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F. W. BERKO

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FEATURES OF POLAR CUSP ELECTRON PRECIPITATION ASSOCIATED WITH A LARGE MAGNETIC STORM

F. W. BERKO

LABORATORY FOR PLANETARY ATMOSPHERES
GODDARD SPACE FLIGHT CENTER
GREENBELT, MD. 20771

ABSTRACT

Measurements of precipitating electrons made by the OGO-4 satellite on October 31, 1968, reveal several interesting phenomena in the polar cusp. Extremely high fluxes of 0.7 keV electrons were observed in the polar cusp ninety minutes following the sudden commencement of a very large magnetic storm. Structured, fairly high fluxes of 7.3 keV electrons were also observed in the cusp region, accompanied by very strong search coil magnetometer fluctuations, indicative of strong field-aligned currents. In addition, the observations confirm previously reported latitudinal shifts in the location of the polar cusp in response to southward interplanetary magnetic fields.

INTRODUCTION

Large magnetic storms occurred for several days beginning on October 31, 1968. Extensive particle and field observations in the dayside cusp made during this period by OGO-5 have previously been reported by Russell et al. (1971). Scarf et al. (1972) and Fredericks and Russell (1973) have presented additional OGO-5 measurements from this epoch bearing on plasma waves. Measurements of precipitating protons in the early morning hours were reported by Cornwall et al. (1971) using data taken on October 31 and November 1 from the polar-orbiting satellite OV1-15. A very strong transverse magnetic disturbance measured at high latitudes near 9 hours local time on November 1 has been reported by Armstrong and Zmuda (1970) as signaling strong field-aligned currents. Data taken in the polar cusp on November 1 by OGO-5 have also been interpreted by Fredericks et al. (1973) as indicating the presence of field-aligned currents.

In this paper we present observations of precipitating electrons and of magnetic fluctuations made in the dayside polar cusp from the polar orbiting satellite OGO-4 on October 31, 1968. These high-latitude data show the enormous energy influx during this large magnetic storm, as well as the existence of strong field-aligned electron currents. Previous presentations of simultaneous field and particle data obtained on OGO-4 (Berko et al., 1975) have demonstrated the validity of inferring field-aligned current flow when certain characteristic features appear in the measurements.

The primary set of data to be presented were obtained by the OGO-4 Auroral Particles Experiment (Hoffman and Evans, 1968). This experiment measured electrons with near 0° pitch angles in narrow energy bands centered about 0.7, 2.3, 7.3, and 23.8 keV. In addition, measurements of 2.3 keV electrons with pitch angles of 30°, 60°, and 90° were made with three other detectors. Data from the Ogo-4 Search Coil Magnetometer Experiment (Frandsen et al., 1969) will also be presented. Search coil data from this stabilized satellite measures the total time derivative of the magnetic field encountered by the spacecraft (Berko et al., 1975), and can often be interpreted as signatures of field-aligned currents.

GEOMAGNETIC CONDITIONS

October 31 was one of the most geomagnetically disturbed days during 1968. Figure 1 shows the interplanetary magnetic field (IMF) conditions as measured by Explorer 34, the Kp and Dst indices, and the times of the four OGO-4 passes on this day (orbital information for these passes is presented in Table 1). The IMF was southward for the first eight hours of the day. Following this long period of southward IMF, the field turned northward shortly after 0800 U.T. Magnetometer tracings were available from several stations which are listed in Table 2, and a strong sudden commencement, which occurred at 0859 U.T., can be seen on the ground magnetograms (Figures 2 and 3) for this day (Akasofu and Kawasaki, 1970), and as a sudden increase of about 10γ in the IMF magnitude. A minimum in the Dst index of -206 is observed in the 15 to 16 hour UT interval, with Kp values of 8 in the two successive three-hour intervals beginning at 12 hours UT.

Examination of the H component magnetograms from six low latitude stations (Figure 2) exhibits the sudden commencement at 0859 in all but the San Juan trace. Low latitude activity continued at all six stations until about 1400 U.T., after which a main phase is clearly evident. The sudden commencement is also evident in the H component magnetograms from ten high latitude stations shown in Figure 3 (note the great difference in scale between Figures 2 and 3). The first of the OGO-4 passes considered, Pass 6803, occurred around 0715 UT, more than 90 minutes prior to the sudden commencement. Most of the high latitude magnetograms were relatively quiet during this pass. Note that high magnetic activity was recorded at high latitudes during each of the later passes, with bays at College and Meanook during Pass 6805. Rather large disturbances were evident in all the magnetometer traces during Pass 6809. Smaller bays were evident at Tixie Bay and Cape Wellen during Pass 6810, almost ten hours after the sudden commencement.

