shows that the solar particle intensity began to increase at least by 2100 UT on 23 May. However, there is evidence for an increased background already present at 2100 UT over that observed prior to the x-ray burst number 1. This background may be due to solar particles associated with any one of the three x-ray increases or a weak ≥20 keV x-ray background from the activated center. The latest onset time consistent with the present observations is ≃2100 UT. It is important to note that this onset time is about 5 hours earlier than that observed for protons >10 MeV by Singer et al. (1968) with detectors aboard the Vela satellite. The earlier onset time observed by OGO-III ion chamber could be due to its higher sensitivity (≃0.01 protons $cm^{-2}$ $sec^{-1}$ >12 MeV) compared to the Vela satellite detectors. A difference in onset times can also be caused by the screening of the solar particles by the outer magnetosphere (Kane et al., 1968). The exact energy of the particles responsible for the observed onset seen in Figure 1 at ≃2100 UT is not known. Undoubtedly the proton energy spectrum changes rapidly with time in the initial moments of the event. The transit time is thus uncertain.

The slow rise of the particle event is consistent with its association with an east limb solar flare. The three solar x-ray bursts which occurred immediately before the onset of the event were discussed in the last section. On the basis of the observations presented here it is not possible to determine which one of the two larger x-ray bursts was associated with the particle event. The structure of the event (Figure 4) indicates that the observed particle intensity was probably a result of the superposition of more than one solar particle event.

When compared with the solar x-ray and particle events observed by the OGO-III ion chamber on 7 July 1966, 28 August 1966 and 27 February 1967, it can be seen that the 23 May event is basically similar to other events observed in the past. Each one of the four solar flare events is characterized by an x-ray event followed closely by a particle event. In fact in all the cases the energetic particles apparently arrived at the earth even before the x-ray event had completely decayed. The rise time of the particle event seems to depend somewhat on the location of the flare. For example, in the 23 May 1967 event, which was apparently associated with a solar flare at 25°E solar longitude, the particle intensity increased very slowly compared to that in the 7 July 1966 event which was associated with a flare at 48°W longitude.

Thanks are due to Dr. Karl Pfitzer for a major effort on the OGO data reduction. This work was supported by the National Aeronautics and Space Administration Contract No. NAS 5-2071.

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## 6. SOLAR PROTONS BY SATELLITE

"Solar Protons and Alphas from the May 23, 1967 Solar Flares"

by

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### Introduction

The low energy protons and alpha particles emitted during a series of three east limb solar flares (McMath plage region 8818; 27-30N, 25-28E) on May 23, 1967, were measured in interplanetary space by the Bell Telephone Laboratories experiment on board the earth orbiting Explorer 34 (IMP F) satellite. This report describes the time history of the solar particle observations made by the BTL experiment and discusses the particle fluxes and spectra associated with the storm sudden commencements and the onset of the large Forbush decrease observed on the earth. A number of observations of, and details concerning, this series of flares have previously been published and they will not be reviewed in this report (Castelli, et al., 1968; Masley and Goedeke, 1968; Smith and Webber, 1968; Van Allen, 1968).

The Explorer 34 satellite was launched into a highly eccentric polar orbit at approximately 1420 UT May 24, during the onset of the solar flare particle observations at the earth. Explorer 34 is a spin stabilized (with spin axis perpendicular to the ecliptic plane) satellite with an apogee of approximately 34 $R_E$. The BTL experiment consists of a four element solid state telescope oriented perpendicular to the spin axis. The half angle of the detector telescope defining collimator is 20°; the flux measured by the experiment is the spin averaged flux of particles in the ecliptic plane. Protons and alphas up to an energy of approximately 4 MeV/nucleon are distinguished by the energy deposited in the first two detectors of the telescope and subsequently measured in a five channel analyzer. Particle species above this energy are distinguished by the use of an on-board pulse multiplier (Lanzerotti, et al., 1969). The location of Explorer 34 in its first orbit during the solar event is shown in Fig. 1.

### Observations

The half-hour averaged solar proton fluxes measured in eight energy channels during May 24-27, 1967, are shown in Fig. 2. The half-hour averaged solar alpha particle fluxes measured in five energy channels for the same time interval are shown in Fig. 3. Plotted at the bottom of each figure is the super neutron monitor counting rate from Alert and the spectral index, n, for the alpha and proton observations. The spectral index was obtained for each species of particle by least squares fitting a power law dependence on the energy/nucleon to the half-hour averaged flux measurements.

The temporal behavior of the solar proton fluxes in the approximately 10-25 MeV energy range prior to the launch of Explorer 34 can be inferred from the riometer measurements published previously by Masley and Goedeke (1968). From this riometer data and the data in Figs. 2 and 3 it is observed that, after the occurrence of the flares in the 1800-1900 UT interval of May 23, the solar particle fluxes observed at the orbit of the earth began increasing slowly, typical of an east limb flare, until they reached their peak measured values near 1200 UT on May 25.

The proton spectral index in Fig. 2 indicates that during the onset stage of the event, except for the several hour interval around the time of the sudden commencement (sc) at 1726 UT May 24, the spectrum was harder than during the remainder of the event. The alpha spectral index of Fig. 3 also suggests this behavior, although to a lesser extent. For a given energy/nucleon, the ratio of the proton flux at approximately the time of the May 24 sc to the proton flux at ∿2100 UT May 24 is larger than the corresponding alpha flux ratio. However, the same flux ratios are found to be approximately similar when the 1.3 MeV/nucleon (5.2 MeV) alpha and 4.7 MeV proton channels are compared.

These observations imply that there is a rigidity dependence rather than a velocity dependence to the particle storage or trapping mechanisms behind or in the plasma cloud and shock wave associated with the May 24 sc. The trapping of low energy solar cosmic rays in an expanding plasma cloud has recently been discussed in a review by Obayashi (1967). [The plasma cloud and shock wave associated with the May 24 sc were perhaps due to the solar event that produced the large complex radio burst at 1922 UT on May 21 (Castelli, et al., 1968)].

The propagation characteristics of the low energy proton and alpha particle diffusion from the east limb flare region through interplanetary space to the earth also appears to be more dependent upon particle rigidity than upon particle velocity. That is, particles with a higher rigidity are observed at the earth first. This is demonstrated in Fig. 4 where the alpha/proton ratio is plotted for alphas and protons of approximately equal energy/nucleon (velocity). After the May 24 sc and until approximately 0800 UT on May 25, the alpha flux increased more rapidly than the proton flux. However, after 0800 UT, the ratio dropped slightly due to an increased proton flux.

The rigidity dependence of the particle propagation during the onset stage of the event is further demonstrated by the data in Fig. 5. Plotted in this figure is the time history of the alpha/proton ratio for 5.3 MeV alphas and 4.7 MeV protons (approximately equal rigidities). Note that the ratio in Fig. 5 is taken between fluxes expressed as $(cm^2 \text{ sec ster MeV})^{-1}$ for both the protons and the alphas. The alpha/proton ratio is approximately constant during the period of the May 24 sc, increases by approximately fifty percent prior to May 25, and then remains quite constant as both particle fluxes increase uniformly during the first half of May 25, prior to the 1235 UT sudden commencement. The constancy of the alpha/proton ratio for equal rigidity particles during the May 25 flux increases is in marked contrast to the more rapid alpha particle increases when equal velocity particles were compared in Fig. 4.

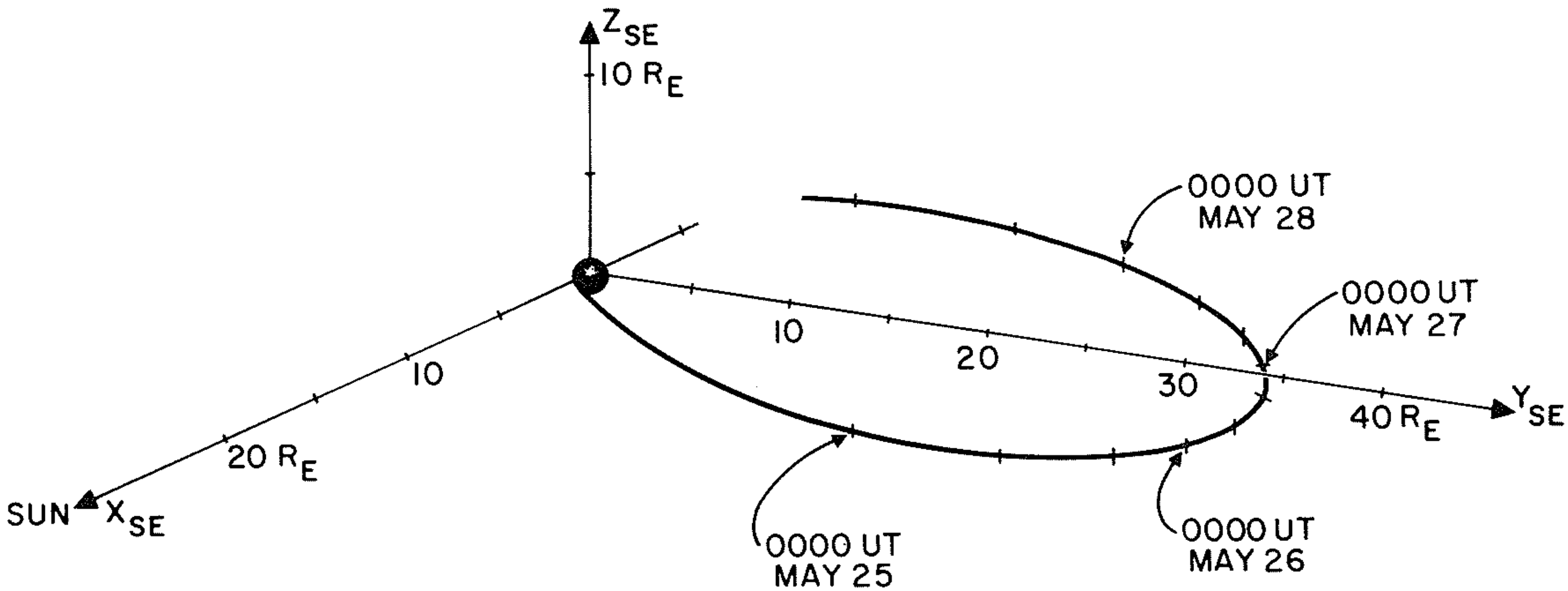


Fig. 1. Perspective view of the Explorer 34 satellite in solar-ecliptic coordinates during the period from launch to May 28, 1967.

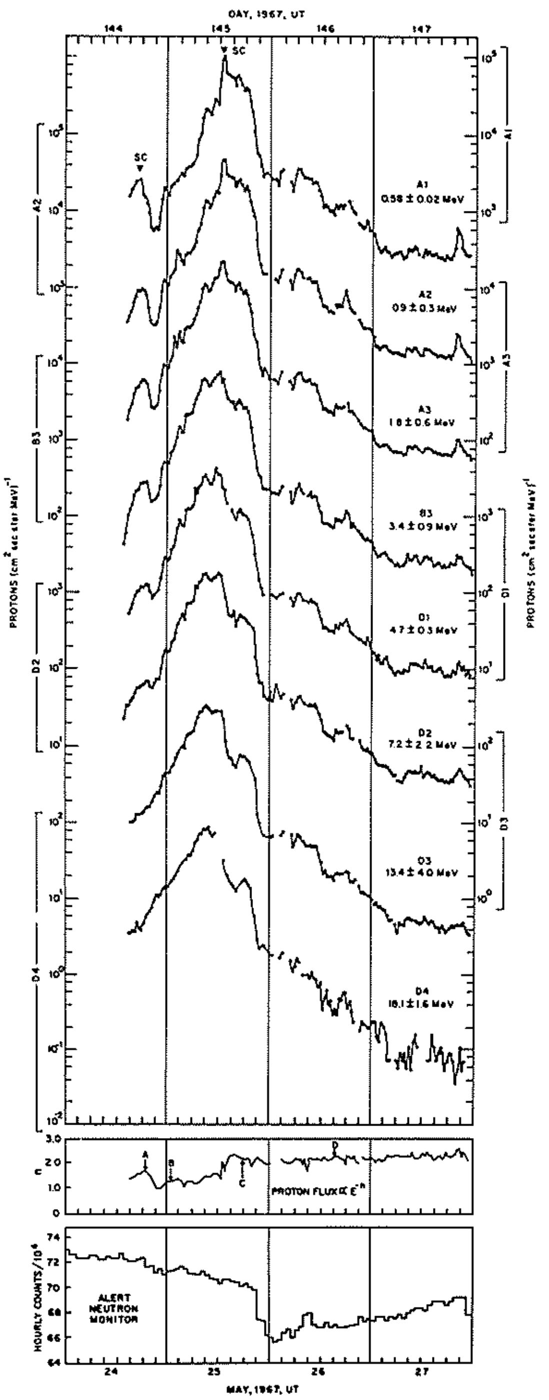

Fig. 2. Solar proton fluxes during May 24-27, 1967. Plotted at the bottom of the figure are the proton spectral index, n, and the Alert neutron monitor counting rate.

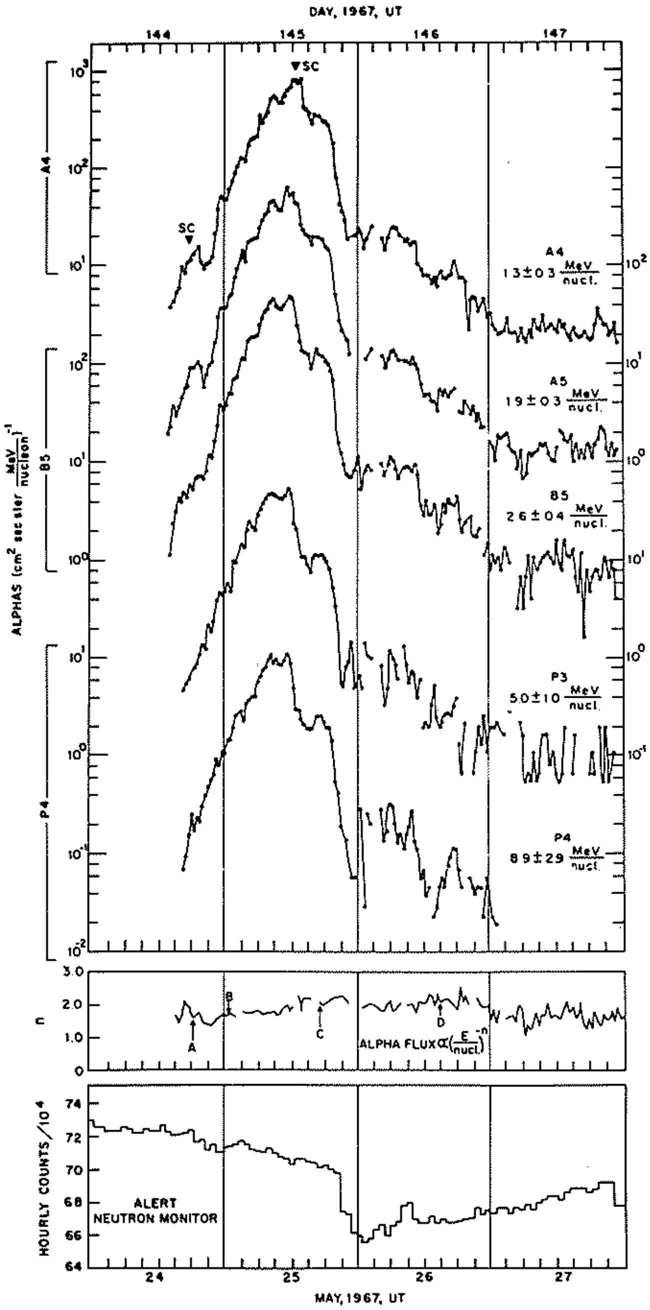


Fig. 3. Solar alpha particle fluxes during May 24-27, 1967. Plotted at the bottom of the figure are the alpha spectral index, n, and the Alert neutron monitor counting rate.

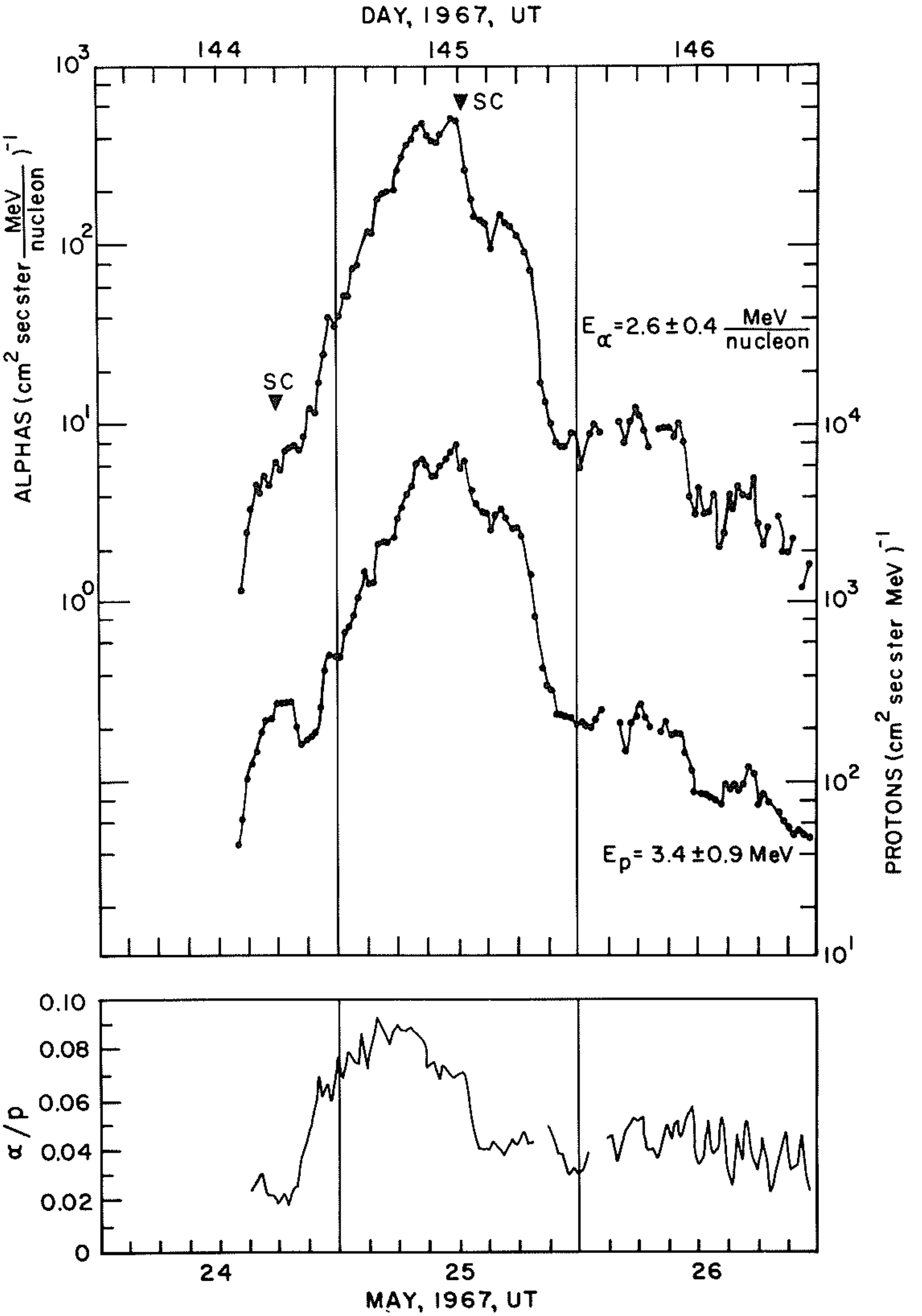


Fig. 4. Alpha particle and proton data and the alpha/proton ratio for approximately equal velocity particles.

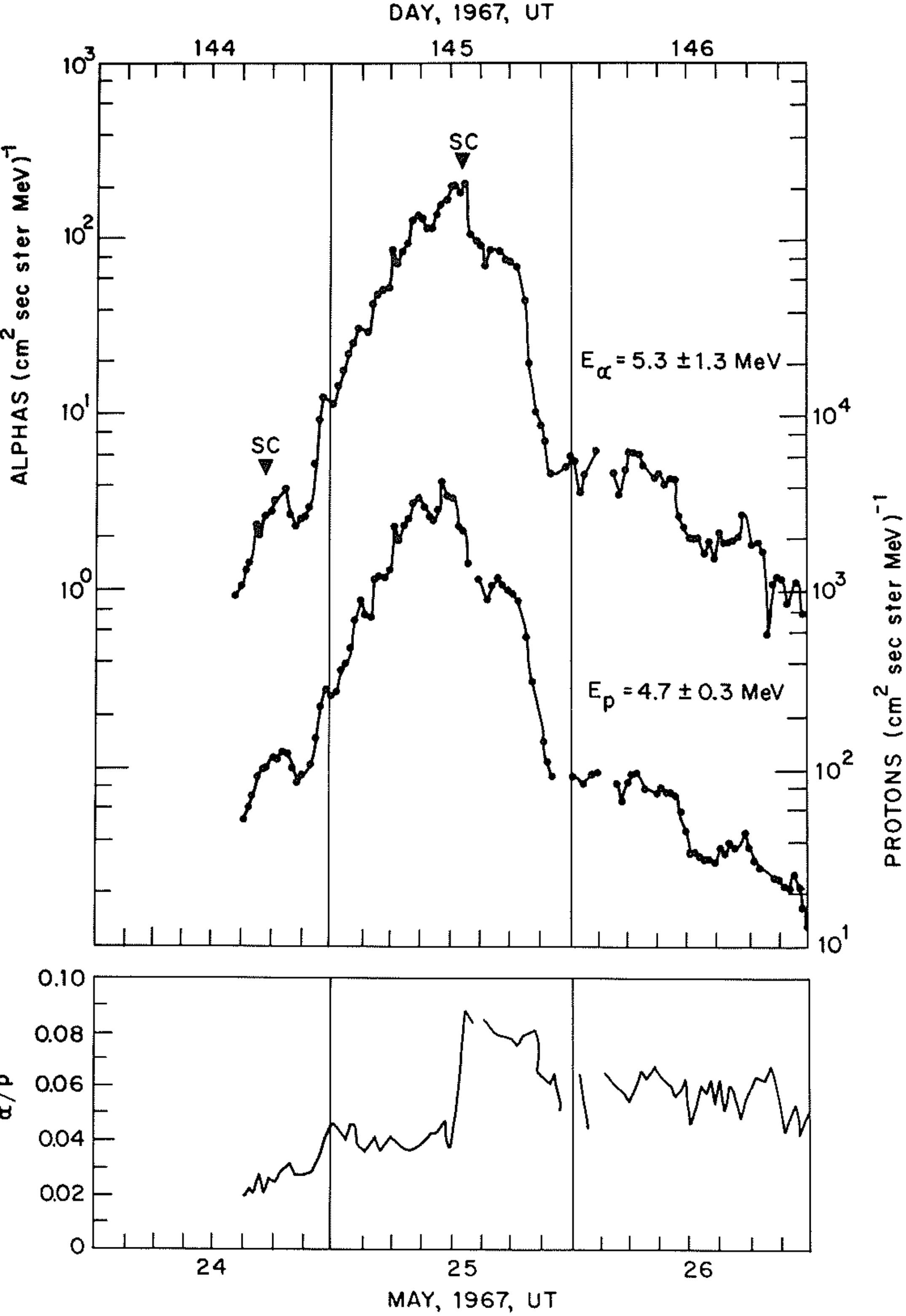


Fig. 5. Alpha particle and proton data and the alpha/proton ratio for approximately equal rigidity particles. The ratio is taken between particle fluxes expressed as (cm$^2$ sec ster MeV)$^{-1}$.

The two major proton and alpha particle flux decreases subsequent to the May 25 sc were quite dissimilar with respect to the rigidity dependence of the decreases. Both flux decreases were observed essentially simultaneously in all energy channels, however. Figure 6 contains the ratios of the half-hour averaged proton and alpha fluxes at 1600-1630 UT to the fluxes at 1230-1300 UT plotted as a function of rigidity. The same flux ratios as a function of rigidity for the large decreases beginning at $\sim$1900 UT are plotted in Fig. 7.

The initial flux decreases after the May 25 sc (Fig. 6) have a strong rigidity dependence, the decreases being observed primarily in the higher energy channels. These decreases are reflected in the softening of both the proton and alpha spectra after the sc as indicated by the spectral indices in Figs. 2 and 3. No large changes in the Alert neutron monitor rate were observed simultaneously with these flux decreases.

As the data plotted in Fig. 7 indicates, the percentages of the flux decreases, beginning at $\sim$1900 UT, are approximately the same for all rigidities and species of particles. Correspondingly, no significant changes in the spectra of either the protons or alphas are observed subsequent to the decreases (Figs. 2 and 3). Approximately one to two hours after the beginning of the solar particle decreases, the Alert neutron monitor rate decreased $\sim$4% and eventually decreased a total of $\sim$7% by the beginning of May 26.

The May 25 sc is probably the resultant of an interplanetary shock generated by the May 23 flares. However, the very high energy galactic cosmic rays measured by the Alert neutron monitor were not strongly modulated by the enhanced plasma clouds presumably accompanying and following the shock until $\sim$8 hours after the occurrence of the sc. The initial strong galactic cosmic ray modulation also occurred $\sim$5 hours after the higher energy solar proton and alpha particles had already once decreased significantly.

As has been seen, the solar particle flux decreases, their rigidity dependencies, and the subsequent galactic cosmic ray flux modulations after the May 25 sc are quite complex. A complete understanding of the fluxes' temporal developments will require a detailed correlation of other interplanetary and geophysical observations made during this time interval with the proton and alpha particle measurements presented in this report.

Solar flare proton and alpha spectra for four time intervals (denoted A-D in Figs. 2 and 3) during the event are shown in Figs. 8 and 9. It can easily be seen that each spectrum does not obey a single simple power law over the entire energy range. Therefore the spectral indices in Figs. 2 and 3 are only roughly indicative of the hardness or softness of the spectra.

