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EXPLORER 12 OBSERVATIONS OF THE
TEMPORAL VARIATIONS OF LOW-ENERGY
ELECTRON INTENSITIES IN THE
OUTER RADIATION ZONE
DURING GEOMAGNETIC STORMS*

by

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Abstract

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Large increases of electron $100 \text{ eV} \lesssim E_e \lesssim 40 \text{ keV}$ energy fluxes over $L \simeq 2.8$ to $L \simeq 4.0$ were observed at the onset of magnetic storms on 1 October and 29 October 1961 with instrumentation on Explorer 12. The omnidirectional energy fluxes at $L = 3.5$ were $\sim 1000 \text{ ergs}(\text{cm}^2\text{-sec})^{-1}$ for these two events, the duration of these events was approximately one day and the peak energy flux was positioned at $L \simeq 3.0$. The large enhancement of electron $100 \text{ eV} \lesssim E_e \lesssim 40 \text{ keV}$ energy fluxes on 1 October is coincident with large decreases of electron $E_e \gtrsim 1.6 \text{ MeV}$ intensities and with increases of electron $40 \text{ keV} \leq E_e \leq 100 \text{ keV}$ intensities in the outer radiation zone. Although no spectral information concerning the electron $100 \text{ eV} \lesssim E_e \lesssim 40 \text{ keV}$ fluxes is available, estimates of the decrease of the magnetic field on the surface of the earth at the magnetic equator for monoenergetic electron intensities corresponding to the observed energy fluxes are $\sim 120 \gamma$ for $E_e = 100 \text{ eV}$, $\sim 60 \gamma$ for $E_e = 500 \text{ eV}$ and $\sim 30 \gamma$ for $E_e = 2 \text{ keV}$ during the main phase of the magnetic storm. The observations reported here strongly suggest that these electrons form a ring

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current centered at $\sim 3 R_E$ which is responsible for a substantial fraction of the main phase and the rapid-decay component DRI of magnetic storms.

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I. Introduction

Observations of electron intensities near the geomagnetic equator in the outer radiation zone have been obtained with satellite instrumentation over a broad range of electron energies extending from ~ 1 eV to ~ 10 MeV. The temporal variations and radial profiles of intensities of electrons at the geomagnetic equator in the outer radiation zone are dependent upon the energy of the electrons under observation. For example, a comparison of observations of electron $E_e \sim 50$ keV and $E_e \sim 1$ MeV intensities in the outer radiation zone reveals (1) the radial dependence of electron $E_e \sim 50$ keV intensities is typically by a factor of $\lesssim 10$ over the radial distance 3 to $8 R_E$ (R_E = earth radius) [cf. Frank, Van Allen, Whelpley and Craven, 1963; Freeman, 1964] whereas the corresponding variation of electron $E_e \sim 1$ MeV intensities is typically by a factor $\sim 10^3 - 10^4$ with a peak of intensities at $L \sim 4$, and (2) during the onset of geomagnetic activity the electron $E_e \sim 50$ keV intensities are observed to increase by a factor $\sim 10 - 100$ coincident with a decrease of electron $E_e \sim 1$ MeV intensities by a factor $\sim 10 - 100$ within the temporal resolution of the

measurements (~ 1 day) [cf. Freeman, 1964; Frank, Van Allen and Hills, 1964]. Of specific interest in this present study are observations of the temporal variations of the energy flux of electrons $100 \text{ eV} \lesssim E_e \lesssim 40 \text{ keV}$ during periods of geomagnetic activity with instrumentation utilizing cadmium sulfide crystals flown on Explorer 12 and comparison of these variations of energy flux with simultaneous observations of higher energy electron ($E_e \sim 50 \text{ keV}$ and $E_e \sim 1 \text{ MeV}$) intensities. These observations contribute further to the growing body of information concerning outer radiation zone electrons which should eventually delineate the principal source and loss mechanisms for electrons in this region.

II. Instrumentation

Explorer 12 was launched on 16 August 1961 into an orbit with initial apogee 83,600 km and perigee 6,700 km geocentric radial distances, inclination 33° and period 26.5 hours. Transmission of data extended from launch to 6 December 1961. At launch the line of apsides of the spacecraft orbit was within $\sim 5^\circ$ of the solar direction as viewed from the center of the earth; hence the ranges of local times of the spacecraft position in the outer radiation zone ($L \sim 4$) were approximately $\sim 7:00$ to $1:00$ and $14:00$ to $8:00$ for outbound and inbound passes, respectively, over the period of data reception.

The University of Iowa complement of detectors included a shielded ($\sim 1 \text{ gm (cm)}^{-2}$) Anton type 302 G.M. tube, a magnetic spectrometer utilizing three thin-windowed (1.2 mg (cm)^{-2} mica) Anton type 213 G.M. tubes, and three cadmium sulfide crystals for measurements of the total energy flux of protons $E_p \gtrsim 1 \text{ keV}$ and electrons $E_e \gtrsim 200 \text{ eV}$. A summary of the characteristics of these various detectors is given in Table I. A more complete description has been given previously by Freeman [1964].

Table I
Geometric Factors And Particle Energy Thresholds
For The University Of Iowa Detectors On
Explorer 12

Detector	Symbol	Omnidirectional			Unidirectional		
		Shielding	Penetrating Particles	Geometric Factor (cm ²)	Shielding	Penetrating Particles Detected	Geometric Factor (cm ² -sr)
302 G.M. Tube	302	265 mg(cm) ⁻² Mg 400 mg(cm) ⁻² Stainless Steel	Protons > 23 MeV Electrons > 1.6 MeV	0.6*	----	----	----
Electron Magnetic Spectrometer	SPL	3.5 g(cm) ⁻² Pb	**Protons > 70 MeV	0.2	1.2 mg(cm) ⁻² mica	Electrons 40 keV ≤ E _e ≤ 50 keV	10 ⁻⁵
	SPH	1 g(cm) ⁻² Mg	Electrons > 20 MeV	0.2	1.2 mg(cm) ⁻² mica	Electrons 80 keV ≤ E _e ≤ 100 keV	10 ⁻⁵
	SPB	860 mg(cm) ⁻² Stainless Steel		0.2	----	----	----
CdS Total Energy Flux Detector	CDSTE***	~ 1 g(cm) ⁻² Mg	Protons > 25 MeV	(0.66 sr)	----	Electrons 200 eV ≤ E _e ≤ 500 keV	3 × 10 ⁻⁴
			Electrons > 3 MeV			Protons 1 keV ≤ E _p ≤ 10 MeV (LIGHT)	
CdS Proton Energy Flux Detector	CDSB***	~ 2.6 g(cm) ⁻² Pb	Protons > 50 MeV	(12 sr)	(MAGNET)	Protons 1 keV ≤ E _p ≤ 10 MeV	3 × 10 ⁻⁴
			Electrons > 6 MeV			Electrons E _e > 250 keV (LIGHT)	
CdS Light Monitor	CDSO***				550 mg(cm) ⁻² Quartz	(LIGHT)	3 × 10 ⁻⁴

* For detailed description, see Frank, Van Allen and Hills [1964]

** Ackerson [private communication, 1966]

*** Freeman [1964]

The response of each detector was accumulated for 10.24 seconds by the on-board experiment encoder and the contents of the accumulators redundantly telemetered at the end of each sampling interval. The encoder accumulators were time-shared such that each detector response was sampled once every 79 seconds.