No extensive discussion of data obtained during Passes 6809 and 6810 will be presented in this paper, since it is highly questionable whether either of these passes encountered the polar cusps. As can be seen from Table 1, both of these passes were at about 7 hours MLT, where polar cusp morphology is not well established. Furthermore, the fluxes measured during these passes were most certainly affected by phenomena occuring on the nightside.

DAYSIDE PRECIPITATION AND FIELD-ALIGNED CURRENTS

Consider first data taken during Pass 6803, which occurred more than

90 minutes prior to the sudden commencement at a time of relative magnetic quiescence. Fluxes of 0.7 and 7.3 keV electrons for three minutes during this pass are plotted in Figure 4, as well as the energy input (integrated over pitch angle and energy from 0.7 to 23.8 keV). High, structured fluxes of low-energy, 0.7 keV electrons are seen beginning around 0715:35 and extending to about 0716:00. With the exception of a few isolated spikes, 7.3 keV fluxes were low during this high-latitude portion of the pass. A distinct, albeit weak "band" of 7.3 keV electrons (Hoffman, 1970, 1972) is evident from $\Lambda = 68^{\circ}$ to $\Lambda = 64^{\circ}$, during which time the low-energy flux was fairly low and smooth. The energy input was less than about 1 erg/cm^2-sec until about 0715:40, when the 0.7 keV precipitation first showed a great increase. Structure evident in the energy input curve closely follows the peaks in the 0.7 keV flux, demonstrating that the lowest energy electrons were the prime contributors to the energy input in the higher latitude portion of this pass ($\Lambda \geqslant 68^{\circ}$). This is not unexpected, since the fluxes observed from 0715:35 to 0716:00 are characteristic of polar cusp electron fluxes (Burch, 1972).

Search coil magnetometer data taken during portions of this pass (lower panel of Figure 4) show relatively small excursions in all three axes until about 0715:32 (segment "A"), when the 0.7 keV fluxes first began increasing. Moderately large magnetometer fluctuations lasted from 0715:35 to 0715:56, as illustrated in segment "B". The magnetometer output was rather quiet after 0715:56 (see segment "C"), as the 0.7 kev fluxes decreased, although the Z axis search coil remained saturated until almost 0715:57. Large fluctuations were observed in the search coil outputs throughout the region of peak 0.7 keV electron precipitation, with full-scale values observed at the time of the peak in the energy input around 0715:54. Field-aligned current values, calculated by integrating over pitch angle and energy (Berko et al., 1975) , reached 10^{-5} amp/m^2 at this time.

Electron fluxes, energy input, and search coil magnetometer responses obtained during three minutes of Pass 6805 are displayed in Figure 5. Fluxes of 0.7 keV electrons were extremely high from 1031:10 to 1032:00, with peak values exceeding any ever before seen in data from this experiment (see e.g., Hoffman and Evans, 1968; Hoffman and Berko, 1971; Burch, 1972; Berko, 1973). In fact, fluxes at all energies sampled, even 23.8 keV, were very high during this time interval, and it is probable, though impossible to confirm from the data, that the 0.7 keV detector may have saturated at this time. In addition, the 2.3- and 7.3-keV fluxes were quite structured at this time. This latter feature is typical of lower energy precipitation at high latitudes on the dayside (Hoffman and Berko, 1971; Burch, 1968).

Unlike the previous data example, no "band" region of 7.3 keV precipitation is evident anywhere during Pass 6805. Although this pass follows a fairly large substorm at Great Whale River by more than two hours, no other significant substorm activity occurred between 0400 and 0800 UT (Figure 3). Furthermore, no significant precipitation was observed at energies > 0.7 keV during this pass at latitudes below about 69°. Thus, the lack of a 7.3 keV band region during this pass is consistent with the interpretations of Hoffman (1970) and Hoffman and Burch (1973) that mantle aurora fluxes take about six hours to drift from midnight through the morning hours to noon. This also tends to indicate that the weak band region observed during Pass 6803 was a result of some earlier substorm activity (not shown in Figure 3), and that all the electrons present in that band had been precipitated-out prior to Pass 6805.

The high 7.3 keV fluxes during Pass 6805, coupled with the pronounced structure in the precipitation at energies greater than 1 keV, leads to an identification of this precipitation with the polar cusp, although typical polar cusp electron energies are in the hundreds of electron volts (Heikkila and Winningham, 1971; Frank, 1971). Although this precipitation appears at somewhat lower latitudes than usual polar cusp precipitation, Burch (1972) has shown that the polar cusp can move appreciably in latitude under the influence of strong southward IMF, and Russell et al. (1971) and Kivelson et al. (1973) have reported latitudinal motion of the polar cusp with changes in the direction of the IMF on November 1, 1968. The energy input for energies from 700 eV to 23.8 keV plotted in Figure 5 regularly exceeded 10 ergs/cm^2-sec from 1031:14 to 1032:00, reaching a peak of 91 ergs/cm^2-sec at 1031:35.9.

