Study of the Temporal Variations of 40 keV Electrons in the Magnetosphere During and After the Magnetic Storm on April 18, 1965*

by

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ABSTRACT

Temporal variations of the intensities of electrons $E > 40$ keV during the main phase and post-storm period of a large magnetic storm which occurred on April 18, 1965 are studied in this paper from the data obtained at high latitudes by the University of Iowa Satellite Injun IV and at low latitudes by the NASA satellite OGO-1.

The high latitude observations show a large inward movement of the cutoff boundary for trapped electrons to lower latitudes by as much as 8°. On the storm day and during the post-storm period, the cutoff latitude shows a close and direct correlation with D_{st} and inverse correlation with 3-hour K_p index. The 'slot', which is present at an invariant latitude of 61° before the storm, disappears on the storm day and is replaced by a peak. The post-storm variations of these storm-induced electrons at higher latitudes are uncorrected with the K_p index. The intensities decay according to an exponential law. There appears to be an injection and inward diffusion of fresh electrons during the post-storm period, leading to the formation of the normal quiet day profile. Variations for precipitated electrons are generally similar.

The suggestion that additional field lines extend into the tail region and lead to lowering of the cutoff boundary during the storm does not appear to be completely satisfactory.

At low latitudes the available OGO-1 observations on the magnetospheric tail side indicate that the cutoff boundary, which was at $L \sim 7.5$ one day before the storm for electrons $E > 40$ keV, had extended to $L \sim 9.5$ one day after the storm, and strong electron 'islands' were seen between $L \sim 15$ and $L \sim 21$. On the next two orbits, four and seven days after the storm, the boundary was at the normal value and electron 'islands' were not present. The extended boundary and the 'islands' consisted mainly of low energy electrons.

It is also of interest to note that while OGO-1 was observing strong electron islands at low latitudes one day after the storm, Vela 2A satellite at a distance of 17 earth radii was also looking at strong electron intensities. The occurrence of such an event simultaneously at different latitudes could possibly be explained in terms of plasma movements along the magnetic lines of force on the tailside and neutral sheet instabilities.

INTRODUCTION

Temporal variations of the distribution of electrons (of energy greater than 40 keV) at high latitudes and low altitudes have been studied [Frank et al., 1963; Armstrong, 1965] and limits of durable trapping have been well established. Craven [1965] has shown from observations during geomagnetically disturbed periods that these distributions undergo large changes. Studies of trapped electrons at high latitudes during magnetic storms have been reported earlier by Maehlum and O'Brien [1963] for electrons of energy greater than 40 keV, by Williams and Ness [1966] and Williams [1966] for electrons of energy greater than 280 keV, and by Rothwell and McIlwain [1966], Van Allen and Lin [1960], Forbush, Pizzella, and Venkatesan [1962], and others for electrons of $\sim$ 1.5 MeV. The latter studies have shown that the high latitude boundary of trapped electrons suddenly moved in at the start of the maximum phase of a magnetic storm and recovered soon after the maximum phase was over.

Observations at equatorial and near equatorial latitudes of the temporal variations of electrons are also available. According to Rosser [1963], the outer boundary of the geomagnetic cavity of the magnetosphere contracted during the period immediately after a magnetic storm which occurred on September 30, 1961 and a turbulent solar plasma was observed beyond the limits of the outer radiation zone after the magnetic storm. A study by Freeman [1964] indicated enhancement of soft electron fluxes and diminution of hard electrons in the outer zone during magnetically disturbed periods and a confirmation of the general Chapman-Ferraro picture of the compression of the geomagnetic field during the initial phases of the magnetic storms. Frank [1966] observed large increases of electron 100 eV $\lesssim E_e \lesssim 40$ keV fluxes over $L \simeq 2.8$ to $L \simeq 4.0$ with the onset of magnetic storms on October 1 and October 29, 1961, with the peak energy flux at $L \simeq 3.0$ which he interpreted as evidence of a ring current centered at $3R_e$ responsible for some portion of the main phase of the storm.

The object of this paper is to report a study of the temporal behavior of electrons of energy greater than 40 keV made from the data obtained at high latitude -low altitudes by the Injun IV satellite of the University of Iowa and from the data obtained at low latitudes by the University of Iowa particle counters on board the OGO-1 (also called the EGO) satellite during the main phase and recovery period of a large magnetic storm which occurred on April 18, 1965. The main phase of this storm started in the early hours on that day reaching a maximum depression of -149 γ just after

0900 U.T. The recovery period lasted several days. Inflation of the inner magnetosphere and the consequent possible formation of an axially symmetric ring current during this storm have been discussed by Cahill [1966]. McIlwain [1966] has studied the adiabatic deceleration and re-acceleration of trapped protons during the build-up and decay of a time dependent diamagnetic ring current. Williams [1966] has reported the sudden collapse of the high latitude boundary of trapped electrons during this storm. We study in this paper the movement of the high latitude boundary and the time history of trapped and precipitated electrons during this storm. Low latitude effects are also studied.

INSTRUMENTATION

The University of Iowa satellite Injun IV (Explorer 25) was launched on November 21, 1964 into an orbit of inclination 81°. Its apogee altitude was 2502 Km and the perigee altitude, 527 Km. The satellite was magnetically aligned to the geomagnetic field vector by means of a permanent magnet and a bundle of hysteresis damping rods. The departures from idealized alignment were measured by two Schonstedt magnetometers in mutually perpendicular directions. The particle detectors of interest in this study are two Anton type 213 GM counters designated 213B and 213D. Detector 213B was oriented to recieve particles moving at right angles to the B vector and detector D, at 160° to the B vector. Magnetic alignment during the period considered here maintained the nominal angles to an accuracy of ± 7°. A description of Injun IV has been given by Whelpley [1965].

The OGO-1 satellite was launched into a highly eccentric orbit of inclination 31° on September 5, 1964 with an initial apogee altitude of 92,827 miles and a perigee altitude of 175 miles. Its initial period was 64 hours. The University of Iowa complement of instruments on board this satellite that are of interest to this study consisted of a system of three pairs of detectors in mutually perpendicular directions with the central axis of the 'trioka' directed along the major axis of the spacecraft. One detector of each pair designated A was sensitive to electrons $E > 40$ keV and protons $E > 500$ keV and the other (designated B) sensitive to electrons $E > 150$ keV and protons $E > 3.5$ MeV. In addition there was also an omnidirectional detector (designated C) which was sensitive to electrons $E > 1.6$ MeV and protons $E > 16$ MeV. For this satellite, the desired attitude control could not, however, be obtained and the satellite rotated about the yaw axis with an initial spin rate of 5 r.p.m.

Summaries of the characteristics of the several detectors on these satellites are given in Tables 1 and 2.

DATA

Telemetered data from the two satellites were received by a number of ground stations and recorded on magnetic tape. These were merged with the ephemerides given by the Goddard Space Flight Center of NASA.

For Injun IV, a master tape was prepared which contained eight second averages of the experimental data and other relevent parameters of the orbits such as B, L, etc. For OGO-1, the date have been plotted from a plot program from the merged tapes.

The period of this study is from April 16, 1965 to May 1, 1965. For this period Injun IV data are available for 3-4 early morning (0300 to 0530 hours local time) northbound passes in the northern hemisphere at a mean height range of 2,200 Km for each day and for 3-4 afternoon (1400-1600 hours local time) southbound passes at a mean height of 900 Kms in the northern hemisphere.

OGO-1 sampled different sections of the magnetosphere once every 64 hours, corresponding to its orbital period. For this satellite, data are studied for the period, April 17 - April 27, 1965. On the magnetospheric tailside data are available for April 17 (orbit 83-out), April 19 (orbit 84-out), April 22 (orbit 85-out), and April 25 (orbit 86-out). These data are all for satellite local time 00-03 hours and for a magnetic latitude range 30° - 48°.

On the sunward side data are available for April 19 (orbit 83-in) and April 27 (orbit 86-in). These data correspond to local time ~08 hours and magnetic latitude ~9°.

These data form the basis of this analysis.

RESULTS

Injun IV Results

Trapped Electrons (Local Time 0300-0530 Hours)

Data are obtained from the 213-B detector. Data for a sequence of northbound passes between April 17 and April 30, 1965 for local time 0300-0530 hours and for a mean altitude 2,200 Km are plotted against the invariant latitude, λ, (defined by $L \cos^2\lambda=1$) and shown in Figure 1. The pass for April 17 shows a typical quiet-day profile with a well defined high latitude cutoff boundary at $\lambda \sim 72°$ and a deep 'slot' at 61° with two clear-cut zones of particle concentration. In the following discussions the zone up to $\lambda \sim 61°$ will be referred to as zone 1 and the one from $\lambda \sim 61°$ to the cutoff boundary as zone 2. On April 18, the storm day, there is a 'catastrophic' inward movement of the boundary to a latitude of 65° and a complete filling up of the whole region up to this boundary, with a peak intensity of the particles at the latitude corresponding to the position of the slot on the previous day. After the peak value is reached, the fall in intensity with increase in latitude is precipitous, being by three orders of magnitude within 3° of latitude. The profile for April 19 shows a tendency for the formation of the slot with peaks on either side. The peak which was at 62° on April 18 has moved out by 5° to $\lambda \sim 67°$ and the cutoff boundary has moved to $\lambda \sim 75°$, which is 2-3° higher than the normal cutoff value. The pass for April 20 is similar to that on April 19, except that the latitudes of peak intensity and cutoff have moved in again by about 2°. The next two passes which are for April 23 and April 25 show the gradual decay of electrons in zone 2. The last two passes, for April 28 and April 30, show the possible formation of a new zone 2 by freshly injected electrons super-imposed on decay of the storm induced electrons. Due to malfunctioning of the 213B counter after April 30, the complete formation of zone 2 and the slot between zones 1 and 2 cannot be completely traced.

The variations in the profiles for four different passes (early morning local time) between 0500-1300 U.T. on April 18 are examined in more detail in Figure 2. The first pass at 0515 U.T., corresponding to a reduction of $\sim 50\ \gamma$ in D_{st} field, indicates that the boundary has already moved in to about 68° from 73° (on the previous day) and that the slot disappeared giving rise to a broad peak between 60° - 68°. The second pass at $\sim$ 0900 U.T., which very nearly corresponds to the maximum depression in D_{st} field shows a further inward movement of the boundary to 65° and a narrowing of the peak. The pass at 1050 U.T., which is about an hour and a half after the maximum depression, shows a slight outward movement of the boundary; and this tendency is continued in the next pass at 1250 hours. On this day there was also a magnetic bay between 0620-0800 U.T. However, the moving in of the boundary and a large apparent injection of particles is already evident in the pass at 0515 hours. These are indications that the changes observed on the morning of April 18 were mainly due to the magnetic storm.

A correlation study of the variation of the cutoff boundary latitude with D_{st} field for the period April 16 - April 23 is presented in Figure 3. The D_{st} variation is based on magnetograms from eight stations. The cutoff latitude, λ_c, is shown for all available good passes, which are similar in local time and mean altitude. On April 16 and April 17, two days prior to the storm, λ_c for different passes on each day varies by less than 1° and is quite stable; though between the two days, it varied by 2-3°. On the storm day, April 18, λ_c closely follows the D_{st} variation and is also anti-correlated with the 3 hour K_p index. On April 19, the boundary has moved out to a high value of $\lambda_c \sim 74°$ (higher than the normal value) for the pass at $\sim$ 1000 U.T. But for the next two passes at $\sim$ 1200 and $\sim$ 1600 U.T., λ_c has suddenly come down to 68°. This sudden change is attributable to a strong polar substorm, observed at College, Alaska, and the fact that the 3 hour K_p indices also showed increases on the afternoon and evening on that day. Subsequent days show near normal and stable values of the boundary.

The significant injection of electrons during the main phase of the storm and their subsequent decay at different L values are studied in Figure 4. To investigate any possible dependence of the population of different shells on magnetic activity during this period, values of ΣK_p, the daily sum of the 3 hour K_p indices, are also shown in the Figure. At L = 2, the intensity on the storm day is half or less than half its value on the pre-storm days; during subsequent days, the intensity gradually recovers towards normal values. The sudden decrease corresponds to the sudden increase in ΣK_p, from the pre-storm days to storm day. Thereafter, the gradual decrease is not similar to ΣK_p variation.

At L = 4, there is a dramatic increase in population on storm day and the post-storm decrease is also rapid until April 28. On the next day, however, there is a sudden increase again, indicative of a possible fresh inward diffusion of electrons. This becomes evident as we consider the population at higher L values. Variation at

L = 5 is similar but not as dramatic as at L = 4. Post-storm similarity between Σk_p and intensities is not good for these L values also.

At L = 6 the intensity falls on the storm day due to the inward movement of the boundary but on the next day there is a sudden increase due to the outward movement of the boundary and the consequent redistribution of the particles. Also, the second peak, which was observed on April 29 at L = 4, is observed at an earlier date, April 27, at this value of L. This may possibly be considered due to inward diffusion of freshly injected electrons

At L = 7 the intensity goes down to zero on the storm day since the boundary has moved to a lower L value, but on the next day it reaches a high value and decreases thereafter. A second broad peak between April 26 and April 30 is also present. Variation at L = 8 is generally similar to that at L = 7.