Of particular interest in this present study are the responses of the cadmium sulfide crystals in the outer radiation zone. Pertinent characteristics of these three detectors [Freeman, 1964] are

- 1) CDSTE (cadmium sulfide total energy detector) is an unshielded cadmium sulfide crystal with a collimated field of view of 10^{-2} steradian which has a response proportional to the total energy flux of protons $E_p \gtrsim 1$ keV and $E_e \gtrsim 200$ eV. The efficiency of this detector for particles of these energies is $\sim 0.2 \text{ count-cm}^2\text{-sr(erg)}^{-1}$ and decreases with decreasing charged particle energies below $E_p \sim 1$ keV and $E_e \sim 200$ eV. Throughout the present discussion the maximum efficiency as quoted above will be assumed. The efficiency of CdS crystals has been shown to be nearly the same for electrons, protons, alpha particles and x-rays [Freeman, 1961].

The minimum detectable energy flux for CDSTE is
 $\sim 1 \text{ erg}(\text{cm}^2\text{-sec-sr})^{-1}$.

- 2) CDSB (cadmium sulfide detector with broom magnet) is an unshielded cadmium sulfide crystal identical to CDSTE with the exception of a "broom" magnet positioned in the collimator to prohibit electrons $E_e \lesssim 250 \text{ keV}$ from reaching the crystal. The efficiency of this crystal is within a factor of approximately two that of the CDSTE discussed above. Protons $E_p \gtrsim 400 \text{ eV}$ are able to reach the crystal and hence CDSB can be used to distinguish the response of CDSTE as being attributable to electrons $E_e \lesssim 250 \text{ keV}$ and protons $E_p \lesssim 400 \text{ eV}$ or electrons $E_e \gtrsim 250 \text{ keV}$ and protons $E_p \gtrsim 400 \text{ eV}$.
- 3) CDSO (cadmium sulfide optical monitor) is a cadmium sulfide crystal equipped with a collimator identical to CDSTE and CDSB but with a quartz window as shielding to monitor the background response of the detectors to light and x-rays.

All unidirectional detectors were mounted on the spacecraft such that the axes of their fields-of-view were perpendicular to the spacecraft spin axis. Since the spin period of Explorer 12 was ~ 2 seconds and the accumulation interval was 10.24 seconds,

the telemetered response of the detectors is essentially a spin-average over several spacecraft rotations with the responses of all unidirectional detectors averaged over a common circle of directions on the celestial sphere. The spin axis of Explorer 12 was directed toward right ascension 47° and declination -27.5° at launch. In the outer radiation zone the detectors were averaging predominantly over trapped particle pitch angles (the half-angle of the dumping cone at $L = 5$ is $\sim 5^\circ$).

III. Observations

A summary of the responses of CDSTE, CDSB and CDSO is displayed in Figure 1 for the period 21 September through 14 October 1961 for $L = 2.5, 3.0, 3.5$, and 4.0 . The temporal resolution of the measurements is determined by the orbital period (~ 1 day); observations during several orbits during this period are missing due to lack of reception of the satellite telemetry signal. For $L = 3.0$ and 3.5 the CDSTE response shows strong enhancements of energy flux on 1 October 1961 which are unique with respect to the smoothly varying profiles before and after this date. On the adjacent L-shells, $L = 2.5$ and 4.0 , only a relatively small increase occurs during the period 1-2 October 1961. Inspection of the response of the optical monitor, CDSO, reveals that its response remained at background levels throughout the period, thus eliminating light and x-rays as predominant contributors to the CDSTE response. The dark-current responses (counting rate near apogee, no light contamination) of CDSTE, CDSB and CDSO are $1.9, 1.1$ and 0.2 counts $(\text{sec})^{-1}$, respectively, for this period of observations. Further, at $L = 3.0$, the increase of the response of CDSTE on 1 October was by a factor of ~ 5 over the response during the preceding orbit on 30 September

whereas the increase of the response of CDSB (with broom magnet) was $\lesssim 50\%$ for the same orbits. These observational evidences show that the response of CDSTE on 1 October is predominantly attributable to electrons $E_e \lesssim 250$ keV or protons $E_p \lesssim 400$ eV. The corresponding peak energy fluxes, spin-averaged by the rotation of the spacecraft and assuming maximum efficiency of the detector (i.e., a lower limit to the energy flux), observed on 1 October 1961 are ~ 125 ergs(cm²-sec-sr)⁻¹ and 100 ergs(cm²-sec-sr)⁻¹ at $L = 3.0$ and 3.5, respectively. Also shown in Figure 1 (top) is the daily variation in mean horizontal intensity at Guam. The enhancement of energy flux observed by CDSTE is coincident with the main phase of a large magnetic storm on 1 October 1961. A further similar observation of severe enhancement of energy fluxes during the main phase of a geomagnetic storm is displayed in Figure 2 for the period 21 October through 13 November 1961. On 29 October, an energy flux of ~ 200 ergs(cm²-sec-sr)⁻¹ ($\lambda_m = -21^\circ$) was observed coincident with a large decrease in the horizontal intensity of the earth's magnetic field observed at the surface of the earth near the magnetic equator. A similar event, although clouded by loss of telemetry, occurs during 7-8 November.

