N69-31156
NASA CR-103258

U. of Iowa 69-13

LARGE TEMPORAL VARIATIONS OF ENERGETIC ELECTRON INTENSITIES AT MID-LATITUDES IN THE OUTER RADIATION ZONE*

by

D. M. Yeager and L. A. Frank

CASE FILE
COPY

Department of Physics and Astronomy
THE UNIVERSITY OF IOWA
Iowa City, Iowa

U. of Iowa 69-13

LARGE TEMPORAL VARIATIONS OF ENERGETIC ELECTRON INTENSITIES AT MID-LATITUDES IN THE OUTER RADIATION ZONE[*]

by

D. M. Yeager and L. A. Frank

Department of Physics and Astronomy
University of Iowa
Iowa City, Iowa 52240

February 1969

NGR-16-001-002

---

[*] Research supported in part by the National Aeronautics and Space Administration under grant ~~NsG-233-62~~ and by the Office of Naval Research under contract Nonr-1509(06).

Distribution of this document is unlimited.

Abstract

A thorough search of Explorers 12 and 14 observations of electron ($40 \text{ keV} \lesssim E \lesssim 2 \text{ MeV}$) intensities within the outer radiation zone during the period 1961-1963 has provided evidences of several catastrophic rapid decreases and recoveries of these electron intensities within periods ~ several minutes at L-values ~ 5 to 6. Typical values for these intensity fluctuations are by factors $\gtrsim 500$, $\gtrsim 100$ and $\gtrsim 1000$ for electrons $E > 40$ keV, 230 keV and 1.6 MeV, respectively. A comparison of the temporal variations of integral energy spectrums of electron intensities, latitudes of the observed events, ground-based observations of auroral magnetic activity, and low-altitude measurements of electron intensities within the above energy range allow this striking phenomenon to be interpreted in terms of redistribution of these outer zone electrons during the distortion of the geomagnetic field by the low-energy plasma producing the associated magnetic disturbance and of conservation of the first two adiabatic invariants μ and I. The principal features of these events are adequately accounted for with the above interpretation, as the signature of the motion of the 'trapping boundary' for energetic

electrons at mid-latitudes in the dark hemisphere of the magnetosphere, which eliminates the alternative assumption of an almost unreasonably strong acceleration mechanism for outer zone energetic electrons.

I. Introduction

Temporal variations of electron intensities over the energy range ~ 10 keV to 1 MeV within the earth's outer radiation zone have been extensively surveyed during the past several years [cf Frank, 1965a; Davis, 1965; Craven, 1966; Owens and Frank, 1968; Williams, Arens and Lanzerotti, 1968; Kaufmann and Konradi, 1969]. These intensity variations are the signatures of time-dependent acceleration and loss mechanisms operative upon these higher energy electrons and of dynamical changes in the topology of the geomagnetic field. Of immediate interest to our current investigation are observations of rapid, catastrophic fluctuations of these energetic electron intensities, by factors of 10^2 to 10^4 within periods ~ several minutes, at L-values ~ 5 to 6 earth radii deep within the outer radiation zone. Several examples of this phenomenon during geomagnetically disturbed periods have previously been noted in the surveys of the energetic charged particle populations of the outer radiation zone with Explorer 14 [Frank, 1965a], Explorer 26 [Brown, Cahill, Davis, McIlwain and Roberts, 1968] and Explorer 12 [Konradi, 1968]. Characteristic periods for increases of electron ($E \gtrsim 250$ keV) fluxes to peak intensities at near-equatorial and moderate latitudes in the outer radiation zone following the onsets of geomagnetic storms are typically ~ days [cf Owens and Frank, 1968]; observations of similar increases of electron intensities but with typical time scales of ~ minutes as presented in our following discussion and previously reported as noted above would appear to indicate that an extremely strong acceleration mechanism for energetic outer zone electrons was occasionally operative during periods of relatively severe geomagnetic activity. Our present examination of the magnetic and local time coordinates of these striking events, and of observations of associated magnetic disturbances and measurements of similar phenomena obtained with satellite-borne instrumentation at low altitudes, allows us to reinterpret the gross character of these severe temporal variations of energetic electron intensities observed with Explorers 12 and 14 in terms of spatial redistribution of outer zone electrons with conservation of the first two adiabatic invariants, μ and I, in the changing topology of the magnetic field in these regions during magnetically disturbed periods.

II. Observations

Observations of energetic outer zone electron intensities over the energy range ~ 40 keV to ~ 2 MeV reported here were obtained with arrays of Geiger-Mueller tubes borne on the earth-satellites Explorer 12 (initial apogee 83,600 km and perigee 6700 geocentric radial distances, inclination 33°, and period 26.5 hours) and Explorer 14 (initial apogee 104,900 km and perigee 6650 km geocentric radial distances, inclination 33°, and period 36.4 hours). Periods of data transmission extended from launch on 16 August 1961 to 6 December 1961 for Explorer 12 and from launch on 2 October 1962 to 9 August 1963 for Explorer 14. Descriptions of the instrumentation and of the orbital characteristics have been previously provided in the literature for Explorer 12 [Freeman, 1964; Ackerson and Frank, 1966; Frank, 1966] and for Explorer 14 [Frank, Van Allen and Hills, 1964; Frank and Van Allen, 1964, 1966; Frank 1965a,b,c], and comprehensive plots of all of the detector responses for the above periods of data collection are available [Frank, Bohlin and DeCoster, 1966; Frank, Bohlin and McClain, 1966].

A typical set of observations of energetic electron ($E > 40$ keV, > 230 keV, and > 1.6 MeV) omnidirectional intensities with Explorer 14 during the outbound segment of the spacecraft's orbit through the outer radiation zone at moderate geomagnetic latitudes is presented in Figure 1. These measurements were obtained during a period of relative magnetic quiescence within the local evening-midnight quadrant of the outer radiation zone. The salient feature of the observations summarized in Figure 1 pertinent to the present discussion is the generally monotonic decrease of energetic electron intensities with increasing L-values from $L = 5.0$ to the abrupt decrease of intensities at $L = 8.3$, the so-called 'trapping boundary'. All magnetic coordinates, B and L, used as reference coordinates in the following discussion for organization of intensity measurements have been calculated by invoking the Jensen and Cain [1962] model of the geomagnetic field derived from ground-based magnetic surveys. The striking phenomena which has attracted our current interest is displayed in Figure 2 which summarizes the observations of energetic electron intensities during the next outbound pass of Explorer 14 through the outer radiation zone following the series of observations depicted in Figure 1 and provides a previously published example [Frank, 1965a], at $L \simeq 5$, of catastrophic decreases and increases of electron intensities at remarkably low L-values within the outer zone. For example, the decrease of electron ($E > 1.6$ MeV) intensities by a factor of 10^4 centered at 20:38 U.T. occurred within a period of ~ 7 minutes (~ 1500 km of displacement of the spacecraft along its trajectory or ~ 150 Larmor radii for 2-MeV electrons mirroring in this region). The magnetic latitudes and local times for a given L-value for these two series of measurements are, for all practical purposes, equal. These severe gradients deep within the outer radiation zone appear to preclude the possibility that the intensity profiles given in Figure 2 can be interpreted as the signature of quasi-stationary spatial features of the charged particle distributions as viewed along the spacecraft's trajectory and strongly indicate that these severe intensity variations are primarily temporal fluctuations with characteristic time scales ~ several minutes. Further, the fluctuations of electron intensities for all energies during the period 20:49 through 21:36 U.T. after the recovery of intensities generally track with respect to maximum and minimum intensities hence eliminating the possibility of interpretation of these fluctuations in terms of 'drift-periodic echoes' [Brewer, Schulz and Eviatar, 1969], or bunching of electrons in longitude, since the dispersion of drift velocities over such a broad energy range is inconsistent with the above character of the intensity profiles. Konradi [1968] has previously demonstrated that these sudden variations of outer zone proton and electron intensities as observed with instrumentation borne on Explorer 12 are closely associated with polar substorms. Figure 3 summarizes observations of large negative bays at three magnetic observatories for the period of measurements displayed in Figure 2 and further establishes the close association of the occurrence of polar substorms and these large electron intensity fluctuations within the outer radiation zone. Further information regarding the nature of the mechanism responsible for these intensity variations may be gained by a comparison of the omnidirectional, integral electron spectrums for a typical period of magnetic quiescence at selected L-values shown in Figure 4 (see also Figure 1) with the electron spectrums before and after the intensity drop-out at $L = 4.7$ and 5.8, respectively, presented in Figure 5 for 20 December 1962 (see also Figure 2). The electron spectrums at $L \simeq 6$ for both these periods do not differ significantly with regard to the spectral slope or general level of intensities; i.e., there is no dramatic disparity between the post-event electron ($E > 40$ keV) integral spectrums and electron spectrums observed at similar magnetic coordinates during periods of relative magnetic quiescence.

The entire body of Explorer 14 observations of electron intensities within the outer radiation zone has been examined and three further abrupt intensity variations similar to the event discussed above were found. These further observations are summarized in Figures 6, 7 and 8 for events occurring on 6, 9 and 23 November 1961, respectively, and the corresponding pertinent coordinates and associated magnetic bays at magnetic observatories located in the vicinity of the instantaneous geographic longitude of the satellite

TABLE I

Several Coordinates For Electron Intensity Minima

Satellite (Date)	Orbit	Time, U.T.	Radial Distance, km	Geocentric Longitude	B*, gammas	L*, earth radii	Geomagnetic Latitude*	Solar Magnetospheric Longitude
Explorer 12 (27 October 1961)	66 out	0313 0318 0325	22,575 23,772 25,401	8.3° 9.7° 11.2°	865 742 609	4.79 5.01 5.31	-28.6° -28.4° -28.1°	249.4° 251.6° 255.5°
Explorer 12 (1 December 1961)	98 out	1235 to 1330	13,336 to 27,120	161.9° to -169.7°	5558 to 554	3.66 to 5.76	-40.2° to -30.2°	192.7° to 233.0°
Explorer 14 (6 November 1962)	24 out	2040 to 2050	19,838 to 22,464	49.8° to 53.9°	1479 to 1034	5.23 to 5.99	-38.6° to -39.3°	174.6° to 182.8°
Explorer 14 (9 November 1962)	26 out	2210 to 2235	29,857 to 35,168	44.3° to 44.7°	425 to 257	7.34 to 8.38	-36.2° to -35.1°	195.7 to 204.9°
Explorer 14 (23 November 1962)	35 out	1305	19,426	146.1°	1803	5.81	-43.4°	174.8°
Explorer 14 (20 December 1962)	53 out	2045	23,927	17.0°	748	5.57	-32.7°	128.3°

* $\vec{B}$ derived from Jensen and Cain [1962] coefficients.

