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LOW-ENERGY ELECTRON INTENSITIES AT LARGE DISTANCES OVER THE EARTH'S POLAR CAP*

by

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Abstract

The eccentric-orbiting satellite IMP-5 penetrated the distant polar magnetosphere at positions corresponding to those for magnetic field lines which intersect the earth's Northern polar cap. Measurements of electron intensities with $E \geq 250$ eV in these regions of extremely low plasma densities were gained with an electrostatic analyzer, a LEPEDEA. The observational period utilized here was January through October 1970. Electron intensities within the energy range 250 eV $\leq E \leq$ 50 keV were lesser by orders of magnitude than those typically encountered within the plasma sheet and over the auroral oval. However, dramatic temporal variations of average electron intensities in the polar cap region were found for orbit-to-orbit comparisons. Differential intensities at 400 eV varied from 1.5×10^2 to 7.5×10^3 electrons $(cm^2\text{-sec-sr-eV})^{-1}$, and electron densities within the above energy range fluctuated from 1.5×10^{-3} to 4.5×10^{-2} electrons $(cm)^{-3}$. These intensity variations showed a remarkable correlation with the polarity of the magnetic sector structure in the interplanetary medium -- high intensities for 'away from the sun' sectors and low intensities for 'toward' sectors.

I. Introduction

The magnetic field lines which thread the earth's polar caps and extend into the lobes of the distant magnetotail are endowed with one of the most dilute plasmas of the earth's environs. Electron energy spectra within the lobes of the magnetotail are characteristically similar to those of the high-energy tails of magnetosheath plasmas, but overall electron densities are in the range of a mere 10^{-3} of magnetosheath electron densities [Bame, 1968; Akasofu _et al_., 1973]. Because of these extremely low densities along polar-cap field lines no definitive observations of the corresponding proton spectra have yet been reported. This region may or may not be populated with positive ions of magnetosheath or ionospheric origins. Little is known of the temporal variations or spatial distributions of these thin polar-cap plasmas. At low altitudes over the earth's polar cap, similar electron intensities have been encountered and are found to increase during geomagnetic storms [Winningham and Heikkila, 1974]. Corresponding energy influxes into the polar ionosphere are only 10^{-3} to 10^{-2} erg $(cm^2\text{-sec})^{-1}$-- to be compared with energy fluxes of 1 to 100 ergs $(cm^2\text{-sec})^{-1}$

over the auroral zone at lower latitudes. Indeed the distinquishing feature of these polar-cap plasmas at first glance is their apparent insignificance.

Although it can be probably concluded that plasmas of these densities do not provide a major impact on the energetics, origins or dynamics of magnetospheric plasmas, there is a strong possibility that these weak polar-cap intensities can eventually aid in resolving major features of polar magnetospheric topology and its responses to fluctuations of solar wind parameters. It has become increasingly clear over the past several years that the weak magnetic fields in the solar wind exert a striking influence on the polar magnetosphere. Wilcox and Ness [1965] have demonstrated that the average interplanetary magnetic field displays a persistent 'sector' structure with fields directed alternately away and toward the sun. Even though the energy fluxes impinging upon the geomagnetic cavity are massively dominated by those of solar-wind ions, the effects of the interplanetary sector structure upon phenomena along both auroral and polar geomagnetic field lines are remarkable. For examples, Williams [1966] has found marked enhancements of energetic electron intensities in the outer radiation zone with the passage of sector boundaries, and the similar correlation with the magnetic disturbance index K_p is well-known [Wilcox and Ness, 1965]. Among the effects which depend upon the polarity of the sector, i.e., 'away' or 'toward', are the polar-cap electric field configuration [Heppner, 1972] and the ionospheric current systems near the boundaries of the polar cap [Svalgaard, 1968; Mansurov, 1969; Friis-Christensen et al., 1971]. If such substantial control of some polar cap phenomena is effected by the interplanetary magnetic field, then it might be expected that there is a corresponding influence upon the plasmas thinly populating polar geomagnetic field lines.

We report here the results of our initial study of the character and temporal fluctuations of electron intensities in the energy range of hundreds of electron volts, which were measured at high latitudes and altitudes on geomagnetic field lines corresponding to those of the polar cap and magnetotail lobes. Albeit that such electron intensities are diminutive relative to those found in other regions of the magnetosphere, severe variations of intensities were found and the magnitudes of electron intensities appear to be strongly coupled to the directions of the interplanetary magnetic fields.

II. Observations

An electrostatic analyzer, a LEPEDEA, for measurements of plasmas was included in the scientific complement of instruments on board the highly eccentric-orbiting spacecraft IMP-5. This earth satellite was launched on June 21, 1969 into an orbit with initial apogee and perigee geocentric radial distances of 28.8 and 1.05 R_E, respectively, an inclination of 86.8°, and an orbital period of 3.4 days. The fortuitous orbit of IMP 5 provided first *in situ* surveys of magnetosheath plasma entry into the distant polar cusp and first traversals of polar-cap magnetic field lines at great distances over the earth's polar caps [cf. Frank, 1971]. The LEPEDEA was capable of sensing the directional, differential intensities of electrons and positive ions, separately, over the energy range 80 eV to 50,000 eV in 16 essentially contiguous energy passbands. The fields-of-view of the electrostatic analyzer were approximately rectangular with dimensions 8° x 25°. The axes of these fields-of-view were directed orthogonally to the spacecraft spin axis with the 25°-dimension lying parallel to this spin axis. The spin axis was directed nearly normal to the ecliptic plane. Sampling of proton and electron intensities was slaved to the telemetry stream, and indivi accumulations of detector responses were of a duration corresponding to about 55° of spacecraft rotation. The corresponding instantaneous directions of the fields-of-view relative to the local magnetic field vector and to a set of inertial coordinates were computed via the magnetometer (courtesy of N. Ness and D. Fairfield) and the optical aspect arrays on board the spacecraft. The reader is referred to Frank [1971] for further information and references concerning details of the plasma instrumentation.

Observational situation. In order to provide insight into the relationship of the positions of various plasma regimes of the magnetosphere with the orbit of the IMP-5 satellite we present a series of typical observations at low and high magnetic latitudes, which are followed by an overview of the observational opportunities over the earth's polar cap. During the outbound segments of the orbit the satellite was located near the magnetic equatorial plane. A typical series of such observations in the dayside magnetosphere is summarized in Figures 1 and 2. Directional, differential intensities of low-energy electrons within two energy passbands, $305 \leq E \leq 510$ eV and $3.3 \leq E \leq 5.4$ keV, and directional intensities of more energetic electrons with $E > 45$ keV are plotted as functions of geocentric radial distance in Figure 1. Simultaneous measurements of proton intensities within the passbands $690 \le E \le 1100$ eV and $12 \le E \le 19.5$ keV are displayed in the upper two panels of Figure 2. The plasma features of dayside traversals are well-known and evident in Figures 1 and 2--with increasing radial distance, the energetic proton and electron intensities of the outer magnetosphere, the magnetopause and its close correspondence with the 'trapping boundary' for energetic electron intensities with $E > 45$ keV, the lower energy plasmas of the magnetosheath, and the highly directional flow of ions of the interplanetary medium. We have chosen the viewing quadrant $225° \le \phi^L_{SE} \le 315°$ for the low-energy plasma measurements, where ϕ^L_{SE} is the direction of the field-of-view in spacecraft-centered solar-ecliptic coordinates, to enhance the distinction between magnetosheath and interplanetary domains. A viewing sector centered in the solar direction is simply not as effective for distinquishing these regions in this type of graphical display. These observations near the magnetic equator are in marked contrast to those for higher latitudes during the preceding inbound segment of IMP-5 trajectory. A summary of these measurements at higher latitudes is offered in Figures 3 and 4. The format for the presentation of these observations is identical to that for the two previous figures which display the equatorial measurements in order to aid in the comparison. With decreasing radial distances, the satellite passes from the interplanetary medium into the magnetosheath, thence into the high-latitude outer radiation zone, across the polar cusp and finally into the plasma 'void' of the polar cap region. Note that at high latitudes substantial intensities of low-energy protons, $690 \le E \le 1100$ eV, are found along with the more energetic protons, $12 \le E \le 19.5$ keV, of the ring current in the outer radiation zone. This interesting feature which suggests penetration of magnetosheath plasmas into the outer zone at high latitudes is not currently understood and is mentioned only to point out to the reader one of the current enigmas of the polar magnetosphere. Our interests herein are drawn toward the weak intensities of electrons, $305 \le E \le 510$ eV, in the polar cap region.

Since the average intensities of low-energy electrons in the polar cap region are to be displayed for a ten-month period of 1970, it is of use to summarize several positional coordinates of the satellite for these observations. Two geocentric radial distances, 5 and 10 R_E, have been chosen and the corresponding magnetic latitudes

λ_m and solar-magnetospheric longitudes ϕ_{SM} are displayed as functions of day count in Figure 5 for all inbound trajectory segments utilized in the current survey. The satellite is in the vicinity of the noon meridional plane in June and near the midnight plane in January (lower panel, Figure 5). Due to the asynchronous period of the orbit relative to the earth's rotational motion the overall sampling of magnetic latitudes is not severely restricted, and ranges from about 45° to 65° at 5 R_E and 65° to 85° at 10 R_E. A summary of the coordinates of the satellite for each inbound entry into the polar cap region is given in Figure 6. These coordinates are geomagnetic latitude, radial distance, and earth-centered solar-ecliptic longitude ϕ_{SE} of the satellite position. For the inbound pass of Figures 3 and 4, as an example, the entry into the polar cap region occurred at a radial distance of 37,000 km. Often IMP 5 did not penetrate the outer radiation zone or polar cusp, especially when the inbound segment was positioned near local midnight. For these traversals of the polar magnetosphere the satellite either passed directly from magnetosheath into the polar cap region, or from magnetosheath into the plasma mantle [Rosenbauer et al., 1975] and then into the polar cap region. The low-altitude departures of the spacecraft from the polar cap region are not shown in Figure 6 since the cycle time for plasma measurements with the analyzer relative to the rapid spacecraft motion in magnetic coordinates rendered such a determination practically meaningless. Reference to Figure 6 shows that the typical coordinates for entry into the polar cap region are geomagnetic latitudes $\sim 70°$ and geocentric radial distances $\sim 7\ R_E$.