Returning to Figure 1, the large range of magnetic latitudes ($20^\circ \lesssim \lambda_m \lesssim 45^\circ$) of the observations necessitates an investigation of the latitude dependence of the responses of these detectors in order to ascertain that the enhancement of energy fluxes on 1 October 1961 is not a manifestation of differing magnetic latitudes of the observations. In Figure 3 all CDSTE responses shown in Figure 1 for $L = 3.5$ are displayed as a function of the magnetic latitude of the observation. For the periods preceding and following 1 October, 21-30 September, and 2-14 October 1961 the CDSTE responses are smoothly increasing with decreasing geomagnetic latitude and indicate that the energy fluxes during the recovery phase are higher by a factor of ~ 2 compared with pre-storm fluxes over the latitude range $25^\circ - 45^\circ$. The variations of intensities shown in Figure 1, excluding 1 October, can be accounted for by the latitude dependence of the observations for these two periods. Further reference to Figure 3 clearly shows that the enhancement of energy flux on 1 October is not a manifestation of the latitude dependence of the observations but is indeed a large temporal variation of the electron energy fluxes. The same analysis applies to the data for $L = 3.0$. Simultaneous measurements obtained with the G.M. tubes are displayed in Figure 4 for

$L = 3.5$. The 302 G.M. tube response decreases by a factor of ~ 2 at the onset of the geomagnetic storm coincident with the increase of low-energy electron energy fluxes observed by CDSTE. These rapid decreases of 302 G.M. response (predominantly attributable to temporal variations of the electron $E_e \gtrsim 1.6$ MeV intensities in the outer radiation zone) coincident with the onset of geomagnetic activity have been reported previously [cf. Freeman, 1964; Frank, Van Allen and Hills, 1964]. The responses of the magnetic spectrometer G.M. tubes, SpL and SpH, ($40 \text{ keV} \leq E_e \leq 50 \text{ keV}$ and $80 \text{ keV} \leq E_e \leq 100 \text{ keV}$, respectively) have also been included in Figure 4. The responses of these detectors show a sharp peak on 1 October. Unfortunately the background G.M. tube in the spectrometer failed previous to the period of present interest but its response usually decreases coincident with the decrease in the 302 G.M. tube response at the onset of geomagnetic activity [Freeman, 1964]. Solid upper limits on the intensities of electrons $40 \text{ keV} \leq E_e \leq 50 \text{ keV}$ and $80 \text{ keV} \leq E_e \leq 100 \text{ keV}$ are $2 \times 10^7 (\text{cm}^2\text{-sec})^{-1}$ and $1.5 \times 10^7 (\text{cm}^2\text{-sec})^{-1}$, respectively. Omnidirectional intensities J_o are obtained from the observed spin-averaged unidirectional intensities \bar{j} by the relationship $J_o \simeq 10 \bar{j}$ and are accurate to within a factor of 2 for a large range of pitch angle

distributions ($\sin^n \alpha$) with arbitrary direction of the spin axis of the spacecraft with respect to the direction of the local magnetic field vector (See Frank, Van Allen and Hills [1964] for a similar analysis). Similarly the spin-averaged unidirectional energy fluxes corresponding to the CDSTE responses are multiplied by a factor of 10 to obtain omnidirectional energy fluxes. Hence an upper limit of the energy flux of electrons $40 \text{ keV} \leq E_e \leq 100 \text{ keV}$ is $\sim 10 \text{ ergs}(\text{cm}^2\text{-sec})^{-1}$ compared with the simultaneous CDSTE observation of $\sim 1000 \text{ ergs}(\text{cm}^2\text{-sec})^{-1}$, electrons $E_e \lesssim 250 \text{ keV}$ or protons, $E_p \lesssim 400 \text{ eV}$. The relatively slow variations in SpL and SpH responses during the periods 21-30 September and 2-14 October of Figure 4 are manifestations of a latitude dependence of the responses of these detectors as shown by a similar analyses as that given for CDSTE in Figure 3.

Further restrictions on the energy range of the electrons contributing predominantly to the enhanced CDSTE response on 1 October are provided by the responses of the 302 G.M. tube on 30 November and 1 October shown in Figure 5. The responses of both the CDSTE and the 302 G.M. tube are displayed as a function of L for the outbound pass preceding the storm (30 September) and the first outbound pass following the onset of the storm (1 October). The CDSTE response on

1 October is substantially greater than pre-storm values from $L = 2.8$ to 4.0 and is peaked at $L \simeq 3.0$ whereas the 302 G.M. response has catastrophically decreased beyond $L \simeq 4$ when compared to pre-storm values and shares a similar L-shell profile with CDSTE on 1 October. Assuming that the energy flux observed by CDSTE at $L = 3.0$, $\sim 1000 \text{ ergs}(\text{cm}^2\text{-sec})^{-1}$, is due to monoenergetic electrons of energy E_e , the responses of the 302 G.M. tube to non-penetrating electrons ($E_e \lesssim 1.6 \text{ MeV}$) of these intensities via the bremsstrahlung process have been calculated using the efficiency curve for a similarly shielded 302 G.M. tube given by Frank [1962] and are given in Table II. Comparison of the results of Table II with the observed 302 G.M. tube response of $\sim 10^3 \text{ counts}(\text{sec})^{-1}$ at $L = 3.0$ eliminates electron $E_e \gtrsim 80 \text{ keV}$ energy fluxes as predominant contributions to the CDSTE response. Hence the SpL, SpH and 302 G.M. tube responses restrict the energy range of electrons observed by CDSTE to $E_e \lesssim 40 \text{ keV}$. On the other hand, if the electron spectrum observed with SpL and SpH (neglecting background corrections) is extrapolated to $\sim 300 \text{ keV}$, the response of the 302 G.M. tube on 1 October can be attributed to bremsstrahlung from electrons $50 \text{ keV} \lesssim E_e \lesssim 300 \text{ keV}$. In summary the enhanced energy fluxes observed at the onset of

Table II

302 G.M. Tube Response Corresponding To
Monoenergetic Electrons With
Energy Flux 1000 Ergs(Cm²-Sec)⁻¹

Electron Energy E _e (keV)	J _o (cm ² -sec) ⁻¹	302 Efficiency, ε Count-cm ² (electron) ⁻¹	302 Counting Rate, R, counts (sec) ⁻¹
15	4 × 10 ¹⁰	2.5 × 10 ⁻¹²	0.1
20	3 × 10 ¹⁰	2.5 × 10 ⁻¹¹	0.8
30	2 × 10 ¹⁰	7 × 10 ⁻¹⁰	13
40	1.5 × 10 ¹⁰	10 ⁻⁸	150
50	10 ¹⁰	4.5 × 10 ⁻⁸	550
80	8 × 10 ⁹	5 × 10 ⁻⁷	4 × 10 ³
125	5 × 10 ⁹	2 × 10 ⁻⁶	10 ⁴
300	2 × 10 ⁹	5 × 10 ⁻⁶	10 ⁴

geomagnetic storms with the CDSTE from $L \simeq 2.8$ to $\simeq 4.0$ must be attributed to electrons $E_e \lesssim 40$ keV or protons $E_p \lesssim 400$ eV as delineated by the simultaneous responses of companion detectors as noted above.