TABLE II

Pertinent Magnetic Disturbances*

Date	Station	Time Bay Begins	Time Bay Ends	Geographic Longitude	Magnetic Latitude	Magnetic Longitude	Magnitude of Bay, gammas
27 October 1961	Leirvogur	0345	0700	21°42' W	70.2°	71.0°	600
27 October 1961	Halley Bay	0300	0350	26°37' W	-65.8°	24.3°	800
27 October 1961	Godhavn	0330	0420	53°31' W	79.9°	32.5°	300
1 December 1961	Sitka	1300	1430	135°20' W	60.0°	275.3°	1200
1 December 1961	College	1330	1445	147°50' W	64.6°	256.5°	1000
1 December 1961	Barrow	1330	1445	156°45' W	68.5°	241.1°	1200
6 November 1962	Murmansk	1930 2130	2100 2330	33°05' E	63.5°	125.8°	200 400
6 November 1962	Mawson	2100	2245	62°53' E	-73.1°	102.9°	360
6 November 1962	Leirvogur	2100	2200	21°42' W	70.2°	71.0°	200
6 November 1962	Kiruna	2045	2230	20°25' E	65.3°	115.6°	350
9 November 1962	Leirvogur	2230	2330	21°42' W	70.2°	71.0°	100
9 November 1962	Mawson	2215	2315	62°53' E	-73.1°	102.9°	200
9 November 1962	Kiruna	2230	2430	20°25' E	65.3°	115.6°	150
23 November 1962	College	1305	1405	147°50' W	64.6°	256.5°	490
23 November 1962	Tixie	1300	1400	129°00' E	60.4°	191.4°	350
23 November 1962	Wellen	1300	1400	169°50' W	61.8°	237.1°	150
23 November 1962	Macquarie Is.	1300	1400	158°57' E	-61.1°	243.1°	100
20 December 1962	Leirvogur	2045	2200	21°42' W	70.2°	71.0°	1000
20 December 1962	Mawson	2045	2145	62°53' E	-73.1°	102.9°	250
20 December 1962	Kiruna	2015	2215	20°25' E	65.3°	115.6°	1160

* World Data Center 'A', Rockville, Maryland.

position are provided by Tables I and II. With the exception of the event centered at relatively large L $\simeq$ 8 of 9 November 1961, the remaining two abrupt intensity variations were also located at L $\simeq$ 5 to 6. A cursory inspection of Table I also reveals that all such events observed with Explorers 12 and 14 were located in the dark hemisphere of the magnetosphere, although measurements were equally available for all local times at moderate geomagnetic latitudes ~ 30° to 40°.

Two of these striking electron intensity variations in the outer radiation zone were discernible in the responses of the G.M. tube complement borne on Explorer 12 over its useful lifetime. The coordinates and associated magnetic bays are summarized in Tables I and II for these two events of 27 October and 1 December 1961. Observations of outer zone electron intensities and of associated magnetic bays for 1 December are displayed in Figures 9 and 10, respectively. Konradi [1968] has previously discussed similar severe temporal variations of the intensities of protons ($>$ 100 keV) and of low energy electrons (20-100 keV) observed with an ion-electron detector borne on the same satellite. Of major interest in the present discussion of this event is the comparison of simultaneous measurements of the magnetic field (unpublished data, courtesy of L. J. Cahill) and observations of energetic electron intensities presented in Figure 11. Although there is no one-to-one correspondence of maxima and minima in the observed scalar magnetic field $|\vec{B}|$ and electron intensity profiles, it is of importance to note that the time scales for large fluctuations of these two parameters are grossly similar.

In order to provide further evidences concerning the mechanism responsible for the occasional, abrupt variations of electron intensities reported here, an initial survey of Injun I measurements of energetic electron intensities at low altitudes (~ 1000 km) in the outer radiation zone was undertaken. An example of similar severe temporal variations of electron ($E > 40$ keV) intensities is displayed in Figure 12 and differs in character from the Explorer 12 and 14 observations only in the time scale (~ 30 seconds), but this particular event is an exception to the low-altitude observations of this phenomenon since the recovery of intensities is not often seen at these low altitudes [cf Figure 14, Craven, 1966] presumably due to the rapid (~ minutes) motion of the satellite through the low-altitude region of the outer radiation zone within time intervals comparable to or less than the durations of the events observed at high altitudes.

III. Interpretation and Discussion

Our current investigation of observations of catastrophic fluctuations of energetic electron ($40 \text{ keV} \lesssim E \lesssim 2 \text{ MeV}$) intensities by factors of 10^2 to 10^4 within periods ~ minutes at L-values ~ 5 to 6 within the outer radiation zone with instrumentation borne on Explorer 12 and 14 and comparisons with ground-based and additional satellite measurements have provided the following information concerning the phenomenological nature of these events.

(1) These events are not frequently observed in the outer radiation zone. Only six decisive examples of this phenomenon are evident in the approximately 450 available passes of Explorers 12 and 14 through the outer radiation zone.

(2) Magnetic bays and world-wide magnetic storms are closely associated with these events [cf Konradi, 1968; Owens and Frank, 1968]. This association implies that these abrupt intensity variations are concurrent with large-scale distortion of the distant geomagnetic field and development of the storm-time extraterrestrial 'ring current'.

(3) Simultaneous measurements of the magnetic fields and omnidirectional electron intensities with Explorer 12 show that the time scales for fluctuations of the scalar magnetic field and of the electron intensities are similar.

(4) Electron integral spectrums ($E > 40$ keV) observed before and after these striking intensity decreases are not greatly dissimilar to electron spectrums at similar magnetic coordinates during periods of relative magnetic quiescence.

(5) All of these six intensity variations occurred at moderate magnetic latitudes ~ 30° to 40° and in the dark hemisphere of the magnetosphere although an almost equal number of measurements were available at near-equatorial latitudes and in the sunlit hemisphere of the magnetosphere in the outer radiation zone. A close relative of these intensity variations has been observed at low-altitudes (~ 1000 km) in the outer radiation zone at similar L-values [cf Craven, 1966; Williams and Ness, 1966] although the recovery of intensities is not usually seen presumably due to the rapid transit of these satellites through the narrow 'horns' of the outer radiation zone at these low altitudes.

These large fluctuations of energetic outer zone electron intensities observed with Explorers 12 and 14 are the signature of either (1) an extremely effective acceleration (deceleration) mechanism occasionally operative in the outer radiation zone or (2) spatial redistribution of the electron distributions in response to the varying topology of the geomagnetic field during geomagnetically disturbed periods. An acceleration mechanism for electrons ($E > 1.6$ MeV) sufficient to replenish a major fraction of the outer zone energetic electron population within periods of $\sim$ several minutes is grossly incompatible with typical replenishment times of $\sim$ days [cf Owens and Frank, 1968] and would satisfy the above observational restraints only by ad hoc construction, whereas a simple, direct interpretation of these severe variations of electron intensities in terms of redistribution of the electron populations (more specifically, as the motion of the 'trapping boundary' at *mid-latitudes* in the dark hemisphere of the magnetosphere across the satellite position) in a time-dependent distorted geomagnetic field and of the conservation of the first two adiabatic invariants of charged particle motion, μ and I, satisfies all of the major observational requirements. Accordingly, reasonable models of the quiescent and distorted geomagnetic field in the dark hemisphere of the magnetosphere were graphically constructed with the guidance of previously published models of the distant geomagnetic field [Williams and Mead, 1965; Akasofu, 1966; Roederer, 1968a,b; Schield, 1969] and the locus of mirror points for outer zone electrons in the quiescent model were transformed into the distorted topology of the storm-time geomagnetic field resulting from enhanced magnetic tail fields and exterrestrial 'ring current' with the assumption that $\mu = E/B_m =$ constant (electron energy $E \simeq$ constant, i.e., acceleration is relatively unimportant) and $\ell =$ constant where

$$I = \int_{M}^{M*} (1 - \frac{B}{B_m})^{\frac{1}{2}} ds \simeq \ell \ ,$$

B_m is the field magnitude at the mirror points M and M*, B is the field magnitude along the magnetic field line for which the integral is to be evaluated and ℓ is the length of the field line between mirror points. The approximation $\ell \simeq$ constant is sufficiently accurate at magnetic latitudes $\lambda_m \gtrsim 25°$ for our present purposes [cf Mead, 1966]. An example of graphic solutions is presented in Figure 13 which displays a quiescent geomagnetic field model A and distorted model A'. The position of Explorer 14 during the event of 20 December 1962 (see Figure 2) is plotted in dipole coordinates (magnetic latitude and radial distance) in each of the six coordinate axes shown in Figure 13. Charged particles mirroring at sample coordinates B_m and I were selected (B) and then graphically transformed into the distorted field model B'. The envelope of a sensible set of these points provided the envelope C' of the outer radiation zone in the distorted magnetic field from the initial distributions C as previously given by Frank [1965a] during relatively quiescent conditions. It should be noted that a reasonable inflation of the outer magnetosphere (C') is sufficient to force a significant collapse of the night-time trapping boundary at mid-latitudes ~ 30°

to 40° and geocentric radial distances ~ 3 to 4 R_E to lower latitudes and that the catastrophic fluctuations of electron intensities centered at 20:45 U.T. on 20 December, for example, as displayed in Figure 2 can be attributed to the displacement of the trapping boundary to a position below the satellite location for periods ~ several minutes and its subsequent recovery to a more frequent envelope which encloses the satellite position (C). In conclusion, our present survey of these catastrophic temporal variations of electron ($40 \text{ keV} \lesssim E \lesssim 2 \text{ MeV}$) intensities by factors 10^2 to 10^4 within the outer radiation zone with Explorers 12 and 14 delineates this phenomenon as attributable to a temporary redistribution of the electron distributions within this region arising from large-scale changes in the topology of the distant geomagnetic field for periods ~ several minutes during magnetic storms, as opposed to the alternative of assuming these fluctuations reflect the presence of an almost unreasonably strong acceleration mechanism occasionally effective in the outer radiation zone.

