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MAGNETOPAUSE CROSSING OF THE GEOSTATIONARY SATELLITE ATS 5 AT 6.6 R_E

T. L. SKILLMAN
M. SUGIURA

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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T. L. Skillman and M. Sugiura

Laboratory for Space Physics, Goddard Space Flight Center, Greenbelt, Maryland 20771

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ABSTRACT

During the moderate magnetic storm of September 29-30, 1969 an unusually large magnetic field decrease preceded by an impulsive increase of about 100γ was observed by the geostationary satellite ATS 5 at about 1733 UT on September 29. The field remained low for about 1 minute and returned to the pre-event level as abruptly as it decreased. From the ATS 1 and 5 observations and magnetograms from ground observatories, it is inferred that the magnetosphere was greatly compressed prior to the above event; the magnetopause distance was probably near 7 R_e at the subsolar point. Comparing the changes observed by ATS 5 with the field measured by ATS 1 which was 3 hours behind ATS 5 in local time, the event is interpreted as being a magnetopause crossing of ATS 5, caused by a localized, rapid inward motion of the magnetopause and its subsequent recession, creating temporarily an indentation on the magnetopause surface and exposing ATS 5 to the magnetosheath field for a brief period of time. It is suggested that the apparent "holes" in the magnetic field observed by OGO's 3 and 5 in the magnetosphere near the magnetopause may have been, at least in some cases, caused by similar localized magnetopause motions.

Introduction

An exceptionally deep penetration of the magnetopause past the orbit of the geostationary satellite ATS 1 at 6.6 R_e (earth radii) has been reported in a collection of papers in No. 17, Volume 73 of the Journal of Geophysical Research by Opp (1968), Cummings and Coleman (1968), Freeman et al., (1968), Lezniak and Winckler (1968), Paulikas et al., (1968), and Lanzerotti et al., (1968). According to these authors several magnetopause crossings were observed during a one hour period in the early main phase of the magnetic storm of January 13-14, 1967.

The present paper reports a similar event observed by the magnetometer on ATS 5 during the magnetic storm of September 27-30, 1969. From the magnetic data obtained by ATS 5 and the ground records from several stations it is inferred that the magnetosphere was greatly compressed, probably to near 7 R_e at the subsolar point, immediately prior to the event. Further, examining these data together with the ATS 1 results obtained by P. J. Coleman, Jr. and his collaborators it is concluded that the boundary crossing by ATS 5 is likely to have been a localized indentation of the magnetopause near the position of ATS 5.

Observations

ATS 5, launched on August 12, 1969, did not achieve gravity gradient stabilization as was initially designed, though it entered a synchronous equatorial orbit. The spacecraft was spin-stabilized about the spacecraft Z axis which is approximately parallel to the earth's rotational axis. The spin rate during the period concerned here was 76.20 rpm, or 0.787 seconds per revolution. The satellite was at 106.6°W longitude.

The magnetic field monitor aboard ATS 5 is a triaxial fluxgate magnetometer with a range of $\pm$ 500γ (gamma) and a sensitivity of 1γ. A detailed description of the instrumentation has been given by Skillman (1970).

A magnetic storm of moderate intensity began on September 27, 1969 with a sudden commencement at 2125 UT, and was followed by another, more intense magnetic storm with a sudden commencement at 0453UT on September 29.

Figure 1 shows the ATS 5 magnetic field data plots for the Z component along the spin axis and the X component which is normal to the spin axis. The sampling rate of the data is 5.12 seconds, and hence the satellite makes about 6.5 revolutions during each sampling interval; 30 second averages are plotted in Figure 1. The scattered points are due to noise, the principal cause of which is that the coarse and fine readings that are combined to obtain each field reading are taken at different times in the telemetry frame of 5.12 seconds. The noise is more extensive during the night hours because of larger field components in the spin plane at night. Noises from other spacecraft sources, when they exist, are of order 10γ.

The Z traces for two quiet days, one before the storm (Day 269, September 26) and another after the storm (Day 281, October 8) are shown in Figure 1 for comparison. A large increase above the average quiet level in the Z component of the magnetic field, which is approximately the north component X in the conventional designation used in ground observatory records, is seen between about 1300 and 2000 UT. During this time, the data, especially for the Z component, are of good quality, being nearly free from noise. The field component (marked X in Figure 1) in the plane normal to the spin axis is spin modulated; its average magnitude between 1300 and 2000 UT is approximately 6 to 10γ: Comparing this component with the large Z component, it is inferred that the magnetic field is very nearly horizontal and northward.

Figure 2 gives, from the top, the north component of the magnetic field observed by ATS 5, the same component of the field measured on ATS 1 by P. J. Coleman, Jr., and the horizontal component H, of the magnetic field observed at five middle to low latitude, ground observatories. The ATS 5 record is based on 1 minute averages after eliminating noise as much as possible, and the ATS 1 data are 10 minute averages. The positions of ATS's 1 and 5 at the instances of the three outstanding variations marked A, B, and C are indicated in Figure 2. The event which we are concerned with in this paper is the sudden large decrease of the field in Event B. For Event B, plots of the spacecraft Z component for ATS 5 and the spacecraft X, Y, and Z components for ATS 1 are shown in Figure 3. The expanded plots are shown because the averaging process used in preparing the ATS 5 trace in Figure 2 distorted the actual change appreciably. For the ATS 1 data there are off-sets in the zero levels, but we are concerned only with variations and not with absolute values. At the location of ATS 5 the north component of the magnetic field increased by about 100γ in 1 minute, approximately from $17^h\ 31^m\ 50^s$ to $17^h\ 32^m\ 50^s$, and then decreased steeply by about 410γ in about 10 seconds. The field recovered to the pre-event level in approximately 1 minute. At ATS 1 there were no sharp variations during the event, and only a gradual increase of about 28γ in the north component (Z), a change of roughly 40γ in Y, and a smaller change in X were observed in association with the sudden change observed by ATS 5; here the X and Y axes are approximately parallel to the equatorial plane. The variation in Y referred to above is more of a part of a quasi-periodic wave that began nearly simultaneously with the sudden change at ATS 5 than being an isolated variation as in the case of the Z component.

