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The Cusp as a Source of Magnetospheric Energetic Particles, Currents, and Electric Fields: A New Paradigm

Theodore A. Fritz
Center for Space Physics
Boston University
Boston, MA 02215

INTRODUCTION

The source, energy distribution, and radial structure of energetic ions and electrons in the radiation belts are well explained by the process of radial diffusion. Radial transport of charged particles by diffusion processes driven by fluctuations in the geomagnetic field or from electric field variations from a reservoir of particles in the outer magnetosphere has been studied by many authors (e.g., Tverskoy, 1965; Cornwall, 1971; Spjeldvik and Fritz, 1978). Such transport occurs while conserving the first and second adiabatic invariants of the particles. For ions these radial diffusive transport codes are coupled with loss processes such as charge exchange and coulomb collisions. Published work usually begins with a measured energy spectrum of the ions and/or electrons in the range of L>7 as the input source of the subsequent radial diffusion (Tverskoy, 1965; Spjeldvik and Fritz, 1978). The source of such energetic particles in the plasma sheet and outer nightside magnetosphere has remained undetermined while measurements have shown them to be continuously present in these regions and responsive to geomagnetic activity. In this paper observations from the Polar satellite will be presented and discussed which offer a new source associated with the high altitude polar cusps for energetic particles, which compose the source spectrum of the outer magnetosphere. These observations conclusively establish the existence of the source in the cusp to accelerate ions to energies of 100s and 1000s of keV with phase space densities equivalent to those of the trapped fluxes in the geostationary orbit region of the nightside magnetosphere. It will also be shown by particle trajectory calculations in a realistic model of the geomagnetic field that the energetic particles from the cusp can readily and efficiently drift to the nightside equatorial magnetosphere as close as six earth radii routinely.

The Polar satellite has observed energetic particles to be consistently and continuously present in the high latitude, high altitude frontside magnetosphere where they cannot be stably trapped. The source of these particles remains controversial and there are three sources under active consideration as the supplier of these particles.

Source 1 has the particles produced upstream of the magnetosphere at the location of the bow shock when a "quasi-parallel" condition exists between the bow shock normal and the interplanetary magnetic field. Once energized in such a configuration the particles then move along their trajectories guided by the magnetic field and arrive in the dayside cusp.

Source 2 has the particles being accelerated insitu by an unknown mechanism in association with deep diamagnetic cavities that have been observed to be coexistent with enhanced fluxes of the energetic particles and are associated with the cusp. Once the particles are energized they are subject to gradient and curvature effect in the geomagnetic field and will drift away from the cusp location.

Source 3 has the particles being energized by processes in the geomagnetic tail associated with substorms and drifting to the dayside where over a narrow range of nightside radial distances they will move into the cusp when drifting to the dayside due to the fact that the minimum along a magnetic field line is no longer at the equator but bifurcates and moves into each of the high altitude cusps.

All three of these mechanisms are active to some degree and probably do generate some energetic particles that show up in the cusp. Rather than argue against the role of sources 1 and 3 which due to geometry alone and the time variable nature of their acceleration process can not produce energetic particles on a continuous basis, this paper will concentrate on source 2. This paper will review the evidence that shocked solar wind ions enter the high altitude, high latitude cusp from the magnetosheath and are energized to 100s and 1000s of keV. These magnetosheath ions apparently produce individual diamagnetic cavities in which the magnetic field is observed to decrease from ~100 nT to values approaching zero with a great deal of magnetic field turbulence associated with the cavity [Chen et al., 1997, 1998; Fritz, et al., 1999a]. The power contained in the fluctuations is correlated to the intensity of the MeV ions observed [Chen and Fritz, 1998]. The mechanism associated with this process seems to be continually active but individual cavities are impulsive in nature with an event having a lifetime of a few 10s of minutes. These facts appear to be well-established by the charge-state, composition, and energy spectral measurements that have been made with Polar and in comparison to simultaneous Geotail measurements in the region upstream and downstream of the bow shock [Chen and Fritz, 1998; Fritz and Chen, 1999b].

This cusp mechanism is capable of producing an energetic particle layer that straddles the magnetopause along the flanks of the magnetosphere and of filling the pseudo-trapping region on the dayside of the magnetosphere with energetic particles where they are often observed to exhibit striking energy dispersion signatures [Karra and Fritz, 1999; Fritz, et al., 2000]. Many authors have reported observations of these energetic particles in the magnetosheath near the magnetopause [Meng and Anderson, 1970; Sarris, Krimigis, and Armstrong, 1976; Baker and Stone, 1978; Williams et al., 1985]. They can enter the magnetosphere as a result of gradients in the magnetic field and the resultant drifts they cause; ions entering along the dawn flank drifting to the west and electrons entering along the dusk flank drifting east will carry a current. They provide a rapid coupling of the variations in the subsolar region to the substorm region of the tail magnetosphere. They will also be the source population for the radial diffusion, which does a very good job of explaining the radial variation of radiation belt fluxes as a function of energy. This result has the potential to be a new paradigm for the way we view the source of particles and flow of information in the magnetosphere.

THE CONCEPT OF PSEUDO TRAPPING

The geomagnetic field is compressed on the dayside by the pressure of the impacting solar wind and is drawn out on the nightside into a long tail. This non-dipole nature of the field leads to the existence of pseudo trapping regions and drift shell splitting effects in the drift motion of the energetic particles. Figure 1 is reproduced from Roderer [1970] and demonstrates three regions where the motion of energetic charged particles has different characteristics. In the inner magnetosphere the particles are stably trapped and can execute the three types of motion: gyration around the magnetic field, bounce along the field line, and drift around the Earth. In the region of open magnetic field lines particles will most likely be lost from the system out the open end of the field line very quickly. In the intermediate pseudo-trapping region, particles can execute bounce and gyro motion but will be lost to the system before completing a drift around the Earth. When particles are observed in either the dayside or the nightside pseudo trapping region they have entered the system on a time scale of half their drift period or less and must be replenished on the same time scale. For energetic particles in the 100s of keV these periods are of the order of tens of minutes. The most striking finding by the Polar satellite launched into a 1.8 R_E by 9 R_E [Earth radii] polar orbit in February 1996 is that the pseudo trapping region on the dayside of the magnetosphere is continually filled with energetic particles with energies of many 100s and even 1000s of keV. Figure 2 is an example of a Polar satellite pass near the noon-midnight meridian and shows an energy spectrogram of ions as the satellite crosses through the radiation belt inbound on the nightside, over the southern polar region, then northward through the radiation belts on the dayside and into the pseudo trapping region noted in Figure 1. The Solar Magnetospheric coordinate projection of the Polar orbit is shown at the bottom of the figure. Note the continuous presence of energetic ions to times beyond 1400 UT with a small spike at 1600 UT. On almost every pass through this region time-energy dispersion features are observed as seen in two cases in Figure 2 from 1030 UT to 1200 UT

THE TIME ENERGY DISPERSION [TED] EVENT

Karra and Fritz [1999] have studied these time energy dispersion [TED] features and have found that over 800 such TED events were observed in the period from March 1996 to May 1997. The features always begin with the arrival first of the most energetic particles followed by lower energy regardless of the direction Polar is moving. The maximum energy often exceeds 1 MeV. The difference in time between the observation of the maximum energy and the instrument threshold energy is variable and covers the range from three minutes [threshold for classification as a TED] and three hours with a nominal event lasting 30 minutes to 50 minutes. Figure 3 shows the distribution of these events in Magnetic Local Time and shows that they are observed mainly in the dayside pseudo trapping region show in Figure 1. When the charge composition of these features is examined they are seen in both the H^+ and He^{++} but very significantly on about 20% of these events Karra and Fritz [2000] have reported that O^+ ions have been observed to be present and to demonstrate the same rate of change of their energy as that observed in H^+ and He^{++}. Since the O^+ ions must originate in the Earth's ionosphere it appears that the source of these TED features must be internal to the magnetosphere. The differential drift rate due gradient and curvature drift of substorm injected fluxes is often used to explain such features but the large variation observed in the dE/dt would argue for a different source. What is the source of the TED feature?

THE CUSP ENERGETIC PARTICLE [CEP] EVENT

Chen et al. (1997, 1998) and Chen and Fritz (1998) have shown that energetic particles of recent solar wind/magnetosheath origin appear to be energized insitu in the high altitude polar cusp. An example of such a cusp energetic particle or CEP event is shown in Figure 4, which occurred on August 27, 1996. The data presented are of the measured intensity of helium and oxygen ions with energy between 1 keV and 1.2 MeV, and it is seen that fluxes of the very energetic ions are found in association with the depressed magnetic field that is an indication of the cusp region of the dayside high altitude magnetosphere. There are enhanced fluxes associated with those ions of solar wind origin (He^{++} and $O^{>+2}$). Each of these CEP events lasts up to 40 or 50 minutes and the period during which they were observed by Polar in this case was over two hours from 8.5 UT to 10.6 UT. In each occurrence of the CEP fluxes the magnetic field becomes depressed and extremely variable. There were no equivalent intensities of such energetic ions present upstream of the magnetopause in the interplanetary medium (Chen and Fritz, 1998; Fritz and Chen, 1999 a,b). Chen and Fritz (1998) also demonstrated that the intensity of the very energetic helium ions associated with CEP events is correlated with the intensity of the magnetic turbulence occurring at the same location and time. This argues very strongly for the local nature of the source of the acceleration of these CEP ion fluxes. The depressed magnetic field indicative of a diamagnetic cavity must be integral to the CEP energization process. During the first eight months of Polar operations about 70 CEP events were observed. These CEP events are found only near local noon when Polar was near its apogee (Chen et. al., 1998).