The output of the search coil magnetometer was fairly smooth prior to the onset of the intense electron precipitation (segment "A" in the lower panel of Figure 5). Throughout the region of intense electron fluxes, magnetometer fluctuations were extremely large, and often very rapid, as in segment "B". Current densities calculated from the fluxes measured in the bandpasses of the electron detectors were $> 10^{-6}$ amp/m^2 throughout this region. Peak current densities of 4×10^{-5} amp/m^2 were observed at 1031:35, in coincidence with the peak in the energy input. At 1032:00, the magnetometer outputs again became quiet (segment "C"), exactly in coincidence with the cut-off of the intense electron precipitation. A similar simultaneous feature in the data from these two experiments has previously been identified by Hoffman (1972) as signaling the existence of a field-aligned sheet current. While the search coil outputs are too complicated during the time of very high electron fluxes to identify any specific field-aligned current forms (as in Berko et al., 1975) , the high flux levels and rapid, large magnetometer fluctuations can certainly be largely attributed to field-aligned currents.

DISCUSSION

From the work of Arnoldy and Chan (1969), Lezniak and Winckler (1970), and DeForest and McIlwain (1971), among others, the concept of electron injection in the midnight region followed by drift in local time has become well established. Recently, Gustafsson (1973) and Hoffman and Burch (1973) have discussed drift times through the morning hours for low-energy electrons injected near midnight during substorms.

Using the results of Chen (1970), we can calculate the approximate time required for 7.3 keV electrons injected near midnight to drift through the morning hours to the local time of the satellite. Taking the convection electric field to be 0.39 mV/meter and assuming injection to be at 10 to 12 R_E, we compute the time required for 7.3 keV electrons to drift from midnight to 10 hours local time to be ~3hours. This is probably an upper limit, but higher dawn-dusk electric fields and smaller injection radii would only lower this drift time to about 2 hours (A. J. Chen, private communication, 1973).

The appearance of significant fluxes of 7.3 keV electrons during Pass 6805, less than one and one-half hours after the sudden commencement, and near 10.5 hours MLT thus cannot be accounted for by midnight injection and drift, since the first large substorms did not appear until $\sim$ 1000 UT at Great Whale River and Meanook and $\sim$ 1100 UT at College (Figure 3). Furthermore, those 7.3 keV electrons observed during this pass displayed the type of structure usually associated only with dayside, low-energy electron precipitation (Hoffman and Berko, 1971; Hoffman, 1972). Furthermore, there was no 7.3 keV precipitation in the usual latitude region of band-like precipitation. Thus, we conclude that these electrons were associated with the polar cusp.

As noted previously, very high field-aligned current densities were observed during Pass 6805. In fact, the nature of the electron precipitation during this pass was substantially different from that during the other OGO-4 passes on October 31, 1968. An indication of the nature of the precipitation during the passes under discussion is presented in Table 3, where the times chosen are representative of the peak precipitation periods in each pass. Clearly, the maximum energy input and total flux during Pass 6805 were very much greater than during Pass 6803. The increase in these quantities in Pass 6805 over those during Pass 6803 is striking, since both passes were at about the same local time, although Pass 6805 was after the sudden commencement.

The average energy tabulated for the two times in Table 3 is very meaningful. During Pass 6803, a quiet time pass, average energies ranging from 0.8 to 1.4 keV were observed, typical for such a daytime pass (cf Hoffman and Berko, 1971). An average energy > 1.5 keV was observed during several seconds around 1031:35, indicating a hardening of the spectrum over the pre-storm late morning pass.

CONCLUSIONS

During the period of the great magnetic storm of October 31, 1968, large fluxes of precipitating electrons were observed on the dayside by the low-altitude polar-orbiting satellite OGO-4. Fluxes of low-energy (0.7 keV) electrons were extremely high following the sudden commencement at 0859 UT, and were accompanied by very strong search coil magnetometer fluctuations, indicating the presence of strong field-aligned currents. Appreciably high fluxes of 7.3 keV electrons were also observed around 1031 UT. These higher energy electron fluxes were quite structured, and appeared much sooner than can be explained by midnight injection and drift through the morning hours to 10.5 hours magnetic local time; additionally, no "band" of 7.3 keV electrons was seen at this time. Thus, we conclude that large fluxes of electrons with energies at least as high as 7.3 keV penetrated the dayside cusp region during the magnetic storm of October 31, 1968, and that the cusp itself was appreciably lowered in latitude as a consequence of the southward, strong IMF.

ACKNOWLEDGEMENTS

I am grateful to R. A. Hoffman for the use of his OGO-4 data and for beneficial discussions and criticisms. Additional discussions with J. L. Burch proved very helpful. R. K. Burton and R. E. Holzer graciously provided the OGO-4 Search Coil Magnetometer data used in this study. Explorer 34 Magnetometer data of N. F. Ness were obtained from the NSSDC at Goddard Space Flight Center.