Interpretation

Referring to the ATS 5 record in Figure 2, the magnetic field began to increase at about 1200 UT. The beginning of a similar increase at ATS 1 appears to be a little earlier, but the general trend is the same as at the ATS 5 location during the period of several hours from 1200 to 2000 UT. At 1200 UT the position of ATS 1 was near 0200 LT (local time) and that of ATS 5 approximately 0500 LT.

The magnetic field strength at ATS 5 near 1732 UT (i.e. just prior to Event B) is about 220γ (Figure 3). Using the Mead model of the magnetosphere (Mead, 1964), the field strength at the geomagnetic equator at the ATS 5 (or ATS 1) position for 1733 UT is given in Figure 4 as a function of the subsolar magnetopause distance. On the basis of the idealized Mead model, the field at ATS 5 is expected to be 220γ if the subsolar magnetopause distance is about 7 R_e. There is a possibility that the inflation of the inner magnetosphere caused by a storm-time ring current may have increased the field at the ATS altitude, but this effect is likely to be small for the following reason. Near 1730 UT, values of H are above the pre-storm level, defined by the interval from 0 to 3 hours UT, by about 30 to 50γ at all the observatories shown in Figure 2 except for Fredericksburg. At Fredericksburg the local time of Event B was near noon, and hence the Sq field would decrease H. The Sq range varies greatly from day to day, but the probable value of this decrease is 20 to 40γ. Hence after correcting for Sq, H at 1730 UT for Fredericksburg may be estimated at about 30γ above the pre-storm level. The local time of Honolulu at Event B is about 0630, and the local times for the pre-storm interval 0 to 3 hours UT are 13 to 16 hours. Since Sq in H during these hours is normally positive at Honolulu, an estimate of ΔH of $\sim 30\gamma$ at 1730 UT above the pre-storm level would be a very conservative estimate. The magnetograms from Kakioka (geographic longitude 140°E; geomagnetic latitude 26°N), Gnangara (116°E; 43°S), and Yangi-Bazar (69°E; 32°N), which are not shown in Figure 2 indicate that H at 1730 UT was near the pre-storm level or within about 10γ above it at these longitudes. There was a decrease in H in this Eastern sector from about 1500 to 1900 UT with a minimum of roughly -30γ near 1630 UT. Thus, there may have been a weak partial ring current in this sector (i.e., within a few hours of midnight). Otherwise there is no available evidence that the inner magnetosphere was inflated appreciably compared with its average state, and therefore, the high field level at ATS 5 near Event B is interpreted as being mainly due to a compression of the magnetosphere by a large solar wind pressure. On the basis of the Mead model then the subsolar magnetopause distance was in the vicinity of 7 R_e. Since ATS 5 was within about 23° of the noon meridian, the magnetopause distance in the meridian plane containing the satellite would not differ greatly from that for the noon meridian. Hence, immediately prior to Event B, the magnetopause was probably within 1 R_e of ATS 5.

Figure 3 shows that at the onset of Event B the field at ATS 5 increased by approximately 100γ. According to the curve for ATS 5 in Figure 4, a 100γ increase from the level of 220γ would correspond to an inward movement of the magnetopause from 7 R_e to well within 6 R_e

at the subsolar point on the basis of an idealized quasi-static compression model. With this model the field increase at ATS 1 should be of the same order of magnitude as at ATS 5. Figure 3 indicates however that the increase in the north component (i.e., the spacecraft Z component) at the ATS 1 location was only 28γ, which is less that 1/3 of the increase at ATS 5. This difference is too large to accept the quasi-static compression model or any other similar model invoking an overall compression of the magnetosphere. Also, the changes in H observed on the earth's surface at the time of Event B (Figure 2) are not what is expected from the simple compression model as seen in the lower curves of Figure 4.

We therefore interpret that the large field increase observed by ATS 5 was caused by a local indentation of the magnetopause. The subsequent large decrease of the field with an initial reversal in the north component is then interpreted as meaning that ATS 5 was in the magnetosheath for about 1 minute.

The charged particle measurements by Sharp and Shelley support the view that ATS 5 was in the magnetosheath for the brief period of time. Figure 5, provided by Shelley in a private communication, gives electron (top four plots) and proton (lower three plots) flux measurements on ATS 5, covering a 20-minute interval including Event B. The flux of 0.6 to 1.9 kev electrons increased, while those of higher energies, 1.8 to 5.4 kev, 6 to 18 kev, and 17 to 35 kev electronics, decreased during Event B. A sudden decrease of high energy electron fluxes and a simultaneous increase in low energy electron fluxes are indicative of a magnetopause crossing from the magnetosphere into the magnetosheath (Ogilvie et al., 1970).