Further evidence toward the identification of the particles predominantly contributing to the response of CDSTE on 1 October may be obtained by evaluating the energy densities of monoenergetic electrons and protons, separately, corresponding to the observed energy flux of $\sim 1000 \text{ ergs}(\text{cm}^2\text{-sec})^{-1}$. In Tables III (protons) and IV (electrons) are given the velocity v , energy density \bar{E} and omnidirectional intensity J_0 for protons and electrons of selected energies E . The magnetic latitude of the observation on 1 October was 33° at $L = 3.5$; the corresponding magnetic field energy density, $B^2/8\pi$, is $2.1 \times 10^{-5} \text{ erg}(\text{cm})^{-3}$. Also given in Tables III and IV are the ratios, β , of the charged particle energy density to the magnetic field energy density where

$$\beta = \frac{\bar{E}}{\left(\frac{B^2}{8\pi}\right)}$$

is evaluated at $L = 3.5$, $\lambda_m = 33^\circ$.

Table III

Intensities And Energy Densities Of Monoenergetic Protons
Corresponding To An Energy Flux
Of $1000 \text{ Ergs}(\text{cm}^2\text{-Sec})^{-1}$

Proton Energy $E_p(\text{keV})$	Velocity $\text{cm}(\text{sec})^{-1}$	Proton Energy Density \bar{E} $\text{ergs}(\text{cm})^{-3}$	Omnidirectional Intensity J_o $(\text{cm}^2\text{-sec})^{-1}$	$\beta = \frac{\bar{E}}{\left(\frac{B^2}{8\pi}\right)}$ B: $L=3.5, \lambda_m=33^\circ$
0.1	1.4×10^7	7.2×10^{-5}	6×10^{12}	3.4
0.2	2.0×10^7	5.1×10^{-5}	3×10^{12}	2.4
0.5	3.1×10^7	3.2×10^{-5}	1.2×10^{12}	1.5
1	4.4×10^7	2.3×10^{-5}	6×10^{11}	1.1
2	6.2×10^7	1.6×10^{-5}	3×10^{11}	0.76
5	9.8×10^7	10^{-5}	1.2×10^{11}	0.48
10	1.4×10^8	7.2×10^{-6}	6×10^{10}	0.34
20	2.0×10^8	5.1×10^{-6}	3×10^{10}	0.24
50	3.1×10^8	3.2×10^{-6}	1.2×10^{10}	0.15
100	4.4×10^8	2.3×10^{-6}	6×10^9	0.11
200	6.2×10^8	1.6×10^{-6}	3×10^9	0.08
500	9.8×10^8	10^{-6}	1.2×10^9	0.05

Table IV

Intensities And Energy Densities
Of Monoenergetic Electrons Corresponding
To An Energy Flux Of $1000 \text{ Ergs}(\text{Cm}^2\text{-Sec})^{-1}$

Electron Energy E_e (keV)	Velocity $\text{cm}(\text{sec})^{-1}$	Electron Energy Density \bar{E} $\text{ergs}(\text{cm})^{-3}$	Omnidirectional Intensity J_0 $(\text{cm}^2\text{-sec})^{-1}$	$\beta = \frac{\bar{E}}{\left(\frac{B^2}{8\pi}\right)}$ B: $L=3.5$, $\lambda_m=33^\circ$
0.1	5.9×10^8	1.7×10^{-6}	6×10^{12}	8.1×10^{-2}
0.2	8.4×10^8	1.2×10^{-6}	3×10^{12}	5.7×10^{-2}
0.5	1.3×10^9	7.9×10^{-7}	1.2×10^{12}	3.8×10^{-2}
1	1.9×10^9	5.3×10^{-7}	6×10^{11}	2.5×10^{-2}
2	2.7×10^9	3.8×10^{-7}	3×10^{11}	1.8×10^{-2}
5	4.2×10^9	2.4×10^{-7}	1.2×10^{11}	1.1×10^{-2}
10	5.9×10^9	1.7×10^{-7}	6×10^{10}	8.1×10^{-3}
20	8.2×10^9	1.2×10^{-7}	3×10^{10}	5.7×10^{-3}
50	1.2×10^{10}	8.1×10^{-8}	1.2×10^{10}	3.9×10^{-3}

It is generally believed that $\beta \lesssim 0.1$ for the earth's magnetosphere [cf Dessler and Vestine, 1960; Van Allen, 1966]. Application of this restriction to the values of β for protons given in Table III eliminates protons $E_p \lesssim 50$ keV as predominant contributors to the CDSTE response at $L = 3.5$ on 1 October. Reference to Table IV shows that electrons $E_e \gtrsim 100$ eV survive this restriction. Hence the large enhancement of energy flux observed with the CDSTE on 1 October 1961 can be attributed to electrons $100 \text{ eV} \lesssim E_e \lesssim 40 \text{ keV}$.

IV. Summary and Conclusions

Large increases of low-energy electron $100 \text{ eV} \lesssim E_e \lesssim 40 \text{ keV}$ energy fluxes coincident with the onset of two large geomagnetic storms during October 1961 over the L-shell range of $2.8 \lesssim L \lesssim 4.0$ as observed with Explorer 12 have been presented. The observed electron energy fluxes at $L = 3.5$ were $\sim 100 \text{ ergs}(\text{cm}^2\text{-sec-sr})^{-1}$ ($\lambda_m = -33^\circ$) on 1 October 1961 and $\sim 200 \text{ ergs}(\text{cm}^2\text{-sec-sr})^{-1}$ ($\lambda_m = 21^\circ$) on 29 October 1961. The time duration of these enhancements is approximately 1 day. A detailed analysis of the 1 October event provides the following conclusions:

- 1) the peak in the energy flux profile as a function of L occurs at $L \simeq 3.0$,
- 2) the maximum observed energy flux of electrons $100 \text{ eV} \lesssim E_e \lesssim 40 \text{ keV}$ is $\sim 1000 \text{ ergs}(\text{cm}^2\text{-sec})^{-1}$ (accurate to within a factor of 2),
- 3) the 302 G.M. tube response (primarily due to penetrating electrons $E_e \gtrsim 1.6 \text{ MeV}$) catastrophically decreases at $L \sim 4.5$ by a factor $\sim 10^2$ coincident with the enhancement of low-energy electrons $100 \text{ eV} \lesssim E_e \lesssim 40 \text{ keV}$ at $L \simeq 2.8$ to 4.0 ,

- 4) strong support of an increase of electron
 $40 \text{ keV} \leq E_e \leq 50 \text{ keV}$ and $80 \text{ keV} \leq E_e \leq 100 \text{ keV}$
intensities by a factor of ~ 5 at $L = 3.5$ on
1 October coincident with the enhancement of
low-energy electron fluxes is given by the
responses of the magnetic spectrometer G.M.
tubes, SpL and SpH, and
- 5) the charged particle total energy fluxes, as
measured with the CDSTE at $L = 3.5$, were a factor
of ~ 2 larger for the period 2-14 October after
the main phase of the storm when compared to the
pre-storm measurements of 21-30 September over
the geomagnetic latitude range $25^\circ \leq \lambda_m \leq 45^\circ$.

