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SM91: Observations of Interchange Between Acceleration and Thermalization Processes in Auroral Electrons

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Observations of Interchange Between Acceleration and Thermalization Processes in Auroral Electrons

I would like to present some results from a Nike-Tomahawk sounding rocket flight launched from Fort Churchill. The rocket (see fig. 1) was launched into a break-up aurora at magnetic local midnight on 21 March,1968. The rocket was instrumented to measure electrons- the observations I will discuss were obtained with an electrostatic analyzer electron spectrometer which made 29 measurements in the energy interval 0.5 keV to 30 keV. Complete energy spectra were obtained at a rate of 10/sec.

Pitch angle information is presented via 3 computed averages per rocket spin. The spin period was 2 sec. The dumped electron average corresponds to averages over electrons moving nearly parallel to $\vec{B}$ - actually for pitch angles $< 40^\circ$. The mirroring electron average corresponds to averages over electrons moving nearly perpendicular to $\vec{B}$ - actually $60^\circ < \alpha < 90^\circ$. We have also computed the average over the entire downward hemisphere which we call the precipitated electron average.

The observations reported today were obtained in an altitude range of 10 km at 230 km altitude which implies that the ambient plasma was collisionless.

I want to report 5 characteristics of these auroral electrons. We were able to parameterize the differential energy spectrum using two functions - each corresponding to a distinct energy interval. The low energy portion was fitted to a power law energy dependence, $dj/dE = J_o E^{-n}$. The peaked portion of the spectrum was fitted using an energy dependence corresponding to a Maxwellian drifting past the detector. The drift velocity, v_D, would correspond to an electron kinetic energy $1/2\ m\ v_D^2 = E_o \sim 10$ keV. The width of the peak gives the electron temperature , T_e , and the directional density , n_e , is determined by the magnitude of the flux. Typical values for T_e and n_e are 400 eV and 0.5×10^{-3} electrons-cm^{-3}-sr^{-1}.

<u>Frank and Ackerson</u> [1971] have reported that at times they are able to fit their observations of auroral electrons to Maxwellians with temperatures in this ballpark and directional densities 100-1000 times higher than our values. One way to conceptualize our results would be to assume that a parallel electric field with a potential drop of E_o has accelerated the Maxwellians observed by Frank and Ackerson to produce a drifting Maxwellian above the aurora. However we do have indications that the process would not be quite that simple. The drifting Maxwellian contributes between 25% to 50% of the energy flux or 5 - 10 ergs-cm^{-2}-sec^{-1}-sr^{-1}.

We have observed instances where the electron temperature and density increase while the drift energy , E_o , is decreasing - we call this process thermalization. During the reverse situation which we call an acceleration process the drift energy , E_o , increases as T_e decreases.

During these acceleration and thermalization processes the temperature and density are related by the adiabatic compression law , $T_e \sim n_e^{\gamma-1}$ where γ , the ratio of specific heats, has a value of 5/3.

We observe that the mirroring electrons are sometimes heated more than the dumped electrons. Also the mirroring directional density, $n_{e\perp}$, is sometimes greater than the dumped directional density, $n_{e\parallel}$ - this can produce an anisotropy in which the pitch angle distribution is peaked towards 90°.

Several theories involving parallel electric fields indicate that the anomalous resistivity depends upon the magnitude of the parallel current - we shall show that there is no correlation between the drift energy , E_o , and the total downward flux of electrons with energies greater than 500 eV.

In fig. 2 we see two representative differential energy spectra. We have separated them by a factor of 10. The dots represent observed values. The flux scale varies logarithmically from 10^6 to 10^8 electrons-

cm^{-2}-sec^{-1}-sr^{-1}-keV^{-1}. The energy scale varies logarithmically from 500 eV to 50 keV. The two dashed lines correspond to the power law and drifting Maxwellian energy dependence. The solid line is the sum of the two functions,and the fit is very good. The width of the peak in the lower curve is greater than in the upper curve corresponding to a higher electron temperature.