Conclusion

On the basis of the discussions given in the preceding section, we conclude that the sudden field decrease observed by ATS 5 at about 1733 on September 29, 1969 was produced by a localized, momentary inward excursion of the magnetopause, thereby exposing ATS 5 to the magnetosheath field for about one minute. The field change observed during this event is quite similar to what we have previously called "holes" in the magnetic field observed inside the magnetosphere near its boundary (Sugiura et al., 1969), an example of which is shown in Figure 6. Such "holes" were then interpreted as being produced by blobs of a hot magnetosheath plasma as shown schematically in Figure 7 (a). The present study raises the possibility that these "holes" might represent, at least in some cases, localized, rapid inward motions of the magnetopause creating such an indentation as shown in Figure 7 (b) for a short period of time. However, the question of whether the "holes" are produced by localized indentations of the magnetopause or by plasma blobs created, for instance, when such local indentations are pinched off from the magnetopause cannot be resolved with the presently available data. The definitive solution to this question would require, as many other problems of the magnetopause and the bow shock, observations by a cluster of satellites.

ACKNOWLEDGEMENTS

We wish to thank Dr. J. P. Heppner for valuable discussions. We are grateful to Drs. R. D. Sharp and E. G. Shelley of Lockheed Palo Alto Research Laboratory for supplying their particle data for this event, to Drs. P. Coleman and R. McPherron of UCLA for the use of their ATS 1 data, to the numerous magnetic observatories whose magnetograms were used in the present study, and to W. Paulishak of World Data Center A for his assistance in obtaining the magnetograms. We appreciate the support of D. Fordyce, Project Manager for ATS 5, and also the project staff that has enabled us to obtain useful data from the Magnetic Field Monitor aboard this spacecraft.

REFERENCES

Cummings, W. D. and P. J. Coleman, Jr., Magnetic fields in the magnetopause and vicinity at synchronous altitude, J. Geophys. Res., 73, 5699, 1968.

Freeman, J. W., Jr., C. S. Warren, and J. J. Maguire, Plasma flow directions at the magnetopause on January 13 and 14, 1967, J. Geophys. Res., 73, 5719, 1968.

Lanzerotti, L. J., W. L. Brown, and C. S. Roberts, Energetic electrons at 6.6 R_E during the January 13-14, 1967, geomagnetic storm, J. Geophys. Res., 73, 5751, 1968.

Lezniak, T. W., and J. R. Winckler, Structure of the magnetopause at 6.6 R_e in terms of 50- to 150-kev electrons, J. Geophys. Res., 73, 5733, 1968.

Mead, G. D., Deformation of the geomagnetic field by the solar wind, J. Geophys. Res., 69, 1181, 1964.

Ogilvie, K. W., M. Sugiura, and J. D. Scudder, Magnetic field and electron Observations near the magnetopause, Goddard Space Flight Center, X-692-70-159, 1970.

Opp, A. G., Penetration of the magnetopause beyond 6.6 R_e during the magnetic storm of January 13-14, 1967: Introduction, J. Geophys. Res., 73, 5697, 1968.

Paulikas, G. A., J. B. Blake, S. C. Freden, and S. S. Imamoto, Boundary of energetic electrons during the January 13-14, 1967, magnetic storm, J. Geophys. Res., 73, 5743, 1968.

Skillman, T. L., ATS-E magnetic field monitor instrumentation, Goddard Space Flight Center, X-645-70-54, 1970.

Sugiura, M., T. L. Skillman, B. Ledley, and J. P. Heppner, "Holes" in the magnetic field near the magnetopause, (abstract), Trans., Am. Geophys. Union, 50, 278, 1969.

FIGURES

Figure 1. ATS 5 magnetic field observation on September 29, 1969; 30 second averages of the spacecraft X and Z components are plotted together with two quiet day data for the Z component.

Figure 2. From the top: the north component (the spacecraft Z component) of the field observed by ATS 5, the same component observed by ATS 1, and the horizontal component, H, observed at five ground stations.

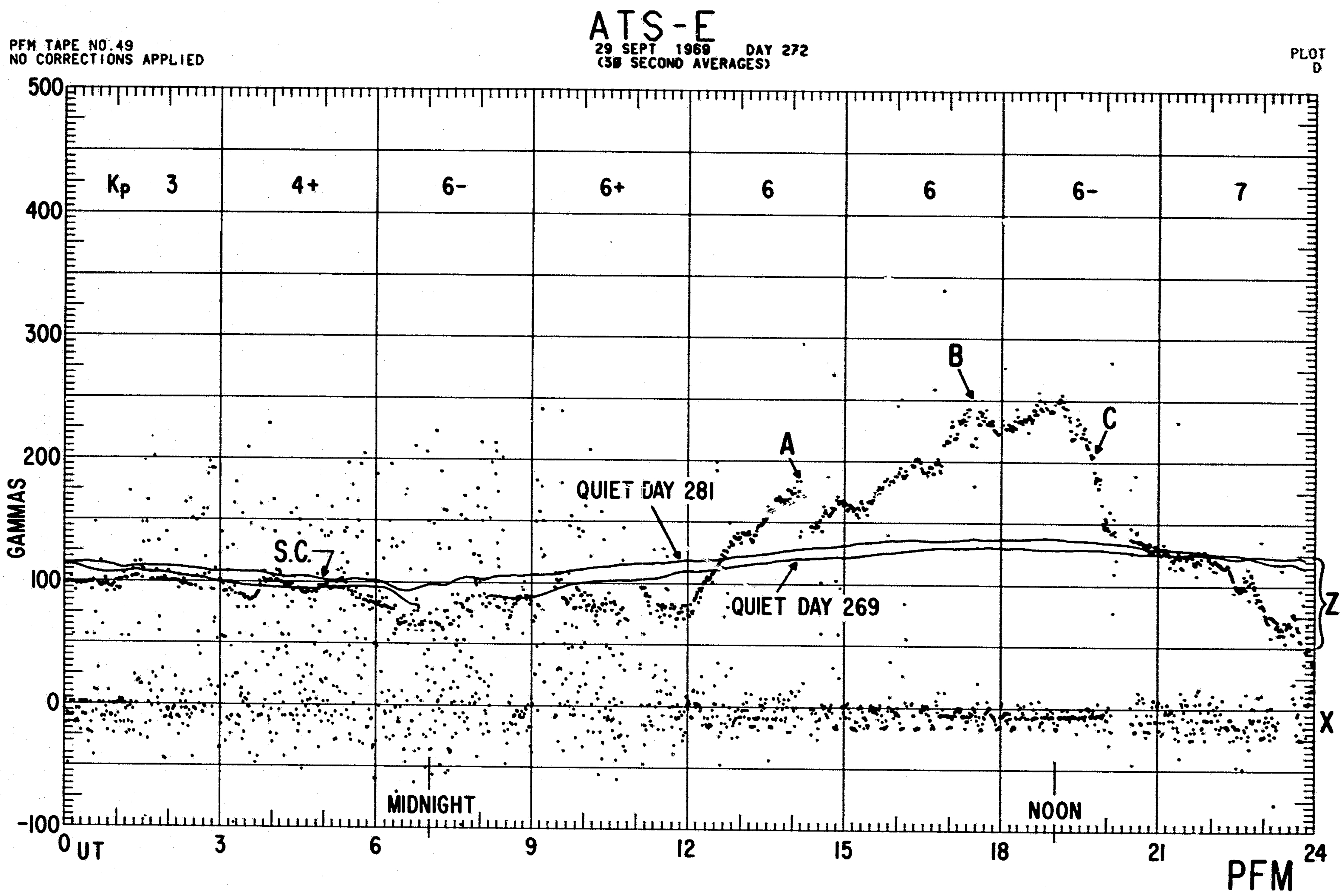
Figure 3. Magnetic field data from ATS's 5 and 1 for event B on an expanded time scale.

