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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 eV $\lesssim E_e \lesssim$ 40 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 ~ 1000 ergs$(cm^2\text{-}sec)^{-1}$ 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 eV $\lesssim E_e \lesssim$ 40 keV energy fluxes on 1 October is coincident with large decreases of electron $E_e \gtrsim$ 1.6 MeV intensities and with increases of electron 40 keV $\leq E_e \leq$ 100 keV intensities in the outer radiation zone. Although no spectral information concerning the electron 100 eV $\lesssim E_e \lesssim$ 40 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 ~ 120 γ for E_e = 100 eV, ~ 60 γ for E_e = 500 eV and ~ 30 γ for E_e = 2 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 DR1 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 eV $\lesssim E_e \lesssim$ 40 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 keV and $E_e \sim$ 1 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 ~ 5° 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 ~ 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 (~ 1 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 $E_p \gtrsim 1$ keV and electrons $E_e \gtrsim 200$ 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

		Omnidirectional			Unidirectional		
Detector	Symbol	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 $\leq E_e \leq$ 50 keV	10^{-5}
	SPH	1 $g(cm)^{-2}$ Mg	Electrons $\gtrsim 20$ MeV	0.2	1.2 $mg(cm)^{-2}$ mica	Electrons 80 keV $\leq E_e \leq$ 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 $\gtrsim 25$ MeV Electrons $\gtrsim 3$ MeV	(0.66 sr)	----	Electrons 200 eV $\lesssim E_e \lesssim$ 500 keV Protons 1 keV $\lesssim E_p \lesssim$ 10 MeV (LIGHT)	3×10^{-4}
CdS Proton Energy Flux Detector	CDSB***	~ 2.6 $g(cm)^{-2}$ Pb	Protons $\gtrsim 50$ MeV Electrons $\gtrsim 6$ MeV	(12 sr)	(MAGNET)	Protons 1 keV $\lesssim E_p \lesssim$ 10 MeV Electrons $E_e \gtrsim$ 250 keV (LIGHT)	3×10^{-4}
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 ~ 0.2 count-cm^2-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 ~ 1 erg$(cm^2\text{-sec-sr})^{-1}$.

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 $E_e \lesssim 250$ keV from reaching the crystal. The efficiency of this crystal is within a factor of approximately two that of the CDSTE discussed above. Protons $E_p \gtrsim 400$ eV are able to reach the crystal and hence CDSB can be used to distinquish the response of CDSTE as being attributable to electrons $E_e \lesssim 250$ keV and protons $E_p \lesssim 400$ eV or electrons $E_e \gtrsim 250$ keV and protons $E_p \gtrsim 400$ 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 $\sim 5°$).

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 $(sec)^{-1}$, 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$(cm^2$-sec-sr$)^{-1}$ and 100 ergs$(cm^2$-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$(cm^2$-sec-sr$)^{-1}$ ($\lambda_m = -21°$) 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 ($20° \lesssim \lambda_m \lesssim 45°$) 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° - 45°. 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 keV $\leq E_e \leq$ 50 keV and 80 keV $\leq E_e \leq$ 100 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 keV $\leq E_e \leq$ 50 keV and 80 keV $\leq E_e \leq$ 100 keV are 2×10^7 $(cm^2\text{-}sec)^{-1}$ and 1.5×10^7 $(cm^2\text{-}sec)^{-1}$, 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 keV $\leq E_e \leq$ 100 keV is $\sim$ 10 ergs$(cm^2\text{-sec})^{-1}$ compared with the simultaneous CDSTE observation of $\sim$ 1000 ergs$(cm^2\text{-sec})^{-1}$, electrons $E_e \lesssim$ 250 keV or protons, $E_p \lesssim$ 400 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, ~ 1000 ergs$(cm^2\text{-sec})^{-1}$, is due to monoenergetic electrons of energy E_e, the responses of the 302 G.M. tube to non-penetrating electrons ($E_e \lesssim 1.6$ 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 ~ 10^3 counts $(sec)^{-1}$ at L = 3.0 eliminates electron $E_e \gtrsim 80$ 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 $E_e \lesssim 40$ keV. On the other hand, if the electron spectrum observed with SpL and SpH (neglecting background corrections) is extrapolated to ~ 300 keV, the response of the 302 G.M. tube on 1 October can be attributed to bremsstrahlung from electrons 50 keV $\lesssim E_e \lesssim$ 300 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$(Cm^2\text{-}Sec)^{-1}$