From the above observations of the second peak, we may infer that there has been an apparent diffusion of electrons from $L \sim 7$ to $L \sim 4$, the rate of such a diffusion being approximately one unit of L per day, leading to the formation of a new zone 2.

Also, if we assume that the storm induced electron decay can be represented by an exponential law $e^{-t/\tau}$ for L = 3, 4, and 5, as suggested by the approximately linear form of the curves in Figure 4, the period τ for the different values of L is as follows:

At L = 3	$\tau \sim 4.5$ days
At L = 4	$\tau \sim 8$ days
At L = 5	τ 9 days

The larger values for L = 4 and L = 5 reflect the part that the intensity increase is maximum at those L values on the storm day.

Trapped Electrons (Local Time 1400-1600 hours)

Data from the 213-B detector for a series of similar south-bound passes at a mean altitude of 1000 Km are studied in this section. In Figure 5 are shown the plots for these passes for the period, April 16 to May 1, 1965.

The pass for April 16 is a typical quiet day one with a slot at $\lambda = 62°$ and the cutoff boundary at $\lambda = 76°$. This value for the cutoff boundary is higher than that for the early morning passes discussed in the previous section and is due to its local time dependence [Frank, Van Allen, and Craven, 1964]. But for this difference, the latitude variation is generally similar to the one at the higher altitude discussed in the previous section with two clear zones of concentration of electrons (zones 1 and 2). The profile for April 17 is similar to that on April 16 with boundary near $\lambda \sim 75°$, where the count rate comes down by one order of magnitude; however, the count rate goes up again to high values at higher latitudes. Such a phenomenon is observed on some other days also and appears to be similar to the 'spikes' reported by McDiarmid and Burrows [1966]. It is being investigated separately. On April 18, the 'slot' has disappeared completely and there is large concentration up to $\lambda \sim 72°$ and a rapid fall thereafter, leading to a cutoff near $\lambda \sim 75°$. The inward movement of the boundary is not present here since this pass was about 14 hours after the start of the maximum phase. The next few curves show the decay of the storm electrons and the formation of a new zone 2. These are similar to the case discussed previously and so are not considered in detail.

Precipitated Electrons (Local Time 0300-0530 hours)

The details of the passes considered here are the same as for trapped electrons for the local time period. Data analysed are those from the detector 213-D.

If it is assumed that the precipitated electrons get lost at a height of 100 Km, then the necessary condition for this detector to measure precipitated electrons is $\sin^2\alpha = B/B_{100}$ from the adiabatic invariant condition, where B_{100} is the value of B at 100 Km altitude for the longitude and L values of the satellite and α is the half angle of the cone of precipitated particles. Since this detector (D) was aligned at an angle of 160° to the $\vec{B}$ vector and had a viewing half angle of 20°, it could be considered as looking at particles within a cone of 40° with respect to the field line. For the satellite positions considered, this angle is about the same as that required to satisfy the invariant condition. We may therefore presume that this detector was essentially looking at precipitated electrons.

The intensity profiles of a set of similar passes between April 17 and April 30 are presented in Figure 6.

The profile for April 17 is representative of quiet day with a peak between $\lambda = 45°-50°$. On some other quiet days, however, there is a tendency for a small peak at $\lambda \sim 62°$. The cutoff boundary is near $\lambda \sim 69°$. On April 18 the main features are a decrease in intensity at lower values of λ, a sharp increase (by more than two orders of magnitude) near $\lambda \sim 60°$, and an inward movement of the cutoff boundary by $\sim 2°$. The pass for the next day shows that the previous day's peak has moved out and also increased in intensity. Simultaneously, the boundary has moved to $\lambda \sim 75°$ (which is much higher than normal). A secondary peak is also visible at $\lambda \sim 56°$. The pass for April 20 shows the general decay of the peaks and a slightly inward movement of the boundary. By April 25 the two peaks have dropped considerably. The pass for April 28 indicates a further decay at low λ values and the appearance of a new peak at $\lambda \sim 62°$, which is possible evidence of fresh injection of electrons. On April 30, the intensity increases at lower λ and decreases at higher λ values due to the inward diffusion of the freshly injected electrons, and the profile on this day is more or less normal.

The variations of the cutoff boundary on different days is similar to those of trapped electrons and are not considered in detail.

The build-up of precipitated electrons during the storm and their post-storm decay at different L values are shown in Figure 7. At $L = 2$ and $L = 3$ the intensities fluctuate day to day, and no clear trends are visible, except for a decreasing tendency at $L = 3$. At $L = 4$, the intensity increases by more than one order of magnitude on storm day and thereafter fluctuates with a general tendency for decrease.

At $L = 5$ and $L = 6$, the increase on storm day is dramatic and is more than two orders of magnitude. After the storm day, the decrease is also rapid up to April 25. A second peak appears at these L values by the 28th.

At $L = 7$ and $L = 8$, the intensity goes to zero on the storm day due to the inward movement of the cutoff boundary to lower L values; however, on the next day it reaches high values and then gradually decays up to 26th. The second peak is apparent at these L values also.

OGO-1 Results

Though data plots for all the detectors on board this satellite are shown in the following figures, the results discussed refer to detectors A_1, A_2, B_1, B_3, and C only.

Observations on the Magnetospheric Tail Side

April 17, 1965 (Orbit 83-out): Data and position coordinates are shown in Figure 8. The count rates for A and B counters remain steady up to L = 7.5 and thereafter reach background values and remain so up to high L values. For counter C the fall in count rate is gradual and cutoff is at a lower L value ~ 7. Electron intensities at L ~ 6 and L ~ 7 are as follows:

E	L ~ 6	L ~ 7
$\gtrsim$ 40 keV	2×10^5	1.9×10^5 $(cm^2\text{-sec-sr})^{-1}$
$\gtrsim$ 150	3.5×10^4	10^4

April 19, 1965 (Orbit 84-out): This corresponds to one day after the maximum phase of the storm. Data are available from L ~ 7 and are shown in Figure 9. From this value of L, count rates of A detectors fall off gradually, unlike in the previous orbit when the fall off was sudden and rapid, and reach background values at L ~ 9.5. At L ~ 7, count rates of B are lower than those of A. The variation of count rates of C is similar to that of the previous orbit; and the cutoff boundary has also not changed and remains at L ~ 7. The count rates of A and B remain at background values until L ~ 12 and start increasing again until they reach a maximum at L ~ 14.5, the intensity of which is comparable to that at L ~ 7. They diminish to low values at L ~ 16.5 but again show another concentration between L ~ 16.5 and L ~ 21. Thereafter, they remain at background values again. It would be observed that in these variations the rates of B are much lower than those of A and that the count rate of C does not show such variations at all once the cutoff boundary is reached at L ~ 7.

From these observations it is clear that the extension of the cutoff boundary on this orbit compared to that on the previous orbit was mainly for low energy particles and that the 'islands' were also of low energy particles.

The electron intensities at L ~ 7 on this day are as follows:

$E \gtrsim 40$ keV	3×10^5 $(cm^2 - sec - sr)^{-1}$
$E \gtrsim 150$	3×10^3

Compared to the values of the previous orbit, the intensity of electrons E $\gtrsim$ 40 keV is higher, while that of electron E $\gtrsim$ 150 keV is lower, which again indicates predominence of low energy particles in this orbit.

April 22, 1965 (Orbit 85-out): Figure 10 shows the data plots for this orbit. No data are available between L ~ 6.9 and L ~ 9, so that the exact position of the boundary cannot be delineated. However, from the fact that count rates were substantial at L ~ 6.9 and at background values at L ~ 9 for A and B counters, one can say that the boundary terminated between these two values of L. So far as counter C is concerned, its count rates are near zero at L ~ 6.9 and so its boundary has not changed appreciably.

On this orbit no electron 'islands' are seen at high L values.

April 25, 1965 (Orbit 86-out): Counter data and position co-ordinates are shown in Figure 11. Count rates for A and B start falling before L ~ 8 and reach background values at that value. For Counter C the termination is at L ~ 7. No electron 'islands' are seen in this orbit also.

Observations on the Sunward Side

April 19, 1965 (Orbit 83-in): In Figure 12, which shows the data, it would be seen that the count rates of A and B detectors are steady up to $L \sim 12$ and then they suddenly go down by two orders of magnitude indicating that the magnetospheric boundary has been approached. The detector C shows a gradual decrease and cutoff at $L \sim 11.2$.

After $L \sim 12$ and up to $L \sim 14$ for which data are available, the variations are large and erratic, typical of the transition region.

April 27, 1965 (Orbit 86-in): Figure 13 shows this pass. Count rates of A detectors come down to low values at $L \sim 12.7$ corresponding to the approach of the magnetospheric boundary. The fall in count rate of B is more gradual but the cutoff is same as that of A. For detector C the count rate starts diminishing from $L \sim 5$ and gets cut off at $L \sim 12$. Beyond $L \sim 12.7$, the fluctuations are again wide, indicating the transition region.

SUMMARY AND DISCUSSION

High Latitude Observations From Injun IV

Trapped Electrons (Local Time 0300-0530 Hours)

1) The high latitude cutoff boundary shows a rapid movement to lower invariant latitude, the change being as much as 8° at the maximum phase of the storm; it moves back again towards normal values after the maximum phase is over.

2) On the storm day the cutoff boundary follows closely the D_{st} variation.

3) During the post-storm period, the cutoff latitude is directly correlated with D_{st} and inversely with the 3-hour K_p index.

4) On a quiet day, the intensity profile has a deep 'slot' at $\lambda \sim 62°$ showing two clear zones of concentration of particles (Zones 1 and 2). Simultaneously with the moving in of the boundary during the storm, the 'slot' disappears and instead, becomes a peak; however, no correspondence is evident between the re-appearance of the slot and the K_p index during the post-storm period. The latter appears to be unrelated to the variation of intensities in and around the region of the 'slot', once the 'slot' is filled up during the maximum phase of the storm.

5) Electrons apparently injected by the storm into the 'slot' region and zone 2 decay according to the exponential law $e^{-t/\tau}$, where the period τ is 4.5, 8 and 9 days respectively for $L = 3$, 4, and 5.

6) There is presumptive evidence of injection and inward diffusion of fresh electrons during the post-storm period, which lead to the formation of the normal quiet day zone 2.

Trapped Electrons (Local Time 1400-1600 Hours)

1) Variations are generally similar to those of trapped electrons in the local early morning period, except that the cutoff boundary is at a higher latitude, which is due to the well established diurnal variation.

2) 'Islands' of electrons are observed on some days during the period of interest. These, however, need further analysis.

Precipitated Electrons (Local Time 0300-0530 Hours)

1) The inward movement of the boundary during the storm and its variation with K_p index are similar to those of trapped electrons.

2) A large concentration of these electrons is found at higher latitudes after the storm, and it is found to decay rapidly during the post-storm period.

Based on the magnetospheric model of Williams and Mead [1965], Williams and Ness [1966] have suggested that the inward movement of the cutoff boundary during a magnetic storm is due to additional formerly closed lines of force being extended well out into the tail region, thereby increasing the tail field magnitude and lowering the trapping boundary. An alternate possibility is the raising of mirror points due to gradual expansion of field lines under conservation of the first two adiabatic invariants, which would produce a relatively smooth change in the trapping boundary. From Figures 2 and 3, where it has been shown that the boundary changes closely follow the D_{st} variation on the storm day, it appears that the changes in the boundary are smooth rather than abrupt and discontinuous as stated by Williams [1966].

Further, a study of the temporal variation of protons $E > 500$ keV [Krimigis, A.G.U., Paper, April 1967]. has shown that the trapping boundary for these protons, which is generally at $\lambda \sim 64°$, also moves inward by 4°- 5° during the maximum phase of the storm and recovers again after the maximum phase is over. Since the quiet day value of cutoff for protons is already lower than the storm day value for electrons, a further inward movement of the proton boundary on storm day cannot be explained by the opening of field lines. These observations indicate that possibly a general compression of the lines of force also takes place which could be brought about by the large influx of particles in the solar wind, upsetting the balance between the magnetic field energy and the solar wind energy.

It has also been observed that the cutoff boundary for electrons $E > 40$ keV is quite sensitive to auroral and polar substorms and moves in by as much as $3°$ during such periods. Such an effect occurring during a magnetic storm may accentuate the inward movement of the boundary.

Though no generalizations are sought to be made by the analysis of a single storm, the above observations need to be considered in establishing a definite theory.

While the movement of the boundary shows correlation with D_{st} variation and K_p index during the storm and post-storm periods, such a correlation is not apparent in the reappearance of the 'slot' during the post-storm period. When once the 'slot' gets filled up during the storm, the K_p index appears to be unrelated to the variation of electron intensities and can no longer be considered as an index of activity for the outer zone electrons until conditions return to normal after a period of time. The storm induced electrons decay in an exponential manner and it appears that a new zone is formed by fresh electron injection. In this connection, it is also relevant to point out that on quiet days the proton intensities go down to very low values near the latitude corresponding to the slot for electrons; zone 2 can, therefore, be considered as one of low energy electrons. The particles which fill up the 'slot' and higher latitudes during the storm are mainly low energy electrons. Similar evidence is obtained for low latitudes from OGO-1 observations later in this section.

