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ELECTRON OBSERVATIONS BETWEEN THE  
INNER EDGE OF THE PLASMA SHEET  
AND THE PLASMASPHERE\*

by

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Errata

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Page 1, line 18 should read:

was about half an earth radius closer to the earth than the 5 keV near-

Page 7, line 6 should read:

the electron intensities between 90 eV and 750 eV made a negligible

Page 20, line 3 should read:

inner edge at  $\lambda \approx 15^\circ$  near local midnight could map onto an equatorial

Page 24, add to end of page:

Vasyliunas, V. M., Observations of low energy electrons with the  
OGO-A satellite, Ph.D. Thesis, M.I.T., 1966.

Vasyliunas, V. M., A survey of low-energy electrons in the evening  
sector of the magnetosphere with OGO 1 and OGO 3, J. Geophys. Res.,  
73, 2839, 1968.

### Abstract

Electron observations between  $\sim 100$  eV and 50 eV are presented for L values between 3 and  $10 R_E$  ( $R_E$ , earth radii) near local midnight at low magnetic latitudes. These measurements were obtained between June 9 and July 23, 1966, with electrostatic analyzers borne on OGO-3. The inner edge of the plasma sheet is characterized by a sudden exponential decrease in the electron energy density. This near-earth decrease has a very distinct structure with fluxes of higher energy electrons decreasing further from the earth for electron energies between 750 eV and 20 keV. A trough of  $\sim 100$  eV electrons with densities of  $\sim 1 \text{ (cm)}^{-3}$  is observed to fill the region between the inner edge of the plasma sheet and the plasmasphere. The density of electrons above 750 eV is often less than  $0.1 \text{ (cm)}^{-3}$  in this region. The separation between the inner edge of the plasma sheet and the plasmopause was between 1 and  $3 R_E$  in June and increased to between 3 and  $5 R_E$  in July. Analysis of subsequent data should determine whether this is a latitude or local time effect. The plasmopause is commonly located at the minimum of the energy density profile for electron energies above 750 eV. A plasmopause structure consisting of a sharp outer edge and a broad inner edge is observed mainly in the 200 eV electron fluxes. Observed lifetimes of  $\sim 10$  days for lower-energy electrons ( $E \sim 1$  keV) within the plasma-

sphere are in agreement with lifetimes for more energetic electrons ( $E \geq 500$  keV) in the same region. Kilovolt electrons between the plasmasphere and the inner edge of the plasma sheet are removed within the satellite's orbital period of 48 hours. Differential energy spectrums of electron intensities for the plasma sheet, the inner edge, the electron trough and the plasmasphere are presented.

## I. Introduction

The plasma sheet is by its location and nature central to the origin of both the aurora and ring currents. And although the plasma sheet was first observed about ten years ago, experimental design problems have until recently hindered the acquisition of accurate and comprehensive measurements concerning its nature (cf Gringauz [1969] and Frank [1967a,b] and the references therein for a review of low energy plasmas within the magnetosphere). Vasyliunas [1968] observed that the plasma sheet had a 'well-defined sharp inner-boundary'. Between 1700 and 2100 LT (geocentric local time) this inner boundary was located at  $11 \pm 1 R_E$  ( $R_E$ , earth radii) during geomagnetically quiet periods. Characteristically the electron energy density decreased exponentially inward with a scale length of about  $0.4 R_E$  while the number density remained essentially constant across the inner edge of the plasma sheet. During magnetic storms of the bay type the inner boundary moved inward to between 6 and 8  $R_E$ . Frank [1967d, 1968] observed that this near-earth decrease occurred at increasing radial distances for higher energy electrons between 1 and 10 keV. The 2 keV near-earth decrease was about half an earth radii closer to the earth than the 5 keV near-earth decrease. No general relationship was observed between the location of this near-earth decrease and the boundary of trapping for higher

energy ( $E \gtrsim 50$  keV) electrons. The purpose of this paper is to examine the region between the inner edge of the plasma sheet and the plasmasphere in detail. Only electron data acquired at low magnetic latitudes near local midnight are presented.

## II. Orbit and Instrumentation

OGO-3 was launched on June 7, 1966 into a highly eccentric orbit with an apogee of  $\sim 20 R_E$ , an inclination of  $30^\circ$ , a period of  $\sim 48$  hours and with the line of apsides directed to  $\sim 22:00$  LT. An attitude system provided a predetermined, monitored spacecraft orientation. All data presented here were acquired before the electrical failure of the attitude system on July 23, 1966. Figure 1 illustrates several representative inbound passes as functions of magnetic latitude and local time. Local times between 21:20 and 01:20 were covered on these inbound passes from 10 to  $5 R_E$  during this period.

The University of Iowa instrumentation utilizes four Bendix Channeltrons and four cylindrical-plate electrostatic analyzers. The analyzers were paired in order to measure simultaneously and separately the differential energy spectrums of proton and electron intensities with an energy range extending from  $\sim 100$  eV to  $\sim 50$  keV. These two pairs of Low Energy Proton and Electron Differential Energy Analyzers designated LEPEDEA's A and B had orthogonal fields of view. The fields-of-view for LEPEDEA A were directed earthward and those for LEPEDEA B were directed perpendicular to LEPEDEA A's fields-of-view in the satellite-earth-sun plane. See Frank [1967a] and the references therein for additional details concerning instrumentation.



Energy bandpasses for the electron channels are shown in Table I. The analyzer plate voltages were stepped every 19 seconds and the corresponding channels were sampled at least 15 times per step. A complete spectrum including all 15 channels was acquired in approximately 5 minutes.

TABLE I

Energy Bandpasses for OGO-3 LEPEDEA

Electron Channels 'A' and 'B'

Electron Channel	Energy Bandpasses	
	'A'	'B'
3	90 - 160 eV	80 - 140 eV
4	190 - 330 eV	170 - 300 eV
5	310 - 540 eV	280 - 500 eV
6	410 - 720 eV	380 - 680 eV
7	640 - 1100 eV	610 - 1100 eV
8	.99 - 1.7 keV	.94 - 1.7 keV
9	1.5 - 2.7 keV	1.5 - 2.7 keV
10	2.6 - 4.6 keV	2.8 - 5.0 keV
11	3.8 - 6.8 keV	4.1 - 7.2 keV
12	6.8 - 12 keV	5.8 - 10 keV
13	10 - 18 keV	9.8 - 17 keV
14	14 - 24 keV	14 - 24 keV
15	27 - 47 keV	26 - 46 keV

### III. Observations

In the first two sections electron measurements for several inbound passes are presented and analyzed. Observational periods on June 23, and July 17 and 19, 1966 were chosen to represent those of typical inbound passes during quiet conditions. In subsequent sections data from other inbound passes are utilized to evaluate the main features observed in these measurements.

June 23, 1966. OGO-3 was inbound within one hour of local midnight at low magnetic latitudes as  $L$  decreased from 8 to  $4 R_E$ . Figure 2 illustrates the differential electron intensities across the inner edge of the plasma sheet and into the plasmasphere. Initially the higher energy fluxes (tens of keV) decreased while the keV fluxes remained constant. Within a geocentric radial distance of  $0.5 R_E$  the lower energy fluxes ( $E \sim 1$  keV) also began to decrease and the peak flux shifted from channel 8 to channel 7. Within  $1 R_E$  the higher energy fluxes began to stabilize while the lower energy continued to decrease. Simultaneously significant electron fluxes with  $E \sim 100$  eV were first observed. Within  $1.5 R_E$  the plasmopause was encountered at 06:22. Inside the plasmasphere the differential intensities between 100 eV and 50 keV increased smoothly and simultaneously as the radius decreased.

Figure 3 illustrates the radial dependence of the electron energy and number density corresponding to the fluxes illustrated in Figure 2. Above 750 eV the electron energy density decreased by a factor of 20 across the inner edge of the plasma sheet while the number density decreased by about an order of magnitude. Although the electron intensities between 90 eV and 750 eV made a negligible contribution to the energy density, they were sufficiently large to maintain an essentially constant number density outside the plasmasphere. The region between the inner edge of the plasma sheet and the plasmapause containing electrons with energies of  $\sim 100$  eV and densities of  $\sim 1 \text{ (cm)}^{-3}$  will be denoted as the 'electron trough'. As such, this region is definitely a part of (but not necessarily identical with) Carpenter's [1966] 'plasma trough'. At the plasmapause both the number density and energy density increased abruptly. See the discussion of Figure 5 for further details.