Electron Energy E_e(keV)	J_o $(cm^2\text{-}sec)^{-1}$	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 ~ 1000 ergs$(cm^2\text{-sec})^{-1}$. In Tables III (protons) and IV (electrons) are given the velocity v, energy density $\overline{E}$ and omnidirectional intensity J_o 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 2.1×10^{-5} erg$(cm)^{-3}$. Also given in Tables III and IV are the ratios, β, of the charged particle energy density to the magnetic field energy density where

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

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

Table III

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

Proton Energy E_p(keV)	Velocity cm$(sec)^{-1}$	Proton Energy Density $\bar{E}$ ergs$(cm)^{-3}$	Omnidirectional Intensity J_o $(cm^2\text{-sec})^{-1}$	$\beta = \frac{\bar{E}}{\left(\frac{B^2}{8\pi}\right)}$ B: L=3.5, λ_m=33°
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 Ergs$(Cm^2$-Sec$)^{-1}$

Electron Energy E_e (keV)	Velocity cm$(sec)^{-1}$	Electron Energy Density $\bar{E}$ ergs$(cm)^{-3}$	Omnidirectional Intensity J_o $(cm^2$-sec$)^{-1}$	$\beta = \frac{\bar{E}}{\left(\frac{B^2}{8\pi}\right)}$ B: L=3.5, λ_m=33°
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 eV $\lesssim E_e \lesssim$ 40 keV.

IV. Summary and Conclusions

Large increases of low-energy electron 100 eV $\lesssim E_e \lesssim$ 40 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 ~ 100 ergs$(cm^2$-sec-sr$)^{-1}$ (λ_m = - 33°) on 1 October 1961 and ~ 200 ergs$(cm^2$-sec-sr$)^{-1}$ (λ_m = 21°) 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 eV $\lesssim E_e \lesssim$ 40 keV is ~ 1000 ergs$(cm^2$-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 MeV) catastrophically decreases at L ~ 4.5 by a factor ~ 10^2 coincident with the enhancement of low-energy electrons 100 eV $\lesssim E_e \lesssim$ 40 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 $25° \leq \lambda_m \leq 45°$.

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 ~ 1 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 ~ 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 $\Delta B = k\ (W_e/W_B)\ B_o$ where ΔB is in units of gauss if $B_o = 0.31$, 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 ergs$(cm^2\text{-sec})^{-1}$ over a volume contained by the surfaces $L = 2.8$ and 4.0 between geomagnetic latitudes $\lambda_m = +\ 35°$ and $-\ 35°$ (2×10^{28} 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 Ergs$(Cm^2\text{-}Sec)^{-1}$ Distributed Over $L = 2.8$ to 4.0, $\lambda_m = -35°$ to $+35°$

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 $L = 3.5$, $B/B_o = 1$ 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 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 eV $\lesssim E_e \lesssim$ 40 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 keV energy fluxes is $\sim$ 100 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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References

Akasofu, S.-I., S. Chapman, and D. Venkatesan, The main phase of great magnetic storms, J. Geophys. Res., 68, 3345-3350, 1963.

Dessler, A. J., and E. H. Vestine, Maximum total energy of the Van Allen radiation belt, J. Geophys. Res., 65, 1069-1071, 1960.

Frank, L. A., Efficiency of a Geiger-Mueller tube for non-penetrating electrons, J. Franklin Inst., 273, 91-106, 1962.

Frank, L. A., Inward radial diffusion of electrons of greater than 1.6 million electron volts in the outer radiation zone, J. Geophys. Res., 70, 3533-3540, 1965.

Frank, L. A., J. A. Van Allen, W. A. Whelpley, and J. D. Craven, Absolute intensities of geomagnetically trapped particles with Explorer 14, J. Geophys. Res., 68, 1573-1579, 1963.