OGO-1 Observations

Magnetospheric Tail Side

1) One day previous to the storm, the boundary for electrons $E > 40$ keV and $E >$ keV terminates suddenly at $L \sim 7.5$ at lower latitudes. However, one day after the storm, this boundary extended up to $L \sim 9.5$ and terminated gradually. After this termination, strong electron 'islands' were seen between $L \sim 15$ and $L \sim 21$.

2) Four days after the storm the boundary was at an L value less than 9 and no electron islands were observed; a week after the storm the boundary was at $L \sim 8$.

3) Electrons $E > 1.6$ MeV did not show any significant change in the boundary or any 'islands' during those orbits.

4) From the above observations, it appears that the extended boundary and the 'islands' were mainly due to lower energy particles.

5) Data for electrons $E > 40$ keV from Vela 2A satellite which was orbiting on the tail side at a distance of 17.3 earth radii during this period also show similar phenomenon. Strong electron spikes are seen between 2315-0015 hours (magnetospheric latitude -9°, longitude 144°) on April 19 and 20 and between

0230-0330 hours (magnetospheric latitude -5°, longitude 155°) on April 20. This is shown in Figure 14.

The relation of electron islands in the magnetospheric tail to magnetic field changes has been studied by Anderson [1965] and Anderson and Ness [1966]. Akasofu [1966] has suggested the neutral sheet instability as a possible cause for the occurrence of particles at very high latitudes during the expansive phase of an auroral substorm and Hones et al. [1967] have found correlation between the existence of electron spikes seen by Vela and magnetic bays. Ness [1965] also suggests that the neutral sheet in the magnetospheric tail is a possible source of energetic particles.

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TABLE I

Characteristics of Injun IV Detectors

Designation	213B	213D
Axis of viewing cone with reference to $\vec{B}$ vector:	90°	160°
Viewing cone half angle:	40°	20°/40°
Window Shielding	⟵ mica - 1.2 mg/cm^2 ⟶	
Energy Threshold Window: E_e (keV)	40	40
E_p (keV)	500	500
Directional Geometric Factor (cm^2 - sr)	1.6×10^{-2}	1.0×10^{-2}

TABLE II

Characteristics of OGO-1 Detectors

Designation	A_1	A_2	A_3	B_1	B_2	B_3	C
Viewing cone half angle	30	20	27	28	35	35	--
Window Shielding	← 1.2 mg/cm^2 - mica →			← 1.2 mg/cm^2 - mica +10.2 mg/cm^2 Al			
Wall Shielding		2.8 g/cm^2			2.8 gm/cm^2		0.91g/cm^2
Energy Threshold							
(Window) E_e		$\gtrsim$ 40 keV			$\gtrsim$ 150 keV		
E_p		$\gtrsim$ 500 keV			$\gtrsim$ 3.6 MeV		
(Wall)		--			--		$E_e \gtrsim$ 1.6 MeV $E_p \gtrsim$ 1.6 MeV
Geometric Factor (Directional cm^2-sr)	$2.9x10^3$	$1.85x10^{-3}$	$2.1x10^3$	$1.55x10^{-2}$	$2.1x10^{-2}$	$1.55x10^{-2}$	
Omni-directional (cm^2)	--	--	--	--	--	--	0.56

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FIGURE CAPTIONS

Figure 1: Temporal variation of intensities of trapped electrons $E > 40$ keV at local time between 0330-0530 hours during the period April 17 - April 30, 1965.

Figure 2: Variation of intensities of trapped electrons for four passes on April 18, 1965.

Figure 3: Variation of the high latitude cutoff boundary of trapped electrons with D_{st} and 3-hour K_p index.

Figure 4: Temporal variation of the intensity of trapped electrons at different L values at local time 0300-0530 hours during the period April 14 - April 30, 1965.

Figure 5: Temporal variation of intensities of trapped electrons $E > 40$ keV at local time 1400-1600 hours during the period April 16 - May 1, 1965.

Figure 6: Temporal variation of intensities of precipitated electrons $E > 40$ keV at local time 0330-0530 hours during the period April 17 - April 30, 1965.

Figure 13: Count rate data for the different counters and the position coordinates for OGO-1 on April 27, 1965 (Orbit 86-in).

Figure 14: Data for Vela 2A satellite corresponding to orbit 84-out of OGO-1, when the latter was seeing strong electron islands at high values of L.

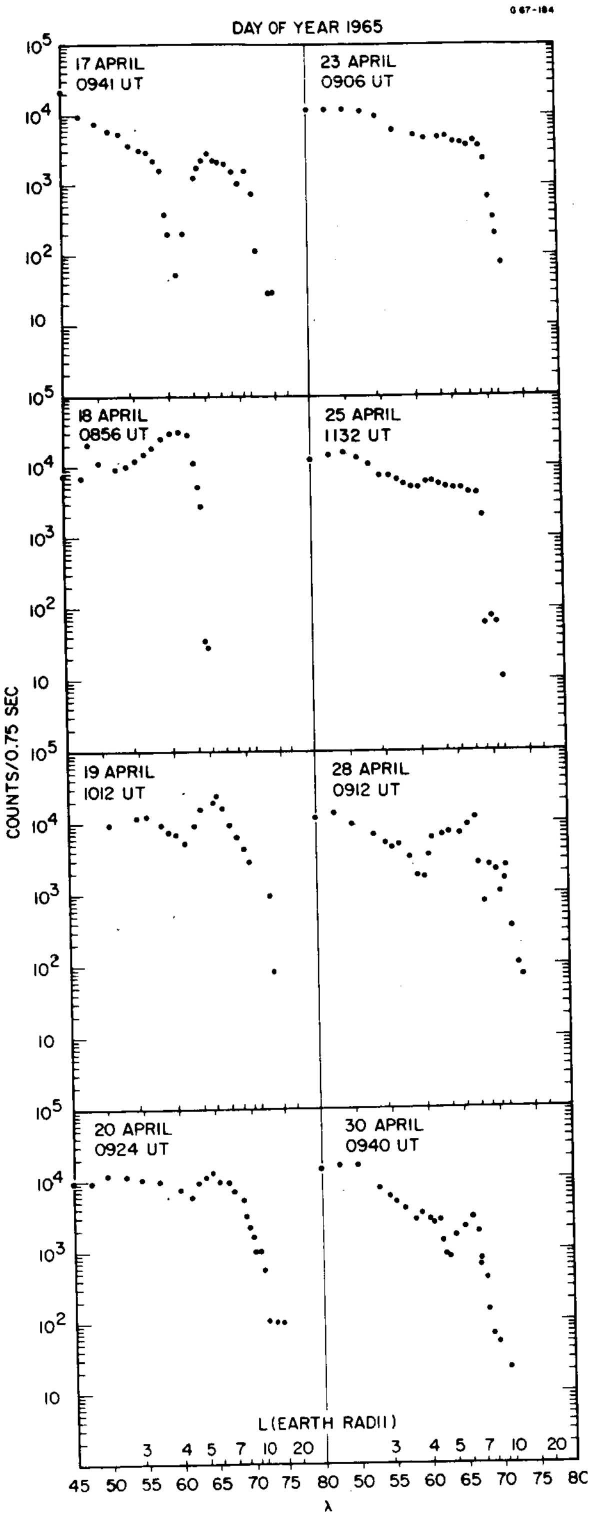
G 67-184
DAY OF YEAR 1965
17 APRIL
0941 UT
23 APRIL
0906 UT
18 APRIL
0856 UT
25 APRIL
1132 UT
19 APRIL
1012 UT
28 APRIL
0912 UT
20 APRIL
0924 UT
30 APRIL
0940 UT
COUNTS/0.75 SEC
L (EARTH RADII)
λ

FIGURE 1

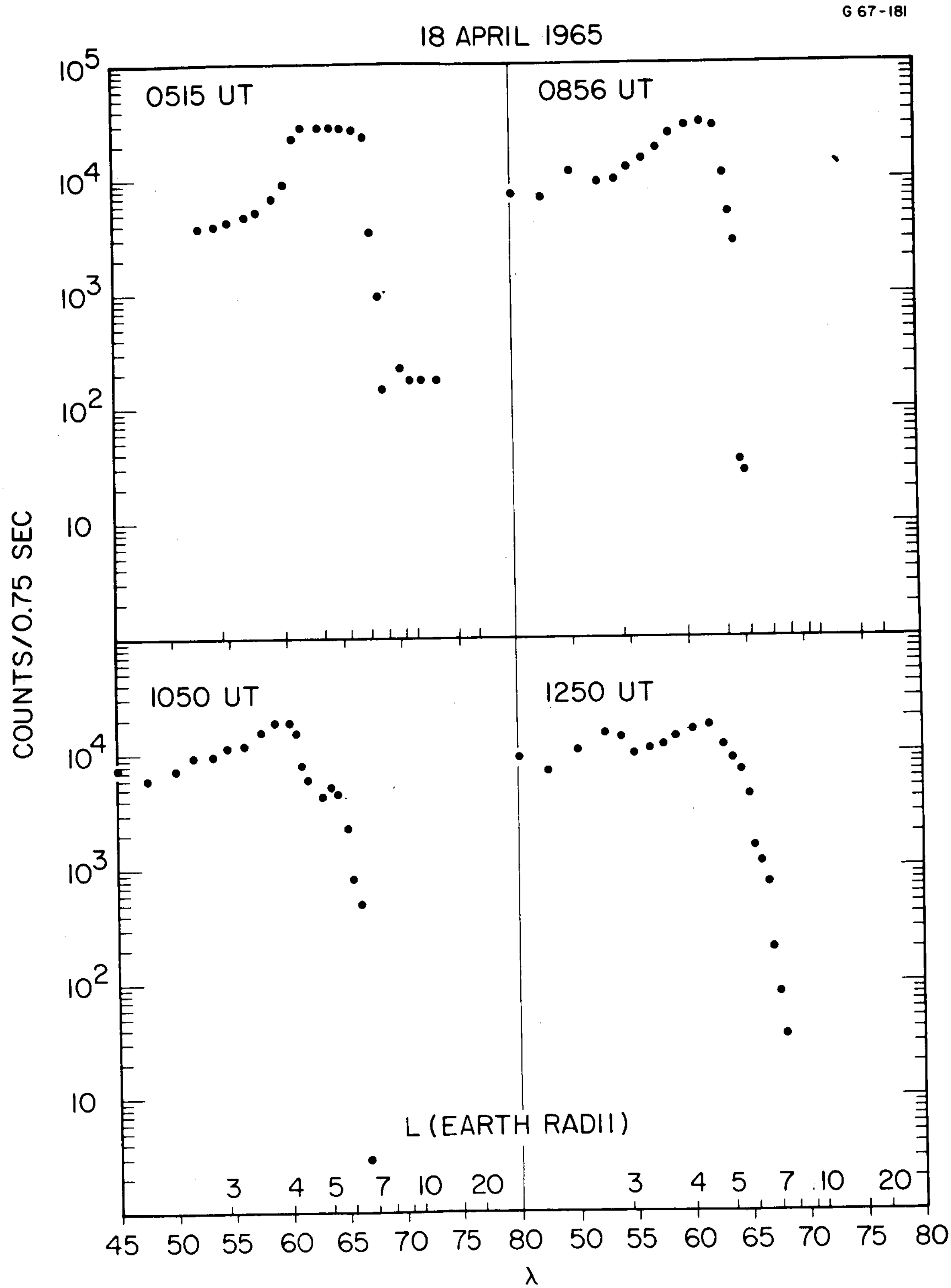
G 67-181
18 APRIL 1965
0515 UT
0856 UT
1050 UT
1250 UT
COUNTS/0.75 SEC
10^5
10^4
10^3
10^2
10
L (EARTH RADII)
3 4 5 7 10 20
3 4 5 7 10 20
45 50 55 60 65 70 75 80 50 55 60 65 70 75 80
λ