Figure 4 illustrates the radial dependence of the differential spectrums of electron intensities for the measurements summarized in Figures 2 and 3. In the plasma sheet these electron spectrums are quite flat between 1 and 6 keV and then fall off rapidly. If the directional, differential intensities,  $dJ/dE$ , are fitted to an  $E^{-n}$  energy dependence,  $n$  is  $\approx .5$  between 1 and 6 keV and then softens to  $\approx 2.7$  between 6 and 20 keV. Across the inner edge of the plasma sheet

the higher energy fluxes decrease initially (spectrum 2a) and then the keV fluxes decrease while the 100 eV fluxes appear (spectrum 2b). Inside the plasmasphere the differential intensities are fairly smooth with  $n \approx 1.5$  between 300 eV and 50 keV (spectrum 3b). Below 300 eV the spectrum is quite soft with  $n \approx 3.5$ . The energy and particle fluxes for these spectrums are summarized in Table II.

Figure 5 indicates that for electron intensities above 90 eV the plasmopause has a broad inner edge as well as a sharp outer edge. The outer edge has a scale of tens of kilometers. This is indicated by the factor of three increase in counting rate for channel 4A in less than five seconds at 6:22:18. The thickness of this outer edge would be about 15 km assuming the plasmopause velocity is much less than the satellite's radial velocity of about  $4 \text{ km}(\text{sec})^{-1}$ . Fifteen km is the cyclotron radius for a 200-eV proton in the equatorial dipole field at  $5.8 R_E$ .

The inner edge of the plasmopause has a scale of hundreds of kilometers and is displayed in Figures 2, 3 and 4. This structure is illustrated in Figure 5 by the shaded area in both frames. Within the plasmopause the electron fluxes between 90 and 750 eV decrease earthward. This inner edge has a thickness of between 200 km (based on the decay rate of the channel 5A responses within the 06:22 frame) and 1200 km (based on the decay rate of the channel 5A responses by

TABLE II

## Electron Energy and Particle Fluxes

OGO 3; Inbound; 23 June 1966

 $90 \text{ eV} \leq E \leq 50 \text{ keV}$ 

Spectrum	L, earth radii	$\Phi_E,$ ergs(cm <sup>2</sup> -sec-sr) <sup>-1</sup>	$J_e,$ (cm <sup>2</sup> -sec-sr) <sup>-1</sup>
1a	8.2	5.6	$6.3 \times 10^8$
1b	7.1	7.5	$8.5 \times 10^8$
2a	6.4	1.8	$4.5 \times 10^8$
2b	6.0	.66	$1.9 \times 10^8$
3a	5.8	.62-.64	$4.-6. \times 10^8$
3b	5.6	.49	$2.4 \times 10^8$

the 06:27 frame). Even if the plasmopause were moving with a constant velocity the ratio of the thickness of the inner and outer edges should be invariant. This ratio is between 20 and 120, which brackets the ratio of the cyclotron radii for protons and electrons with equal energies.

July 19-21, 1966. OGO-3 was inbound near the magnetic equator at about 22:00 LT for  $L \approx 9$ . Figure 6 illustrates the electron number and energy density, and average energy across the inner edge of the plasma sheet and into the plasmasphere. Unlike the June 23 pass the inner edge of the plasma sheet is located several earth radii beyond the plasmopause and the electron trough begins at  $L \approx 9.5 R_E$ . On July 21 at 1300 U.T. at  $L \leq 7$  substorm-related phenomena were observed. At  $L \leq 8 R_E$  the July 19 measurements closely resemble the July 21 pre-substorm measurements and are included in Figure 6. Above 90 eV the electron trough merges smoothly into the plasmasphere at  $L \approx 5.65 R_E$ . The electron trough is easily identified by the sudden decrease in the average energy from  $\sim 2-5$  keV to  $\sim 50-80$  eV due to the rapid decrease in the energy density versus a relatively constant number density.

Figure 7 illustrates electron spectrums characteristic of four electron regions within the magnetosphere: plasma sheet, inner edge, electron trough and plasmasphere. The inner edge spectrum illustrates characteristics of both the plasma sheet spectrum and of the electron trough spectrum. Although the electron trough spectrum somewhat

resembles the plasmasphere spectrum there are significant differences. Below 300 eV the electron-trough spectrum ( $n \approx 2$ ) is somewhat harder than the plasmasphere spectrum ( $n \approx 3$ ). Furthermore the electron trough spectrum should peak near  $\sim 100$  eV while the plasmasphere spectrum should peak at  $\leq 30$  eV in order to produce the observed total electron densities of  $\sim 1 \text{ e/cm}^3$  and  $\sim 100 \text{ e/cm}^3$  in the respective regions [Carpenter, 1966]. During this pass the electron trough intensities increased steadily until at the plasmopause they matched the plasmasphere electron intensities at  $L = 5.3 R_E$ . Normally there is an abrupt increase in the number density above 90 eV at the plasmopause.

In the following sections the remainder of the observations will be utilized to evaluate the electron observations of the plasmopause, the location and structure of the inner edge of the plasma sheet and the relationship with magnetic activity and local time.

Plasmopause Identification. A comparison of the plasmopause locations utilizing proton and electron data is illustrated in Table III. The proton plasmopause observations are based on the measurements by Taylor et. al., [1968] of ambient thermal ions between 1 and 45 atomic mass units using a radio-frequency ion spectrometer. The electron identification of the plasmopause is most easily made by identifying the localized enhancement of the 200 eV fluxes in channel 4A. During



TABLE III

## Comparison of Plasmopause Locations

OGO-3; Inbound; 1966

DATE	PROTONS <sup>a</sup> (Ion Detector)		ELECTRONS (LEPEDEA)		DIFFERENCE	
	Time, U.T.	L, R <sub>E</sub>	Time, U.T.	L, R <sub>E</sub>	$\Delta T$ minutes	$\Delta L$ , R <sub>E</sub>
11 June	02:20	7.04	~ 2:20	7.0	0	0
15 June	04:08	5.79	data gap		—	—
17 June	04:44	5.76	~ 04:47	5.6	~ 3	.15
19 June	04:54	6.70	~ 05:00	6.4	~ 6	.3
21 June	—	—	05:54	5.7	—	—
23 June	06:20	5.91	06:22	5.9	2	0
25 June	07:46	3.73	07:48	3.6	2	0
27 June	07:24	5.91	07:27	5.9	3	0
29 June	07:49	6.19	~ 07:53	6.0	~ 4	.2
1 July	09:01	4.76	~ 09:02	4.7	~ 1	0
3 July	08:45	6.44	~ 08:54	6.2	~ 9	.25
5 July	09:54	5.24	~ 09:53	5.2	~ 1	0
7 July	—	—	unidentifiable <sup>b</sup>		—	—
9 July	11:56	3.31	" "	"	—	—
11 July	11:55	4.62	" "	"	—	—
13 July	11:39	6.20	" "	"	—	—
15 July	—	—	~ 12:45	5.3	—	—
17 July	13:10	5.63	~ 13:10	5.6	0	0
19 July	13:44	5.64	~ 13:44	5.6	0	0
21 July	14:32	5.18	missing frame		—	—
23 July	14:46	5.78	unidentifiable		—	—

a. H. A. Taylor, Personal Communication, March 1969.

b. Intense fluxes above 700 eV precluded a decisive observation.

the July 9 storm, scattering from intense kilovolt fluxes masked this identification. Electron and proton observations of the plasmopause are normally within the five minute cycle time of the LEPEDEA experiment.

Structure and Location of the Inner Edge. Figure 8 summarizes the inbound profiles of the electron energy density between  $L = 10 R_E$  and the plasmopause as a function of  $L$ . The tendency for the lower energy fluxes to decrease closer to the earth is illustrated by the relative earthward displacement of the flux 'bar' for the lower energy channel. This tendency is clearly seen on every non-storm pass. Thus the structure illustrated in Figure 2 is a basic characteristic of the inner edge of the plasma sheet.

The location of the inner edge of the plasma sheet relative to the plasmopause is considerably different in July than in June for magnetically quiet days. In June the separation between the plasmopause and the inner edge of the plasma sheet is  $\sim 1.5 R_E$ . In July this separation increases to  $\sim 3-5 R_E$  as the inner edge of the plasma sheet withdraws to  $\sim 8.6 R_E$ . This change could be a latitude effect owing to the distortion of the earth's dipole field or a local time effect. Further analysis of the remaining OGO-3 data should clarify this point. During both June and July the plasmopause was often located at the minimum in the electron energy density profile.