Pass	Times(U.T.)	Magnetic Local Times(hours)	Invariant Latitude Range(degrees)
6803	0715-0718	11.04-10.43	71.82-61.65
6805	1030-1033	11.01-10.21	76.28-66.34
6809	1659-1701	06.27-07.14	73.51-67.85
6810	1836-1838	06.42-07.13	69.51-63.46

TABLE 1

GROUND STATIONS

NAME	ABBREVIATION	INVARIANT LATITUDE (DEG.)
Abisko	AB	65.2
Cape Wellen	CW	62.6
Chelyuskin	CH	71.1
College	CO	64.6
Dixon Island	DI	67.7
Great Whale River	GW	67.7
Honolulu	HO	20.3
Kakioka	KA	26.5
Leirvogur	LE	66.4
M' Bour	MB	9.7
Meanook	ME	62.4
Nurmijarvi	NU	57.0
San Juan	SJ	33.1
Tangerang	TG	-0.5
Tashkent	TS	34.5
Tixie Bay	TI	65.1

TABLE 2

PASS	U.T.	AVERAGE ENERGY* (KEV)	ENERGY INPUT* (ERGS/CM^2-SEC)	TOTAL FLUX* (ELECTRONS/CM^2-SEC)
6803	0715:53.8-0715:54.3	1.24	8.71	4.25×10^9
6805	1031:35.5-1031:36.0	1.75	39.06	1.10×10^{10}

* From 0.7 to 23.8 keV

TABLE 3

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FIGURE CAPTIONS

Figure 1. Top: Explorer 34 measurements of IMF latitude (GSM coordinates) and field strength on October 31, 1968; Bottom: Dst index (Sugiura and Poros, 1971) and Kp index for the same day. Times of the Ogo-4 passes on October 31, 1968 are indicated by vertical lines.

Figure 2. Magnetometer traces from six low latitude stations on October 31, 1968 (from Akasofu and Kawasaki, 1970). See Table 2 for stations.

Figure 3. Magnetometer traces from ten high latitude stations on October 31,1968 (adapted from Akasofu and Kawasaki, 1970). Local midnight at each station is designated by the letter M. See Table 2 for station identifications.

Figure 4. Top: Fluxes of 0.7 and 7.3 keV electrons measured during Pass 6803; Center: Energy input from 0.7 to 23.8 keV for the same pass, plotted to the same time scale; Bottom: Three brief segments of search coil magnetometer outputs during this pass. The times of the segments A, B, and C are also noted in the top panel.

Figure 5. Similar to Figure 4 for data obtained during Pass 6805.