A larger statistical study of the occurrence of CEP events was performed [Fritz, et al., 1999b] by identifying those times when Polar was in the cusp in an independent manner using the response of the Hydra instrument [Scudder, et al., 1995] on board Polar and requiring the measured ion intensity to exceed 5×10^6 particles$(cm^2\text{-}s\text{-}sr\text{-}\Delta E/E)^{-1}$ in the energy range from 1 to 10 keV. This corresponded to the color red on the energy spectrogram format of the Hydra Key Parameter summary plots. 328 cusp crossings were identified from launch through the end of 1997 in this manner. For each such crossing two additional points were investigated. It was determined (a) if the magnetic field was depressed by more than 5 nT from its baseline value of around 90 nT using data from the Magnetic Field Experiment [Russell, et al., 1995] and (b) whether measurable fluxes of energetic alpha particles with energy above 25 keV were present. For twenty-eight of the cusp crossings either the magnetic field data or the energetic particle data were not available. Therefore 300 cusp crossings had both data sets available. On 289 crossings there was a magnetic field disturbance and on 289 crossings energetic particles were present. Taking a CEP event to be a cusp crossing with both (a) and (b) present, 279 or 93 % of the crossings satisfied the criteria. Therefore we can conclude that the occurrence of CEP events are a common feature of the dayside cusp. The distribution in MLT of the 279 events is presented in Figure 5.

When simultaneous upstream solar wind and interplanetary magnetic field parameters are investigated there is essentially no dependence on IMF B_Y or IMF B_Z as shown in Figure 6. This lack of dependence on the IMF orientation can be understood in a very revealing comparison of the time variation of the charge-state of Fe ions in the upstream solar wind at the ACE spacecraft located at the L1 point and at Polar with the CAMMICE MICS sensor in the pseudo-trapping region of the magnetosphere [Perry, et al., 2000] during the period of May 1-3,1998. In the lower two panels of Figure 7 the measurement of charge states by the ACE/SWICS (solid line) and the Polar/CAMMICE (+) are displayed where the time associated with the ACE data have been shifted to the subsolar magnetopause using the measured solar wind velocity. Note that in the right hand section of the panel labeled "near cusp" the two sets of charge-state determinations agree remarkably well with one another. The top panel shows the energy spectrogram of all ions recorded during parts of four passes by Polar during this period. The regions of red are when Polar is passing through the pseudo trapping region on the dayside shown in Figure 1. This can be determined from the orbital properties of Polar indicated in the second panel. These regions are then labeled as "near cusp". If we use the Fe charge-state as a tag for an element of solar wind plasma we note in the energy spectrogram [top panel] of Polar that the bulk of these ions were energized to 100s of keV while preserving the variation of the Fe charge state. Further during this period there was a change in the orientation of the interplanetary magnetic field which demonstrated a possible role of the IMF orientation in the CEP process. As indicated in the top of the fourth panel the IMF had a northward component but switched to a southward direction around 03 UT on May 2. It is remarkable that the charge-state determinations track well when B_Z is negative but still appear to track with a delay of a couple of hours.

Therefore it appears that this process can occur rapidly for southward B_Z but be delayed if B_Z is northward [but very importantly still occur]. In this manner B_Z might be viewed as a gate that opens ready access for the shocked solar wind to the cusp when southward and can delay but not stop assess when northward. Figure 7 also demonstrates that the energization process associated with the cusp is very rapid. As these diamagnetic cavities collapse the energetic particles will leak out with the most energetic particles escaping first followed by lower energy particles giving rise to the TED signature noted above. What happens to the energized particles after they are accelerated?

PARTICLE TRAJECTORY MODELING

An adaptive fourth order Runge Kutta method has been developed at Boston University [Glasel et al., 1999] which traces the motion of energetic ions using their Lorentz motion in a realistic model of the geomagnetic field. In Figure 8 we show the motion of a 200 keV proton starting at the location of Polar in the dayside cusp. These ions are found to execute drift motion that has been described previously by Shabansky [1972] and is related to the fact that the magnetic field minimum along a field line on the dayside of the magnetosphere is bifurcated with minima at the cusps rather than at the equatorial plane due to the compressed subsolar magnetopause. These ions will drift westward at high altitude and move to the equator as they begin their drift from dawn across the nightside. Note that this particle completes a full orbit in the magnetosphere in about 30 minutes. Delcourt and Sauvard [1999] have recently shown that such an orbit exists only for a narrow range of radial distances when the particles are started from the nightside equatorial plane. At closer radial distances the particles execute normal drift motion bouncing in latitude across the equatorial plane at all local times. At greater radial distances the drift motion will cause the particle to penetrate the magnetopause and be lost to the system. The converse of starting the particles in the cusp in not true. Such particles will have almost complete access to the nightside equatorial magnetosphere and geomagnetic tail beyond six earth radii. This means that the high altitude cusps are directly coupled by the efficient process of ion gradient drift to the nightside equatorial plasma sheet. As these particles drift to distances less than 6 earth radii in the night side equatorial plane, their variations in time probably control the dynamics of the magnetosphere in the range $6 < L < 13$ and these particles are probably the source of the quiet and storm time ring current and will provide the plasma sheet energetic particle population. They provide rapid coupling of the variations in the subsolar region to the substorm region of the tail magnetosphere. They will also be the source population for the radial diffusion, which does a very good job of explaining the radial variation of radiation belt fluxes as a function of energy. Such particles find themselves in the pseudo-trapping region on the nightside shown in Figure 1 and will have a lifetime to loss from the system that is a fraction of their drift period. Is there evidence for such a particle loss associated with drift into the magnetopause?

THE BUTTERFLY PITCH ANGLE DISTRIBUTION

Studies involving measurements made by the ISEE satellites near the equatorial plane [$B/B_0 < 1.3$] on the night side of the magnetosphere have revealed the existence of butterfly pitch angle distributions in both the energetic electrons and ions. A butterfly-type distribution is associated with a minimum in the particle flux at pitch angles of 90^0. An example is shown in Figure 9 for electrons with energy from 189 keV to 1.2 MeV. The radial profiles of the intensity of electrons and ions for pitch angles of 90^0 and 30^0 recorded during the ISEE-1 inbound orbit from which the data of Figure 9 were extracted are shown in Figures 10 and 11 [Bhattacharjya and Fritz, 1998; Fritz et al., 2000). The shaded region indicates the region in which the butterfly distributions were observed. Note in Figure 10 that the electron profiles all show the presence of such butterfly distributions for the energy range covered [22.5 keV to 1.2 MeV] with the maximum difference in the flux of the 90^0 and 30^0 pitch angles increasing with increasing energy. West, Buck, and Walton (1973) first observed these butterfly distributions in the electron pitch angle distributions in measurements made by the OGO-5 satellite. The distributions were observed all of the time when the satellite was close to the magnetic equator and beyond the geostationary orbit on the night side of the magnetosphere. Those authors explained these distributions as being produced by the azimuthal drift of electrons conserving their first two adiabatic invariants. The drift trajectories for these two different pitch angle particles are shown in Figure 12 drawn from Lyons and Williams (1984). Note that the small pitch angle particles will drift around the Earth at all radial distances associated with where the butterfly distributions were observed in Figures 10 and 11. This is not the case for the particles, which mirror at the equator. They will follow drift paths which take them to the magnetopause over the region beyond 6 earth radii if they are near the midnight meridian.

Both electrons and ions will be affected in this manner, electrons drifting into the dawn magnetopause and ions drifting into dusk magnetopause. For such equatorially mirroring particles this will be done in a manner independent of energy. Why then does Figure 10 and 11 show an energy dependence to the fluxes of both electrons and ions? In fact the lowest energy ion channel [24 keV to 44.5 keV] actually shows an enhancement of the intensity of such ions in the region where other channels are demonstrating butterfly distributions. The most straightforward explanation of these observations is that the region just outside the magnetopause can act as a source of these ions and possibly electrons. These distributions are indicative of a source of particles along the dusk and dawn flanks, which is modulated at their origin, which we believe to be in the dayside cusp. When such a source is not supplying particles the butterfly distributions appear, as the particles are lost due to their drift into the magnetopause and out of the magnetosphere. The electrons exhibit butterfly distributions around 80% of the time that they can be observed in the range $6 < L < 10$ but are isotropic at larger L. The ions on the other hand demonstrate such butterfly distributions only about one third of the time [Bhattacharjya, et al., 2000].

IMPLICATIONS FOR A DAWN TO DUSK ELECTRIC FIELD

The location of the evolution or transition of the butterfly distribution as a function of radial distance from a trapped distribution at L-values around 6 and to an isotropic distribution around L of 9 has a reverse dependence on energy. At the inner edge these dependencies are inconsistent with the existence of a steady state dawn to dusk electric field acting on these drifting particles. In order to demonstrate this we present in the first columns of Table 1 the passband characteristics of the ISEE-1 energetic particle experiment [Williams, et al., 1978] for the energy channels shown in Figures 9, 10, and 11. In column 4 the average energy associated with an energy spectrum whose intensity decreases with increasing energy with each of the eight electron and eight ion passbands is presented. In the next column the drift time for particles of those average energies at six earth radii in a dipole field is presented. In the absence of sources the transition from the trapped, peaked at 90-degree pitch angle distributions to the butterfly distribution should be determined by the position of the subsolar magnetopause. Any dawn to dusk electric field present across the inner magnetosphere will then act on these drifting particles from the subsolar position until they arrive at the point of observation around 0100 MLT which we take to be about one half of their drift period. Let us assume that the electric field is 100 kV, which causes a subsequent ExB drift of 2.6 km/sec that will be toward the sun [GSM X]. When applied to each of the energy passbands for their respective half drift period a displacement in the GSM X direction given in the eighth column with respect to that of the largest energy passband should be observed. The actual location of the transition is given in column nine and the comparable measured displacement is given in the final column of the table. It is clear that the actual displacement and their dependence on energy are opposite to that which would be found if such a steady state electric field were to exist across the inner equatorial magnetosphere. This result is interpreted to mean that such an electric field is not present.

The transition of the butterfly distributions to isotropic distributions at larger distances does have characteristics associated with the existence of dawn to dusk electric field that will displace the inner edge of these distributions earthward. It is suggested here that the existence of a cross tail electric field is probably not a product of reconnection/convection but is possibly due to a charge separation that is generated by the energetic ions drifting westward from the cusp to the nightside and the energetic electrons drifting eastward. Such a charge separation electric field would tend to maximize near midnight in a manner similar to that determine empirically by McIlwain [1974]. This result has the potential to be a new paradigm for the way we view the dynamics of the magnetosphere.

