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RAPID INCREASES IN THE PROTON AND ELECTRON FLUXES IN THE MAGNETOSPHERE

ANDREI KONRADI

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GODDARD SPACE FLIGHT CENTER
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ABSTRACT

Three rapid increases in the low energy electron (20 to 100 kev) and proton (>100 kev) flux were observed on October 27, October 28, and December 1, 1961. The time histories of the intensities and spectra are presented. The close association between the events and the occurrence of polar sub-storms is shown. The similarity of the events and those of December 20, 1962 and April 15, 1965 is discussed. It is also shown that the October 28, 1961 event is consistent with adiabatic acceleration of particles during a storm sudden commencement.

INTRODUCTION

A large number of studies have shown that both electrons and protons trapped in the outer Van Allen belt respond characteristically to disturbances in the earth's magnetic field. (Forbush et al., 1962; Hoffman et al., 1962; McIlwain, 1963; Freeman, 1964; Frank et al., 1964; Frank, 1965; Williams, 1966a; Williams, 1966b; Davis and Williamson, 1966; McIlwain, 1966a.)

Among other things the analyses performed establish a correlation between changes in the intensities of different energy electrons and protons populating various L shells and several indices of geomagnetic activity such as U, K_p, and D_{st}.

Various categories of changes in the electronfluxes have been described by McIlwain (1966b). Such surveys provide a picture of the temporal character of the magnetosphere with the time resolution of hours. In addition, it has been shown previously (Frank, 1965; Davis and Williamson, 1966; Konradi, 1967) that the particle population of the trapping region can undergo much more rapid changes which put more stringent requirements on any theory proposing to explain the dynamics of the magnetosphere. These changes are evidently non-adiabatic and thus currently not well understood.

The purpose of the present paper is to discuss three more examples of such rapid changes, thus adding to the pool of factual knowledge needed to provide a correct theoretical explanation of the temporal behavior of the magnetosphere. No attempt will be made to provide a physical interpretation of the observations until more data including those from the on-board magnetometer become available and a study similar to that of the 18 April 1965 event (Brown et al., 1967) can be undertaken.

APPARATUS

The instrument used in this analysis is the ion-electron detector flown by Davis and Williamson on Explorer 12 [Davis and Williamson, 1963; Davis, 1965]. It is a scintillation counter consisting of a photomultiplier tube on the face of which is deposited a 5 mg/cm^2-thick layer of crystalline ZnS covered by a 1000A thick layer of Al. A wheel driven by a stepping motor introduces varying thicknesses of Ni absorber between the collimator and the phosphor, thus permitting acquisition of energy information on the incident particles. The wheel also carries three Au discs, which in three wheel positions scatter the incident flux entering through an alternate collimator into the phosphor, thus making the detector selectively sensitive to electrons alone.

The detector has a geometric factor of 5.65×10^{-4} cm^2 ster for protons with $E > 105$ kev and 8.06×10^{-3} cm^2 ster for all others (These numbers differ slightly from previously quoted values as a result of refined calculations, J. M. Williamson, private communication).

A collimator allows particles to enter from a viewing cone with a half angle of about 11°.

There are three modes of operation:

1. Pulse output from the anode measures the number of incident protons above 105, 140, 200, 255, 460, 970, and 1700 kev.
2. Normally the eight dynode current measures the total incident flux from both protons and electrons.
3. Electrons are however, selected preferentially by scattering the incident beam of both protons and electrons from the Au discs. In this mode of operation the eight dynode current measures the total incident flux only due to electrons in the energy range between 20 and 100 kev.

In all three modes of operation the energy cutoff can be raised by introducing varying thicknesses of Ni absorbers mounted on the wheel.

The lowest detectable proton flux is about 10^3 p/cm^2 sec ster. The minimum detectable electron flux, however, depends on the energy of incident electrons and varies from $3.6 \times 10^5/cm^2$ sec ster at 20 kev to $1.4 \times 10^5/cm^2$ sec ster at 100 kev.

The proton cutoff energies of the detector are defined to be those energies at which the efficiency of the detector with a particular absorber in front of the aperture is 50%.

Owing to the directionality of the detector and the spin of the satellite, it is possible to measure the pitch-angle distribution of particles if the direction of the magnetic field is either known experimentally or can be calculated.

The dwell time at each wheel position is 5.2 seconds during which time the count rates and currents are read out 16 times at .325 sec. intervals. Thus a complete set of information can be obtained every 83 seconds.

ANALYSIS

In this study we shall describe three events which occurred October 27, October 28, and December 1, 1961 and which were observed by the ion-electron detector flown onboard Explorer 12 by Davis and Williamson (1963).

An event is defined as a drastic change in the intensity and/or the spectrum of the measured radiation within 2 to 3 minutes. In general, our description of the events will be limited to reporting the behavior of the electron flux and that of the integral proton flux for protons with E > 100 kev. Due to the intensities of the encountered electrons, electron pulse pile-up occurred in all but the lowest energy proton channel (which has a smaller geometric factor) and made the observation of higher energy protons impossible. All three events were observed on out-bound passes of the satellite.

In performing the present analysis we have observed fluxes of electrons sufficiently higher than those of protons so that the eighth dynode current can be used as a measure of electrons for both the direct and scatter geometries.

To obtain physically meaningful parameters such as the total flux of electrons above a certain energy and a measure of the energy spectrum such as the e-folding energy we proceeded as follows:

1. We assumed that the electron spectrum can be approximated by a relationship of the form

$$\frac{dJ}{dE} = Ae^{-E/E_0}$$

2. Theoretical responses of the detector for the nine absorbers and a set of different A's and E_0's were calculated from the relationship

$$I_{8i,j,k} = \int_0^\infty S_i(E)\, E\, A_j\, e^{-E/E_{0k}}\, dE$$

where I_8 is the eighth dynode current, S_i is the energy flux sensitivity for the ith absorber and j and k signify some particular values of the parameters A and E_0.

3. Those values of A and E_0 were adopted which gave the best fit by minimizing the expression

$$\sum_i \left(\log I_{8i,j,k} - \log i_{8i}\right)^2 = \text{min.}$$

where i_{8i} is the experimental current measured with the ith absorber in place.