And, now, what are the temporal variations of the low-energy electron intensities in the distant polar cap region? The average electron intensities, which were observed during each inbound crossing of the polar cap region during the period January through October 1970, are displayed in the bottom panel of Figure 7. The average electron intensities within the selected energy passband $305 \leq E \leq 510$ eV are given by the solid circles, and the range of intensities encountered for each crossing of the polar cap region are provided by the vertical bars. The corresponding quadrant for directions of the instrument field-of-view was $225° \leq \phi^L_{SE} \leq 315°$. Two features of these low-energy electron intensities are immediately evident with inspection of Figure 7--the average intensities of electrons in the polar cap region fluctuate greatly from orbit to orbit and the electron intensities observed during individual crossings of the polar cap region exhibit similar, substantial variations.

The corresponding daily sums of the planetary magnetic disturbance index, ΣK_p, are given in the top panel of Figure 7 for comparison with the fluctuations of these low-energy electron intensities. An examination of fluctuations of the magnetic index and of the average electron intensities in the polar cap region does not reveal any correlation between these two parameters. In fact it should be noted here that the general character of the temporal fluctuations of electron intensities is such that increases and decreases of intensities are relatively long-lived, typically 6 to 10 days, and that these fluctuations of averaged intensities are in the range of factors of $\sim$ 10 to 50.

Electron energy spectra. It is of immediate interest to examine the electron energy spectra within the polar cap region for periods of high and low electron intensities. Two such examples of differential energy spectra of electron intensities are shown in Figures 8 and 9. These energy spectra represent the averages for entire individual traversals of the polar cap region. Measurements of electron intensities at energies < 250 eV are not displayed because spacecraft charging in this sparsely populated plasma region can possibly affect the electron intensities observed at these lower energies [cf. Montgomery et al., 1972], and there is no diagnostic capability to determine this satellite's potential relative to the ambient medium. Other than the obvious differences in magnitudes of intensities between the two energy spectra shown in Figure 8, the spectra differ substantially in their character at lower energies--rapidly rising intensities with decreasing energy over the entire energy range when the polar cap region is impoverished and a 'flattening' of electron spectra at lower energies during periods of maximum intensities. Even so, the corresponding densities for these two energy spectra are remarkably low relative to densities within the energy range 250 eV $\leq$ E $\leq$ 50 keV typically found in other magnetospheric domains. These densities were 1.6×10^{-3} and 3.2×10^{-2} electrons $(cm)^{-3}$ on 20 and 30 May, respectively. The average energy spectrum observed in the polar cap region during 20 May, which corresponds to a period of depleted electron intensities, is similar to those encountered in the lobes of the downstream magnetotail by the Vela satellites [Akasofu et al., 1973]. We have found no published electron spectra for low altitudes, which could be directly associated with those reported here for the depleted state of the polar cap region. The overall spectral characters of both examples for the polar cap region, as shown in Figure 8, are demonstrably more reminiscent of electron spectra within the magnetosheath [cf. Montgomery et al., 1970] rather than those within the plasma sheet of the magnetotail [cf. Frank, 1967]. Electron intensities for 250 eV ≤ E ≤ 10 keV in the magnetosheath are of the same order of magnitude as electron intensities for the enhanced state of the polar cap region. Of course, the overwhelming bulk of the magnetosheath electron distributions is at lower energies than 250 eV. For the depleted state of the polar cap region electron intensities in the energy range 250 eV ≤ E ≤ 1 keV appear to be significantly less than even those of the tail, or 'halo', of the solar-wind electron spectrum [cf. Feldman et al., 1975]. Further examples of electron spectra in the distant polar cap during high- and low-intensity periods are given in Figure 9. These observations support further the conclusion that there are dramatic, persistent variations of low-energy electron intensities in the polar cap region.

Simultaneous measurements of proton spectra would be extremely useful in delineating the source region for the low-energy electron intensities. However, even during periods of enhanced electron intensities, corresponding proton intensities are at or below the threshold of the electrostatic analyzer. The corresponding upper limit for proton densities in the energy range 80 eV $\leq$ E $\leq$ 50 keV is $\sim 5 \times 10^{-2}$ protons $(cm)^{-3}$. If there are no substantial proton intensities at energies < 80 eV, then plasma densities in the polar cap region are less than magnetosheath densities by factors of 10^3 to 10^4. The only viable source for a positive-ion population at energies < 80 eV appears presently to be the ionosphere, i.e., the 'polar wind' [Banks and Holzer, 1968; Hoffman et al., 1974]. Such 'polar wind' ion densities are expected to be also negligible relative to magnetosheath densities. Unfortunately the measurements of the positive ions must await analyses of surveys of the magnetic lobes with later-generation LEPEDEA's with improved sensitivities and energy ranges, such as have been included on board IMP-6 and other spacecraft.

Angular distributions. A typical example of the angular distributions of electron intensities in the polar cap region for a period of enhanced intensities is shown in Figure 10. Electron intensities within the energy passband 305 $\leq$ E $\leq$ 510 eV are plotted as functions of satellite-centered solar-ecliptic longitude ϕ^L_{SE}, i.e., essentially the satellite roll angle. These measurements include all such samples of electron intensities during the traversal of the polar cap region on June 26,

1970. The corresponding energy spectrum was given in the preceding Figure 9. The average intensities for angular 'buckets' of 30° are displayed as dashed lines in Figure 10. These angular distributions of electron intensities are isotropic within the overall accuracy of these measurements. Pitch-angle distributions for these electron intensities can be gained by employing the satellite's magnetometer and are displayed in Figure 11. The pitch angles α sampled during this crossing of the polar cap region ranged from 45° to 135°. Amidst the substantial scatter of individual intensity samples, no clear signature of anisotropy of electron intensities is discernible.

Correlation of electron intensities with interplanetary sector structure. Many geomagnetic and interplanetary parameters were tested in order to find an association with the periods of depleted and enhanced intensities of low-energy electrons in the distant polar cap region. One such parameter provided a remarkable correlation with these fluctuations of electron intensities--the polarity of the interplanetary magnetic field. This result is displayed in Figure 12. At the top of this figure are given the polarities of the interplanetary magnetic field, which were gained with satellite-borne magnetometers and reported by Wilcox and his colleagues

[1975]. The polarities of the interplanetary field as inferred by Svalgaard [1974] from ground-based magnetometry at high magnetic latitudes are shown also in Figure 12. In the bottom panel of this figure are given the average intensities of electrons within the energy passband $305 \leq E \leq 510$ eV for each crossing of the polar cap region during the period January through October 1970. The error bars assigned to each intensity value denote the standard deviations for the average intensities. Superposed upon the intensity profile are shaded and unshaded bars which identify well-defined 'away' and 'toward' sectors, respectively, for the interplanetary magnetic field at earth [Wilcox _et al_., 1975]. Only a brief inspection of this comparison of interplanetary sectors and electron intensities yields the fact that, in general, high electron intensities in the polar cap region accompany 'away' sectors and low intensities are found when the magnetosphere is immersed in a 'toward' sector. There appear to be occasional exceptions. For example, reference to Figure 12 shows that enhanced electron intensities were observed on 19 June during a 'toward' sector. No simultaneous observations of the interplanetary field were available during the period of this measurement of electron intensities [Wilcox _et al_., 1975].

However, we have examined the magnetometer measurements gained with IMP 5 in the interplanetary medium for the period about six hours prior to entry into the polar cap region and the interplanetary field was directed 'away' from the sun, in agreement with the result reported here. There are a few other such anomalous correlations of sector polarity and electron intensities, which are evident in Figure 12, but these probably are the signatures of short-duration reversals of polarity in the interplanetary sector structure. The question immediately arises as to whether these large variations of electron intensities are effected by a reversal of the azimuthal, or Y, component of the interplanetary field. Since the interplanetary field is characteristically directed along the Archimedean spiral, there are relatively few cases when, for example, there will be prolonged periods for which the interplanetary field is directed away from the sun and the Y component of the field is negative. Thus far our data base is insufficiently large to clearly discern whether or not these large fluctuations of electron intensities are to be associated with the direction of the azimuthal component of the interplanetary magnetic field. Further, there appears to be no notable effect of the local time of the observation of electron intensities on either the sense or magnitude of the correlation. For the measurements shown in Figure 12, the satellite was in the following zones of the polar cap region; near local midnight in January, local evening in April, local noon in June and local morning in October. Indeed it would appear that the correlation of the intensities of low-energy electrons in the polar cap region with the polarities of the sector structure in the interplanetary medium is one of the most persistent and striking associations of magnetospheric phenomena with solar wind parameters.

III. Discussion

We have reported here our first results of a survey of low-energy electron intensities with the eccentric-orbiting satellite IMP-5 in the most barren regime of the earth's magnetosphere--the distant polar cap region. The geomagnetic field lines threading the region of our measurements intersect the earth's polar cap and, at greater distances, thread the lobes of the magnetotail. Electron densities within the energy range 250 eV $\leq$ E $\leq$ 50 keV ranged from a scant 1.5×10^{-3} $(cm)^{-3}$ to 4.5×10^{-2} $(cm)^{-3}$. Upper limits for proton intensities with 80 eV $\leq$ E $\leq$ 50 keV support the suggestion that total densities within the polar cap region do not greatly exceed the above density range. Pitch-angle distributions of these low-energy electrons are best described as isotropic within factors of 3 or 4 which are set by intensity fluctuations during the sampling period for a determination of the angular distribution. The most remarkable feature of these electron intensities in the polar cap region was their great temporal variations from orbit to orbit. The Northern polar cap region was usually traversed at radial distances in the range of $\sim$ 3 to 7 R_E, and at magnetic latitudes

~ 45° to 70°, for periods of typically several hours once every 3.4 days, the orbital period of the satellite. Intensities of electrons with 250 eV ≤ E ≤ 50 keV, which were averaged over individual, entire crossings of the polar cap region, fluctuated by factors as much as 50. The magnitudes of these electron intensities were strikingly correlated with the polarity of the interplanetary field (cf. Figure 12). High intensities of low-energy electrons were persistently present when the interplanetary magnetic field was directed away from the sun and low intensities were encountered during 'toward' sectors.