No mechanism for providing these large energy fluxes of electrons $100 \text{ eV} \leq E_e \leq 40 \text{ keV}$ is proposed here due to lack of energy spectra, angular distributions, and sensitivity for definitive measurements at higher L-values, i.e., $L > 4$. It is clear that a slow diffusion across L-shells as suggested for $\sim 1 \text{ MeV}$ electrons [cf. Frank, 1965] is inadequate, without fundamental modification, to account for the rapid enhancement (within 1 day or less of the onset of the geomagnetic storm) deep in the earth's magnetosphere at $L \sim 3.0$ since the increase

of electron $E_e \sim 1$ MeV intensities at $L \simeq 3.5$ is observed to occur after a period ~ 1 week following the onset of a magnetic storm. The observational evidence strongly suggests an acceleration mechanism for electrons $E_e \sim 1 - 100$ keV which is active deep in the earth's magnetosphere, $L \gtrsim 2.8$.

It is of interest to estimate the perturbation in the horizontal component of the earth's magnetic field as seen by a magnetic observatory at the surface of the earth near the magnetic equator which is produced by the enhanced electron energy fluxes as reported here during the main phase of a geomagnetic storm. An estimate of the decrease in the magnetic field intensity, ΔB , at the magnetic equator on the earth's surface due to these low-energy electrons is given by $\Delta B = k (W_e/W_B) B_0$ where ΔB is in units of gauss if $B_0 = 0.31$, W_e is the total energy in ergs of these electrons in the geomagnetic field, W_B is the total energy of the geomagnetic field (8.4×10^{24} ergs) and k is a dimensionless factor of the order of unity [cf Parker, 1965]. The total energy W_e of the low-energy electrons reported here is estimated by assuming an energy flux of $1000 \text{ ergs}(\text{cm}^2\text{-sec})^{-1}$ over a volume contained by the surfaces $L = 2.8$ and 4.0 between geomagnetic latitudes $\lambda_m = +35^\circ$ and -35° ($2 \times 10^{28} \text{ cm}^3$); the resulting estimate is

Table V

Estimates Of The Magnetic Field Perturbation, ΔB ,
 Seen At The Earth's Surface For An Electron Energy Flux
 $1000 \text{ Ergs}(\text{Cm}^2\text{-Sec})^{-1}$ Distributed Over
 $L = 2.8 \text{ to } 4.0, \lambda_m = -35^\circ \text{ to } +35^\circ$

Electron Energy E_e , keV	Total Electron Energy W_e , ergs	ΔB , gammas
0.1	3.4×10^{22}	120*
0.2	2.4×10^{22}	88*
0.5	1.6×10^{22}	58
1	1.1×10^{22}	39
2	7.6×10^{21}	28
5	4.8×10^{21}	18
10	3.4×10^{21}	12
20	2.4×10^{21}	9
50	1.6×10^{21}	6

* $\beta > 0.3$ at $L = 3.5, B/B_0 = 1$ in this approximation.

judged to be accurate to within a factor of 3 for the
 1 October 1961 observations. In Table V are summarized
 the estimates of ΔB for monoenergetic electrons with energy
 E_e corresponding to an energy flux of $1000 \text{ ergs (cm}^2\text{-sec)}^{-1}$
 throughout the above volume. For electron energies $E_e = 0.2$,
 1 and 5 keV, the decrease in field intensity, ΔB , is 90, 40
 and 20 γ , respectively. The $D_{st}(H)$ values for 1 October
 were $\sim -150 \gamma$ ($1 \gamma = 10^{-5}$ gauss). Hence, although the present
 experiment is unable to provide the energy spectra of electrons
 $100 \text{ eV} \lesssim E_e \lesssim 40 \text{ keV}$, the above estimates of the total energy
 of the observed electron energy fluxes, the correlation of the
 large enhancements of these electron energy fluxes with the
 main phases of two magnetic storms (see Figures 1 and 2) and
 the rapid decay ($\lesssim 24$ hours) of both phenomena strongly suggest
 that these electrons form a ring current centered at $\sim 3 R_E$
 which is responsible for a substantial fraction of the main
 phase and the rapid-decay component (designated as the DR1
 component by Akasofu, Chapman and Venkatesan [1963]) of magnetic
 storms. It is further noted here that the CDSB upper limit on
 the proton $E_p \gtrsim 400 \text{ keV}$ energy fluxes is $\sim 100 \text{ ergs (cm}^2\text{-sec)}^{-1}$
 at $L \sim 3$ during the main phases of these two magnetic storms,
 an upper limit which is not low enough to eliminate a low-energy
 proton ring current of similar or greater magnitude when compared
 with the above low-energy electron ring current.

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Figure Captions

- Figure 1. The responses of CDSTE, CDSB and CDSO for the period 21 September through 14 October 1961 for $L = 2.5, 3.0, 3.5$, and 4.0 . The range in geomagnetic latitude $|\lambda_m|$ is 20° to 45° . The daily mean variation of the horizontal intensity measured at Guam is included for comparison.
- Figure 2. A continuation of Figure 1 for $L = 3.5$ and the period 21 October through 13 November.
- Figure 3. Latitude dependence of CDSTE responses for $L = 3.5$ of Figure 1 separated into the periods of pre-storm, first day of storm (1 October), and post-1 October data.
- Figure 4. Responses of the spectrometer channels SpL and SpH and the 302 G.M. tube at $L = 3.5$ compared with the responses of CDSTE for the period 21 September through 14 October 1961 (refer to Figure 1).
- Figure 5. Comparison of the profiles of 302 G.M. tube and the CDSTE responses as a function of L for two similar outbound passes of Explorer 12 on 30 September and 1 October 1961. Geomagnetic latitudes for these passes have been included for several values of L .