Figure 4. Theoretical values of the north component of the magnetic field at the geomagnetic equator at the ATS 1 and 5 locations and on the earth's surface, calculated on the basis of the Mead model of the magnetosphere.

Figure 5. Electron (e^-) and proton (p^+) flux measurements made on ATS 5 by Sharp and Shelley.

Figure 6. A "hole" in the magnetic field observed by OGO 3 near the magnetopause.

Figure 7. Schematic models of a "hole": (a) a magnetosheath plasma blob, and (b) an indentation on the magnetopause surface due to a localized, rapid motion of the magnetopause.



ATS-E
PFM TAPE NO.49
NO CORRECTIONS APPLIED
29 SEPT 1969 DAY 272
(30 SECOND AVERAGES)
PLOT
D
Kp 3
4+
6-
6+
6
6
6-
7
GAMMAS
500
400
300
200
100
0
-100
S.C.
QUIET DAY 281
QUIET DAY 269
A
B
C
Z
X
MIDNIGHT
NOON
0 UT
3
6
9
12
15
18
21
24
PFM

FIGURE 1

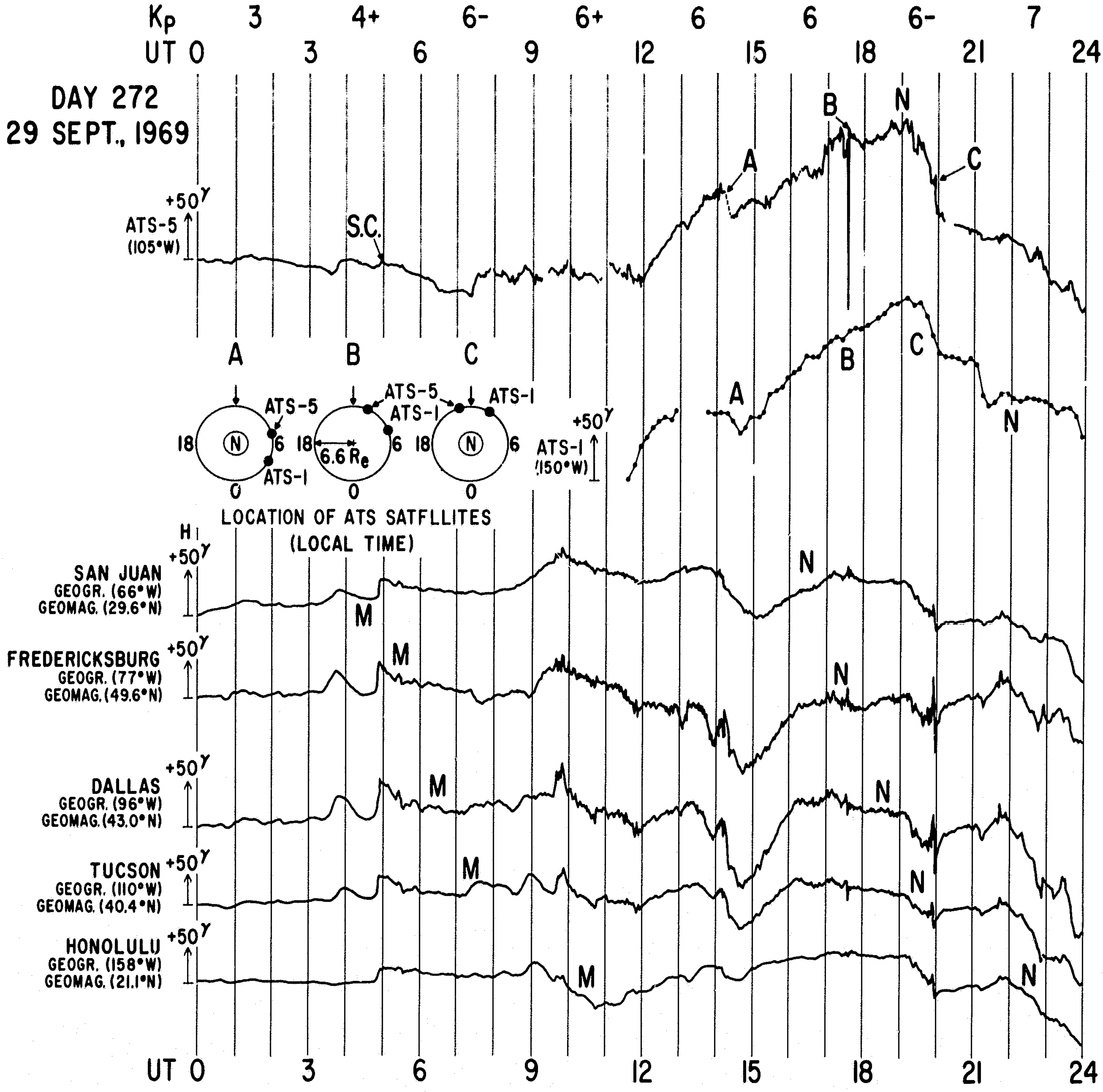

Kp 3 4+ 6- 6+ 6 6 6- 7
UT 0 3 6 9 12 15 18 21 24
DAY 272
29 SEPT., 1969
+50γ
ATS-5
(105°W)
S.C.
A
B
N
C
ATS-5
ATS-1
18
6
0
6.6 Re
ATS-1
(150°W)
LOCATION OF ATS SATFLLITES
(LOCAL TIME)
H
SAN JUAN
GEOGR. (66°W)
GEOMAG. (29.6°N)
M
FREDERICKSBURG
GEOGR. (77°W)
GEOMAG. (49.6°N)
DALLAS
GEOGR. (96°W)
GEOMAG. (43.0°N)
TUCSON
GEOGR. (110°W)
GEOMAG. (40.4°N)
HONOLULU
GEOGR. (158°W)
GEOMAG. (21.1°N)

FIGURE 2

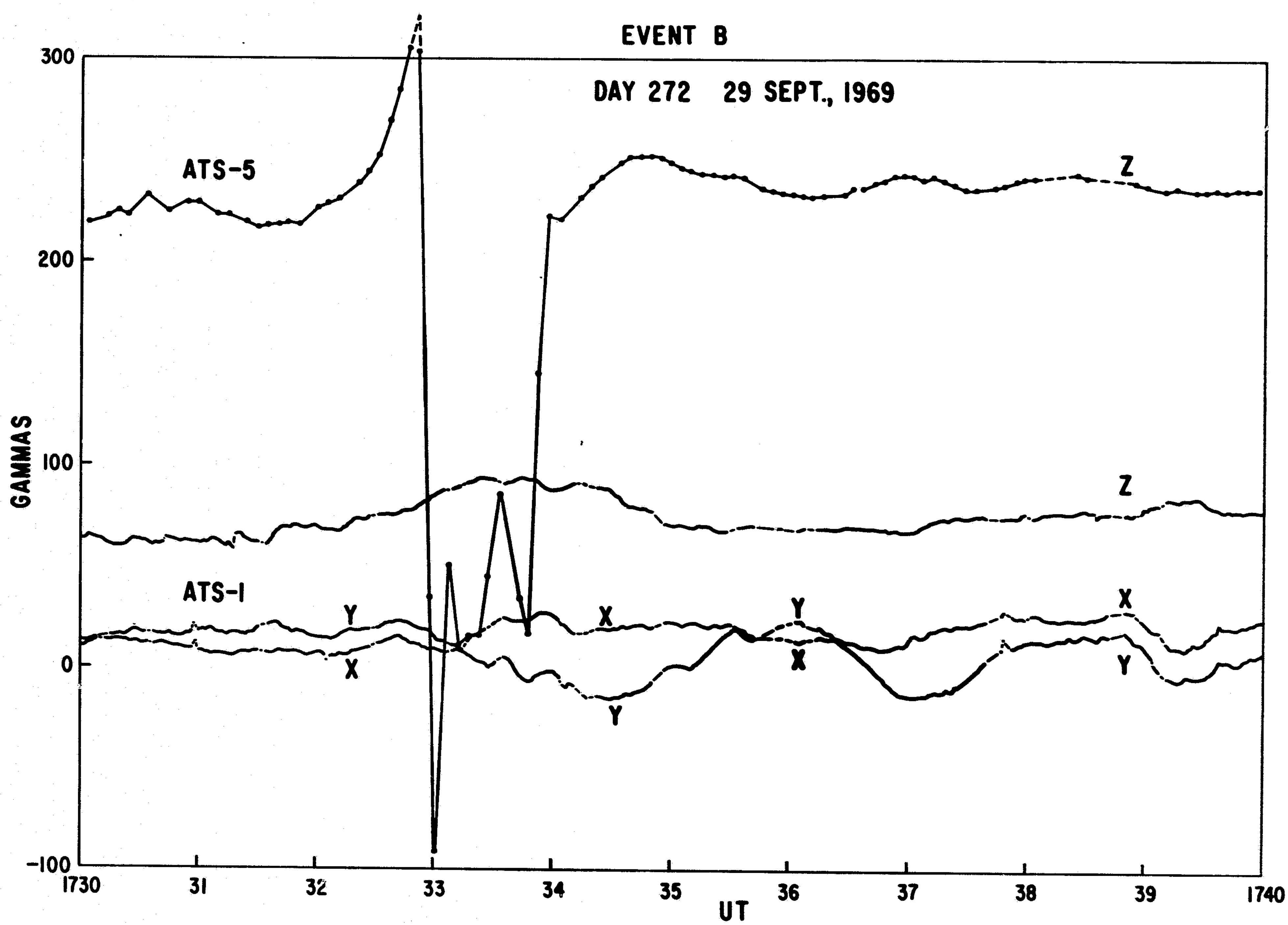

EVENT B
DAY 272 29 SEPT., 1969
ATS-5
Z
ATS-1
Z
Y
X
X
Y
Y
X
X
Y
GAMMAS
300
200
100
0
-100
1730
31
32
33
34
35
36
37
38
39
1740
UT