Our observations of electron spectra at great distances over the earth's polar cap are generally consistent with the character of such electron intensities reported for low altitudes over the polar ionosphere and for much greater distances in the lobes of the magnetotail. Akasofu and coworkers [1973] have presented several electron spectra which were gained with a Vela satellite in the lobes of the magnetotail. These measurements were similar in both spectral shape and intensities to the electron spectra presented here for periods of low intensities, i.e., during 'toward' sectors of the interplanetary medium. The differential intensities of electrons with E ≥ 250 eV during periods of enhancement, or 'away' sectors, are of the same magnitudes as those found in the high-energy 'tails' of magnetosheath and polar-cusp plasmas [cf. Montgomery _et al_., 1970; Frank, 1971]. Winningham and Heikkila [1974] have reported the presence of similar weak intensities of low-energy electrons at low altitudes over the earth's polar caps. The corresponding energy influxes into the atmosphere were $\sim 10^{-3}$ to 10^{-2} erg $(cm^2\text{-sec})^{-1}$. The larger influxes of these electrons reportedly occurred during worldwide geomagnetic storms. Our measurements of energy influxes at ~ 5 to 10 R_E over the earth's polar cap yield values ranging from $\sim 5 \times 10^{-4}$ to 5×10^{-2} ergs $(cm^2\text{-sec})^{-1}$. Thus the energy fluxes at low and high altitudes over the earth's polar cap are similar, and there appears to be no reason to assume a major acceleration mechanism at some intermediate position along these field lines in order to account for polar-cap energy influxes and aurora. It is stressed here that the corresponding topological feature in the distant magnetosphere is the magnetotail lobe, _not_ the polar cusp or the regions associated with inverted 'V' precipitation at lower latitudes. We disagree with Winningham and Heikkila [1974] that control of the magnitudes of polar-cap intensities is best associated with geomagnetic storms. Our results show that these intensities are very strikingly under the influence of the polarity of the interplanetary magnetic field. Although electron intensities during the periods of enhancement associated with 'away' interplanetary sectors can be identified with magnetosheath and polar-cusp plasmas as above, the extremely low intensities within the polar cap region during 'toward' sectors remain an enigma. Not only are electron intensities lower by factors of 10 to 50, but the spectra rise more rapidly at the lower energies, hundreds of eV. These electron intensities are substantially less than those found in the solar wind in our energy range. It will take considerably more comprehensive surveys of the magnetosphere to identify the origins of the sparse plasmas of the polar cap region during the 'toward' sectors of the interplanetary medium.

Variations of the geomagnetic field as observed at polar-cap latitudes with ground-based magnetometers have been associated with the polarity of the interplanetary magnetic field or, more precisely, its azimuthal component [Svalgaard, 1968; Mansurov, 1969; Friis-Christensen et al., 1971]. Heppner [1972] has been able to show clearly that polar-cap electric fields are also controlled by the east-west component of interplanetary magnetic field. Our present series of observations of polar-cap electron intensities, which were used for this initial survey, are insufficient to discern whether or not the strong correlation with sector polarity reported here is in fact the signature of the azimuthal component of interplanetary magnetic fields.

Current models and theories for the magnetosphere are of little quantitative value in assessing the electron intensities in the polar cap region as reported here. This situation no doubt partially arises from the fact that little information concerning these sparce plasmas has been available. For example, Stern [1973] has proposed a model of the distant magnetosphere, which is in qualitative agreement with the observed dependence of polar-cap currents and electric fields upon the azimuthal component of the interplanetary magnetic field. In a few words, the critical features of this model include (1) a 'separatrix' which is the boundary between closed geomagnetic field lines, geomagnetic field lines connected with interplanetary field lines, and field lines not connected to those from the earth and (2) geomagnetic field lines connecting with those of the interplanetary medium as magnetosheath plasmas flow along this separatrix. The asymmetry of the electric fields over the polar cap and the reversal of direction of the polar cap currents are presumed to be effected by the azimuthal, or Y, component of the interplanetary magnetic field. Either the dawn or dusk portion of the separatrix will be favored with a greater sweeping effect which will depend upon the sign of the Y component of the interplanetary field. With this magnetospheric model one might expect to not only observe a dependence of the magnitudes of electron intensities in the polar cap region upon interplanetary sector polarity as reported here, but also a clear asymmetry of this correlation for measurements at local dawn relative to those at local evening. Such a dawn-dusk asymmetry is not found in our present survey, the electron intensities increase at all local times within the Northern polar cap region when the interplanetary field is directed away from the sun.

This exploratory investigation of low-energy electron intensities in the distant polar cap region has demonstrated the dramatic correlation of these intensities with the polarity of the interplanetary magnetic field. Several future researches of this region are evident, which could lead to important facts concerning the connectivity of geomagnetic field lines to those within the solar wind and the entry of plasma into the magnetosphere. Are the temporal variations of electron intensities out of phase for the Northern and Southern polar cap regions? What is the character of positive ions in these regions? Are the intensities of polar-cap aurora dependent upon polarity of the interplanetary magnetic field? What is the corresponding influence of interplanetary sector polarity upon plasmas in the lobes and plasma sheet of the magnetotail? And does the Northern plasma mantle which encases the lobe field lines disappear or thin drastically when the interplanetary field is directed toward the sun? Most of these questions can be probably answered with measurements already available.

Acknowledgments

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Figure Captions

Figure 1. A typical series of observations of electron intensities as functions of geocentric radial distance as IMP-5 traverses the dayside magnetosphere near the geomagnetic equatorial plane. Major plasma regimes are identified by the figure legends. The earth-centered, solar-magnetospheric longitude ϕ_{SM} and geomagnetic latitude λ_m of the satellite position are given at the top of this figure. The longitudes of the directions of the detector's field of view in satellite-centered, solar-ecliptic coordinates are ϕ_{SE}^{L}.

Figure 2. Continuation of Figure 1 for proton intensities within two energy passbands of the electrostatic analyzer.

Figure 3. A series of observations of electron intensities as functions of geocentric radial distance as the satellite traverses the dayside polar magnetosphere. Our

interest here is directed toward the relatively weak intensities of electrons in the polar cap region which is encountered in this example at radial distances ≤ 37,000 km.

Figure 4. Continuation of Figure 3 for proton intensities within two energy passbands of the electrostatic analyzer. The polar cusp is encountered just prior to entry into the polar cap region.

Figure 5. The magnetic latitude λ_m and the solar-magnetospheric longitude ϕ_{SM} of the satellite position at radial distances 5 R_E and 10 R_E for each of the inbound crossings of the polar magnetosphere during January through October 1970. The orbital period of IMP 5 was 3.4 days.

Figure 6. Coordinates for entry of the satellite into the polar cap region for the inbound segment of each orbit. The earth-centered, solar-ecliptic longitudes are ϕ_{SE} which indicate the local time for each measurement. The configuration of the magnetosphere and

the local time of the observation determined the plasma regime adjacent to the polar cap region: magnetosheath, plasma mantle, or polar cusp.

Figure 7. Electron intensities within the energy passband $305 \leq E \leq 510$ eV, which are averaged over each crossing of the polar cap region, for January through October 1970. These averaged intensities are denoted by the solid circles in the bottom panel, and the ranges of intensities encountered for these crossings are identified by the vertical lines. The daily sum of the geomagnetic disturbance index, ΣK_p, is given in the top panel. There is no apparent correlation of electron intensities in the polar cap region with ΣK_p.

Figure 8. Electron energy spectra for two traversals of the polar cap region. Each spectrum is averaged over the entire corresponding crossing of the polar cap region.

Figure 9. Continuation of Figure 8 showing one further example of electron spectra for each state of the polar cap region,

i.e., high intensities on 26 June and low intensities on 13 July.

Figure 10. Angular distributions of electron intensities within the energy passband $305 \le E \le 510$ eV as functions of solar-ecliptic longitude of the detector's field-of-view (essentially roll phase of the satellite) for the crossing of the polar cap region on 26 June.

Figure 11. Continuation of Figure 10 but with electron intensities displayed as functions of pitch angle, α, which was determined with the on board magnetometer (courtesy of N. Ness and D. Fairfield).

Figure 12. In the bottom panel, comparison of interplanetary sector polarities as determined by Wilcox et al. [1975] and electron intensities within the Northern polar cap region. Shaded bars denote sectors with interplanetary magnetic fields directed away from the sun. The two bar graphs at the top of the figure are the observed polarities

of the interplanetary magnetic fields from *in situ* measurements [Wilcox *et al*., 1975] and the inferred polarities from ground-based magnetometry at polar magnetic latitudes [Svalgaard, 1974].