Acknowledgments

The authors are greatly indebted to Professor L. J. Cahill of the University of Minnesota for providing unpublished Explorer 12 magnetometer data. This research was supported in part by the National Aeronautics and Space Administration under grant NsG-233-62 and by the office of Naval Research under contract Nonr-1509(06).

References

Ackerson, K. L. and L. A. Frank, Explorer 12 observations of charged particles in the inner radiation zone, J. Geophys. Res., 72, 951-957, 1967.

Akasofu, S.-I., Model ring current belts, U. of Iowa Res. Rept. 66-28, 1966.

Brewer, H. R., M. Schulz and A. Eviatar, Origin of drift-periodic echoes in outer-zone electron flux, J. Geophys. Res., 74, 159-167, 1969.

Brown, W. L., L. J. Cahill, L. R. Davis, C. E. McIlwain and C. S. Roberts, Acceleration of trapped particles during a magnetic storm on April 18, 1965, J. Geophys. Res., 73, 153-161, 1968.

Craven, John D., Temporal variations of electron intensities at low altitudes in the outer radiation zone as observed with satellite Injun 3, J. Geophys. Res., 71, 5643-5663, 1966.

Davis, L. R., Low energy trapped protons and electrons, in Proc. Plasma Space Sci. Symp., edited by C. C. Chang and S. S. Huang, pp. 212-226, D. Reidel Publishing Company, Dordrecht, Holland, 1965.

Frank, L. A., A survey of electrons E > 40 keV beyond 5 earth radii with Explorer XIV, J. Geophys. Res., 70, 1593-1626, 1965a.

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, 1965b.

Frank, L. A., On the local-time dependence of outer radiation zone electron ($E > 1.6$ Mev) intensities near the magnetic equator, J. Geophys. Res., 70, 4131-4138, 1965c.

Frank, L. A., Explorer 12 observations of the temporal variations of low-energy electron intensities in the outer radiation zone during geomagnetic storms, J. Geophys. Res., 71, 4631-4639, 1966.

Frank, L. A., R. C. Bohlin and R. J. DeCoster, Graphic summary of the responses of the University of Iowa charged particle detectors on Explorer 12, U. of Iowa Res. Rept. 66-15, 1966.

Frank, L. A., R. C. Bohlin and I. L. McClain, Graphic summary of the responses of the University of Iowa charged particle detectors on Explorer 14, U. of Iowa Res. Rept. 66-40, 1966.

Frank, L. A. and J. A. Van Allen, Measurements of energetic electrons in the vicinity of the sunward magnetospheric boundary with Explorer XIV, J. Geophys. Res., 69, 4923-4932, 1964.

Frank, L. A. and J. A. Van Allen, Correlation of outer radiation zone electrons ($E_e \sim 1$ Mev) with the solar activity cycle, J. Geophys. Res., 71, 2697-2700, 1966.

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., 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.

Jensen, D. C. and J. C. Cain, An interim geomagnetic field (abstract), J. Geophys. Res., 67, 3568-3569, 1962.

Kaufmann, R. L. and A. Konradi, MeV particles in the outer zone: Explorer 12, U. of New Hampshire Res. Rept. R69-5, 1969.

Konradi, A., Rapid increases in the proton and electron fluxes in the magnetosphere, J. Geophys. Res., 73, 3449-3458, 1968.

Mead, G. D., The motion of trapped particles in a distorted field, Radiation Trapped in the Earth's Magnetic Field, ed. B. M. McCormac, D. Reidel Publishing Company, Dordrecht, Holland, 481-490, 1966.

Owens, H. D. and L. A. Frank, Electron omnidirectional intensity contours in the earth's outer radiation zone at the magnetic equator, J. Geophys. Res., 73, 199-208, 1968.

Roederer, J. G., Shell splitting and radial diffusion of geomagnetically trapped particles, Earth's Particles and Fields, ed. B. M. McCormac, Reinhold Book Corporation, New York, 193-208, 1968a.

Roederer, J. G., Quantitative models of the magnetosphere, U. of Denver Res. Rept., 1968b.

Schield, M. A., The auroral oval and the Alfvén layer, J. Geophys. Res., (submitted for publication, 1969).

Williams, D. J., J. F. Arens and L. J. Lanzerotti, Observations of trapped electrons at low and high altitudes, J. Geophys. Res., 73, 5673-5696, 1968.

Williams, D. J., and G. D. Mead, Nightside magnetosphere configuration as obtained from trapped electrons at 1100 kilometers, J. Geophys. Res., 70, 3017-3029, 1965.

Williams, D. J. and N. F. Ness, Simultaneous trapped electron and magnetic tail field observations, J. Geophys. Res., 71, 5117-5128, 1966.

Figure Captions

Figure 1. Omnidirectional intensities of electrons ($E > 40$ keV, > 230 keV and > 1.6 MeV) as functions of Universal Time for the outbound pass of Explorer 14 through the outer radiation zone on 19 December 1962. Several pertinent position coordinates are included in the top margin. The dashed lines designate the intensity thresholds of the instrumentation.

Figure 2. Continuation of Figure 1 for the next outbound pass of Explorer 14 through the outer radiation zone on 20 December 1962. The feature of interest in the present investigation is the catastrophic fluctuations of intensities over the period 20:35 to 20:50 U.T. centered at $L \simeq 5.5$.

Figure 3. Ground-based magnetometer records for the period of observations displayed in Figure 2.

Figure 4. Electron integral spectrums at selected L-values for the outer radiation zone observations on 19 December 1962 during a period of relative magnetic quiescence (refer to Figure 1).

Figure 5. Electron integral spectrums prior to and after the abrupt decrease and increase of intensities on 20 December 1962 during a geomagnetic storm (refer to Figure 2).

Figure 6. Continuation of Figure 1 for the outbound pass of Explorer 14 through the outer radiation zone on 6 November 1962.

Figure 7. Continuation of Figure 1 for the outbound pass of Explorer 14 through the outer radiation zone on 9 November 1962.

Figure 8. Continuation of Figure 1 for the outbound pass of Explorer 14 through the outer radiation zone on 23 November 1962.

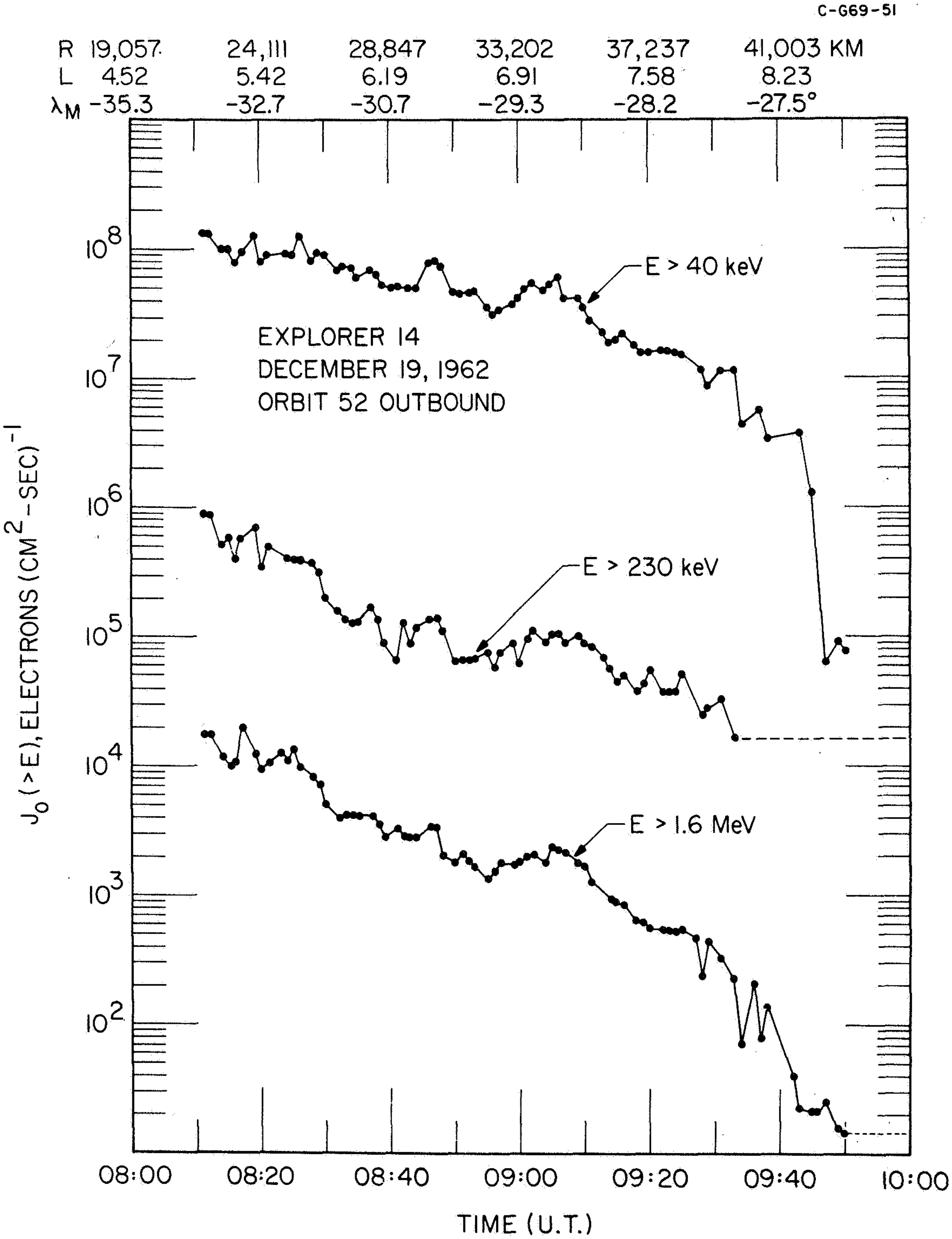
Figure 9. Omnidirectional intensities of electrons ($40 \leq E \leq 50$ keV and > 1.6 MeV) as functions of Universal Time for the outbound pass of Explorer 12 through the outer radiation zone on 1 December 1961. The dashed lines designate the intensity thresholds of the instrumentation.

Figure 10. Ground-based magnetometer records for the period of satellite observations displayed in Figure 9.

Figure 11. Comparison of simultaneous measurements of the scalar magnetic field (courtesy of L. J. Cahill) and of the omnidirectional electron ($E > 1.6$ MeV) intensities for a segment of the observations shown in Figure 9.

