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PRIMARY ELECTRON INFLUX TO THE DAYSIDE AURORAL OVAL

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AURORAL OVAL

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ABSTRACT

Data from the OGO-4 Auroral Particles Experiment have been analyzed to determine properties of the higher latitude region of electron precipitation in the dayside hemisphere. From seven months of data a probability map of occurrence of this structured, low energy precipitation was compiled. The highest probabilities are concentrated predominantly between 4 and 14 hours magnetic local time, and from 75° to $82\frac{1}{2}^{\circ}$ invariant latitude. It is shown that there is excellent congruity of these high probabilities of occurrence and the high probability of occurrence of discrete auroral optical emissions, which define the auroral oval in these hours. The soft energy spectrums measured and the estimated total energy influx during a particular precipitation event are appropriate for producing the type of aurora observed in these hours. It is concluded that the structured, low energy electron precipitation is the primary energy source for the dayside auroral oval.

INTRODUCTION

Satellite measurements of precipitating low energy electrons during the late morning and early afternoon hours of magnetic local time have indicated the existence of two fairly distinct precipitation regions. The first region, at lower invariant latitudes, is characterized by relatively hard, isotropic radiation, displaying little structure in its latitude profile. It has been labeled the "hard day zone" by Sharp and Johnson (1968), the "auroral zone" by Burch (1968), and the "band region" by Hoffman (1969). In the second, higher latitude region, the radiation normally exhibits a very soft electron spectrum and produces a highly structured counting rate profile from a low energy electron detector traversing the region. This region has been designated the "soft day zone", the "soft zone", and the "burst region" by the aforementioned experimenters.

Data from the OGO-4 Auroral Particles Experiment have been analyzed to determine further properties of the higher latitude region of electron precipitation in the noon hemisphere. Special emphasis has been directed towards defining the boundaries of this region and associating this radiation with optical emissions in the dayside auroral oval.

THE EXPERIMENT

The OGO-4 satellite was launched on July 28, 1967 into a low altitude polar orbit having an apogee of 908 km and a perigee of 412 km, with an inclination of 86^{o}. Precession of the orbit due to this inclination together with the motion of the earth around the sun causes a change in local time of the orbital plane of about $1\frac{1}{2}^{o}$ per day. Thus the satellite passed through all local times every 120 days.

The Auroral Particles Experiment contained an array of eight detectors, each comprised of an electrostatic analyzer for species and energy selection and a Bendix channel electron multiplier as the particle detector (Hoffman and Evans, 1967). Four of the detectors, (the "0^o" detectors), always pointed radially away from the earth, and measured electrons in narrow energy bands about the energies 0.7, 2.3, 7.3, and 23.8 keV. Three other detectors were positioned 30^o, 60^o and 90^o from the earth-spacecraft vector and measured electrons at 2.3 keV; the eighth detector served as a background detector.

The data used for this paper were obtained over the northern high latitude region primarily by the 0.7 keV, 0^o detector, which in the high latitude region measured particles with pitch angles near 0^o. This detector had a bandpass of +19% and - 13% of the center energy, and a geometric factor of about 6×10^{-5} cm^2 - ster at the peak of the energy bandpass.

EXAMPLE DATA

We first show an example of the measurement of precipitating low energy electrons for a dusk to dawn pass during a magnetically quiet period early in the life of the satellite. The one-second average flux of 0.7 kev electrons is plotted in Figure 1, as well as the satellite orbit during the same time interval in a magnetic local time versus invariant latitude polar projection. To facilitate comparison of the two plots, universal time increases from right to left, corresponding to the direction of travel of the satellite along the plotted portion of this orbit.

High flux levels appeared immediately at turn-on at 0549:54 U.T. at a latitude of 77.5°, ended abruptly at 0551:04 U.T. at 81.7°, reappeared abruptly at 0553:39 U.T. at 83.8° and finally ended on the dawn side at about 0556:18 U.T. at 74.8°. This high latitude region of structured electron precipitation was initially observed in the quick look data received from the experiment during the early revolutions of the satellite in the dusk-to-dawn meridian, and was designated a "burst region" (Hoffman and Evans, 1968). The term "burst" was chosen only as a subjective description of the appearance of the data, not to necessarily imply temporal behavior.

During this pass, the electron fluxes were barely measureable between 81.5° on the dusk side and 83.7° on the dawn side. This low flux level portion of the pass corresponded to the traversal of the polar cap region by the satellite. The high latitude boundaries of the bursts were characterized by rather sharp flux changes, especially noticeable at the cutoff occurring at about 11 hours local time and 83.7° invariant latitude. In the morning hours the intensities of the bursts appeared noticeably higher than in the afternoon hour bursts.

It is also seen that the 0.7 keV flux in the morning hours remained at a relatively high level at least as far south as 70°, or 0557:30, although the structure in the counting rate was considerably less. At these lower latitudes, low energy electron precipitation has been shown to be associated with a region of precipitation distinct and separate from the higher latitude bursts considered here (Hoffman, 1970).

PROBABILITY OF OCCURRENCE

It is desirable to more precisely define the location of the bursts and determine their probability or frequency of occurrence in the high latitude region. For this study, all data from the 0^{o}, 0.7 keV detector collected from July 30, 1967 through February 26, 1968 were analyzed.