October 27, 1961

This event occurred at 0327 U.T. during a moderate storm starting with a sudden commencement at 1940 U.T. on October 26, 1961 and lasting approximately until 2400 U.T. October 27, 1961. Figure 1 summarizes the main characteristics of the event. During the onset the satellite was at L = 5.4 and was moving outward. Just prior to the event the electrons had an integral intensity of about 1.8×10^7 (cm sec ster)$^{-1}$ with an e-folding energy of about 10 kev. The local pitch angle distribution was practically flat between 90° and 45° and then decreased for smaller angles up to a factor of 1.8 at 10°. The event proper was preceded by three drop-outs of the flux, two of which are shown in Figure 1. (One drop-out, at 0319 U.T., occurred in a time interval shorter than the resolution of the channel used in the diagram and thus is not shown in the figure). The last drop-out, just prior to the event, constitutes a complete disappearance (a drop of more than two orders of magnitude) of all energetic electrons for about two minutes to be followed by a recovery of the flux at 0327 U.T. with a harder spectrum. Initially the intensity recovered to the previous value with a change of the e-folding energy to 40 kev, but then within about 4 minutes rose by a factor of 4 to 8 x 10^7 $(cm^2 \text{ sec ster})^{-1}$. After this both the intensity and the e-folding energy declined with time. After the onset the local pitch angle distribution remained virtually flat between 90° and 30° which was the range of the scan, until, about 0500 U.T. at which time the flux stopped decreasing, stabilized, and apparently became roughly constant until the satellite crossed the magnetopause. While there were low energy protons observed before the event, a combination of electron spectrum hardening and an increase in the electron flux produced sufficient pile-up even in the channel with the smallest geometric factor to obscure completely any increase in the proton flux. As can be seen from the figure there was also observed a large negative bay at Halley Bay with an onset about 30 minutes before the onset of the observed event. Similar bays were seen at Marie Byrd, Godhaven and Leirvogur. While the onset of the bays at Marie Byrd and Halley Bay agree to within three minutes, the bay at Godhaven (considerably above the auroral zone) is delayed until 03:33 U.T., thus virtually coinciding with the time of the event.

The flux dropouts, mentioned before, deserve further discussion. Figure 2 shows a detailed time plot of the proton intensity (E > 140 kev) and of the relative response to electrons with E $\gtrsim$ 20 kev. This plot shows more detail than that of Figure 1 because in order to increase the resolution, responses from channels with different absorbers were utilized by normalizing them to a standard value. This was possible because of the continuous and smooth change in the particle spectrum. As can be seen, there are three sudden dropouts of particles at 0313, 0319, and 0325. The first one lasts for about 35 seconds, the second one for about 45 seconds, and the last one for about 2 minutes and it occurs just prior to the event.

An important thing to notice is that the protons track the electrons and disappear simultaneously.

In the case of the first and the third dropout the electron flux decreases by over two orders of magnitude because it falls below the threshold of detectability. In the second case the electron flux decreases by two orders of magnitude. The protons, however, fall below the threshold in each case and thus the flux change must be greater than a factor of 30, 18, and 10 respectively. An interesting observation is that the pitch angle distribution stays virtually constant and quite flat before the dropout, on the slopes, and after the dropout. On the slope some scatter is observed but it can be accounted for by the rapid change in the flux.

The detector response changes monotonically and is not affected by the intermittent dropouts, except, of course, for the change after the last dropout. It should also be noted that the dropouts occur almost exactly 6 minutes apart.

The two points, A and B, on the curve in Figure 2 mark instances when due to a fortuitous circumstance the detector was measuring the intensity of the lowest energy protons and electrons. During those moments the change in the flux was observed to be 3 orders of magnitude at A and 2 orders of magnitude at B during an interval of .3 seconds!

<u>October 28, 1961</u>

This event started at 0811 U.T. coincident with the sudden commencement of a moderately severe to severe re-current magnetic storm which lasted until 1400 U.T. October 29. The event is shown on Figure 3. As can be seen from the diagram, coincident with the sudden commencement and apparently triggered by it was an 800 γ bay at Marie Byrd.

The picture presented by this event is different from the event of the preceding day. In this case the satellite was at L = 8.1 and low-geomagnetic latitude, $\lambda_m = -12.0°$ during the onset. The onset is marked by a change in the intensity of electrons above 20 kev by a factor of about 4 and protons above 100 kev by a factor of about 10. Before the onset the electrons had an integral intensity of about 3.5×10^6 $(cm^2 \text{ sec ster})^{-1}$ and the protons about 6×10^4 $(cm^2 \text{ sec ster})^{-1}$. The local pitch angle distribution stayed quite flat between 90° and 45° and then decreased toward the smaller angles by about a factor of 1.5. It should be noted that there was no change in the e-folding energy of electrons through the onset which was about 15 kev. This condition prevailed for about 30 minutes, at which time E_0 began to increase and reached a maximum of 22 kev at 0852 U.T. while the electron integral flux decreased to 1×10^7 $(cm^2 \text{ sec ster})^{-1}$. Then the e-folding energy began to decrease while the flux began to increase. At the same time rapid fluctuations in the flux ensued. At 0905 U.T. the flux began to fall rapidly while the rapid fluctuations made measurements of E_0 impossible. At the onset the proton flux increased to 7×10^5 $(cm^2 \text{ sec ster})^{-1}$ whereupon it decreased monotonically with time until about 0920 U.T. when it went below the threshold of observation of 10^4 $(cm^2 \text{ sec ster})^{-1}$.

December 1, 1961

This event was observed during the initial phase of a moderately severe to severe storm without a sudden commencement which started at about 0300 U.T. and lasted until about 1300 U.T. December 3, 1961. Several stations also recorded a sudden commencement or a sharp impulse at 1302 U.T. December 1, 1961. As can be seen from Figure 4 there was also observed a 1200 γ negative bay at College at 1330 U.T. Similar bays were also observed at Barrow and Sitka.