FIGURE 3

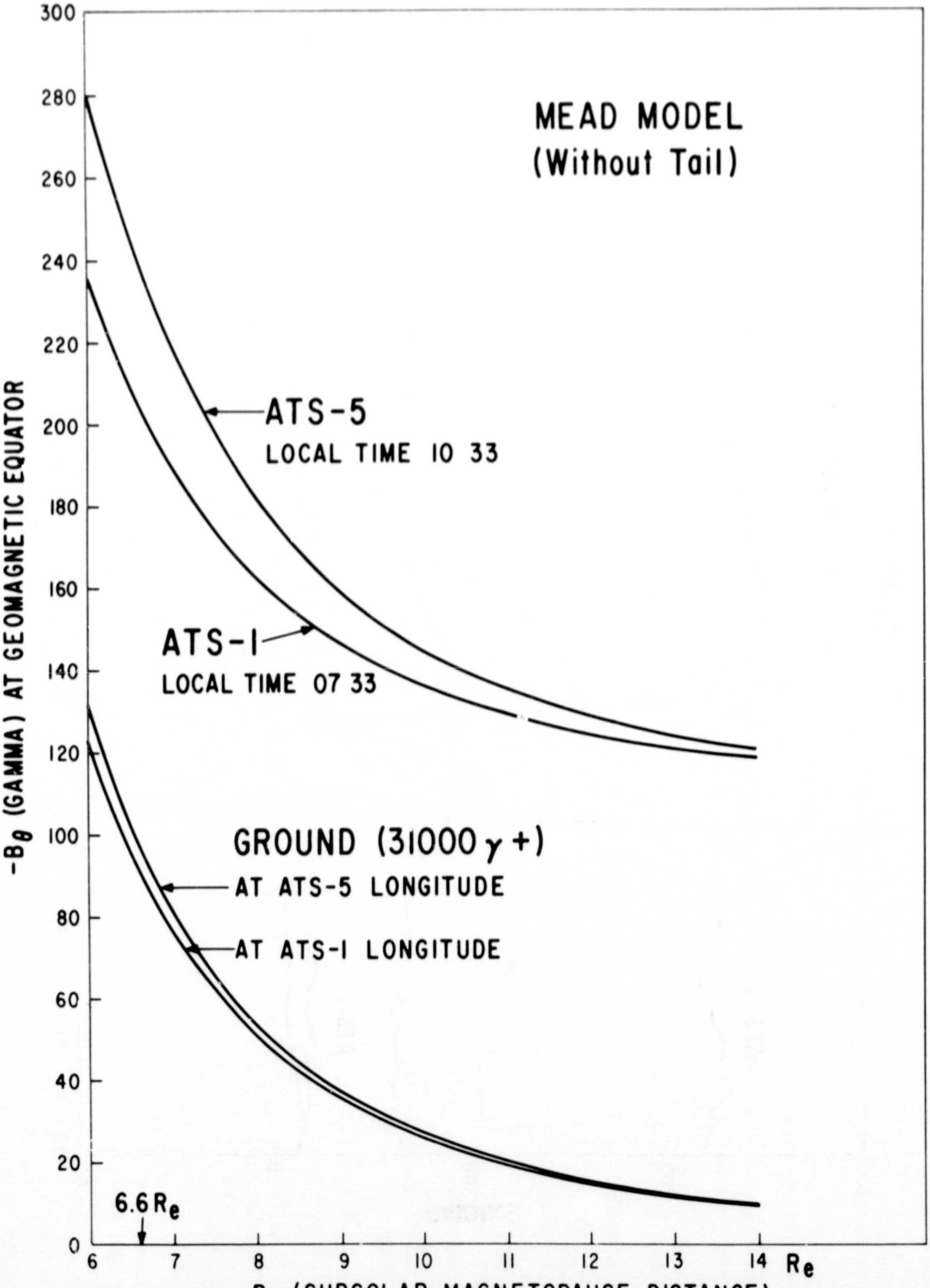

MEAD MODEL
(Without Tail)
ATS-5
LOCAL TIME 10 33
ATS-1
LOCAL TIME 07 33
GROUND (31000 γ +)
AT ATS-5 LONGITUDE
AT ATS-1 LONGITUDE
6.6 R_e
$-B_\theta$ (GAMMA) AT GEOMAGNETIC EQUATOR
R_b (SUBSOLAR MAGNETOPAUSE DISTANCE)
R_e
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
6
7
8
9
10
11
12
13
14