Figure 12. Observations of large fluctuations of electron ($E > 40$ keV) intensities at low altitudes (~ 1000 km) in the outer radiation zone with earth-satellite Injun 1. The geocentric local time of the position of the satellite during these measurements was $\sim$ 22:00.

Figure 13. Graphic analysis of the redistribution of energetic electrons ($E \sim 1$ MeV) in a meridional plane in the dark hemisphere of the magnetosphere during a magnetically disturbed period (see text).



C-G69-51
R 19,057 24,111 28,847 33,202 37,237 41,003 KM
L 4.52 5.42 6.19 6.91 7.58 8.23
λ_M -35.3 -32.7 -30.7 -29.3 -28.2 -27.5°
10^8
10^7
10^6
10^5
10^4
10^3
10^2
E > 40 keV
E > 230 keV
E > 1.6 MeV
EXPLORER 14
DECEMBER 19, 1962
ORBIT 52 OUTBOUND
$J_0(>E)$, ELECTRONS $(CM^2-SEC)^{-1}$
08:00
08:20
08:40
09:00
09:20
09:40
10:00
TIME (U.T.)

Figure 1

C-G69-56

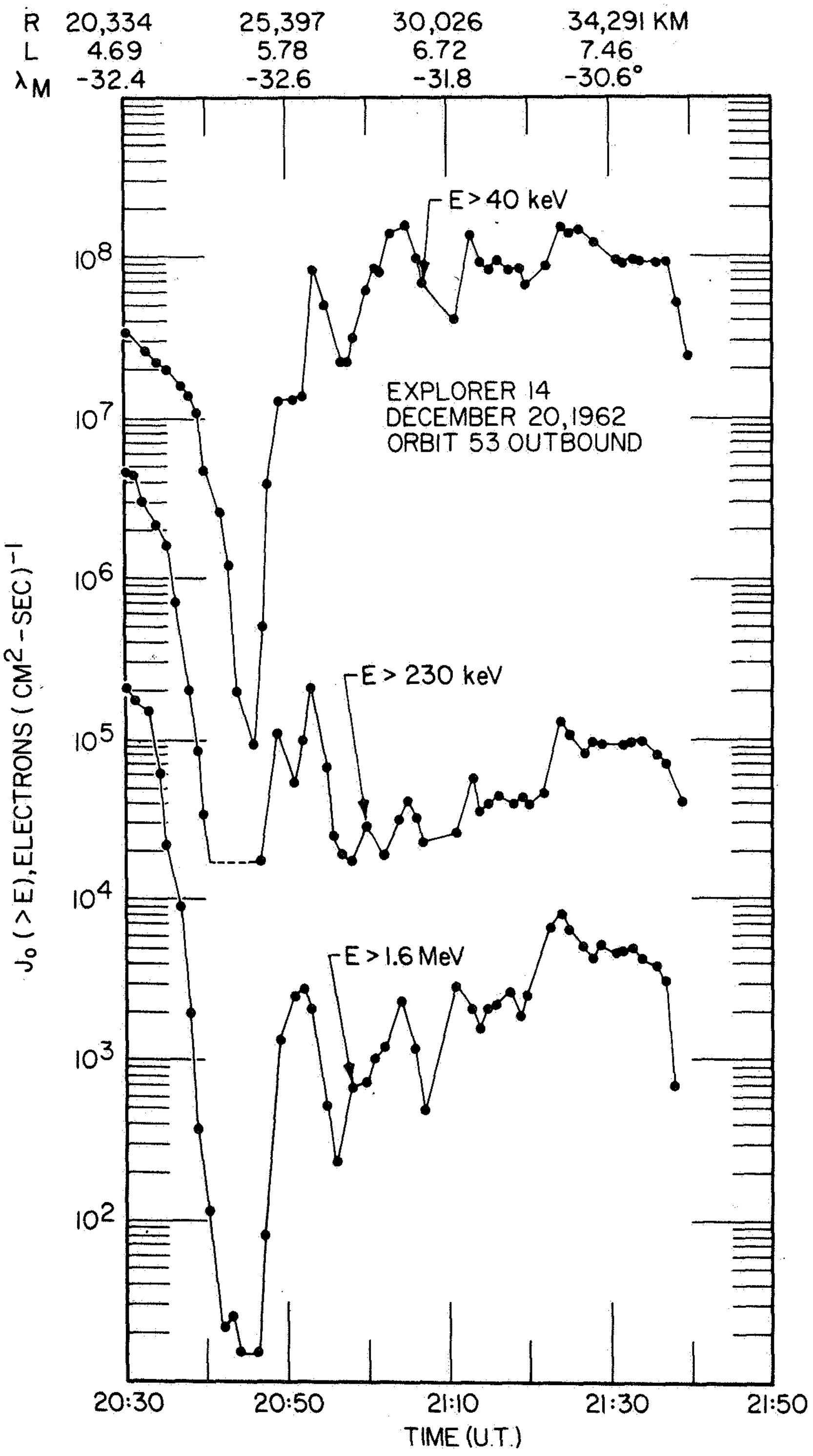


Figure 2

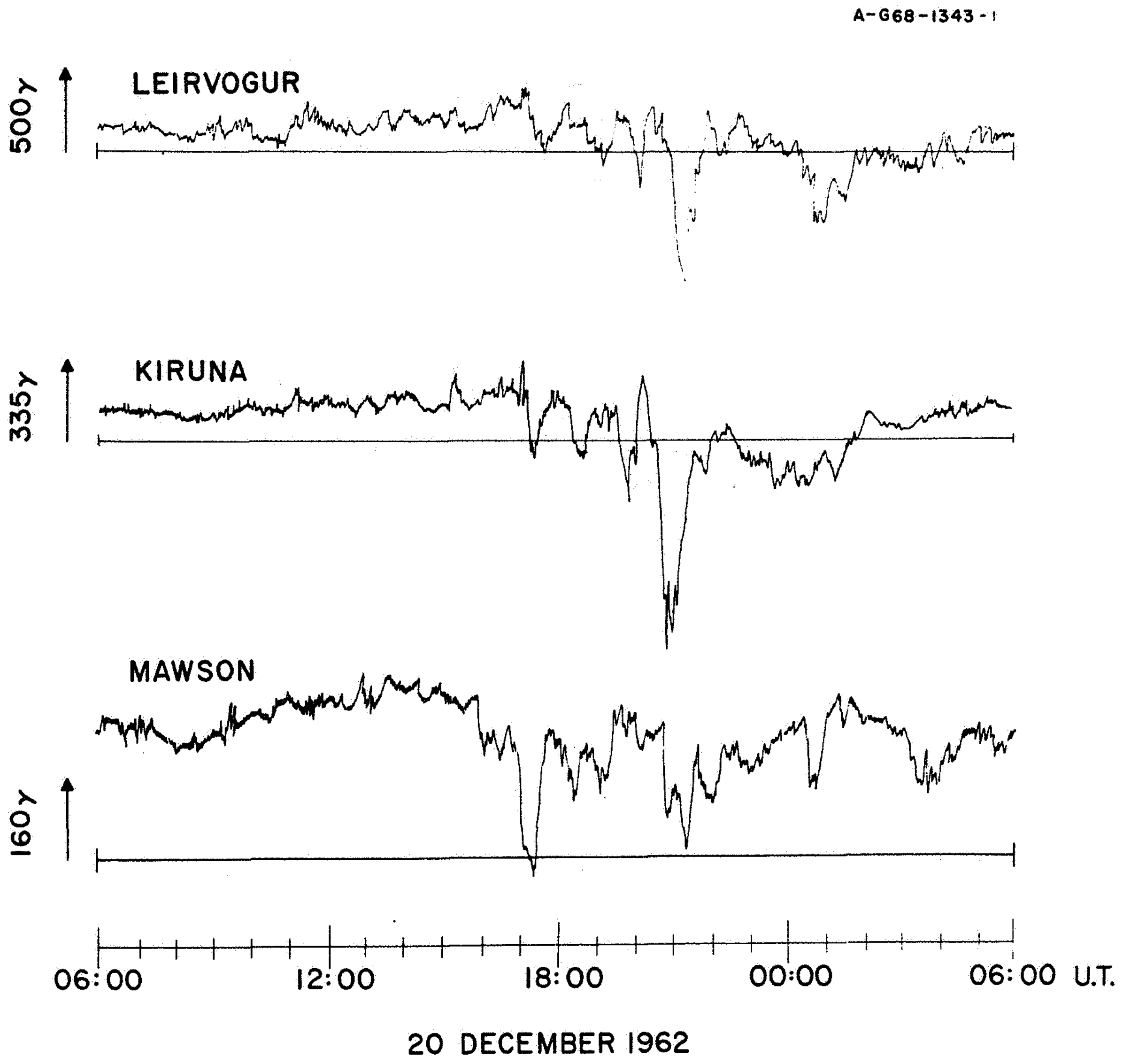

A-G68-1343-1
500γ
LEIRVOGUR
335γ
KIRUNA
MAWSON
160γ