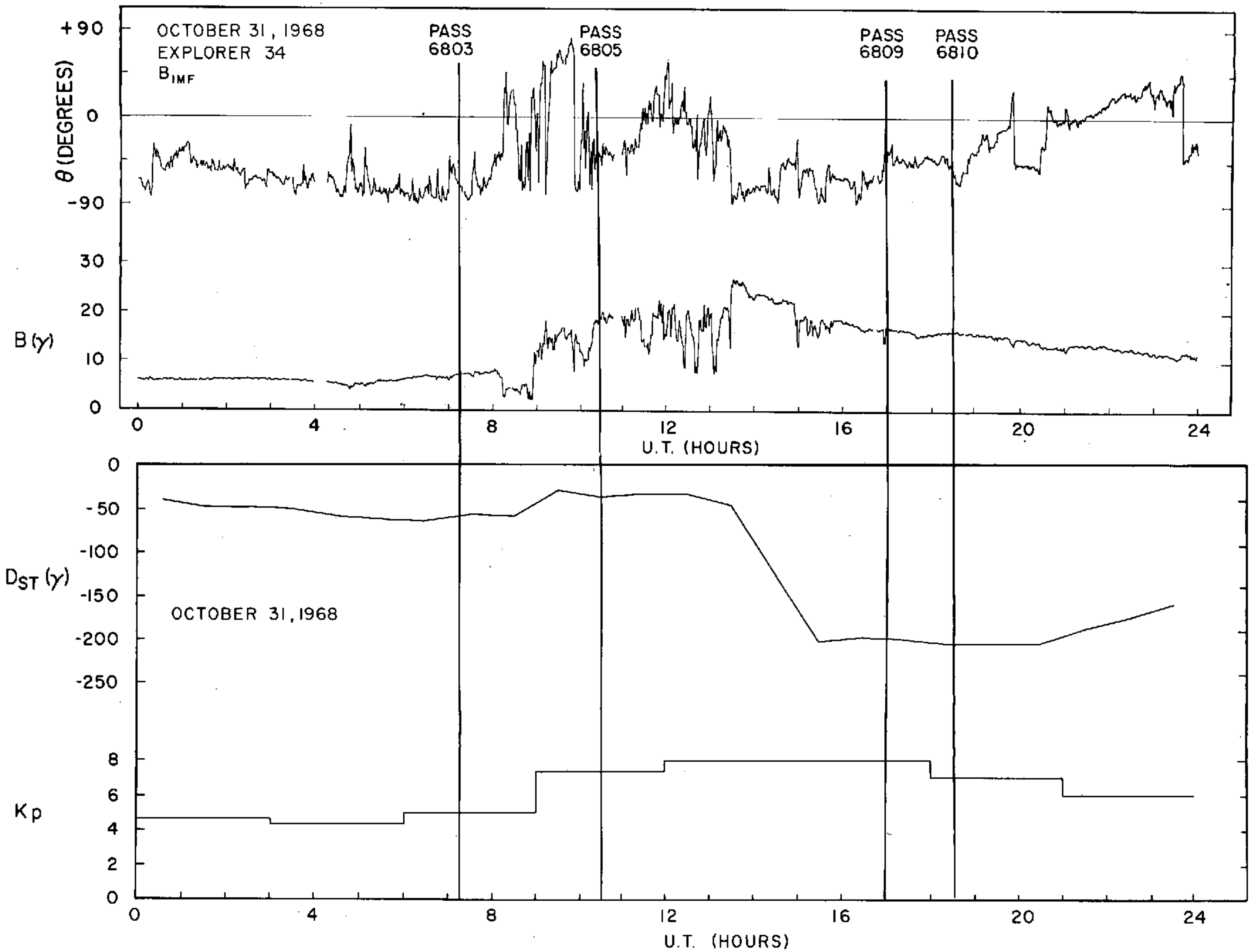
OCTOBER 31, 1968
EXPLORER 34
B_{IMF}
PASS 6803
PASS 6805
PASS 6809
PASS 6810
θ (DEGREES)
+90
0
-90
B (γ)
30
20
10
0
0
4
8
12
16
20
24
U.T. (HOURS)
D_{ST} (γ)
0
-50
-100
-150
-200
-250
OCTOBER 31, 1968
Kp
8
6
4
2
0
0
4
8
12
16
20
24
U.T. (HOURS)