In fig. 3 we show the time variations of the drifting Maxwellian parameters from 4m 20s to 5m 00s. The E_o scale varies from 7 to 15 keV, and the T_e scale varies from 0 to 1.5 keV. For both the dumped and mirroring electrons we observe that a thermalization process is followed by an acceleration process and then this cycle is repeated. The thermalization process time scale $\sim$ 1 - 10 sec is in good agreement with the time scale for the growth of electrostatic waves resulting from the unstable bump-in-tail like appearance of the electron energy spectrum. We note that near 5:00 the temporal profiles of the dumped and mirroring electrons differ somewhat. We shall discuss the differences between the dumped and mirroring values of the parameters later.

In fig. 4 we show the agreement with adiabatic compression of the drifting Maxwellian for the 40 sec time interval which includes two complete thermalization-acceleration processes. We have plotted the log of the temperature from -1.50 to 0.50 versus the log of the directional density from -4.50 to -2.50. The best fit values of γ for the dumped and precipitated averages are almost exactly 5/3 (1.66). Within error all three values of γ are consistent with 5/3. Clearly $\gamma = 2$ or $\gamma = 3$ would be inconsistent with the observed compression. We emphasize that the compression time scale is $\sim$ 10 sec, and we would not wish to suggest that this would be a time scale for a substorm compression of the tail.

In fig. 5 we show the values of the ratios of the mirror electron averages to the dumped electron averages from 4m 20s to 5m 00s. The E_o ratio scale varies from 0.50 to 1.50. A ratio of unity is indicated by the dashed line. The other two scales vary from 0 to 4 . We observe that the mirror values of T_e and n_e frequently exceed the dumped values, but we never observe the reverse case. These anisotropies occur at the same time and are quite pronounced near 5:00. At this time the dumped and mirroring values of E_o are separated by 1 keV which would either cast doubt upon the parallel electric field acceleration concept or perhaps more likely suggest that the perpendicular electrons may may be more susceptible to wave-particle interactions during or after undergoing the potential drop.

In fig. 6 we compare the temporal variations of the drift energy parameter , E_o , with the integral number flux in the drifting Maxwellian from 4m 20s to 5m 00s. The integral number flux scale varies from 0 to 0.3×10^9 electrons-cm^{-2}-sec^{-1}-sr^{-1}. The E_o scale varies from 7.0 keV to 13.0 keV. Note that the E_o value varies considerably and would not be consistent with a drop through a <u>static</u> parallel electric field. I might also comment that this drift velocity is greater than any Alfvén velocity within the magnetosphere. We see in this figure that if a finite resistivity is responsible for the peak in the spectrum the finite resistivity does not depend upon the integral number flux of energetic electrons.

In summary I would like to say that we have demonstrated that the drifting Maxwellian does fit the peaked portion of the energy spectrum; we have observed thermalization and acceleration of this peak; the density and temperature are related by adiabatic compression; the perpendicular electrons may be more susceptible to wave-particle interactions,and that current dependent resistivity does not produce the peak.

Frank, L.A., and Ackerson, K.W., Observations of Charged Particle Precipitation into the Auroral Zone, *J. Geophys. Res.*, *76*, 1971, p. 3612 - 3643.