FIGURE 4

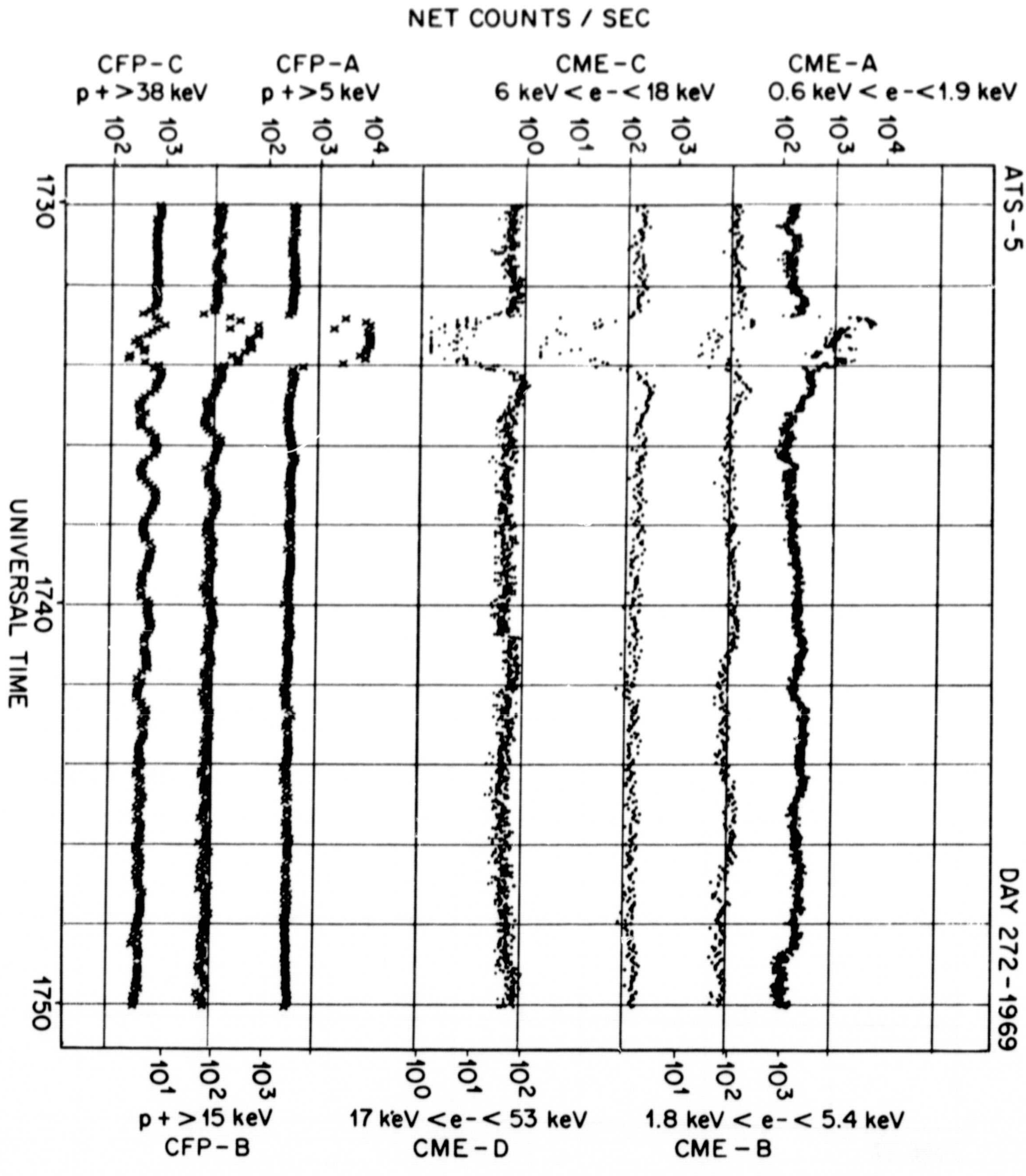

NET COUNTS / SEC
CFP-C
p + > 38 keV
CFP-A
p + > 5 keV
CME-C
6 keV < e- < 18 keV
CME-A
0.6 keV < e- < 1.9 keV
ATS-5
1730
1740
UNIVERSAL TIME
1750
DAY 272-1969
p + > 15 keV
CFP-B
17 keV < e- < 53 keV
CME-D
1.8 keV < e- < 5.4 keV
CME-B