Relation of Magnetic Activity. On June 25 the plasma sheet was first encountered at  $L \approx 9.3 R_E$  at  $\lambda \approx 20^\circ$ . The plasma sheet electrons penetrated to  $4 R_E$  with a peak energy density of  $\sim 3 \times 10^{-8}$  ergs $(\text{cm})^{-3}$  and a number density of  $\sim 10-30 (\text{cm})^{-3}$  above 90 eV. Within the plasmasphere this enhanced energy density decayed slowly with a lifetime of  $\sim 10$  days. On July 7 the inner edge of the plasma sheet withdrew to  $L \approx 9 R_E$  and the plasmopause was not readily identifiable in either the electron or ion measurements.

The storm of July 9 is clearly indicated by both the location and magnitude of the electron energy-density peak. This storm has been analyzed in detail by Frank [1967c]. On July 9 the electron energy of  $5 \times 10^{21}$  ergs was about a fourth the proton energy of  $21 \times 10^{21}$  ergs for  $1 \leq L \leq 8$ . These proton and electron energy reservoirs were shown to be capable of explaining the observed decrease of  $\sim 70\%$  at the earth's surface.

Unlike the protons which have charge-exchange lifetimes of about a day at  $L = 4$  [Swisher and Frank, 1968] the electron peak persists with a lifetime of  $\sim 10$  days. Thus the lifetime of low energy electrons ( $1 \leq E \leq 50$  keV) appears to be similar to the lifetime of high-energy electrons ( $E \geq 500$  keV) in the same regions [Roberts, 1969]. Outside the plasmopause the enhanced electron energy densities are quickly dissipated within 2 days.

On July 21 the inner edge of the plasma sheet was encountered at  $L = 9.7 R_E$ . At 13:00 U.T. a substorm began at College, Alaska, which had just moved through the pre-midnight sector. One hour later the electron energy-density increased by a factor of four near  $L = 6 R_E$ . If this was indeed a second encounter with the inner edge of the plasma sheet, its inward radial velocity must have exceeded 5.5 km/sec during that hour. An electric field of  $\sim .6$  mv/m would drift plasma at this velocity in a 100 $\gamma$  field. Further analysis of the proton population will be necessary to interpret the substorm behavior.

#### IV. Discussion

Structure of the Inner Edge. The simplest explanation for the existence of an inner edge to the plasma sheet would be that the electrons were being drifted across a retarding potential  $\Delta\Phi$ . Assuming a uniform magnetic field the general features of this model would be:

- (1) the high energy tail ( $E > e\Delta\Phi$ ) of the electron spectrum would remain unchanged across the potential,
- (2) the integral flux, energy flux and energy density should all decrease earthward,
- (3) for a peaked differential-energy spectrum, both the energy and magnitude of the peak intensity should decrease earthward.

This simple model is inadequate to explain the transition from the plasma sheet spectrum 1b (Figure 4) to the spectrum of the inner edge of the plasma sheet 2b. Between spectra 1b and 2a the energy of the peak flux decreases by about 500 eV. Yet the fluxes above 4 keV have decreased considerably while the peak flux has actually increased. Between 2a and 2b, the first two criteria are satisfied but there is not an accompanying decrease in the energy of the peak flux. Beyond 2b the total flux, energy density and number density all increase across the plasmopause.

Vasyliunas [1966] has speculated that resonant interaction with VLF waves would enhance electron precipitation. This charge imbalance would induce a steady state electric field along the field lines which

would draw up thermal ionospheric electrons to maintain charge neutrality. Such a mechanism would not necessarily affect the proton distribution and would be consistent with a constant number density across the inner edge of the plasma sheet. Furthermore it would explain the order of magnitude decrease in the 'temperature' of the plasma sheet electrons. For a further discussion of pitch angle scattering see Roberts [1969]. One implication of this pitch angle scattering mechanism is that the structure of the inner edge should be strongly dependent upon pitch angle. The plasma sheet should extend further earthward in measurements of equatorial electron intensities with  $\alpha \approx 90^\circ$  as compared with high latitude electron intensities which must precipitate out quite rapidly in order to decrease the energy density. Figure 9 illustrates the differential flux across the inner edge of the plasma sheet measured at two different pitch angles. No radial dependence of electron flux on pitch angle is observed. This is not to say that pitch angle scattering is not occurring, only that it does not appear to be a dominant feature in forming the inner edge of the plasma sheet.

A third possibility is that the inner edge of the plasma sheet is an Alfvén layer. In this case plasma sheet particles are convected into the dipolar magnetic field and are then deflected by the resultant gradient drift. See Schield et al., [1969] and the references therein for a review. This Alfvén mechanism would deflect higher energy particles at greater distances and could result in an inward decrease in

the number density of the convected plasma sheet particles. The associated charge separation would result in field-aligned currents which consist mainly of  $\sim 100$ -eV electrons [Schild, 1968]. Although the Alfvén Layer theory is consistent with the observations of the structure of the inner edge it has further implications which remain unchecked (such as the simultaneous deflection of protons). However the relatively constant separation between the locations of the plasmopause and the inner edge of the plasma sheet is an indication that a common mechanism is involved.

Comparison with Other Observations. In general, earlier observations of the plasma sheet are in fair agreement with those presented here. Peak integral electron fluxes above 200 eV of  $\sim 2 \times 10^8$  (cm<sup>2</sup>-sec)<sup>-1</sup> over a hemisphere were measured on board Lunik 1. The integral electron fluxes of  $\sim 10^{10}$  (cm<sup>2</sup>-sec)<sup>-1</sup> measured with OGO-3 exceeded these by about an order of magnitude. Freeman [1964] noted that the electron flux would be  $\sim 10^9$  (cm<sup>2</sup>-sec-sr)<sup>-1</sup> if the observed energy flux were produced by 10 keV electrons. This equivalent energy flux of 16 ergs(cm<sup>2</sup>-sec-sr)<sup>-1</sup> is within a factor of two of those presented here. The OGO-3 measurements of the plasma sheet within  $12 R_E$  indicate the average electron energy,  $\bar{E} = (U_e/n_e)$ , is  $\sim 3$ -5 keV although the energy of the peak differential intensities occurs at  $\sim 1$  keV.

The ATS low-energy detector observed particle fluxes of  $.3 - 2 \times 10^7 \text{ (cm}^2\text{-sec-sr)}^{-1}$  at  $6.6 R_E$ . Particles observed include electrons above 3 keV and all protons [Freeman and Maguire, 1967]. On June 23, 1966, inbound at  $L = 6.6 R_E$  at local midnight OGO-3 observations indicate the integral electron flux in the inner edge of the plasma sheet above 3 keV was  $3.2 \times 10^8 \text{ (cm}^2\text{-sec-sr)}^{-1}$ , a factor of twenty greater than the integral proton flux above 100 eV. Although the efficiencies of the ATS low-energy detector for both electrons and protons have not been published, Frank [1965] and Frank et. al., [1969] have shown that the Channeltron efficiency in counting 3 keV electrons is  $\sim 20$  to  $40\%$  of the efficiency in counting protons between 3 and 30 keV. Even so, on June 23 the electron flux would have produced at least  $80\%$  of the counts in such a detector. On July 19 at  $L = 6.6 R_E$  the electron flux in the electron trough above 3 keV was  $2.8 \times 10^7 \text{ (cm}^2\text{-sec-sr)}^{-1}$ , about  $80\%$  of the proton flux above 100 eV. The protons would produce at least  $75\%$  of the counts in such a detector. Even if the calibration of this instrumentation were available the identification of the plasma component observed by the ATS low-energy detector above 50 eV in this environment would probably remain impossible.

Although Vasyliunas' [1968] main conclusions are substantiated his observation of the inner edge at  $11 \pm 1 R_E$  was not. The differences



in the location of this inner edge may be entirely latitude and local time differences between the measurements. OGO-3 observations of the inner edge at  $L \approx 15^\circ$  near local midnight could map onto an equatorial crossing radius of  $\sim 10 R_E$ . Furthermore Vasyliunas' quiet time observations were made between 1700 and 2100 LT whereas these OGO-3 measurements were made between 2100 and 0100 LT. Analysis of subsequent OGO-3 data should clarify this difference.