For all passes during which Kp was less than or equal to 2, the orbit was divided into elements of local time and invariant latitude, one hour by $2\frac{1}{2}^{o}$, except above 85^{o}, where the element size was increased to two hours by 5^{o}. An element was considered sampled if the path length of an orbit through the element was at least one-half the dimension of the element in the direction of travel. If bursts existed over at least half of this path length, then the element was considered to contain bursts. The criteria for bursts were rapid fluctuations in the counting rate from the 0.7 keV detector, with peak particle fluxes of at least 10^{8} electrons/ cm^{2}-sec-ster-kev.

An attempt was made to eliminate the precipitation in the midnight sector which was associated even with low level magnetic disturbances. Precipitation associated with magnetic activity is generally characterized by a fairly hard energy spectrum. Therefore, when the counting rate of the 0^{o}, 7.3 keV detector rose rapidly and in coincidence with increases in the 0.7 keV detector counting rate, it was assumed that the precipitation was associated with magnetic activity, and these data were simply not counted.

We then assembled the burst probability map shown in Figure 2. The probability or frequency of occurrence of bursts in each element, (F), was calculated from the cumulative data from more than three hundred passes during the first seven months of satellite operation. On the probability map we show a cutoff value of 5, indicating that an element was considered adequately sampled only if at least five passes were made through it. Figure 3 lists the total number of times each element was sampled during the data period used to prepare Figure 2.

The most striking feature of the burst probability map in Figure 2 is the concentration of high (i.e. ≥ 40%) probabilities between 5 and 14 hours, and from 75° to 82½° latitudes in these hours. Although there are non-zero burst probabilities at all local times, the overall probability tends to decrease and move to lower latitudes on the night side. Also, the moderate probabilities appearing near midnight still may be associated with magnetic activity. For this reason the burst probability map in Figure 2 is most meaningful during the daytime hours.

COMPARISON WITH OPTICAL MEASUREMENTS

Considering only the dayside region of the burst probabilities, we sought an association of these low energy precipitating electrons with optical aurora. Many investigators have used all-sky camera and photometric data to determine the frequency of occurrence of auroral forms at different local times. In order to make a meaningful comparison of the optical data with the burst probability results, we want to choose the optical study which employed procedures most analogous to those we used to compile the burst probability map. Thus, a suitable study must be synoptic in nature, occur during a similar epoch of the solar cycle, and should include data acquired only during magnetically quiet periods. Resolution in local time and invariant latitude should be comparable to the element size of the burst probability map. Finally, it would be desirable to use an optical study which discriminated between types of auroral forms.

Among the many optical auroral frequency studies available, four were found to satisfy many of the criteria we had thus established. Feldstein (1966) had used IGY data taken during low Kp times to produce auroral probability contours, based on occurrences of any type of auroral form in half hour intervals. Lassen (1969) used all-sky camera data taken in Greenland during the winters of 1964-65 and 1965-66 and produced an auroral frequency pattern based on auroral occurrences during quarter hour intervals, without discriminating between different auroral forms or magnetic activity index values. Sandford (1964) has distinguished two distinct types of auroral forms, the mantle aurora and discrete aurora in photometric studies of southern hemisphere auroral zone displays, and using a local magnetic activity index has produced probability contours based upon two hour data samples (Sandford, 1968). Stringer and Belon (1967) produced probability contours based on auroral occurrences in quarter hour intervals which provide reasonably complete noontime coverage, and distinguished between types of auroral forms and magnetic activity. Of these four ground based optical studies, the work of Stringer and Belon was the one which best conformed to the established criteria, and is thus the most suitable for comparison with our satellite auroral particle observations.

Using data acquired by an all-sky camera network based in Alaska during the winter of 1964-65, Stringer and Belon (1967) produced contour maps showing the probabilities of observing discrete and homogeneous auroral ns in 15 minute intervals during magnetically quiet periods. They were able to complete the isoauroral probability contours during the noontime hours on the basis of the necessary continuity of each isoauroral contour and their detailed visual inspection of all-sky camera films. It is their isoauroral diagram for discrete auroral forms which we wish to compare with the burst probability map, because discrete aurora are the dominant auroral form in the quiet time dayside hemisphere, and have been used by Feldstein (1966), Feldstein et al (1967), Lassen (1969) and Stringer and Belon (1967) to define the auroral oval in this hemisphere.

In Figure 4, we have shaded the region between 4 and 18 hours local time where the 0.7 keV electron burst probability (from Figure 2) is greater than at least 50%. The cross-hatched area in these same hours denotes the region of greater than 15% probability of discrete auroral optical emissions presented by Stringer and Belon (1967). The superposition of these two regions during these dayside hours is quite striking. Furthermore, both regions are considerably broader in latitude during the pre-noon hours than the afternoon hours.

ELECTRON SPECTRUMS AND INFLUX

Average four point electron energy spectrums have been compiled for the data acquired in the burst region during Revolution 142 shown in Figure 1. In Figure 5 we plot these average energy spectrums for the data occurring when the satellite was passing first through the afternoon portion of the burst region, then during the morning portion, and finally during the morning portion with a relatively hard burst of about 14 seconds duration (beginning at 0554:02 U.T. in Figure 1) subtracted out. These average spectrums are based upon the average of all fluxes encountered by the individual detectors while traversing the specified regions.