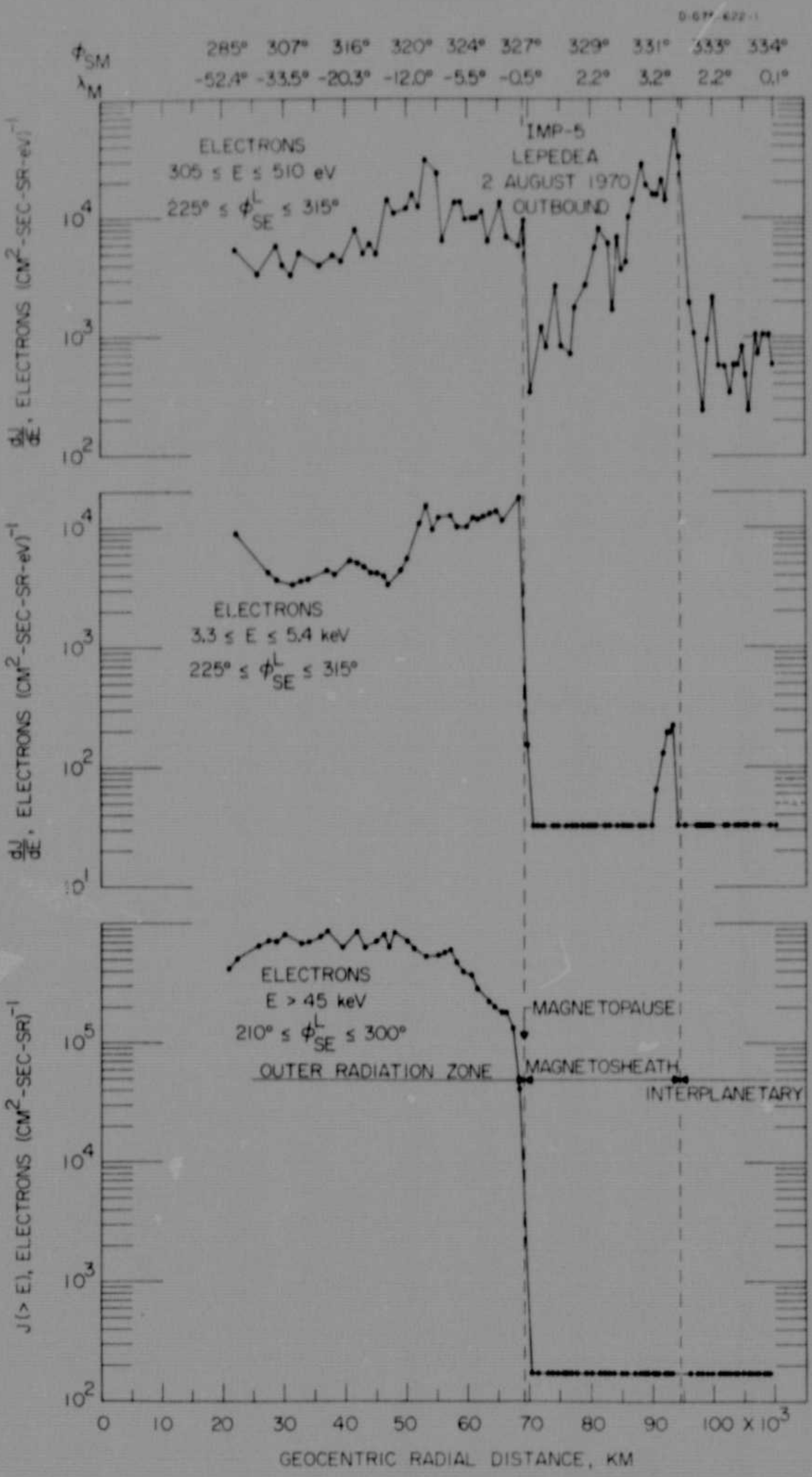
D-G77-422-1
ϕ_{SM}
λ_M
285° 307° 316° 320° 324° 327° 329° 331° 333° 334°
-52.4° -33.5° -20.3° -12.0° -5.5° -0.5° 2.2° 3.2° 2.2° 0.1°
ELECTRONS
305 ≤ E ≤ 510 eV
225° ≤ ϕ^L_{SE} ≤ 315°
IMP-5
LEPEDEA
2 AUGUST 1970
OUTBOUND
$\frac{dJ}{dE}$, ELECTRONS $(CM^2\text{-SEC-SR-eV})^{-1}$
ELECTRONS
3.3 ≤ E ≤ 5.4 keV
225° ≤ ϕ^L_{SE} ≤ 315°
ELECTRONS
E > 45 keV
210° ≤ ϕ^L_{SE} ≤ 300°
MAGNETOPAUSE
OUTER RADIATION ZONE
MAGNETOSHEATH
INTERPLANETARY
J(> E), ELECTRONS $(CM^2\text{-SEC-SR})^{-1}$
0 10 20 30 40 50 60 70 80 90 100 X 10^3
GEOCENTRIC RADIAL DISTANCE, KM

Figure 1.

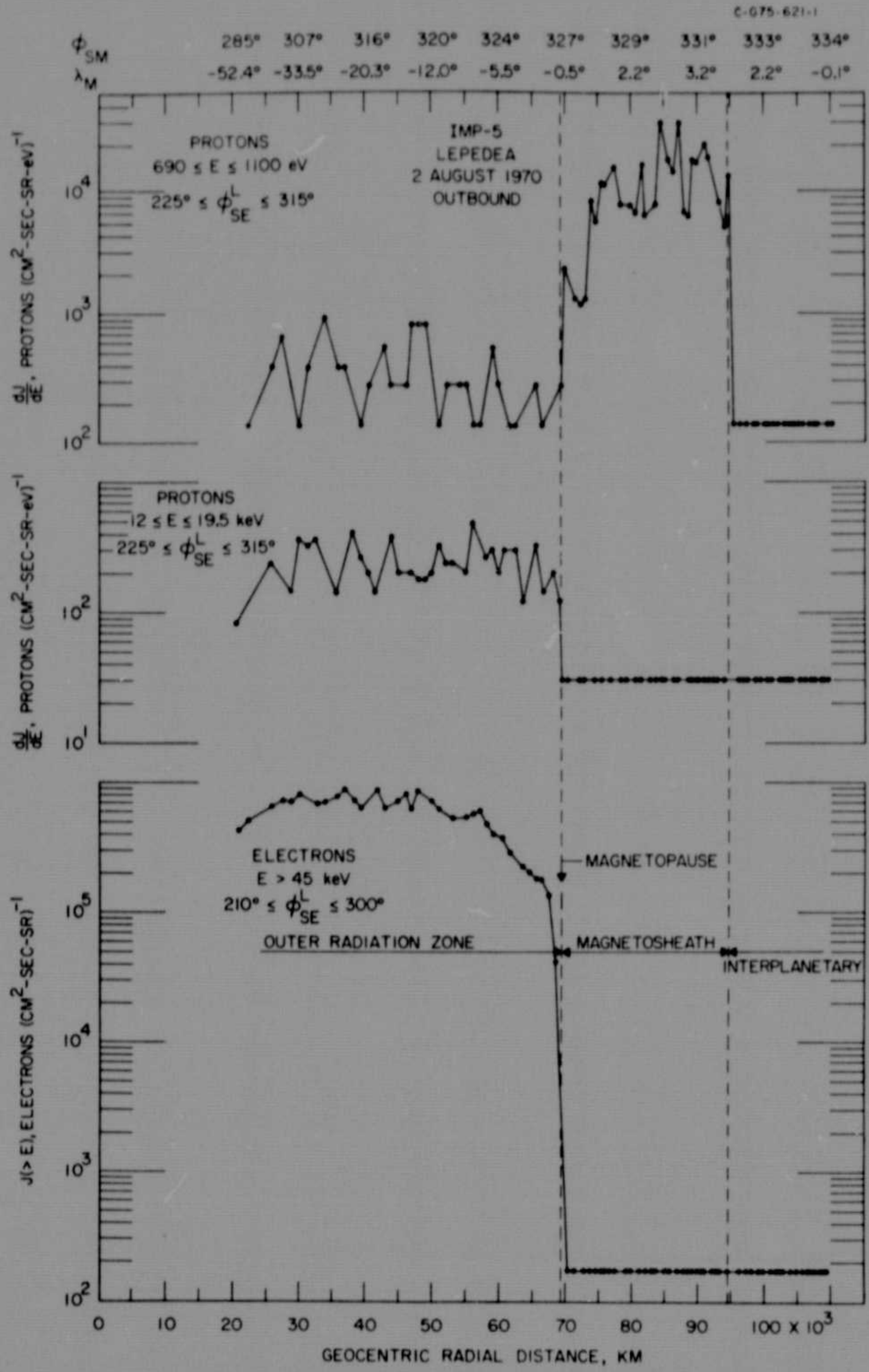
C-075-621-1
ϕ_{SM} 285° 307° 316° 320° 324° 327° 329° 331° 333° 334°
λ_M -52.4° -33.5° -20.3° -12.0° -5.5° -0.5° 2.2° 3.2° 2.2° -0.1°
PROTONS
690 ≤ E ≤ 1100 eV
225° ≤ ϕ^L_{SE} ≤ 315°
IMP-5
LEPEDEA
2 AUGUST 1970
OUTBOUND
dJ/dE, PROTONS (CM²-SEC-SR-eV)⁻¹
PROTONS
12 ≤ E ≤ 19.5 keV
225° ≤ ϕ^L_{SE} ≤ 315°
dJ/dE, PROTONS (CM²-SEC-SR-eV)⁻¹
ELECTRONS
E > 45 keV
210° ≤ ϕ^L_{SE} ≤ 300°
MAGNETOPAUSE
OUTER RADIATION ZONE
MAGNETOSHEATH
INTERPLANETARY
J(> E), ELECTRONS (CM²-SEC-SR)⁻¹
0 10 20 30 40 50 60 70 80 90 100 X 10³
GEOCENTRIC RADIAL DISTANCE, KM

Figure 2.