FIGURE 5

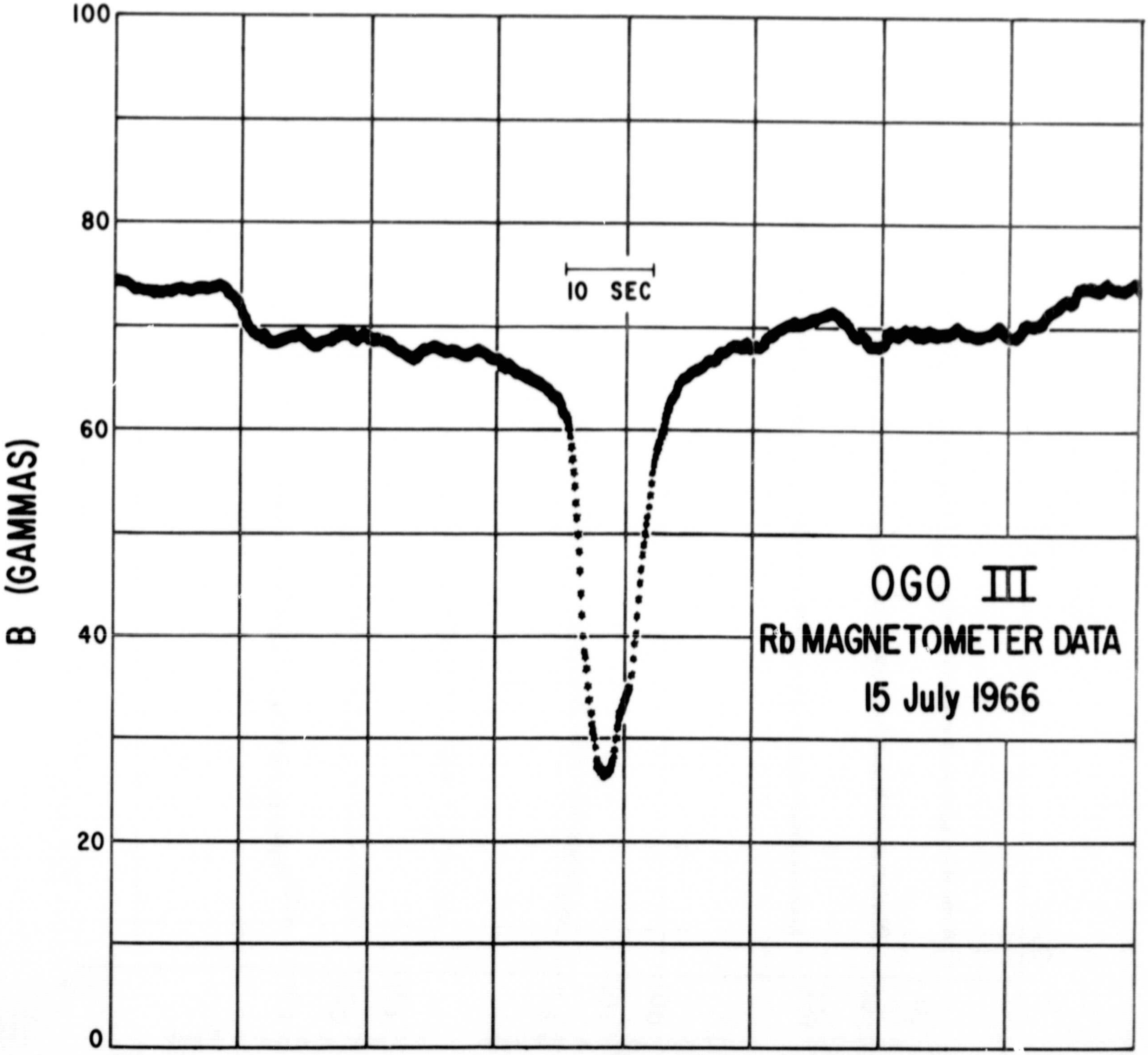
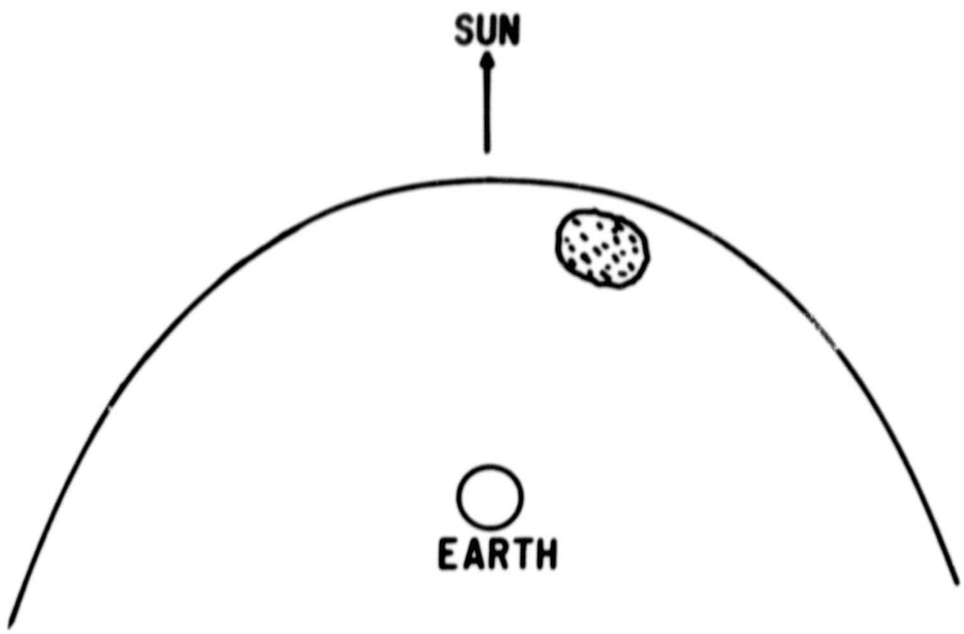
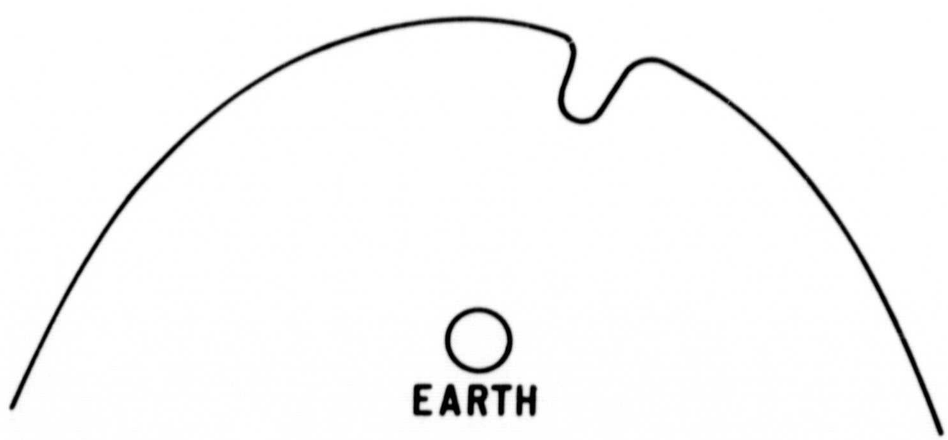

100
80
60
40
20
0
B (GAMMAS)
10 SEC
OGO III
Rb MAGNETOMETER DATA
15 July 1966
2028 UT
2029
2030

FIGURE 6



(d) Plasma Blob



(b) Localized Indentation

FIGURE 7