Figure 1

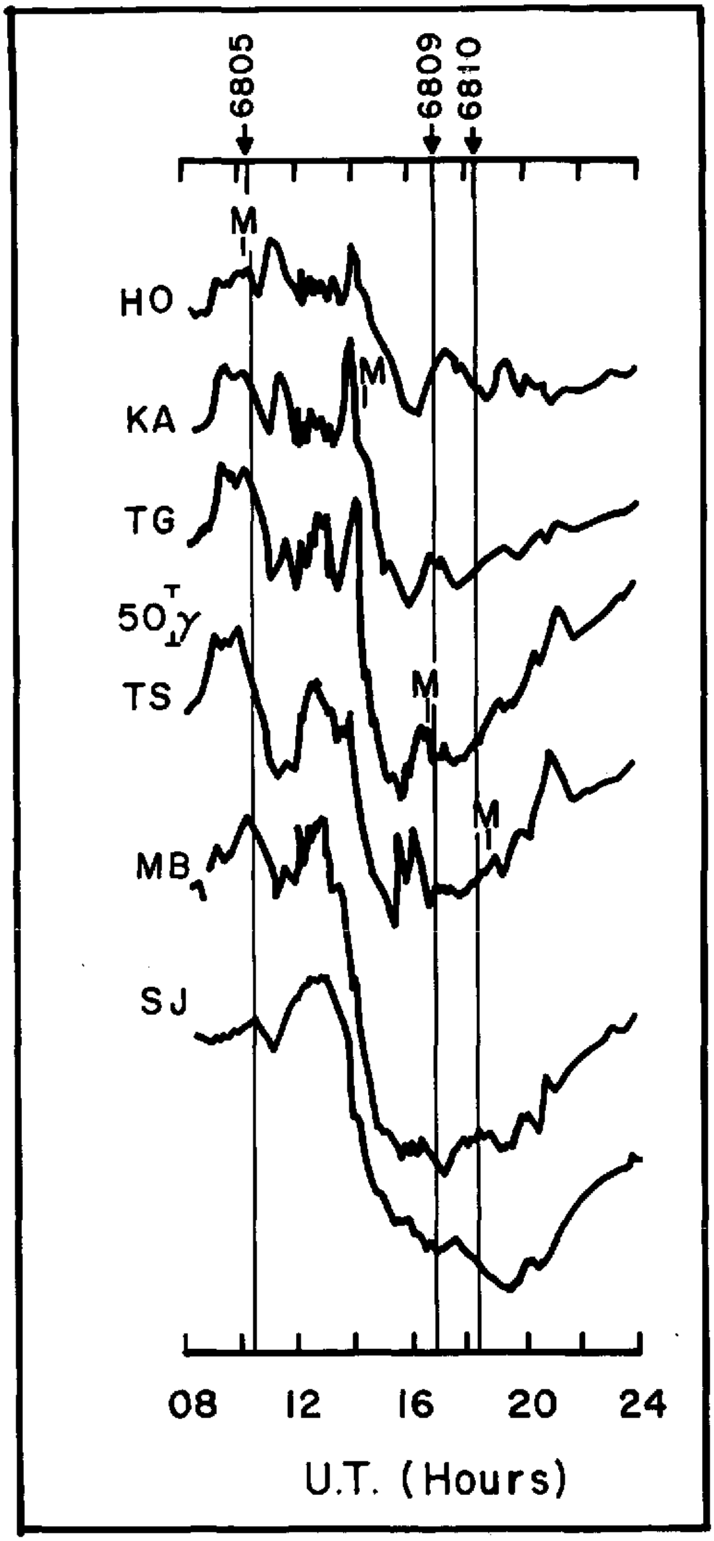

Figure 2

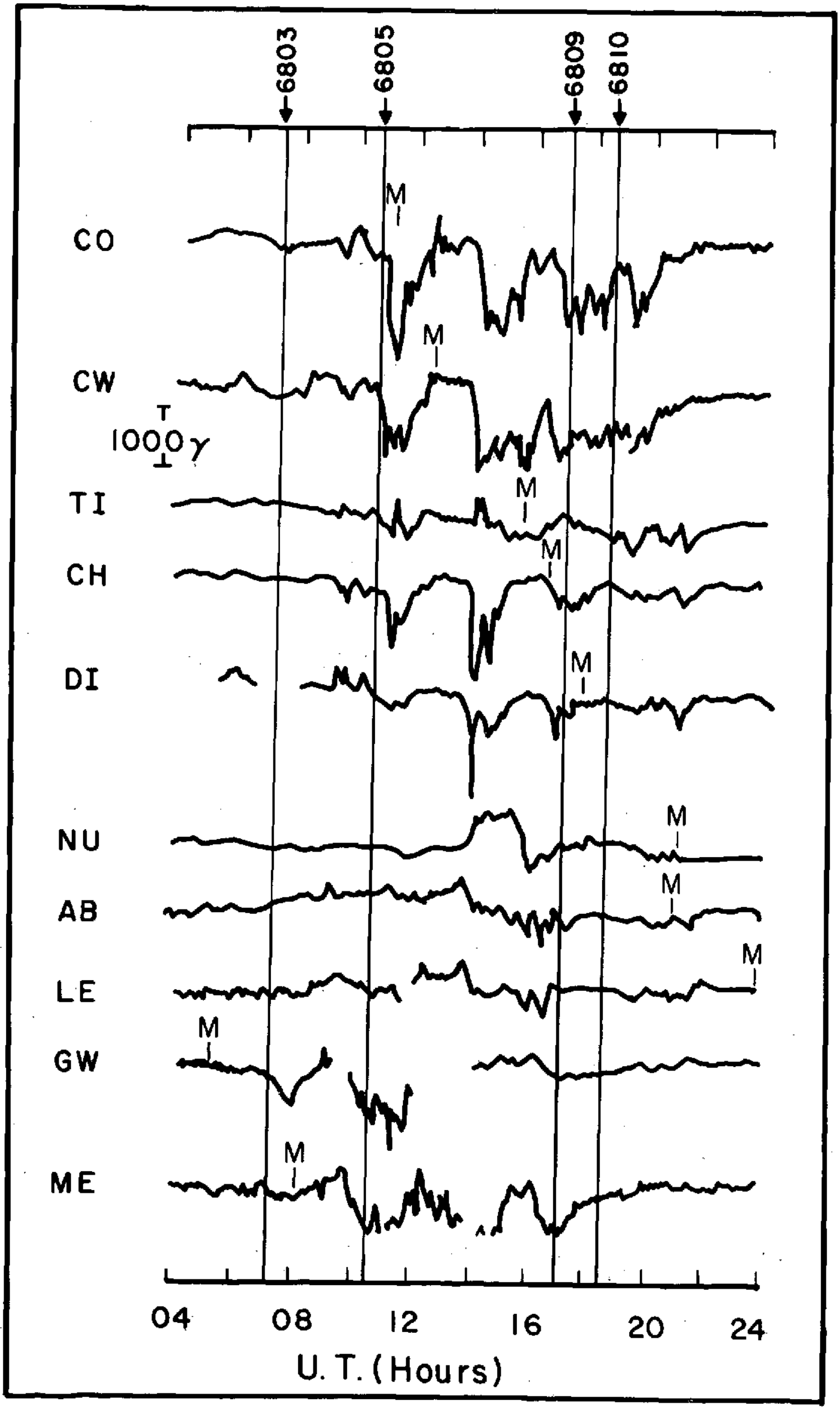
6803
6805
6809
6810
CO
CW
1000γ
TI
CH
DI
NU
AB
LE
GW
ME
M
04
08
12
16
20
24
U. T. (Hours)