Spectra A in Fig. 8 were observed during the flux enhancements coincident with the May 24 sc. Spectra B in Fig. 8 were observed during the flux increases prior to the May 25 sc and show distinct "bending-over" of the spectra at lower energies. Spectra C, plotted in Fig. 9, show the soft spectra observed near the time of the May 25 sc. Data on May 26, during a period after the large flux decreases, are shown as Spectra D in Fig. 9.

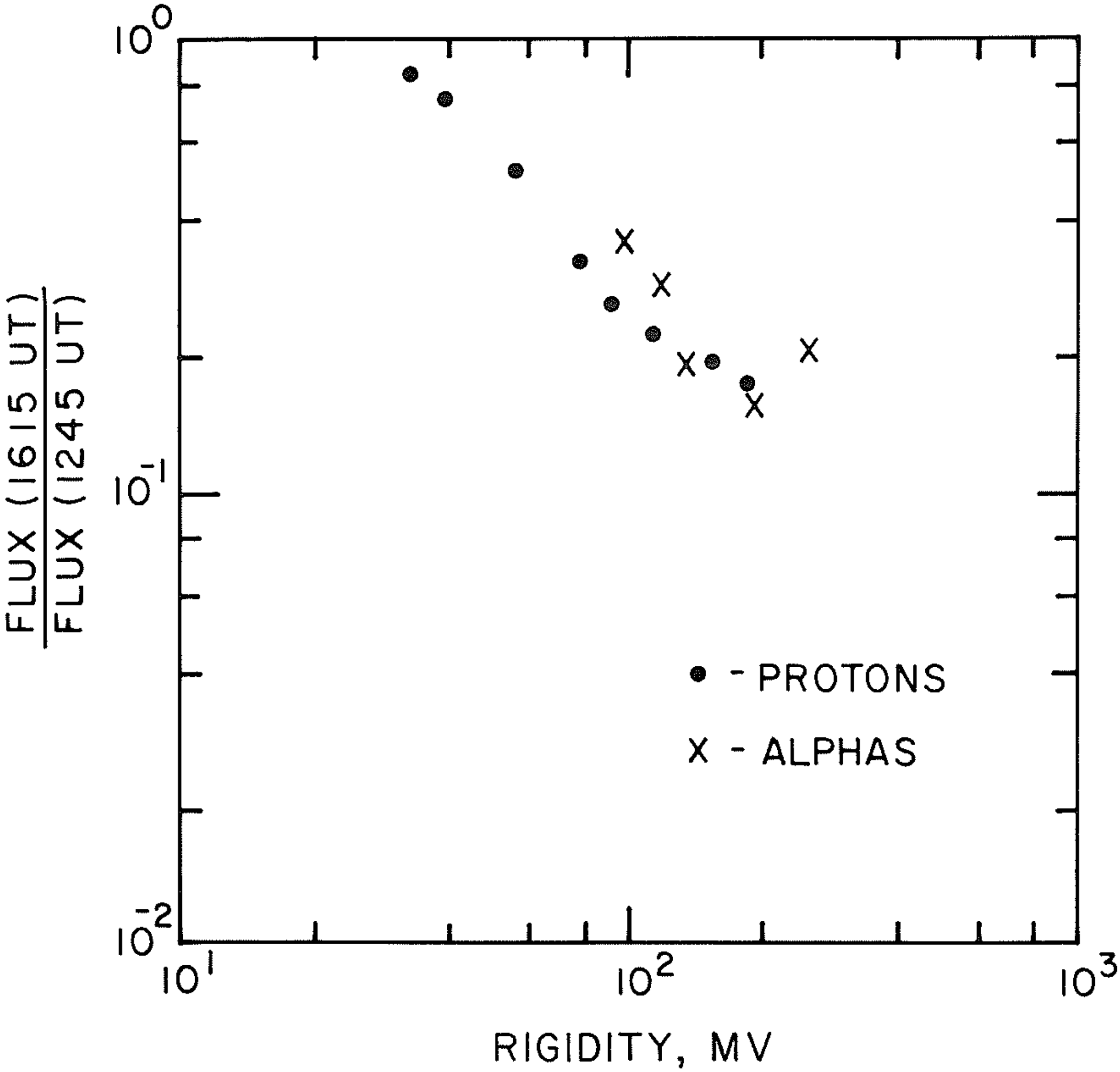


Fig. 6. The percentage proton and alpha particle flux decreases from 1230 UT to 1630 UT May 25 as a function of particle rigidity.

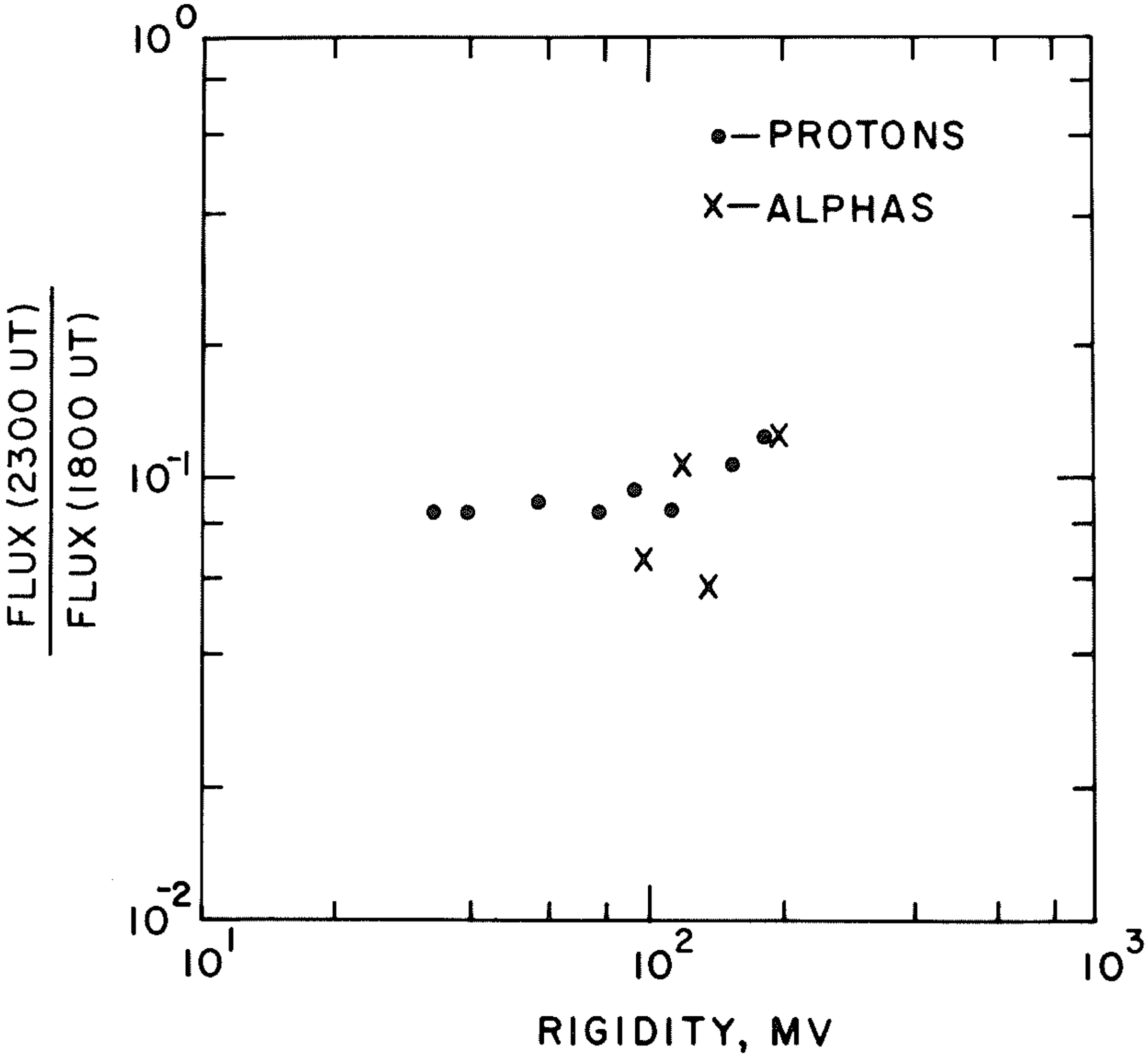


Fig. 7. The percentage proton and alpha particle flux decreases from 1800 UT to 2300 UT May 25 as a function of particle rigidity.

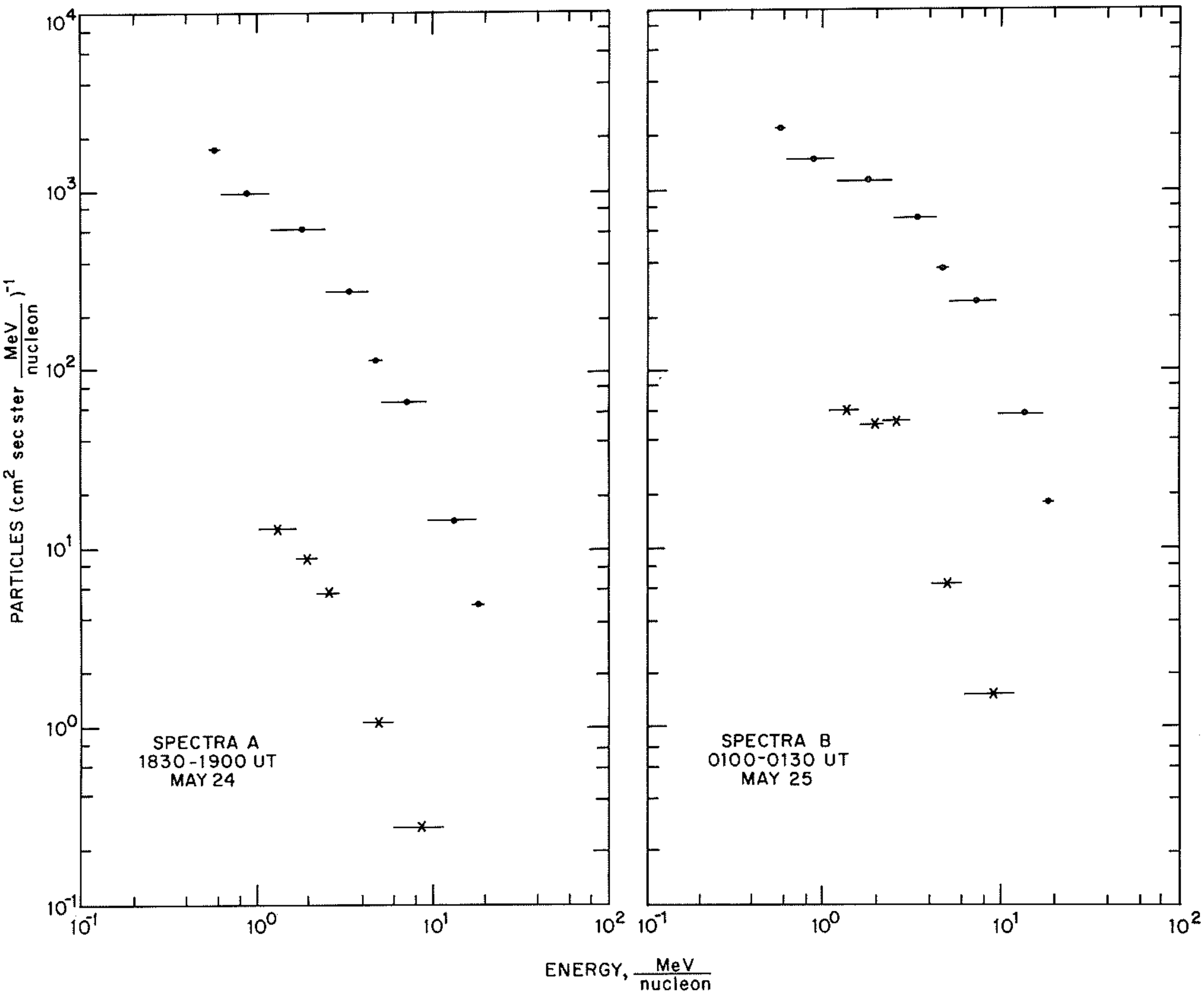


Fig. 8. Proton and alpha particle spectra during May 24 and May 25. Solid points are protons; crosses are alphas.

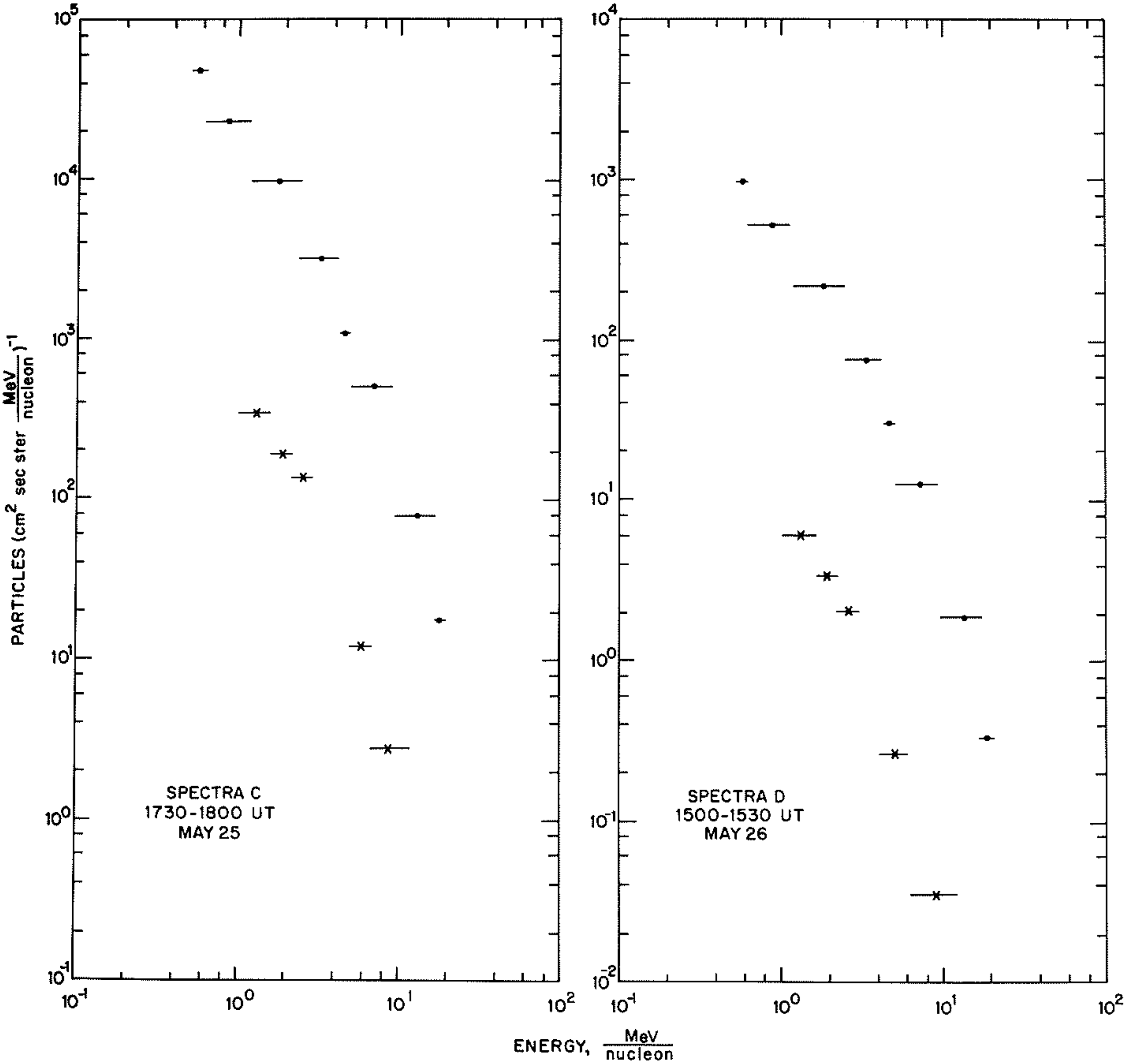


Fig. 9. Proton and alpha particle spectra during May 25 and May 26. Solid points are protons; crosses are alphas.

Summary

The observations of low energy solar particles from the east limb flares of May 23, 1967, have been discussed. A distinct softening of the solar flare proton and alpha particle spectra was observed at the times of the May 24 and May 25 sudden commencements. The particle confinement within or behind the shock that produced the May 24 sc was observed to be rigidity dependent rather than velocity dependent. The particle propagation prior to the May 25 sc was also observed to be rigidity dependent. The interplanetary solar particles were observed to decrease twice prior to the sharp Forbush decrease at approximately 2100 UT May 25. The percentage decreases in the first case were larger for higher rigidity particles. In the second case, approximately one to two hours prior to the Forbush decrease, the percentage decreases were approximately independent of particle rigidity. The alpha to proton ratio, for the same rigidity particles, varied from approximately 0.02 to 0.08 during the course of the event.

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"The Solar Cosmic Ray Events in May, 1967"

by

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[The abstract of this paper as it appears in "Transactions American Geophysical Union, 49, 274, 1968 is repeated here.

The solar cosmic-ray events that began on May 23 and May 28, 1967, were observed in the polar regions at 1100-km altitude by satellite 1963-38C, and in interplanetary space by Explorer 34 (IMP F), which was launched on May 24, 1967. The May 23 event is probably a composite resulting from several importance 2 east limb flares on May 21-23. Maximum intensities occurred between 0800 and 1400 UT on May 25, the higher energy particles peaking earlier. The May 28 event was produced by one or more of three west limb flares that were observed between 0527 and 0707 UT. This event had the rapid rise characteristic of west limb flare events reaching peak intensity for $E_p \geq 60$ Mev at ~0800 UT on May 28. Maximum intensities observed were: $J(E_p \geq 60$ Mev$)$ = $10(cm^2$ sec ster$)^{-1}$ on May 28; and $J(E_p \geq 1$ Mev$)$. = $5 \times 10^4$ $(cm^2$ sec ster$)^{-1}$ on May 25.

These results are shown in Fig. 1. The hourly values in Table 1 are published in "Solar-Geophysical Data" IER-FB 282, February 1968.]

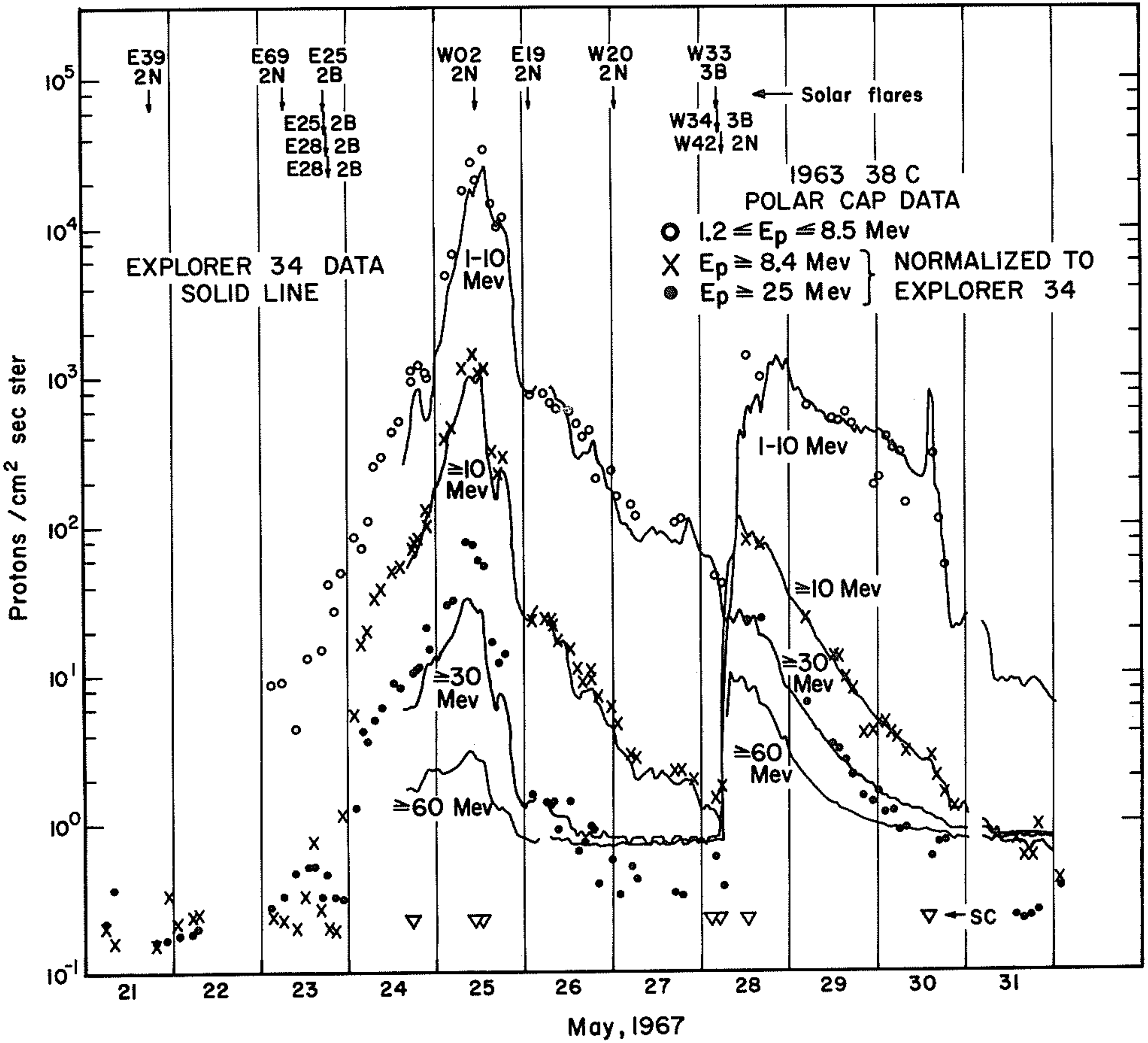


Fig. 1. Solar cosmic-ray events May 23, 1967 on Explorer 34.

Table 1. Solar protons by satellite Explorer 34 (1967-51A), May 24-31, 1967.

PROTON ENERGY GREATER THAN 60 MEV. HOURLY AVERAGES. IMP F SOLAR PROTON MONITOR. JHU/APL AND GSFC

YEAR 1967

| DATE | DAY OF YEAR | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 24 | 144 | | | | | | | | | | | | | | | 32.9 | 1.71 | 1.74 | 1.72 | 1.65 | 1.82 | 2.07 | 2.31 | 2.29 | 2.36 |
| 5 25 | 145 | 2.20 | 2.16 | 2.21 | 2.29 | 2.34 | 2.43 | 2.67 | 2.99 | 3.09 | 2.86 | 2.64 | 2.63 | 2.55 | 1.69 | 1.38 | 1.30 | 1.21 | 1.29 | 1.19 | 1.10 | 0.92 | 0.81 | 0.80 | |
| 5 26 | 146 | | | 0.74 | 0.79 | | | 0.81 | 0.78 | 0.79 | 0.76 | 0.78 | 0.77 | 0.70 | 0.71 | 0.71 | 0.71 | 0.71 | 0.70 | 0.72 | 0.69 | 0.69 | 0.70 | 0.72 | 0.69 |
| 5 27 | 147 | 0.72 | 0.74 | 0.73 | 0.71 | 0.70 | 0.71 | 0.72 | 0.72 | 0.72 | 0.72 | 0.74 | 0.73 | 0.70 | 0.74 | 0.72 | 0.74 | 0.71 | 0.76 | 0.74 | 0.75 | 0.73 | 0.76 | 0.70 | 0.73 |
| 5 28 | 148 | 0.73 | 0.72 | 0.73 | 0.74 | 0.75 | 0.74 | 4.82 | 10.2 | 8.56 | 8.66 | 9.50 | 8.62 | 7.20 | 7.84 | 8.06 | 6.12 | 6.07 | 5.82 | 5.34 | 4.51 | 3.85 | 3.55 | 3.70 | 2.72 |
| 5 29 | 149 | 2.60 | 2.34 | 2.14 | 2.03 | 1.93 | 1.80 | 1.68 | 1.55 | 1.50 | 1.43 | 1.36 | 1.33 | 1.30 | 1.19 | 1.20 | 1.13 | 1.12 | 1.05 | 1.05 | 1.01 | 1.00 | 0.99 | 0.96 | 0.96 |
| 5 30 | 150 | 0.94 | 0.93 | 0.89 | 0.89 | 0.93 | 0.87 | 0.89 | 0.89 | 0.87 | 0.85 | 0.85 | 0.85 | 0.87 | 0.86 | 0.82 | 0.85 | 0.81 | 0.83 | 0.82 | 0.78 | 0.74 | 0.79 | 0.78 | |
| 5 31 | 151 | 0.75 | | | | 0.76 | 0.75 | 0.71 | 0.78 | 0.75 | 0.74 | 0.75 | 0.77 | 0.76 | 0.76 | 0.79 | 0.76 | 0.77 | 0.74 | 0.75 | 0.78 | 0.75 | 0.76 | 0.76 | 0.74 |