TIME VARIATIONS AND THE RING CURRENT

Time variations in magnetospheric particle fluxes are mostly associated with geomagnetic activity. For many years the concept of the injection of particles into the inner magnetosphere near midnight as a result of substorms has formed the basis of that area of study. The appearance of particles along and tailward of an injection boundary introduced by Mauk and McIlwain [1974] and extended by Konradi, et al. [1976] and Mauk and Meng [1983] has proved difficult to reconcile with injection near midnight. With a source in the cusp supplying particle along a contour of constant B magnitude, the injection boundary has a very straightforward explanation. Particles will appear along and tailward of such a constant B contour which has its closest approach to the Earth at midnight.

The ring current forms in the inner magnetosphere as a result of a significant change in the properties of the upstream interplanetary medium and produces a depression in the measured surface magnetic field of up to 300 nT or more. The source of the ring current remains undetermined but it occurs in the range of $3.5 < L < 7$ and has an average energy of 85 to 100 keV. The source of the ring current due to the cusp mechanism discussed above provides straightforward explanations of some unexplained properties of the ring current. With a source in the cusps the radial location of the ring current will be determined by the amount of compression that occurs at the subsolar point. As the magnitude of B at the subsolar magnetopause increases, the energetic particles from the cusp will have access to equivalent values of B and therefore will move to closer distances on the nightside magnetosphere than those given in Figure 12a. The initial phase of the ring current is asymmetric and this asymmetry can last for hours to tens of hours. The nominal azimuthal drift period of a 100 keV ion is less than an hour. The cusp source must continually supply particles that then drift across the nightside magnetosphere and are lost out of the opposite magnetopause. The asymmetric phase of the ring current will continue until enough ions are diffused somewhat in pitch angle to the point that they can execute their full drift motion. This can be thought of as particles executing drift described by Figure 12a until enough ions are scattered to pitch angles whose drift motion is described by Figure 12b.

CONCLUSIONS

Evidence and arguments have been presented for the existence of a mechanism in the dayside high altitude cusp that energizes a portion of an incident shocked solar wind population to 100s and 1000s of keV. This mechanism produces the spectral function known as a kappa distribution that has a Maxwellian form at the lower energies associated with the shocked solar wind and a power law tail. This spectral distribution is observed throughout the outer equatorial magnetosphere and plasma sheet. The possible implications of the existence of such a source have also been discussed. This source leads to a natural explanation for the concept of the injection boundary, the location of the ring current, and the asymmetric phase of the ring currentand the source of energetic particles throughout the plasma sheet.

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Figure Captions.

Figure 1. Concept of pseudo-trapping in the Earth's magnetosphere [from Roderer, 1970].

Figure 2. Energy spectrogram on March 25, 1999 recorded by Polar IPS sensor.

Figure 3. Occurrence of Time Energy Dispersion [TED] features as a function of Magnetic Local Time for 802 events observed by Polar from March 1996 to May 1997 [Karra and Fritz, 1999].

Figure 4. The Cusp Energetic Particle (CEP) event of August 27, 1996

Figure 5. The distribution of 279 CEP events versus MLT [Fritz, et al., 1999b].

Figure 6. The distribution of (a) IMF B_Y vs MLT and (b) IMF B_Z vs MLT for the 279 CEP events

Figure 7. The comparison of the ACE and Polar spacecraft measurements of the charge-state of Fe ions at the L1 upstream location and in the dayside magnetosphere [Perry, et al., 2000]

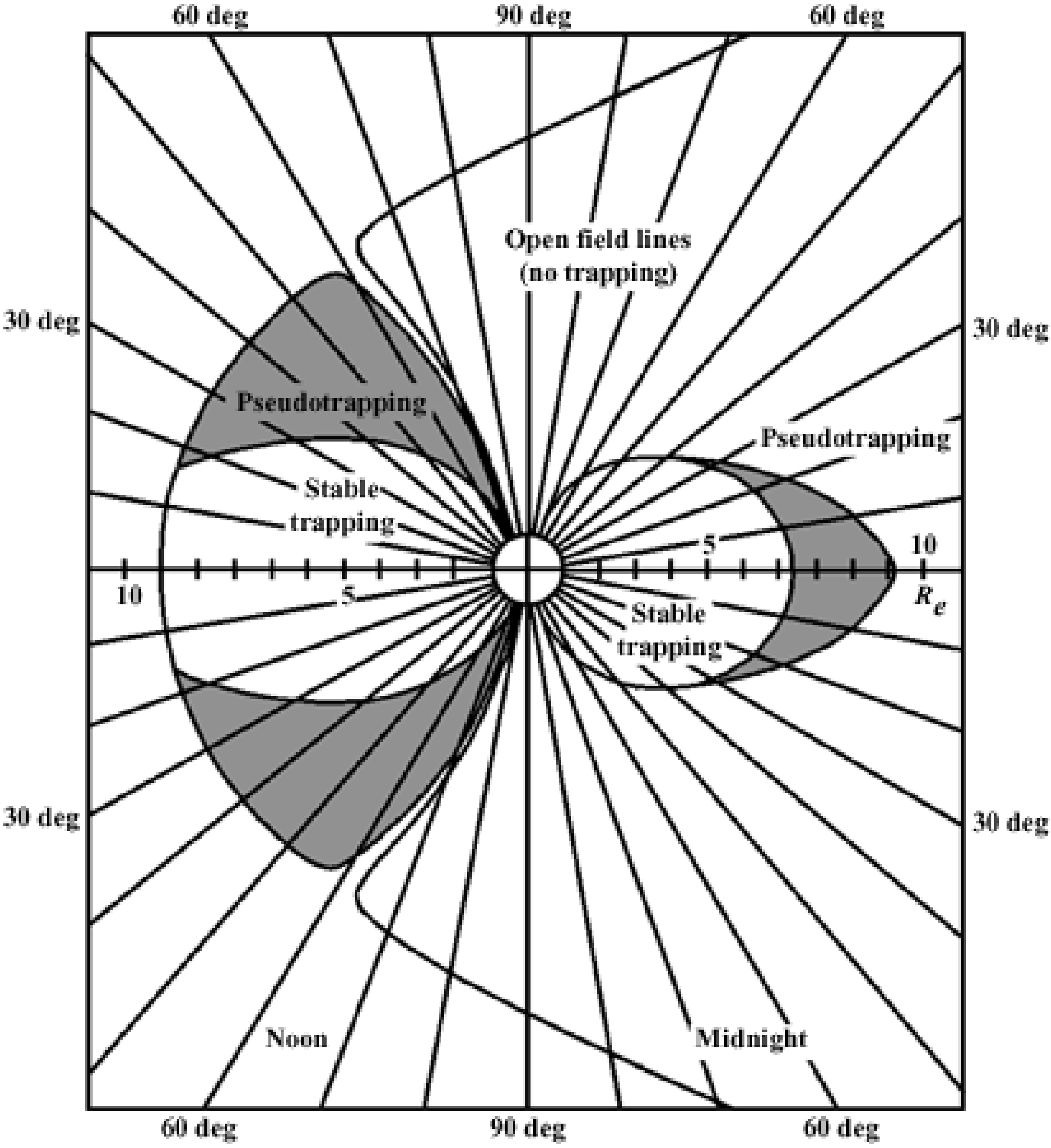
Figure 8. The trajectory of a 200 keV proton in a model magnetic field displaying the characteristic motion predicted by Shabansky [1972]

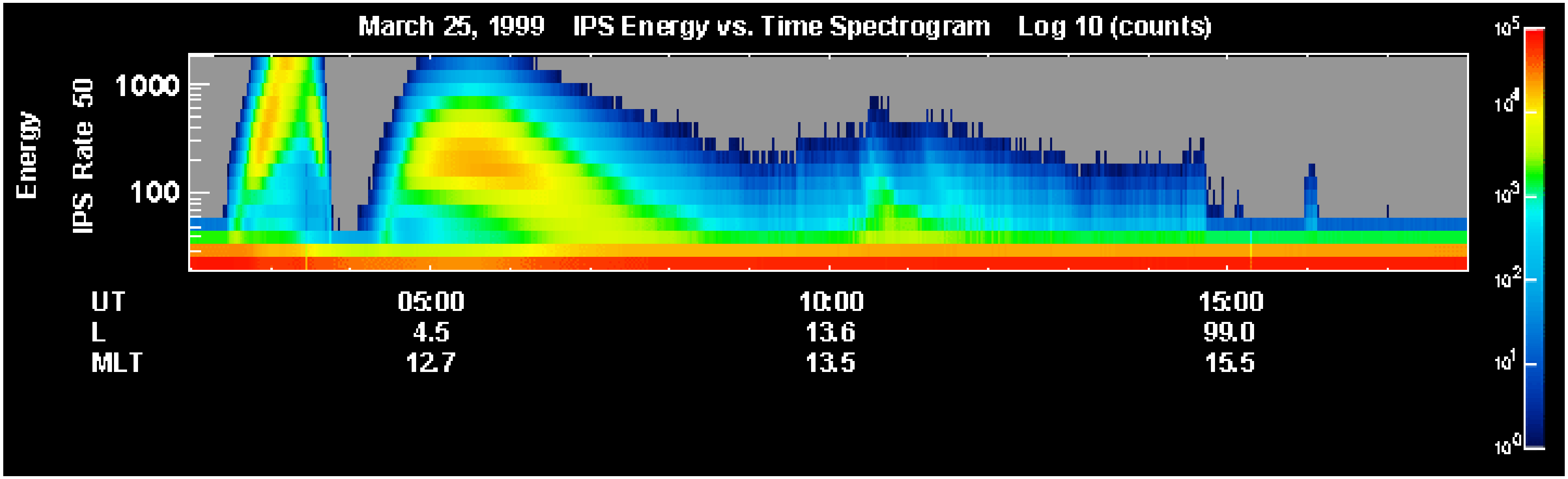
Figure 9. Example of a butterfly distribution measured by the ISEE-1 satellite in the pitch angle distributions of energetic electrons The energy channels presented are 189-302keV (E5), 302-477 keV (E6), 477-756 keV (E7), 756-1200 keV (E8) respectively.

Figure 10. Radial profiles of electrons at two selected pitch angles of 90^0 and 30^0 measured by the inbound ISEE-1 satellite close to the geomagnetic equator near the midnight meridian on April 2-3, 1978. The energy channels presented are (a) 22.5-39 keV (E1), 39-75 keV (E2), 75-120 keV (E3), 120-189 keV (E4) and (b) for the channels presented in Figure 9 respectively (from Fritz, et al., 2000).