FIGURE 2

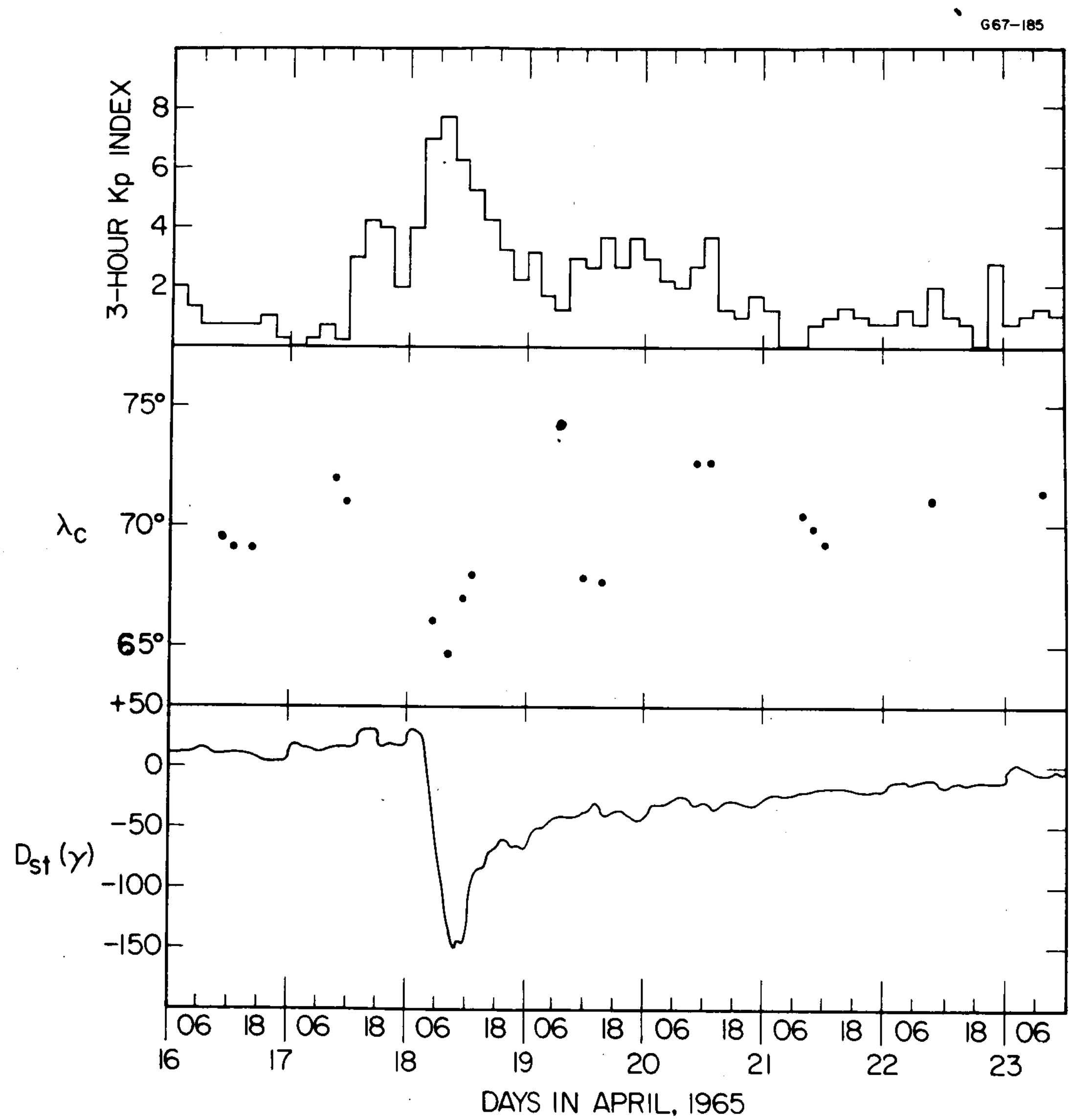
G67-185
3-HOUR Kp INDEX
8
6
4
2
λ_c
75°
70°
65°
D_{st} (γ)
+50
0
-50
-100
-150
06 18 06 18 06 18 06 18 06 18 06 18 06 18 06
16 17 18 19 20 21 22 23
DAYS IN APRIL, 1965

FIGURE 3

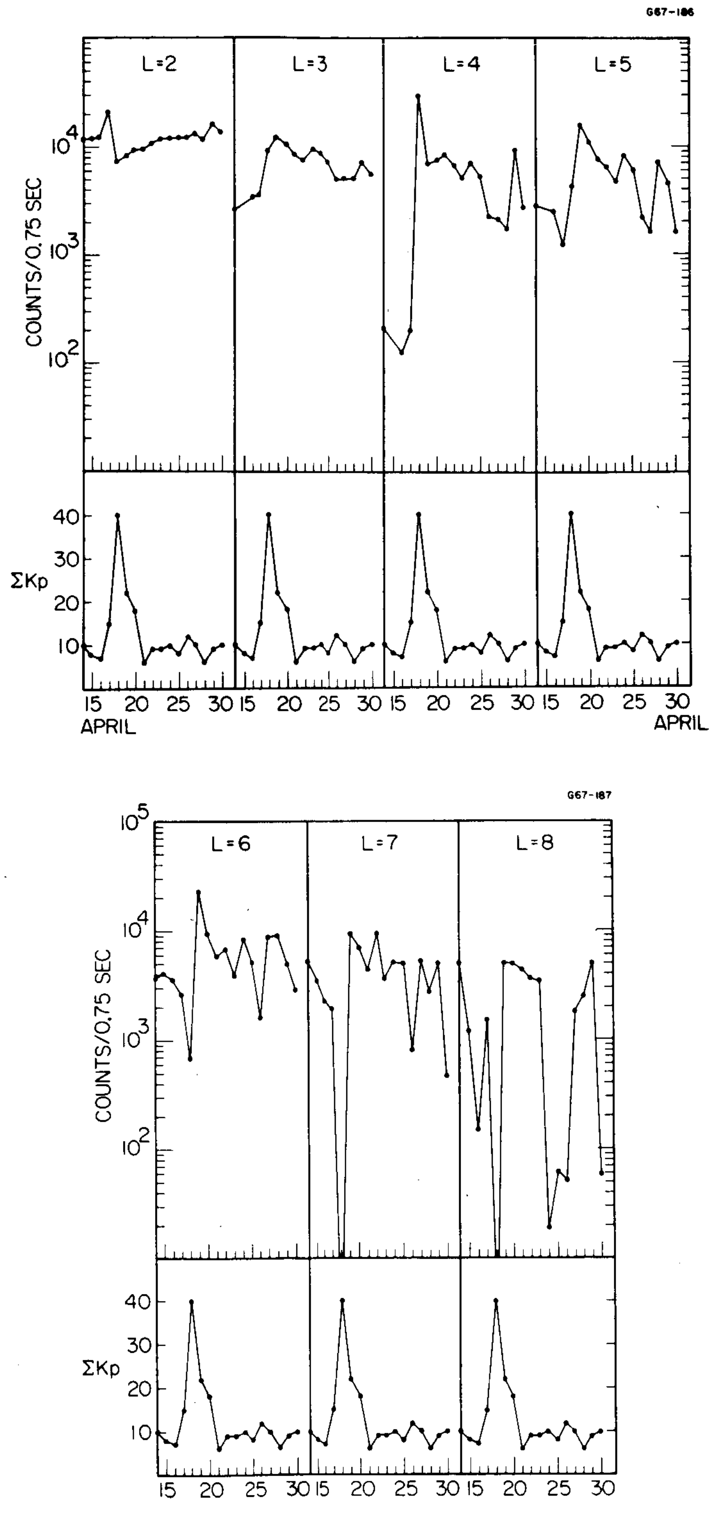
G67-186
L=2
L=3
L=4
L=5
COUNTS/0.75 SEC
10^4
10^3
10^2
ΣKp
40
30
20
10
15 20 25 30 15 20 25 30 15 20 25 30 15 20 25 30
APRIL
APRIL
G67-187
10^5
L=6
L=7
L=8
COUNTS/0.75 SEC
10^4
10^3
10^2
ΣKp
40
30
20
10
15 20 25 30 15 20 25 30 15 20 25 30

FIGURE 4

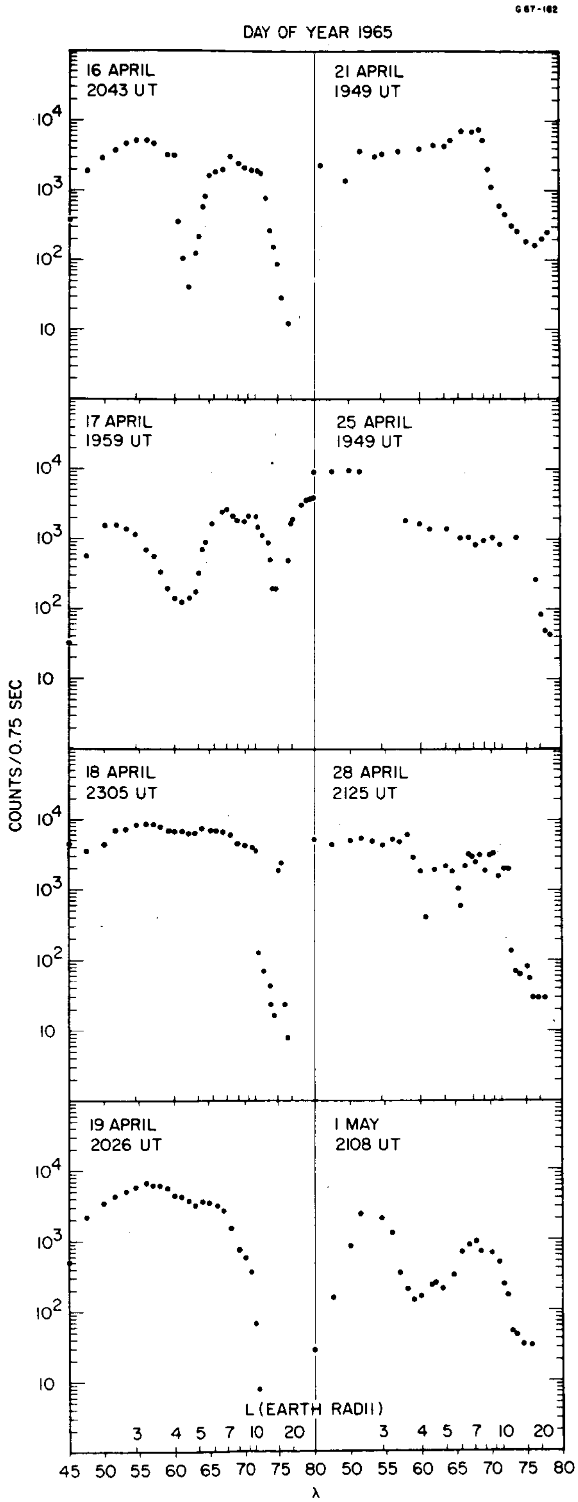
G67-182
DAY OF YEAR 1965
16 APRIL
2043 UT
21 APRIL
1949 UT
17 APRIL
1959 UT
25 APRIL
1949 UT
18 APRIL
2305 UT
28 APRIL
2125 UT
19 APRIL
2026 UT
1 MAY
2108 UT
COUNTS/0.75 SEC
10^4
10^3
10^2
10
L (EARTH RADII)
3 4 5 7 10 20
45 50 55 60 65 70 75 80 50 55 60 65 70 75 80
λ

FIGURE 5

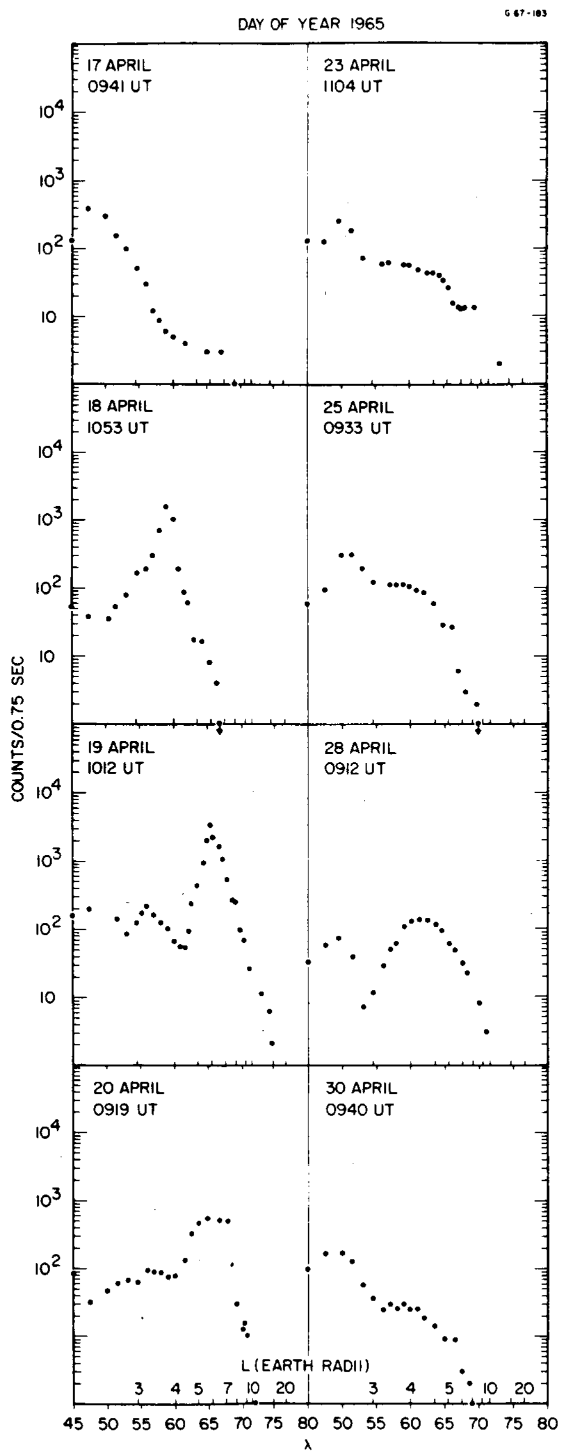
G 67-183
DAY OF YEAR 1965
17 APRIL
0941 UT
23 APRIL
1104 UT
18 APRIL
1053 UT
25 APRIL
0933 UT
19 APRIL
1012 UT
28 APRIL
0912 UT
20 APRIL
0919 UT
30 APRIL
0940 UT
COUNTS/0.75 SEC
10
10^2
10^3
10^4
L (EARTH RADII)
3 4 5 7 10 20
3 4 5 10 20
45 50 55 60 65 70 75 80 50 55 60 65 70 75 80
λ