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References

- Carpenter, D. L., Whistler studies of the plasmopause in the magnetosphere, J. Geophys. Res., 71, 693-709, 1966.
- Frank, L. A., Low-energy proton and electron experiment for the orbiting Geophysical Observatories B and E, U. of Iowa Res. Rep. 65-22, July, 1965.
- Frank, L. A., Initial observations of low-energy electrons in the earth's magnetosphere with OGO 3, J. Geophys. Res., 72, 185-195, 1967a.
- Frank, L. A., Several observations of low-energy protons and electrons in the earth's magnetosphere with OGO 3, J. Geophys. Res., 72, 1905-1916, 1967b.
- Frank, L. A., On the extraterrestrial ring current during geomagnetic storms, J. Geophys. Res., 72, 3753, 1967c.
- Frank, L. A., Recent observations of low-energy charged particles in the earth's magnetosphere, Physics of the Magnetosphere, ed. by R. L. Carovillano, J. F. McClay and H. R. Radoski, D. Reidel Publishing Co., Dordrecht-Holland, 271-289, 1967d.
- Frank, L. A., On the distribution of low-energy protons and electrons in the earth's magnetosphere, Earth's Particles and Fields, ed. by B. M. McCormac, Reinhold Book Co., New York, 57-87, 1968.

- Frank, L. A., N. K. Henderson and R. L. Swisher, Degradation of continuous-channel electron multipliers in a laboratory operating environment, Rev. Sci. Instr., 40, 685, 1969.
- Freeman, J. W., Jr., The morphology of the electron distribution in the outer radiation zone and near the magnetospheric boundary as observed by Explorer 12, J. Geophys. Res., 69, 1691, 1964.
- Freeman, J. W., Jr., and J. J. Maguire, Gross local-time particle asymmetries at the synchronous orbit altitude, J. Geophys. Res., 72, 5257, 1967.
- Gringauz, K. A., Low energy plasma in the magnetosphere, Magnetospheric Physics, ed. by Williams and Mead, William Byrd Press, 339, 1969, and Rev. of Geophysics, 7, nos. 1 and 2, 1969.
- Roberts, Charles S., Pitch-angle diffusion of electrons in the magnetosphere, in Magnetospheric Physics, ed. by Williams and Mead, William Byrd Press, 305, 1969, and Rev. of Geophysics, 7, nos. 1 and 2, 1969.
- Schild, M. A., Configuration of geomagnetic field lines above the auroral zone, Ph.D. thesis, Rice University, Houston, Texas, 1968.
- Schild, M. A., J. W. Freeman and A. J. Dessler, A source for field-aligned currents at auroral latitudes, J. Geophys. Res., 74, 247, 1969.

Swisher, R. L., and L. A. Frank, Lifetimes for low-energy protons in

the outer radiation zone, J. Geophys. Res., 73, 5665, 1968.

Taylor, H. A., H. C. Brinton and M. W. Pharo, III, Contraction of the

plasmasphere during geomagnetically disturbed periods,

J. Geophys. Res., 73, 961, 1968.

Figure Captions

Figure 1. Dipole magnetic latitude and local time profiles for sample OGO-3 inbound orbits. The local time profile shifts westward by  $\sim 1^\circ$  per day. Although the inbound spacecraft is at low latitudes, with  $\lambda_d \leq 25^\circ$  within  $15 R_E$ , the orbit cannot necessarily be described as near-equatorial beyond  $8 R_E$ . An anti-solar neutral sheet hinged to the dipole equatorial plane at  $10 R_E$  would lie within the indicated sectors.

Figure 2. Differential electron intensities across the inner edge of the plasma sheet and into the plasmasphere. During this pass the inner edge of the plasma sheet is located inside the boundary of trapping based on the response of the thin-windowed 213A GM tube as a function of the magnetic shell parameter  $L$ . The near-earth decrease in electron flux occurs at increasing radial distances for higher electron energies. The plasmopause is encountered within  $1.5 R_E$  of the inner edge of the plasma sheet. The differential fluxes above 1 keV are continuous across this boundary. The existence of a plasmopause structure of less than  $0.5 R_E$  is indicated by the localized increase in the electron fluxes below 750 eV.

Figure 3. Electron number and energy density across the inner edge of the plasma sheet and into the plasmasphere. The energy density decreased exponentially by an order of magnitude over  $1.2 R_E$  with a scale length of one-third an earth radii. Initially this decrease was produced by a decrease in the higher energy electron fluxes (tens of keV) without decreasing the electron number density appreciably. Ultimately the decrease in energy density was produced almost entirely by a decrease in the keV fluxes. A constant number density above 90 eV was maintained by the simultaneous appearance of  $\sim 100$ -eV electrons. Note that the plasmopause was located at the minimum of the energy density profile for the fluxes above 750 eV.

Figure 4. Differential electron spectrums across the inner edge of the plasma sheet and the plasmopause. Initially the higher energy flux decreases between spectrums 1b and 2a followed by a decrease in the keV flux between spectrums 2a and 2b. Spectrum 2b illustrates the low energy portion of the electron flux in the electron trough. The plasmopause spectrum 3a quickly decreases to a typical plasmasphere spectrum 3b.

Figure 5. Count rate data are shown for two successive frames from detectors A and B. Data is telemetered every second for 19 seconds from each energy channel in succession. The counts for the 06:17 frame (dashed lines) for channels 4-8 are due mainly to scattered keV electrons. The 06:22 data generally follows that of the previous frame until an abrupt change occurs at 18 seconds, marked by the vertical dashed line. The shaded areas represent the difference between the observed count rate and the average counting rate in the following frame.

Figure 6. Radial profile of the energy and number density and average energy for electrons ( $E \geq 90$  eV) near 22:00 LT. The average energy is the energy density divided by the number density for all observed electrons. The electron trough of  $\sim 100$ -eV electrons is easily discernable between the inner edge of the plasma sheet and plasmapause. The smooth transition into the plasmasphere may be associated with the high fluxes inside the plasmasphere which were trapped during the July 9 storm. (See Figure 8).



Figure 7. Differential electron spectrums from the plasma sheet, the inner edge, the electron trough and the plasmasphere. The electron trough spectrum should peak near  $\sim 100$  eV in order to maintain charge neutrality with the observed proton densities of  $\sim 2-5$  (cm)<sup>-3</sup> above 100 eV.

Figure 8. Radial profile of electron energy density for  $L \leq 10 R_E$ . An inbound measurement was made every orbital period ( $\sim 2$  days). The location of the inner edge of the plasma sheet is identified by the rapid earthward decrease in the electron energy density. (On June 23 this occurs for  $L$  between 7.1 and 5.9  $R_E$ . See Figure 3). The structure of the inner edge is illustrated by the horizontal 'error bars'. These bars designate the position of the earthward decrease from a maximum to a minimum in the flux measured by a given channel. Unless otherwise specified the bars above and below the horizontal column are for channels 10 and 8 respectively as illustrated for June 11. Normally the lower bar is displaced earthward from the upper bar indicating the tendency for the lower energy fluxes ( $E \approx 1$  keV) to decrease closer to the earth. The inward displacement of the plasmopause during magnetic storms is

clearly seen. The trough of low energy electrons is invariably located in the region of low energy density between the inner edge of the plasma sheet and the plasmapause.

Figure 9. Differential electron fluxes measured by two detectors with perpendicular fields-of-view, LEPDEA's A and B, which receive electrons having dipole pitch angles of  $\sim (180-65^\circ)$  and  $\sim 35^\circ$  respectively. By definition  $\alpha$  is zero if the particle velocity is parallel to the magnetic field vector B. Any symmetric inflation of the dipole field should increase both  $\alpha_A$  and  $\alpha_B$  thus decreasing the difference between the sines of their pitch angles. On July 27 at  $L = 3.6 R_E$  a cross-calibration of the detectors while viewing identical pitch angles indicates that there is less than a 30% difference in the responses of the two instruments. No dependence of the electron flux profile on pitch angle has been observed on the six inbound passes for which such an analysis has been performed.