PROTON ENERGY GREATER THAN 30 MEV. HOURLY AVERAGES. IMP F SOLAR PROTON MONITOR. JHU/APL AND GSFC

YEAR 1967

| DATE | DAY OF YEAR | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 24 | 144 | | | | | | | | | | | | | | | 129. | 6.05 | 5.96 | 6.18 | 6.11 | 7.23 | 9.45 | 11.9 | 11.9 | 13.7 |
| 5 25 | 145 | 12.5 | 13.7 | 15.2 | 17.2 | 18.0 | 21.1 | 24.8 | 31.8 | 32.9 | 31.8 | 28.7 | 26.9 | 27.8 | 13.9 | 9.07 | 7.04 | 5.73 | 7.66 | 6.99 | 5.90 | 3.07 | 1.72 | 1.40 | |
| 5 26 | 146 | | | 1.39 | 1.46 | | | 1.28 | 1.23 | 1.11 | 1.12 | 1.13 | 1.08 | 0.92 | 0.87 | 0.84 | 0.85 | 0.84 | 0.89 | 0.84 | 0.85 | 0.82 | 0.85 | 0.82 | 0.82 |
| 5 27 | 147 | 0.79 | 0.77 | 0.75 | 0.77 | 0.74 | 0.76 | 0.75 | 0.75 | 0.75 | 0.73 | 0.74 | 0.77 | 0.76 | 0.80 | 0.75 | 0.74 | 0.77 | 0.79 | 0.76 | 0.75 | 0.74 | 0.76 | 0.76 | 0.73 |
| 5 28 | 148 | 0.75 | 0.73 | 0.76 | 0.77 | 0.77 | 0.76 | 8.33 | 24.3 | 22.3 | 22.3 | 27.6 | 24.4 | 20.9 | 22.2 | 24.4 | 18.3 | 18.3 | 18.1 | 17.1 | 15.0 | 13.1 | 11.6 | 8.72 | 8.03 |
| 5 29 | 149 | 7.68 | 7.20 | 6.29 | 5.91 | 5.46 | 5.08 | 4.53 | 4.14 | 3.96 | 3.62 | 3.36 | 3.05 | 2.91 | 2.73 | 2.58 | 2.37 | 2.27 | 2.12 | 2.07 | 1.97 | 1.88 | 1.79 | 1.76 | 1.64 |
| 5 30 | 150 | 1.55 | 1.51 | 1.49 | 1.43 | 1.42 | 1.35 | 1.30 | 1.28 | 1.26 | 1.19 | 1.20 | 1.17 | 1.19 | 1.11 | 1.13 | 1.10 | 1.04 | 1.02 | 0.98 | 0.91 | 0.86 | 0.88 | 0.92 | 0.86 |
| 5 31 | 151 | 0.89 | | | | 0.85 | 0.85 | 0.82 | 0.83 | 0.83 | 0.81 | 0.82 | 0.81 | 0.77 | 0.80 | 0.79 | 0.79 | 0.81 | 0.80 | 0.78 | 0.77 | 0.79 | 0.81 | 0.81 | 0.81 |

PROTON ENERGY GREATER THAN 10 MEV. HOURLY AVERAGES. IMP F SOLAR PROTON MONITOR. JHU/APL AND GSFC

YEAR 1967

| DATE | DAY OF YEAR | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 24 | 144 | | | | | | | | | | | | | | | 5743 | 51.2 | 54.5 | 63.8 | 63.1 | 77.4 | 92.7 | 120. | 128. | 179. |
| 5 25 | 145 | 180. | 221. | 291. | 408. | 450. | 525. | 630. | 883. | 979. | 1015 | 916. | 917. | 1036 | 435. | 253. | 195. | 148. | 243. | 227. | 189. | 95.3 | 35.4 | 27.0 | 25.0 |
| 5 26 | 146 | | | 26.4 | 29.8 | | | 22.3 | 21.0 | 16.6 | 16.0 | 16.9 | 15.7 | 9.08 | 7.29 | 6.71 | 7.55 | 7.79 | 8.04 | 7.85 | 6.36 | 6.14 | 5.13 | 4.54 | 4.36 |
| 5 27 | 147 | 3.64 | 3.10 | 2.91 | 2.66 | 2.52 | 2.01 | 1.92 | 1.97 | 2.12 | 2.24 | 2.25 | 1.90 | 2.13 | 2.19 | 2.11 | 1.97 | 1.82 | 1.79 | 1.77 | 1.93 | 1.88 | 1.87 | 1.56 | 1.33 |
| 5 28 | 148 | 1.25 | 1.34 | 1.19 | 1.21 | 1.07 | 0.95 | 19.0 | 52.0 | 58.0 | 71.3 | 115. | 98.7 | 84.8 | 80.8 | 92.4 | 72.5 | 67.8 | 74.7 | 71.7 | 63.9 | 56.3 | 50.8 | 334. | 34.5 |
| 5 29 | 149 | 31.7 | 30.8 | 27.4 | 25.2 | 23.4 | 21.6 | 18.8 | 16.7 | 16.5 | 14.7 | 13.2 | 12.5 | 12.1 | 10.4 | 9.90 | 8.94 | 8.03 | 7.36 | 6.76 | 6.71 | 6.21 | 5.73 | 5.24 | 4.97 |
| 5 30 | 150 | 4.81 | 4.44 | 4.19 | 3.93 | 3.81 | 3.39 | 3.39 | 3.32 | 2.96 | 2.88 | 2.76 | 2.65 | 2.51 | 2.59 | 2.50 | 2.08 | 1.87 | 1.81 | 1.69 | 1.20 | 1.21 | 1.22 | 1.16 | 1.32 |
| 5 31 | 151 | 1.12 | | | | 1.00 | 1.01 | 0.91 | 0.84 | 0.85 | 0.73 | 0.72 | 0.73 | 0.65 | 0.73 | 0.70 | 0.66 | 0.70 | 0.64 | 0.72 | 0.71 | 0.71 | 0.71 | 0.55 | 0.61 |

## SOLAR PROTONS GROUND BASED

"Interpretation of Ionospheric Forward-Scatter Observations in High Latitudes during the Solar-Terrestrial Disturbances of Late May 1967"

by

D. K. Bailey and K. W. Sullivan

### Observations

The observations made with the IQSY high-latitude forward-scatter paths are discussed for the last ten days of May 1967 when there were major mesospheric and ionospheric effects associated with three major solar flares on 23 May and one on 28 May. The forward-scatter paths were operated at frequencies between 23 and 24 MHz and were placed in operation in early 1964 to observe with as much sensitivity as possible with the technique any PCA events that might occur during the IQSY (Bailey, 1964; Bailey and Pomerantz, 1965; Bailey, 1968). Since the end of the IQSY the program has been maintained, but on a somewhat reduced basis. Thus data are available from only three of the original six paths during the period of interest. The paths are, in Antarctica, transmission from McMurdo to Vostok, and two paths in Alaska, with transmission from Annette Island to College, and from Barrow to Anchorage. The midpoint L-values for these paths are, respectively, >12, 5.7, and 4.6.

The position of the sun during the major solar flares of 23 May was particularly favorable for good observations with the Annette to College path. Not only was heavy SID absorption seen, but also during the half-hourly transmission interruptions the solar noise emission was evident. Figure 1 presents the observations in the period from 1730 to 2030 UT. Comparable samples of the signal-intensity recordings are not available for the Barrow to Anchorage path because of temporary receiver difficulties, and because the sun was far below the horizon for the McMurdo to Vostok path. The SID absorption during the major flare of 28 May could not be observed because the sun was only barely above the horizon at the midpoint of the Barrow to Anchorage path, and below the horizon for the other two paths.

The less detailed observation for the ten-day period are presented as two consecutive five-day periods in Figures 2 and 3. Two sets of hourly data points are given for each path. The upper represents the signal intensity at the receiving terminal and the lower the background noise intensity recorded during the half-hourly transmission interruptions. In the absence of interference, man-made, precipitation, or solar, the intensity of the background cosmic noise is recorded. The continuous fine lines near and sometimes through the hourly data points represent approximately the values that might have been expected in the absence of disturbance. In the data points representing signal intensity an "x" replaces the black dot whenever Es propagation occurred during the hour. If the Es propagation was sufficiently intermittent the position of the "x" represents a fair estimate of the signal intensity received by the forward scatter mode. "x's" well above the normal trend are probably unreliable as indicators of the forward-scatter signal. Two classes of letter symbols can be found on Figures 2 and 3, as follows:

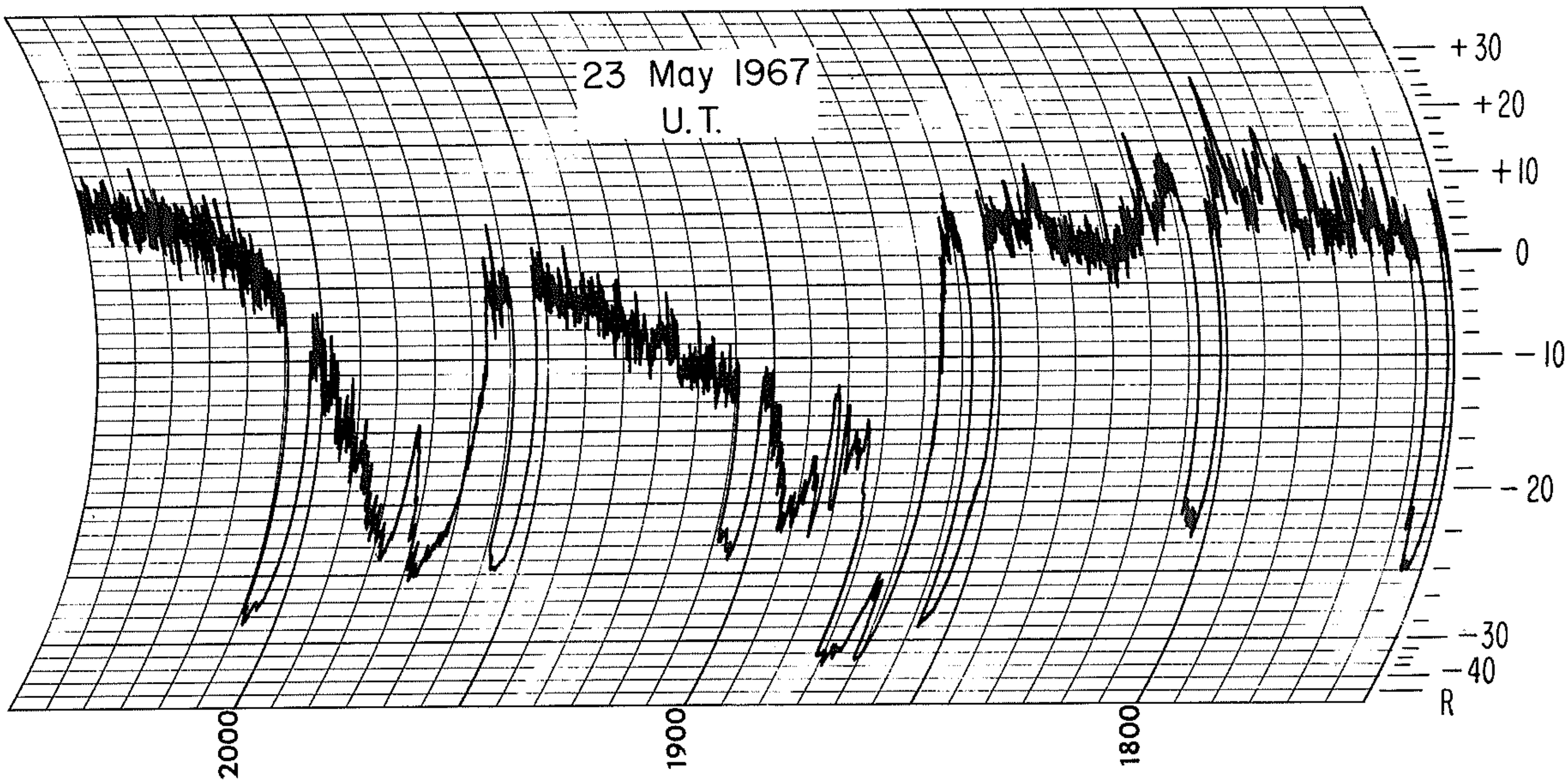


Figure 1. SID absorption Annette to College 23 May 1967

Symbols replacing data points

- E: interfering signals present
- C: loss of data because of calibration
- T: difficulties at the transmitting terminal
- R: difficulties at the receiving terminal
- S: Es propagation saturating the received signal recording

Symbols identifying special characteristics of the signal

- A: thinned trace characteristic of propagation by non great-circle paths by radar aurora
- m: the usual spikes of strong signal propagated via meteor trails are missing owing to heavy absorption above the scattering stratum. The symbol is usually shown when the signal intensity is otherwise normal or showing some enhancement

Because absorption of ionospherically scattered signals as revealed by signal-intensity decrease is only observable by day, and is replaced at night by enhancement of signal intensity (Bailey, 1964), it is necessary to know the position of the sun at all times with respect, for example, to the zenith at the midpoint of each scatter path. Bar symbols are therefore shown below the data points that represent the background noise for each path. An open bar corresponds to twilight and indicates that the solar zenith angle, $\chi$, is between 89 and 101°. A filled or black bar corresponds to night conditions when $\chi > 101°$. All other times correspond to full sunlight, $\chi < 89°$.

At the foot of Figures 2 and 3 the 3-hourly Kp figures are plotted, and the sc magnetic storm onsets are shown with the conventional triangle mark. The times of maximum of each of the principal solar flares are also shown. All times are UT and the signal intensities are in decibels with respect to a defined zero point.

The signal intensity observed at Vostok is always much less relative to the background noise than that observed with the other paths owing to misorientation (resulting from an error by the CRPL installation supervisor) of the receiving antenna. This condition probably emphasizes non great-circle propagation, especially by patchy Es, but relative signal-intensity behavior when scattered signals are observed is still a useful indication of PCA.

## Interpretations

Before going into details it should be mentioned that strong SID absorption was observed late on 21 May on both Alaskan paths. This event, resulting from a strong solar flare, was not followed by any evident PCA or magnetic activity on the 22nd or 23rd. A relationship, if any, with the soft particle precipitation near the midpoint of the McMurdo to Vostok path, made evident by the considerable Es propagation on the 23rd is not known. The precipitation was not observed at the lower L-values of the observing points over Alaska.

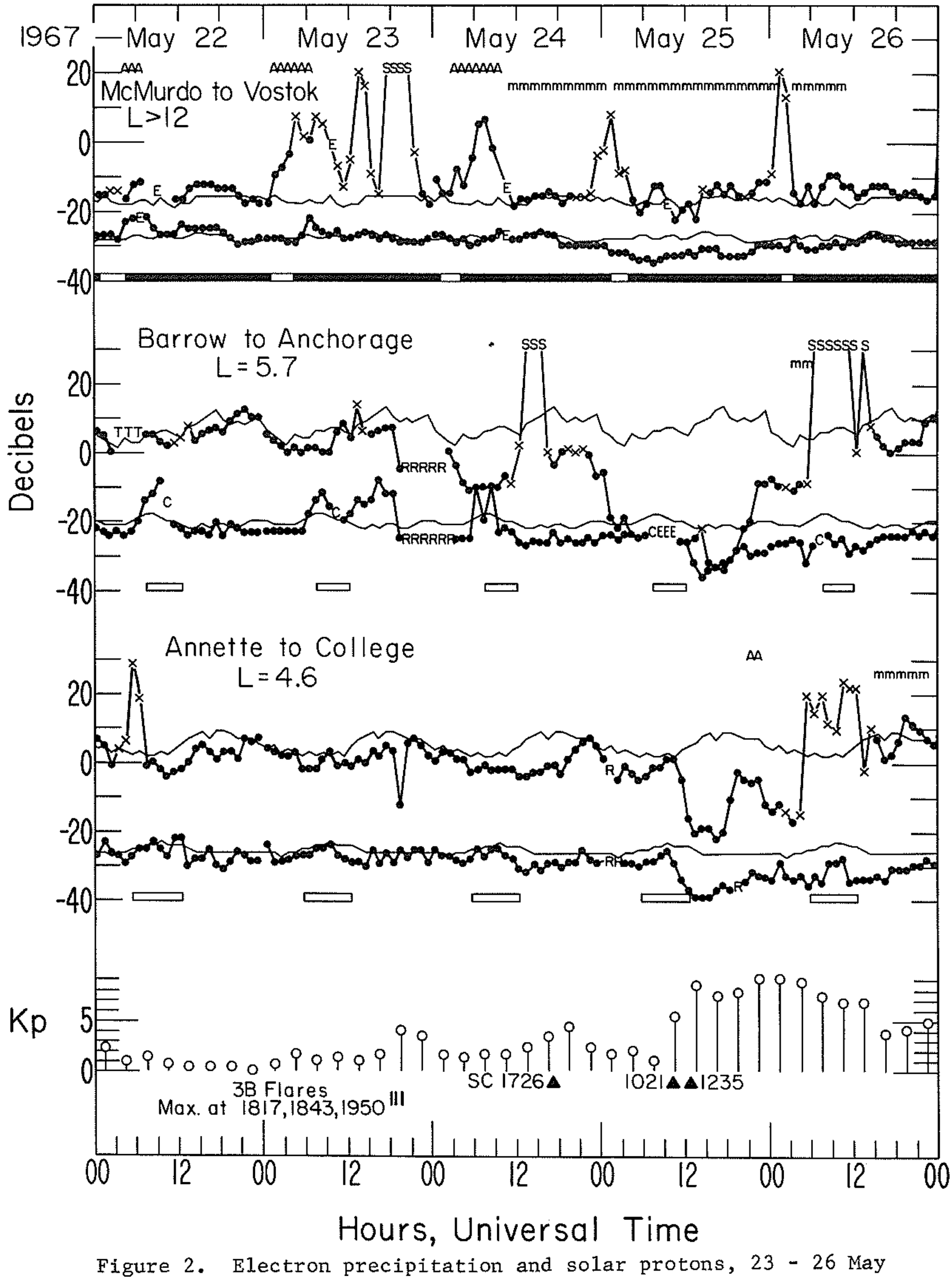


Figure 2. Electron precipitation and solar protons, 23 - 26 May

Solar Protons, 23 - 26 May (Figure 2)

Although there were temporary technical difficulties with the Barrow to Anchorage path, it is evident that a polar cap absorption event began shortly after the flares of 23 May and continued through 24 May. Absorption was also observed with the Annette Island to College path during the same period, but of smaller magnitude. The smaller absorption at the lower L-value is in accordance with the operation of a higher magnetic cutoff rigidity than the atmospheric cutoff of 5 to 10 MeV thought (but see later comment) to govern the Barrow to Anchorage path. Despite the sc at 1726 UT on 24 May the Kp figures did not indicate any major magnetic disturbance and there was no apparent reduction in the cutoff at that time. At about 0000 UT on 25 May the absorption began to show a marked increase on the Barrow to Anchorage path reflecting an increase in the flux of solar protons, which must have been unable to reach the earth earlier, though presumably emitted by the sun more than a day earlier. These new protons were evidently too soft to reach the midpoint of the Annette to College path with significant intensity, and produced no convincing increase in absorption, if the absorption present there is assumed merely to have been restored after a midday recovery a few hours earlier (Leinbach, 1967). The absorption observed in the background cosmic noise at Vostok at the same time confirms that the new protons were mainly quite soft. By about 1300 UT the absorption had reached a maximum for the Barrow to Anchorage path, but the details of the subsequent decay of the particle flux and the absorption are confused and at times entirely masked by electron precipitation associated with the approximately 26-hour period of intense geomagnetic disturbance that began with the two closely spaced sudden commencements at 1021 and 1235 UT. Almost immediately following the sudden commencement at 1021 UT on 25 May the Annette Island to College path experienced a sharp decrease in signal intensity indicating that a decrease in the cutoff rigidity had occurred. It may be inferred, however, that the reduced cutoff did not attain the atmospheric value, for the absorption never reached the value observed simultaneously on the Barrow to Anchorage path. A particularly evident midday recovery of signal occurred between 1800 and 2400 UT on 25 May for the Annette to College path as might be expected during a period when the cutoff was significantly reduced. It should now be noted that the absorption for the Barrow to Anchorage path also showed a marked increase, above an already strong level, following the sc at 1021 UT as reflected both in the behavior of the scattered signal and the background cosmic noise level. The absence of any dramatic effects immediately after the sc at 1021 UT on the signal and background cosmic-noise recordings for the McMurdo to Vostok path at an L-value considerably greater than 12 is difficult to reconcile with the above account which assumes that the magnetic cutoff governing the Barrow to Anchorage observations was atmospheric. If the cutoff had in fact been somewhat higher, and only dropped to atmospheric at the time of the sc, the difficulty would disappear.

Electron Precipitation, 26 May (Figure 2)

Observable PCA effects had nearly vanished by the end of 26 May. However beginning between 0400 and 0500 UT for the Annette to College path, and

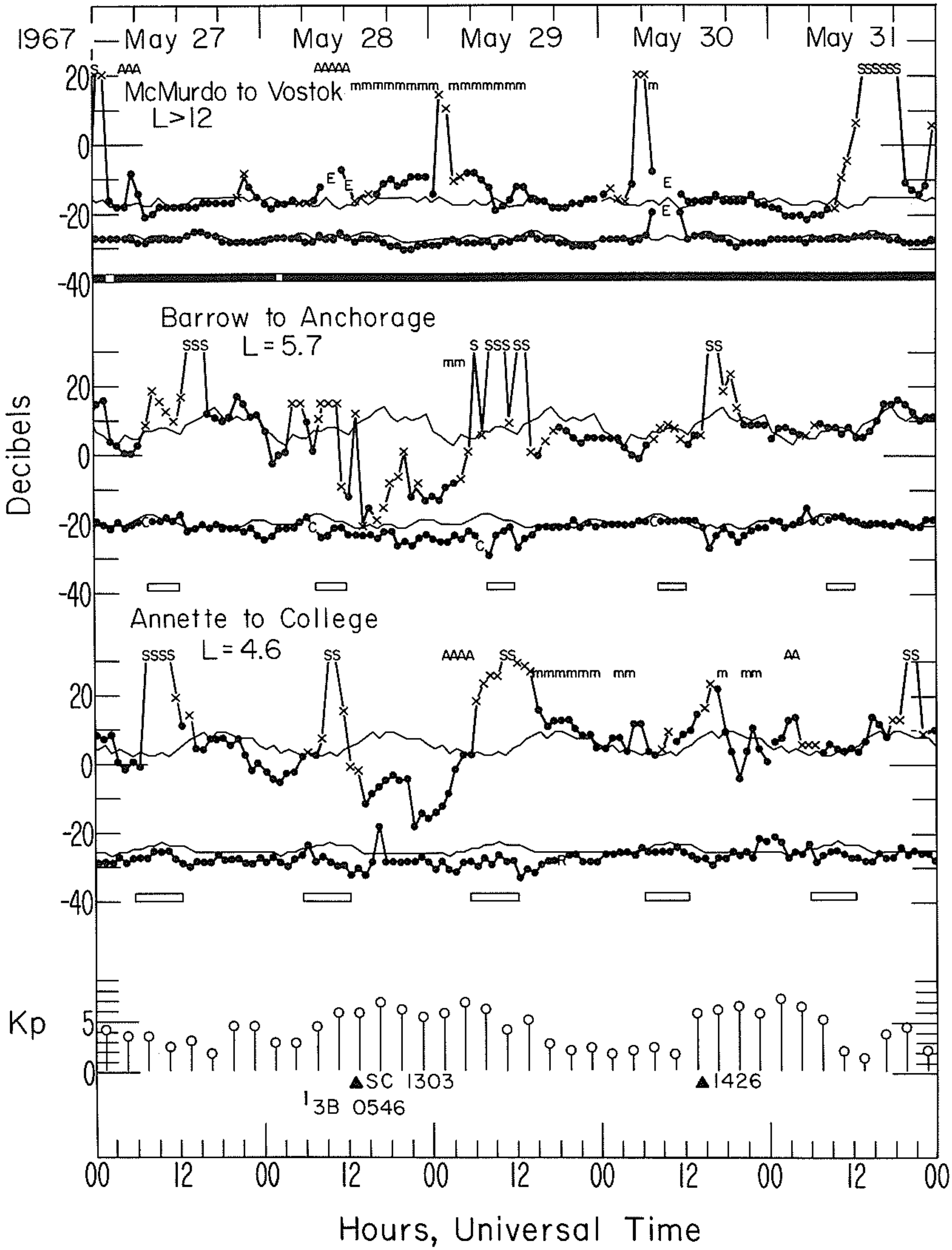


Figure 3. Electron precipitation and solar protons, 27 - 30 May

about an hour later for the Barrow to Anchorage path, auroral activity characterizing the magnetospheric substorm phenomenon occurred with a break-up an hour or two after local midnight. The evidence for this comes from the Es propagation that was observed, and the simultaneous behavior of the background cosmic noise. Both are the result of electron precipitation (Bailey, 1968). Daylight or twilight would probably have prevented or severely hampered any direct auroral observations. The Es propagation which completely masked the scattered signal resulted from Es layers produced by the precipitation with foEs $\geq$5 MHz at the path midpoints. The same electron precipitation was responsible for the ionization below the Es layer that caused the intense absorption of the background cosmic noise. Some 2 to 3 hours after sunrise the spectrum of the precipitating electrons hardened considerably at least partly as a result of the disappearance or considerable reduction in intensity of the electrons at the low energy end of the spectral range capable of producing ionospheric and mesospheric effects of the types observed with a scatter path. The evidence for this statement is the disappearance of the Es propagation which revealed a reduced intensity of the scattered signal characteristic of REP absorption. A fraction of this latter absorption, which lasted throughout the local forenoon, may have been due to the by then greatly reduced flux of solar protons.

Electron Precipitation and Solar Protons, 27 - 30 May (Figure 3)

During this period there was nearly continuous but highly variable electron precipitation activity over Alaska consisting of auroral substorm activity with Es propagation during the local night half of the day (though there was no complete darkness at this season), and some clear examples of hard electron precipitation or REP activity, particularly in the local day period of 27 - 28 May. At about 0635 UT on 28 May, and less than an hour after the maximum of the large solar flare at about 0546 UT, the scattered signal on the Barrow to Anchorage path began to decrease in a manner typical of PCA onset. About an hour later auroral activity with strong Es propagation masked further observations of the scattered signal until some hours after local midnight. The erratic but much reduced signal intensity during the next local daytime period must be regarded as resulting from the simultaneous presence of PCA and REP absorption. The latter was made particularly choppy by the simultaneous magnetic disturbance. During this period the Kp figures were mostly greater than 5 and an sc magnetic storm with onset at 1303 UT on 28 May was in progress. Shortly after the sc a considerable decrease in the signal intensity on the Annette Island to College path took place. The erratic signal behavior during the daytime period on 28 May was comparable to the behavior observed with the Barrow to Anchorage path, though differing in detail. This behavior strongly suggests that cutoff reduction took place following the sc and that the cutoffs must have been essentially atmospheric for both paths following the midday recoveries, for at that time the absorption was about the same for both paths. Recognizable PCA activity is estimated to have been over by about the end of 29 May. A particularly fine example of REP absorption was observed on the Annette Island to College path on 30 May between 1830 and 2100 UT (0930 and 1200 local time). The event was nearly fully masked on the Barrow to Anchorage path by Es propagation resulting from an intense spectral component of soft electrons that was absent farther south.