FIGURE 6

G 67-190

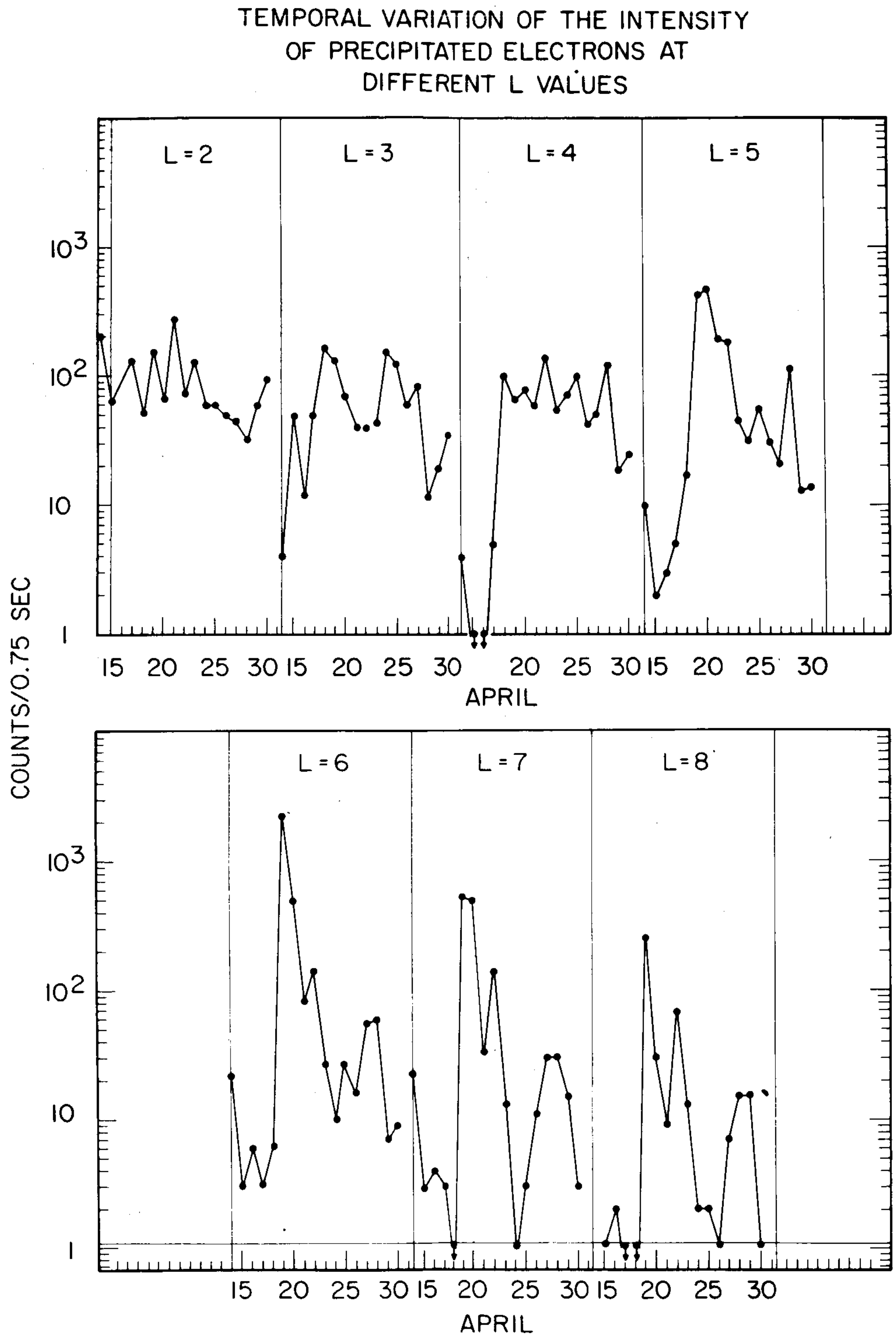

FIGURE 7

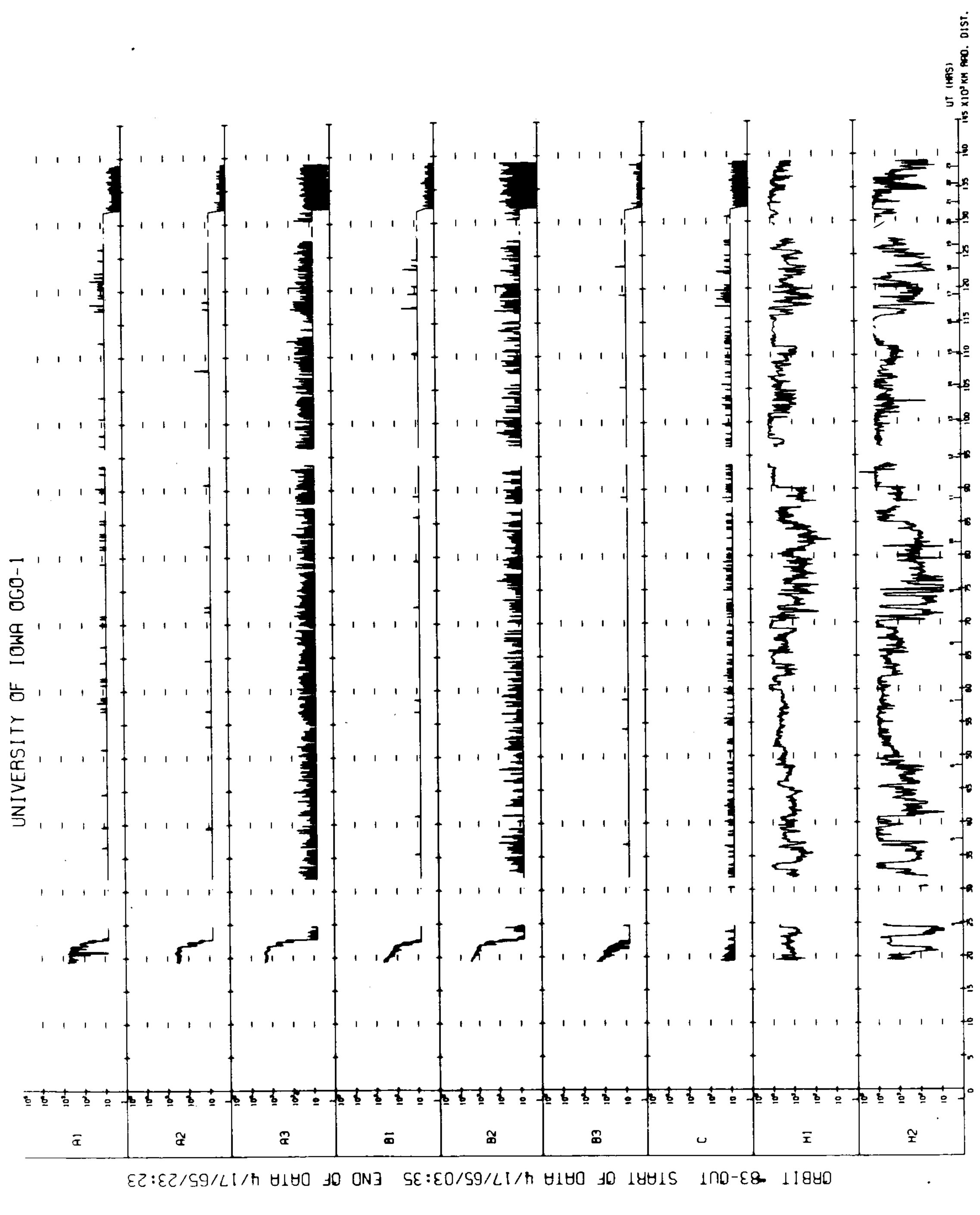
UNIVERSITY OF IOWA OGO-1
ORBIT 83-OUT START OF DATA 4/17/65/03:35 END OF DATA 4/17/65/23:23
A1
A2
A3
B1
B2
B3
C
H1
H2
UT (HRS)

FIGURE 8

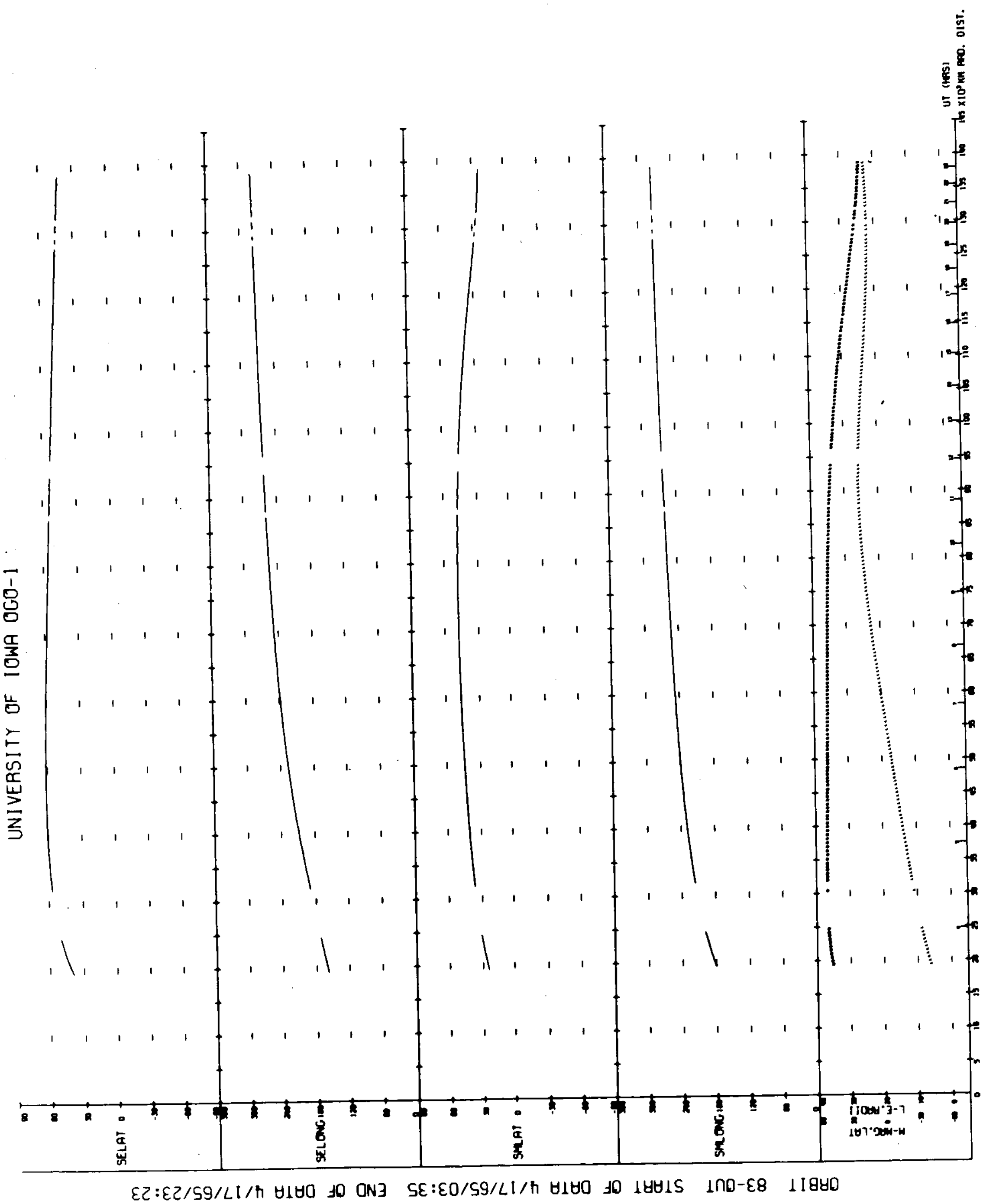

FIGURE 8 (Con't)