It is apparent from these data that electron fluxes over the energy range measured were more intense in the morning hours than those in the afternoon hours. Judging from the steepness of the spectrums, it is reasonable to assume that the experiment was measuring the high energy tail of the total electron influx.

Three comparisons of the morning and afternoon traversal of the burst region were performed. First, the integral electron flux between 0.7 and 24 keV was calculated from each spectrum in Figure 5 defined by the lines connecting the data points for these measurements of near 0^{o} pitch angle electrons. Second, the average energy of the electrons over this energy range was determined in a similar fashion. Third, the total energy influx lost in the atmosphere was computed. For this last calculation, three assumptions were required: isotropy of the pitch angle distribution over the upper hemisphere (which may not be a completely tenable assumption, because pitch angle distributions for some bursts have been observed to be anisotropic, with maximum intensity along the field lines (see Hoffman and Evans, 1968)); all electrons mirroring below 100 km altitude were lost; and the spectrums were independent of pitch angle. In all three calculations we assumed that the energy spectrums contained no fine structure.

The results of these calculations appear in Table 1. These quantities integrated over the measured spectrums show that not only was there a greater particle and energy influx during the morning hours than the

TABLE 1

Region	Total Flux	Energy Influx	Average Energy
Morning	1.01×10^8	0.80	1.32
Morning Minus Hard Burst	7.61×10^7	0.58	1.28
Afternoon	3.57×10^7	0.18	0.86

Units: Total flux: electrons/cm^2-sec-ster from 0.7 to 24 keV

Energy influx: ergs/cm^2-sec

Average energy: keV

afternoon hours, but also that the morning influx was somewhat harder. While these calculations have been performed for only one pass, our experience looking at a large volume of data leads us to believe that the conclusions are applicable in general in a qualitative sense.

Examination of the energy spectrums of several intense individual morning hour bursts explains the differences observed between the average morning and average morning minus hard burst electron spectrums shown in Figure 5. Spectrums for three individual bursts are shown in Figure 6, where spectrums labeled 1 and 2 are considered typical spectrums during fairly intense bursts. Comparing them with spectrum 2 in Figure 5 reveals that these individual burst fluxes are generally an order of magnitude greater than the average fluxes in the morning hours, except at 2.3 keV, where they are only a factor of 2½ or 3 more intense.

On the other hand, the spectrum labeled 3 in Figure 6, for the burst occurring at 0554:04 U.T. during Revolution 142, has a different shape. The flux at 2.3 keV was abnormally high, but whether the spectrum contained a "knee" at about this energy, or a near monoenergetic spike at this energy superimposed on a background spectrum, cannot be determined from this experiment. The observation of a similar, even harder, burst of electrons was previously noted (Hoffman, 1969). In that case, a burst of 7.3 keV electrons was observed at 11.6 hours magnetic local time and 84^{o} invariant latitude and contained some 30 ergs/cm^2-sec of energy flux in the energy bandpass of the 7.3 keV detector, assuming reasonable isotropy over the upper hemisphere. The elimination of this hard burst in Revolution 142 as well as a few smaller hard bursts occurring within several seconds of it from the average morning burst spectrum resulted in the average morning minus hard burst spectrum (labelled 3) in Figure 5.

It has been shown by Rees (1970) that these typical, very intense morning hour electron bursts have sufficient energy influx to produce forms visible on all-sky camera photographs (Davis et al, 1960). Using the energy spectrum for the burst during Revolution 1108 shc on Figure 6, Rees calculated the integrated column emission rates for 3914 Å and 5577 Å lines and obtained 3.5 and 4 Kilorayleighs, respectively.

The energy influx for these intense one-second averaged bursts has been calculated from their four-point electron energy spectrums. For both the morning hour burst during Revolution 1108 as well as for the burst occurring at 0555:13 U.T. during Revolution 142, the energy precipitated into the atmosphere was estimated to be 4 ergs/cm^2-sec. A similar calculation for the hard burst at 0554:04 U.T. during Revolution 142 gave an energy influx as 9.5 ergs/cm^2-sec. Since these calculations were based on fairly typical bursts, we conclude that, in general, intense bursts occurring in these morning hours and between about 77^o and 83^o latitude will produce visible, discrete aurora.

CONCLUSION

The analysis of the OGO-4 Auroral Particles Experiment data has yielded the following relationships and conclusion:

The high latitude region of nominally soft and structured electron precipitation has the highest probability of occurrence between 5 and 14 hours magnetic local time and 75^o to 82½^o invariant latitude. In the daytime hemisphere this region of high probability of occurrence is nearly congruent to the region of high probability of occurrence of discrete auroral emissions as recorded on all-sky camera photographs.

The energy influx in the more intense electron bursts is sufficient to produce discrete aurora visible in all-sky camera photographs. It is this type of aurora which defines the auroral oval in the dayside hemisphere. Therefore, we conclude that the structured electron precipitation which defines the burst region or soft day zone is the primary energy source for the auroral emissions in the dayside auroral oval.

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FIGURE CAPTIONS

Figure 1. One second average flux of 0.7 keV electrons for a dusk-to-dawn pass early in the life of the satellite during a magnetically quiet period. The satellite orbit during the same time interval is also shown in a magnetic local time versus invariant latitude polar projection.