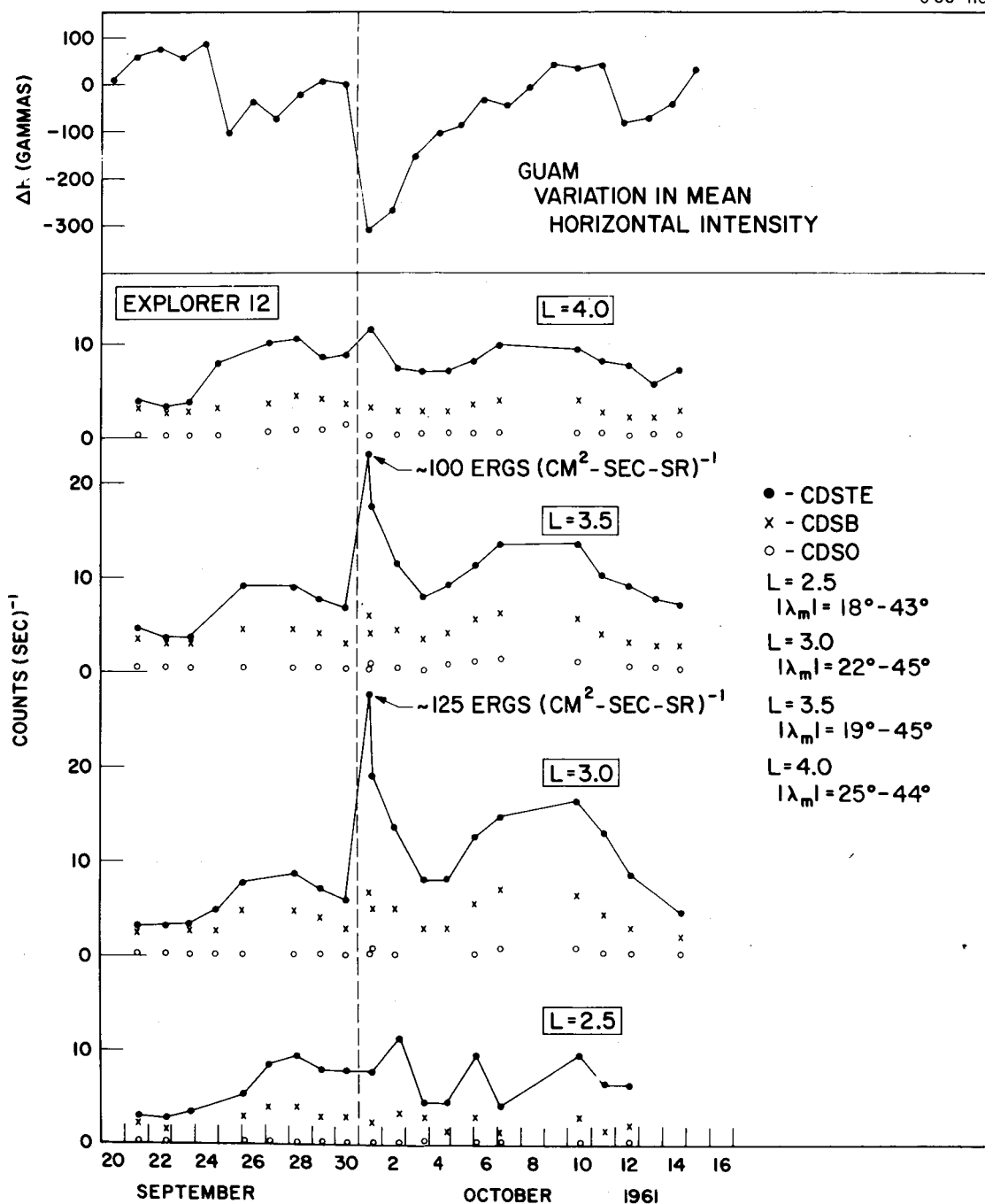


Figure 1

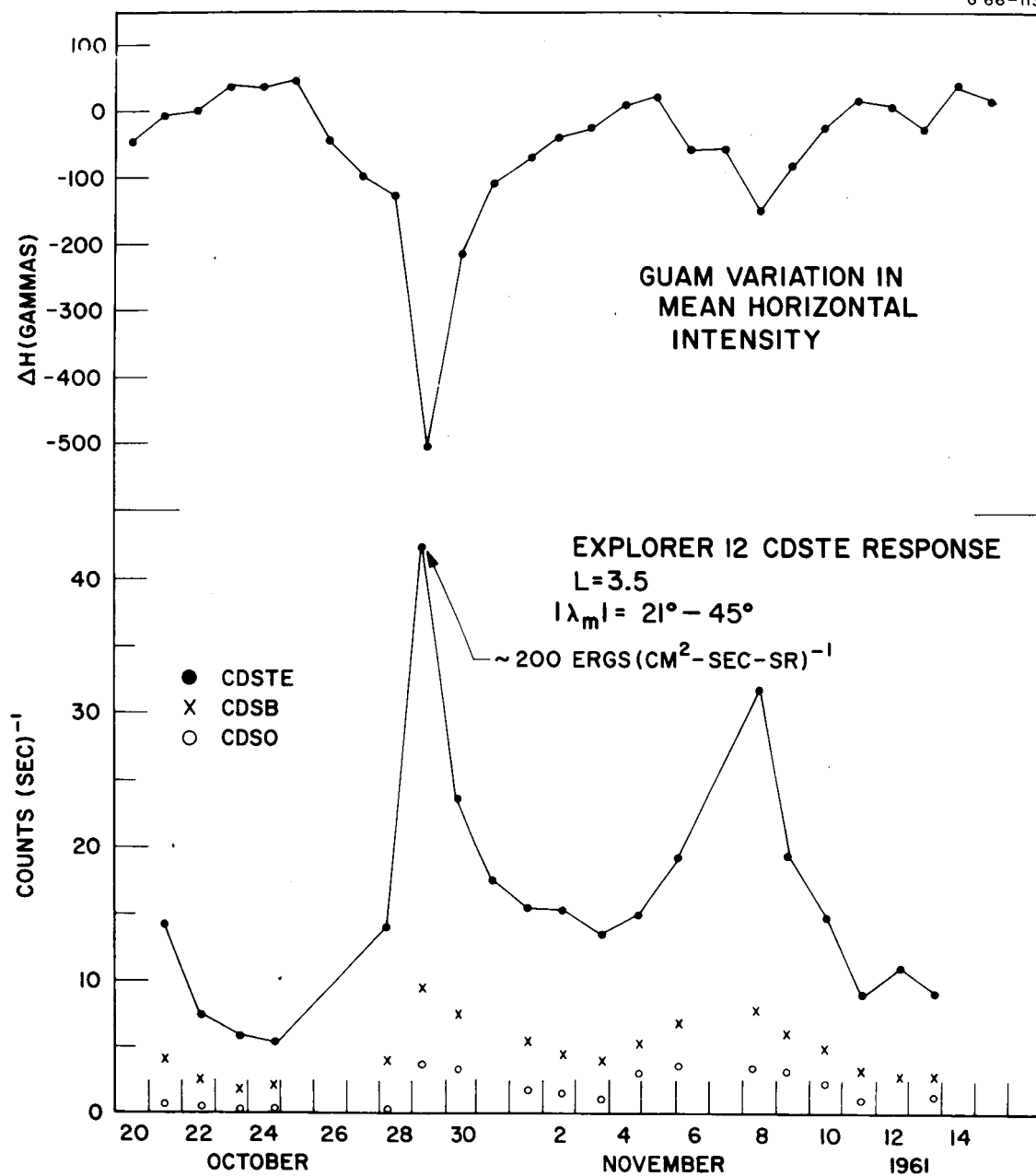


Figure 2

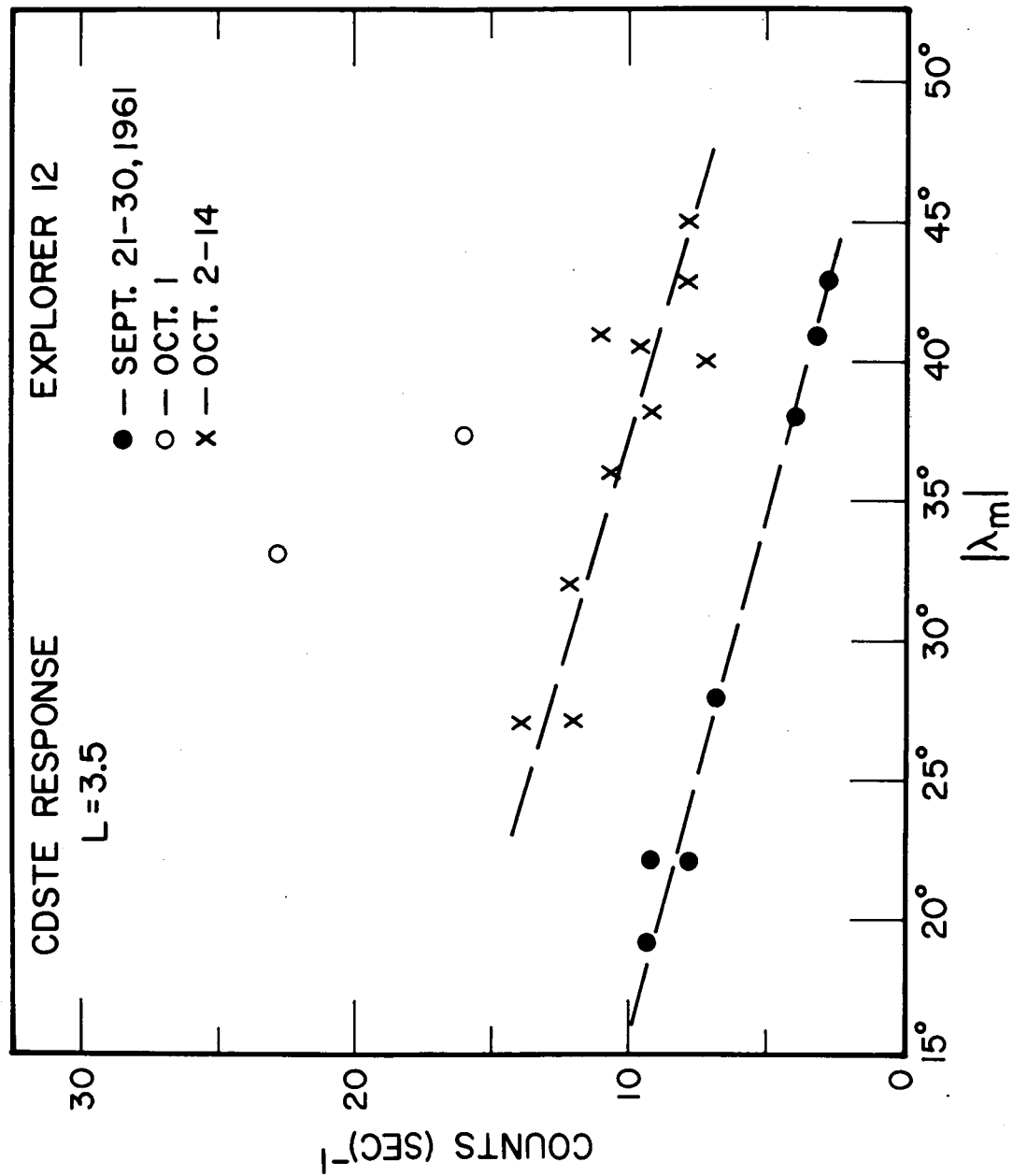


Figure 3

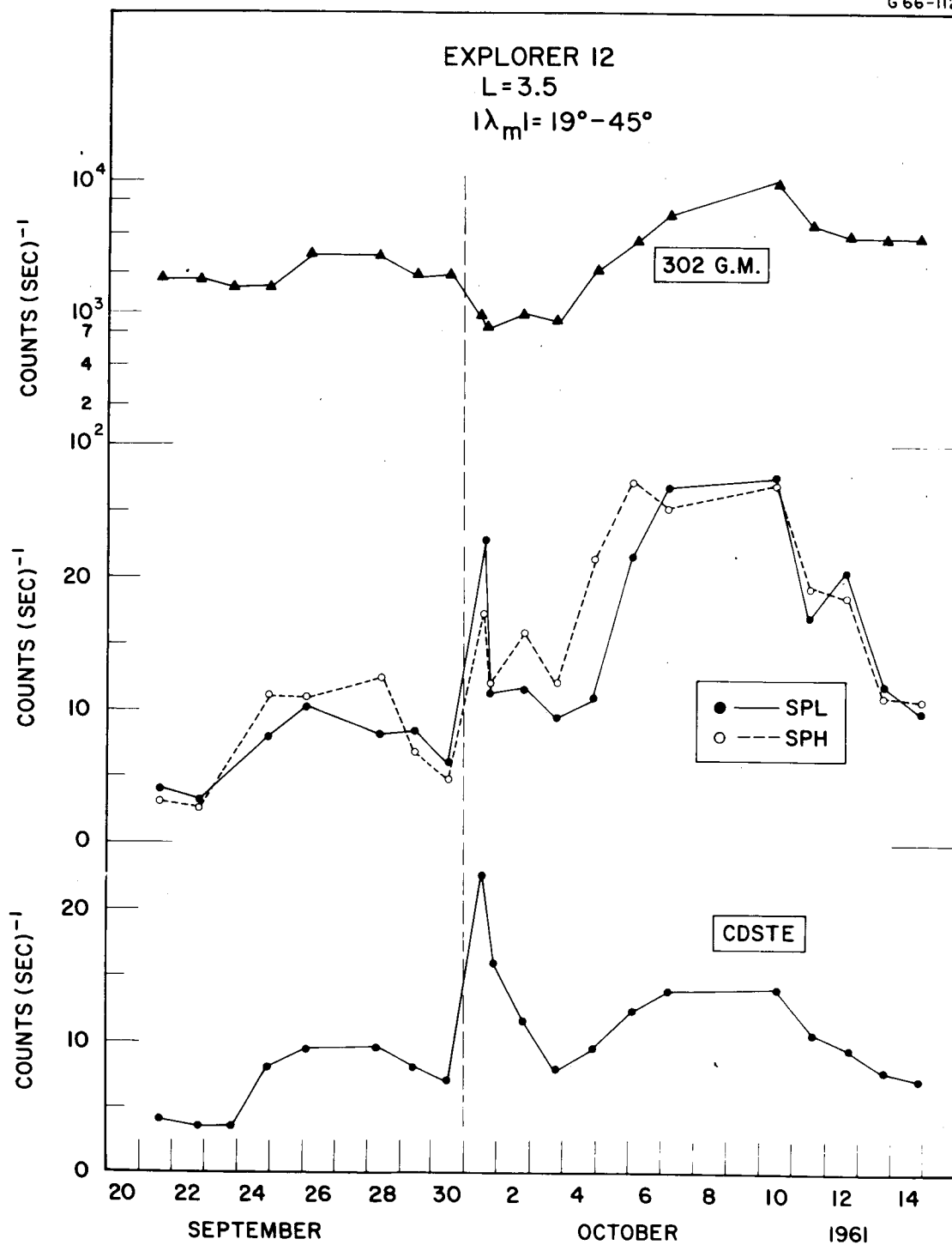


Figure 4

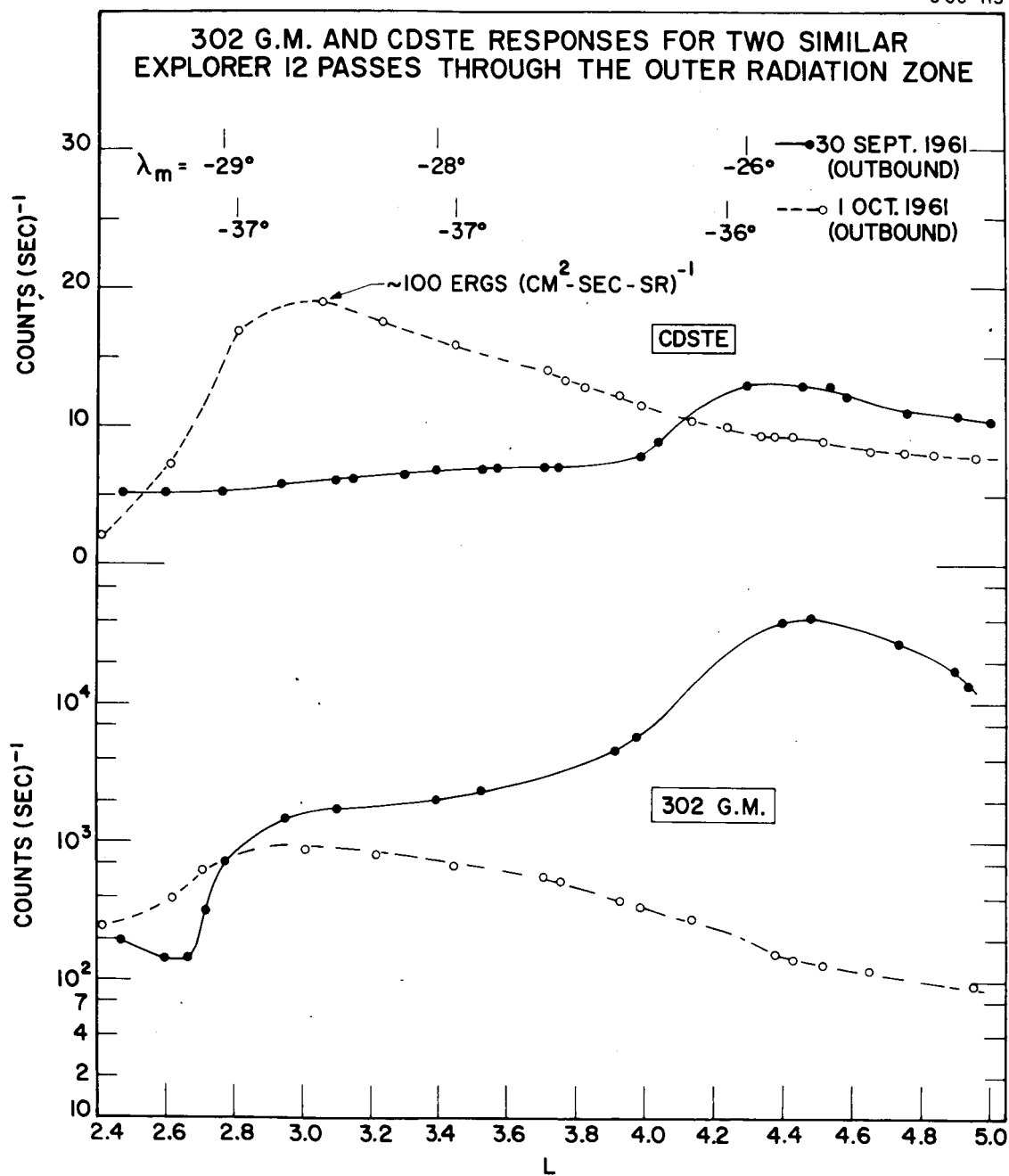


Figure 5

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		2b. GROUP	
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4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Progress			
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b. PROJECT NO.			
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10. AVAILABILITY/LIMITATION NOTICES Qualified requesters may obtain copies of this report from DDC.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Office of Naval Research	