06:00
12:00
18:00
00:00
06:00 U.T.
20 DECEMBER 1962

Figure 3

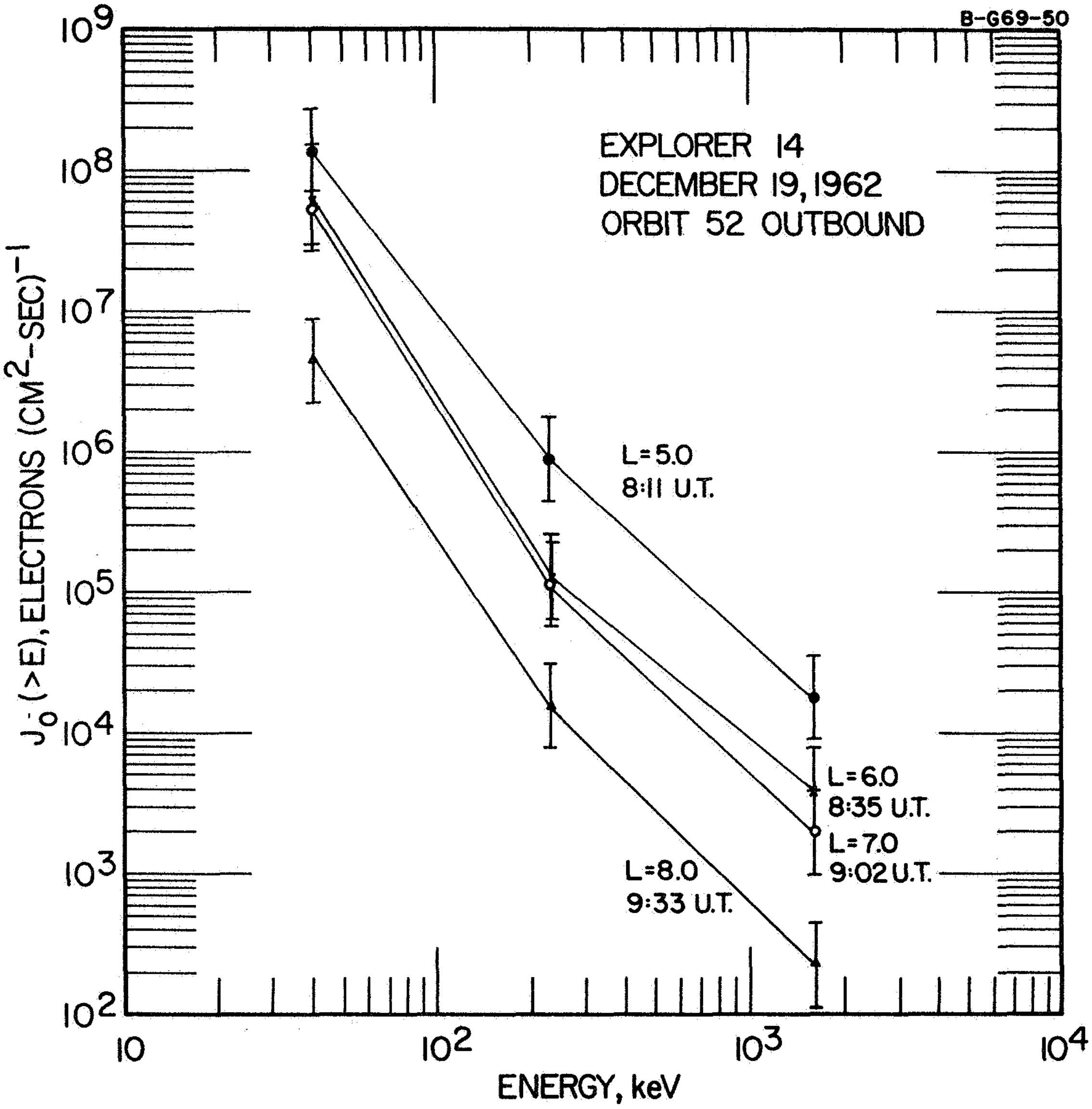

B-G69-50
EXPLORER 14
DECEMBER 19, 1962
ORBIT 52 OUTBOUND
L=5.0
8:11 U.T.
L=6.0
8:35 U.T.
L=7.0
9:02 U.T.
L=8.0
9:33 U.T.
$J_0^-(>E)$, ELECTRONS $(CM^2\text{-}SEC)^{-1}$
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10
10^2
10^3
10^4
ENERGY, keV

Figure 4

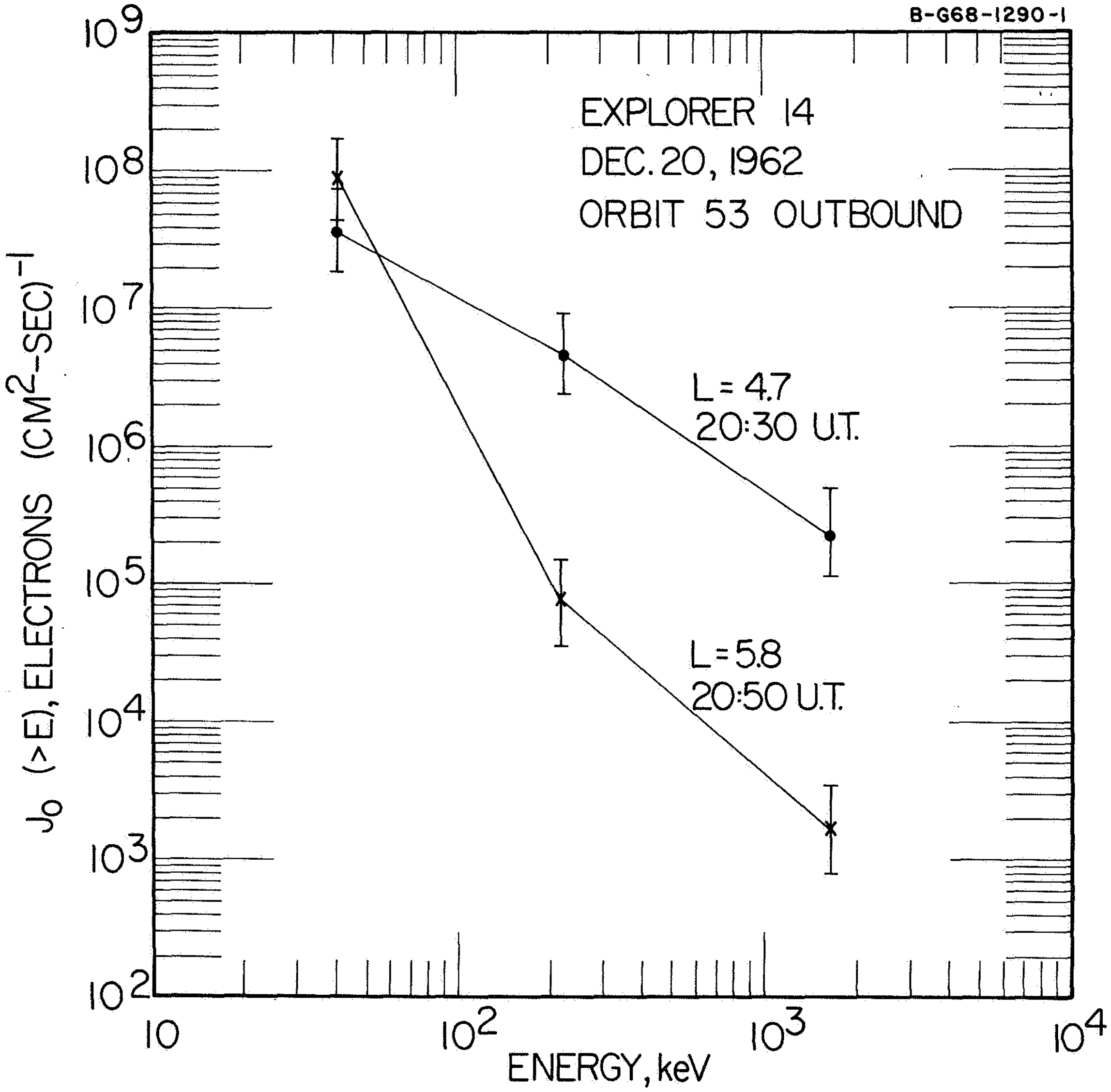

B-G68-1290-1
EXPLORER 14
DEC. 20, 1962
ORBIT 53 OUTBOUND
L = 4.7
20:30 U.T.
L = 5.8
20:50 U.T.
J_0 (>E), ELECTRONS $(CM^2\text{-}SEC)^{-1}$
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10
10^2
10^3
10^4
ENERGY, keV

Figure 5

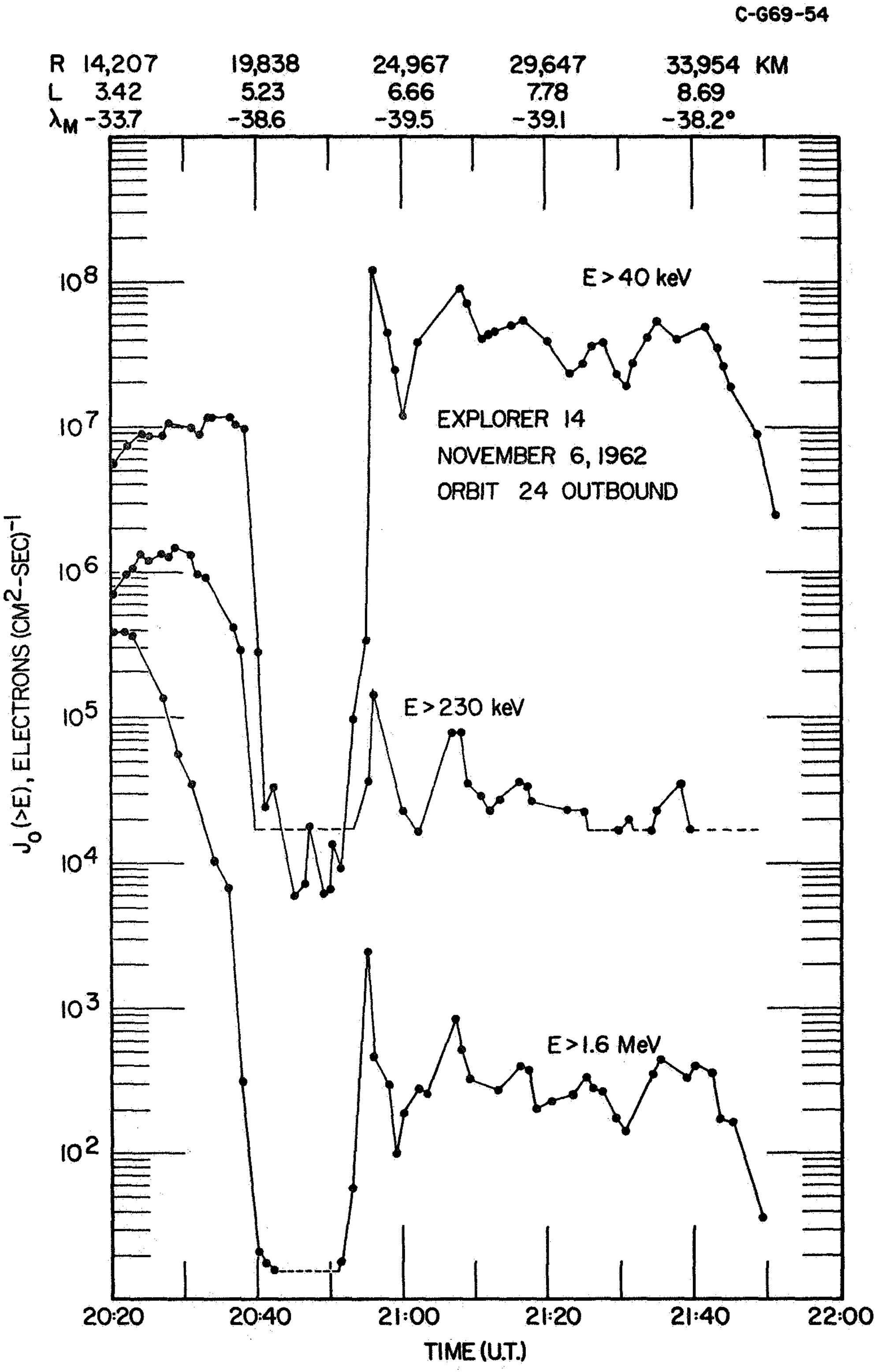

C-G69-54
R 14,207 19,838 24,967 29,647 33,954 KM
L 3.42 5.23 6.66 7.78 8.69
λM -33.7 -38.6 -39.5 -39.1 -38.2°
E > 40 keV
EXPLORER 14
NOVEMBER 6, 1962
ORBIT 24 OUTBOUND
E > 230 keV
E > 1.6 MeV
10^8
10^7
10^6
10^5
10^4
10^3
10^2
J0(>E), ELECTRONS (CM2-SEC)-1
20:20
20:40
21:00
21:20
21:40
22:00
TIME (U.T.)