Figure 2. A map of the probability of occurrence of bursts (F) for magnetic activity with $K_p \leq 2$. See text for the criteria used in defining bursts and for including data in the probability map.

Figure 3. The total number of times each element was sampled during the data period used to prepare Figure 2.

Figure 4. A polar plot of the high probability of the burst region during the dayside hours in comparison with the region of high probability of discrete auroras (Stringer and Belon, 1967) during the same hours.

Figure 5. The average energy spectrums for the afternoon and morning burst regions of Figure 1. Spectrum 3 is for the morning hour burst region with 14 seconds of relatively hard bursts subtracted out.

Figure 6. Three energy spectrums of individual bursts occurring in the morning burst region. Spectrum 1 is from Hoffman (1969), and occurred on October 11, 1967 at 09 hours MLT and 79° invariant latitude. Spectrums 2 and 3 are from Revolution 142 (Figure 1).

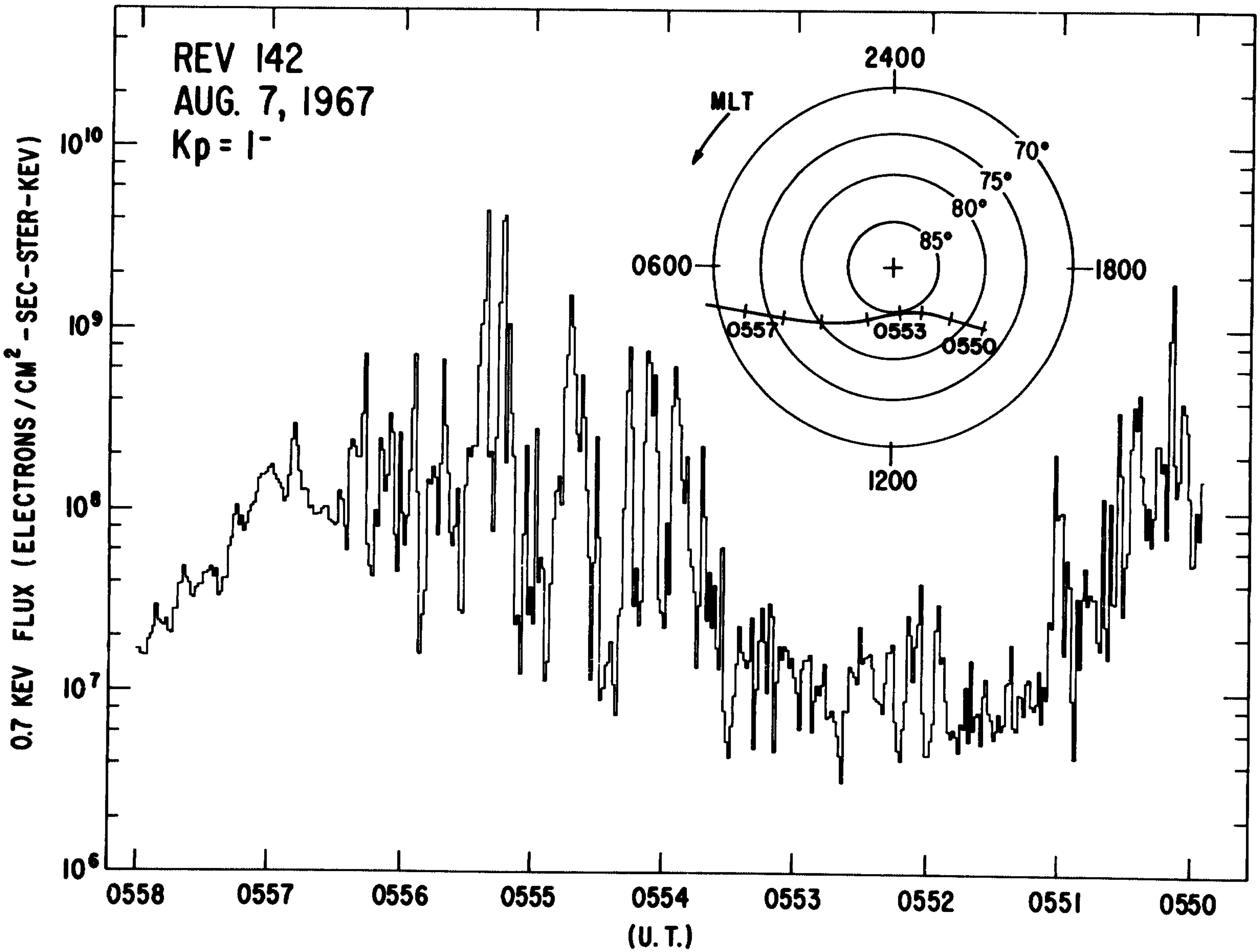
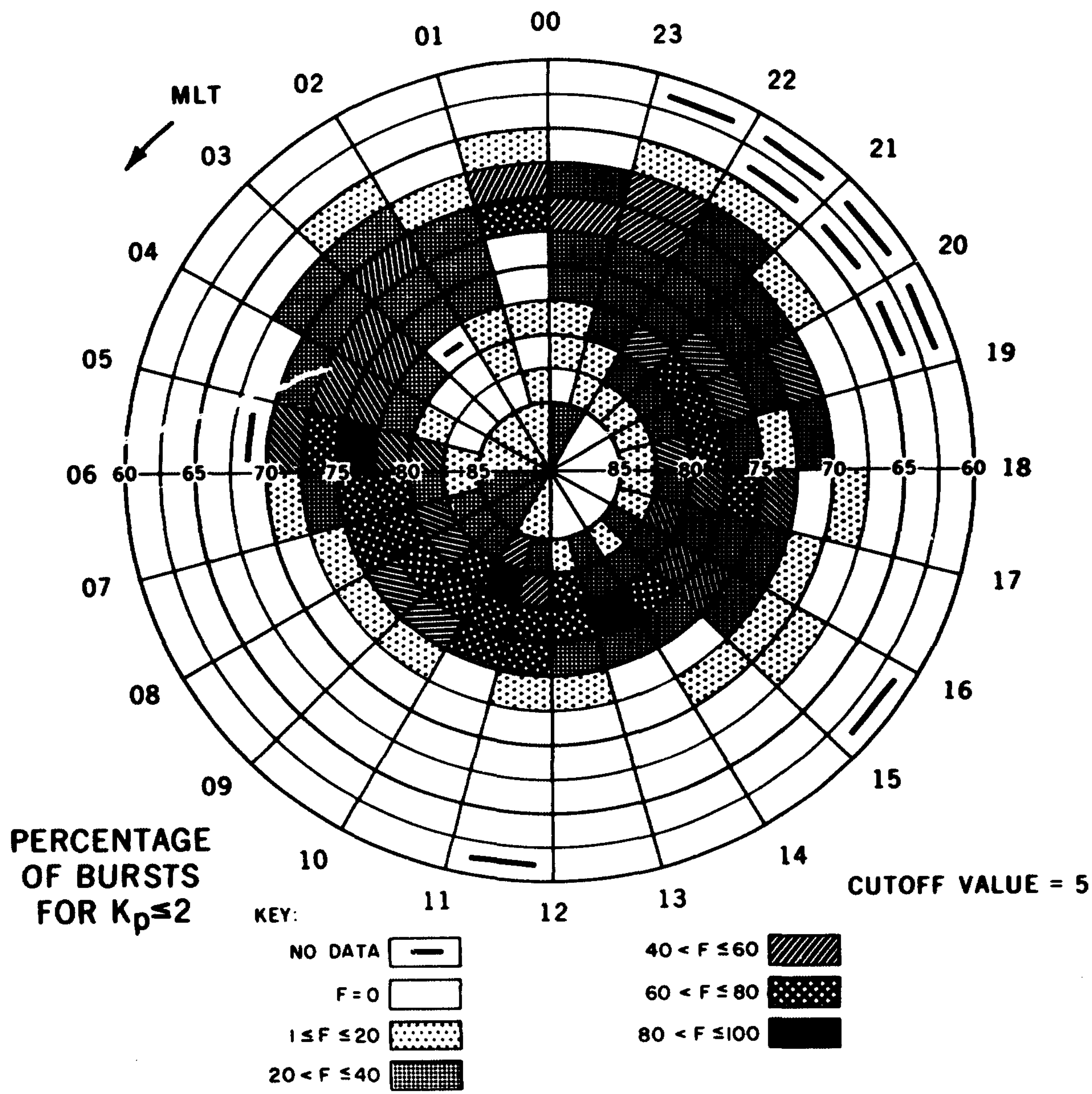
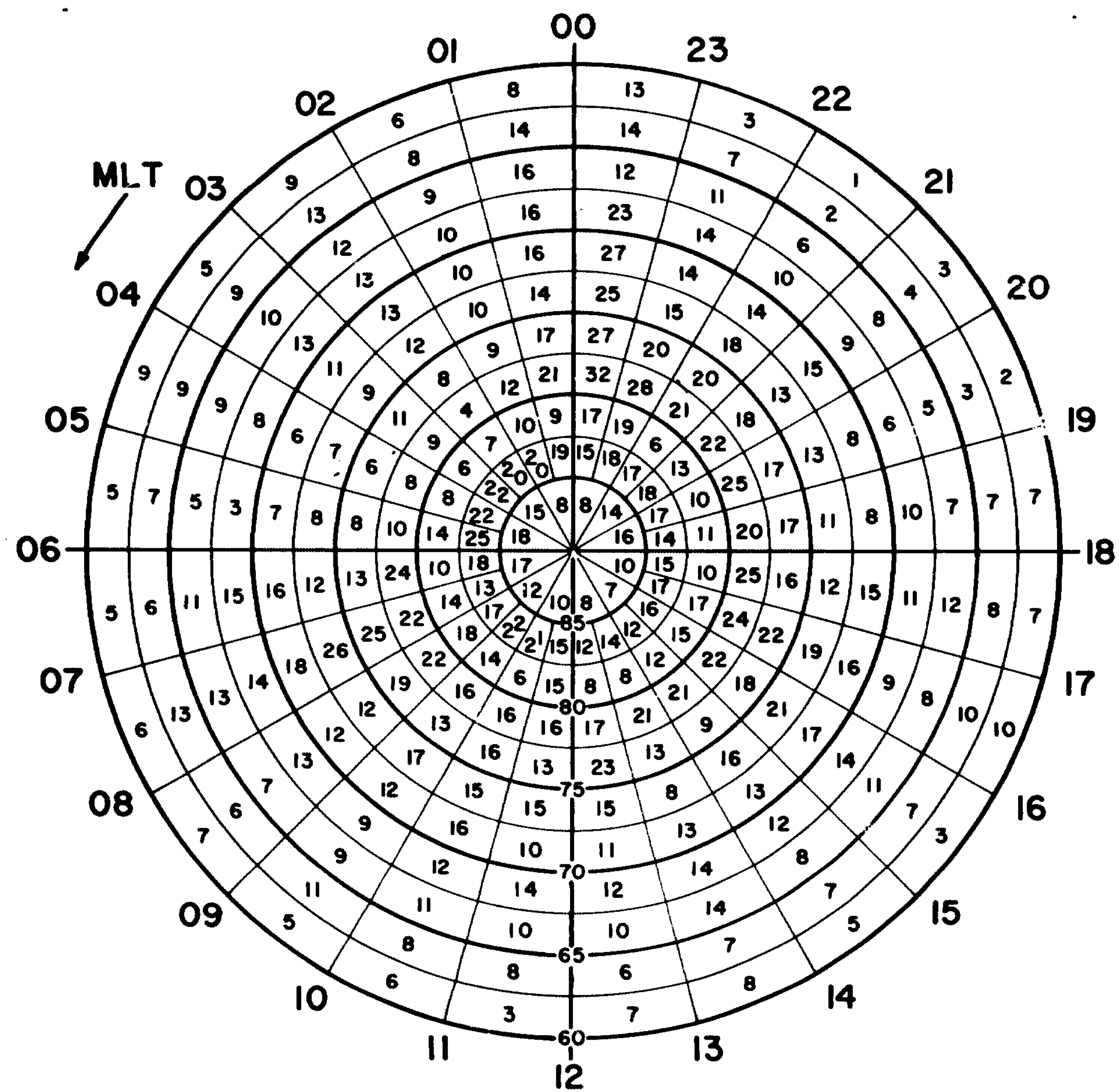