During the onset of this event the satellite was at $L = 5.8$ and $\lambda_m = -30.2°$. Both the electron and the proton fluxes were quite low prior to the onset running about 5×10^4 $(cm^2 \text{ sec ster})^{-1}$ for protons and about 5×10^5 $(cm^2 \text{ sec ster})^{-1}$ for electrons. The onset of the event, which occurred at 1330 U.T., was marked by an order of magnitude change in the proton flux and a two orders of magnitude change in the electron flux. After that, for the next 7 minutes there were strong fluctuations in both proton and electron fluxes which made a good measurement of the electron e-folding energy difficult. The most likely value at that point was E_0 = 18 kev. At about 1337 U.T. both fluxes shot up once more with the protons stabilizing at about 4×10^6 $(cm^2 \text{ sec ster})^{-1}$ for the next hour. The electrons reached a peak of 4×10^7 $(cm^2 \text{ sec ster})^{-1}$ after which time the flux began to decrease with time and dropped to 8×10^6 $(cm^2 \text{ sec ster})^{-1}$ by 1430 U.T., E_0 also initially increased to 30 kev whereupon it started to decrease until it reached about 6 kev at 1430 U.T. As in the previous two cases the pitch angle distribution remained quite flat.

DISCUSSION

The flux increases of October 27, and December 1, 1961 bear a marked resemblance to the "catastrophic change" in the distribution of electrons on December 20, 1962 (Frank, 1965) and the two rapid flux changes in the proton and electron distribution observed on April 18, 1965. (Davis and Williamson, 1966, Brown et al., 1967).

In particular, Frank's event of December 20, 1962 consisted of a decrease by two orders of magnitude in the flux of electrons with energies of about 40 kev which was followed six minutes later by a recovery to a slightly higher level than before the event. Higher energy electrons decreased even more spectacularly but recovered to a lower level than before the event (see Frank's Figure 30). After the onset of the event the 40 kev electrons display intensities of about 10^7 $(cm^2 \ sec)^{-1}$ and the 230 kev electrons about 10^5 $(cm \ sec)^{-1}$.

From these two values we can calculate e-folding energies $E_0 \sim 40$ kev. Surveying ground magnetograms we find that this event occurred during a re-current magnetic storm which started December 18, 1962 and lasted until December 22, 1962. It is also closely associated with negative bays of about 700 γ at Mawson, Leirvogur, Kiruna and Murmansk, and which have onsets about 15 minutes after the start of the event. There is also a smaller bay at Dixon and a positive bay at the low latitude station of Ashkhabad which lies close to the local midnight meridian.

Two events were observed on April 18, 1965 at about 6:10 U.T. and 14:35 U.T. (Davis and Williamson, 1966). In both cases there were noted increases in the rate of protons with energies $E > 134$ kev and of 10 - 100 kev electrons. The electrons began to increase several minutes later than the protons. In both cases closely associated with the events there were negative bays at College.

The dropouts in the flux observed before the event of October 27, 1961, are evidently temporal rather than spatial. This we can infer from the fact that the Larmor radii of locally mirroring 140 kev protons in the ambient field (Jensen and Cain, 1962) are 64, 76 and 88 km for the three dropouts. The spacecraft velocity is about 3.9 km/sec, thus the spacecraft moved through only about 3 - 5 proton Larmor radii during the dropout. The rapidity of the changes in the flux also suggest that not only the third but also possibly the second adiabatic invariant is violated since the times associated with the change in flux are comparable to the bounce period.

The gross features of the three events discussed here are similar to those of the event of December 20, 1962 (Frank, 1965) and the events of April 18, 1965, Davis, 1966; Brown et al., 1967): They have been observed in the outer belt during magnetic storms and are closely associated with large magnetic bays in the auroral region. They also involve rapid increases in the low energy electron (tens of kilovolts) and proton (hundreds of kilovolts to megavolt) population. It is, of course, important to remember that only in exceptional cases it is possible to separate the temporal from the spatial variations. Thus an "event" could also be interpreted as the transition of the satellite between different drift shells with discontinuous particle populations. There are, however, several arguments one might produce on the side of the temporal interpretation:

1. The events are closely associated with large negative bays in the auroral zone.

2. There is no indication of a discontinuity in the trapped particle population during passes preceeding the events by several hours.

3. During the onset of the October 27, 1961 event at 0327 U.T. the electron flux is still not high enough to produce appreciable pile-up in the proton channel. At that instant the pitch angle distribution is already flat for 140 Kev protons and there is no indication of an azimuthal assymmetry in the particle velocities which we should expect if the satellite were to enter a populated drift shell. (cf. Konradi and Kaufmann, 1965).

The rise time for the increases is $\lesssim 5$ minutes. The subsequent enhanced flux is observed for at least an hour or while the satellite is traversing the outer zone. Thus, if the increases are indeed temporal, their onset times are much shorter than, and their duration comperable to or longer than the drift periods of the particles involved, implying that the third adiabatic invariant is not conserved.

In addition to the similarities mentioned above there is a special similarity between the events of October 27, 1961 and Frank's December 20, 1962 event.

As mentioned earlier, Frank's observations indicate a sharp decrease of low energy electrons followed several minutes later by a recovery to a slightly higher level than before the event. Higher energy electrons decreased even more spectacularly but recovered to a lower level than before the event (see Frank's Figure 30). In the case reported here we have information only on 20 - 100 kev electrons. These electrons decrease by about two orders of magnitude and receover to an intensity almost a factor of 4 higher than prior to the event and with a harder spectrum. While in Frank's case the spectrum softens and in our case it hardens after the onset of the event it is noteworthy that the e-folding energy $E_0 \sim 40$ Kev obtained from Frank's data agrees well with our own observations.

As mentioned earlier, in the case of the events of April 18, 1965 (Davis and Williamson, 1966) there was clearly a time delay in the appearance of the increase in the electron flux compared to the proton flux. Such a delay could be caused, in principle, by the different drift periods of the protons and electrons, provided the particles in question originated at a point different from the point of observation. Such delays in the arrival of different energy protons have, indeed, been observed in the outer magnetosphere (Konradi, 1967). However, no time dispersion was observed in the low energy protons. The interpretation given is (Brown et al., 1967), that protons and electrons were produced as a result of an instability which caused the substorm. "Since the satellite was on the western edge of the instability the accelerated protons appeared at once and the electrons after drifting eastward."