The reality of the PCA throughout the very active electron precipitation over Alaska is clearly confirmed by the observations with the McMurdo to Vostok path, which, incidentally, provides much more reliable cosmic noise observations than the two Alaskan paths. Moreover, owing to the high midpoint L-value, the McMurdo to Vostok path is not subject to REP activity, and only comparatively infrequent soft electron (and possibly auroral hydrogen) precipitation occurs. The resulting Es propagation seems to be more frequent and intense during times of low Kp and at local midday. Though there was only full darkness, $\chi > 101°$, the PCA absorption of the cosmic noise was clearly seen beginning shortly after the flare on 28 May; it remained observable well into 29 May. Typical nighttime PCA enhancement of the scattered signal was observed between about 1600 UT on 28 May and 1400 UT on 29 May. By 31 May the main activity of the period was over.

## REFERENCES

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Bailey, D. K., Some quantitative aspects of electron precipitation in and near the auroral zone, Rev. Geophys., 6, 289-346, 1968.

Leinbach, Harold, Midday recoveries of polar cap absorption, J. Geophys. Res., 72, No. 21, 5473-5483, 1967.

"Antarctic Polar-Cap Absorption May 24-26, 1967"

by

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ESSA Research Laboratories, Boulder, Colorado

Absorption recorded by 30-MHz riometers at Byrd and South Pole during the PCA event of May 24-26, 1967, is shown in the accompanying diagram. A single riometer at South Pole was operated with a conventional vertically-directed dipole array, and at Byrd five independent riometers were in operation using separate antennas. Four of these were corner reflectors with the center of the beam directed at 45° to the zenith in the magnetic north, south, east, and west directions, and the fifth was a vertically-directed dipole array similar to the South Pole antenna. Two of the oblique recordings, from the north-pointing (low-latitude) and south-pointing (high-latitude) antennas, are reproduced in the diagram in order to show the direction and magnitude of the absorption gradients.

During this period, the lower ionosphere at both locations was in continual darkness; the approximately constant solar zenith angle at South Pole was about 111°, and the minimum solar zenith angle at Byrd was about 101°. In this situation, the absorption recorded is considerably less than that recorded under daytime conditions. There is evidence from other studies that the nighttime absorption is caused by the very low energy end of the proton spectrum, while protons of higher energy are largely responsible for the daytime absorption.

The onset of the event was very slow and gradual, and it is not possible to assign a unique onset time, though absorption certainly appeared to be present before 0700 UT on May 24. The enhancement in absorption apparent at Byrd between 1330 and 1830 on the 24th is an unexplained feature; its appearance is similar to that of electron-precipitation events often seen at auroral latitudes during daytime hours under quiet magnetic conditions, but the possibility that it represents an enhancement in proton flux cannot be ruled out. A fairly steep increase in absorption began at both locations at about 0000 UT on the 25th, reaching a broad peak by about 0900 UT. At South Pole the absorption remained at a roughly constant level until about 1300 UT, shortly after the sc at 1235 UT, then decayed quite steadily to a constant weak level by 0000 UT on the 26th. At Byrd, however, a sharp decrease occurred between 1100 and 1300 UT; this is clearly a case of local reduction in the proton flux related to the intense geomagnetic activity occurring at that time. The reduction in absorption began shortly after the sc at 1021 UT, and the recovery took place soon after the succeeding sc at 1235 UT. The detailed relationship between this event and the accompanying geomagnetic activity is undergoing further study. The period following 0000 UT on the 26th was characterized by intense and rapidly varying auroral absorption at Byrd, particularly after 1600 UT, when the spatially structured nature of the electron precipitation can be clearly seen from the differences between the two oblique records.

This event displayed a number of unusual and interesting features, and a more detailed study of these will be reported later, with the addition of data obtained from riometers located at Vostok, near the south geomagnetic pole, and at locations in the northern polar cap.

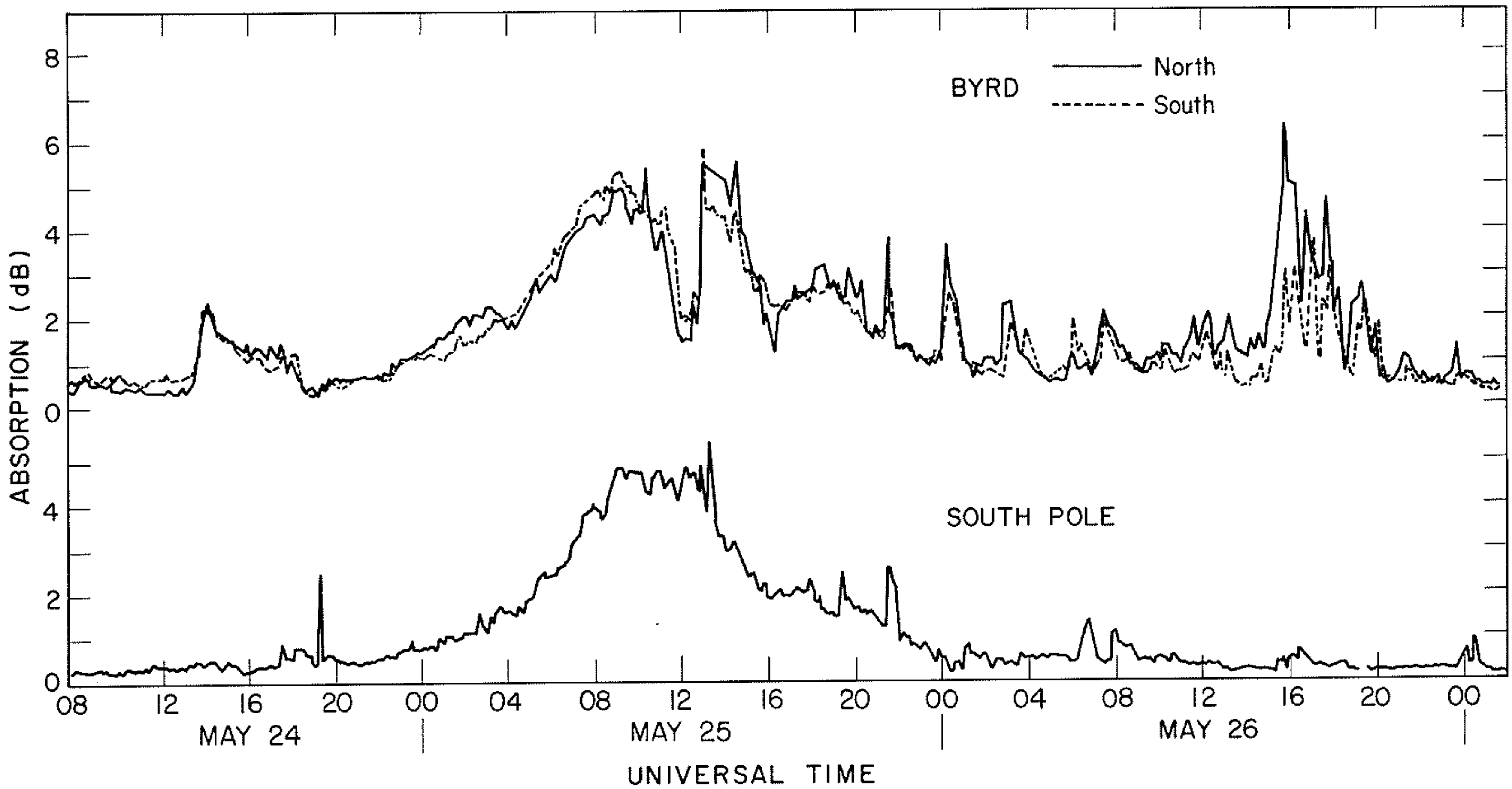
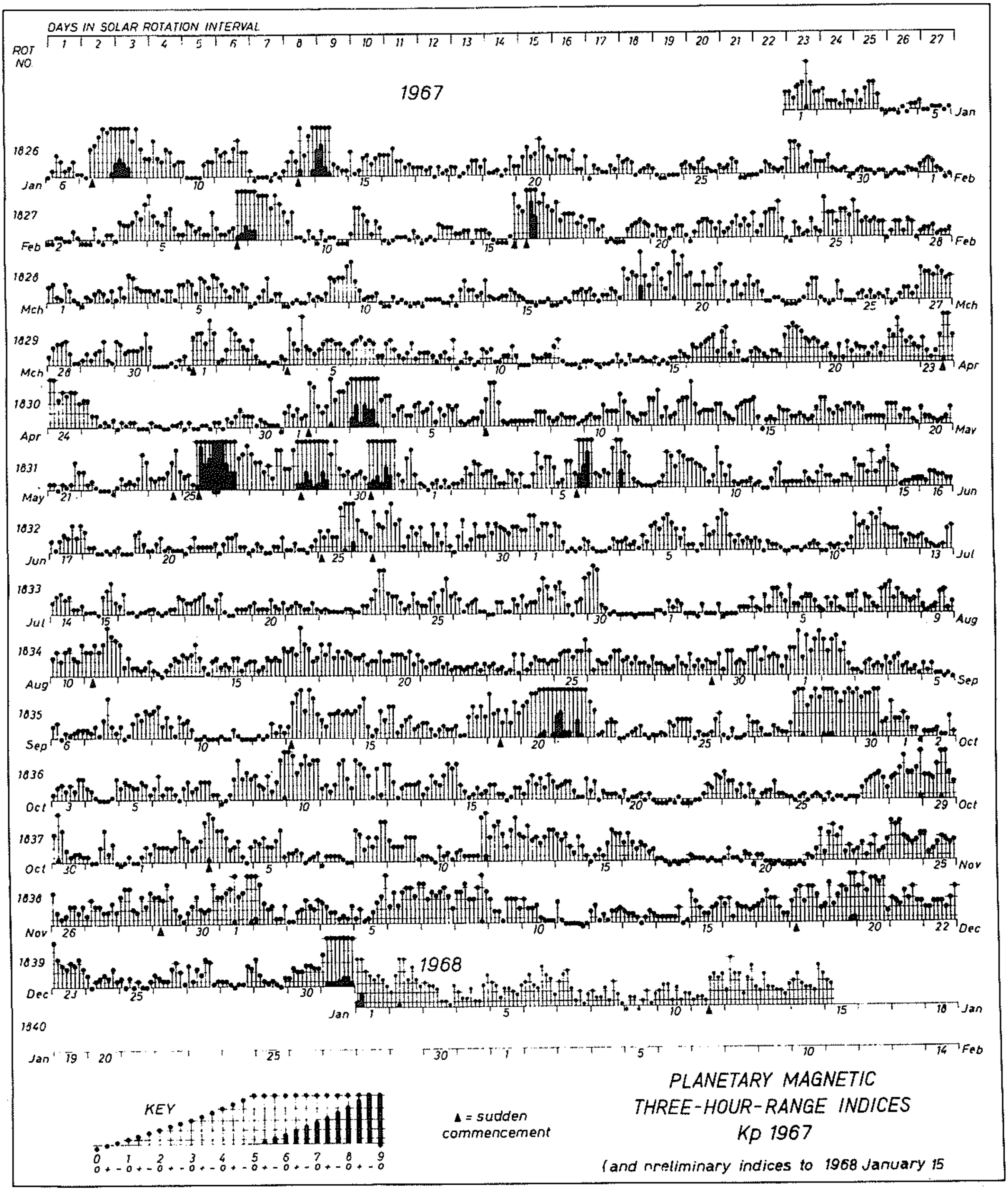



Fig. 1. Polar-cap absorption on 30 MHz at Byrd and South Pole, May 24-26, 1967.

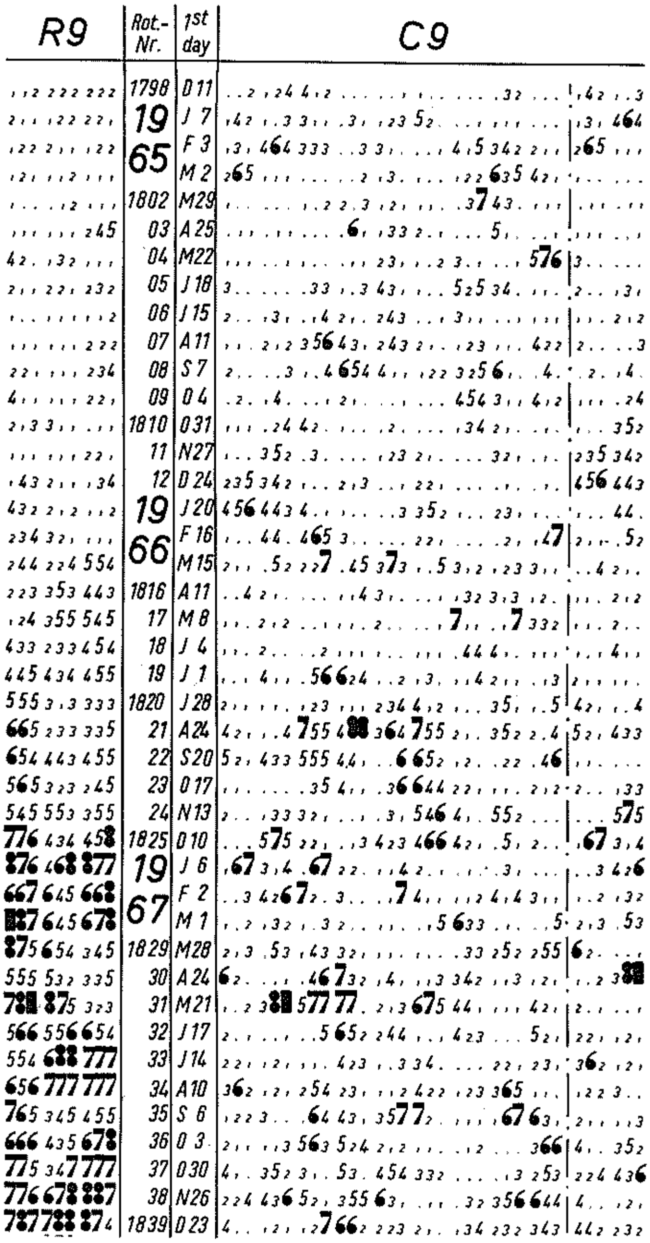
## 7. GEOMAGNETIC INDICES

J. Virginia Lincoln

The musical note diagram of Kp and the C9 figures as published by IAGA for 1967 reproduced below indicates that the storm of May 25-26, 1967 was the greatest of the year, or of this sunspot cycle to date.



## DAILY GEOMAGNETIC CHARACTER FIGURES C9 AND 3-DAY MEAN SUNSPOT NUMBERS R9




| Symbol | . | , | 2 | 3 | 4 | 5 | 6 | 7 | 8 | ▮ |
|---|---|---|---|---|---|---|---|---|---|---|
| $\bar{R}$ = | 0 | 1-15 | 16-30 | 31-45 | 46-60 | 61-80 | 81-100 | 101-130 | 131-170 | 171... |
| R9,C9 = | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Cp = | 0.0-0.1 | 0.2-0.3 | 0.4-0.5 | 0.6-0.7 | 0.8-0.9 | 1.0-1.1 | 1.2-1.4 | 1.5-1.8 | 1.9 | 2.0-2.5 |

The Kp and Ap indices were as follows:

| | Kp | Ap |
|---|---|---|
| May 25 | 2- 2o 1o 5+ 8+ 7+ 8- 9o | 130 |
| 26 | 9o 9- 7+ 7- 7- 4- 4o 5- | 146 |
| 27 | 4o 3+ 3+ 2+ 3o 2- 4+ 4+ | 20 |
| 28 | 3- 3- 4+ 6- 6- 7- 6o 5+ | 55 |
| 29 | 6- 7- 6o 4o 5o 3- 2o 2+ | 45 |

According to IAGA the storm sudden commencements were May 24, 1726 UT from 47 stations (ssc:40 [A:11; B:18: C:11]; si:6; bps:1); May 25, 1021 UT from 19 stations (ssc:13 [A:5; B:8]; si:4; sfe:Eb,T1); May 25, 1235 UT from 50 stations (ssc:45 [A:41, B:4]; si:5); and May 28, 1303 UT from 19 stations (ssc:18 [A:4; B:9; C=5]; si:1).

## 8. FORBUSH DECREASE AND GEOMAGNETIC STORM OF MAY 25, 1967

"Forbush Decrease and Cosmogram May 25-26, 1967"

by

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Graphs of the cosmic ray neutron monitor stations operated in cooperation with Atomic Energy of Canada Limited have been plotted for the period May 21 to June 14, 1967 in Figure 1. The graphs are plotted as a percentage of the maximum rate attained during I.Q.S.Y. (actually the average for May 1965), if the station was operating at that time and as an estimated percentage if it was not. The vertical scale is 5 per cent per division. The graphs are spaced an integral number of divisions apart so that adjacent graphs do not intersect. The percentage nearest the beginning of each graph is printed at the left hand side and the abbreviated station name at the right hand side.

The stations plotted are as follows:

| Station | | Country | Cutoff GV |
|---|---|---|---|
| Chacaltaya | CHAC | Bolivia | 13.10 |
| Kula, Hawaii | KULA | U.S.A. | 13.30 |
| Alert | ALERT | Canada | 0.05 |
| Deep River | D.R. | Canada | 1.02 |
| Goose Bay | G.B. | Canada | 0.52 |
| Inuvik | INUV | Canada | 0.18 |
| Sulphur Mt. | S.M. | Canada | 1.14 |

The cosmogram given here is a projection of the cosmic ray intensity as a function of the spatial angle and time. The anti-solar direction is taken as 0° and the angle increases in the direction of rotation of the earth. The 'garden-hose' angle thus lies between 90° and 180°.

The vertical thickness is proportional to the cosmic ray intensity, zero thickness being equal to the lowest intensity attained by any station during the entire period covered by the event. A scale of per cent is given at the left hand lower corner. Time runs diagonally from the top right to the bottom left of the figure.

Fig. 2 starts at 1800 UT on May 24, and ends at 0600 UT on May 27, 1967. The ends of the days are shown by the vertical lines at the sides. The paths of the stations are vertically downwards ending each local day at the lower edge marked by the initial letters of the station names. The next local day starts at the top of the next lower section of the cosmogram.

The stations used are those of the 'Northern Ring', five in all, and the angles between them are filled in by linear interpolation between simultaneous readings at each station. This type of interpolation is valid if the event is assumed to occur simultaneously at each station as is the case with a Forbush decrease. Each interpolation is judged to be valid for an angle of 30° (2 hours) on each side of the station (after round off to the nearest hour). If the separation is greater than this, the intervening portion of the cosmogram is dotted. One dotted portion occurs over Reykjavik and the other over Noril'sk, U.S.S.R.

After interpolation, the data is passed through a triangular filter in the time direction, having weights 1, 2, 3, 2, 1 (operating on hourly values) in order to reduce statistical fluctuations.

The stations used are as follows:

| Station | Operated by | Asymptotic Angle |
|---|---|---|
| Oula | Finland | 4.31 hrs |
| Tixie | U.S.S.R. | 10.66 |
| Inuvik | Canada | 15.70 |
| Churchill, Canada | U.S.A. | 19.01 |
| Goose Bay | Canada | 22.43 |

Note the normal daily variation shown at the top of the figure.

Since the cosmogram is a perspective view of a solid body, it is inevitable that parts of it are hidden from view. These parts are usually at the bottom of Forbush decreases where the shape of the figure is important. Accordingly, profiles are plotted every six hours alongside the figure and to the same scale. These profiles show the 'spatial anisotropy' existing at the time. The dotted portions of the cosmogram are shown with thin lines, and the solid portions with thick lines crossed by hour angle lines. The position of the Greenwich meridian is denoted by a longer line. Where the shape of the cosmogram is hidden, the profiles intersect, but each one is marked with the day number and hour (UT) so that there is no confusion.

Thanks are due to J. Abels for his cooperation in writing the computer program used in preparing the cosmogram.

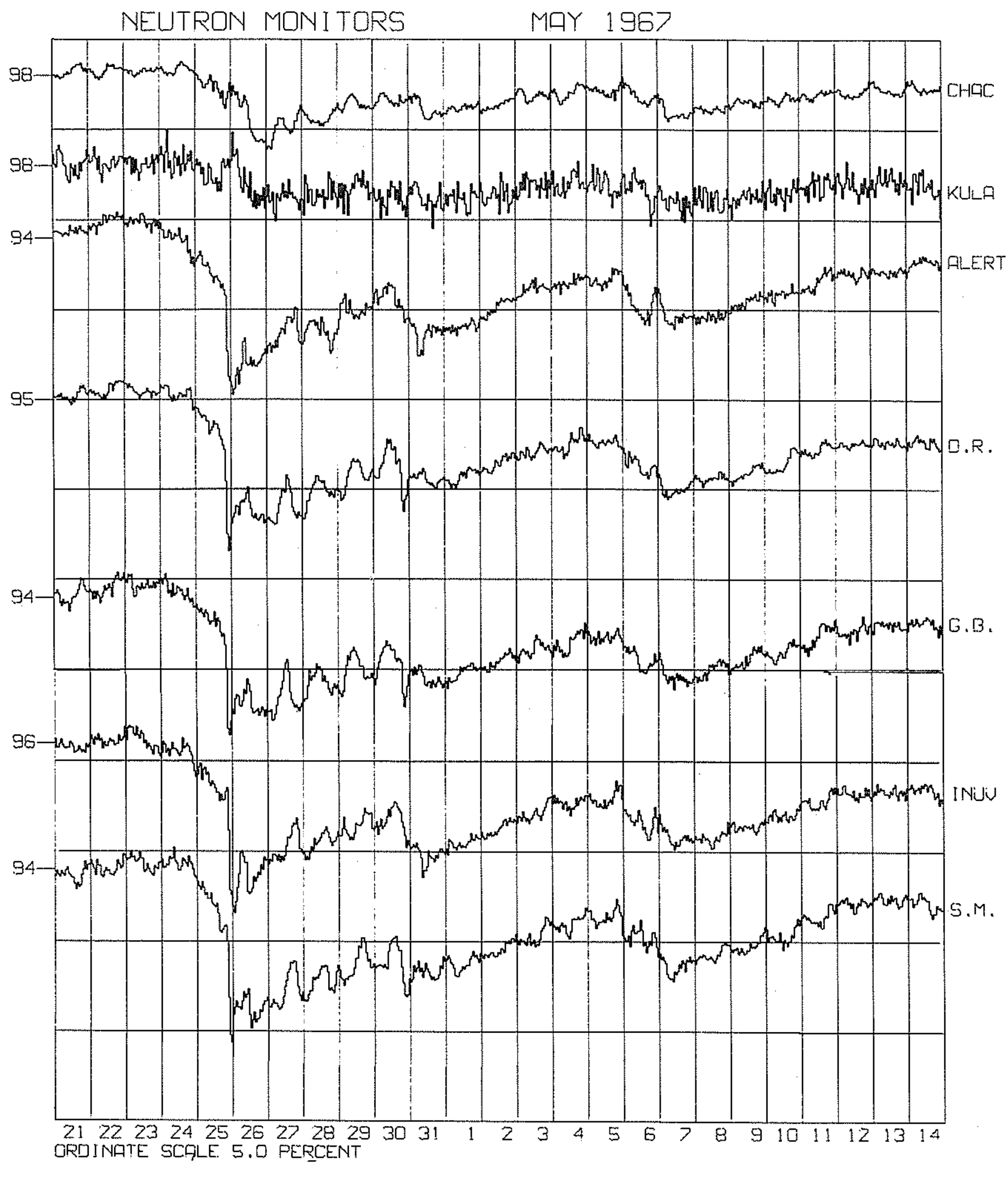


Fig. 1. Neutron monitor counts as percentage of maximum rate during IQSY, May 21 - June 14, 1967.

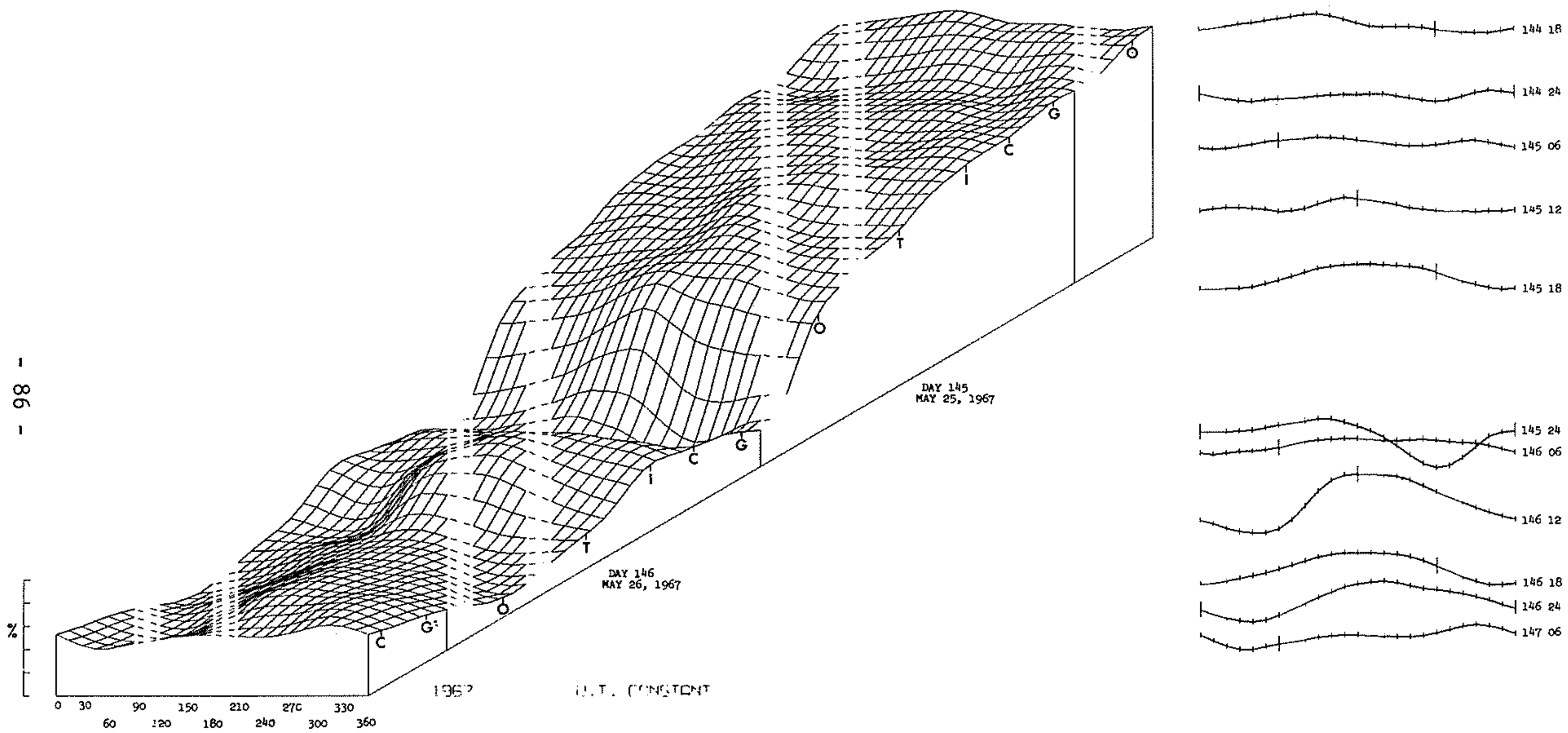


Fig. 2. Cosmogram May 24-27, 1967.