REV 142
AUG. 7, 1967
Kp = 1⁻
MLT
2400
0600
1800
1200
70°
75°
80°
85°
0557
0553
0550
0.7 KEV FLUX (ELECTRONS / CM² - SEC - STER - KEV)
10¹⁰
10⁹
10⁸
10⁷
10⁶
0558
0557
0556
0555
0554
0553
0552
0551
0550
(U. T.)

FIGURE 1



MLT
00
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
23
60
65
70
75
80
85
PERCENTAGE OF BURSTS FOR $K_p \le 2$
CUTOFF VALUE = 5
KEY:
NO DATA
F = 0
1 ≤ F ≤ 20
20 < F ≤ 40
40 < F ≤ 60
60 < F ≤ 80
80 < F ≤ 100

FIGURE 2



NUMBER OF SAMPLES IN EACH ELEMENT

FIGURE 3

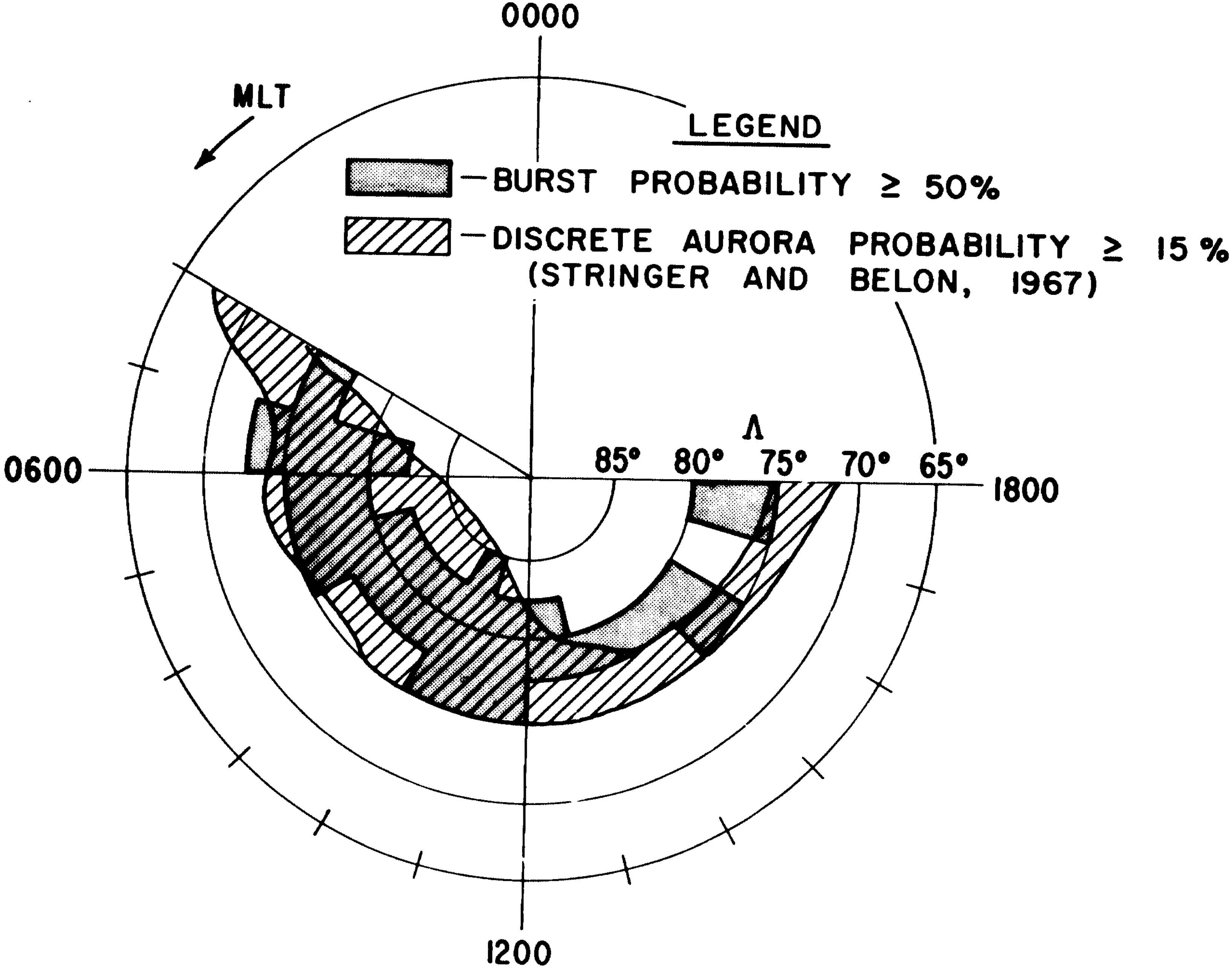

0000
MLT
LEGEND
BURST PROBABILITY ≥ 50%
DISCRETE AURORA PROBABILITY ≥ 15 %
(STRINGER AND BELON, 1967)
Λ
85°
80°
75°
70°
65°
0600
1800
1200