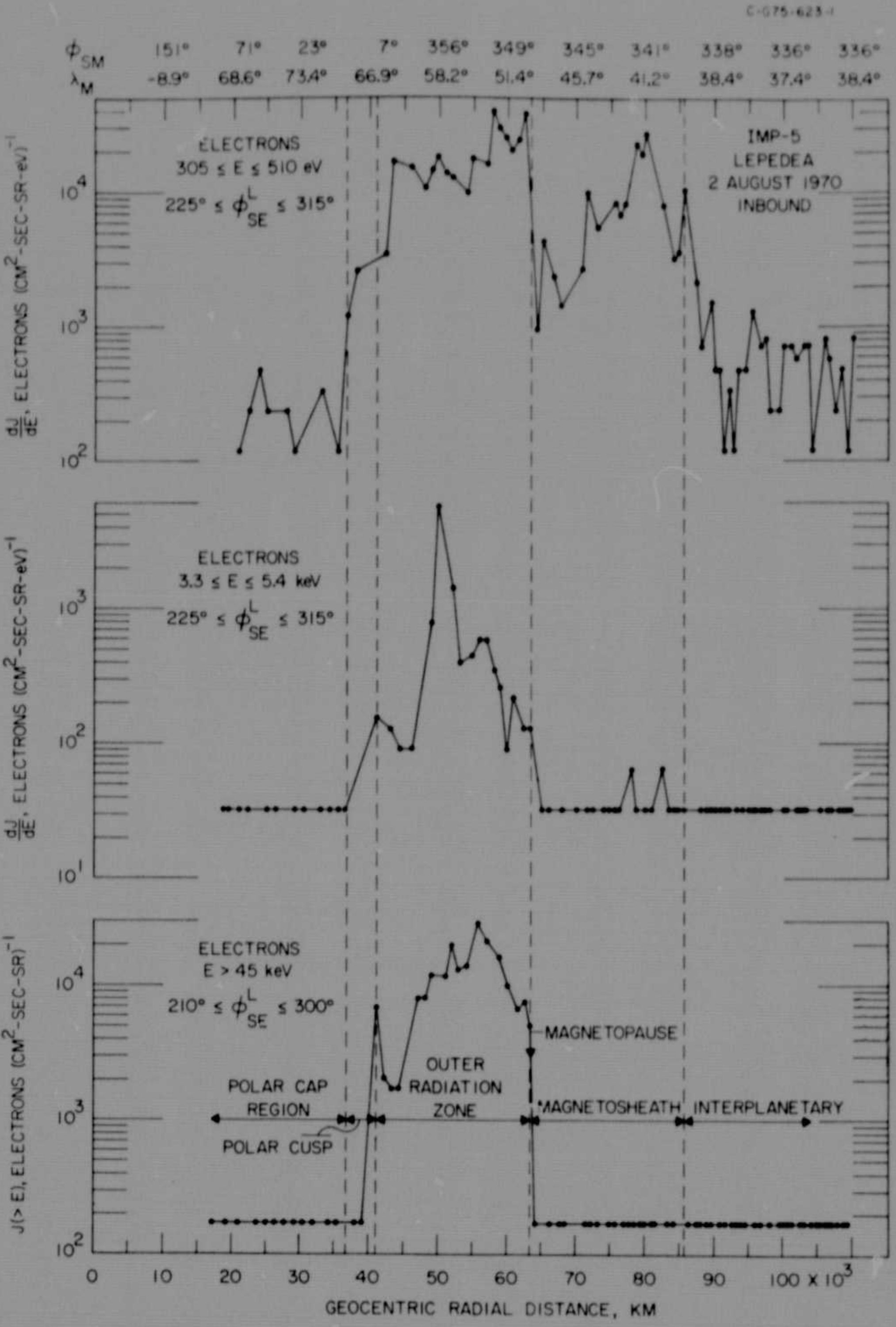
C-G75-623-1
φSM 151° 71° 23° 7° 356° 349° 345° 341° 338° 336° 336°
λM -8.9° 68.6° 73.4° 66.9° 58.2° 51.4° 45.7° 41.2° 38.4° 37.4° 38.4°
ELECTRONS
305 ≤ E ≤ 510 eV
225° ≤ φ^L_SE ≤ 315°
IMP-5
LEPEDEA
2 AUGUST 1970
INBOUND
dJ/dE, ELECTRONS (CM²-SEC-SR-eV)⁻¹
ELECTRONS
3.3 ≤ E ≤ 5.4 keV
225° ≤ φ^L_SE ≤ 315°
dJ/dE, ELECTRONS (CM²-SEC-SR-eV)⁻¹
ELECTRONS
E > 45 keV
210° ≤ φ^L_SE ≤ 300°
J(> E), ELECTRONS (CM²-SEC-SR)⁻¹
MAGNETOPAUSE
OUTER
RADIATION
ZONE
POLAR CAP
REGION
POLAR CUSP
MAGNETOSHEATH
INTERPLANETARY
0 10 20 30 40 50 60 70 80 90 100 X 10³
GEOCENTRIC RADIAL DISTANCE, KM

Figure 3.

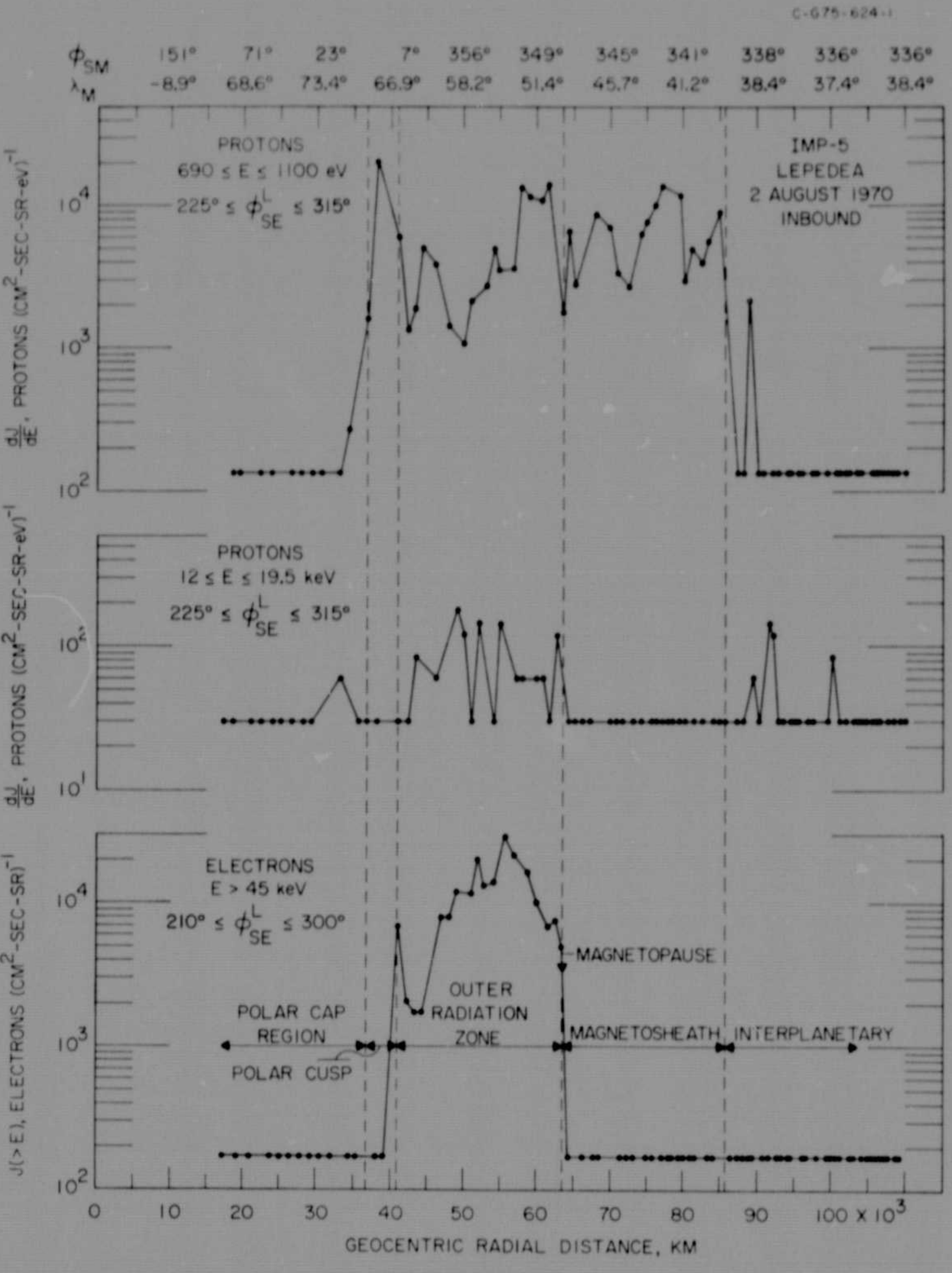
C-G75-624-1
ϕSM 151° 71° 23° 7° 356° 349° 345° 341° 338° 336° 336°
λM -8.9° 68.6° 73.4° 66.9° 58.2° 51.4° 45.7° 41.2° 38.4° 37.4° 38.4°
PROTONS
690 ≤ E ≤ 1100 eV
225° ≤ ϕ^L_SE ≤ 315°
IMP-5
LEPEDEA
2 AUGUST 1970
INBOUND
dJ/dE, PROTONS (CM²-SEC-SR-eV)⁻¹
PROTONS
12 ≤ E ≤ 19.5 keV
225° ≤ ϕ^L_SE ≤ 315°
dJ/dE, PROTONS (CM²-SEC-SR-eV)⁻¹
ELECTRONS
E > 45 keV
210° ≤ ϕ^L_SE ≤ 300°
J(>E), ELECTRONS (CM²-SEC-SR)⁻¹
MAGNETOPAUSE
POLAR CAP
REGION
POLAR CUSP
OUTER
RADIATION
ZONE
MAGNETOSHEATH
INTERPLANETARY
GEOCENTRIC RADIAL DISTANCE, KM
100 X 10³

Figure 4.

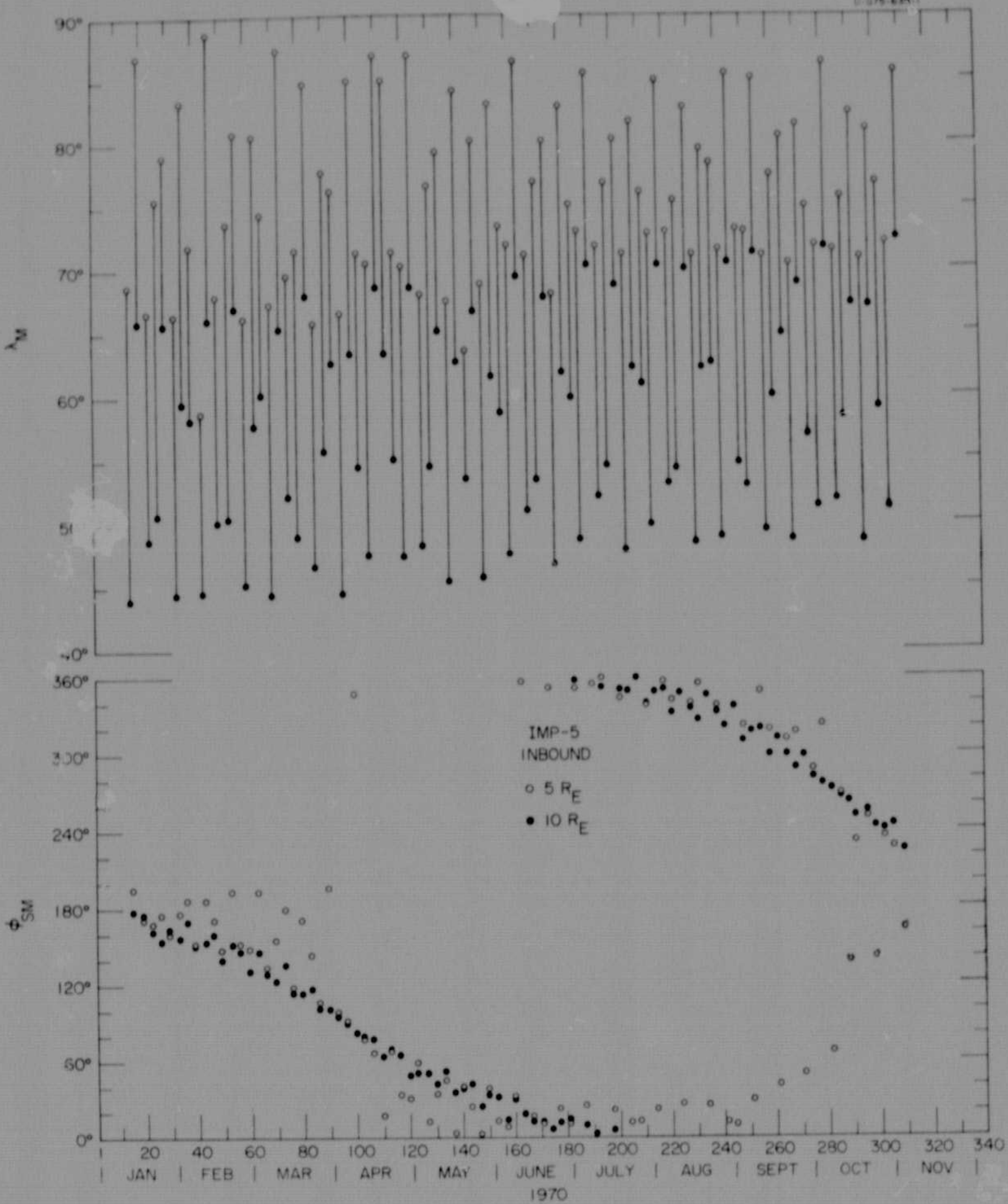
90°
80°
70°
60°
50°
40°
λ_M
360°
300°
240°
180°
120°
60°
0°
ϕ_{SM}
IMP-5
INBOUND
○ 5 R_E
● 10 R_E
1
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
1970

Figure 5.