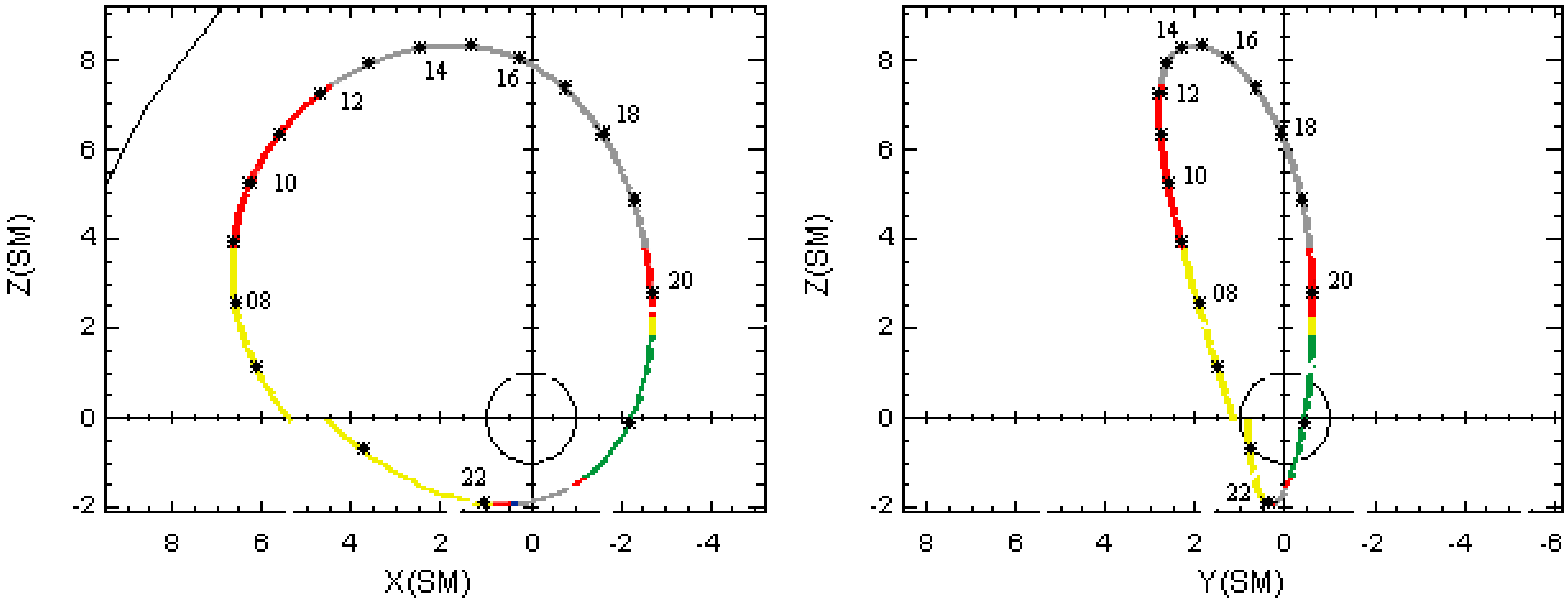
Figure 11. Same as Figure 10 but for the ion energy channels with the following passbands for protons: 24-44.5 keV (P1), 44.5-65.3 keV (P2), 65.3-95.5 keV (P3), 95.5-142 keV (P4) respectively (from Fritz, et al., 2000).

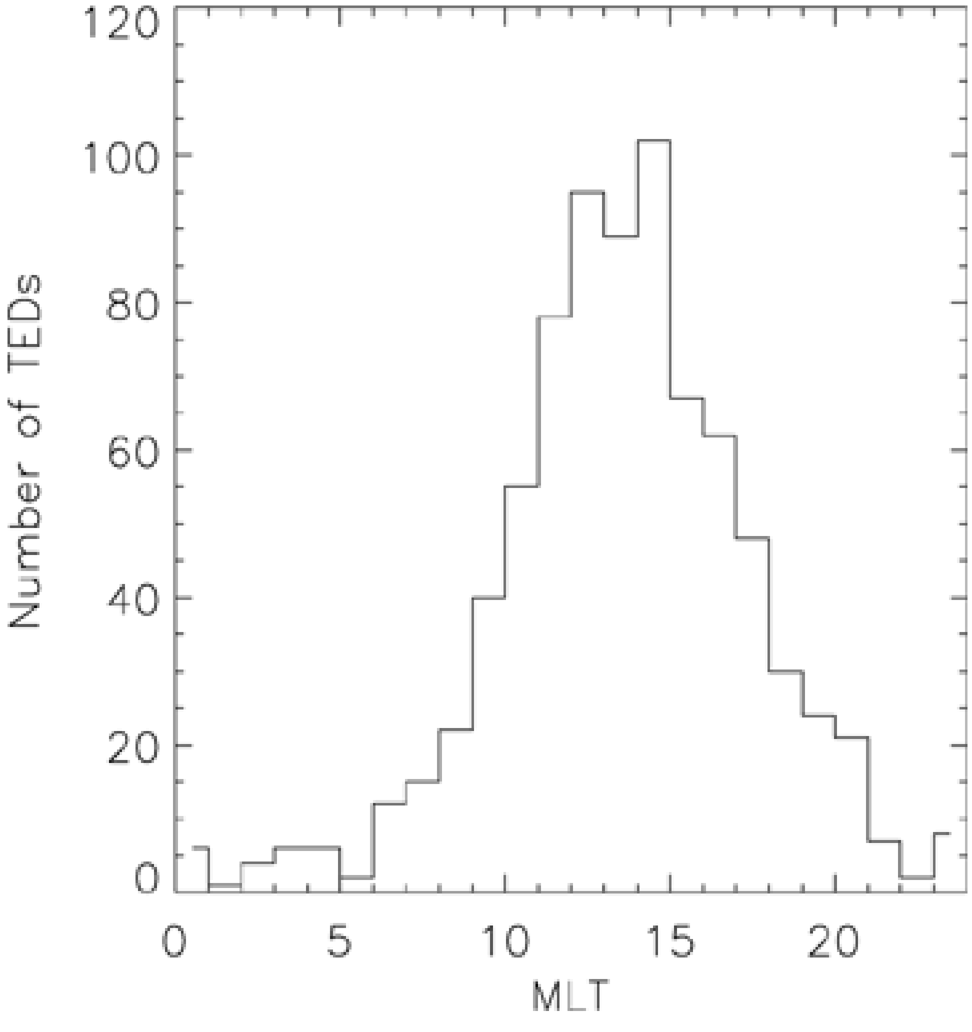
Figure 12. Average magnetic field characteristics projected to the geomagnetic equatorial plane: (a) contours of constant magnetic field intensity: (b) contours in the equatorial plane of the latitude and local time of the point of intersection of a field line with earth's surface. An energetic particle with an equatorial pitch angle of 90^0 will following the constant B-field contours of (a) whereas a particle with a small equatorial pitch angle mirroring just above the atmosphere of the earth will essentially follow the solid contours in (b) as each of these particle types drift in azimuth [from Lyons and Williams, 1984].


60 deg
90 deg
60 deg
Open field lines
(no trapping)
30 deg
30 deg
Pseudotrapping
Pseudotrapping
Stable
trapping
5
10
10
5
R_e
Stable
trapping
30 deg
30 deg
Noon
Midnight
60 deg
90 deg
60 deg