"Dst for the May 25-26, 1967 Magnetic Storm"

by

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NASA Goddard Space Flight Center
Greenbelt, Maryland

Figure 1 shows the Dst data for a one month period including the large magnetic storm which began at 1235 UT on May 25, 1967 following the solar flare of May 23. Several small storms appear to have occurred in close succession after this storm: (i) on May 28 without an unambiguously identifiable sc, (ii) on May 30 with an sc, (iii) on June 4 without an sc, (iv) on June 5 with an sc, and possibly (v) on June 6 without an sc. The maximum Dst decrease for the May 25-26 storm was 385γ, observed near 0300 UT on May 26. This is the third largest Dst decrease observed since the beginning of IGY; the largest two occurred: on September 13, 1957 with 434γ, and on February 11, 1958 with 409γ (Sugiura, 1964).

In Figure 1 the reference level is defined by Dst averaged over two quiet days just before the storm: namely, May 21 and 22, 1967; the daily average Ap values for these days were 6 and 3, respectively. Kp indices are also shown in Figure 1 by broken lines. As has been noted earlier (Sugiura, 1964), Kp activity precedes major Dst decreases by several hours.

REFERENCE

Sugiura, M., Hourly values of equatorial Dst for the International Geophysical Year, Ann. IGY, 35, 9-45, Pergamon Press, Oxford, 1964.

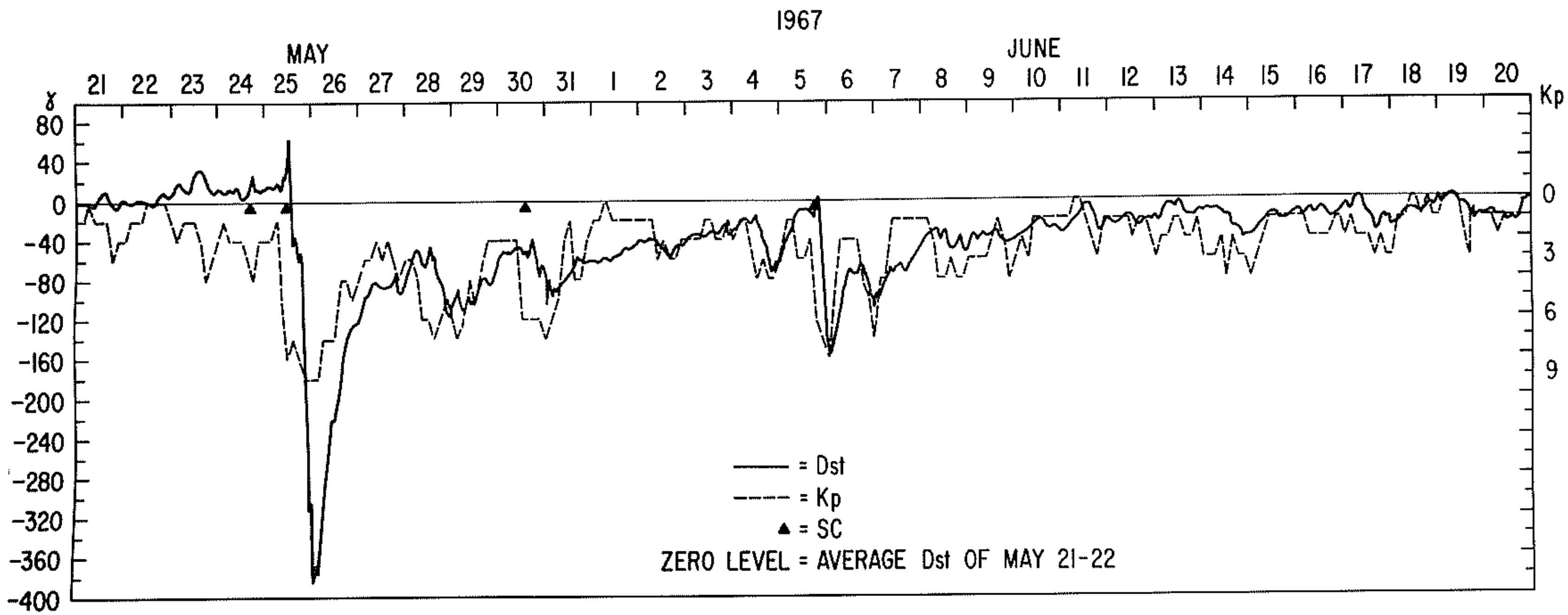


Fig. 1. Dst based on the magnetic records from Hermanus, San Juan, and Honolulu, and Kp for the period from May 21 to June 20, 1967.

"Ionospheric-Magnetic Storm of May 25-26, 1967 at Boulder, Colorado"

by

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The ionosphere and magnetic field were highly disturbed at temperate latitudes on May 25-26, 1967. A magnetic sudden commencement was observed on May 25 at 1020 UT, approximately 42 hours after the flare at 1800 on May 23.

Data observed at Boulder by HANDS (see page 91 of this report) are presented for the 5-hour period 2200 May 25 to 0300 May 26, 1967 during the peak of the disturbance, to disclose possible short-term correlations between variations in the magnetic field and ionospheric parameters observed at steep incidence.

The data presented in Figure 1 were plotted for the 5-hour period using the minimum and maximum data points observed in 1-min intervals. The top trace was obtained from a 30 MHz riometer at Boulder, Colorado. A number of absorption events are indicated with arrows at the top of the trace. It is interesting to compare these events with variations in the magnetic field and other ionospheric measurements.

Variations in the horizontal component of the geomagnetic field are shown in the second trace. Note that the absorption events are accompanied by increases in the horizontal field component of about 15 gamma. Simultaneous spikes in the riometer and magnetic records at 1800 UT resulted from a brief power interruption; the other three spikes in the riometer record are not accompanied by spikes in the magnetic record and are of unknown origin.

The amplitude of the 2 and 4 MHz CW signals reflected from the ionosphere at steep incidence are shown in the third and fourth traces. These signals were weakly received during the first 3 hours of the plots and were increasing in amplitude after about 0100 UT on May 26. Increased absorption can be observed in these signals corresponding in time to the 30 MHz absorption events at 0100, 0132 and 0243 UT on May 26 with one exception; the 2 MHz signal was at the groundwave level at 0132 UT. Note the sharp onset and end of the periods of absorption in the 2 and 4 MHz signals at 0210 and 0239 UT. The absorption scale for these records is greatly compressed at the lower signal levels.

The 2 and 4 MHz Doppler data, not reproduced here, were obtained with a phase detector system. After about 0100 UT when the 2 and 4 MHz signals were above groundwave level, Doppler shifts of ±4 Hz were observed which indicate traveling ionospheric disturbances.

The Boulder, Colorado, ionosonde records were examined at 15 minute intervals for the 5 hour period corresponding to the data described above. The ionosonde records indicate that the 2 and 4 MHz signals were: 1) reflected from the E-region from 2200 to 2245 UT May 25; 2) absorbed from 2300 through 0100 UT; and 3) reflected from a spread region at heights of 130 to 170 km from 0100 to 0200 UT May 26, 1967.

No echoes were observed in the ionograms during the absorption events at 0100, 0132 and 0239 UT but were received at times between these events. The ionogram data therefore confirm the behavior observed in the 2 and 4 MHz vertical incidence signals.

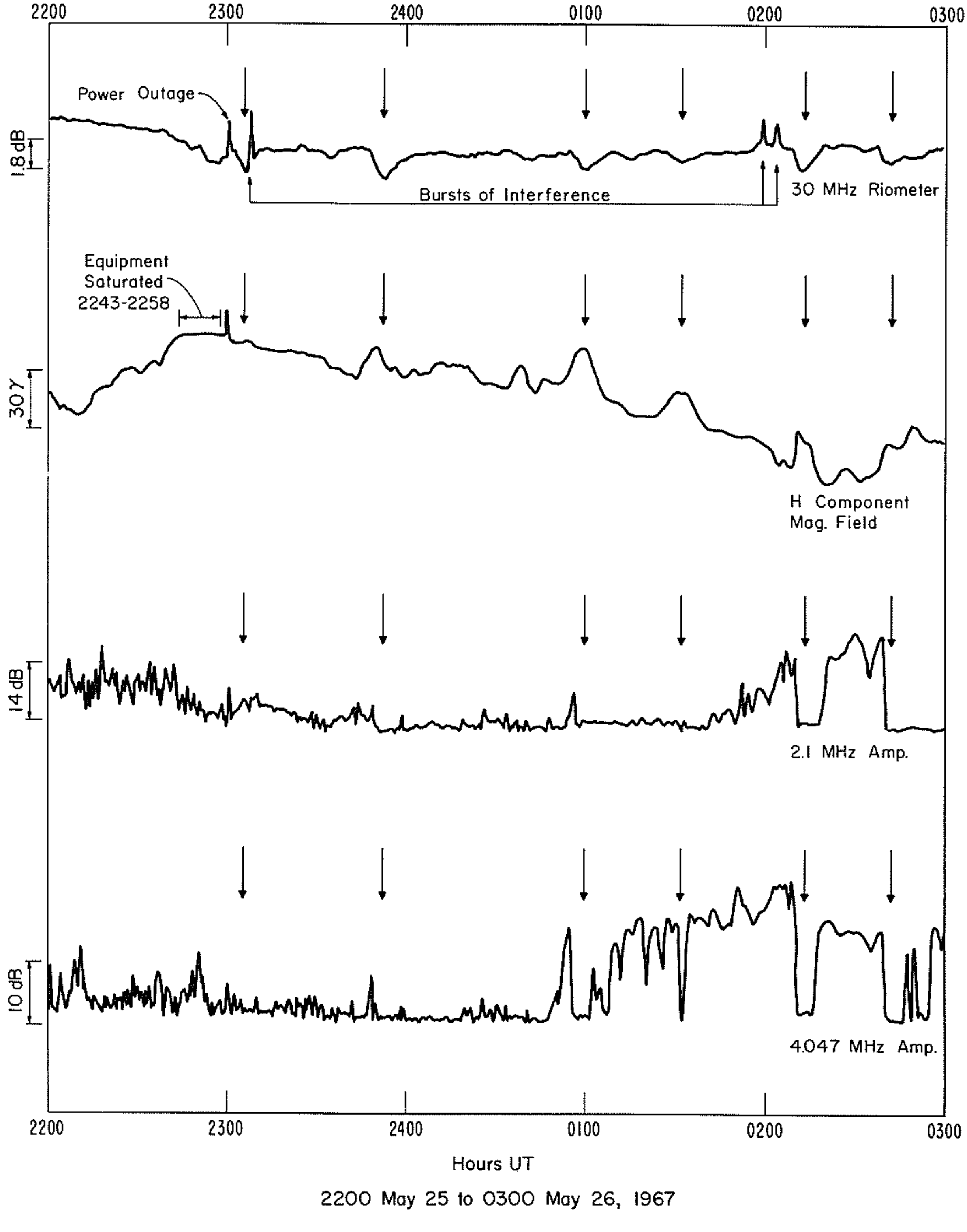


Fig. 1. HF and magnetic observations at Boulder, Colorado, during magnetic storm of May 25-26, 1967. Arrows indicate times of riometer absorption events.

# "The Geomagnetic Storm of May 25-26, 1967"

by

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## ABSTRACT

A series of geomagnetic disturbances caused by the McMath plage region 8818 in the latter half of May 1967 were examined. The systematic changes of the characteristics of storms were observed as the relative location between the responsible flares and the earth changed during the half solar rotation period.

The geomagnetic storm of May 25-26, 1967 was then studied in great detail on the basis of records from 43 magnetic observatories. A large asymmetric main phase field in mid- and low-latitude regions (and thus an asymmetric ring current belt) grew rapidly during the first three successive polar magnetic substorms. However, the onset of a fourth substorm coincided with a large loss of the ring current particles, which marked the onset of the recovery phase.

## Introduction

A series of intense geomagnetic disturbances in the latter half of May 1967 were caused by an active region (McMath plage region 8818) which appeared at the eastern limb on May 18, passed the central meridian on May 25 and disappeared at the western limb on May 31. There have already been a number of studies of the solar-terrestrial events for the above period, for radio emissions by Castelli and Aarons (1967), for x-ray emissions by Van Allen (1968), for solar proton events by Lindgren (1968) and by Goedeke and Masley (1968), and for auroras by Smith and Webber (1968); for VLF emissions and Forbush decrease by Harang (1968). In this paper, our main concern is the geomagnetic disturbances, in particular the geomagnetic storm of May 25-26.

## Solar-Terrestrial Events

Table 1 lists the major solar flares that occurred in the McMath plage region 8818, and also one that occurred in the plage region 8821 at 0156 UT on May 26; it is taken from the paper by Lindgren (1968).

Table 1. Flares and associated geomagnetic disturbances May 18-28, 1967.

| Day | Flare Time (beginning) | Flare Importance (Max) | Location Lat. | Location Long. | | Geomagnetic Disturbances ssc Day | ssc Time | Dst(γ) | $\Sigma K_p$ (12 hours) |
|---|---|---|---|---|---|---|---|---|---|
| 18 | 0857 | 2B | N25 | E84 | | | | | |
| 19 | 1523 | 2B | N24 | E65 | | | | | |
| 20 | 1510 | 2B | N23 | E51 | A | 23 | 0400 | ≈0 | 5 |
| 21 | 1919 | 2B* | N24 | E39 | B | 24 | 1726 | ≈00 | 11 |
| 22 | 0001 | 3B | N24 | E54 | | | | | |
| 23 | 1804 | 2B | N30 | E25 | C | 25 | 1019 | 390 | 28 |
| | 1836 | 3B* | N27 | E25 | | | 1235 | | 32 |
| | 1904 | 2B | N27 | E28 | | | | | |
| | 1935 | 2B | N27 | E28 | | | | | |
| 25 | 0632 | 2B | N28 | E12 | D | 27 | 1940 | ~100 | 14 |
| | 1041 | 2N, 1B | N23 | W04 | | | | | |
| | 1129 | 2B | N23 | W02 | | | | | |
| 26 | 0156 | 3N | N15 | E19 | | | | | |
| | 1230 | 2B | N30 | W05 | | | | | |
| | 1340 | 2B | N31 | W04 | | | | | |
| 28 | 0527 | 4B | N28 | W33 | E | 30 | 1426 | ~150 | 24 |
| | 0529 | 3B | N28 | W34 | | | | | |
| | 0707 | 2B | N25 | W42 | | | | | |
| | 0718 | 2B | N23 | W47 | | | | | |

* White light flare

The first indication of geomagnetic disturbances caused by the active region occurred at about 0400 UT on May 23. It was recorded as a si-like disturbance of magnitude less than 10γ at many low latitude stations. Since no obvious magnetic disturbance followed after that for the next 12 hours, it was not listed as a ssc in "Solar-Geophysical Data, No. 275". The Kp index between 03-06, 06-09, 09-12, 12-15 on May 23 had the values 2-, 1o, 1+, 1o, respectively. We tentatively identify the responsible solar flare for this particular disturbance to be the one that occurred at 1510 UT on May 20; the transit time of the disturbance from the sun was 60 hours and 50 min, and the speed was 685 km/sec.

The next major disturbance occurred at the time of the second flare on May 23 (1836 UT). Obviously, it was a sfe, although it was tentatively listed as a ssc in "Solar-Geophysical Data, No. 275".

The first distinct ssc was observed at 1726 UT on May 24. If it was caused by the white light flare on May 21 (1919 UT), the transit time and the speed of the solar disturbance were 70 hours and 7 min and 596 km/sec, respectively. The Kp index between 15-18, 18-21, 21-24 on May 24 and 0-3, May 25 had the values 3+, 4+, 2+, 2-, respectively. Again, there was little indication of the development of a main phase; see Fig. 1.

The four major solar flares on May 23 are likely to be the cause of the May 25-26 storm; the transit time and the speed of the disturbance from the sun were 40 hours and 3 min and 1040 km/sec, respectively.

The May 25-26 storm began with a double ssc (1019 UT and 1235 UT) and grew to be one of the most intense storms during the last decade. The maximum Dst value was as large as 390γ. The storm is discussed in detail in the next section.

Two more geomagnetic storms were produced by the same active region in the last week of May. The first one began during the recovery phase of the May 25-26 storm. For this reason its onset time cannot clearly be defined. An intense si activity, both positive and negative, began at about 1940 UT on May 27, and lasted until about 2000 UT on May 28; then an appreciable main phase developed, reaching the magnitude of order 100γ. The second storm began with a clear ssc at 1426 UT on May 30; it was followed by an intense si activity until 2330 UT. A clear onset of the main phase was seen at 0020 UT on May 31; the maximum Dst value was of order 100γ or a little more; see Fig. 1. The two storms appeared to be caused by flares on May 25 and 28, respectively. Another intense si activity began at 1550 UT on May 31, but it did not develop into a major storm.

Figure 2 plots for many magnetic storms show the magnitude of the main phase decrease as a function of the central meridian distance; it was constructed by Akasofu and Yoshida (1967). We add here new points for the five storms (denoted by A, B, C, D and E). The failure of the intense white-light flares on May 21 to produce any main phase decrease could partly be due to the rather large central meridian distance of the flare location. On the other hand, the central meridian flares on May 25 were rather weak compared with those on May 21 and 23; further, the flares were not associated with a type II radio burst.

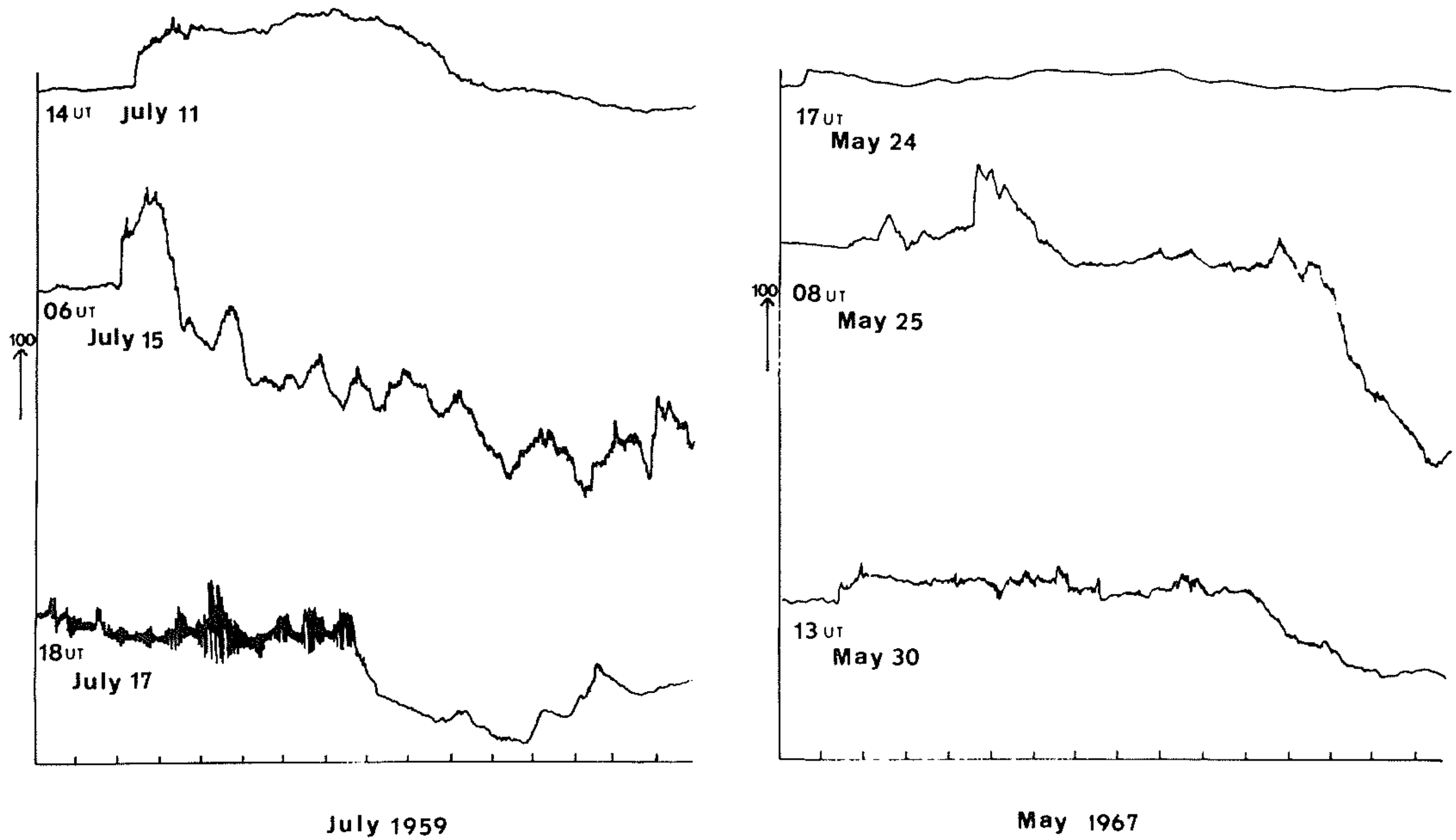



Fig. 1. Comparison of three geomagnetic storms which occurred in July, 1959 and May, 1967.

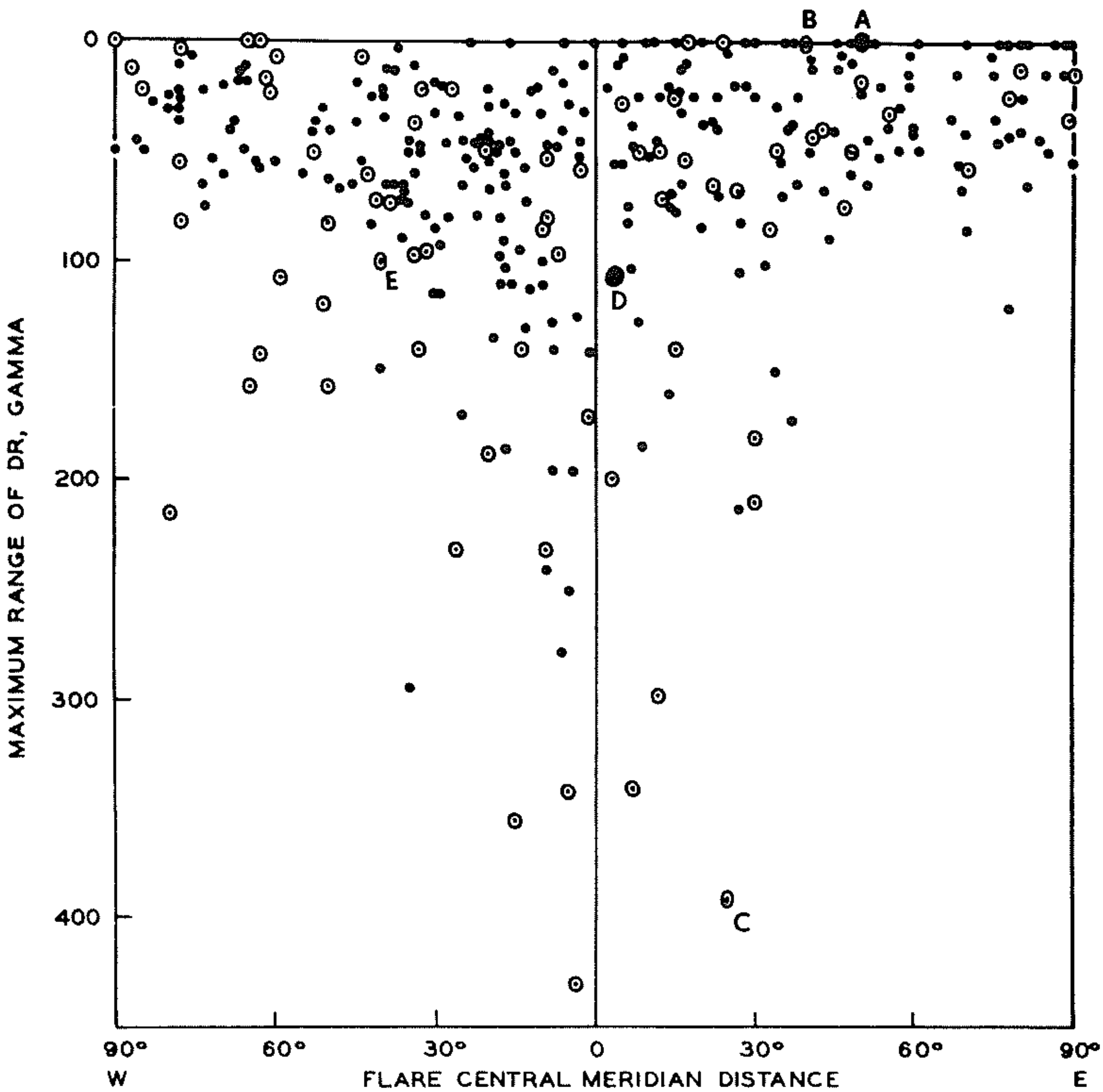



Fig. 2. Magnitude of the main phase decrease (DR=Dst) as a function of the central meridian distance of their responsible flares; the dot with circle indicates a ssc or si which was accompanied by the PCA and the dot not by the PCA.