EVENT :	Break-up aurora 21 March, 1968 Local midnight
PARTICLES:	Electrons
ENERGY:	0.5 keV - 20 keV [electron spectrometer]
PITCH ANGLES:	Dumped (D) - parallel to $\vec{B}$ - $\alpha < 40^\circ$ Mirror (M) - perpendicular to $\vec{B}$ - $60^\circ < \alpha < 90^\circ$ Precipitated (P) - downward hemisphere - $\alpha < 90^\circ$
ALTITUDE:	230 km - collisionless plasma

1. Parameterize differential energy spectrum:

   Low energy - power law- $dj/dE = J_o E^{-n}$

   Peaked portion - drifting Maxwellian energy dependence
   - drift velocity - v_D ; $E_o = 1/2\, m\, v_D^2 \sim 10$ keV
   - electron temperature - $T_e \sim 400$ eV
   - directional density - $n_e \sim 0.5\times10^{-3}$ cm^{-3}-sr^{-1}

   contributes 25%-50% of energy flux

2. Thermalization process: T_e increases - E_o decreases

   Acceleration process: E_o increases - T_e decreases

3. Variations of T_e and n_e correspond to an adiabatic compression $(T_e \sim n_e^{\gamma-1})$

4. Mirroring electrons are heated more than dumped electrons $(T_\perp \gtrsim T_\parallel)$

   Pitch angle anisotropy $(n_{e\perp} \gtrsim n_{e\parallel})$

5. Position of peak , E_o , not correlated with parallel current due to electrons with $E > 500$ eV

FIGURE 1

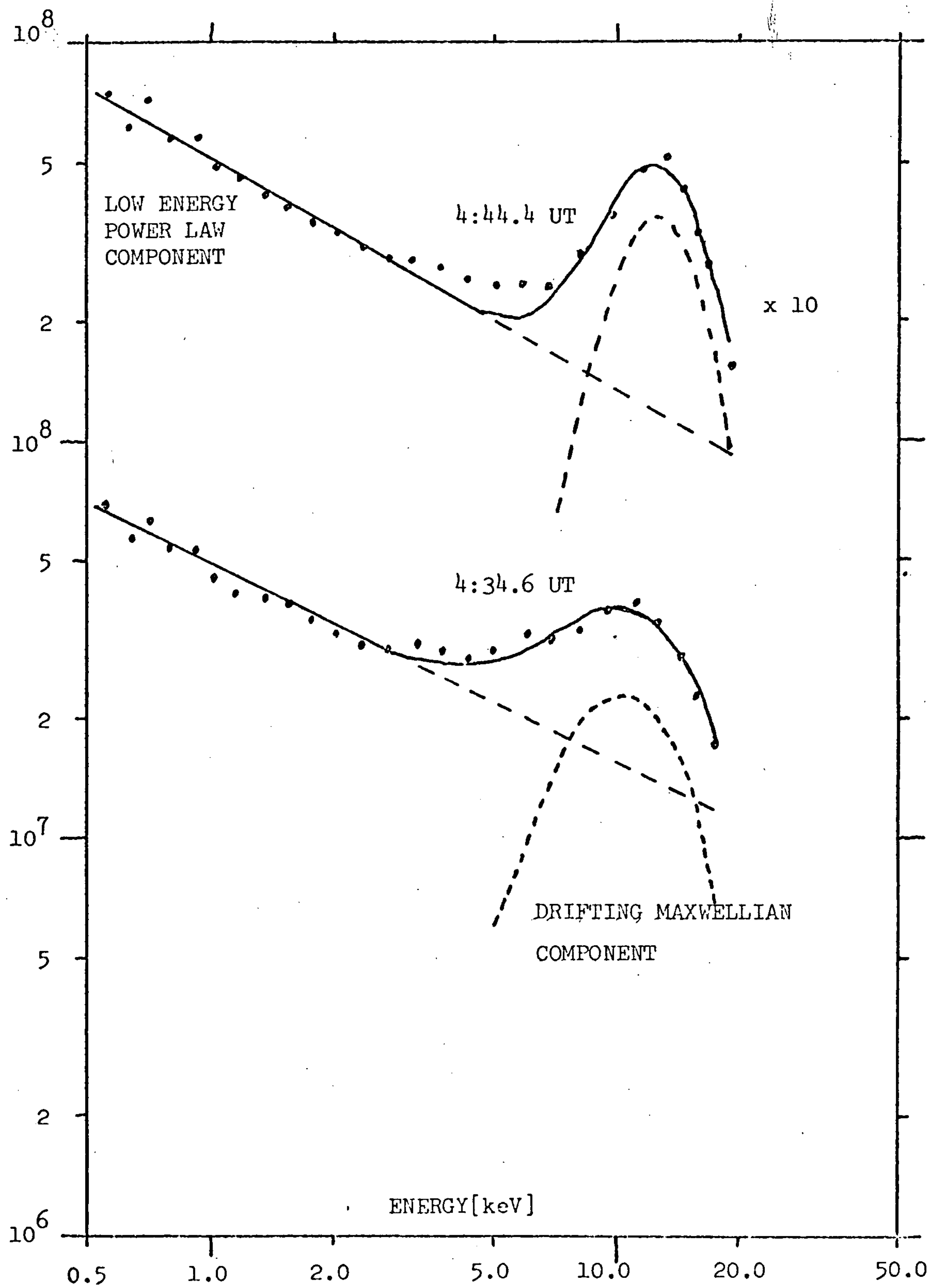
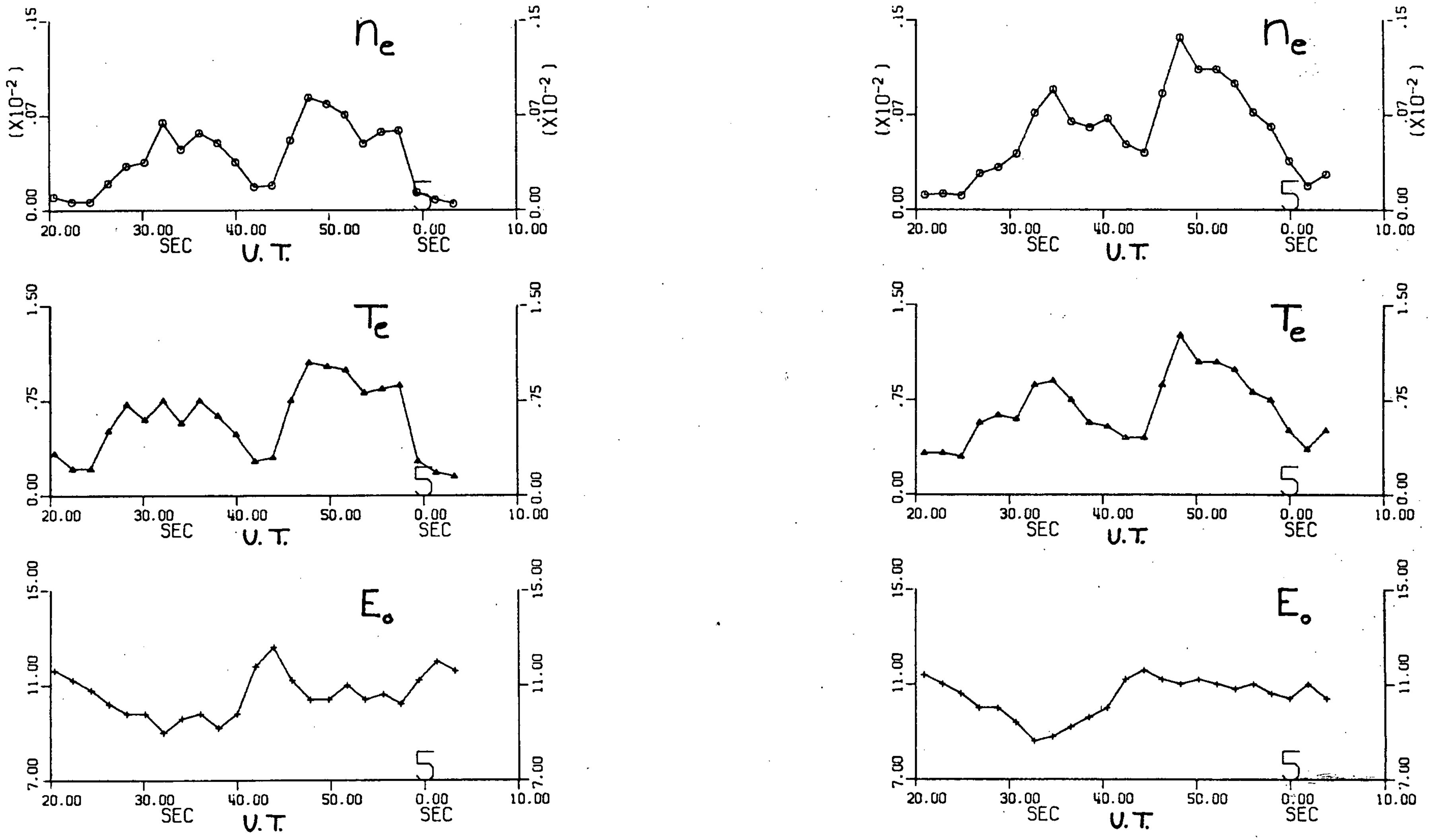