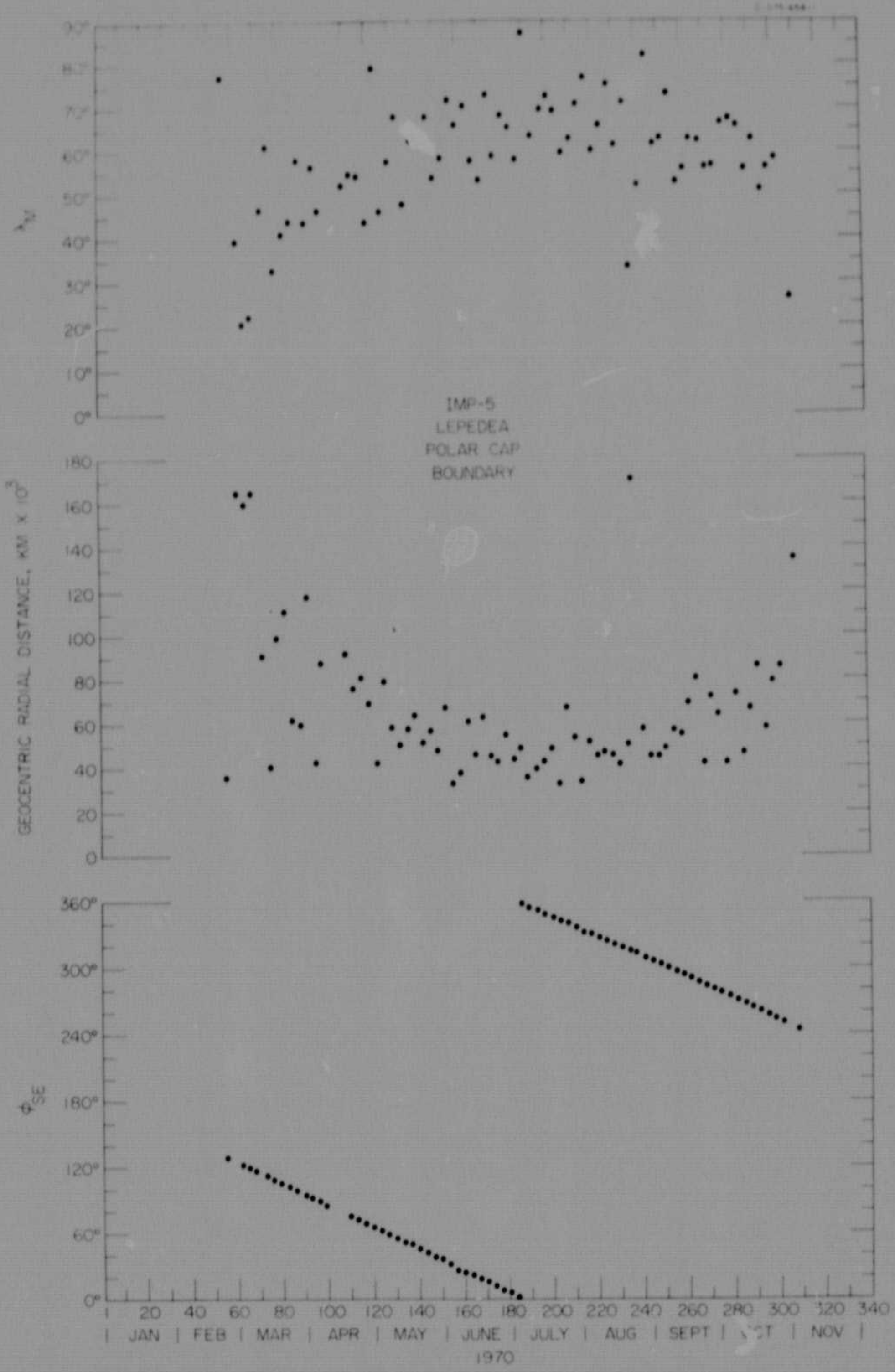
IMP-5
LEPEDEA
POLAR CAP
BOUNDARY
λ_N
GEOCENTRIC RADIAL DISTANCE, KM x 10³
Φ_{SE}
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
NOV
1970

Figure 6.

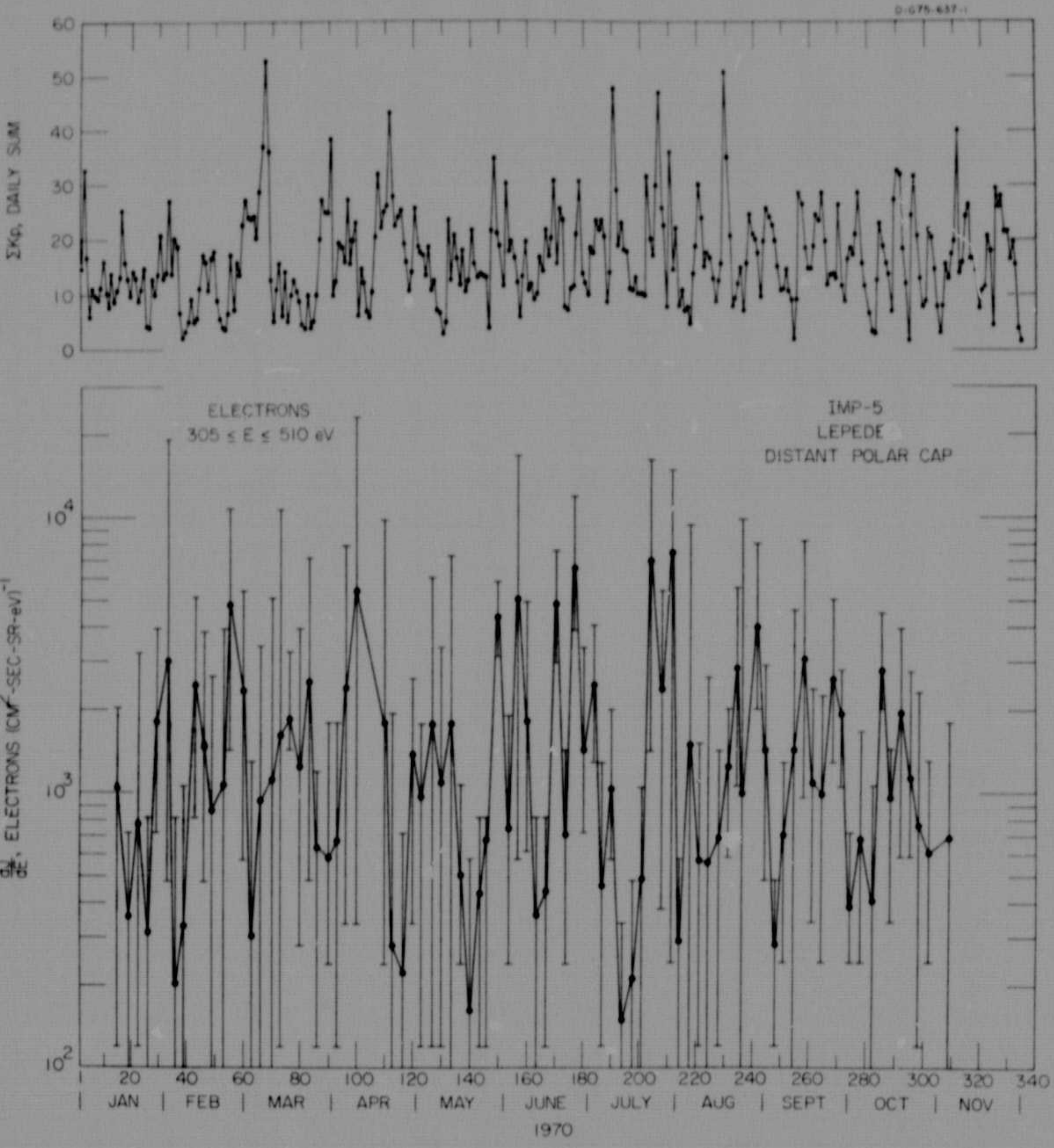
D-675-637-1
ΣKp, DAILY SUM
ELECTRONS
305 ≤ E ≤ 510 eV
IMP-5
LEPEDE
DISTANT POLAR CAP
dJ/dE, ELECTRONS (CM²-SEC-SR-eV)⁻¹
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
1970

Figure 7.