13. ABSTRACT Large increases of electron $100 \text{ eV} \leq E_e \leq 40 \text{ keV}$ energy fluxes over $L \sim 2.8$ to $L \sim 4.0$ were observed at the onset of magnetic storms on 1 October and 29 October 1961 with instrumentation on Explorer 12. The omnidirectional energy fluxes at $L = 3.5$ were $\sim 1000 \text{ ergs}(\text{cm}^2\text{-sec})^{-1}$ for these two events, the duration of these events was approximately one day and the peak energy flux was positioned at $L \sim 3.0$. The large enhancement of electron $100 \text{ eV} \leq E_e \leq 40 \text{ keV}$ energy fluxes on 1 October is coincident with large decreases of electron $E_e > 1.6 \text{ MeV}$ intensities and with increases of electron $40 \text{ keV} \leq E_e \leq 100 \text{ keV}$ intensities in the outer radiation zone. Although no spectral information concerning the electron $100 \text{ eV} \leq E_e \leq 40 \text{ keV}$ fluxes is available, estimates of the decrease of the magnetic field on the surface of the earth at the magnetic equator for monoenergetic electron intensities corresponding to the observed energy fluxes are $\sim 120 \gamma$ for $E_e = 100 \text{ eV}$, $\sim 60 \gamma$ for $E_e = 500 \text{ eV}$ and $\sim 30 \gamma$ for $E_e = 2 \text{ keV}$ during the main phase of the magnetic storm. The observations reported here strongly suggest that these electrons form a ring current centered at $\sim 3 R_E$ which is responsible for a substantial fraction of the main phase and the rapid-decay component DRI of magnetic storms.			

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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