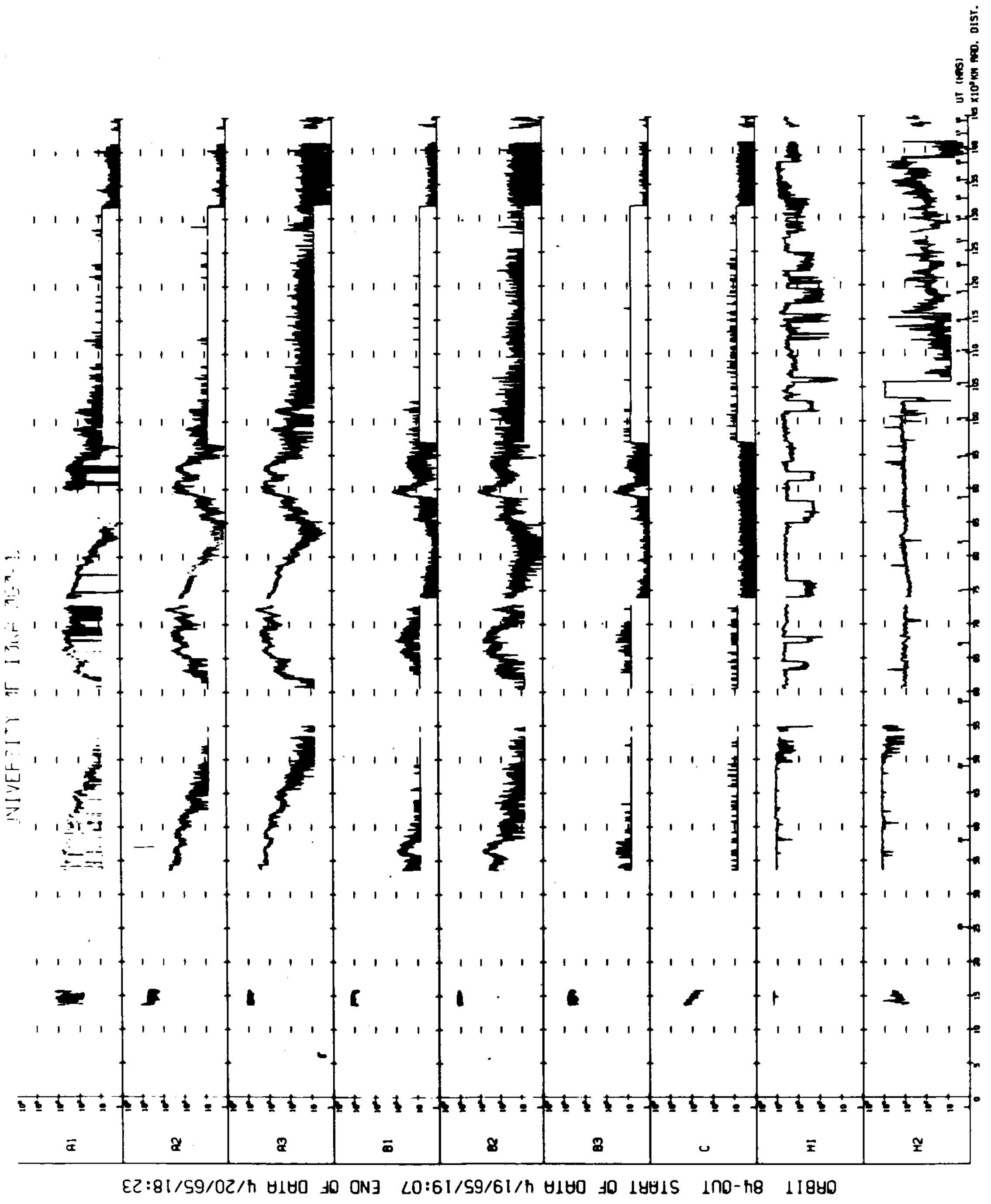
A1
A2
A3
B1
B2
B3
C
H1
H2
UT (HMS)
HS X10⁴KM RAD. DIST.
ORBIT 84-OUT START OF DATA 4/19/65/19:07 END OF DATA 4/20/65/18:23

FIGURE 9

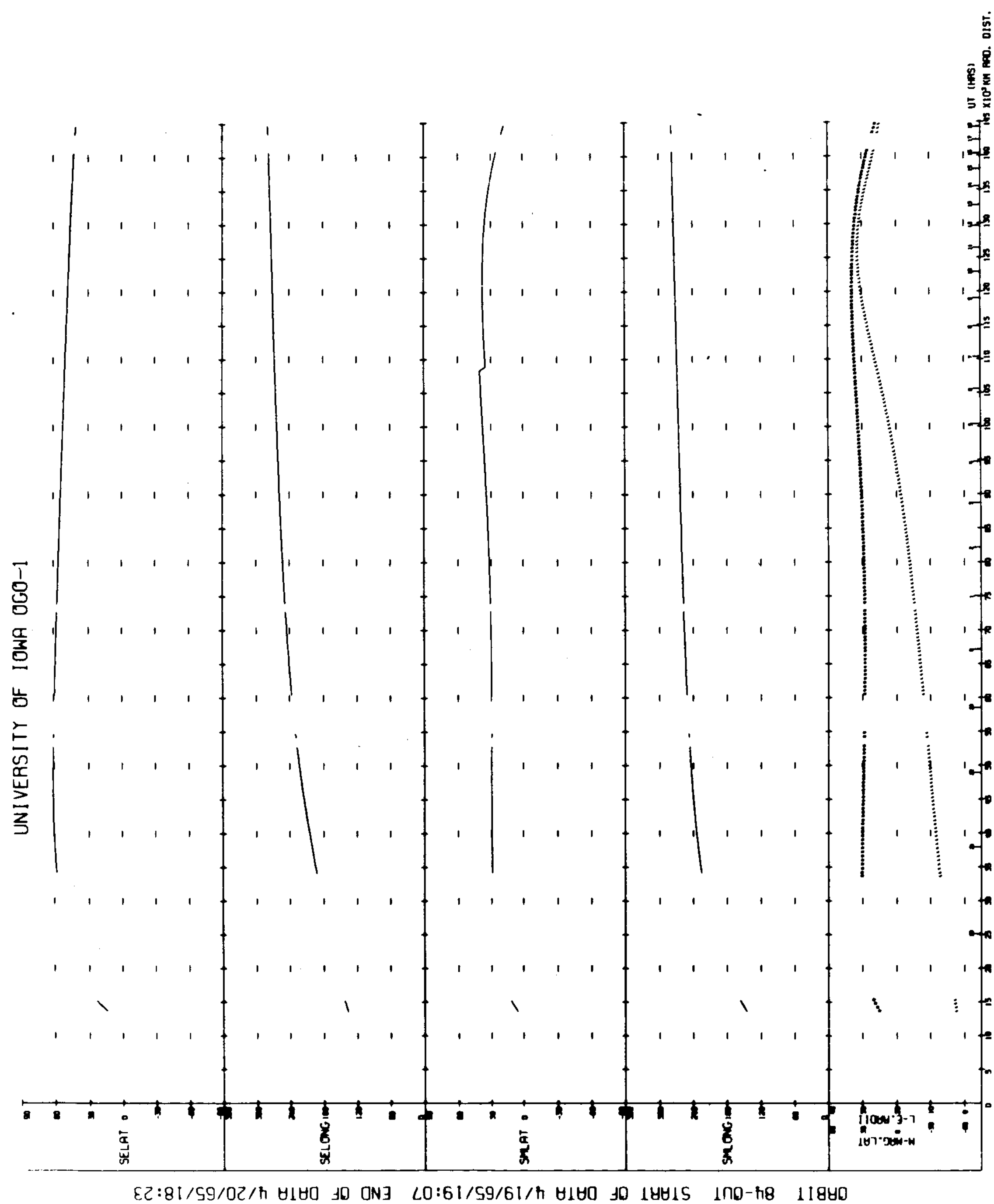

FIGURE 9 (Con't

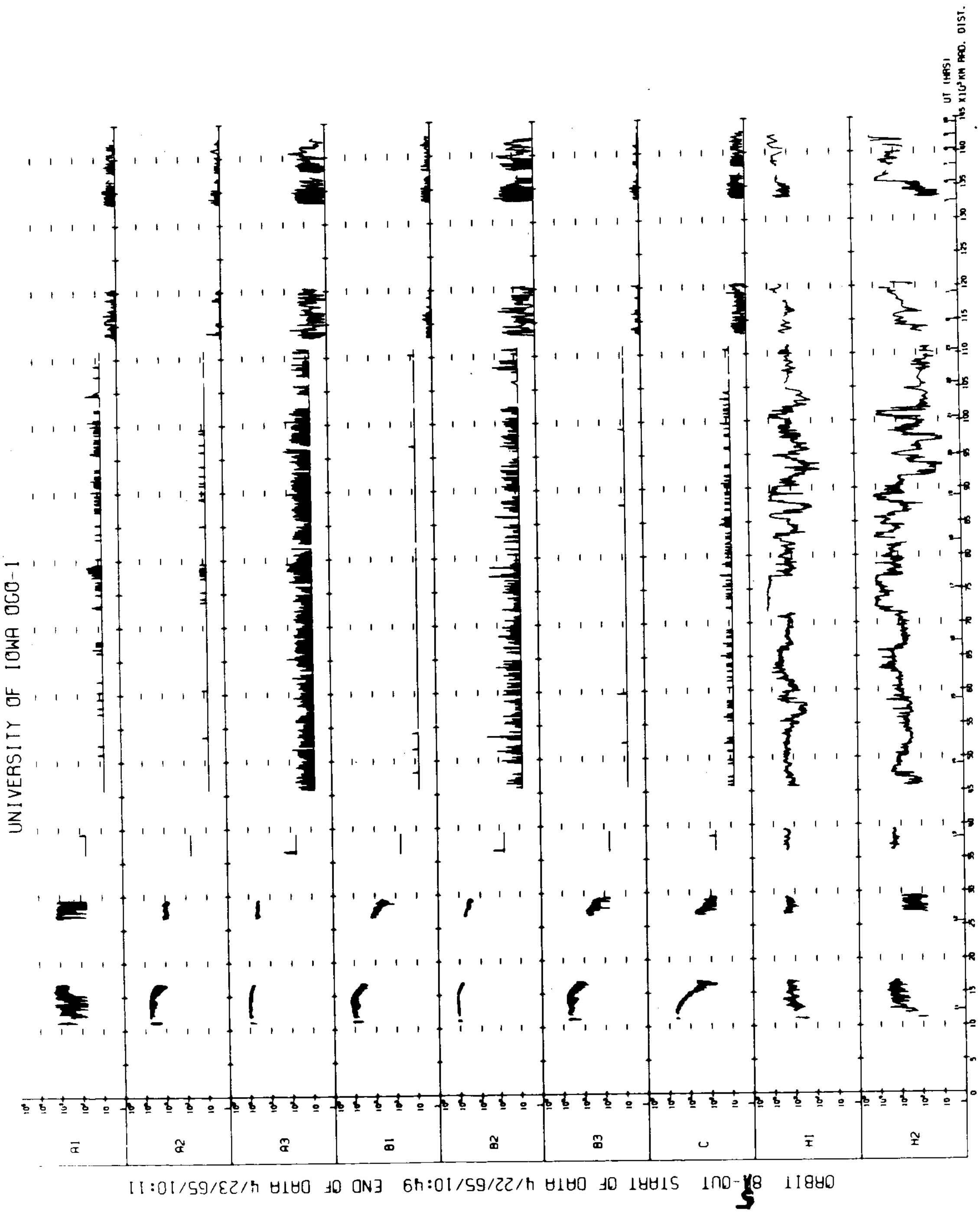
UNIVERSITY OF IOWA OGO-1
A1
A2
A3
B1
B2
B3
C
H1
H2
UT (HRS)
ORBIT 8A-OUT START OF DATA 4/22/65/10:49 END OF DATA 4/23/65/10:11

FIGURE 10

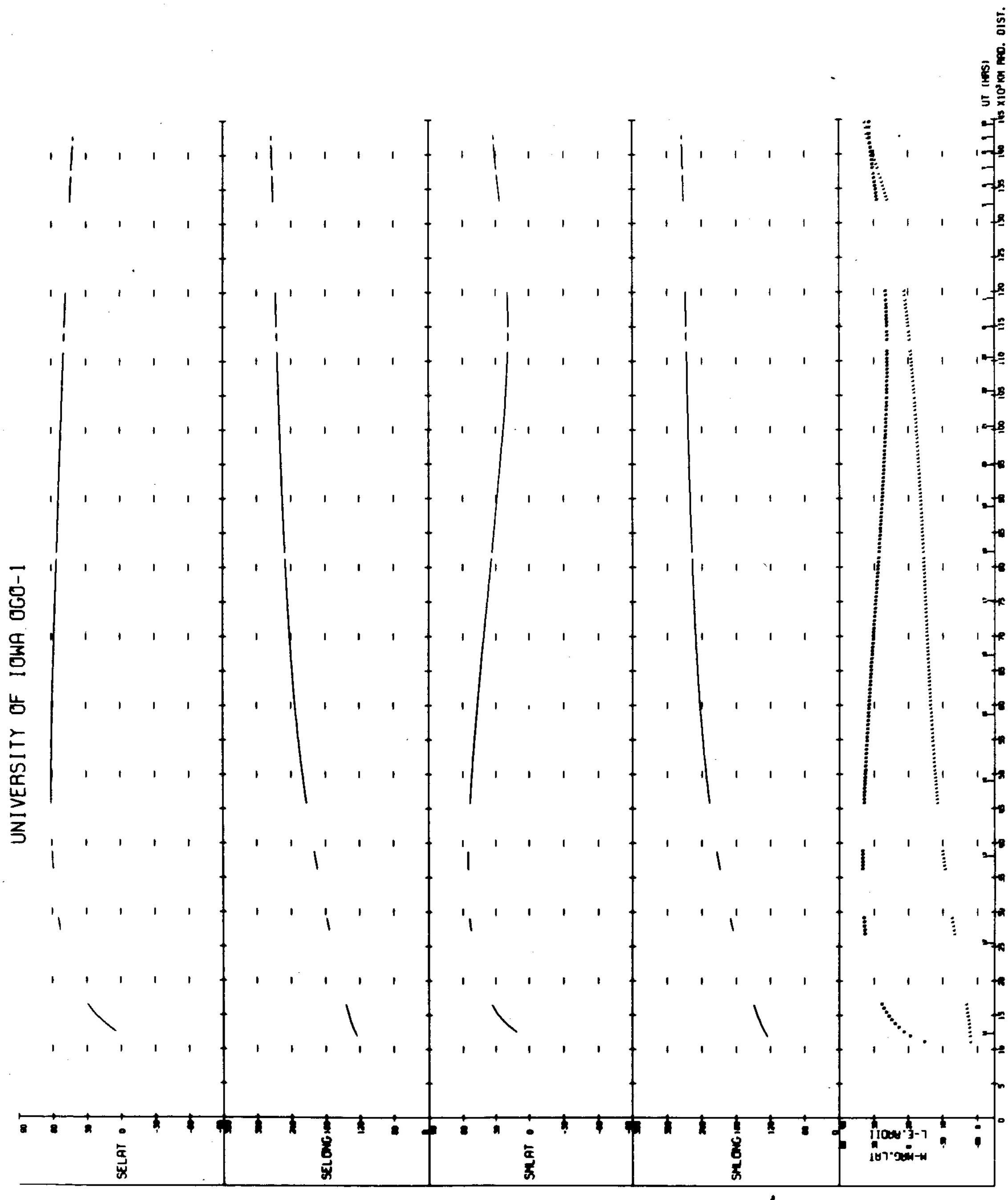

FIGURE 10 (Con't)