FIGURE 4

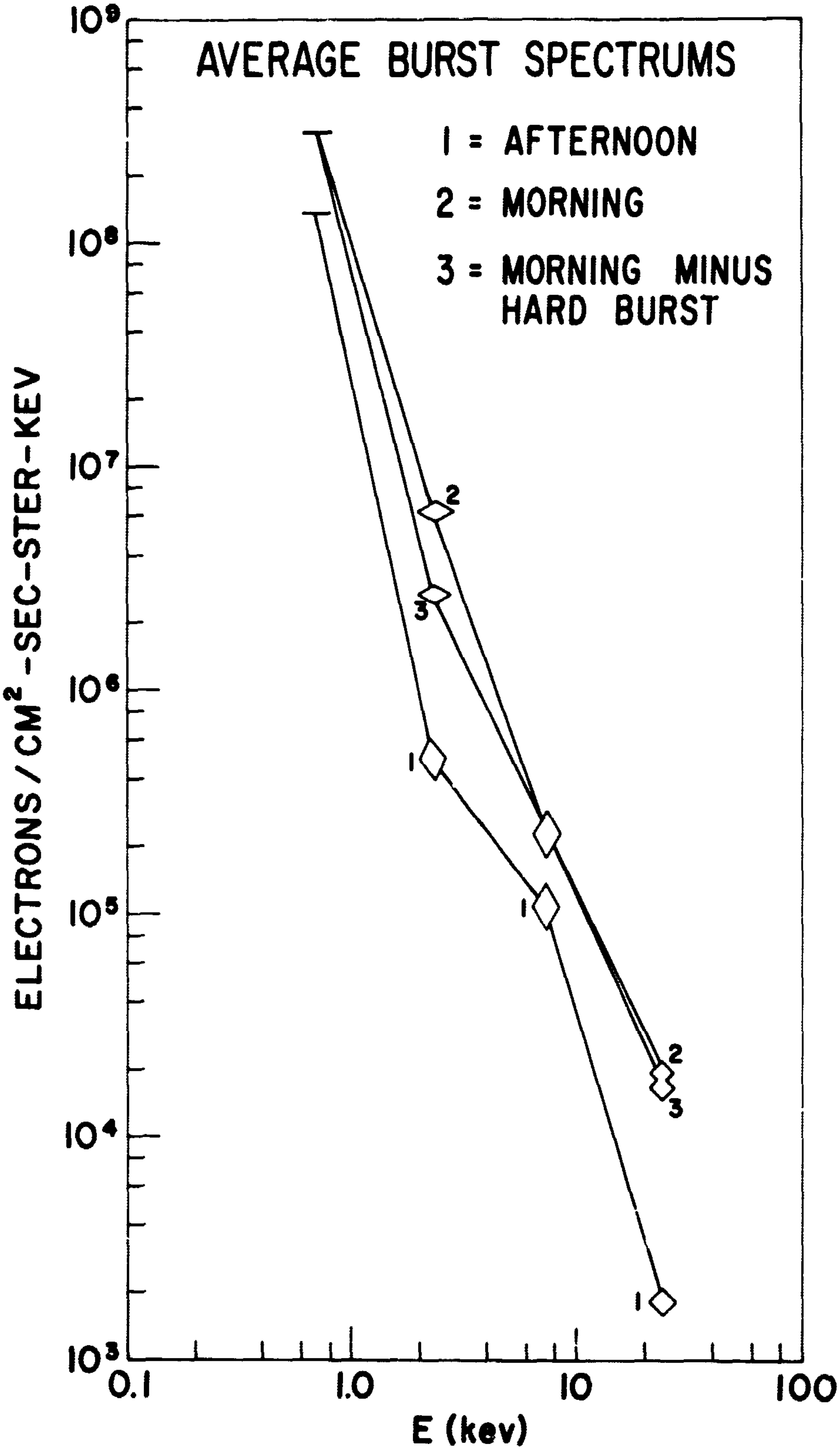

AVERAGE BURST SPECTRUMS
1 = AFTERNOON
2 = MORNING
3 = MORNING MINUS HARD BURST
ELECTRONS / CM² -SEC-STER-KEV
10⁹
10⁸
10⁷
10⁶
10⁵
10⁴
10³
0.1
1.0
10
100
E (kev)

FIGURE 5