Figure 6

C-G69-52

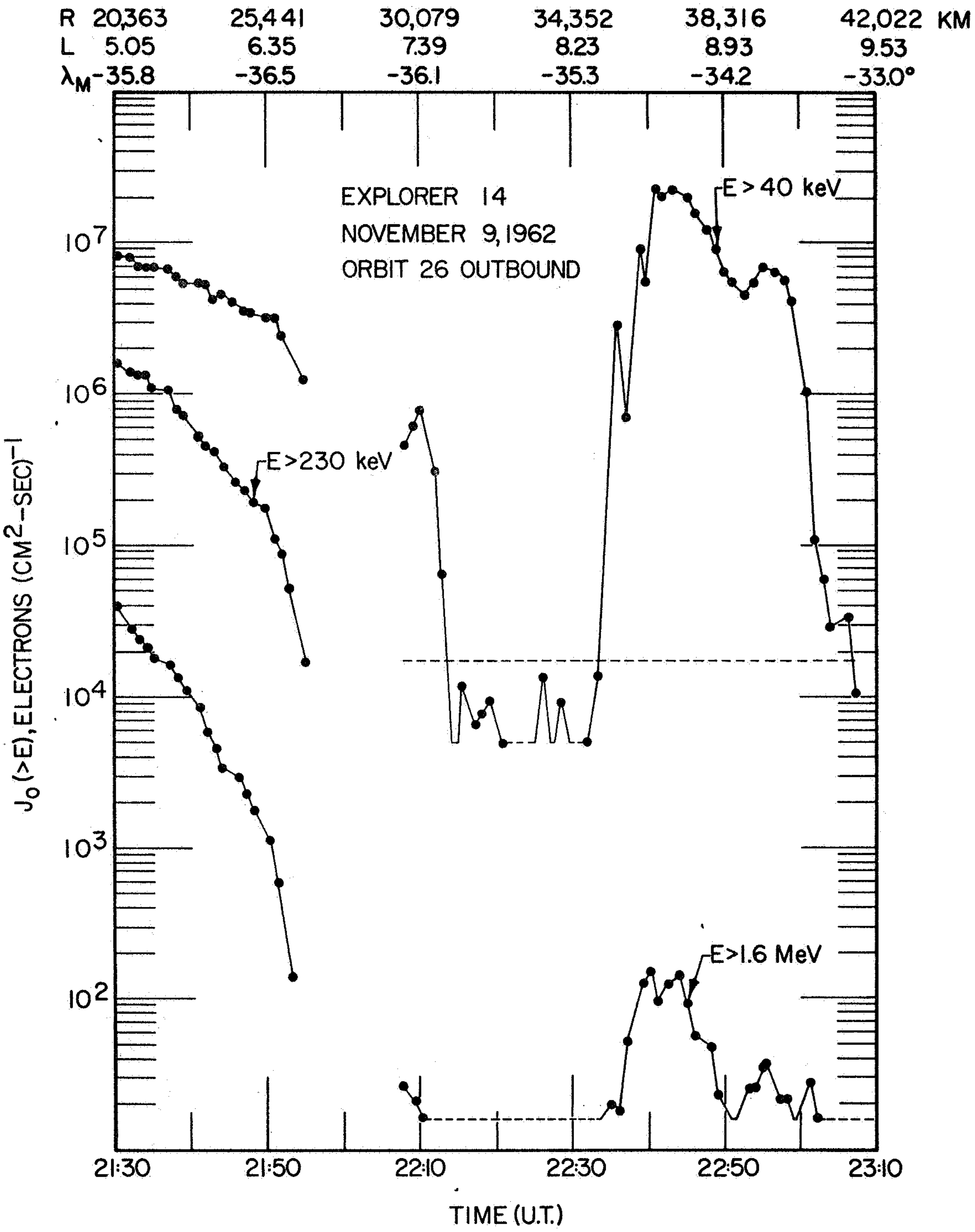


Figure 7

B-G69-57

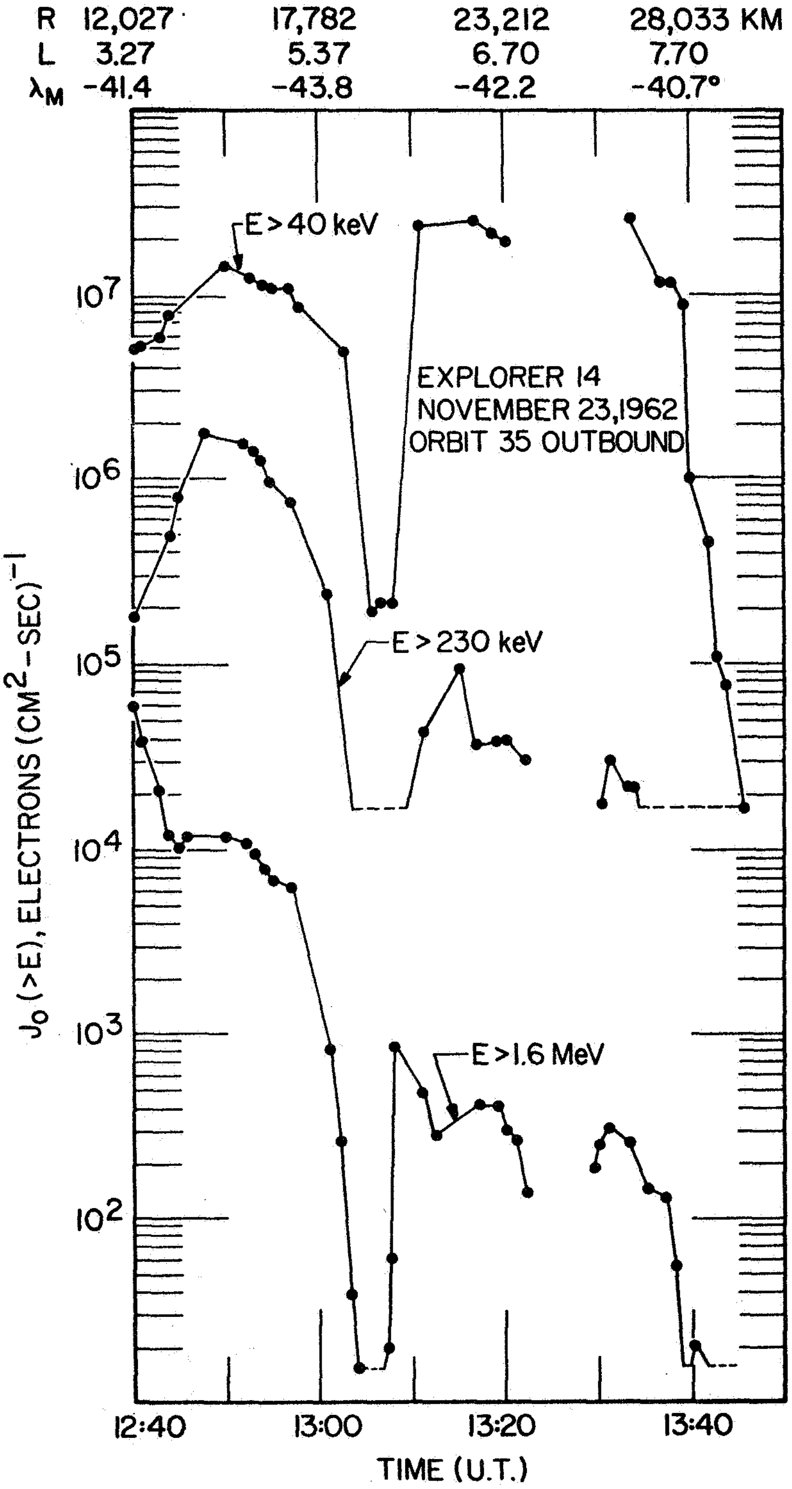


Figure 8

D-G69-55

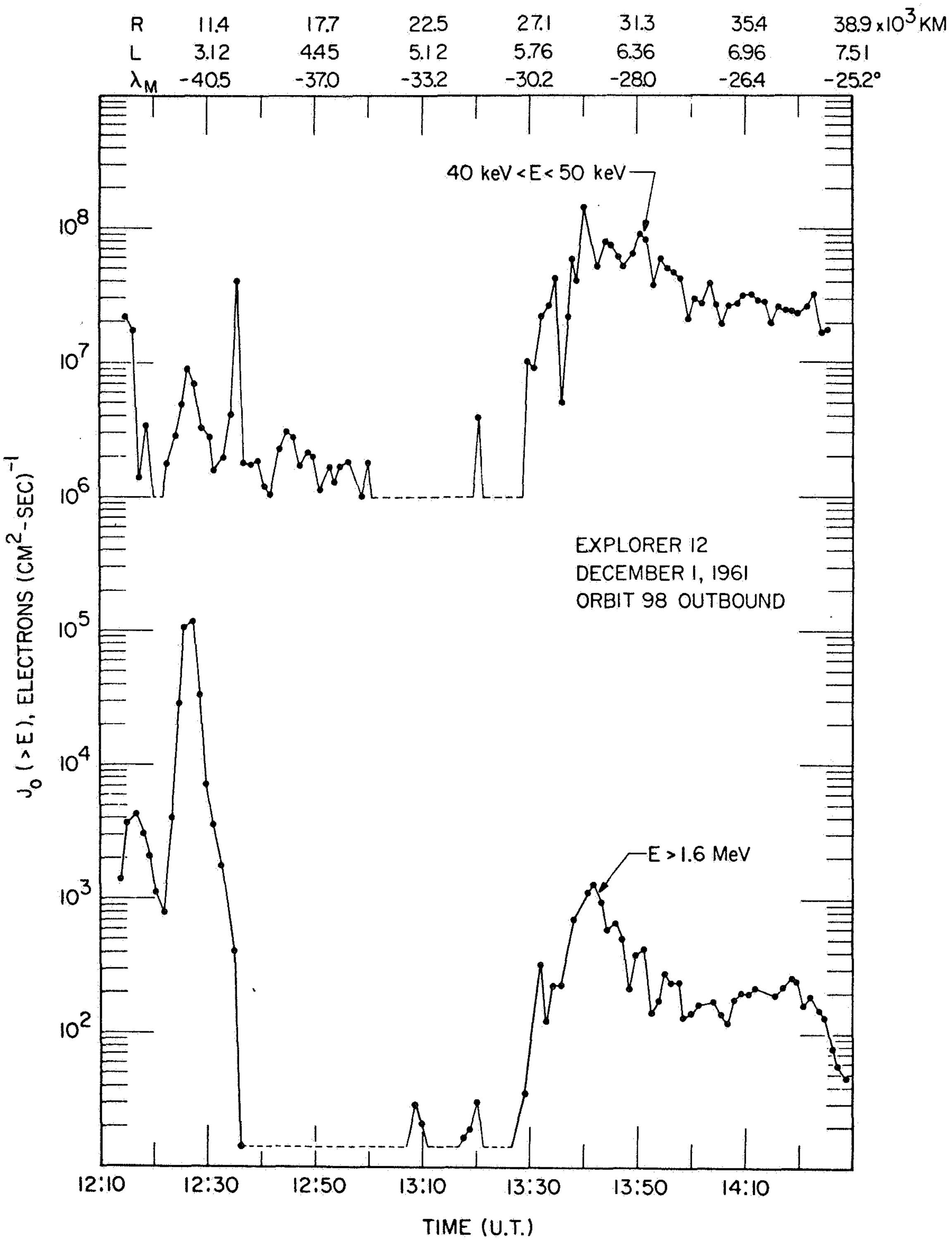


Figure 9

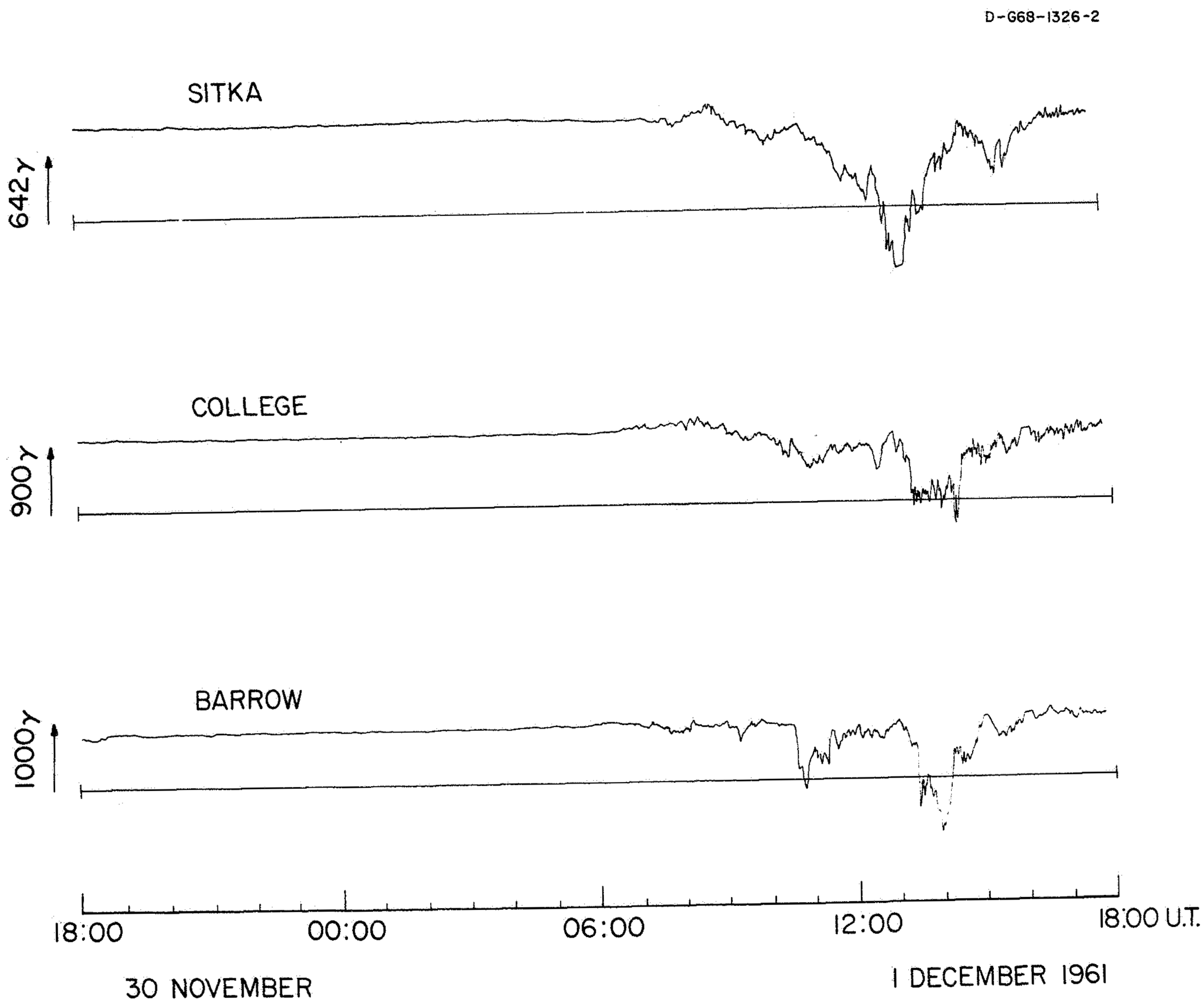

D-G68-1326-2
SITKA
642γ
COLLEGE
900γ
BARROW
1000γ
18:00
00:00
06:00
12:00
18:00 U.T.