Figure 3

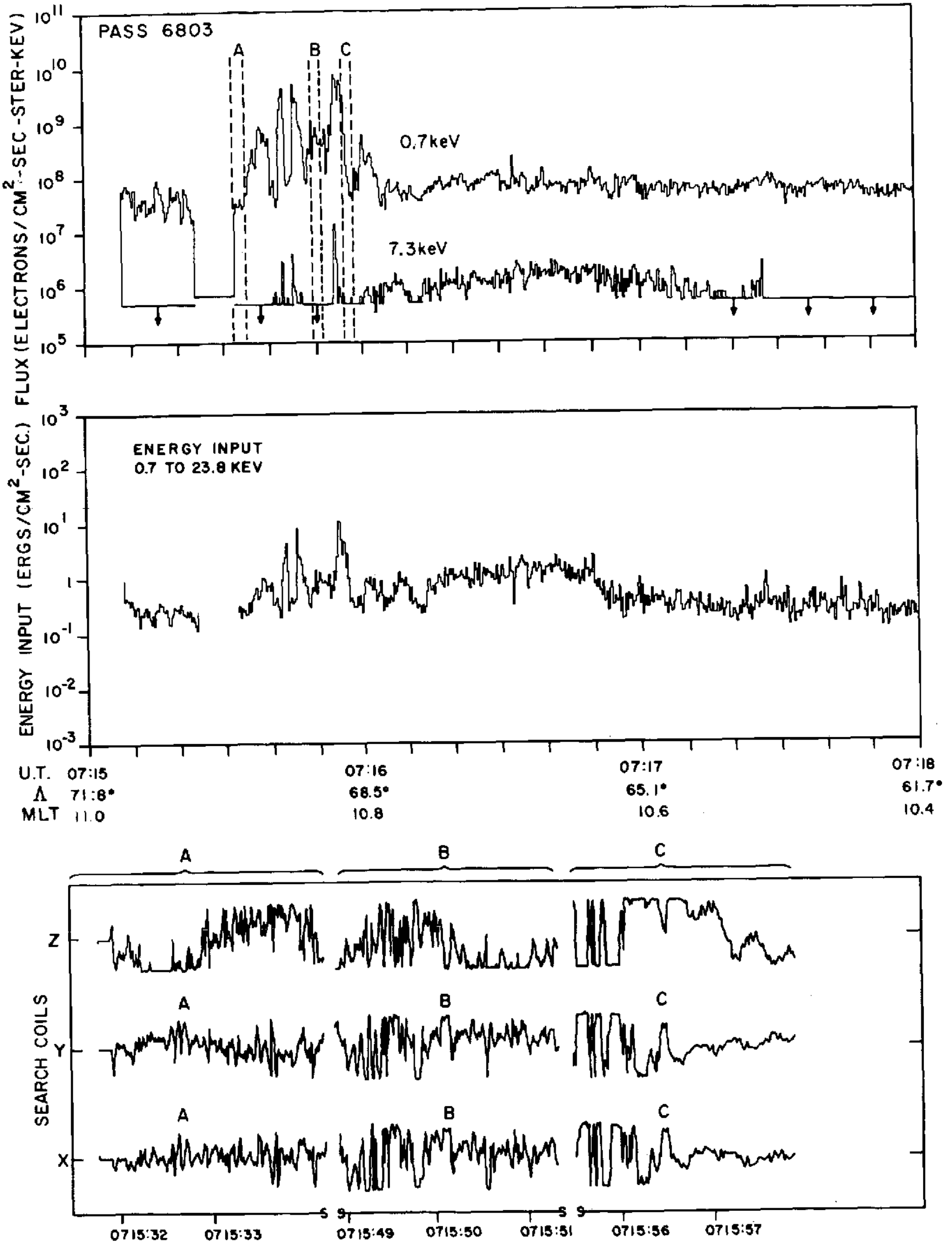
PASS 6803
A
B
C
0.7keV
7.3keV
FLUX (ELECTRONS/CM^2-SEC-STER-KEV)
10^{11}
10^{10}
10^9
10^8
10^7
10^6
10^5
ENERGY INPUT
0.7 TO 23.8 KEV
ENERGY INPUT (ERGS/CM^2-SEC.)
10^3
10^2
10^1
1
10^{-1}
10^{-2}
10^{-3}
U.T. 07:15
Λ 71.8°
MLT 11.0
07:16
68.5°
10.8
07:17
65.1°
10.6
07:18
61.7°
10.4
A
B
C
SEARCH COILS
Z
Y
X
A
B
C
A
B
C
0715:32
0715:33
0715:49
0715:50
0715:51
0715:56
0715:57

