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NGL-05-003-017

EVIDENCE THAT THE PLASMA SHEET IS THE SOURCE OF AURORAL ELECTRONS

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July 11, 1968

Revised, August 15, 1968

This letter describes high resolution energy measurements of electrons and protons precipitating into the auroral zone made on three sounding rockets. The results are compared to measurements made by satellites in the geomagnetic tail. Evidence is presented indicating that the plasma sheet is the source of energetic electrons during auroral breakup.

Three Nike-Tomahawk sounding rockets were launched from Fort Churchill, Canada during the months of February and March, 1968. Two of the rockets were launched into active auroral breakups; the other was launched into a 2 db riometer absorption event at local noon. Each rocket carried two sets of electrostatic analyzers. Each analyzer set consisted of three concentric hemispherical plates. A voltage was applied to the middle plate and varied between 0 and +1.9 KV every 1.4 second throughout each flight; the other two plates were at ground potential. Thus an electron of the proper energy entering between the middle plate and the outer plate would be deflected through 180^o into a funnel-mouthed continuous channel multiplier. The proper energy varied between 0 and 21 KeV depending on the voltage applied to the middle plate. The same applies to protons entering between the middle plate and the inner plate. Each analyzer was calibrated in the laboratory and each was found to have a nearly flat response to particles in the energy range 0.5 to 21 KeV. Thus with every sweep of the voltage on the middle plate a complete energy spectrum of electrons and protons between 0.5 and 21 KeV, with a resolution of 10% was obtained. One analyzer set was oriented to look at the spin axis of the rocket, the other looked out the side of the rocket 90^o to the spin axis. Since the rocket was launched nearly parallel to the earth's magnetic lines of force this corresponds to looking at particles with pitch angles of 0^o and 90^o respectively. A plastic phosphor scintillation counter was aboard each rocket to measure the flux of electrons with energy greater than 80 KeV.

Figure 1 shows a few seconds of raw data from the flight of 2 March 1968. The rocket was launched at 0119 local time (0719 UT) into an active auroral breakup. The top four traces are the output from the analyzers, the lower two are scintillation counter output. The sharp spikes on the analyzer output mark the reset of the plate voltage to zero. As the plate voltage increased with time after reset, the energy of the observable particles increased as shown on the figure. To convert count rate into particle flux, the following formula is used:

$$[\text{particle flux}(\text{cm}^2 \cdot \text{sr} \cdot \text{sec} \cdot \text{KeV})^{-1}] = 1.4 \cdot 10^4 \cdot \left[\frac{\text{count rate}}{\text{particle energy (KeV)}}\right]$$

The shape of the electron energy spectrum can change dramatically in a short time. In Figure 1 the analyzer output shows at least a 4 orders of magnitude decrease in flux of 15 KeV electrons in a few seconds. This decrease is also seen in higher energy electrons as indicated by the scintillation counter output. Electron spectra with more than one peak were often seen during the two flights into auroral breakups. The number of peaks as well as their location varies during the flights. In contrast, the proton energy spectra showed little change during the flights. In general the proton flux was greatest below 1 KeV, falling off rapidly with energy above 1 KeV, whereas the maximum electron flux generally occurred above 1 KeV.

The rapidly changing and sometimes multiple peaked electron energy spectra reported here are in contrast to the stable, singly peaked spectra seen during quiet pre-breakup auroral arcs (Albert, 1967; Evans, 1968). Evans concludes that the electrons responsible for the quiet arcs are simply the result of electrons moving from a point of injection to a region of different electric potential at the point of observation. The more complex spectra found during auroral breakup cannot be explained this way since there was often more than one peak.