30 NOVEMBER
1 DECEMBER 1961

Figure 10

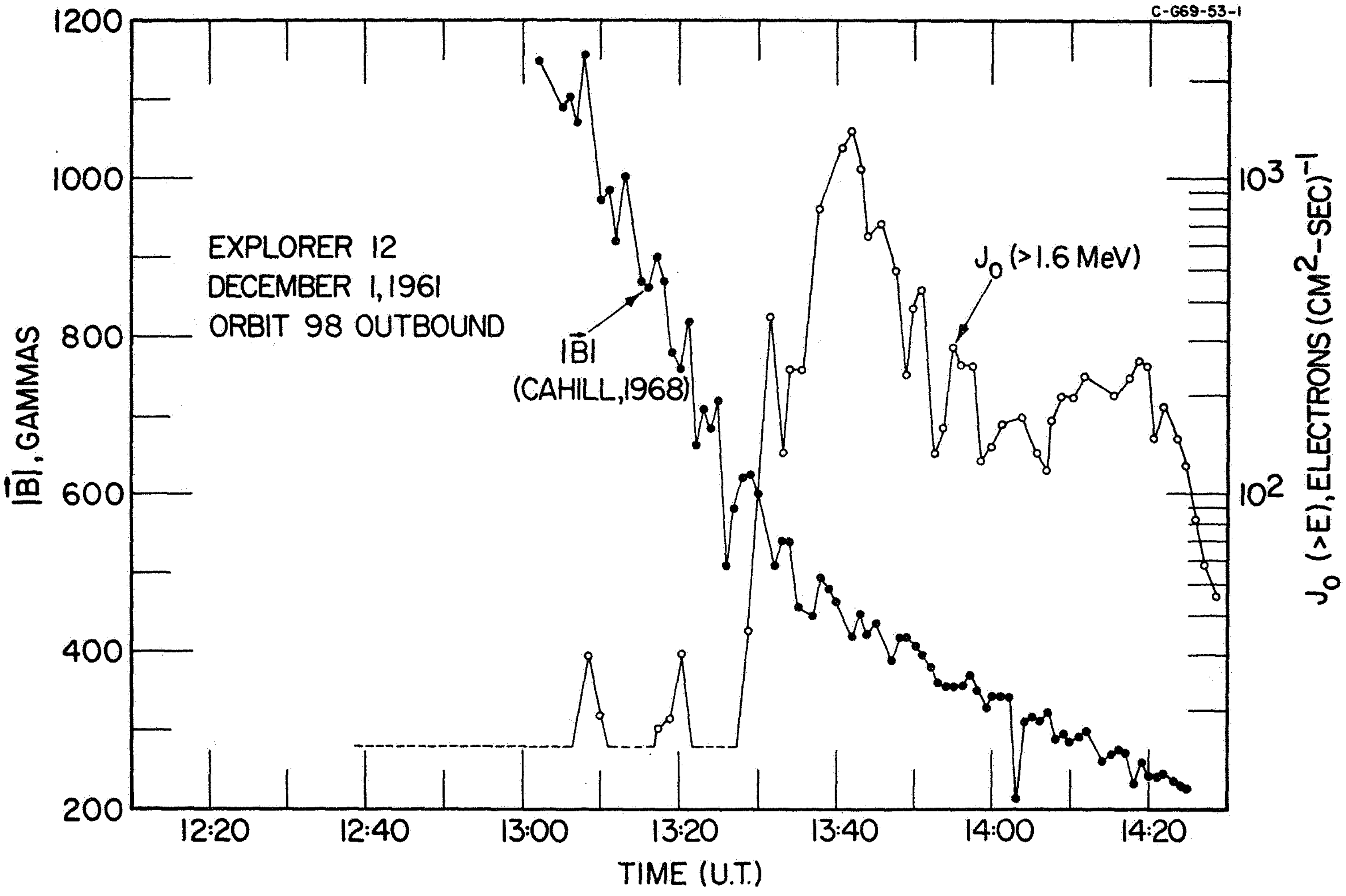

C-G69-53-1
1200
1000
800
600
400
200
$|\vec{B}|$, GAMMAS
10^3
10^2
J_0 (>E), ELECTRONS $(CM^2-SEC)^{-1}$
EXPLORER 12
DECEMBER 1, 1961
ORBIT 98 OUTBOUND
$|\vec{B}|$
(CAHILL, 1968)
J_0 (>1.6 MeV)
12:20
12:40
13:00
13:20
13:40
14:00
14:20
TIME (U.T.)