Frank, L. A., J. A. Van Allen, and H. K. Hills, A study of charged particles in the earth's outer radiation zone with Explorer 14, J. Geophys. Res., 69, 2171-2191, 1964.

Freeman, J. W., A satellite borne cadmium sulfide total corpuscular energy detector, State University of Iowa Research Report, 61-2, February 1961, (unpublished).

Freeman, J. W., The morphology of the electron distribution in the outer radiation zone and near the magnetospheric boundary as observed by Explorer XII, J. Geophys. Res., 69, 1691-1723, 1964.

Parker, E. N., Paper presented at the Advanced Study Institute on Radiation Trapped in the Earth's Magnetic Field, Bergen, Norway, 16 August 1965 (to be published in Proceedings, 1966).

Van Allen, J. A., Some general aspects of the geomagnetically trapped radiation, Proceedings of the Advanced Study Institute on Radiation Trapped in the Earth's Magnetic Field, Bergen, Norway, 16 August 1965 (to be published, 1966).

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.

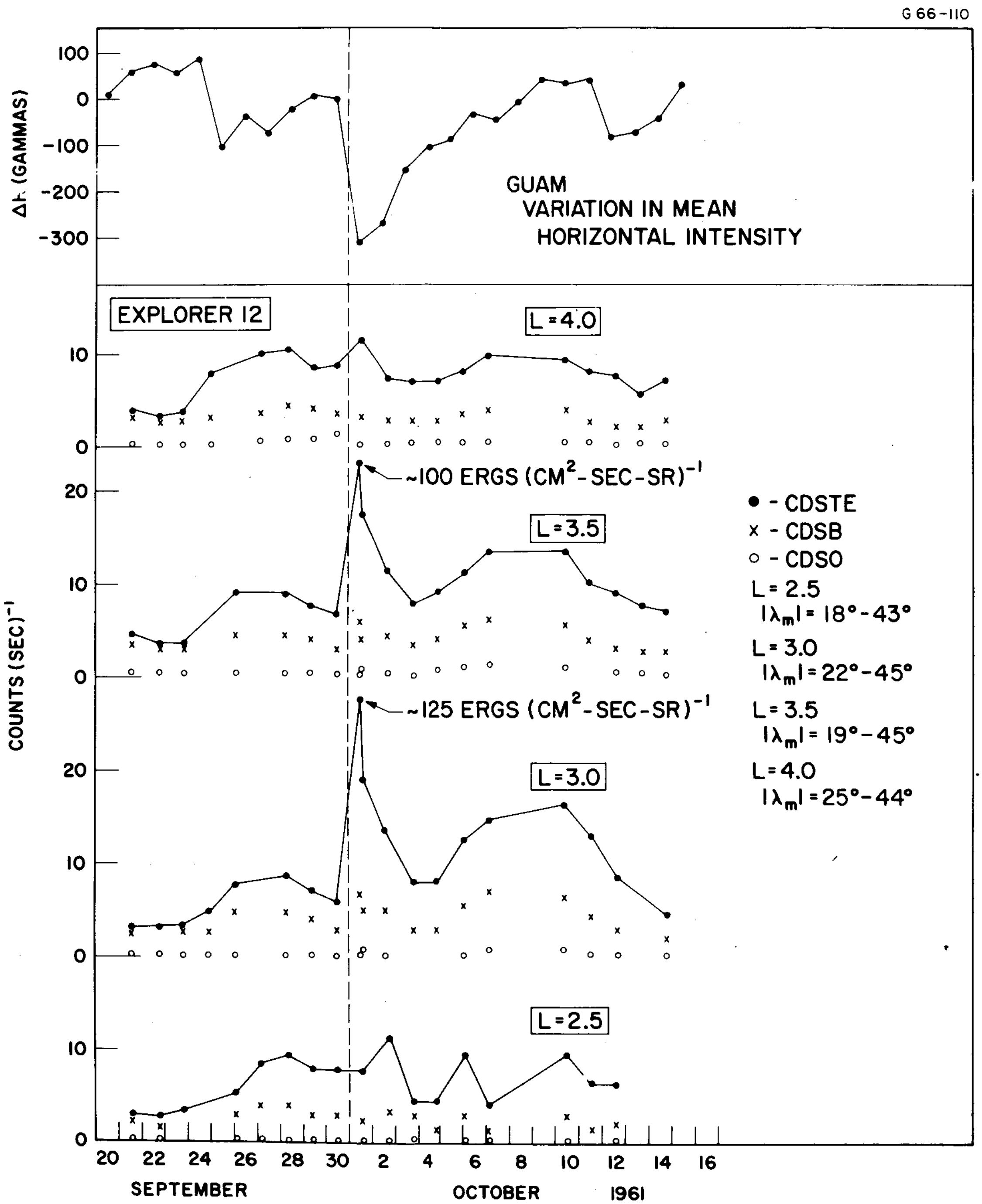
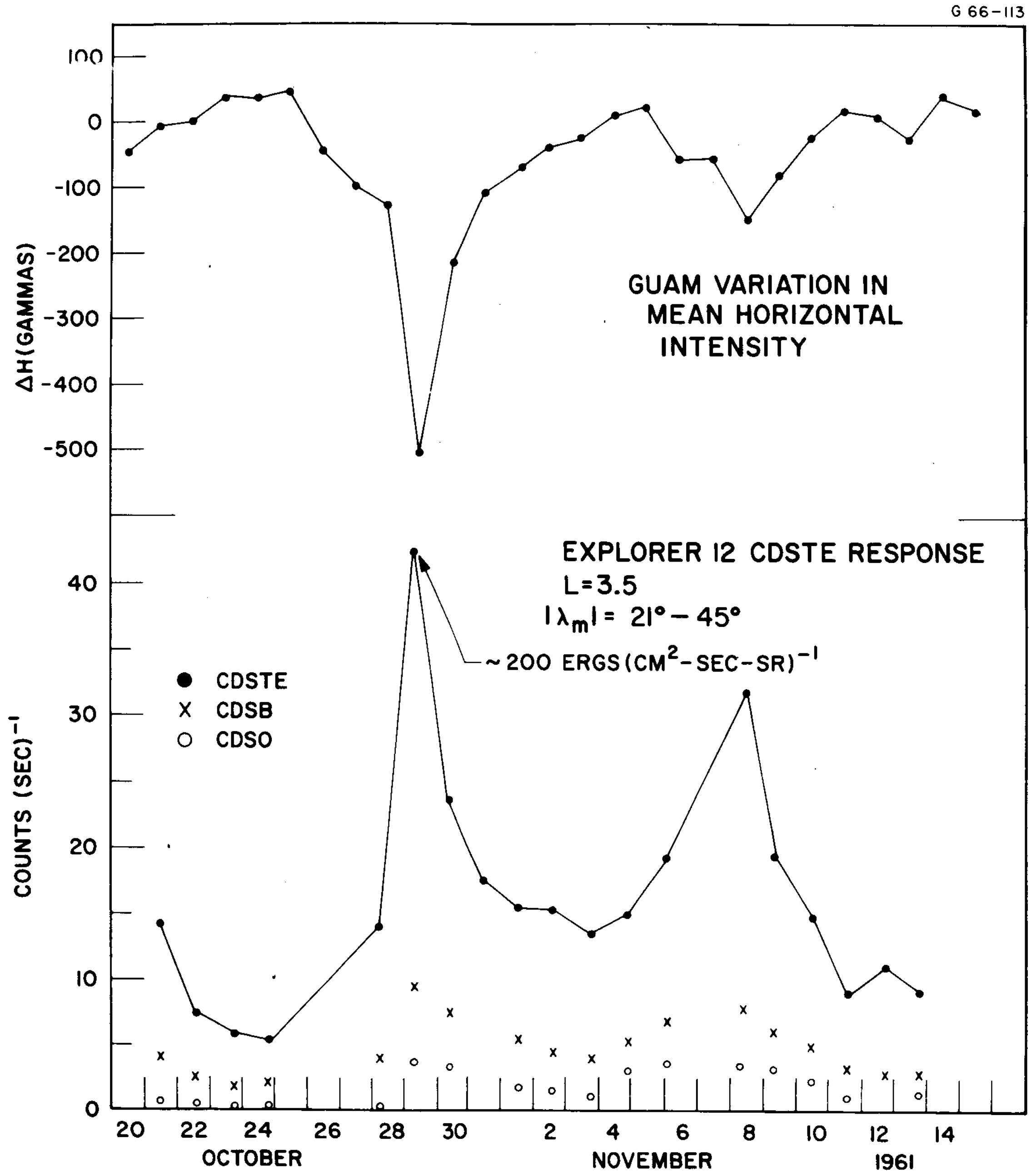