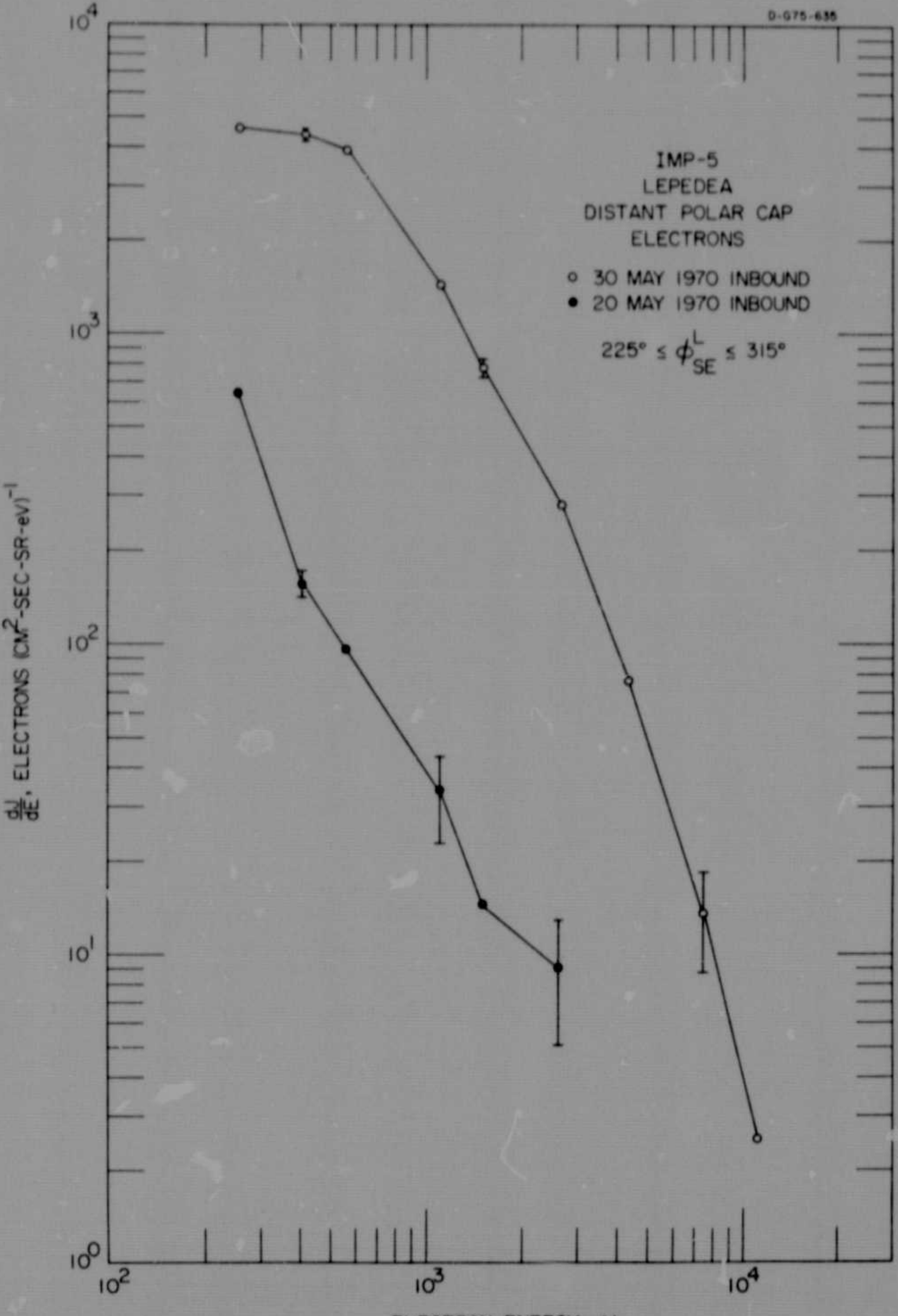
D-G75-635
IMP-5
LEPEDEA
DISTANT POLAR CAP
ELECTRONS
○ 30 MAY 1970 INBOUND
● 20 MAY 1970 INBOUND
225° ≤ ϕ_{SE}^{L} ≤ 315°
$\frac{dJ}{dE}$, ELECTRONS (CM^2-SEC-SR-eV)$^{-1}$
ELECTRON ENERGY, eV
10^0
10^1
10^2
10^3
10^4

Figure 8.

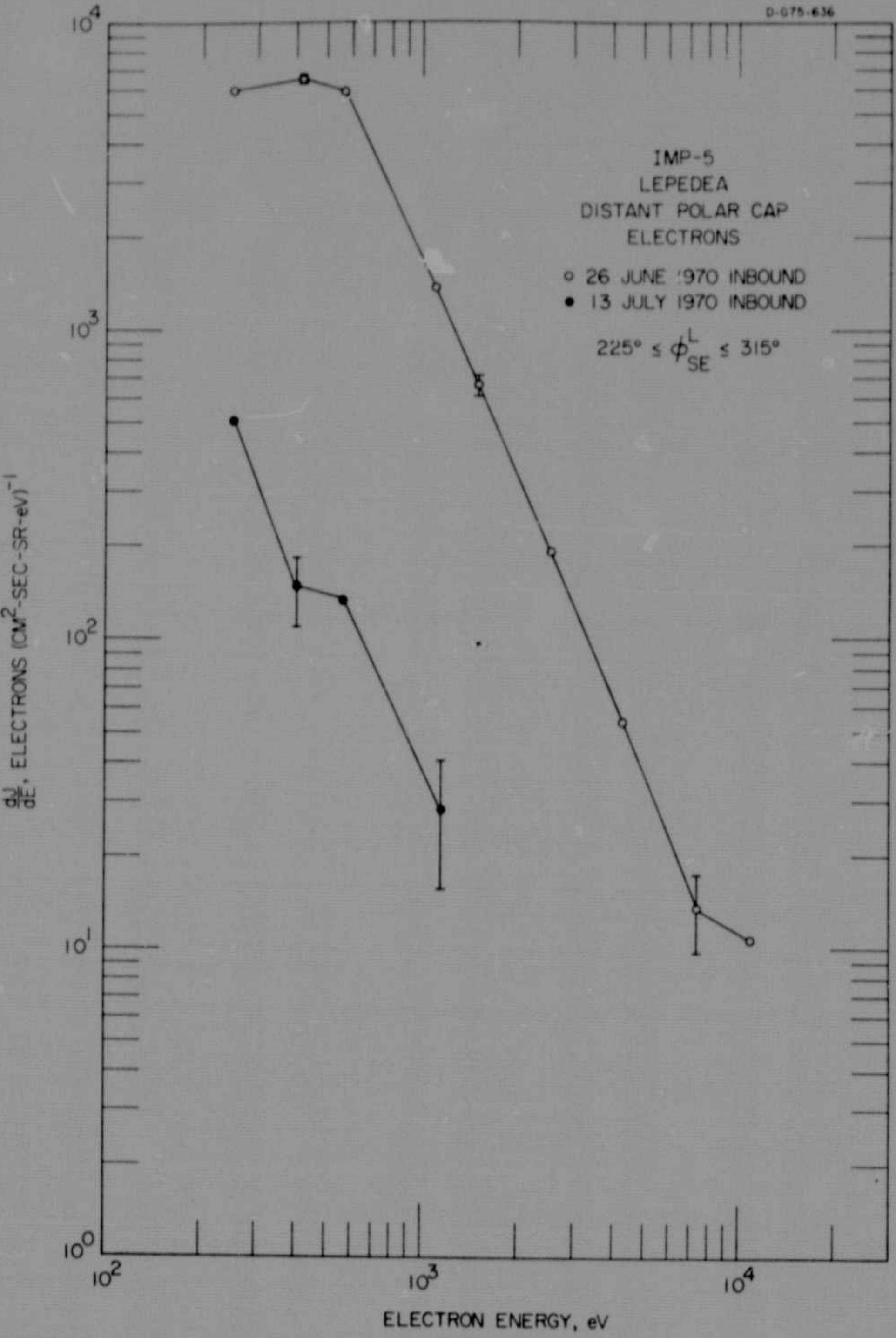
D-075-636
IMP-5
LEPEDEA
DISTANT POLAR CAP
ELECTRONS
○ 26 JUNE 1970 INBOUND
● 13 JULY 1970 INBOUND
225° ≤ ϕ_{SE}^{L} ≤ 315°
$\frac{dJ}{dE}$, ELECTRONS (CM^2-SEC-SR-eV)$^{-1}$
ELECTRON ENERGY, eV
10^0
10^1
10^2
10^3
10^4

Figure 9.

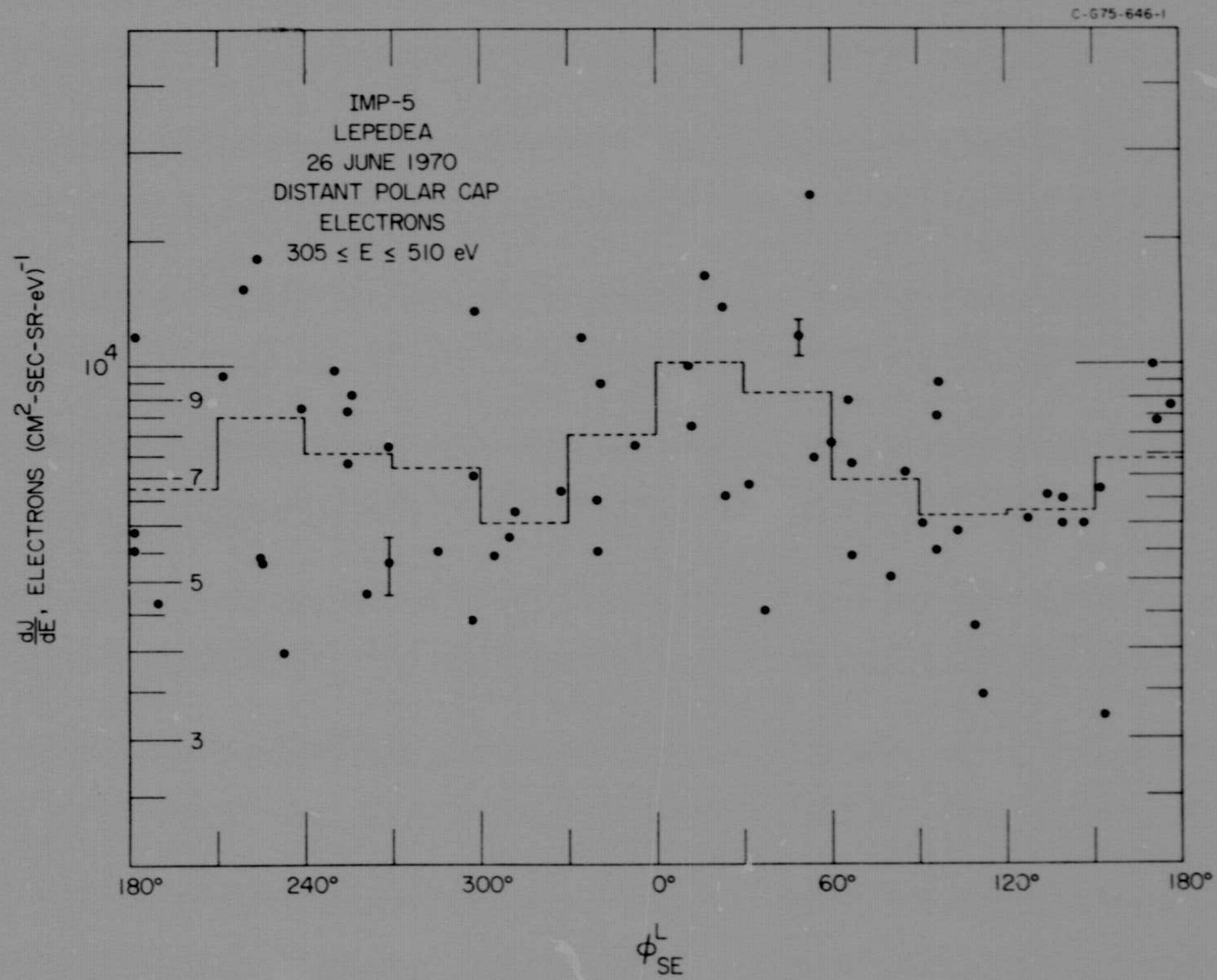
C-G75-646-1
IMP-5
LEPEDEA
26 JUNE 1970
DISTANT POLAR CAP
ELECTRONS
305 ≤ E ≤ 510 eV
dJ/dE, ELECTRONS (CM2-SEC-SR-eV)-1
10^4
9
7
5
3
180°
240°
300°
0°
60°
120°
180°
φ^L_SE