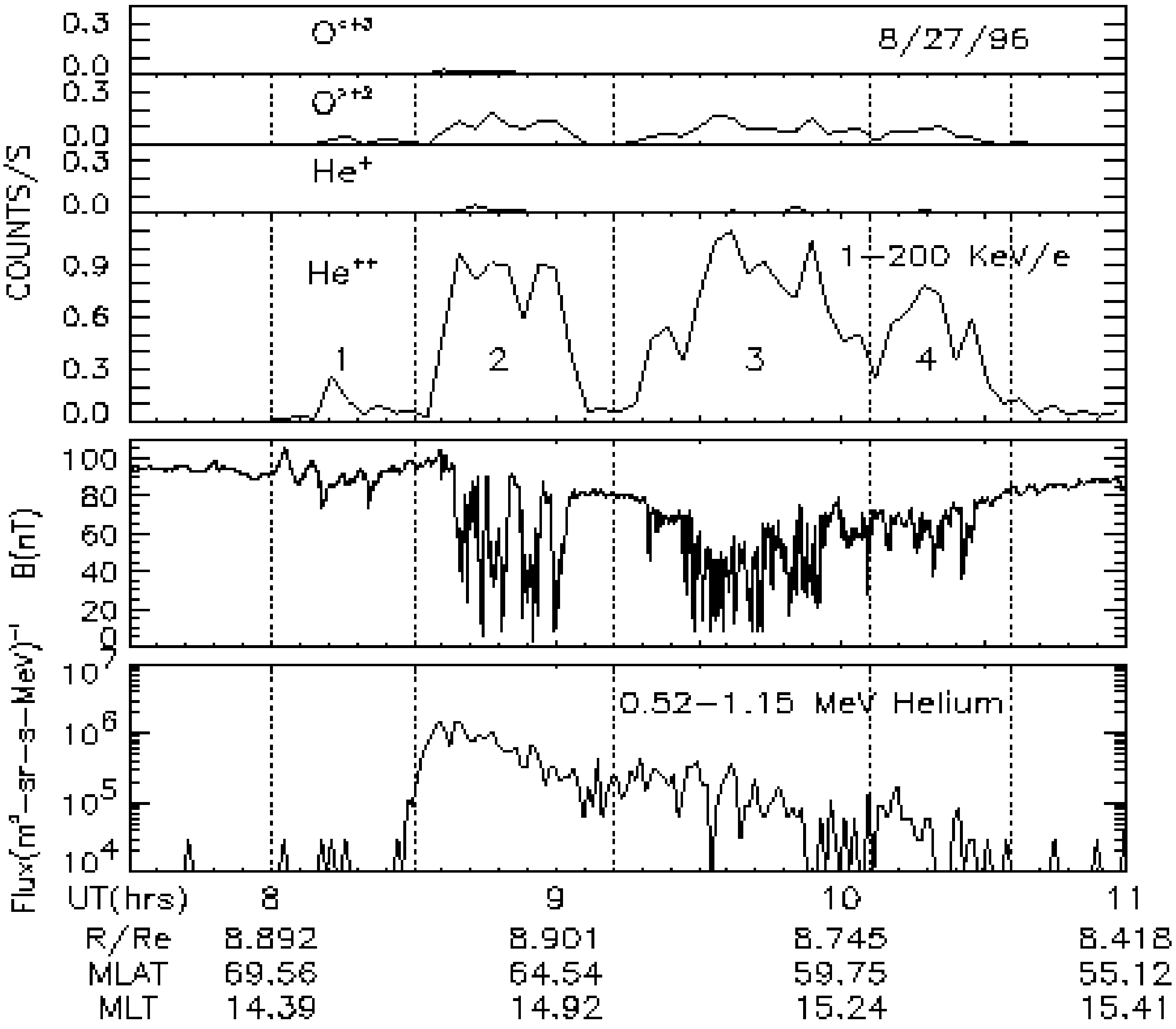


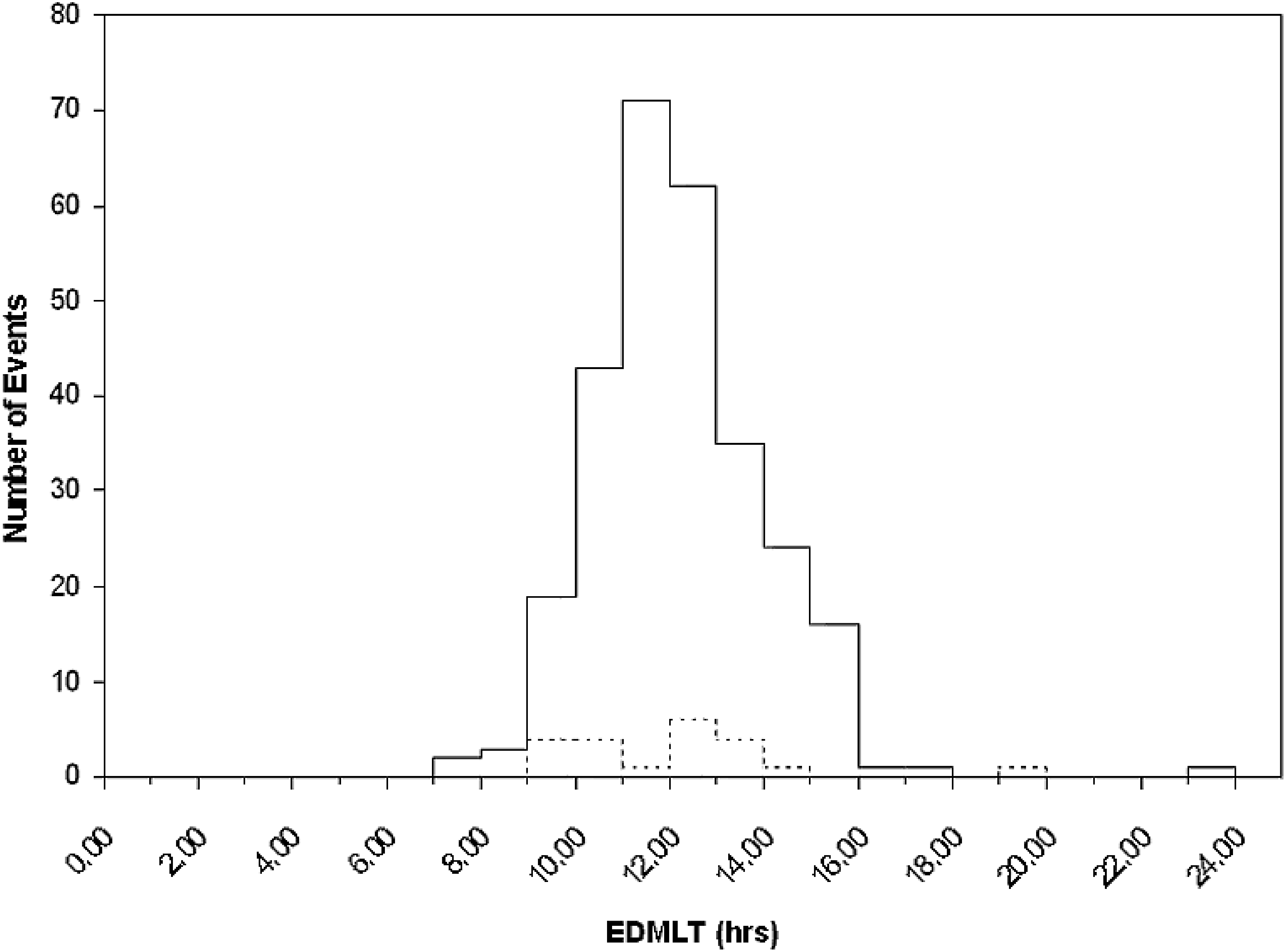
POLAR orbit 1999 084 (03/25) 06:12 UT to 1999 084 (03/25) 23:27 UT