In the case of the event of December 1, 1961, the only pertinent case for which we have information on protons with energies E > 100 kevs, no such delay is noticeable. Since, however, the physical origin of the events is of great importance and the local time of observation, at least in some cases, is significant it seems appropriate to indicate it. Figure 5 presents a plot in L-geomagnetic local time space the events discussed in this paper. For reference the curve on the bottom of the diagram represents the boundary of the magnetosphere as predicted by Mead and Beard (1964).

The event of October 28, 1961 differs from the other two events described here, and those of December 20, 1962 and of April,18, 1965, in that it was observed in the far part of the outer belt in the day magnetosphere and occurred simultaneously with the sudden commencement of the magnetic storm and the onset of the polar substorm. This fact raises the question whether the flux increase observed could not be simply due to the adiabatic heating of the ambient electron flux. This hypothesis can be checked by some rough calculations:

We assume that only the first two adiabatic invariants are conserved during the sudden commencement. We shall also assume that at least the sub-solar magnetosphere can be adequately represented by the Mead model (Mead, 1964). The on-board magnetometer registered a field of 85 γ which rose to about 125 γ within 3 minutes during the sudden

sudden commencement (Kaufmann, private communication). Since the geomagnetic latitude of the satellite was only -12.4° we shall perform our approximate calculations in the equatorial plane. From the two values of the total magnetic field before and after the sudden commencement we can determine that the stand-off distance of the magnetospheric boundary was 12.7 and 7.7 Re, respectively. While the radial distance of the satellite was also about 7.7 R_e, the satellite position was at about 0600 L.T. so that the satellite was well within the magnetosphere. Then, assuming that the feet of the field lines are anchored in the ionosphere and that the particles move with field lines during the initial compression, we can find B_m and the position of the observed electrons before the sudden commencement. From this we can calculate the expected intensity and spectrum of electrons after the sudden commencement provided we know them at their original position. Since the latter is unknown we shall use the locally observed spectrum before the S.S.C. for the calculation. If initially the integral intensity of locally mirroring electron with energy above 20 kev was 3.8×10^6 $(cm^2$ sec ster$)^{-1}$ and E_0 was 14 kev then the calculated intensity is 6.78×10^7 $(cm^2$ sec ster$)^{-1}$ and the new E_0 is 37.6 kev. Since it is well known that the spectra of both electrons and protons soften with distance and during a S.S.C. particles are brought in from outlying shells, the present calculation can produce only an upper limit on the increase of intensity and spectral change. Indeed, the observed intensity after the S.S.C. is about 1.5×10^7 $(cm^2 \text{ sec ster})^{-1}$ while E_0 does not change.

Another way of checking the reasonableness of our hypothesis is to take the observed values of the integral intensity and of E_0 after the S.S.C. and compute the values of these quantities for the same electrons before the S.S.C. Thus we arrive at an electron intensity of 1.7×10^5 $(cm^2 \text{ sec ster})^{-1}$ and an e-folding energy of 5.2 kev at 10 R_e. Similar values of E_0 have, indeed, been previously observed at the edge of the trapping region (Konradi, 1965). Thus it seems that the change in the electron flux on October 28, 1961 is consistent with the assumption that it was caused by a sudden compression during the S.S.C. at 0811 U.T.

It should be noted that there does indeed occur a later hardening of the spectrum and a further increase in the electron flux at approximately 08:40 U.T. which may be associated with the observed polar substorm which coincides with the S.S.C.

CONCLUSIONS

Three electron and proton events were observed on October 27, October 28, and December 1, 1961. These three events are marked by rapid increases in the electron, and where observations permit, proton flux. A virtually flat pitch angle distribution after the onset of the event is also a characteristic feature. In the October 27 and possibly December 1 event there occurs a hardening of the electron spectrum.

Two events (October 27 and December 1) take place during geomagnetic storms, and one event (October 28) following the S.S.C. of a geomagnetic storm. All three events are closely associated in time with polar sub-storms. The October 27 event is preceded by three marked drop-outs in the electron and proton flux. Two of these events (October 27, and December 1) bear a marked similarity to those of December 20, 1962 and April 18, 1965, reported earlier in the literature. The event of October 28 can be interpreted as due to adiabatic leading of the ambient flux during a S.S.C.

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REFERENCE

Brown, W. L., L. J. Cahill, L. R. Davis, C. E. McIlwain, and C. S. Roberts, "Acceleration of Trapped Particles During a Magnetic Storm on 18 April 1965," University of New Hampshire Report UNH-67-4, 1967.

Cahill, L. J., "Inflation of the Inner Magnetosphere During a Magnetic Storm", J. Geophys. Res., 71, 4505-4519, 1966.

Davis, L. R., and J. M. Williamson, "Low Energy Trapped Protons", Space Research, Proc. Intern. Space Sci. Symp., 3rd, Washington, D. C., 1962, North-Holland Publishing Company, Amsterdam, 1963.

Davis, L. R., "Low-Energy Trapped Protons and Electrons", Proceedings of the Plasma Space Science Symposium, edited by C. C. Chang and, S. S. Huang, D. Reidel Publishing Co., 1965.

Davis, L. R. and J. M. Williamson, "Outer Zone Protons," Proc. NATO Adv. Study Inst. Bergen, Norway, August, 1965, Radiation Trapped in the Earth's Magnetic Field, Ed. by B. M. McCormac, D. Reidel Pub. Co., Dordrecht, Holland 1966.

Forbush, S. E., G. Pizzella, and D. Venkatesan, "The Morphology and Temportal Variations of the Van Allen Radiation Belt, October 1959 to December 1960", J. Geophys. Res., 67, 3651-3668, 1962.

Frank, L. A., J. A. Van Allen, and H. K. Hills, "A Study of Charged Particles in the Earth's Outer Radiation Zone with Explorer 14", J. Geophys. Res. 69, 2171-2191, 1964.

Frank, L. A., "A Survey of Electrons E > 40 Kev Beyond 5 Earth Radii with Explorer 14", J. Geophys. Res. 70, 1593-1626, 1965.