Figure 11

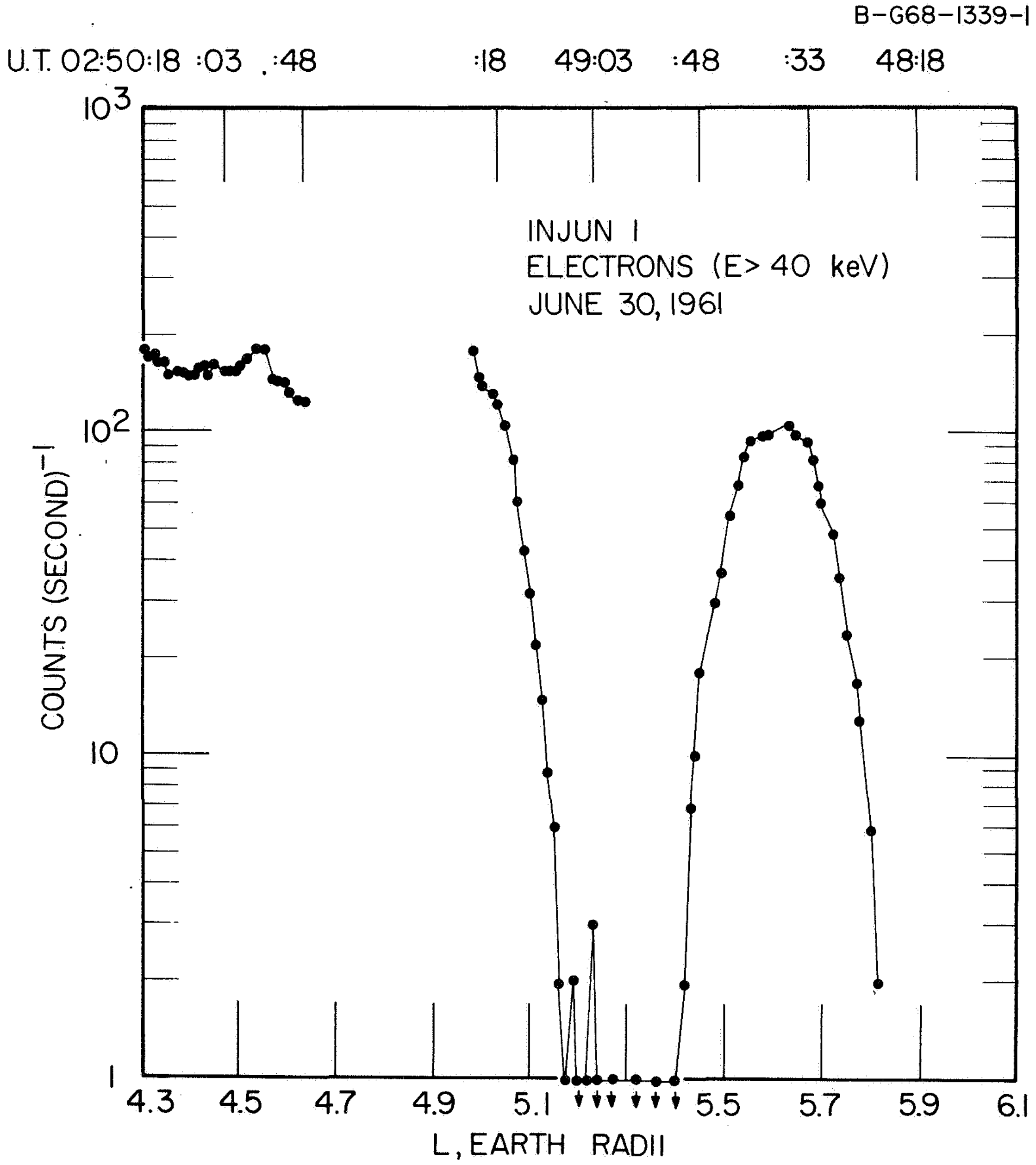

B-G68-1339-1
U.T. 02:50:18 :03 :48 :18 49:03 :48 :33 48:18
10³
10²
10
1
COUNTS (SECOND)⁻¹
INJUN I
ELECTRONS (E> 40 keV)
JUNE 30, 1961
4.3 4.5 4.7 4.9 5.1 5.5 5.7 5.9 6.1
L, EARTH RADII

Figure 12

D-G69-3

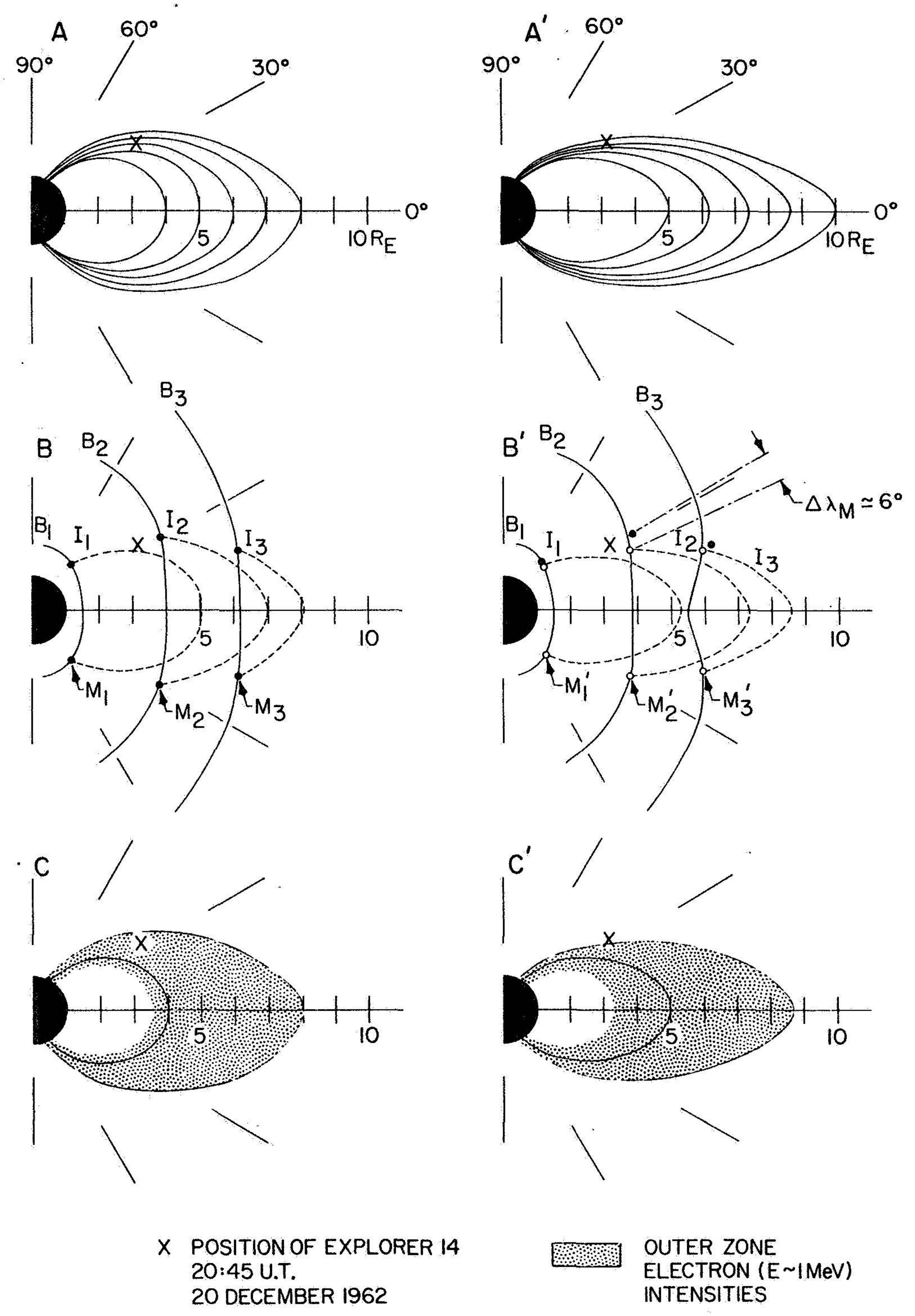


Figure 13

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
University of Iowa
Department of Physics and Astronomy

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. REPORT TITLE
Large Temporal Variations of Energetic Electron Intensities at Mid-Latitudes in the Outer Radiation Zone*

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Progress February 1969

5. AUTHOR(S) *(Last name, first name, initial)*
Yeager, D. M. and Frank, L. A.

6. REPORT DATE
February 1969

7a. TOTAL NO. OF PAGES
39

7b. NO. OF REFS
27

8a. CONTRACT OR GRANT NO.
Nonr 1509(06)

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
U. of Iowa 69-13

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES
Distribution of this document is unlimited

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Office of Naval Research

13. ABSTRACT

A thorough search of Explorers 12 and 14 observations of electron (40 keV $\lesssim E \lesssim$ 2 MeV) intensities within the outer radiation zone during the period 1961-1963 has provided evidences of several catastrophic rapid decreases and recoveries of these electron intensities within periods $\sim$ several minutes at L-values $\sim$ 5 to 6. Typical values for these intensity fluctuations are by factors $\gtrsim 500$, $\gtrsim 100$ and $\gtrsim 1000$ for electrons $E > 40$ keV, 230 keV and 1.6 MeV, respectively. A comparison of the temporal variations of integral energy spectrums of electron intensities, latitudes of the observed events, ground-based observations of auroral magnetic activity, and low-altitude measurements of electron intensities within the above energy range allow this striking phenomenon to be interpreted in terms of redistribution of these outer zone electrons during the distortion of the geomagnetic field by the low-energy plasma producing the associated magnetic disturbance and of conservation of the first two adiabatic invariants μ and I. The principal features of these events are adequately accounted for with the above interpretation, as the signature of the motion of the 'trapping boundary' for energetic electrons at mid-latitudes in the dark hemisphere of the magnetosphere, which eliminates the alternative assumption of an almost unreasonably strong acceleration mechanism for outer zone energetic electrons.

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Outer Radiation Zone						
Magnetosphere						
Geomagnetic Storm						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
______________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
______________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
______________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

UNCLASSIFIED

Security Classification