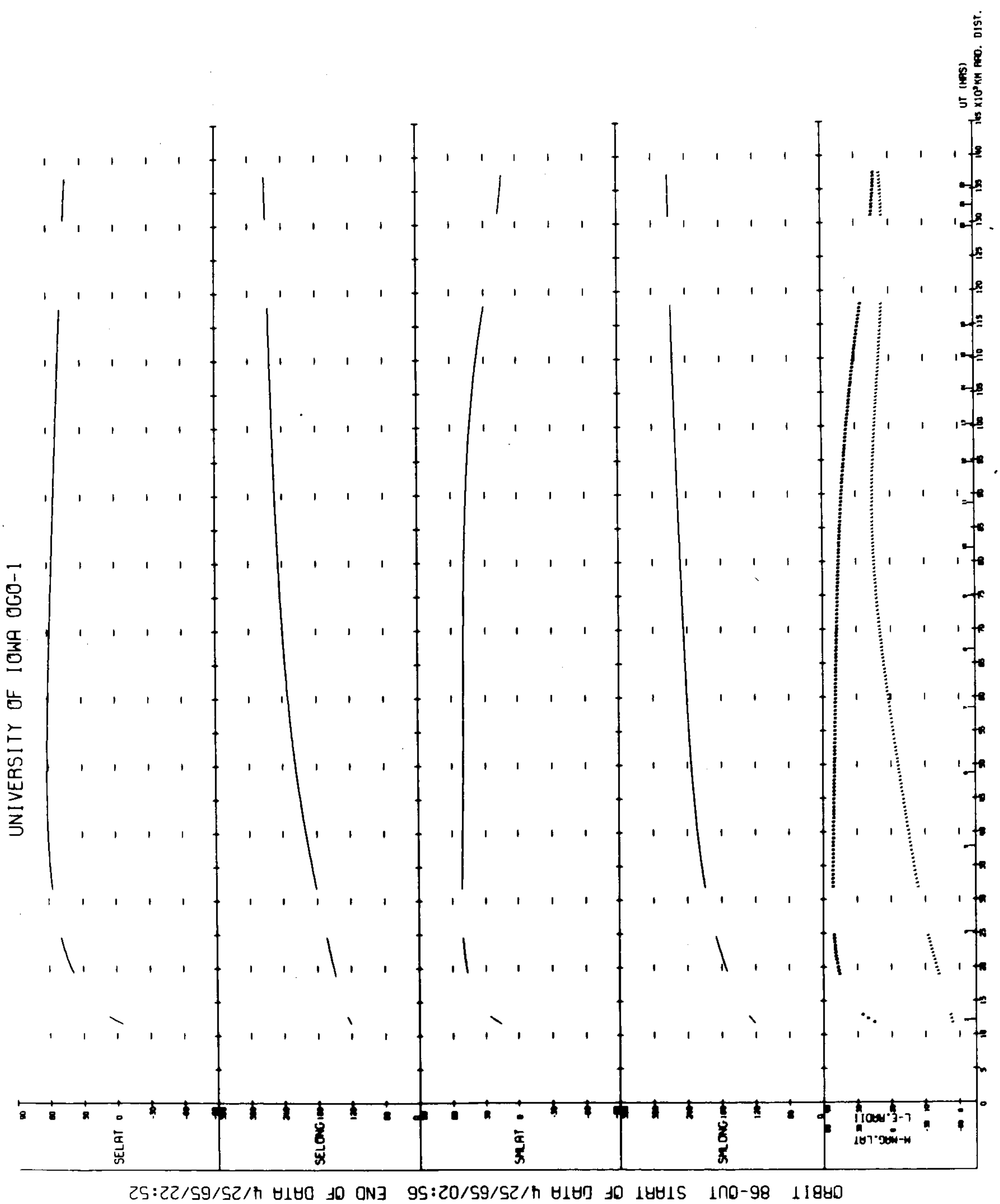

FIGURE 11 (Con't)

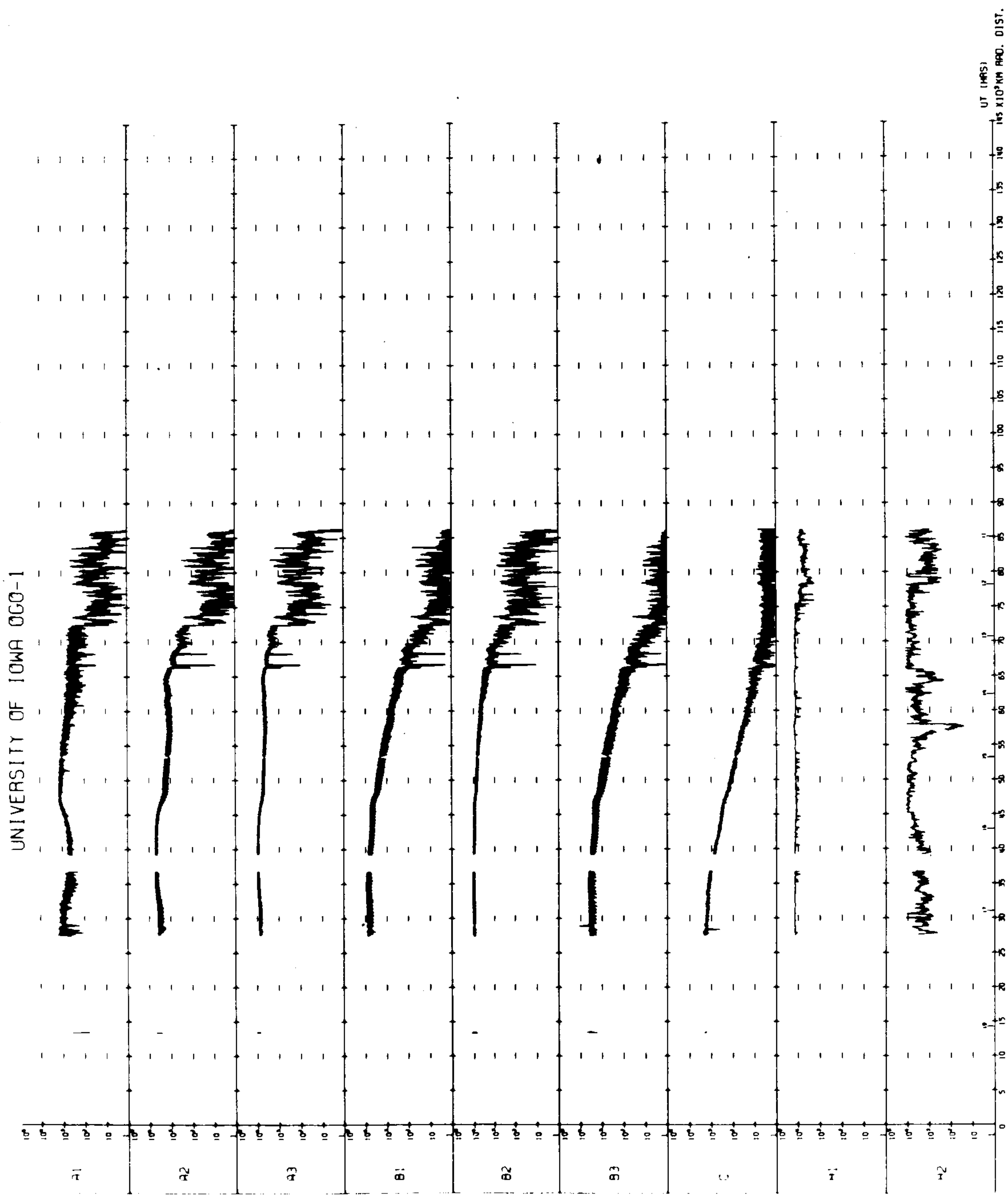

FIGURE 12

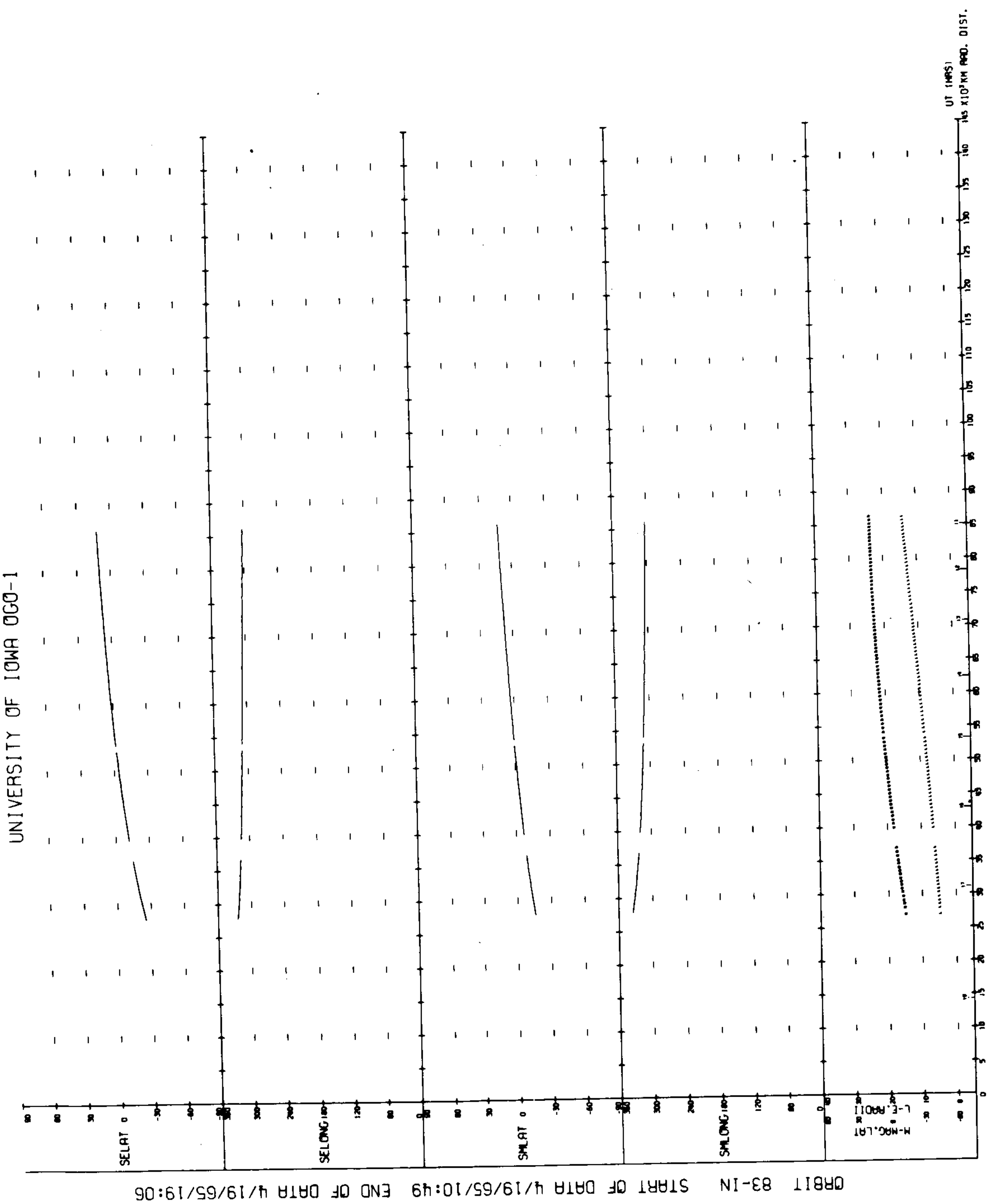

FIGURE 12 (Con't)