Electron energy spectra have been measured by Vela satellites in the plasma sheet region of the earth's magnetic tail (Bame et al., 1967). The electron spectra in the plasma sheet are very similar in shape to the spectra measured in the auroral zone, including some cases of complex double peaked spectra. Measurements of electron energy spectra made by OGO-3 at 8 to 20 R_e on the night side of the earth have been reported by Frank (1967). These measurements show energy spectra that are similar in shape and in magnitude of electron flux to spectra measured in the auroral zone. Figure 2 shows the striking resemblance of a doubly peaked electron energy spectrum measured in the auroral zone to a doubly peaked spectrum measured at 15.3 R_e on the night side of the earth. At the time of Frank's observation (June 12, 1929 UT), OGO-3 must have been in the plasma sheet. This view is supported by the location of the satellite with respect to the expected location of the plasma sheet and by the particles observed by the satellite. The solar magnetospheric altitude Z_{sm} of the satellite is ~ 10 R_e. Speiser and Ness (1967 have observed that in summer the magnetic neutral sheet lies above the solar magnetospheric equator by an amount determined by the magnetic latitude of the subsolar point. At the time of the observation the neutral sheet should be at about $Z_{sm} \sim 5$ R_e. Vasyliunas (1968) has observed that the plasma sheet extends to about ~ 6 R_e above the magnetic neutral sheet in the tail. Thus the satellite was in a region where it is likely to encounter the plasma sheet. Vasyliunas further observed that above the plasma sheet there were no detectable fluxes of electrons in the energy range 40 eV to 2 KeV while within the plasma sheet there were large fluxes of electrons with energies in the vicinity of 1 KeV. The large flux of 1 KeV electrons observed by OGO-3 clearly indicates that the satellite was in the plasma sheet at the time of the observation.

Figure 3 shows some examples of typical electron energy spectra measured by OGO-3 and typical spectra measured during auroral breakup. Since these measurements were made nearly two years apart, it is unreasonable to expect to find spectra that agree identically. However these examples serve to illustrate the similarity of auroral zone electrons to plasma sheet electrons. In particular the spectra in both regions can be characterized the maximum in the electron flux occurring between 1 and 10 KeV and the magnitude of the flux near 10^7 $(cm^2 \cdot sr \cdot sec \cdot KeV)^{-1}$.

The similarity of auroral zone electron fluxes to plasma sheet electron fluxes both in the form of the energy spectra and the magnitude of flux suggests that the plasma sheet is the source of auroral zone electrons. Vasyliunas (1968) has found that during magnetic bays the inner boundary of the plasma sheet moves inward to 6 R_e at tye equator. Particles in this region could then be guided by magnetic lines of force into auroral latitudes.

ACKNOWLEDGMENTS

I am indebted to Professor K. A. Anderson for his support and helpful comments on this paper.

The rocket launchings were supported by the National Aeronautics and Space Administration under grant NGL 05-003-017.

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FIGURE CAPTIONS

Figure 1: Raw data from flight of 2 March 1968. 0719:40.25 UT. (0119:40.25 LT).

Figure 2: Electron energy spectrum obtained in auroral zone compared to spectrum obtained in the earth's magnetic tail.

Figure 3: Typical examples of electron energy spectra measured by OGO-3 in the plasma sheet region of the earth's magnetic tail compared to spectra obtained in the auroral zone during auroral breakup.