It is of interest that the May 1967 events are in many ways similar to those in July 1959; see Fig. 1. The storm of May 24 was similar to that of July 11, 1959, which was caused by an eastern flare; both storms were characterized by a clear ssc, and the initial phase was not followed by definite development of a main phase. The storm of May 25 was similar to that of July 15 in that it was caused by a flare near the central meridian and had a main phase decrease of order 400γ. The storms of May 27 and 30 were similar to that of July 17 which began with an intense si activity, followed by a moderate main phase; for the July 1959 events see Akasofu and Chapman (1960).

## The Geomagnetic Storm of May 25-26, 1967

It is convenient to discuss the geomagnetic storm of May 25-26 by dividing the entire storm period into four sub-periods. The first (I) refers to the time between the two sudden commencements, namely between 1019 UT and 1235 UT. The second period (II) began at 1235 UT and ended at 20 UT; the third (III), between 20 UT and 05 UT on May 26; the fourth (IV), after 05 UT.

The four periods are indicated in both Figure 3 for Dst and in Figure 4 for the auroral electrojet index. The Dst diagram was based on hourly values (H component) from four mid-latitude stations, Kakioka, Honolulu, San Juan and Teheran; the AE diagram was constructed by combining the H-component traces (after reducing original records so as to give the same sensitivity and time scales) from 15 stations in high latitudes, College, Leirvogur, Barrow, Sodankyla, Newport, Rude Skov, Sitka, Valentia, Witteveen, Dixon, Heiss, Cheluskin, Leningrad, Wellen and Tixie. This type polar magnetic index was first devised by Davis and Sugiura (1966). Reduced magnetic records from a number of stations are shown in the Appendix.

Nothing unusual occurred during period I. The H-component change associated with the first sudden commencement was not of step-function type. It was followed by oscillatory changes; see the Appendix. As is usual, the magnitude of the oscillatory changes was larger at the auroral zone stations than at mid- and low-latitude stations. There was no definite indication of polar substorms during period I; see the AE diagram (Fig. 4).

Period I ended at 1235 UT when the second sudden commencement began. In low latitudes, the magnitude of the commencement was of order 50 to 100γ.

At mid-and high-latitude stations in the North American continent, which was then in the morning sector, the sudden commencement was almost immediately followed by a negative change of the H component; see the Barrow, College, Churchill, Sitka, Fredricksburg and Newport records in the Appendix. On the other hand, a large positive change was recorded at Leirvogur and Sodankyla. As can be seen in the AE diagram, this particular high latitude disturbance lasted for about two hours and ended rather abruptly. A similar intense negative change was observed soon after the ssc of the great storms of February 11, 1958 and of July 15, 1959. For the former storm, an intense negative change was recorded at Kakioka, then in the morning sector. For the latter storm, the negative change appeared at almost all the stations in Europe and Africa (then in the morning sector), even at equatorial stations. (cf. Akasofu and Chapman 1960). During period II there was only a little indication of the growth of a ring current; it reached maximum intensity at about 15 UT and then began to decay (Fig. 3). The growth was, however, limited mostly to the African, Middle-East and Pacific sectors, which were then in the afternoon and evening sectors; see the Luanda, Quetta, Guam records. On the other hand, at Honolulu and San Juan, then in the morning sector, there was no definite indication of the growth of a ring current.

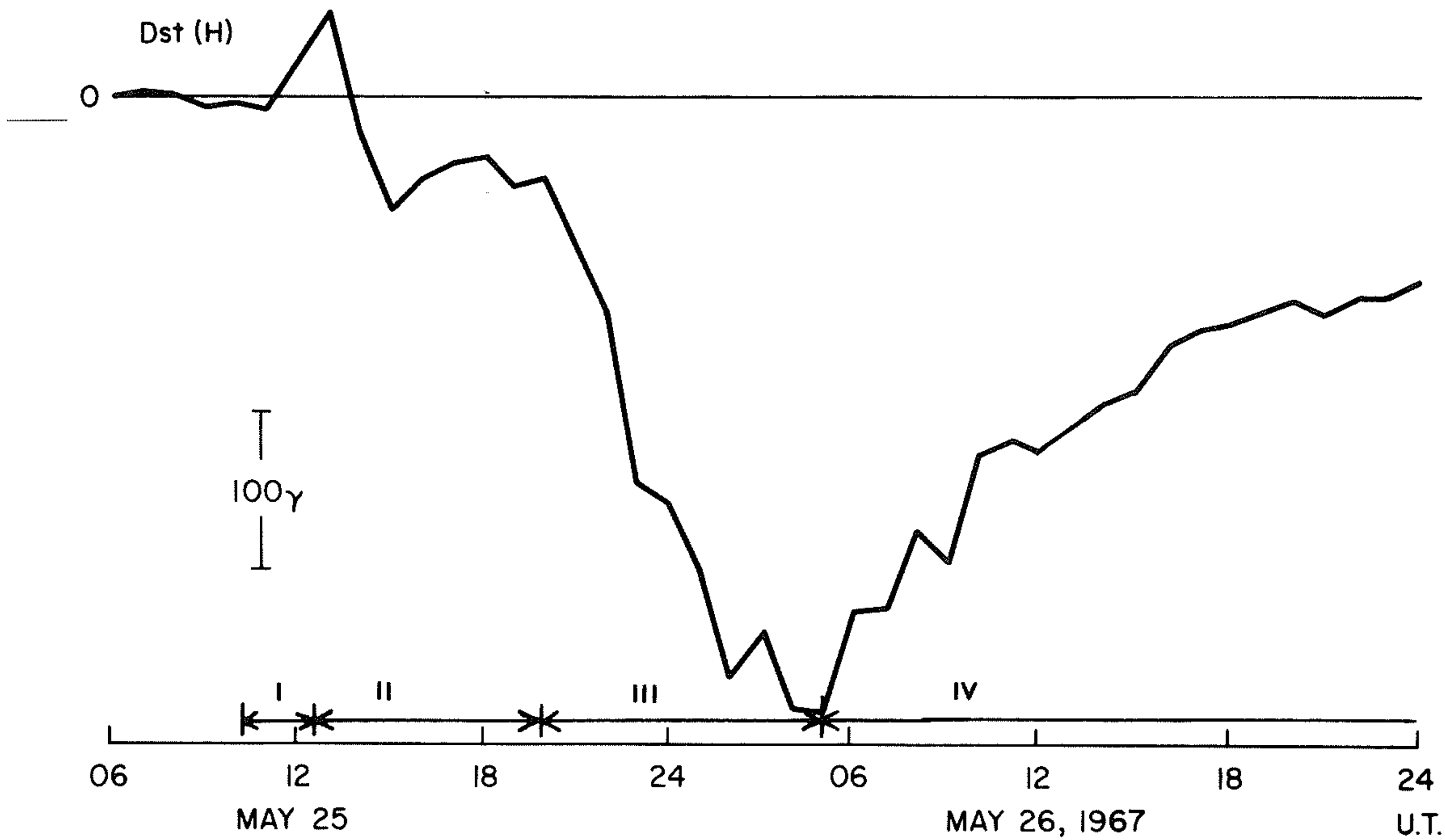



Fig. 3. Dst diagram for the geomagnetic storm of May 25-26, 1967.

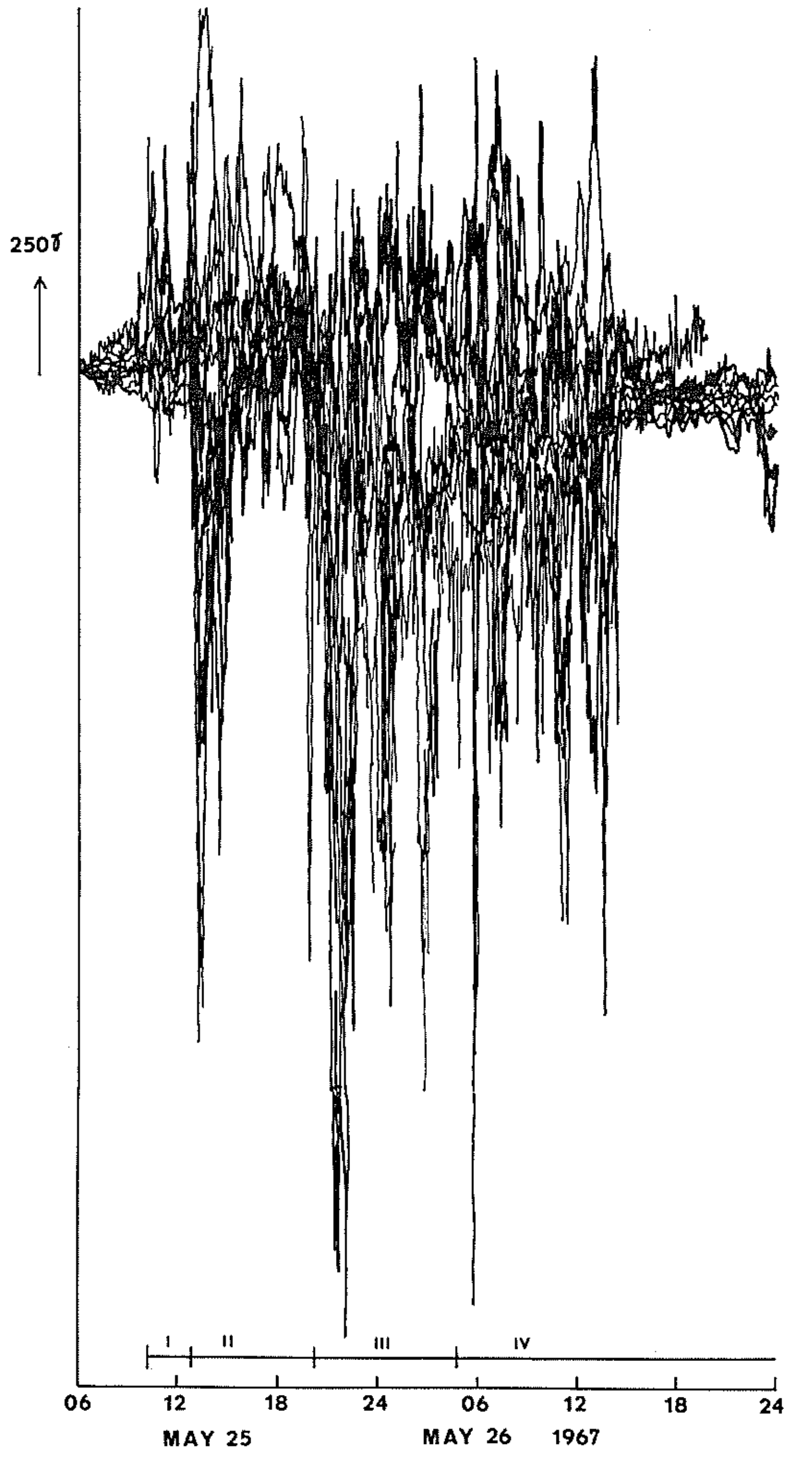



Fig. 4 AE (auroral electroject) diagram for the geomagnetic storm of May 25-26, 1967.

One unusual feature near the maximum epoch of period II was another large negative change which was recorded in mid-latitudes in Europe (including Wien-Kobenzl, Witteveen, Chambon-la-Foret) and at Huancayo. None of the available high latitude records had a corresponding change, except Resolute Bay. We tentatively identify this particular disturbance as the DP2 variation (Nishida 1968), although further study is obviously needed for this particular type of disturbance.

During the last two hours of period II (18-20 UT), there were complicated magnetic disturbances in mid-latitudes, particularly in the European sector, which was then the evening sector. Since there were no definite indications of the growth of polar substorms during that period (see the AE diagram), some of those changes could be the compression effect; on the other hand, there were no clear corresponding changes in the records from the Pacific sector.

The onset of period III is clearly marked by a rapid growth of the main phase decrease (Fig. 3) and of an intense polar magnetic substorm (Fig. 4).

However, the Dst diagram gives only a rough indication of the growth and decay of the ring current. In order to demonstrate this, Fig. 5 shows plots of hourly H-component values for the four stations, on the basis of which the Dst diagram (Fig. 3) was constructed. The onset of period III is not necessarily clearly recognized from each trace.

The first polar magnetic substorm, which began to grow at 20 UT, reached the maximum intensity between 21 and 22 UT; its magnitude was as large as 2250γ at Dixon which was located in the midnight sector at that time. The substorm decayed very quickly until about 2230 UT when a new substorm began to grow. As is clear from the AE diagram, three major substorms occurred during period III.

It is interesting to note that the maximum epoch of the first gigantic substorm coincided approximately with the onset time of a sudden growth of the Forbush decrease. As suggested by Harang (1968), both the substorm and the Forbush decrease could be the manifestation of the arrival of the solar plasma cloud which was responsible for driving the interplanetary shock waves and the double ssc. Harang (1968) reported the onset of intense VLF emissions at about the maximum epoch of the first substorm. It was, however, during the second substorm when bright auroras spread over Middle Europe; Smith and Webber (1968) reported bright auroras at dp lat 54°22'N. This delay is likely to be due to the fact that the expansion of the auroral oval depends on the intensity of the ring current (Akasofu and Chapman 1963); during the first substorm, the ring current was not intense enough to bring the oval down to dp lat 55°.

In spite of the great complexity of the storm, it was possible to draw reasonable contour lines of D(H), except at 20 and 00 UT; Figs. 6a, b and c. The asymmetric growth of the main phase decrease is most clearly seen during period III; even at 20 and 00 UT, the existence of the asymmetry was quite obvious.

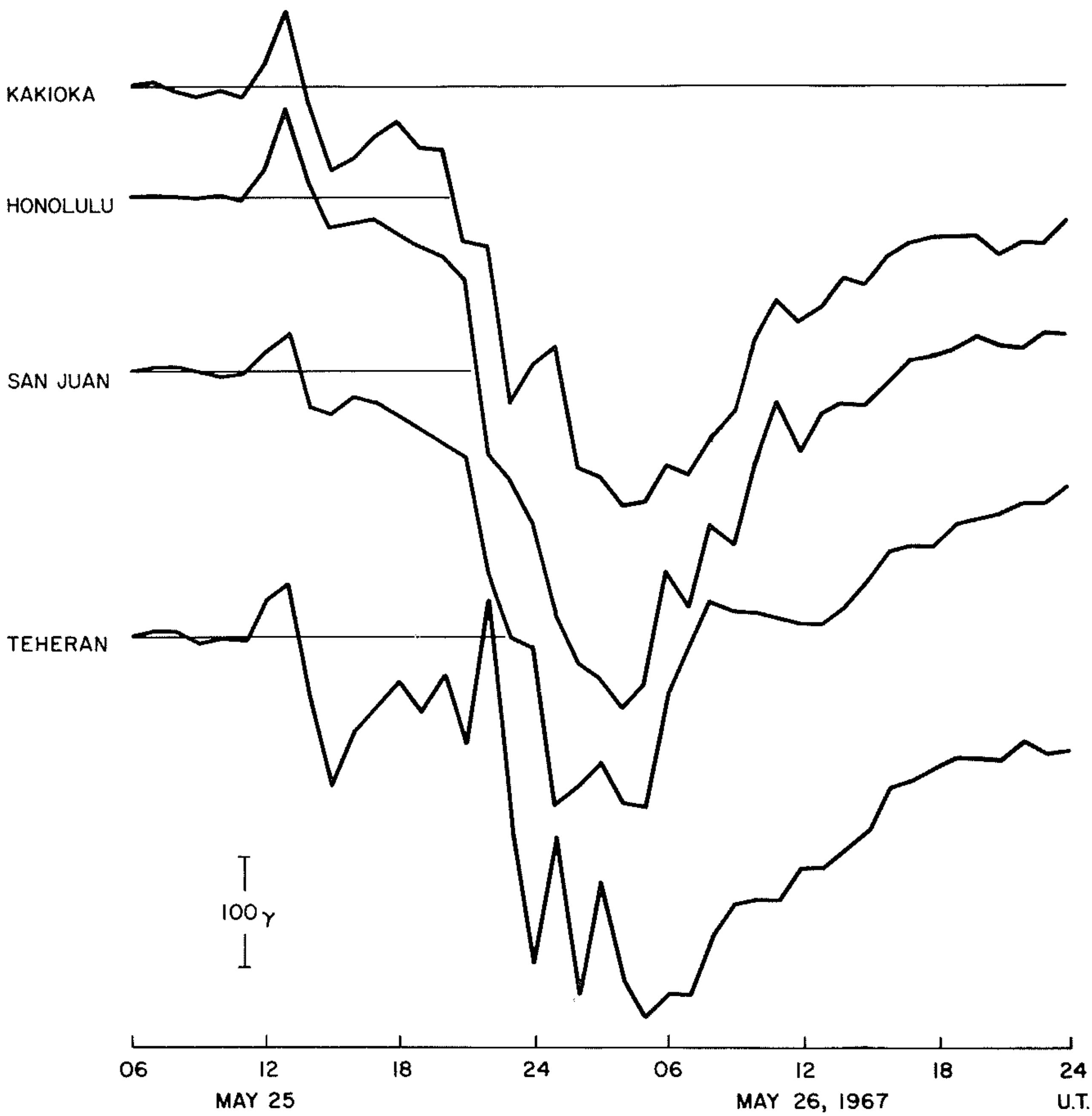



Fig. 5. Hourly H-component curves for the geomagnetic storm of May 25-26, 1967, from four mid-latitude stations.

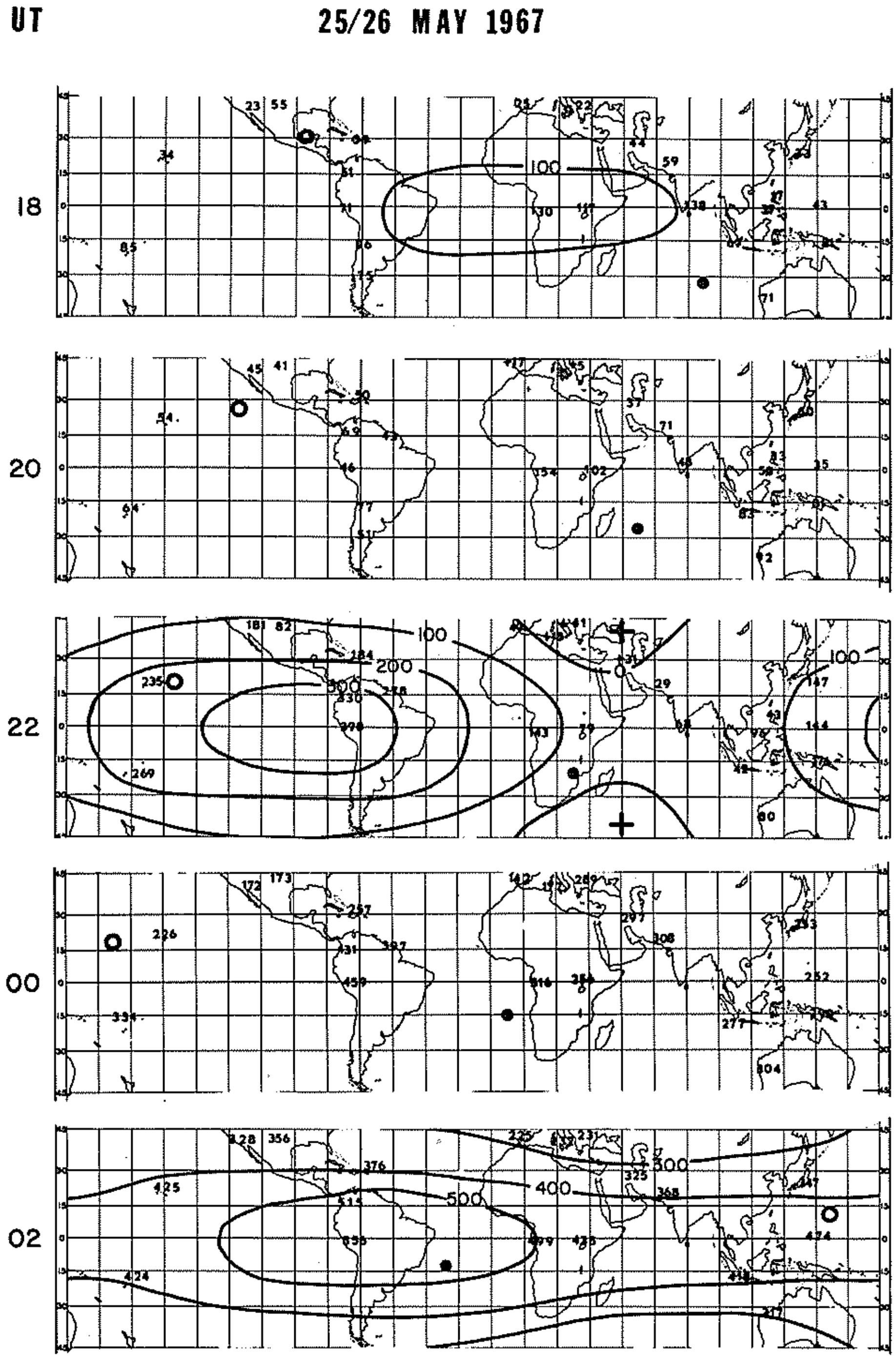



Fig. 6a

Fig. 6a, b, c. Approximate iso-intensity contours of D(H) during geomagnetic storm of May 25-26, 1967.

**UT** **26 MAY 1967**

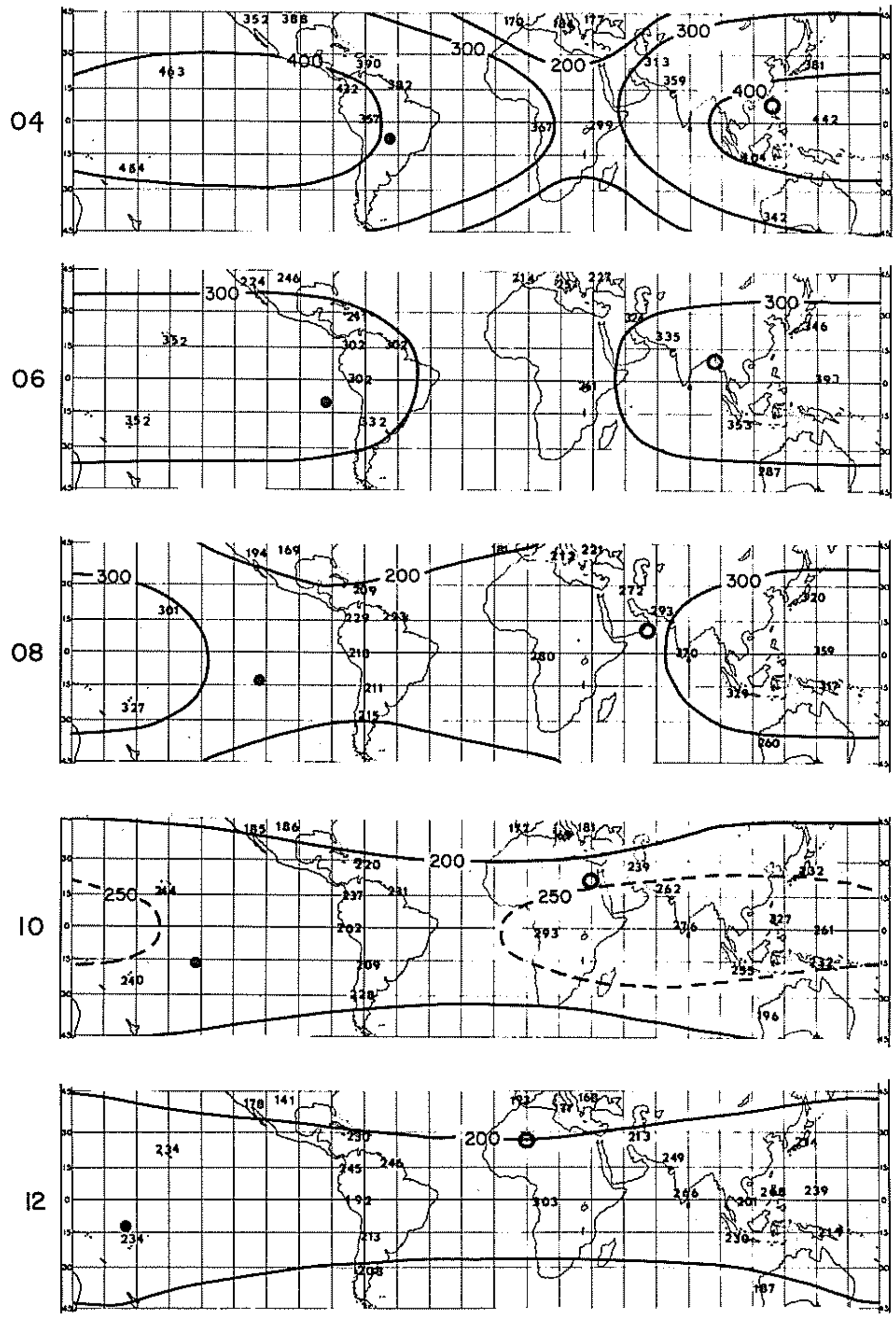
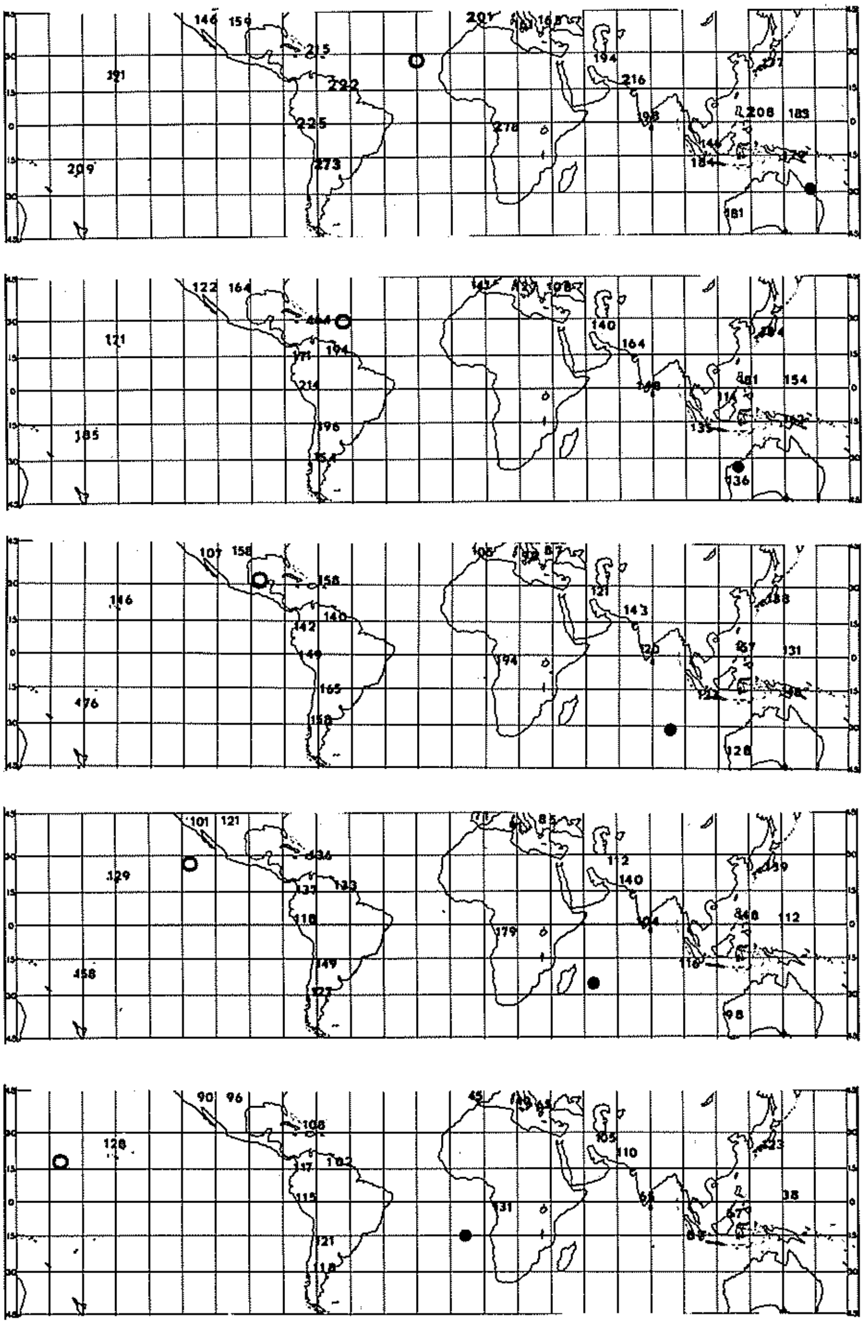



Fig. 6b

UT 26 MAY 1967



14

16

18

20

24

Fig. 6c

The region of the maximum main phase decrease was located in the evening sector at 18 and 20 UT. However, it shifted to the mid-afternoon sector between 20 and 22 UT. A similar shift appeared to occur again between 02 and 06 UT, after the maximum region moved back to the midnight sector between 22 and 02 UT. On the basis of an extensive study of the average characteristics of a large number of storms, Chapman (1952) and Sugiura and Chapman (1960) found that the region of the maximum decrease shifts progressively from about the 23 LT sector to the afternoon sector as storm time progresses. The double shift that occurred during the May 25-26 storm is not surprising on the basis of an interpretation offered by Akasofu and Chapman (1967), since the storm was so intense and complex.