Figure 10.

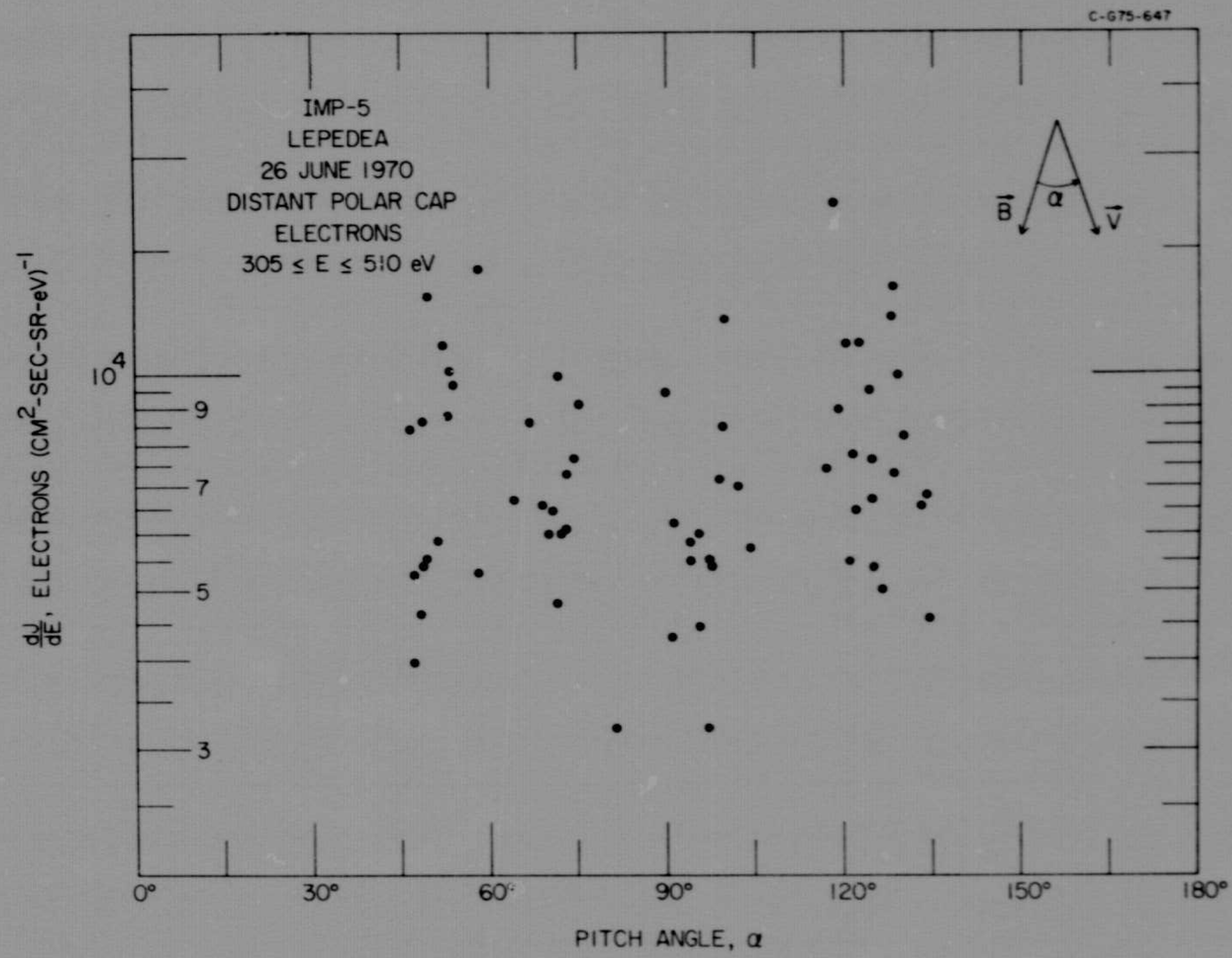
C-G75-647
IMP-5
LEPEDEA
26 JUNE 1970
DISTANT POLAR CAP
ELECTRONS
305 ≤ E ≤ 510 eV
B
α
V
$\frac{dJ}{dE}$, ELECTRONS (CM^2-SEC-SR-eV)$^{-1}$
10^4
9
7
5
3
0°
30°
60°
90°
120°
150°
180°
PITCH ANGLE, α

Figure 11.

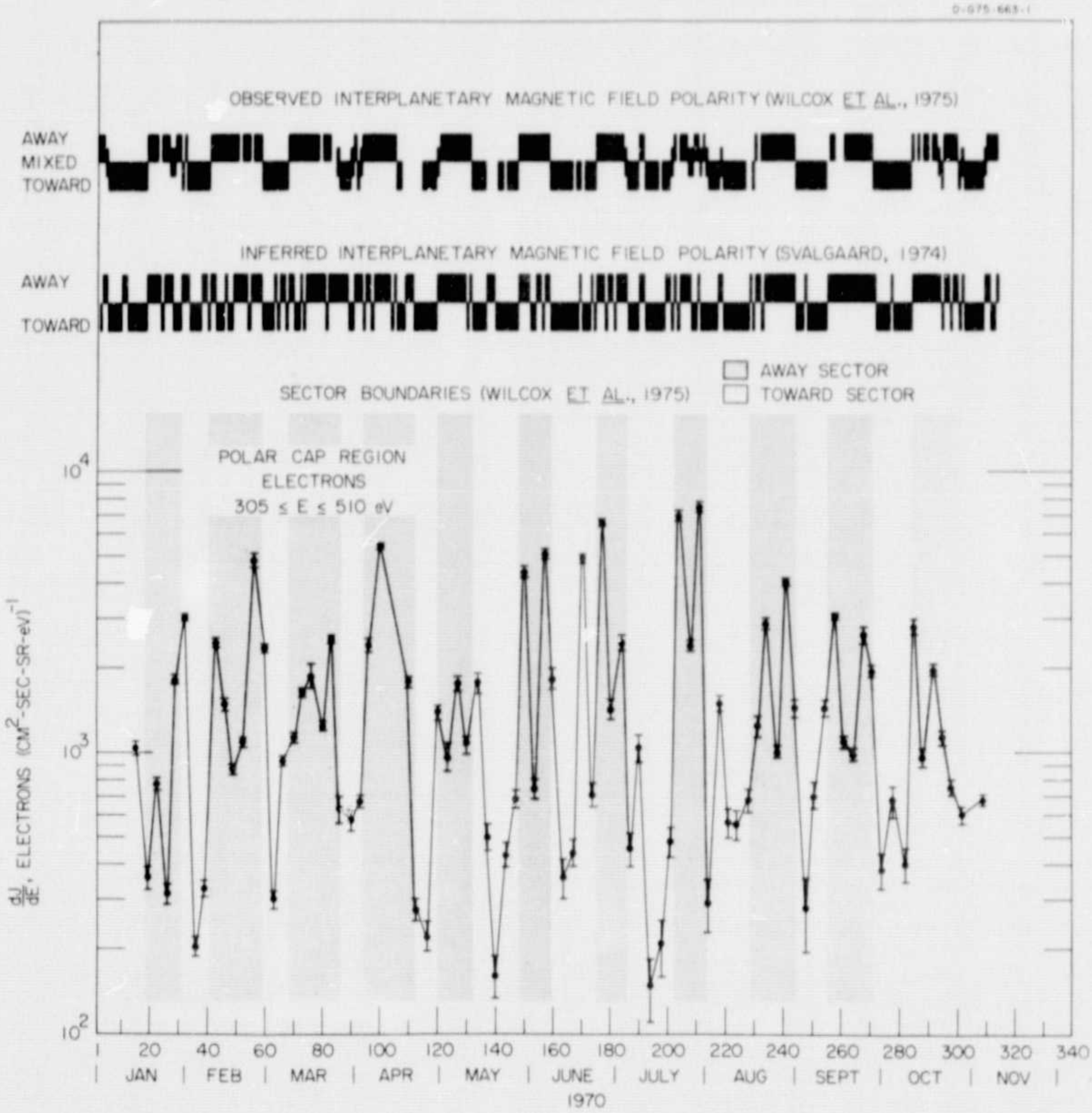
D-075-663-1
OBSERVED INTERPLANETARY MAGNETIC FIELD POLARITY (WILCOX ET AL., 1975)
AWAY
MIXED
TOWARD
INFERRED INTERPLANETARY MAGNETIC FIELD POLARITY (SVALGAARD, 1974)
AWAY
TOWARD
AWAY SECTOR
TOWARD SECTOR
SECTOR BOUNDARIES (WILCOX ET AL., 1975)
POLAR CAP REGION
ELECTRONS
305 ≤ E ≤ 510 eV
dJ/dE, ELECTRONS (CM^2-SEC-SR-eV)^-1
10^4
10^3
10^2
1 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV
1970

Figure 12.