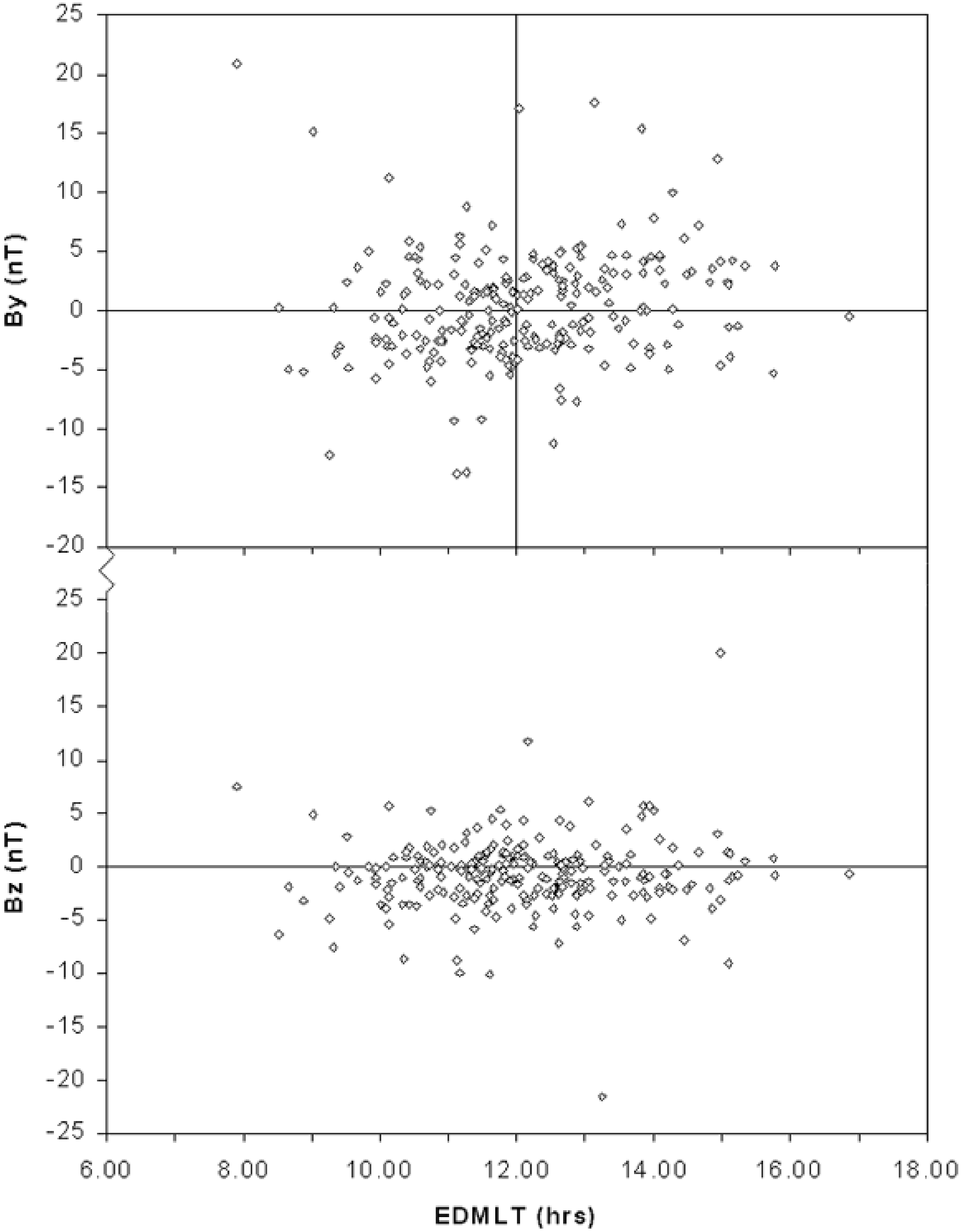


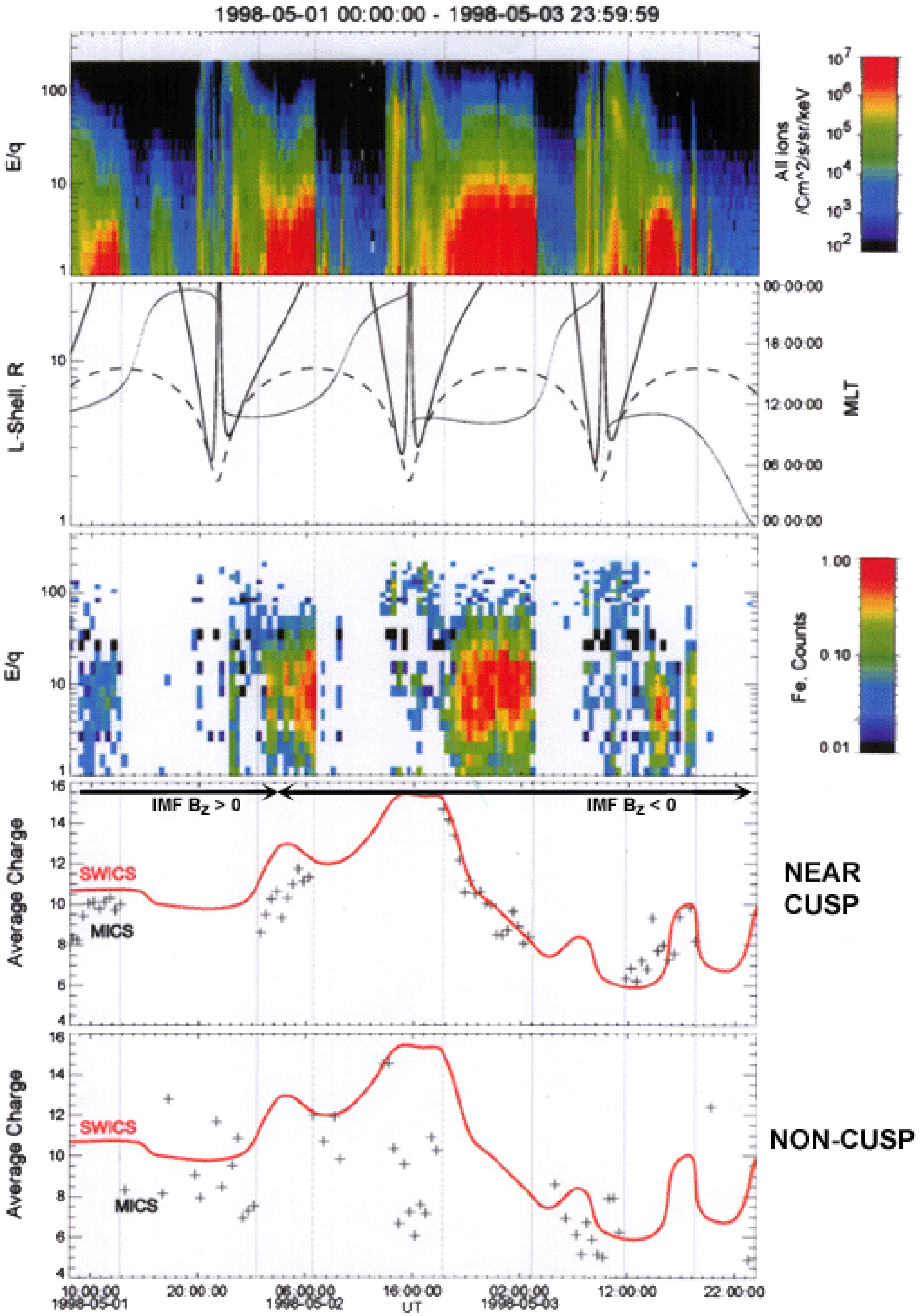


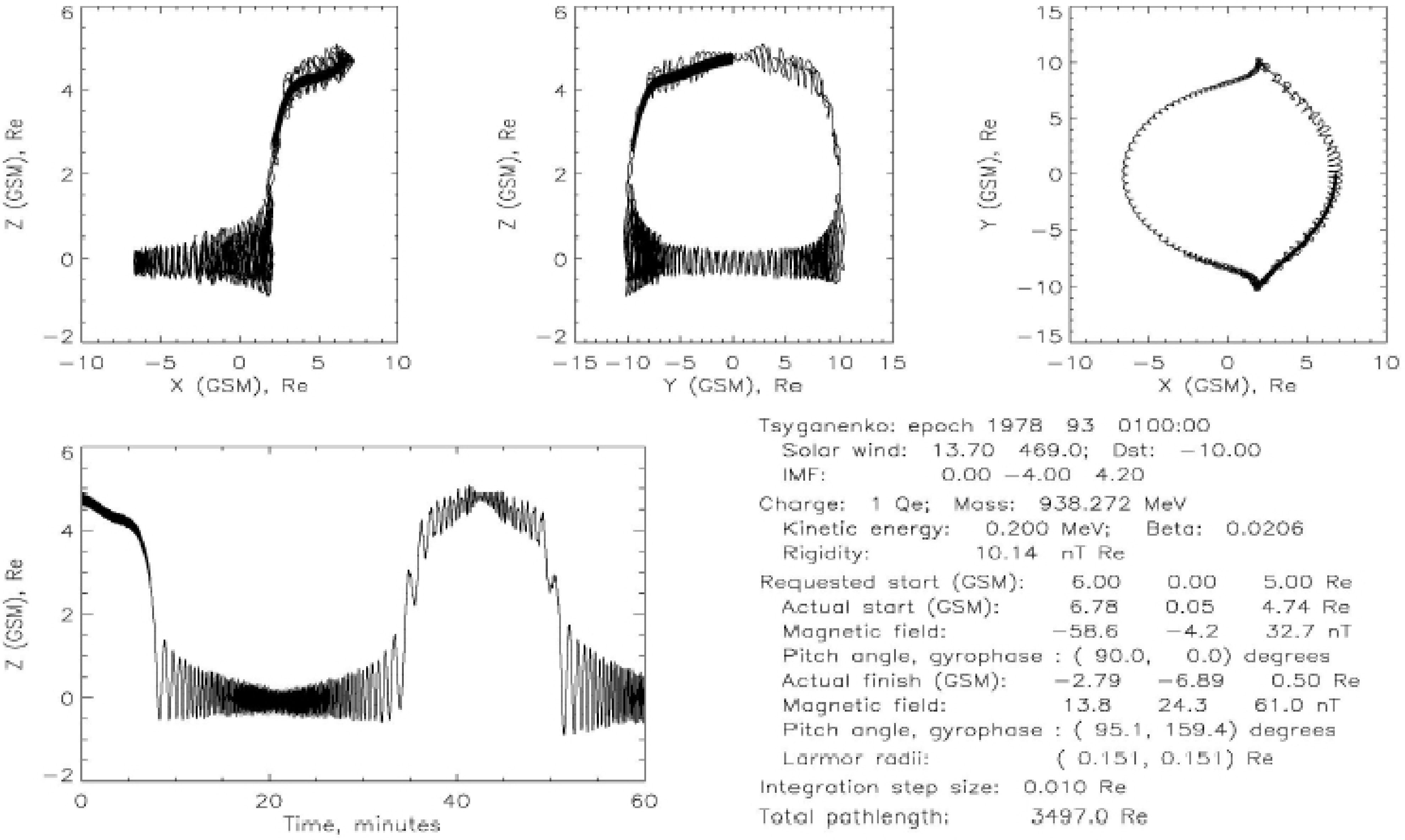
Number of TEDs
0
20
40
60
80
100
120
0
5
10
15
20
MLT


O<+3
8/27/96
O>+2
He+
He++
1–200 KeV/e
1
2
3
4
COUNTS/S
0.3
0.0
0.9
0.6
B(nT)
100
80
60
40
20
0
Flux(m²–sr–s–MeV)⁻¹
10⁷
10⁶
10⁵
10⁴
0.52–1.15 MeV Helium
UT(hrs)
8
9
10
11
R/Re 8.892 8.901 8.745 8.418
MLAT 69.56 64.54 59.75 55.12
MLT 14.39 14.92 15.24 15.41


80
70
60
50
40
30
20
10
0
Number of Events
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
24.00
EDMLT (hrs)

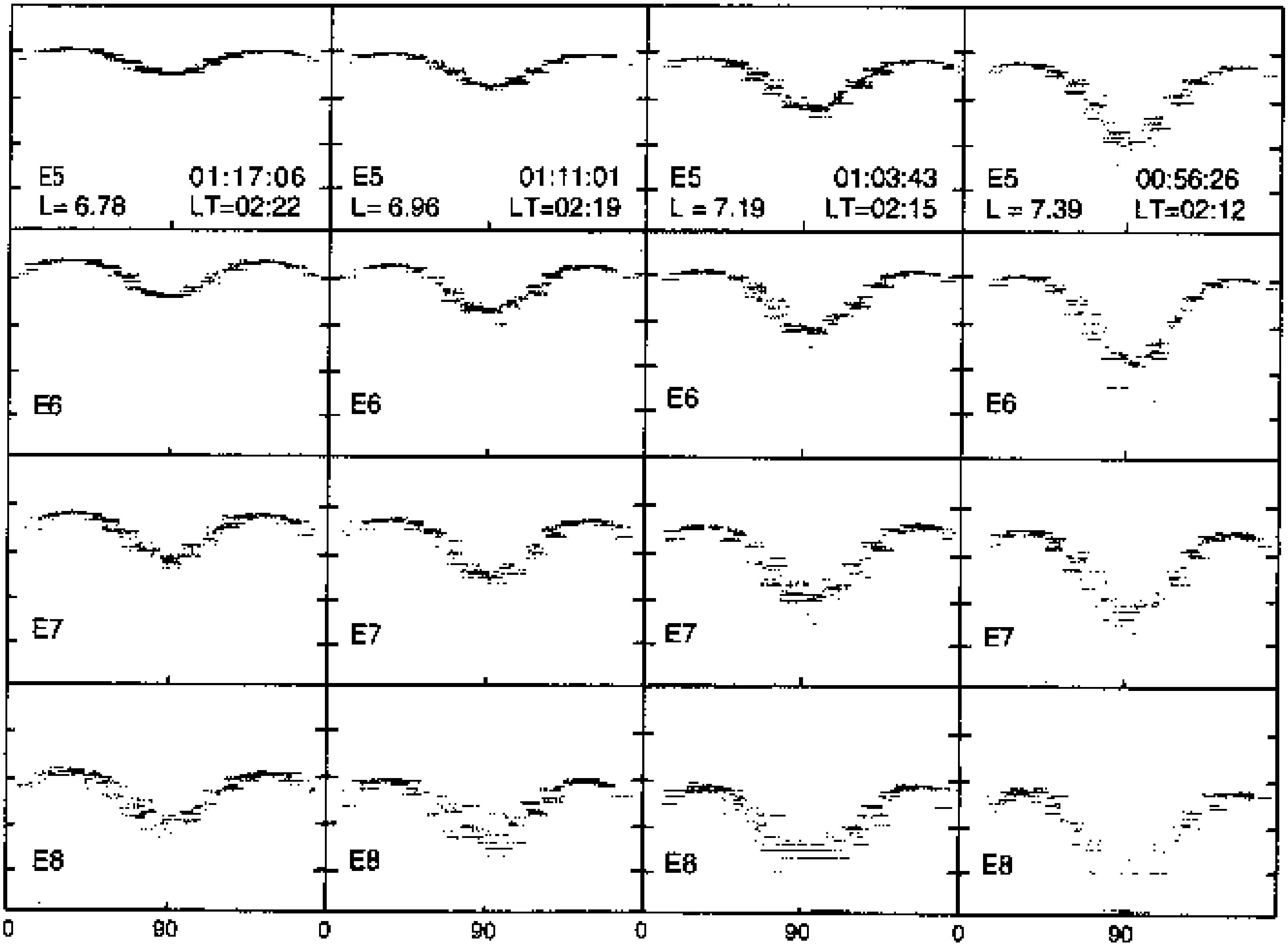

25
20
15
10
5
0
-5
-10
-15
-20
By (nT)
25
20
15
10
5
0
-5
-10
-15
-20
-25
Bz (nT)
6.00
8.00
10.00
12.00
14.00
16.00
18.00
EDMLT (hrs)