G 66-110
ΔH (GAMMAS)
100
0
-100
-200
-300
GUAM
VARIATION IN MEAN
HORIZONTAL INTENSITY
EXPLORER 12
L=4.0
~100 ERGS (CM²-SEC-SR)⁻¹
L=3.5
~125 ERGS (CM²-SEC-SR)⁻¹
L=3.0
L=2.5
COUNTS (SEC)⁻¹
• - CDSTE
x - CDSB
o - CDSO
L=2.5
|λm|= 18°-43°
L=3.0
|λm|= 22°-45°
L=3.5
|λm|= 19°-45°
L=4.0
|λm|= 25°-44°
20 22 24 26 28 30 2 4 6 8 10 12 14 16
SEPTEMBER
OCTOBER
1961

Figure 1



G 66-113
100
0
-100
-200
-300
-400
-500
ΔH (GAMMAS)
GUAM VARIATION IN
MEAN HORIZONTAL
INTENSITY
EXPLORER 12 CDSTE RESPONSE
L=3.5
|λm| = 21° – 45°
~200 ERGS (CM²-SEC-SR)⁻¹
● CDSTE
X CDSB
O CDSO
40
30
20
10
0
COUNTS (SEC)⁻¹
20
22
24
26
28
30
2
4
6
8
10
12
14
OCTOBER
NOVEMBER
1961