Freeman, J. W., "The Morphology of the Electron Distribution in the Outer Radiation Zone and Near the Magneticspheric Boundary as Observed by Explorer 12," J. Geophys. Res., 69, 1691-1723, 1964.

Hoffman, R. A., R. L. Arnoldy, and J. R. Winckler, "Observations of the Van Allen Radiation Regions During August and September 1959, 6. Properties of the Outer Region," J. Geophys. Res., 67, 4543-4575, 1962.

Jensen, D. C. and J. C. Cain, "An Interim Geomagnetic Field (abstract)" J. Geophys. Res., 67, 3568-3569, 1962.

Konradi, A. and R. L. Kaufmann, "Evidence for Rapid Motion of the Outer Boundary of the Magnetosphere," J. Geophys. Res., 70, 1627-1637, 1965.

Konradi, A., "Electron and Proton Fluxes in the Tail of the Magnetosphere," J. Geophys. Res., 71, 2317-2325, 1966.

Konradi, A., "Proton Events in the Magnetosphere Associated with Magnetic Bays," J. Geophys. Res., 72, 3829-3841, 1967.

McIlwain, C. E., "Acceleration of Outer-Zone Electrons," (abstract) Trans. Am. Geophys. Union, 47, 131, 1966a.

McIlwain C. E., "Process Acting Upon Outer Electrons I. Adiabatic Perturbations," University of California at San Diego Report UCSD-SP-66-5, 1966b.

McIlwain, C. E., "The Radiation Belts, Natural and Artificial," Science, 142, 335-361, 1963.

Mead, G. D., "Deformation of the Geomagnetic Field by the Solar Wind", J. Geophys. Res., 69, 1181-1195, 1964.

Mead, G. D., and D. B. Beard, "The Shape of the Geomagnetic-Field Solar-Wind Boundary," J. Geophys. Res., 69, 1169-1179, 1964.

Williams, D. J., "A 27-Day Periodicity in Outer Zone Trapped Electron Intensities," J. Geophys. Res., 71, 1815-1826, 1966.

Williams, D. J., "Outer Zone Electrons," Proc. Advanced Study Institute, Radiation Trapped in the Earth's Magnetic Field, edited by B. M. McCormac, p.p. 151-168, D. Reidel Publishing Co., Dordrecht, Holland.

Figure Captions

Figure 1

October 27, 1961 event. The composit diagram shows calculated integral electron intensities above 20 Kev, e-folding energies of electrons, and the relative response of the detector as a function of geomagnetic latitude, L, and U.T. The bottom scale shows associated negative bays and Dst for the storm time period.

Figure 2

Expanded view of the flux drop-outs preceeding the event of October 27, 1961. The solid curve represents the relative response of detector to electrons in the range between 20 and 100 Kev. The dashed line is the total intensity of electrons above 140 Kev. Points A and B mark instants when flux changes of 3 and 2 orders of magnitude in the electron flux occurred in .325 seconds. The changes in the proton flux were just as abrupt but appear smaller because the intensity fell below the threshold.

Figure 3

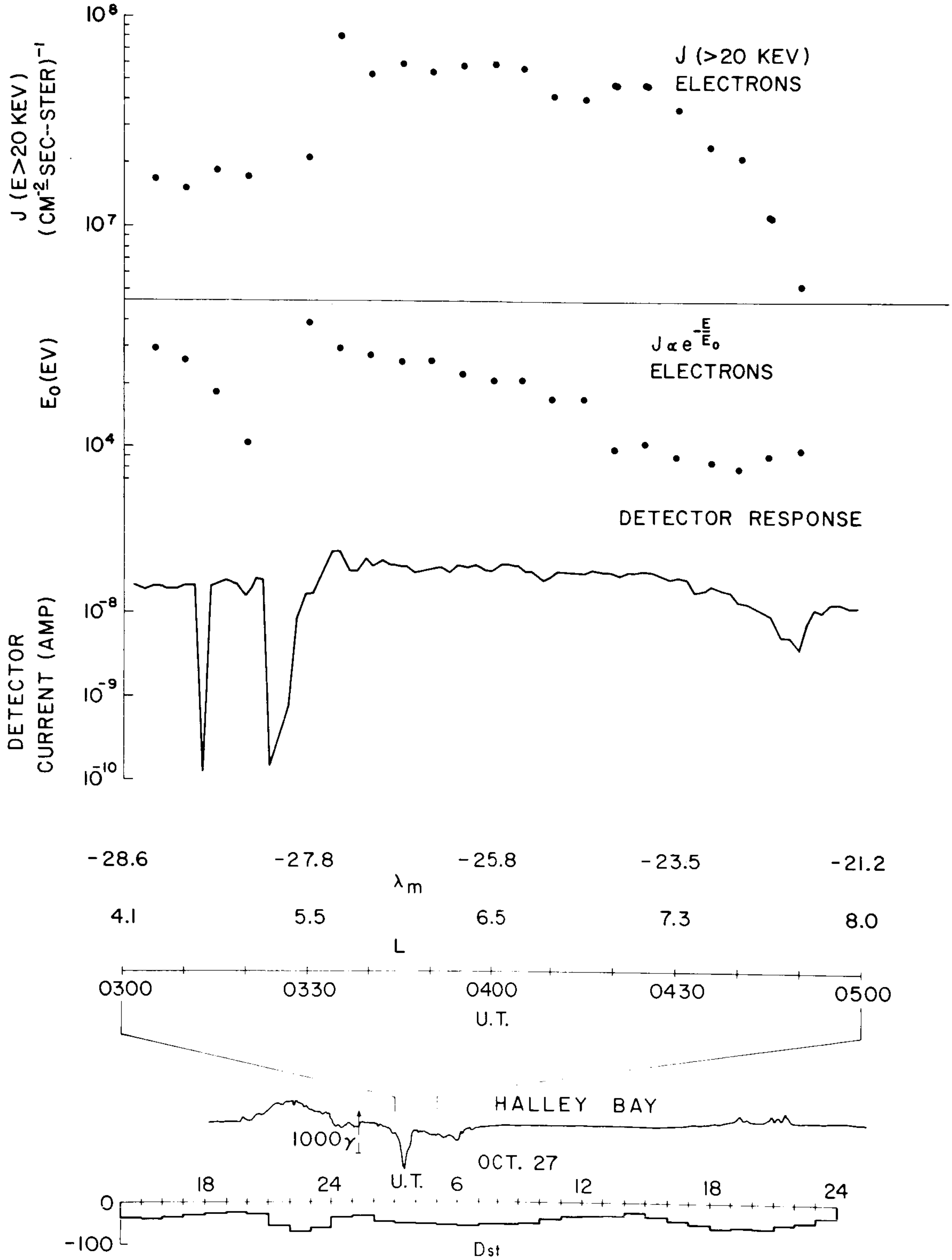
October 28, 1961 event. Diagram is similar to Figure 1 but in addition shows the integral intensity of protons with energies greater than 140 Kev.