The onset of the recovery phase (period IV) was associated with another extremely intense substorm which reached the peak intensity at about 06 UT. In the dark sector in the mid- and low-latitudes, a large positive change of the H component occurred at that time (see the Honolulu and San Juan records in Fig. 5). Since the study of the magnetic records taken from the synchronous satellite demonstrated that low latitude magnetic stations, such as Honolulu, record essentially variations of the population of the ring current particles in that sector (Cummings and Coleman 1968), we can interpret the positive change to be caused by a loss of the ring current particles in the dark sector. It is important to note, however, that the loss did not occur uniformly in longitude and continued in the dark sector (see Fig. 5).

One of the very interesting features in period IV was a very sudden decrease of polar magnetic substorm activity at about 14 UT (Fig. 4). It is quite unlikely that this is due to the lack of suitable auroral zone stations for the AE diagram, since records from several auroral zone stations in the dark sector were used (College, Barrow, Cape Wellen, Tixie, Cheluskin, and Dixon). Figure 6c shows that the ring current belt became symmetric after 14 UT; this tendency was recognized by Cahill (1966) and Meng and Akasofu (1967).

## Acknowledgements

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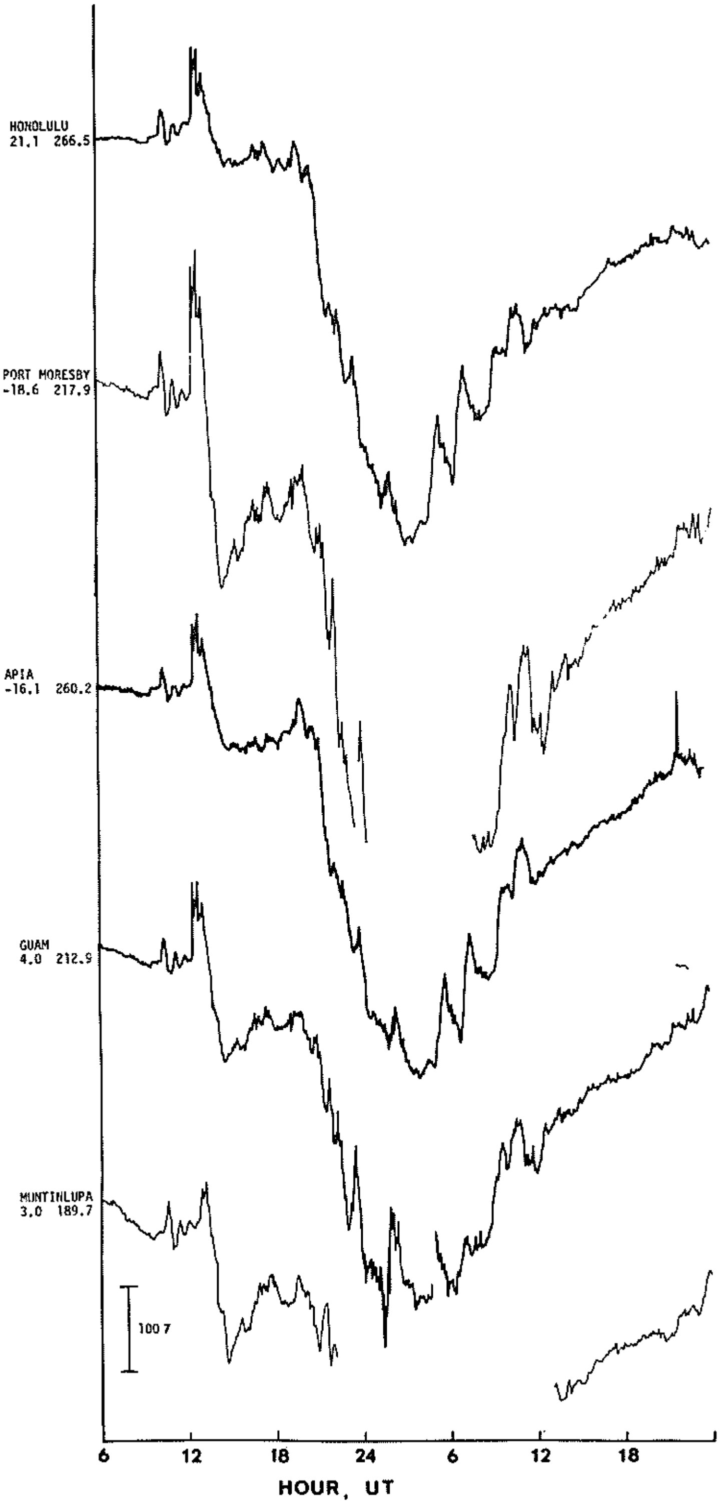
## Appendix

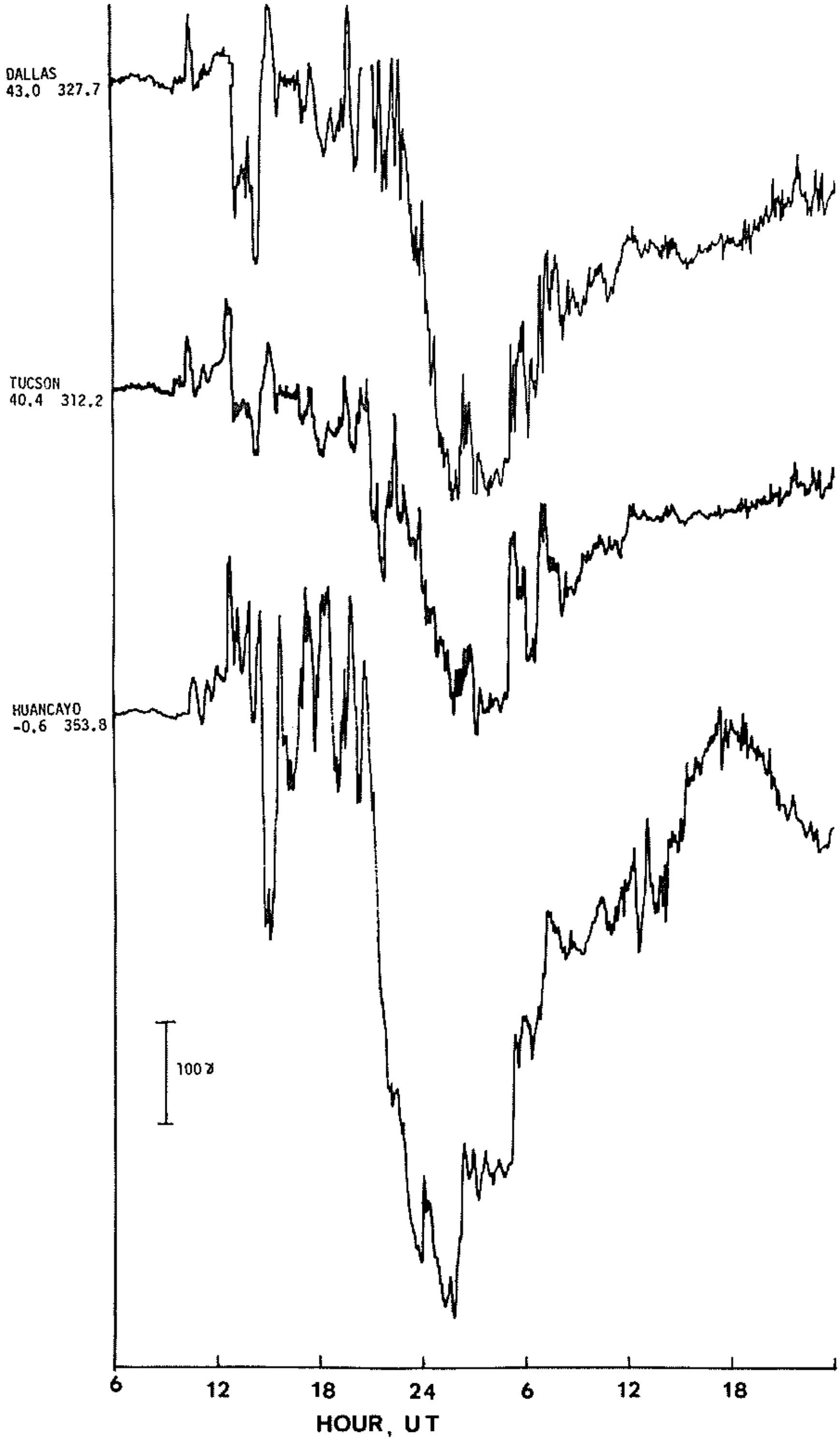
Collection of the reduced magnetic records for the May 25-26, 1967 storm.

| | Station | Geographic Coordinates | | | Station | Geographic Coordinates | |
|---|---|---|---|---|---|---|---|
| 1. | Honolulu | N21°19' | W158°00' | 6. | Rude Skov | N55°51' | E 12°27' |
| | Port Moresby | S 9 24 | E147 09 | | Wien-Kobenzl | N48 16 | E 16 19 |
| | Apia | S13 48 | W171 47 | | Witteveen | N52 49 | E 6 40 |
| | Guam | N13 35 | E144 52 | | Chambon-la-Foret | N48 01 | E 2 16 |
| | Muntinlupa | N14 22 | E121 01 | | Valentia | N51 56 | W 10 15 |
| 2. | Dallas | N32 59 | W 96 45 | 7. | Lvov | N49 54 | E 23 45 |
| | Tucson | N32 15 | W110 50 | | Moscow | N55 29 | E 37 19 |
| | Huancayo | S12 03 | W 75 20 | | Sverdlovsk | N56 44 | E 61 04 |
| 3. | Toledo | N39 53 | W 4 03 | 8. | Pt. Barrow | N71 18 | W156 45 |
| | L'Aguila | N42 23 | E 13 19 | | College | N64 52 | W147 50 |
| | San Juan | N18 07 | W 66 09 | | | | |
| | Paramaribo | N 5 49 | W 55 13 | 9. | Resolute Bay | N74 42 | W 94 54 |
| | Luanda | S 8 55 | E 13 10 | | Sitka | N57 04 | W135 20 |
| | Bangui | N 4 26 | E 18 34 | | | | |
| | Binza | S 4 16 | E 15 22 | 10. | Leirvogur | N64 11 | W 21 42 |
| | | | | | Sodankyla | N67 22 | E 26 38 |
| 4. | Grocka | N44 38 | E 20 46 | | | | |
| | Tehran | N35 44 | E 51 23 | 11. | Tixie Bay | N71 35 | E129 00 |
| | Quetta | N30 11 | E 66 57 | | Cape Wellen | N66 10 | W169 50 |
| | Nairobi | S 1 19 | E 36 49 | | Cape Chelyuskin | N77 43 | E104 17 |
| | Kokaikanal | N10 14 | E 77 28 | | | | |
| | | | | 12. | Heiss Island | N80 37 | E 58 03 |
| 5. | Toolangi | S37 32 | E145 28 | | Dixon Island | N73 33 | E 80 34 |
| | Amberley | S43 09 | E172 43 | | | | |
| | Fredericksburg | N38 12 | W 77 22 | 13. | Alert | N82 30 | W 62 30 |
| | Newport | N48 16 | W117 07 | | Mould Bay | N76 12 | W119 24 |
| | | | | | Baker Lake | N64 20 | W 96 02 |
| | | | | | Ft. Churchill | N58 48 | W 94 06 |

On the Figures the geomagnetic latitude and longitudes are given.

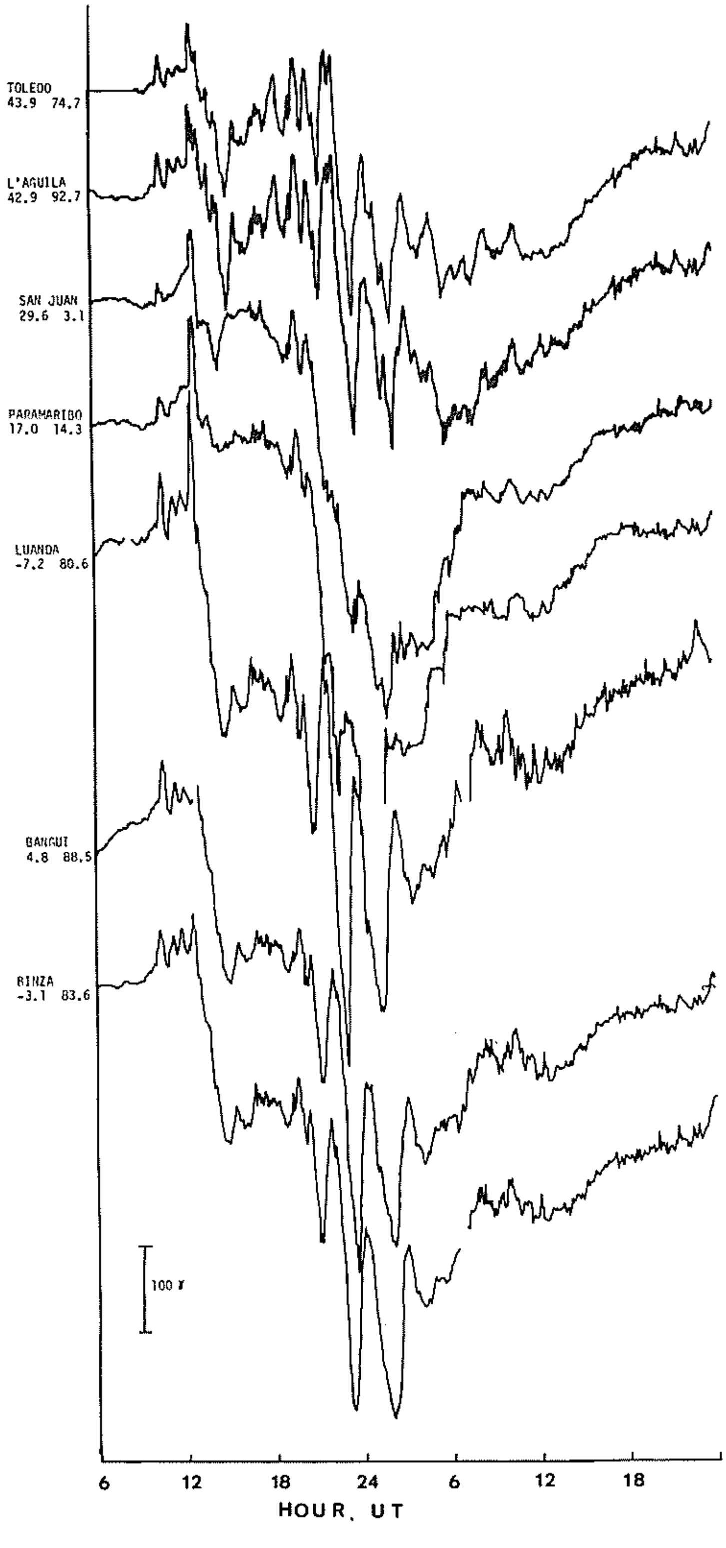

HONOLULU
21.1 266.5
PORT MORESBY
-18.6 217.9
APIA
-16.1 260.2
GUAM
4.0 212.9
MUNTINLUPA
3.0 189.7
100 γ
6
12
18
24
6
12
18
HOUR, UT

Appendix 1



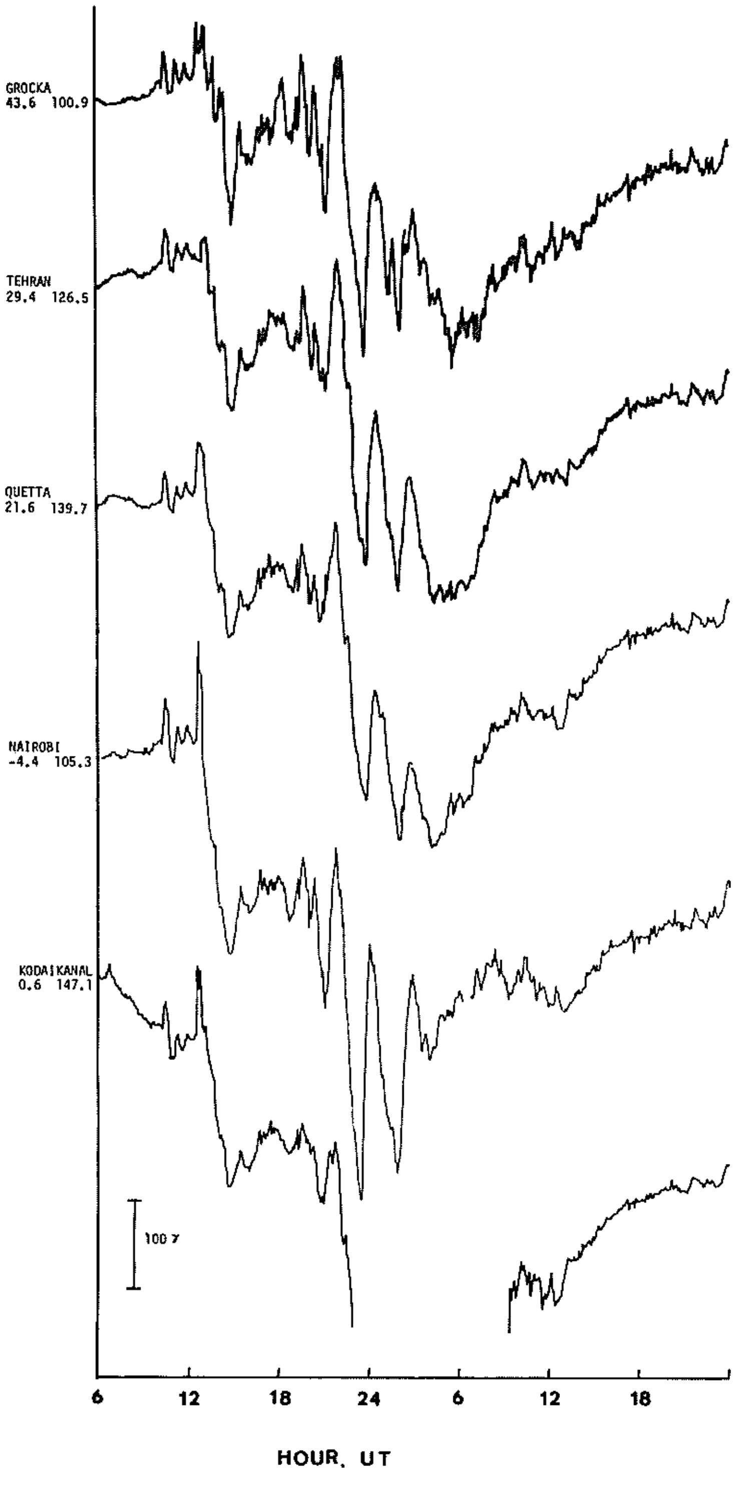
DALLAS
43.0 327.7
TUCSON
40.4 312.2
HUANCAYO
-0.6 353.8
100γ
6
12
18
24
6
12
18
HOUR, UT


Appendix 2

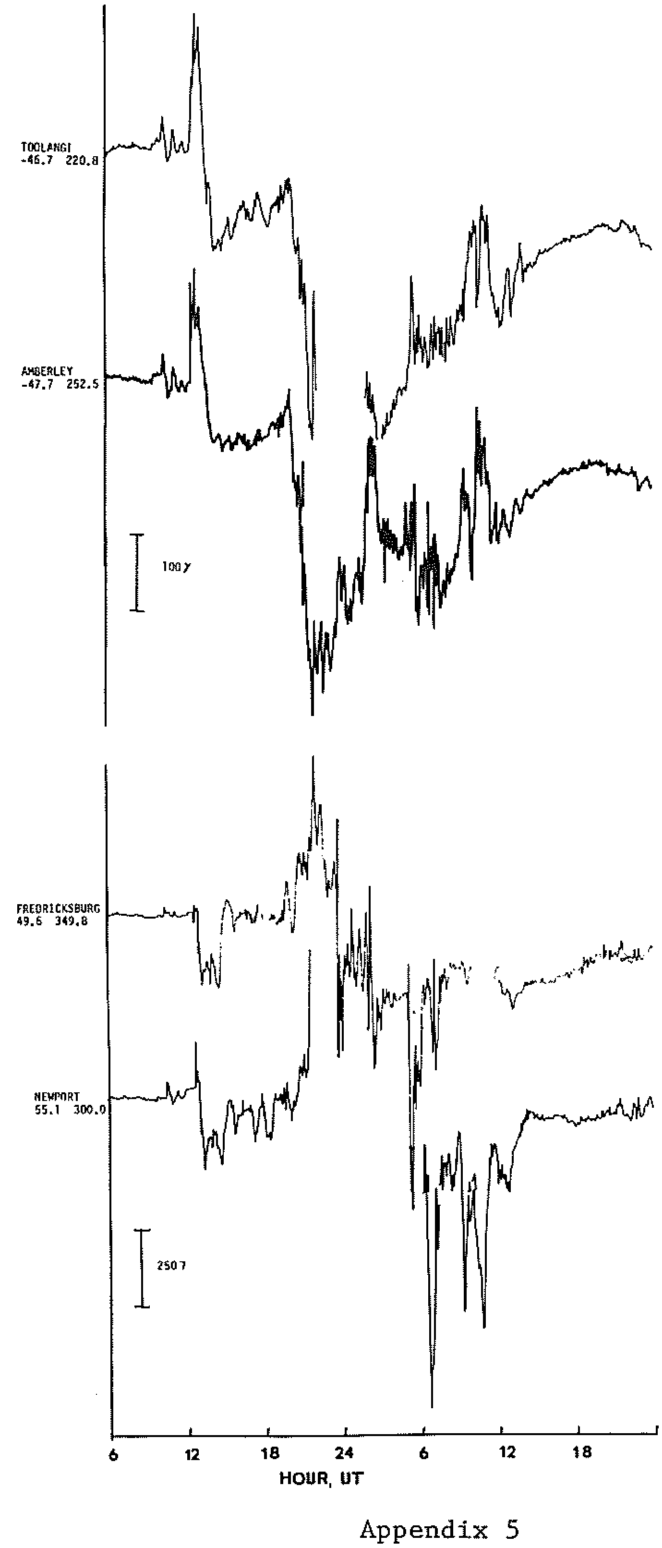


TOLEDO
43.9 74.7
L'AGUILA
42.9 92.7
SAN JUAN
29.6 3.1
PARAMARIBO
17.0 14.3
LUANDA
-7.2 80.6
BANGUI
4.8 88.5
BINZA
-3.1 83.6
100 γ
6
12
18
24
6
12
18
HOUR, UT