A-669-523

SAMPLE OGO-3 ORBITS, INBOUND

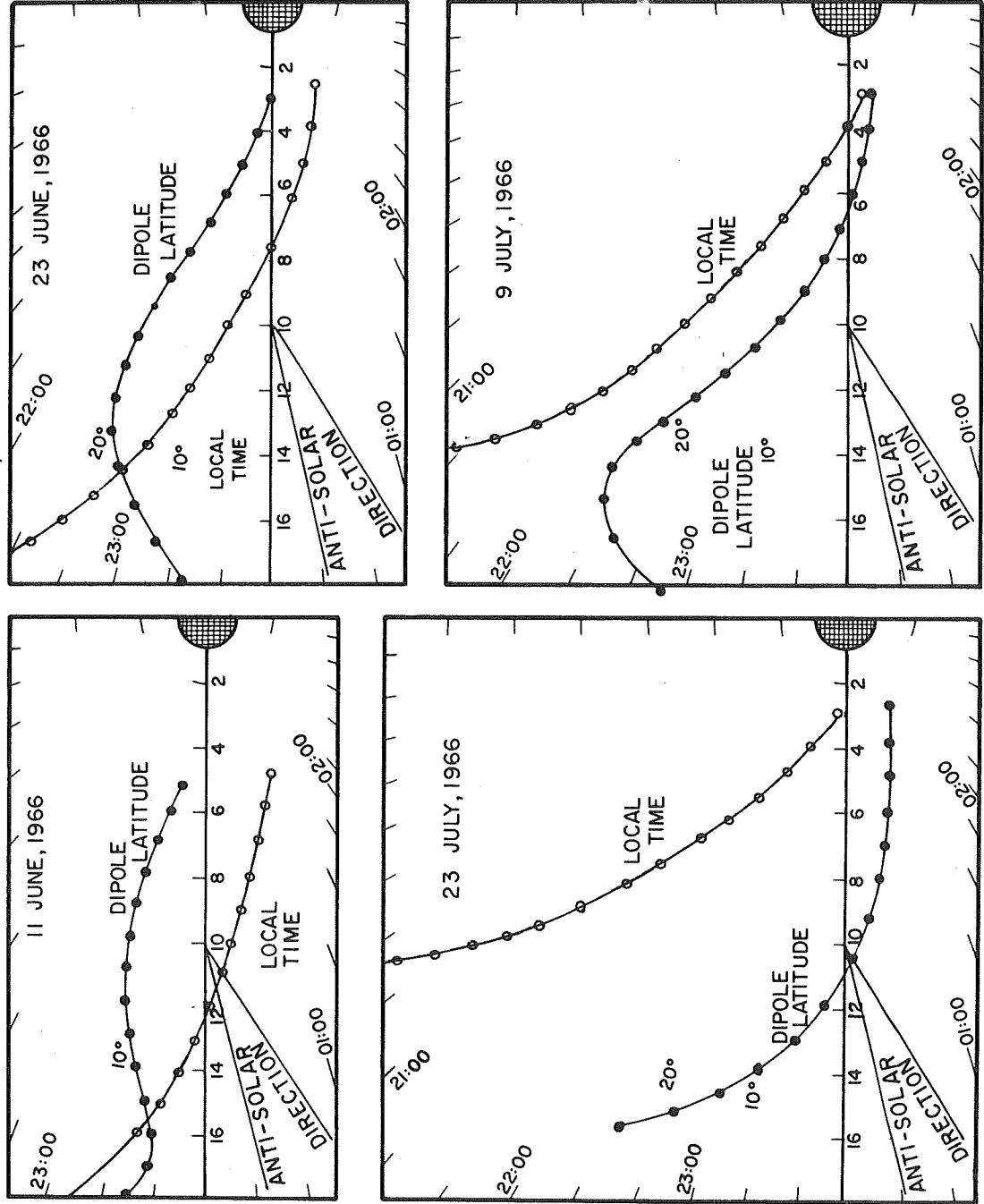


Figure 1

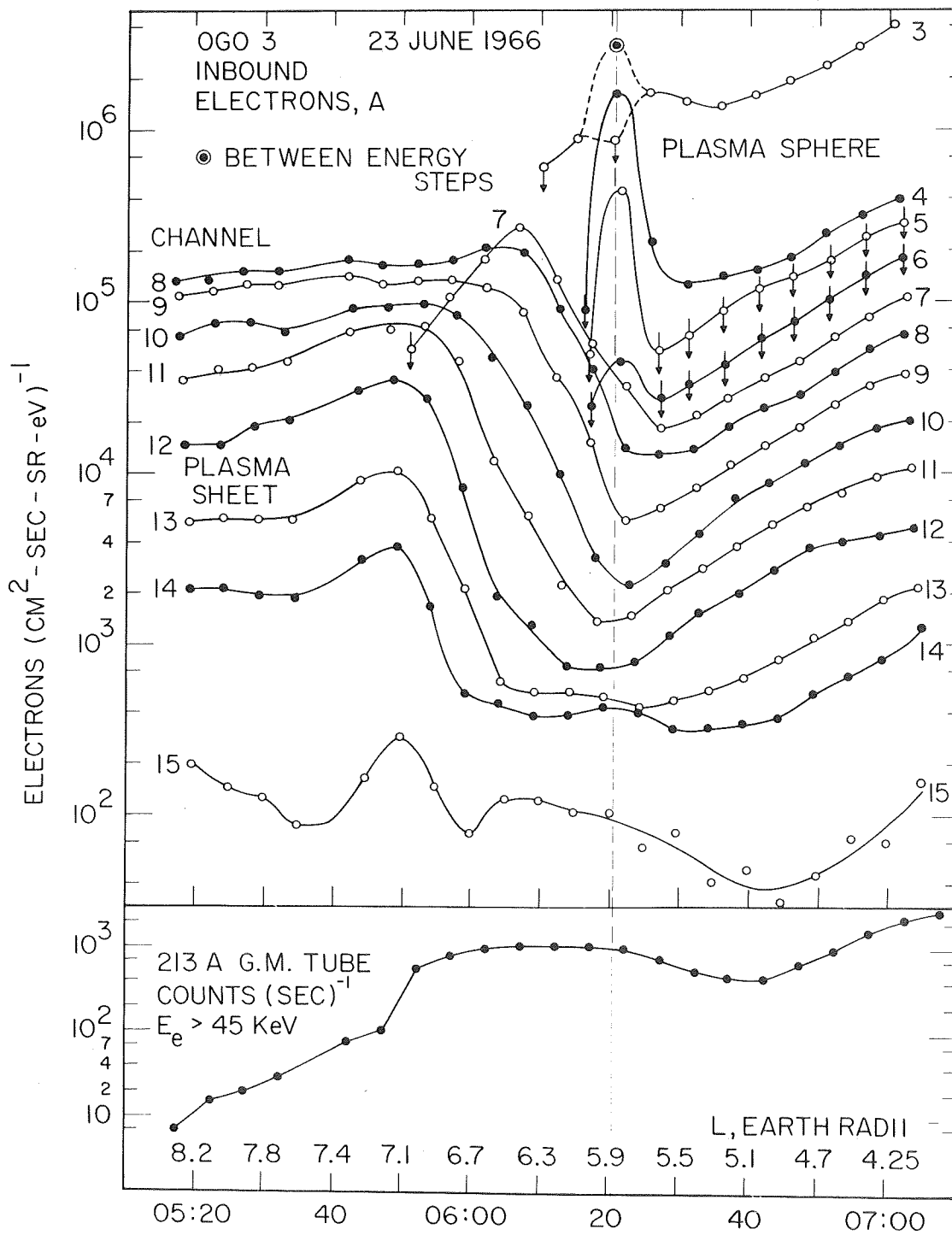