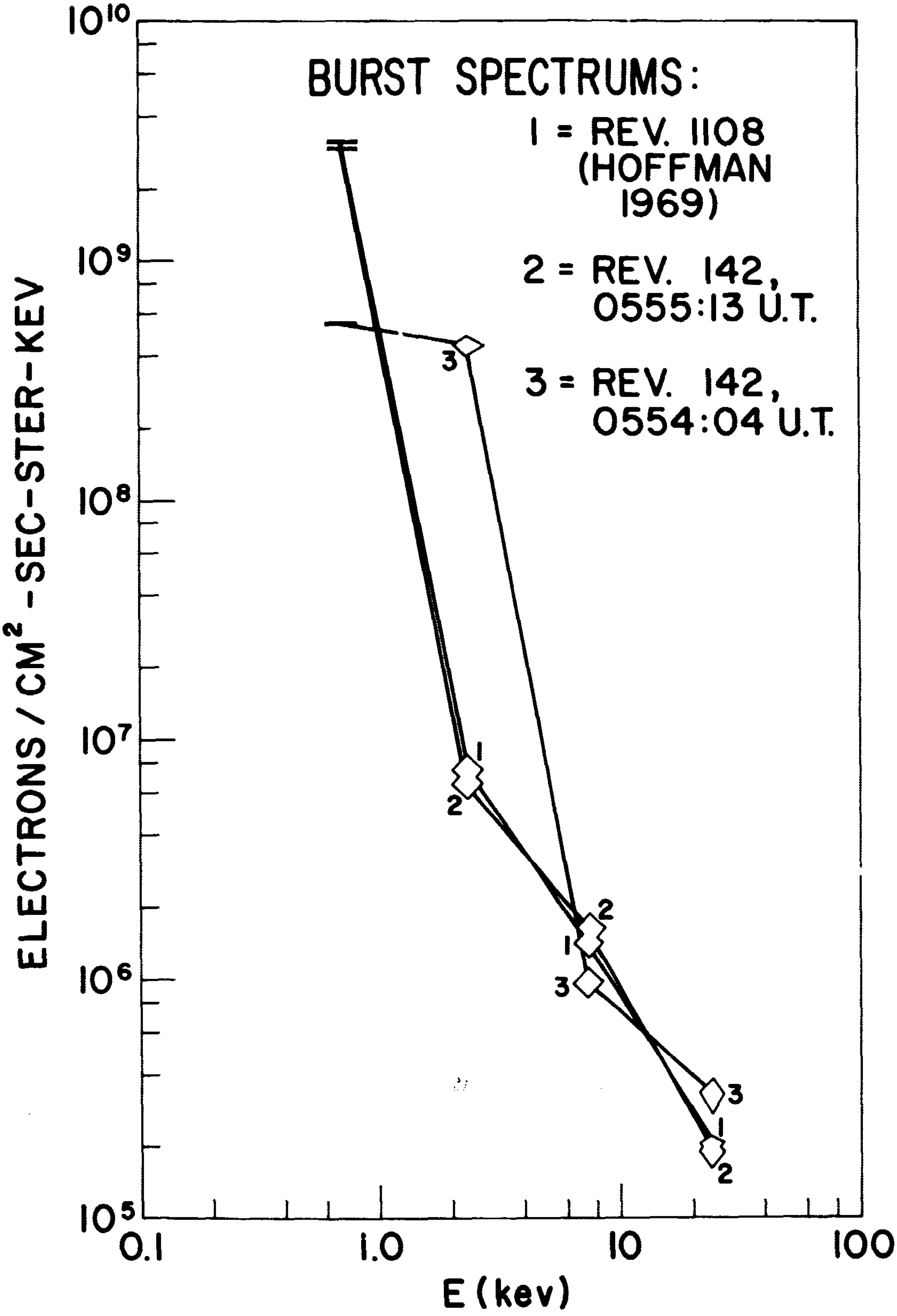

BURST SPECTRUMS:
1 = REV. 1108 (HOFFMAN 1969)
2 = REV. 142, 0555:13 U.T.
3 = REV. 142, 0554:04 U.T.
ELECTRONS / CM² -SEC-STER-KEV
10¹⁰
10⁹
10⁸
10⁷
10⁶
10⁵
0.1
1.0
10
100
E (kev)

FIGURE 6