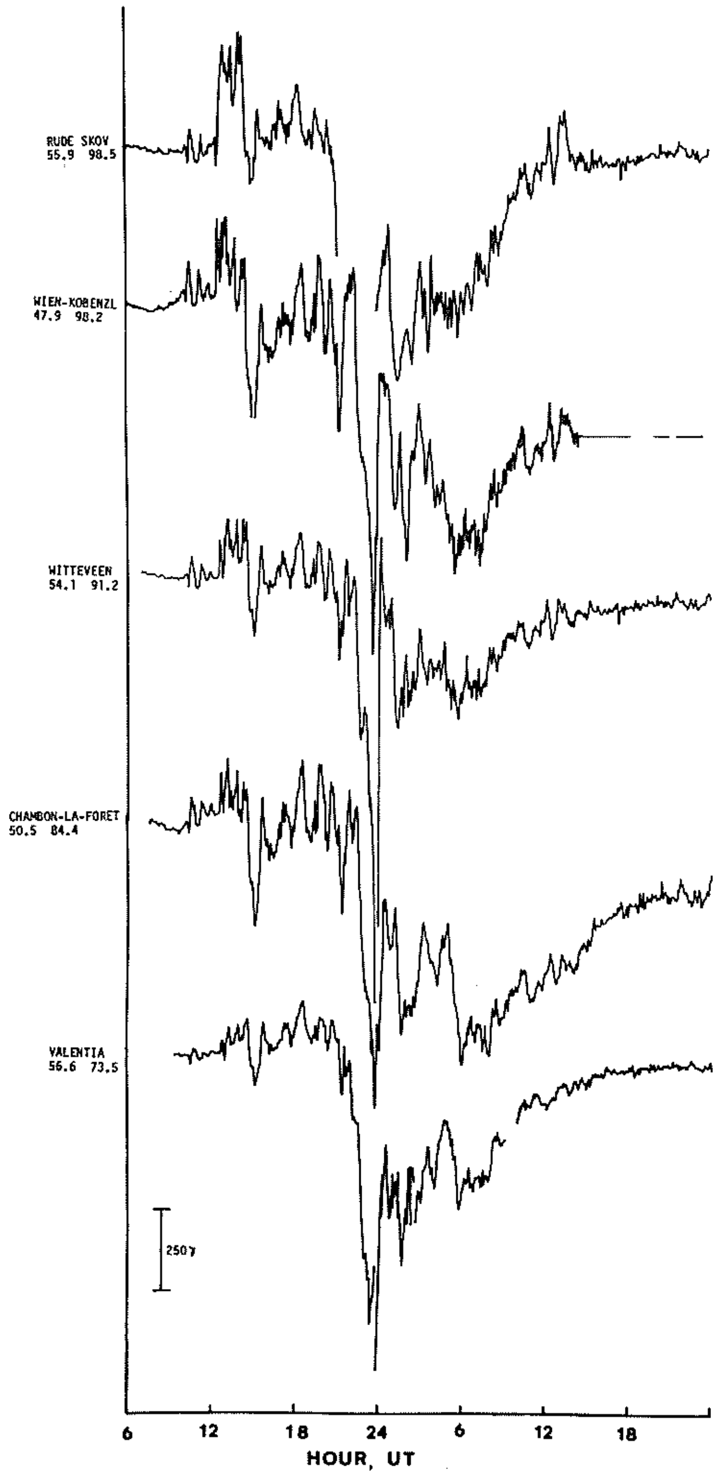

Appendix 3


GROCKA
43.6 100.9
TEHRAN
29.4 126.5
QUETTA
21.6 139.7
NAIROBI
-4.4 105.3
KODAIKANAL
0.6 147.1
100 γ
6
12
18
24
6
12
18
HOUR, UT

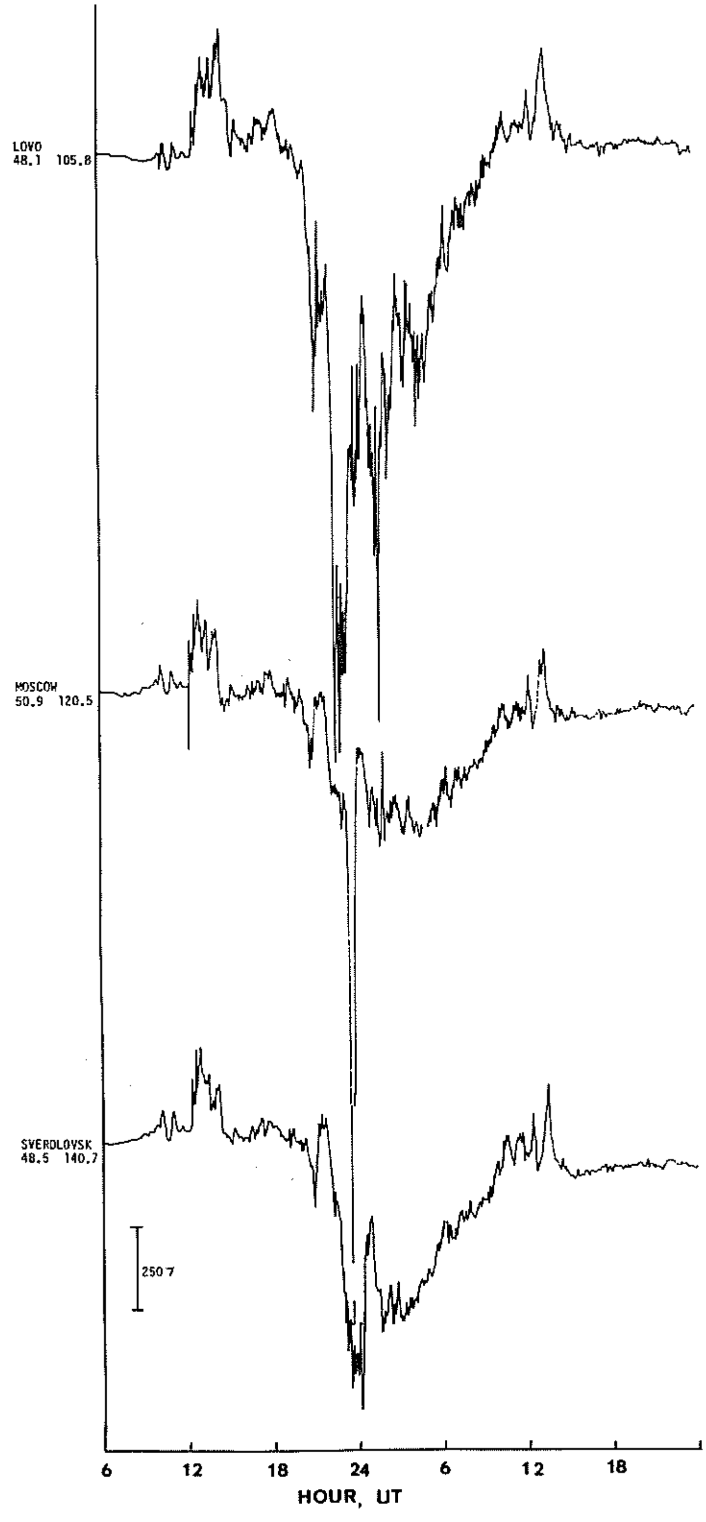
Appendix 4


TOOLANGI
-46.7 220.8
AMBERLEY
-47.7 252.5
100γ
FREDRICKSBURG
49.6 349.8
NEWPORT
55.1 300.0
250γ
6
12
18
24
6
12
18
HOUR, UT

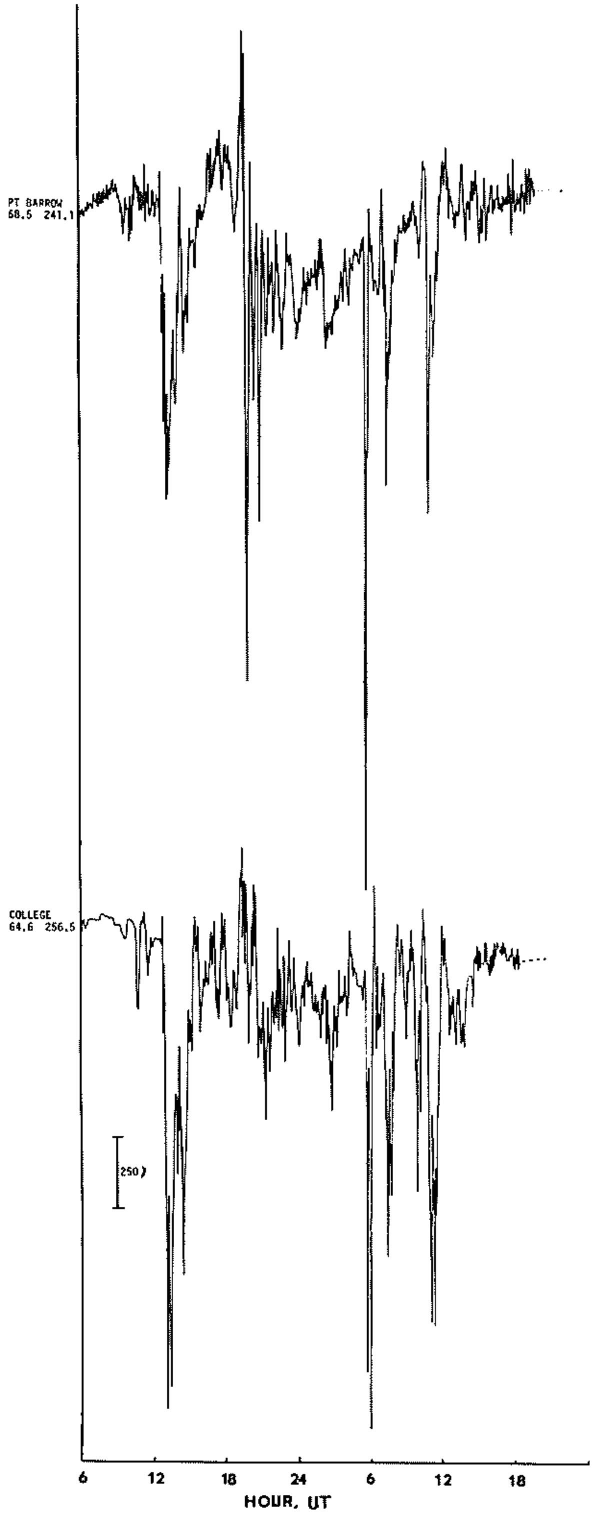
Appendix 5


RUDE SKOV
55.9 98.5
WIEN-KOBENZL
47.9 98.2
WITTEVEEN
54.1 91.2
CHAMBON-LA-FORET
50.5 84.4
VALENTIA
56.6 73.5
250γ
6
12
18
24
6
12
18
HOUR, UT

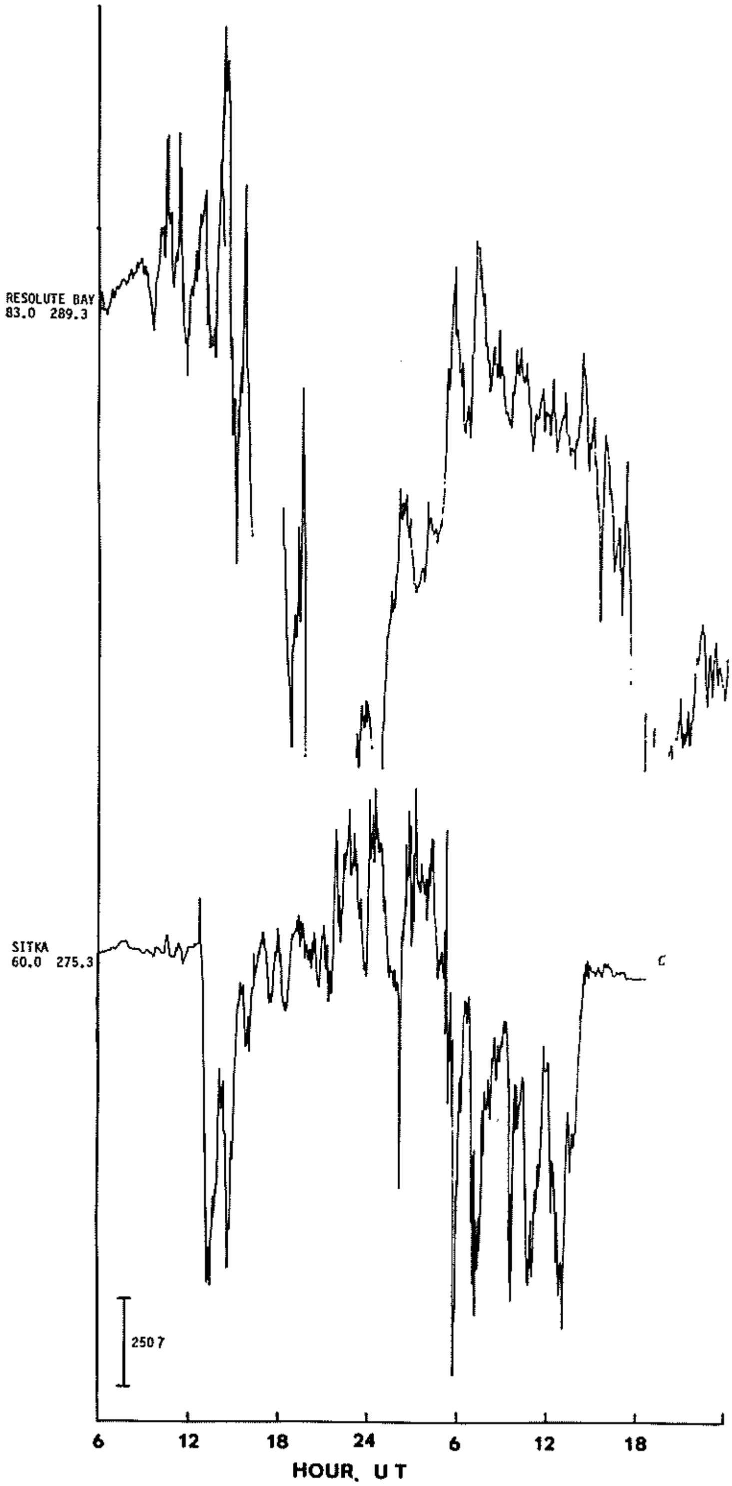
Appendix 6


LOVO
48.1 105.8
MOSCOW
50.9 120.5
SVERDLOVSK
48.5 140.7
250 γ
6
12
18
24
6
12
18
HOUR, UT

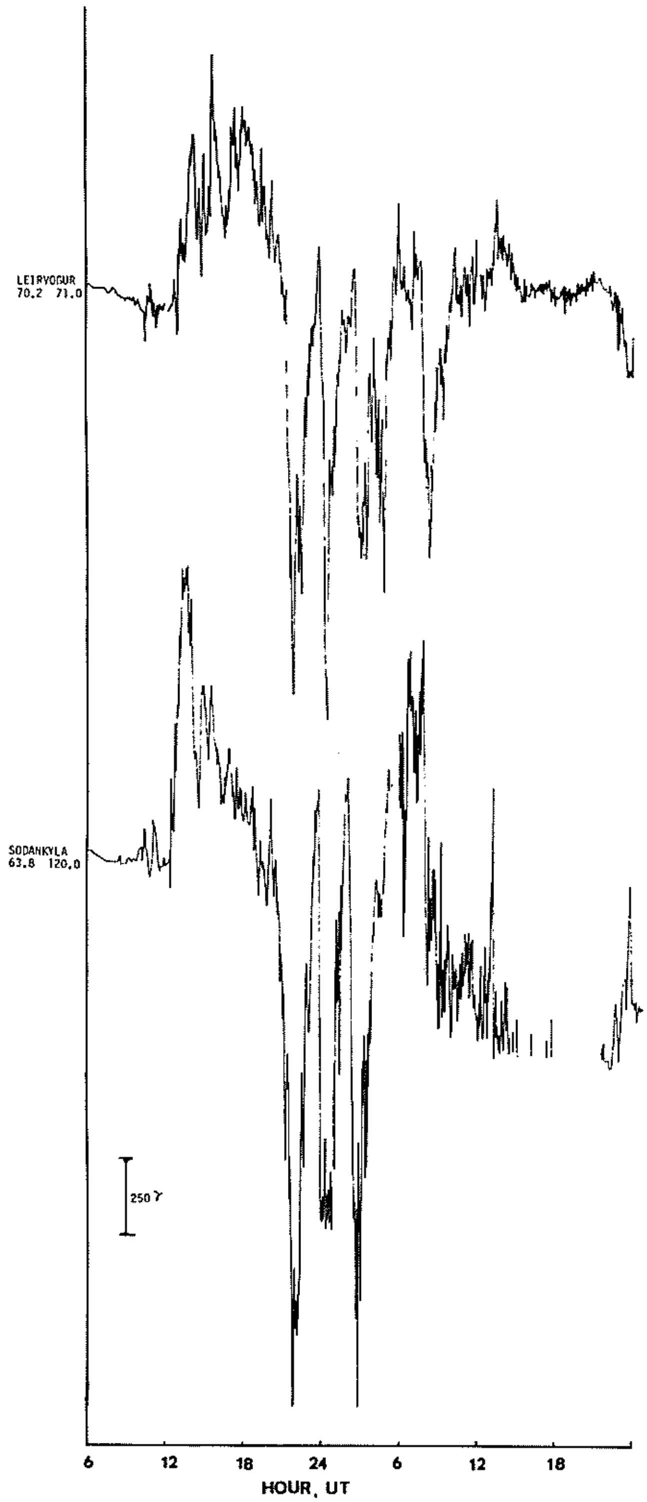
Appendix 7


PT BARROW
68.5 241.1
COLLEGE
64.6 256.5
250γ
6
12
18
24
6
12
18
HOUR, UT

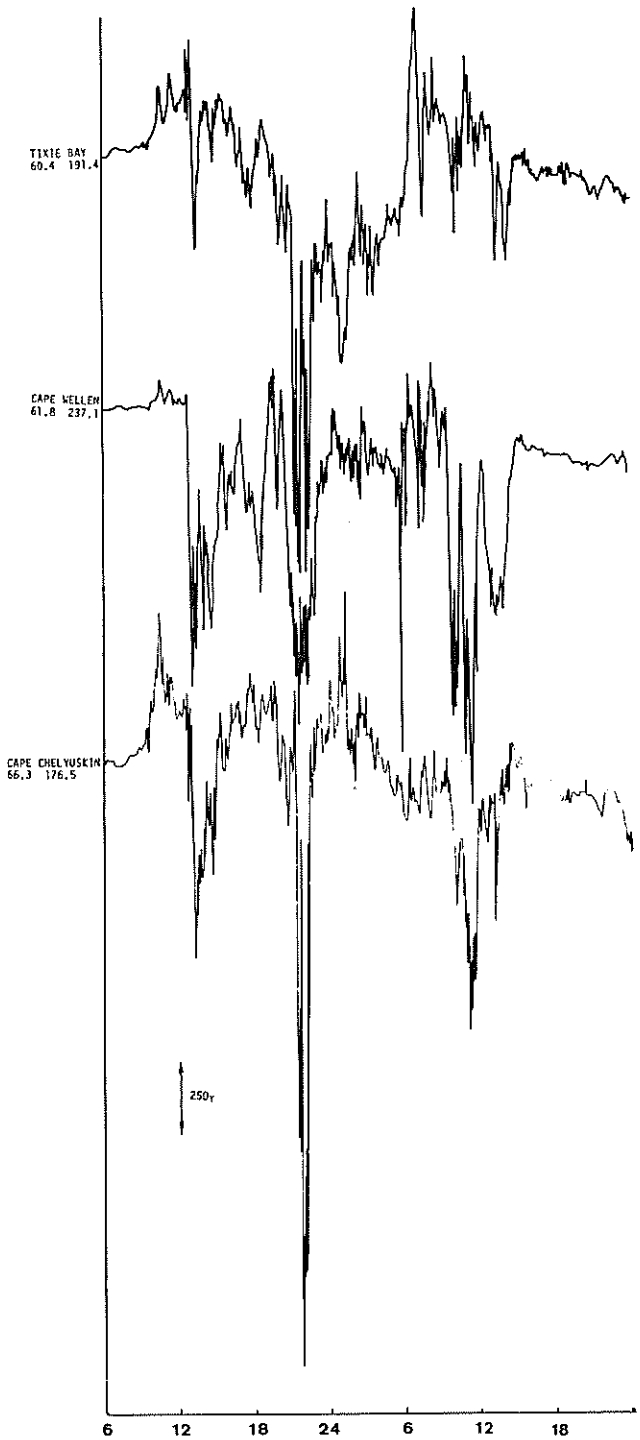
Appendix 8


RESOLUTE BAY
83.0 289.3
SITKA
60.0 275.3
250γ
6
12
18
24
6
12
18
HOUR, UT

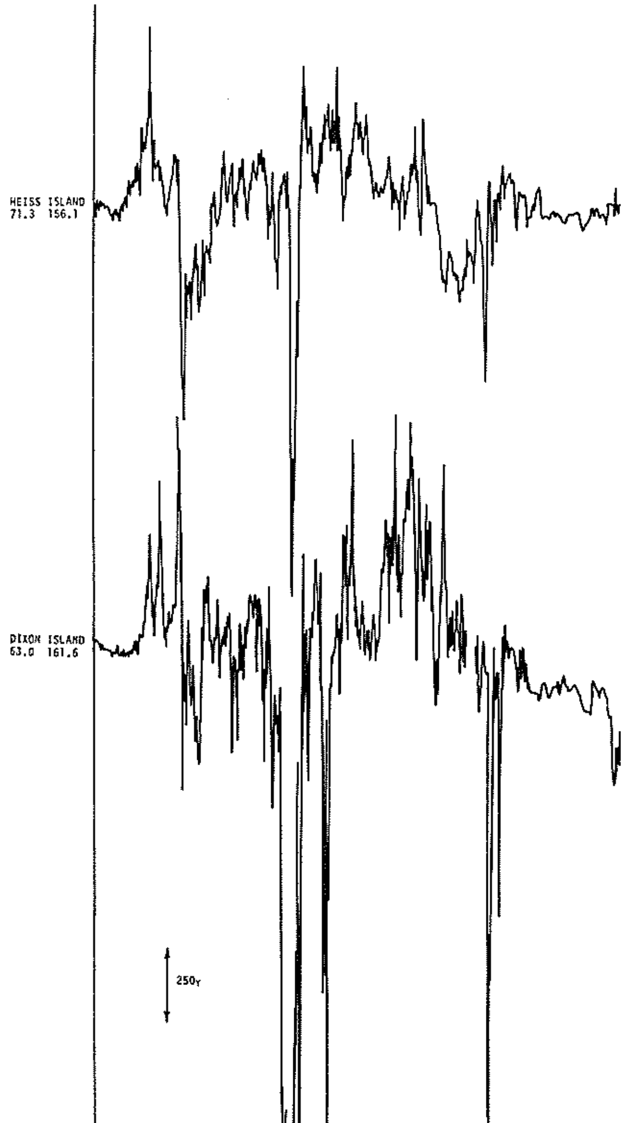
Appendix 9


LEIRVOGUR
70.2 71.0
SODANKYLA
63.8 120.0
250 γ
6
12
18
24
6
12
18
HOUR, UT

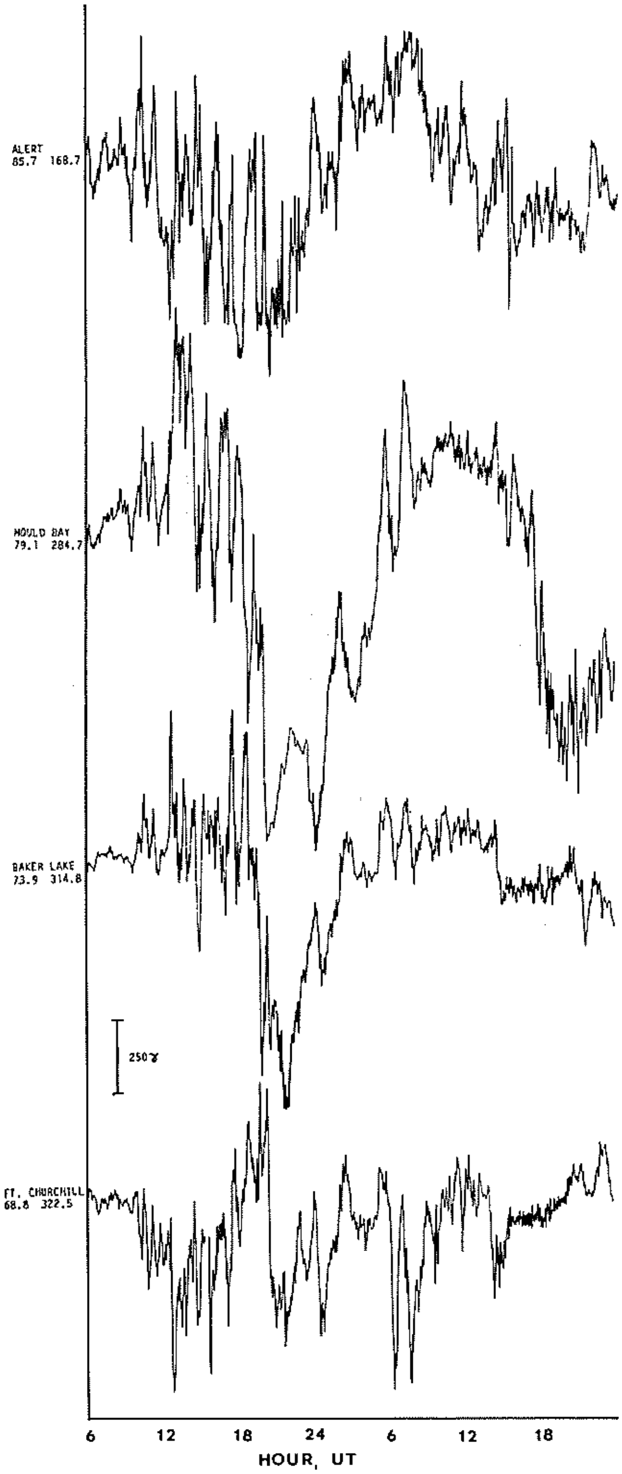
Appendix 10


TIXIE BAY
60.4 191.4
CAPE WELLEN
61.8 237.1
CAPE CHELYUSKIN
66.3 176.5
250γ
6
12
18
24
6
12
18
HOUR, UT

Appendix 11


HEISS ISLAND
71.3 156.1
DIXON ISLAND
63.0 161.6
250γ
6
12
18
24
6
12
18
HOUR,UT

Appendix 12




Appendix 13

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