Figure 2

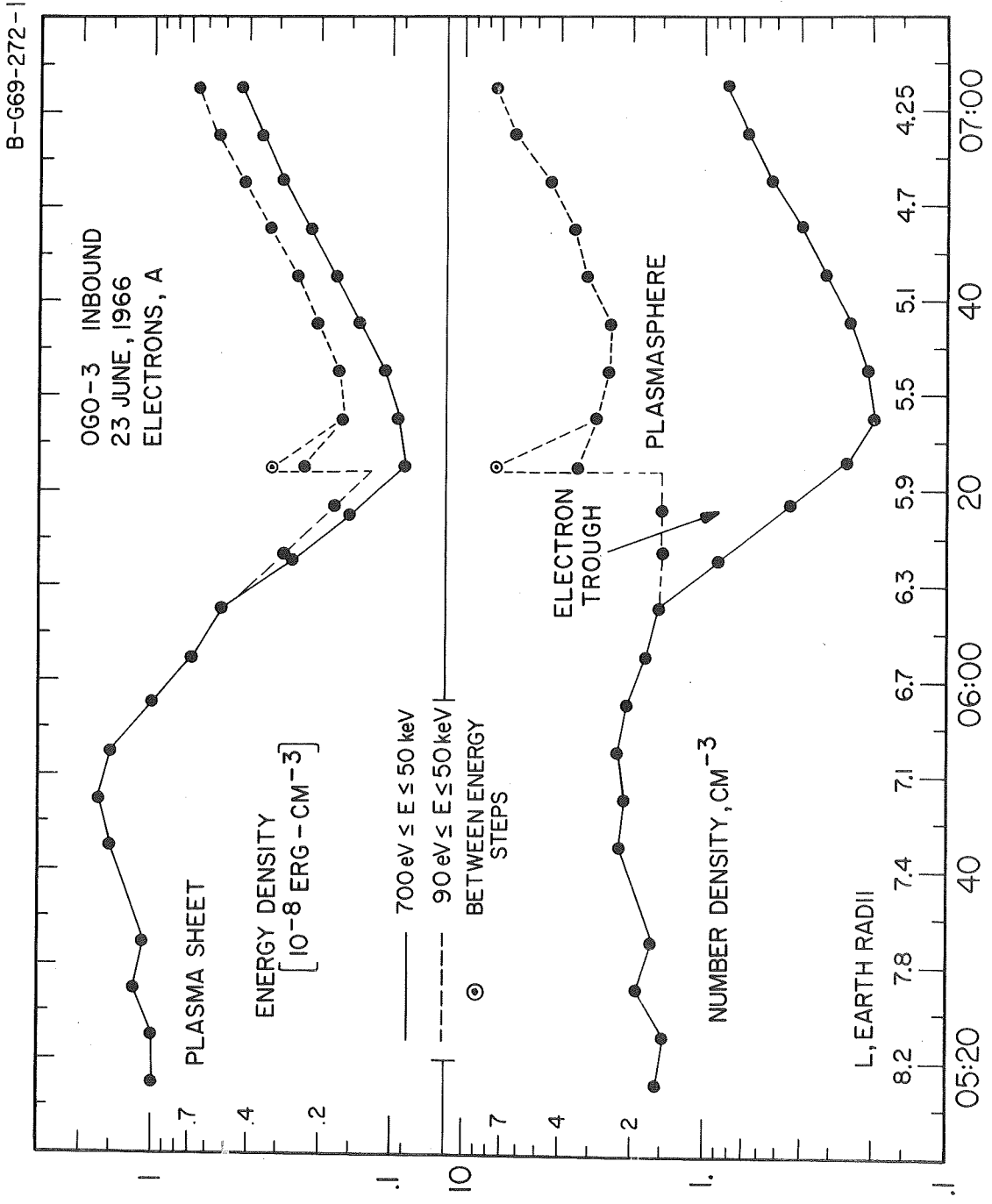


Figure 3

A-669-123-3