Figure 2

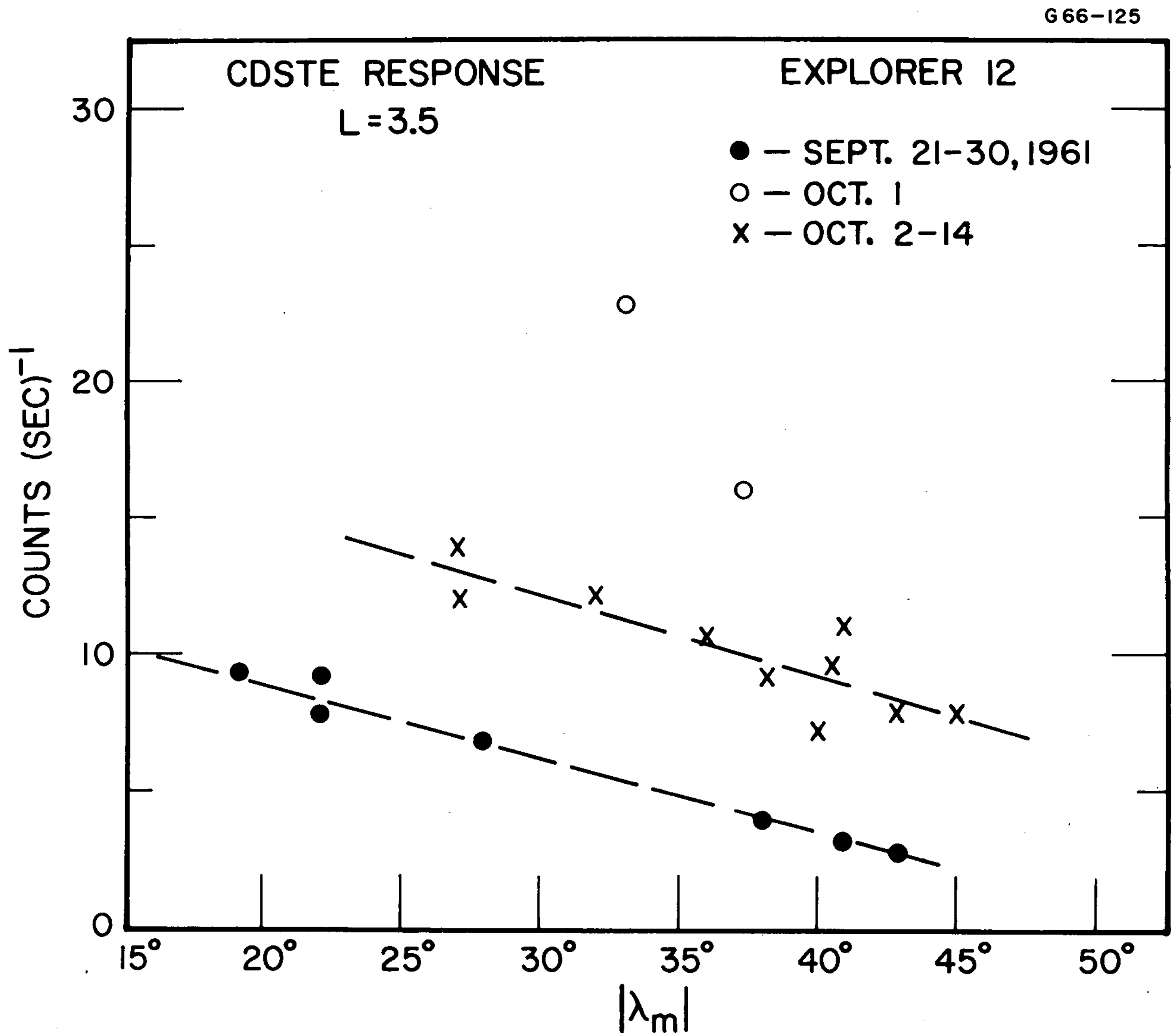

G66-125
CDSTE RESPONSE
L = 3.5
EXPLORER 12
● — SEPT. 21-30, 1961
○ — OCT. 1
x — OCT. 2-14
COUNTS (SEC)^-1
30
20
10
0
15°
20°
25°
30°
35°
40°
45°
50°
|λm|