1998-05-01 00:00:00 - 1998-05-03 23:59:59
E/q
100
10
1
All Ions /Cm^2/s/sr/keV
10^7
10^6
10^5
10^4
10^3
10^2
L-Shell, R
10
1
MLT
00:00:00
18:00:00
12:00:00
06:00:00
00:00:00
E/q
100
10
1
Fe, Counts
1.00
0.10
0.01
IMF B_Z > 0
IMF B_Z < 0
Average Charge
16
14
12
10
8
6
4
SWICS
MICS
NEAR CUSP
Average Charge
16
14
12
10
8
6
4
SWICS
MICS
NON-CUSP
10:00:00
1998-05-01
20:00:00
06:00:00
1998-05-02
16:00:00
UT
02:00:00
1998-05-03
12:00:00
22:00:00

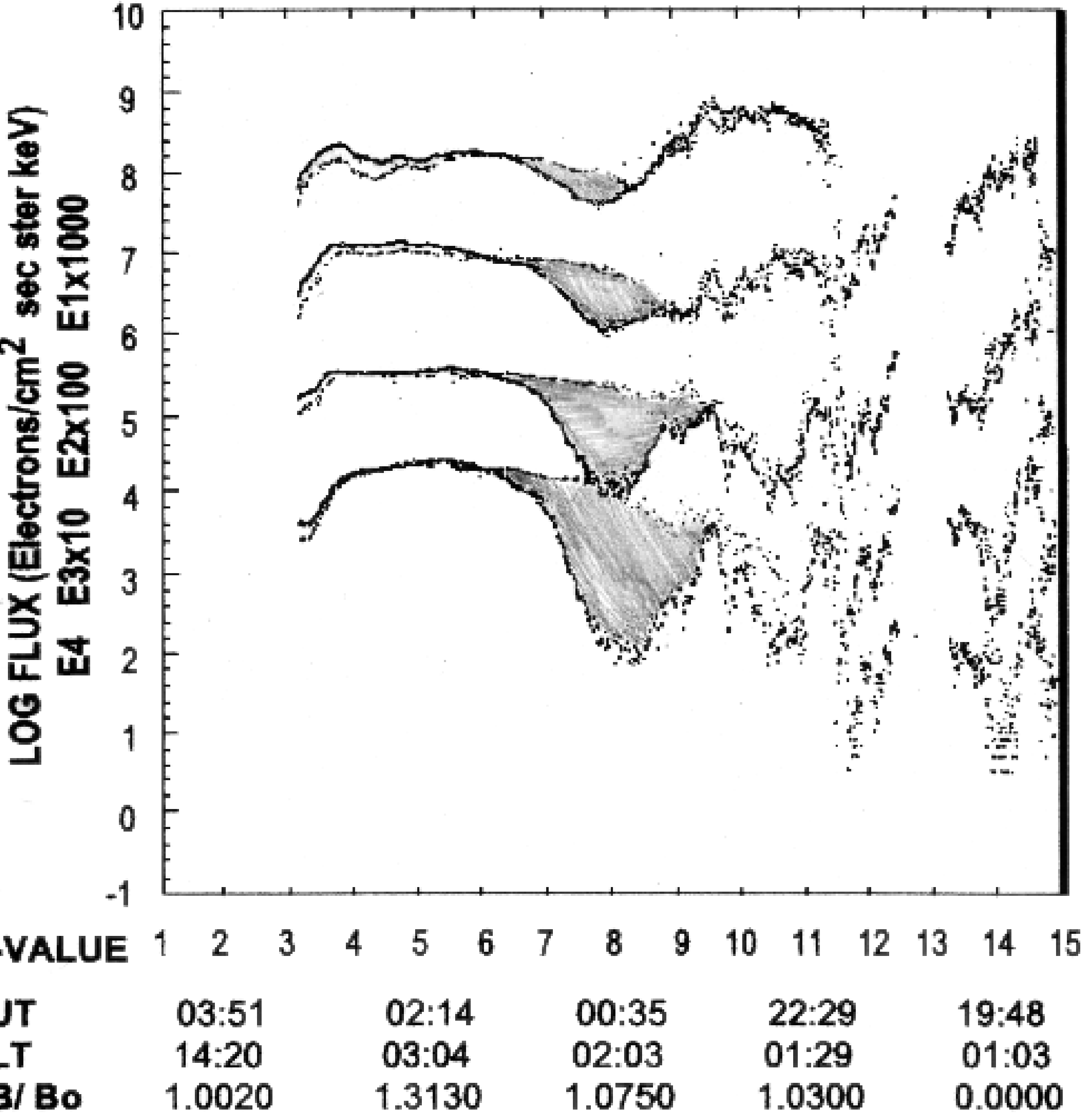


```
Tsyganenko: epoch 1978  93  0100:00
  Solar wind:  13.70  469.0;  Dst:  −10.00
  IMF:          0.00 −4.00  4.20
Charge:  1 Qe;  Mass:  938.272 MeV
  Kinetic energy:   0.200 MeV;   Beta:  0.0206
  Rigidity:          10.14  nT Re
Requested start (GSM):     6.00     0.00     5.00 Re
  Actual start (GSM):      6.78     0.05     4.74 Re
  Magnetic field:         −58.6     −4.2     32.7 nT
  Pitch angle, gyrophase : ( 90.0,    0.0) degrees
  Actual finish (GSM):    −2.79    −6.89     0.50 Re
  Magnetic field:          13.8     24.3     61.0 nT
  Pitch angle, gyrophase : ( 95.1, 159.4) degrees
  Larmor radii:           ( 0.151, 0.151) Re
Integration step size:  0.010 Re
Total pathlength:       3497.0 Re
```