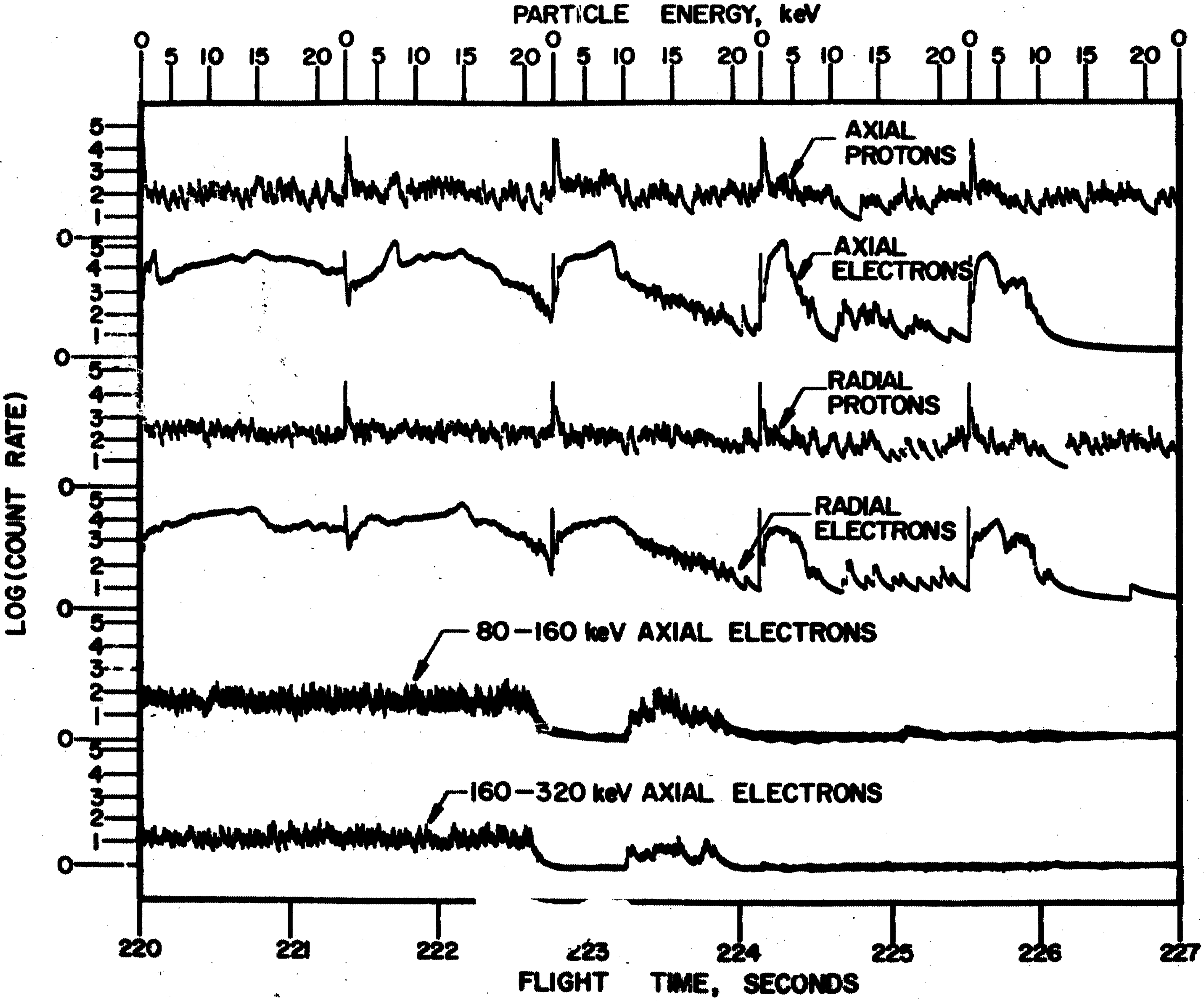
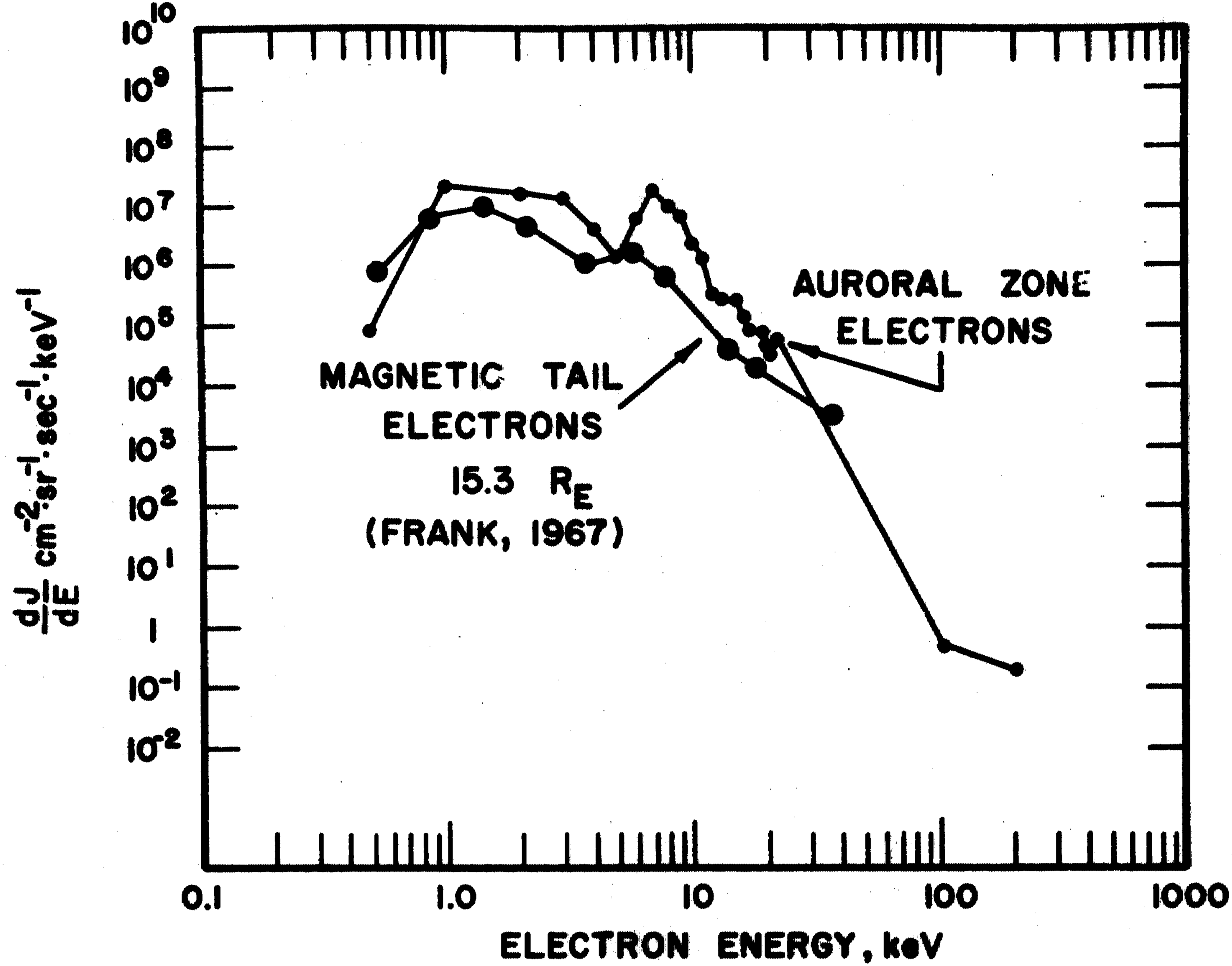
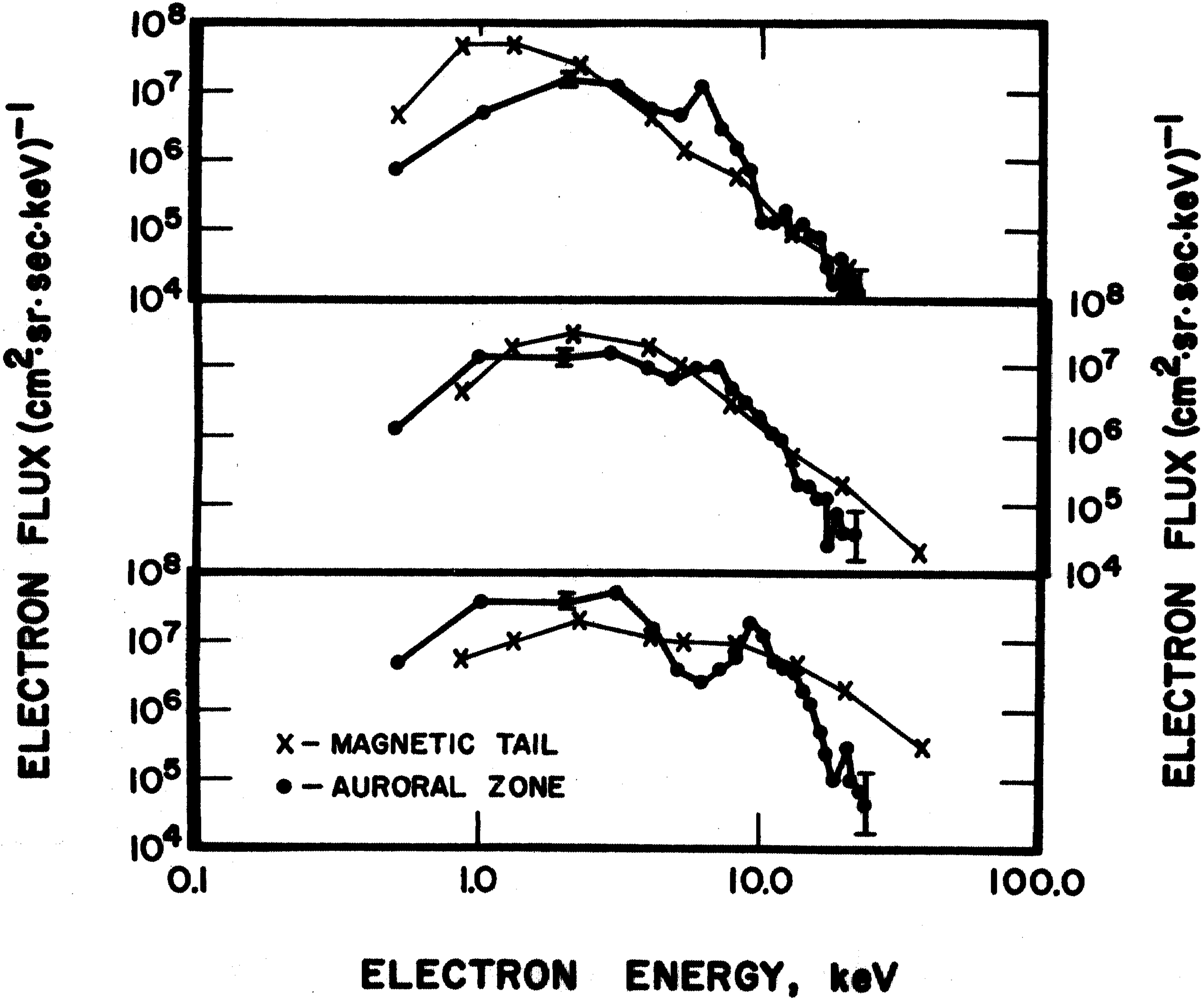

PARTICLE ENERGY, keV
0 5 10 15 20 0 5 10 15 20 0 5 10 15 20 0 5 10 15 20 0 5 10 15 20 0
AXIAL PROTONS
AXIAL ELECTRONS
RADIAL PROTONS
RADIAL ELECTRONS
80-160 keV AXIAL ELECTRONS
160-320 keV AXIAL ELECTRONS
LOG (COUNT RATE)
220 221 222 223 224 225 226 227
FLIGHT TIME, SECONDS

Figure 1



AURORAL ZONE ELECTRONS
MAGNETIC TAIL ELECTRONS
15.3 R_E
(FRANK, 1967)
$\frac{dJ}{dE}$ cm^{-2}·sr^{-1}·sec^{-1}·keV^{-1}
ELECTRON ENERGY, keV
0.1
1.0
10
100
1000
10^{10}
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
1
10^{-1}
10^{-2}

Figure 2



ELECTRON FLUX (cm²·sr·sec·keV)⁻¹
10⁸
10⁷
10⁶
10⁵
10⁴
X – MAGNETIC TAIL
● – AURORAL ZONE
0.1
1.0
10.0
100.0
ELECTRON ENERGY, keV

Figure 3