Figure 3

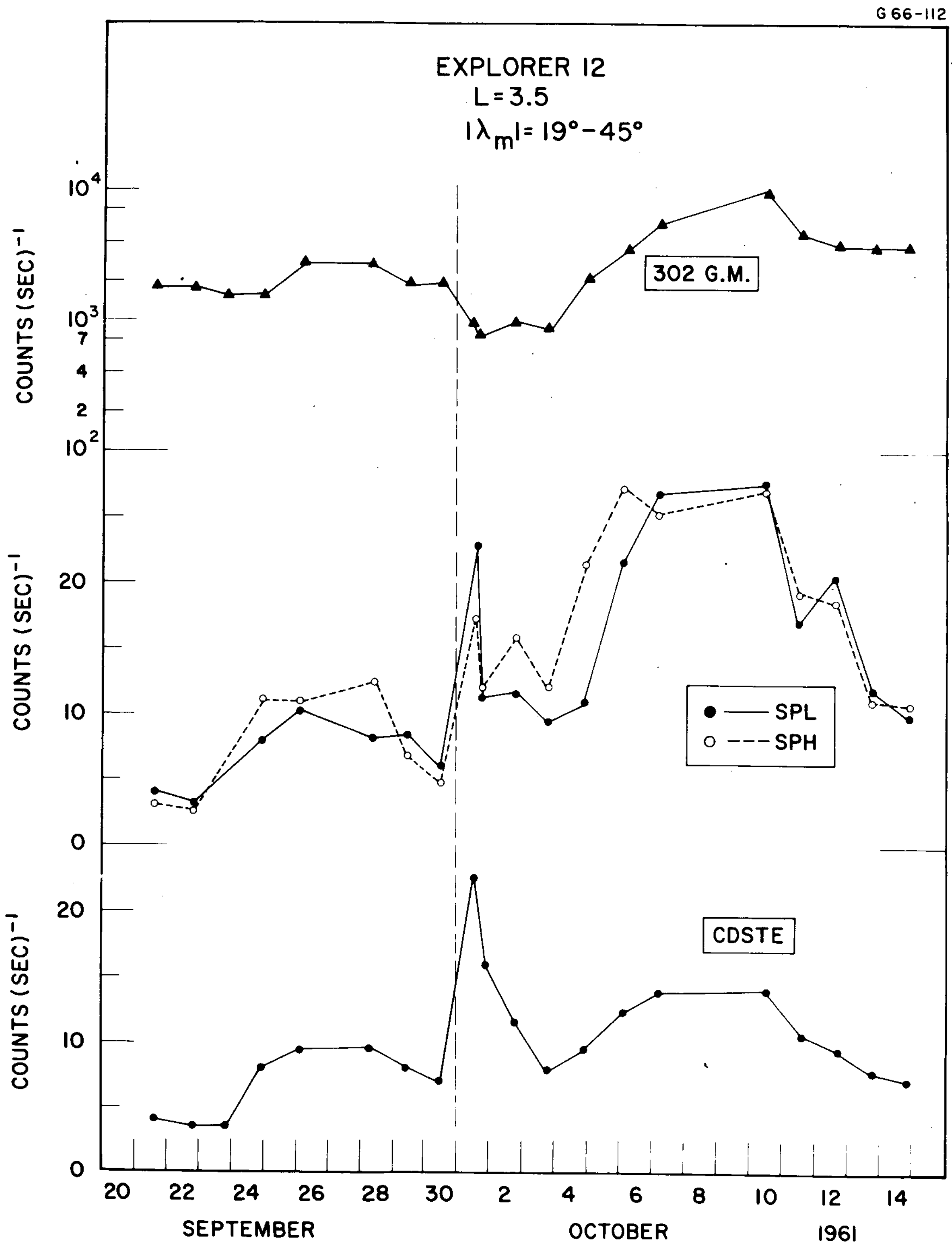

G 66-112
EXPLORER 12
L=3.5
|λm|= 19°-45°
302 G.M.
SPL
SPH
CDSTE
COUNTS (SEC)⁻¹
10⁴
10³
7
4
2
10²
20
10
0
20 22 24 26 28 30 2 4 6 8 10 12 14
SEPTEMBER
OCTOBER
1961