ISEE-1 DAY 93 APR 3, 1978
J (Part / cm sec ster keV) vs α



ISEE-1
DAY 92 APR 2, 1978
90° and 30°



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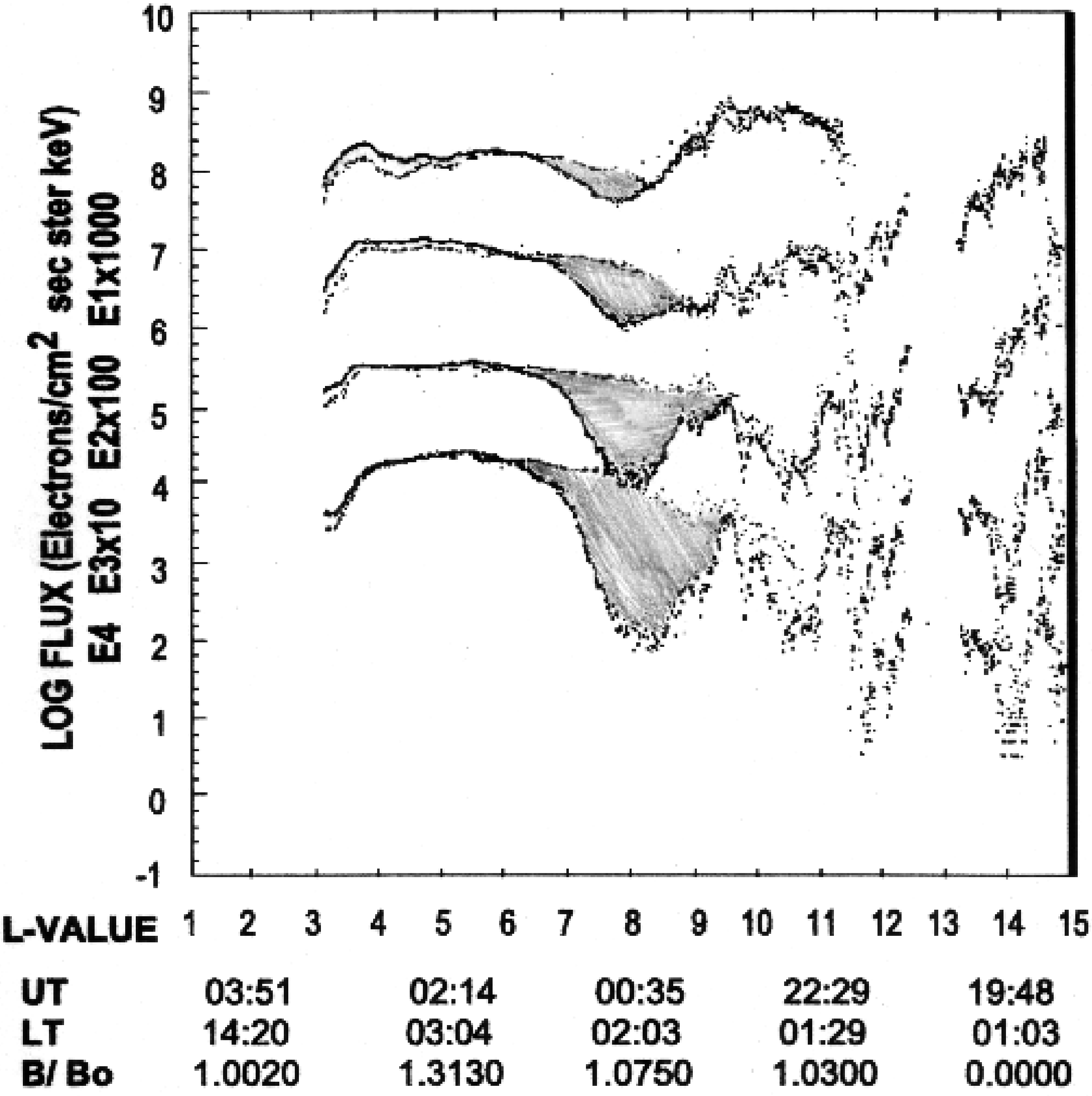
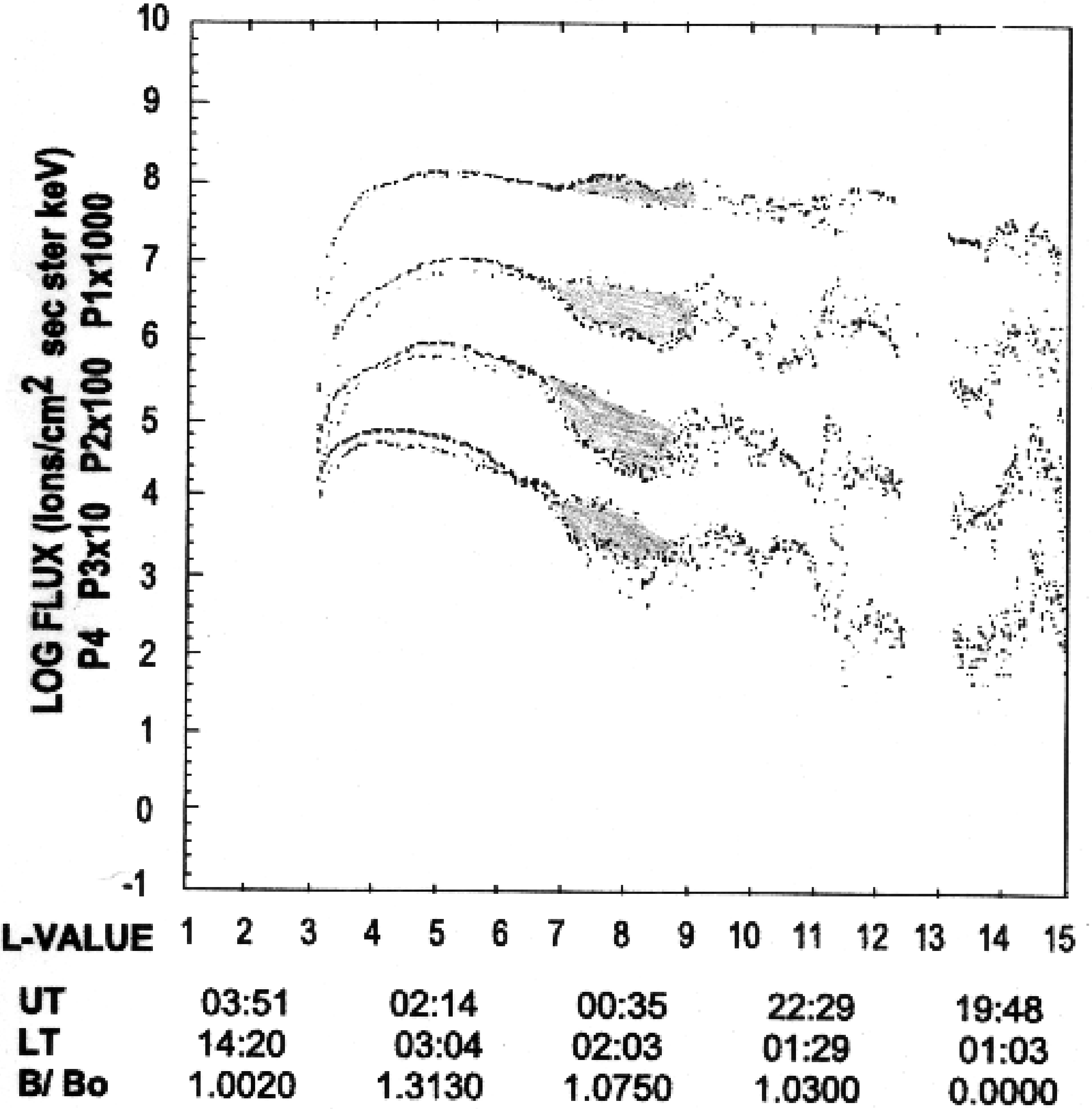
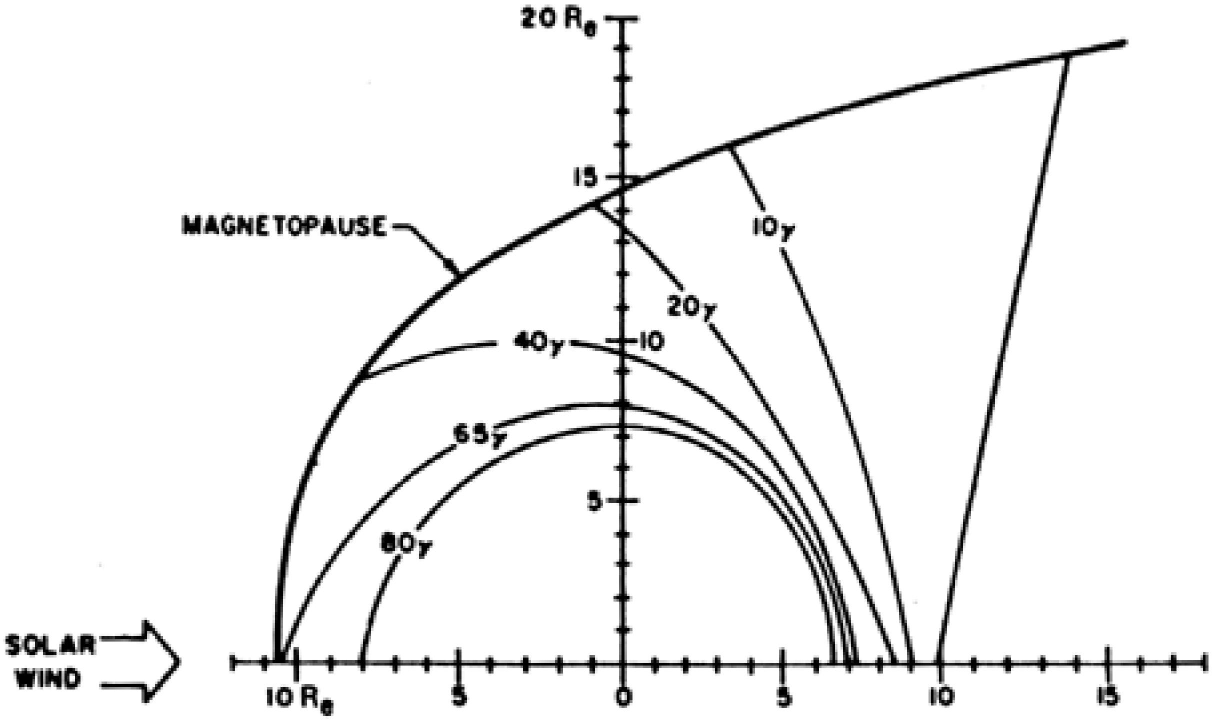
DAY 92 APR 2, 1978
90° and 30°

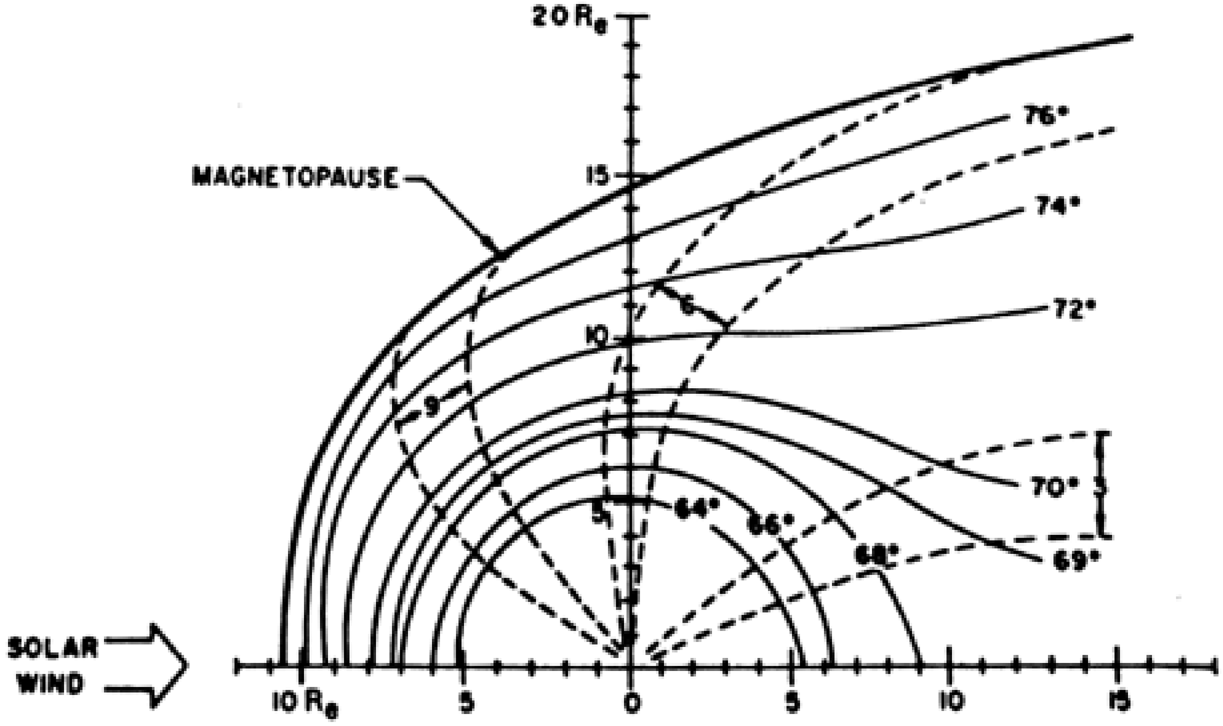


ISEE-1
DAY 92 APR 2, 1978
90° and 30°




20 R_e
15
10
5
MAGNETOPAUSE
10γ
20γ
40γ
65γ
80γ
SOLAR
WIND
10 R_e
5
0
5
10
15

(a)


20 R_e
15
10
5
MAGNETOPAUSE
76°
74°
72°
70°
69°
68°
66°
64°
6
9
SOLAR
WIND
10 R_e
5
0
5
10
15

(b)