Figure 4

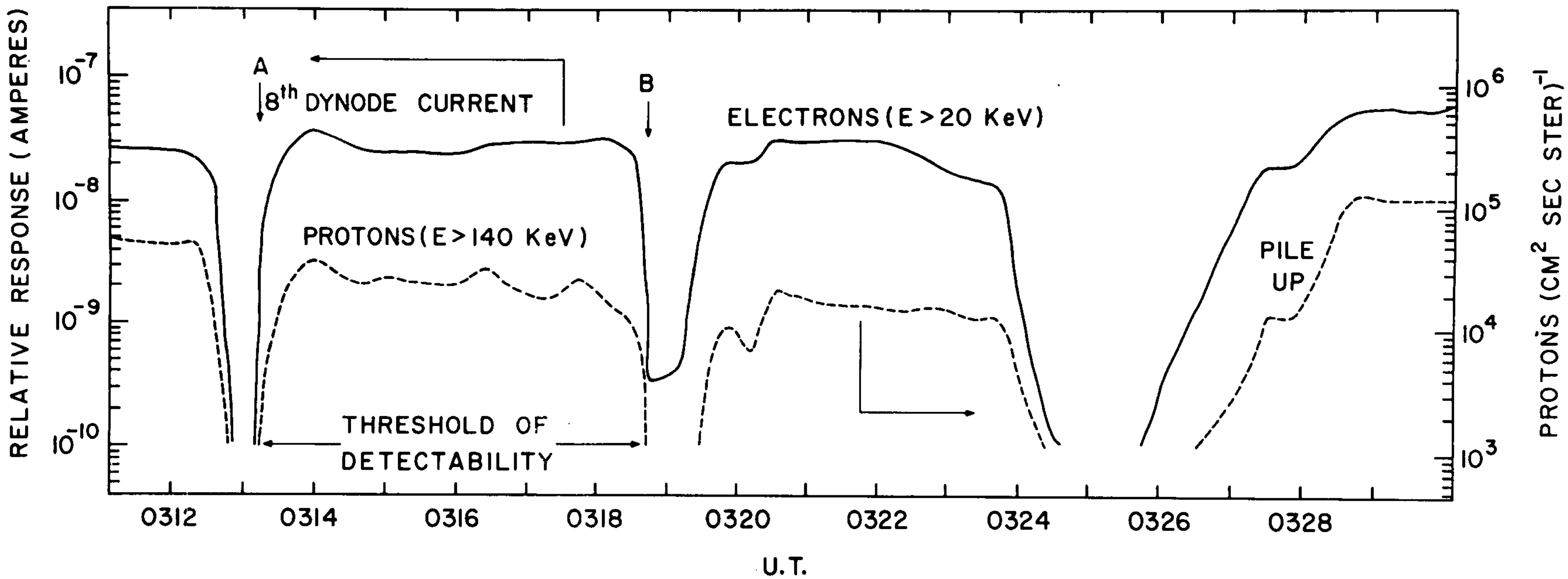
December 1, 1961 event. Diagram similar to Figures 1 and 3.