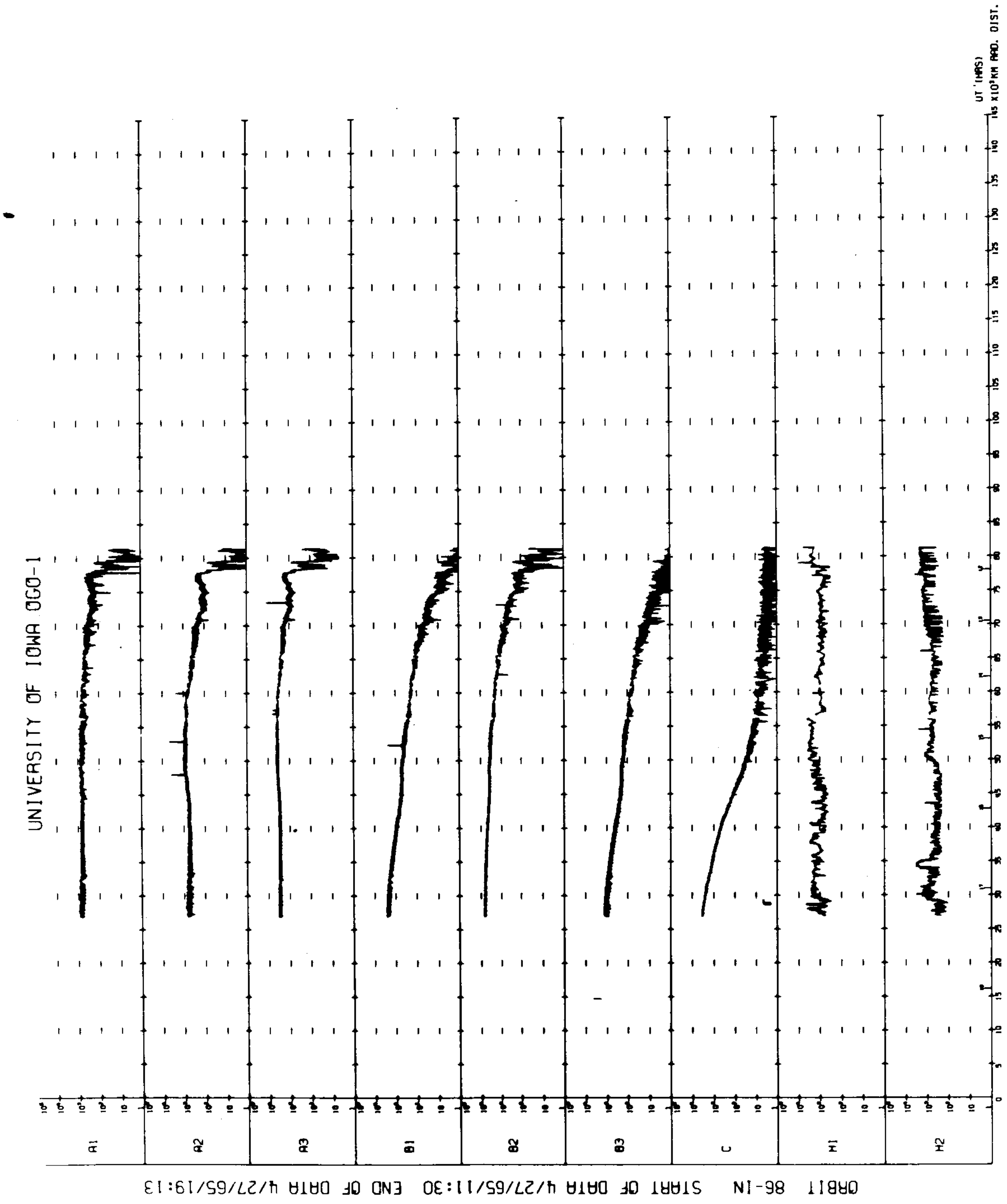
UNIVERSITY OF IOWA OGO-1
A1
A2
A3
B1
B2
B3
C
H1
H2
UT (HRS)
ORBIT 86-IN START OF DATA 4/27/65/11:30 END OF DATA 4/27/65/19:13

FIGURE 13

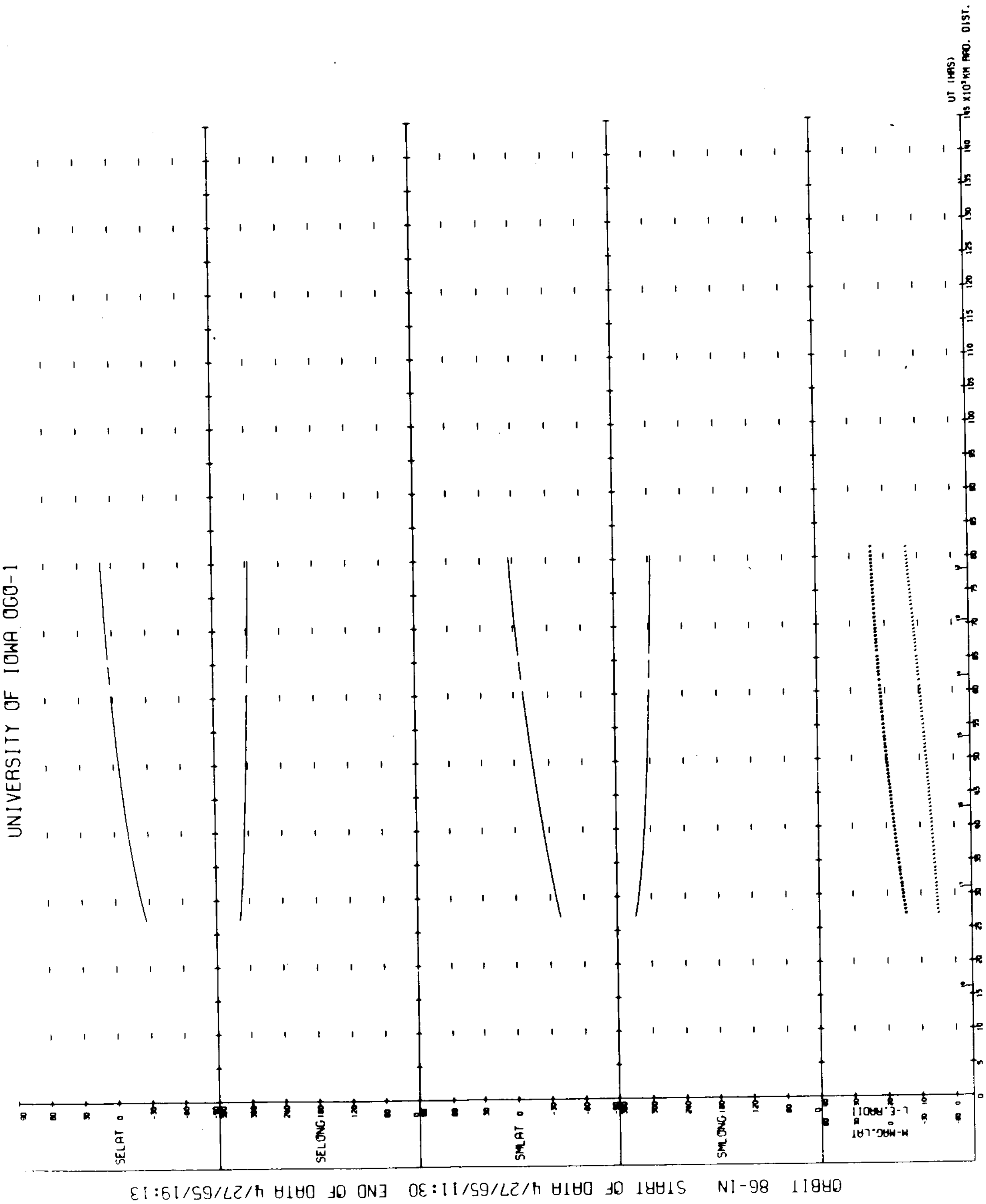

FIGURE 13 (Con't)

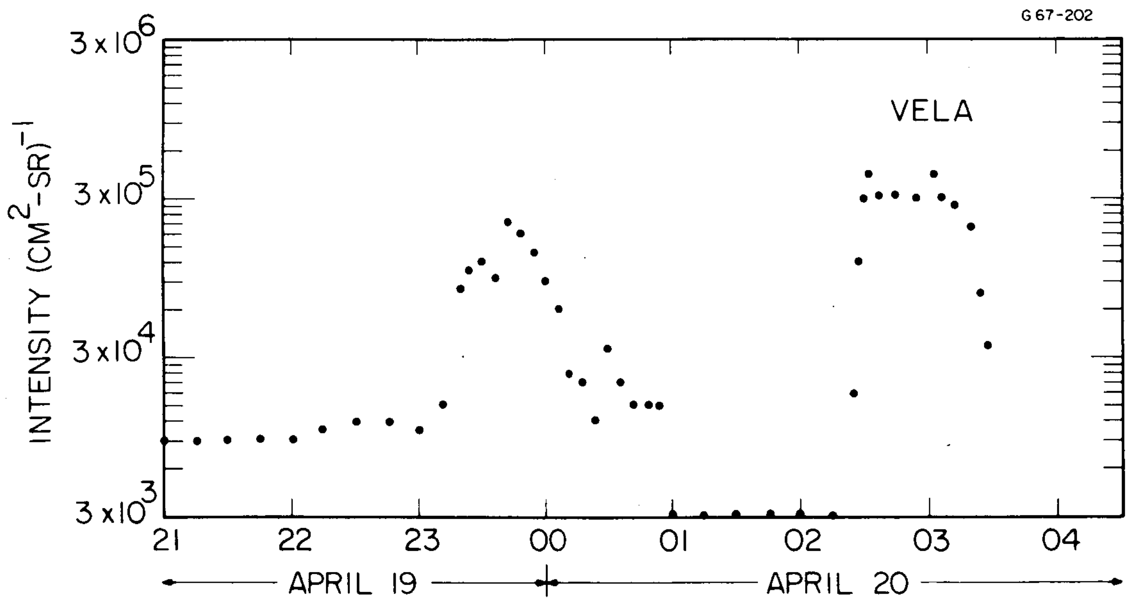
G 67-202
VELA
INTENSITY (CM^2-SR)$^{-1}$
3 x 10^6
3 x 10^5
3 x 10^4
3 x 10^3
21
22
23
00
01
02
03
04
APRIL 19
APRIL 20

FIGURE 14

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1. ORIGINATING ACTIVITY (Corporate author) University of Iowa Department of Physics and Astronomy	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

Study of the Temporal Variations of 40 keV Electrons in the Magnetosphere During and After the Magnetic Storm on April 18, 1965

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Progress May 1967

5. AUTHOR(S) (Last name, first name, initial)

Rao, C. S. R.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1967	60	22

8a. CONTRACT OR GRANT NO. Nonr-1509(06)	9a. ORIGINATOR'S REPORT NUMBER(S) U. of Iowa 67-16
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13. ABSTRACT

Temporal variations of the intensities of electrons E > 40 keV during the main phase and post-storm period of a large magnetic storm which occurred on April 18, 1965 are studied in this paper from the data obtained at high latitudes by the University of Iowa Satellite Injun IV and at low latitudes by the NASA satellite OGO-1.

The high latitude observations show a large inward movement of the cutoff boundary for trapped electrons to lower latitudes by as much as 8°. On the storm day and during the post-storm period, the cutoff latitude shows a close and direct correlation with D_{st} and inverse correlation with 3-hour K_p index. The 'slot', which is present at an invariant latitude of 61° before the storm, disappears on the storm day and is replaced by a peak. The post-storm variations of these storm-induced electrons at higher latitudes are uncorrected with the K_p index. The intensities decay according to an exponential law. There appears to be an injection and inward diffusion of fresh electrons during the post-storm period, leading to the formation of the normal quiet day profile. Variations for precipitated electrons are generally similar.

The suggestion that additional field lines extend into the tail region and lead to lowering of the cutoff boundary during the storm does not appear to be completely satisfactory.

(continued)

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Magnetosphere						
Magnetic Storm						
Electrons						

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ABSTRACT
(continued)

At low latitudes the available OGO-1 observations on the magnetospheric tail side indicate that the cutoff boundary, which was at L ~ 7.5 one day before the storm for electrons E > 40 keV, had extended to L ~ 9.5 one day after the storm, and strong electron 'islands' were seen between L ~ 15 and L ~ 21. On the next two orbits, four and seven days after the storm, the boundary was at the normal value and electron 'islands' were not present. The extended boundary and the 'islands' consisted mainly of low energy electrons.

It is also of interest to note that while OGO-1 was observing strong electron islands at low latitudes one day after the storm, Vela 2A satellite at a distance of 17 earth radii was also looking at strong electron intensities. The occurrence of such an event simultaneously at different latitudes could possibly be explained in terms of plasma movements along the magnetic lines of force on the tailside and neutral sheet instabilities.