Figure 4

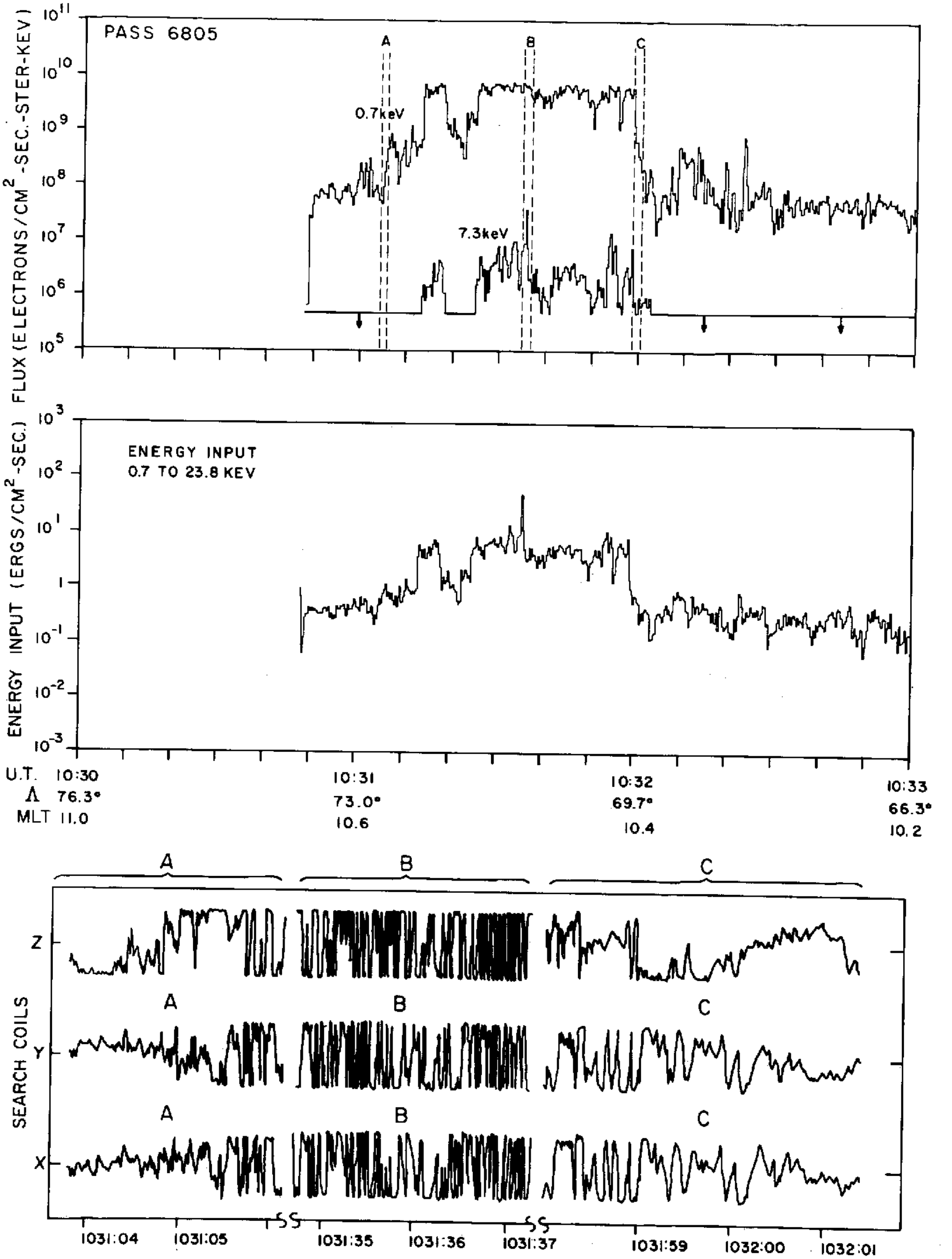
PASS 6805
A
B
C
0.7keV
7.3keV
FLUX (ELECTRONS/CM^2-SEC.-STER-KEV)
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
ENERGY INPUT
0.7 TO 23.8 KEV
ENERGY INPUT (ERGS/CM^2-SEC.)
10^{3}
10^{2}
10^{1}
1
10^{-1}
10^{-2}
10^{-3}
U.T. 10:30
Λ 76.3°
MLT 11.0
10:31
73.0°
10.6
10:32
69.7°
10.4
10:33
66.3°
10.2
A
B
C
SEARCH COILS
Z
Y
X
1031:04
1031:05
1031:35
1031:36
1031:37
1031:59
1032:00
1032:01

Figure 5