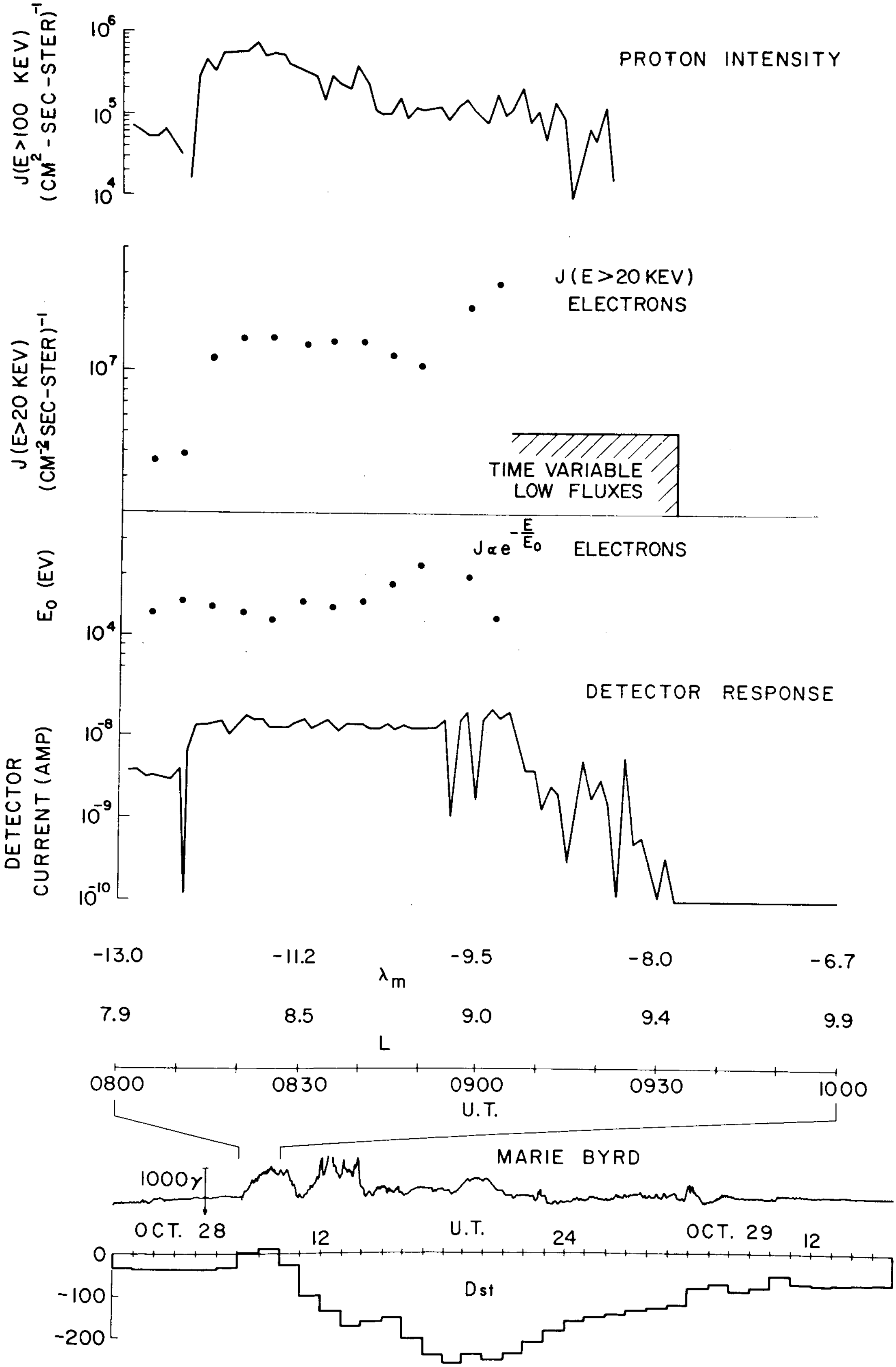
Figure 5

Positions of the satellites in L-geomagnetic local time space during the events discussed in the text. The curved line on the bottom represents the position of the geomagnetic boundary from Mead and Beard, 1964.

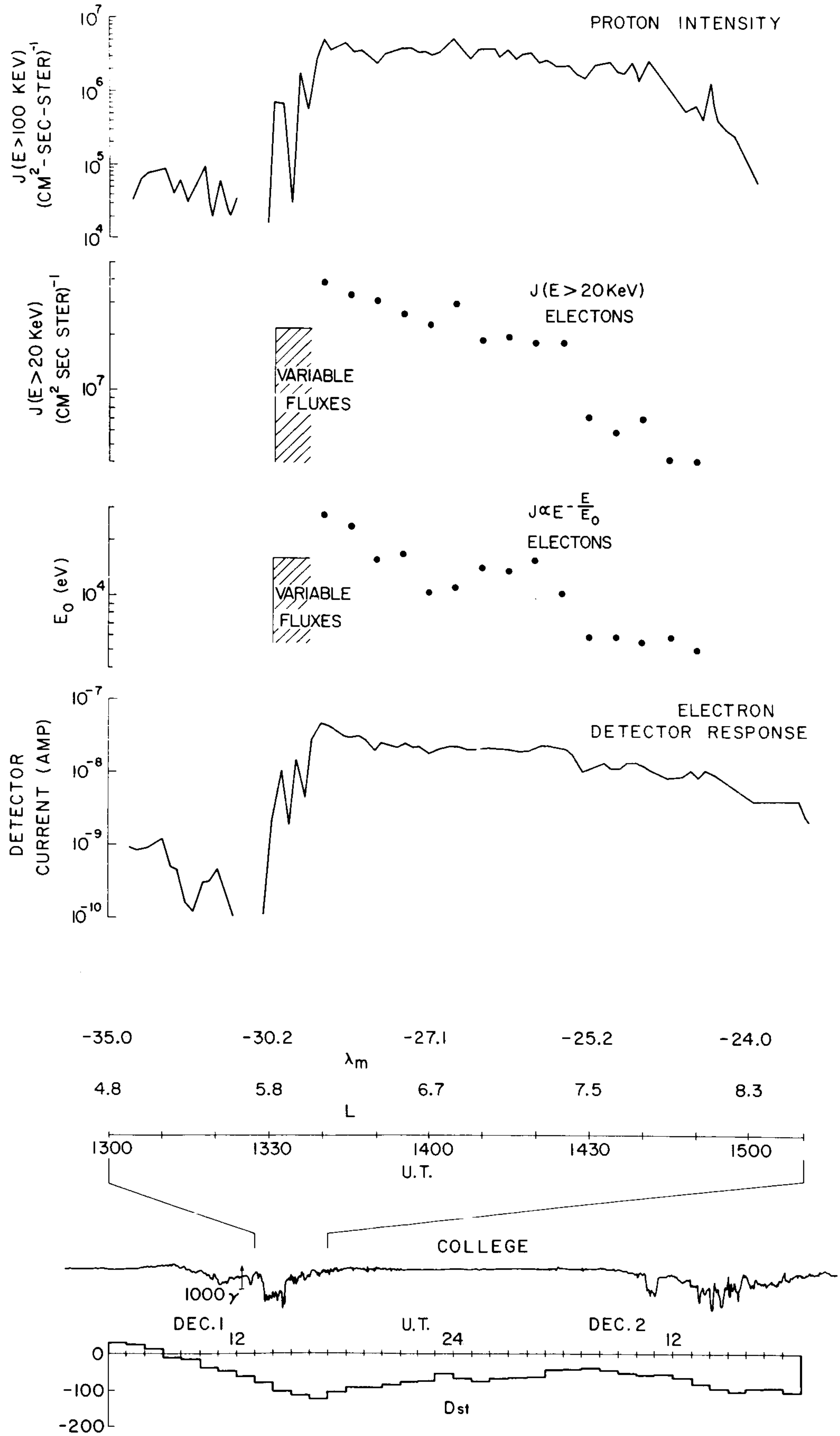


J (E>20 KEV) (CM⁻² SEC-STER)⁻¹
10⁸
10⁷
J (>20 KEV)
ELECTRONS
E₀ (EV)
10⁴
J α e^(−E/E₀)
ELECTRONS
DETECTOR RESPONSE
DETECTOR CURRENT (AMP)
10⁻⁸
10⁻⁹
10⁻¹⁰
-28.6
-27.8
-25.8
-23.5
-21.2
λm
4.1
5.5
6.5
7.3
8.0
L
0300
0330
0400
0430
0500
U.T.
HALLEY BAY
1000γ
OCT. 27
18
24
U.T.
6
12
18
24
0
-100
Dst