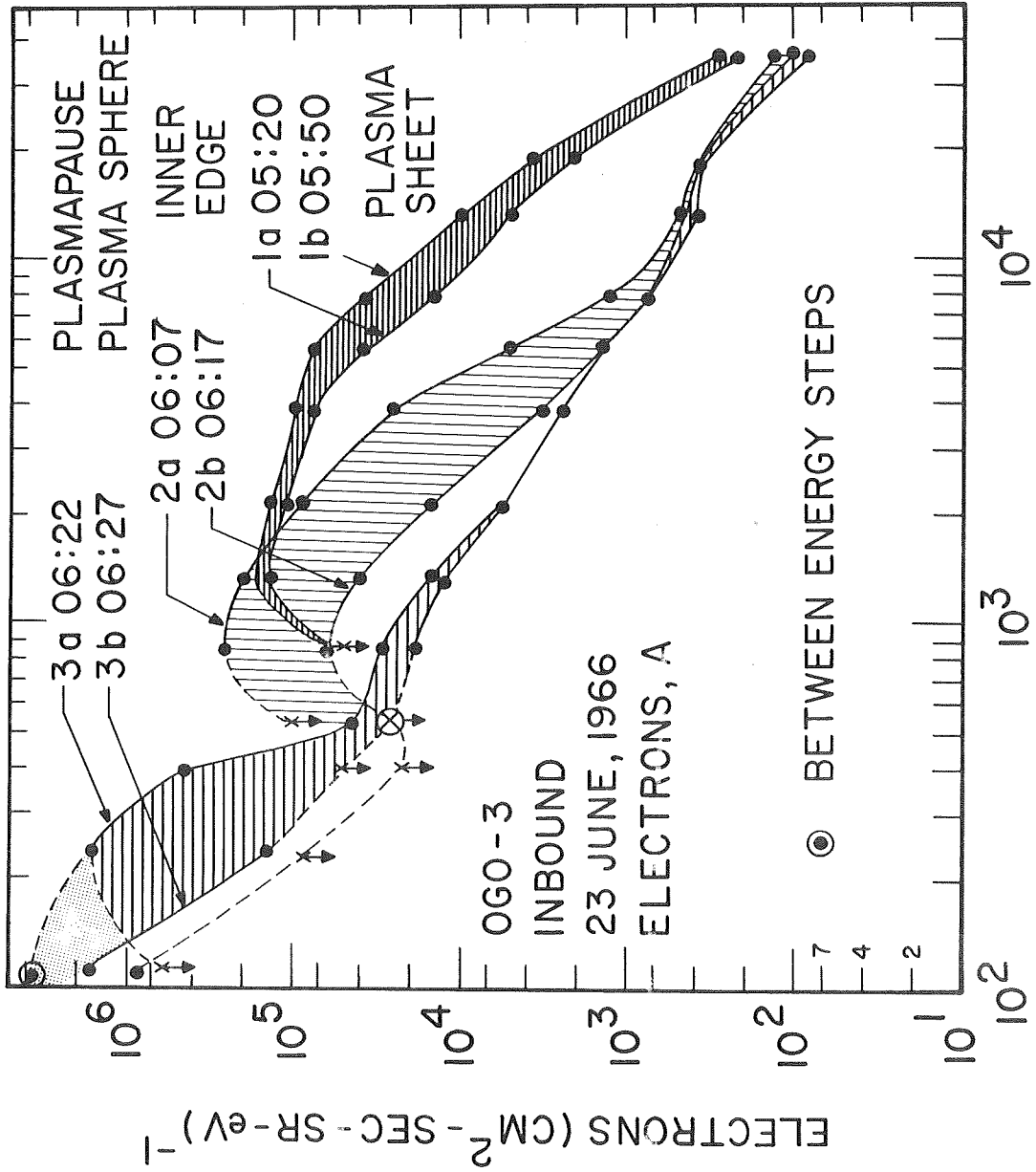


Figure 4

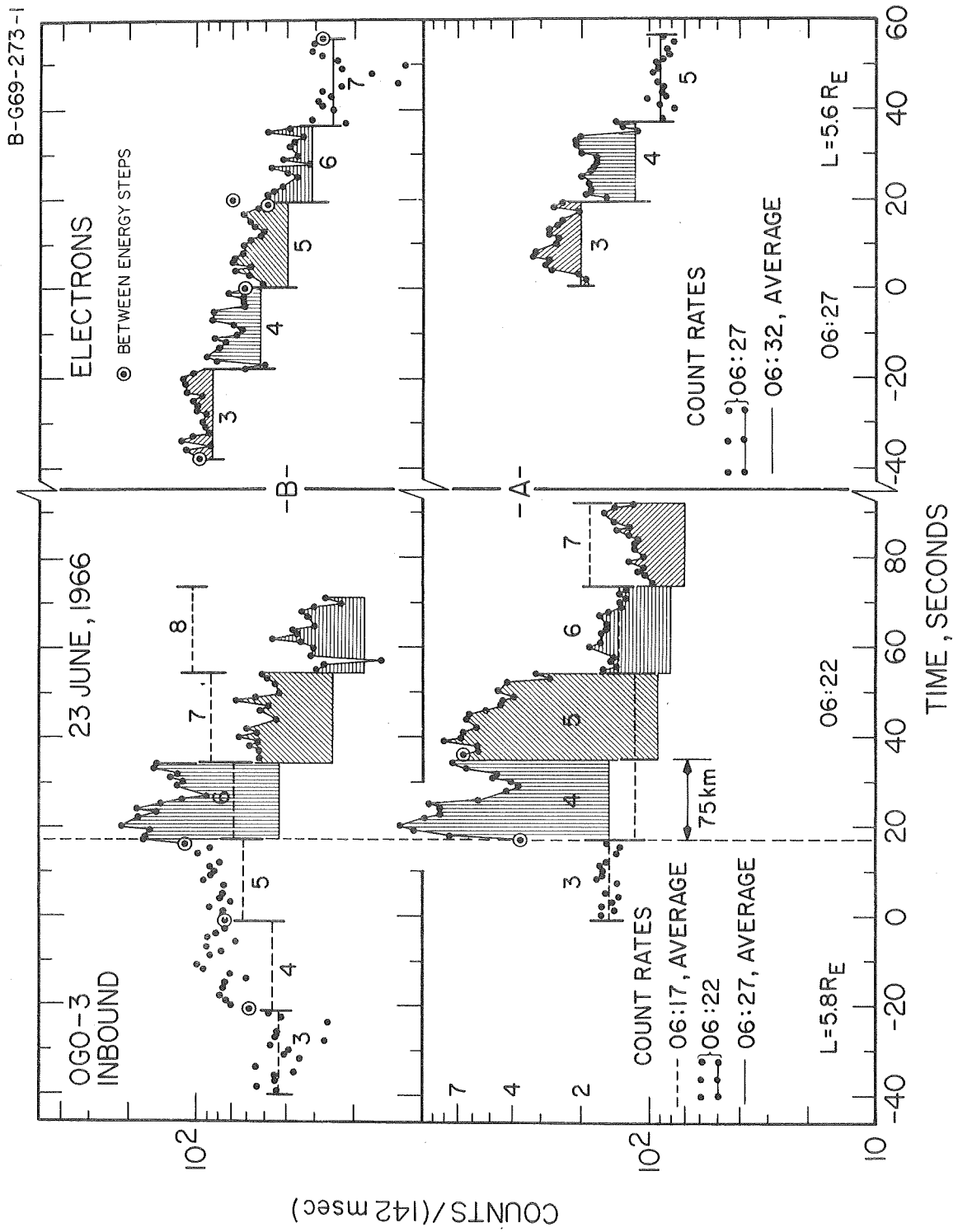
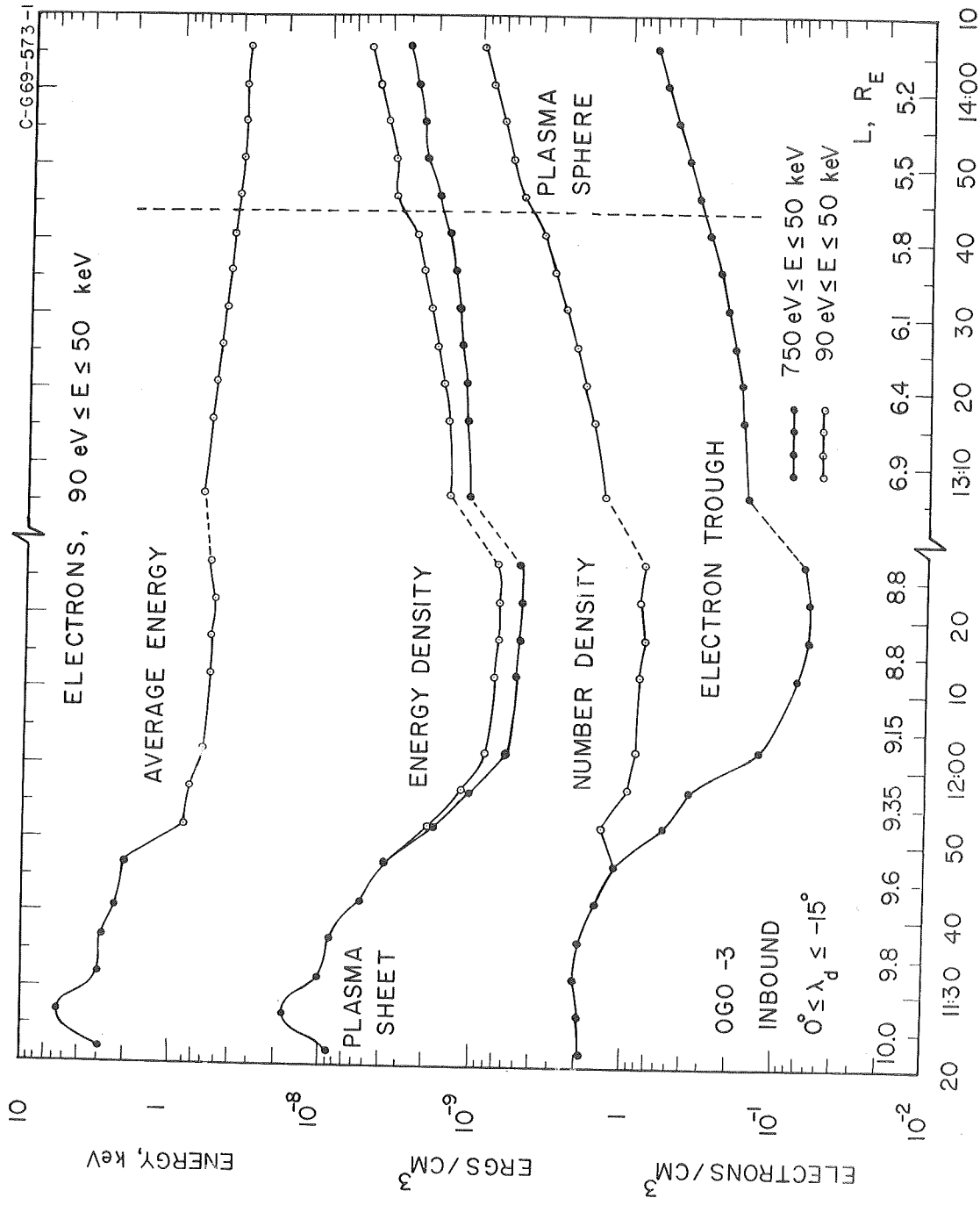