Figure 4

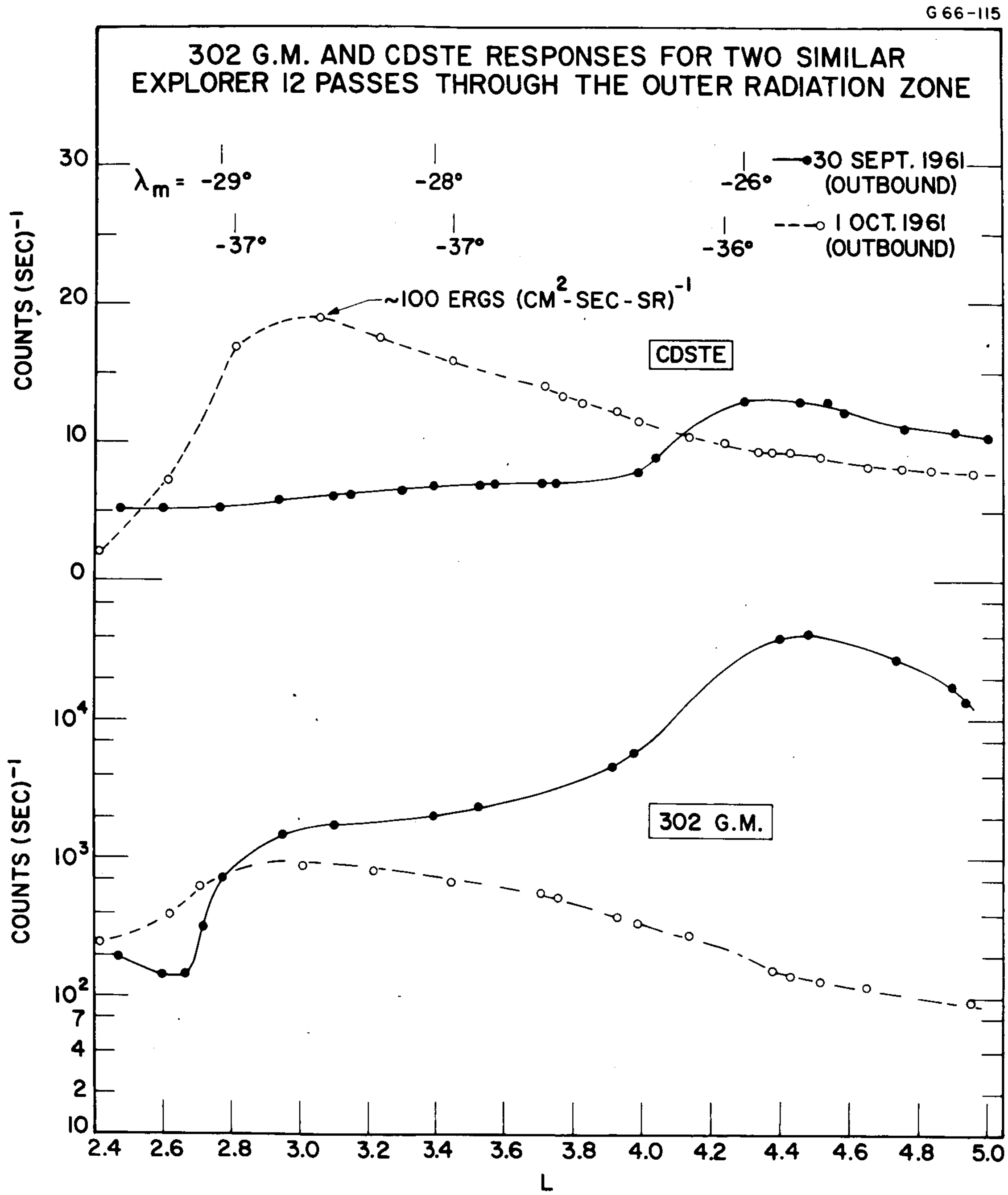

G 66-115
302 G.M. AND CDSTE RESPONSES FOR TWO SIMILAR
EXPLORER 12 PASSES THROUGH THE OUTER RADIATION ZONE
λm = -29° -28° -26°
-37° -37° -36°
30 SEPT. 1961 (OUTBOUND)
1 OCT. 1961 (OUTBOUND)
~100 ERGS (CM2-SEC-SR)-1
CDSTE
302 G.M.
COUNTS (SEC)-1
COUNTS (SEC)-1
30
20
10
0
10^4
10^3
10^2
7
4
2
10
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
L

Figure 5

• UNCLASSIFIED

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DOCUMENT CONTROL DATA - R&D

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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

Explorer 12 Observations Of The Temporal Variations Of Low-Energy Electron Intensities In The Outer Radiation Zone During Geomagnetic Storms

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

Progress

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

Frank, L. A.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1966	36	10

8a. CONTRACT OR GRANT NO. Nonr-1509(06)	9a. ORIGINATOR'S REPORT NUMBER(S) U. of Iowa 66-8
b. PROJECT NO.	
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Large increases of electron $100 \text{ eV} \lesssim E_e \lesssim 40$ 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 ~ 1000 ergs$(cm^2\text{-sec})^{-1}$ 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 $100 \text{ eV} \lesssim E_e \lesssim 40$ keV energy fluxes on 1 October is coincident with large decreases of electron $E_e > 1.6$ MeV intensities and with increases of electron $40 \text{ keV} \lesssim E_e \lesssim 100$ keV intensities in the outer radiation zone. Although no spectral information concerning the electron $100 \text{ eV} \lesssim E_e \lesssim 40$ 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 $E_e = 100$ eV, $\sim 60\ \gamma$ for $E_e = 500$ eV and $\sim 30\ \gamma$ for $E_e = 2$ 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 DR1 of magnetic storms.

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