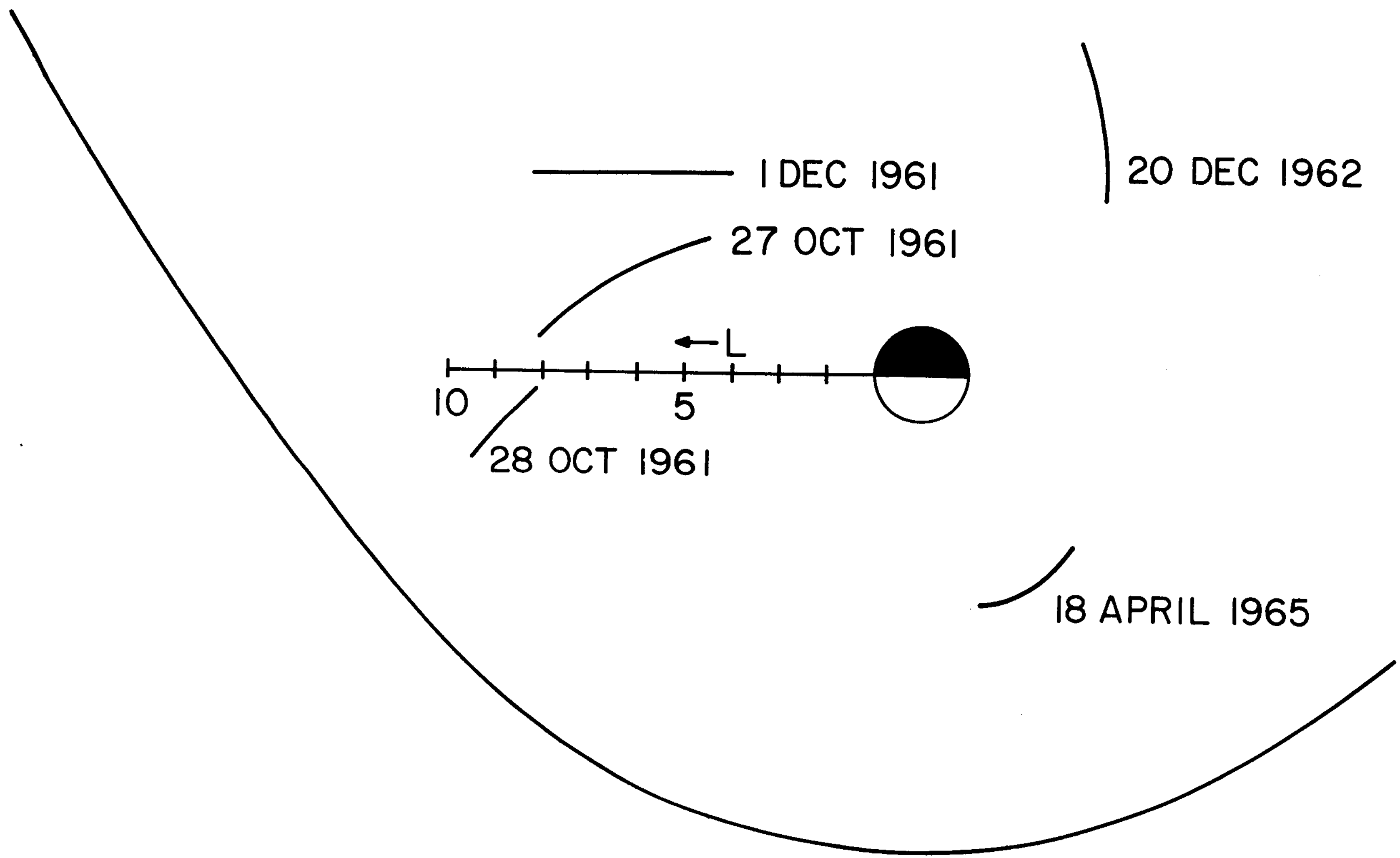

RELATIVE RESPONSE (AMPERES)
10^-7
10^-8
10^-9
10^-10
A
8th DYNODE CURRENT
B
ELECTRONS(E>20 KeV)
PROTONS(E>140 KeV)
THRESHOLD OF
DETECTABILITY
PILE
UP
10^6
10^5
10^4
10^3
PROTONS (CM^2 SEC STER)^-1
0312
0314
0316
0318
0320
0322
0324
0326
0328
U.T.



PROTON INTENSITY
J(E>100 KEV) (CM2-SEC-STER)-1
10^6
10^5
10^4
J(E>20 KEV) ELECTRONS
J(E>20 KEV) (CM-2 SEC-STER)-1
10^7
TIME VARIABLE LOW FLUXES
J α e^-E/E0 ELECTRONS
E0 (EV)
10^4
DETECTOR RESPONSE
DETECTOR CURRENT (AMP)
10^-8
10^-9
10^-10
-13.0
-11.2
-9.5
-8.0
-6.7
λm
7.9
8.5
9.0
9.4
9.9
L
0800
0830
0900
0930
1000
U.T.
MARIE BYRD
1000γ
OCT. 28
12
U.T.
24
OCT. 29
12
0
-100
-200
Dst



PROTON INTENSITY
J(E>100 KEV) (CM²-SEC-STER)⁻¹
10⁷
10⁶
10⁵
10⁴
J(E>20 KeV) (CM² SEC STER)⁻¹
10⁷
J(E>20KeV) ELECTONS
VARIABLE FLUXES
E₀ (eV)
10⁴
J∝E^(-E/E₀) ELECTONS
VARIABLE FLUXES
DETECTOR CURRENT (AMP)
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
ELECTRON DETECTOR RESPONSE
-35.0
-30.2
-27.1
-25.2
-24.0
λm
4.8
5.8
6.7
7.5
8.3
L
1300
1330
1400
1430
1500
U.T.
COLLEGE
1000γ
DEC. 1
12
U.T.
24
DEC. 2
12
0
-100
-200
Dst



1 DEC 1961
20 DEC 1962
27 OCT 1961
L
10
5
28 OCT 1961
18 APRIL 1965