Figure 5





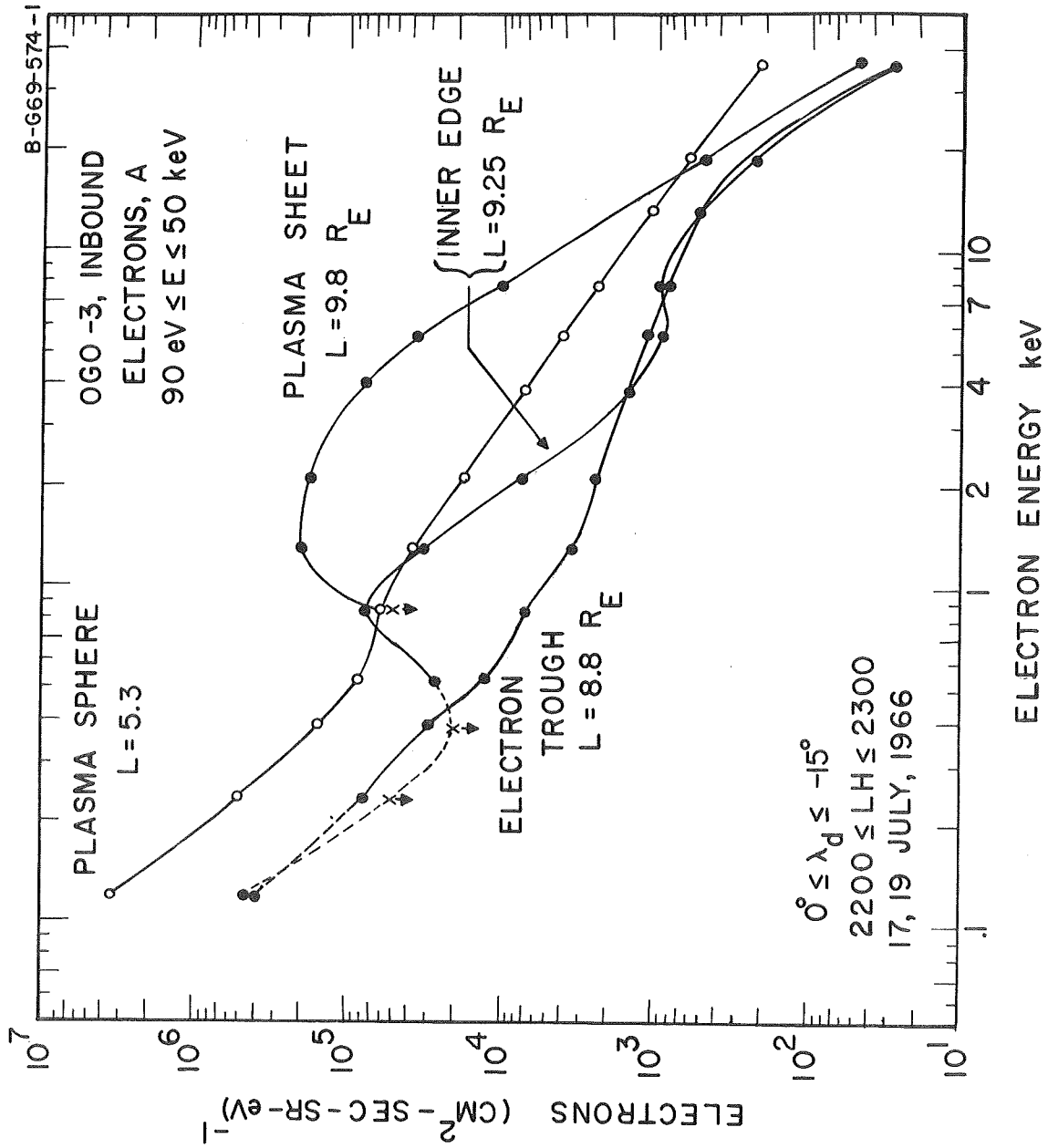


Figure 7

OGO-3, INBOUND, ELECTRONS - A,  $90 \text{ eV} \leq E \leq 48 \text{ keV}$

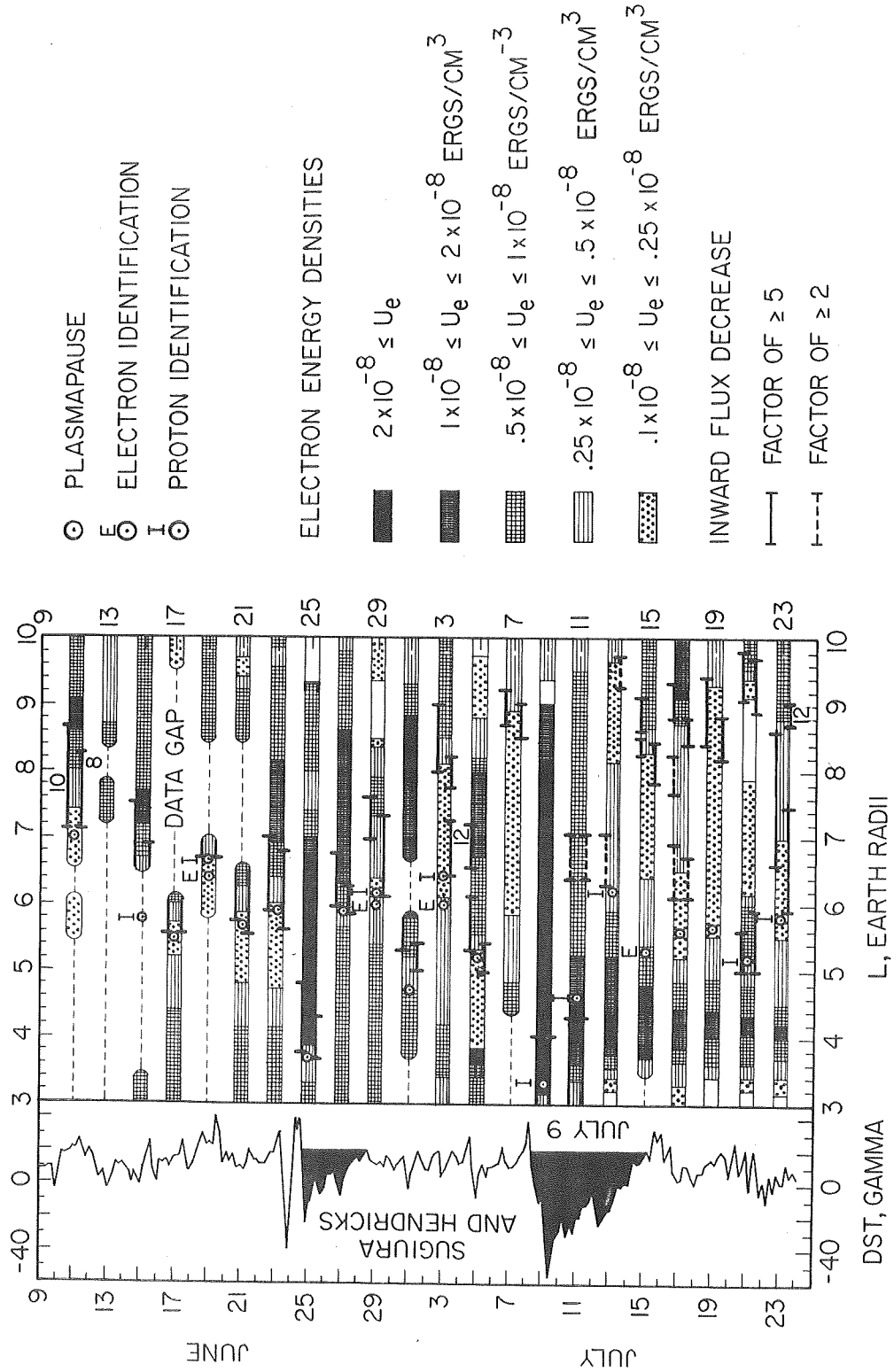


Figure 8

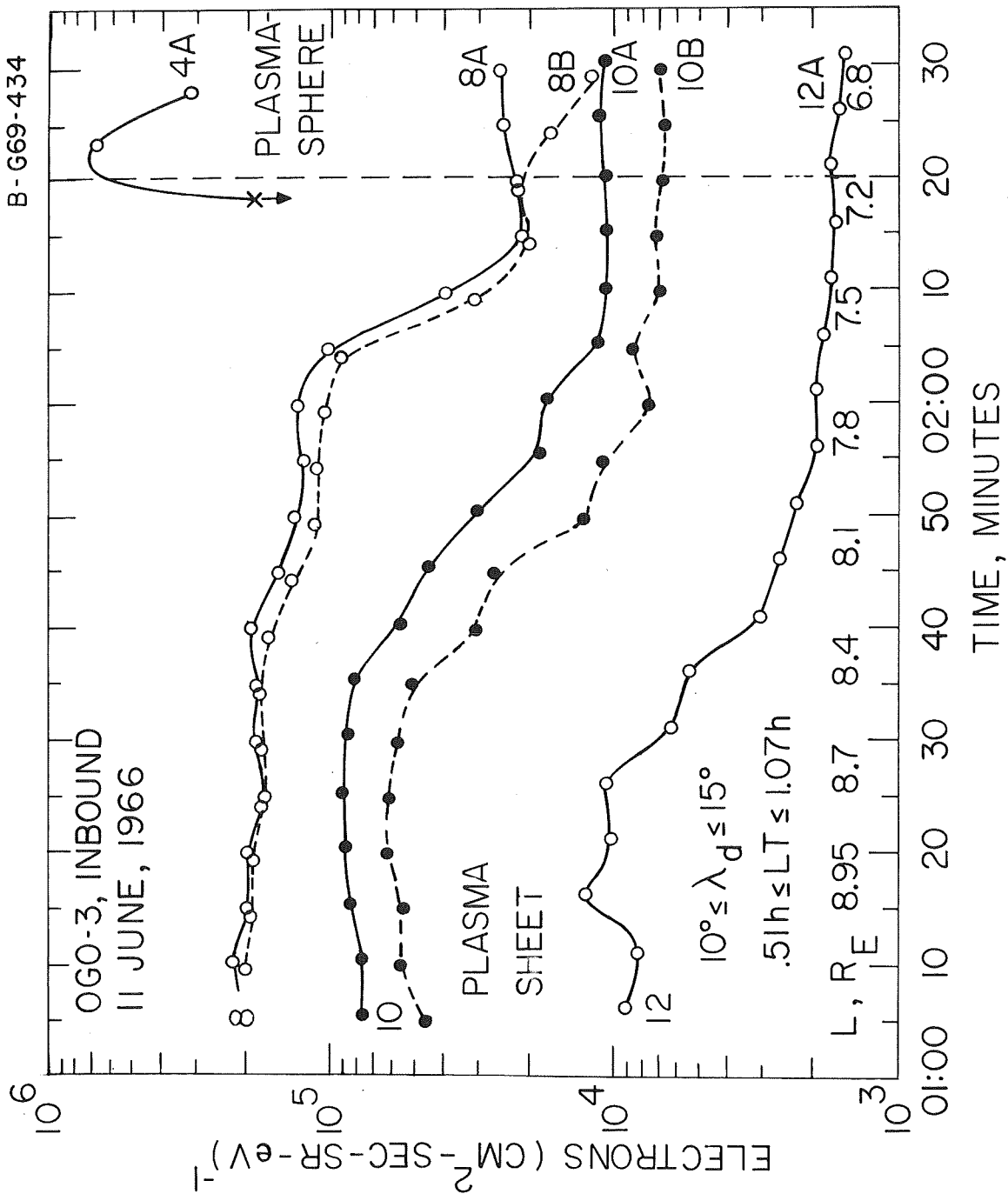


Figure 9



14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Radiation Zones						
Magnetic Storm						
Plasma Sheet						
Plasmasphere						
Plasmapause						

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