Figure 6.3. Results of fitting differential energy spectra.

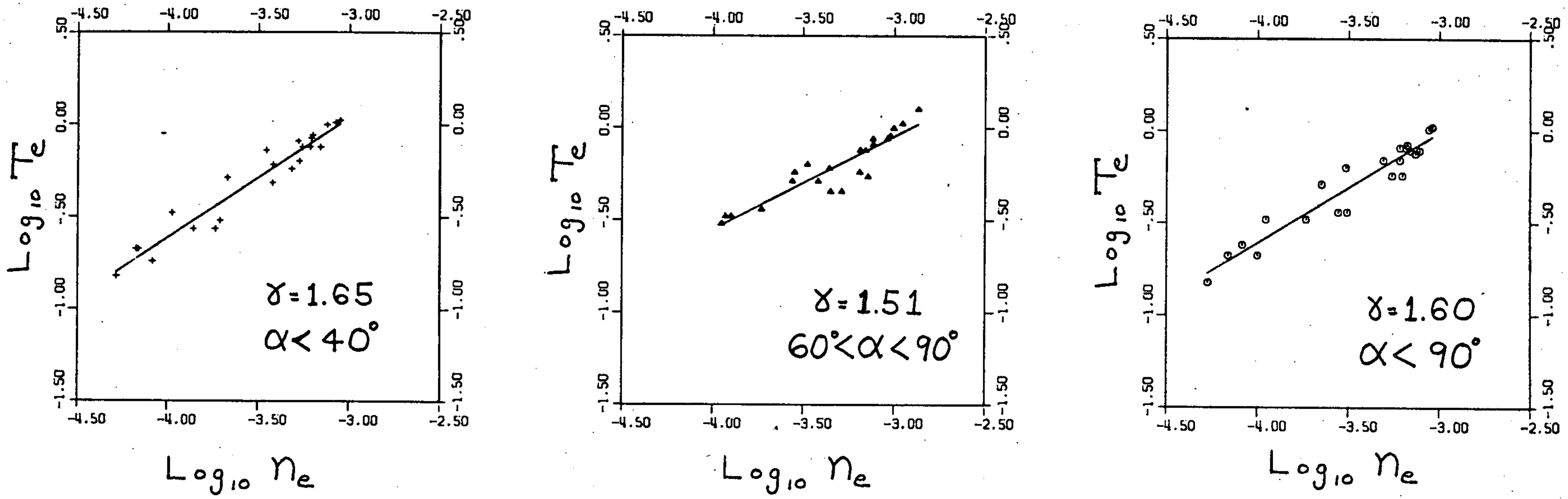
FIGURE 2



DUMPED ELECTRONS $\alpha < 40°$

MIRRORING ELECTRONS $60° < \alpha < 90°$

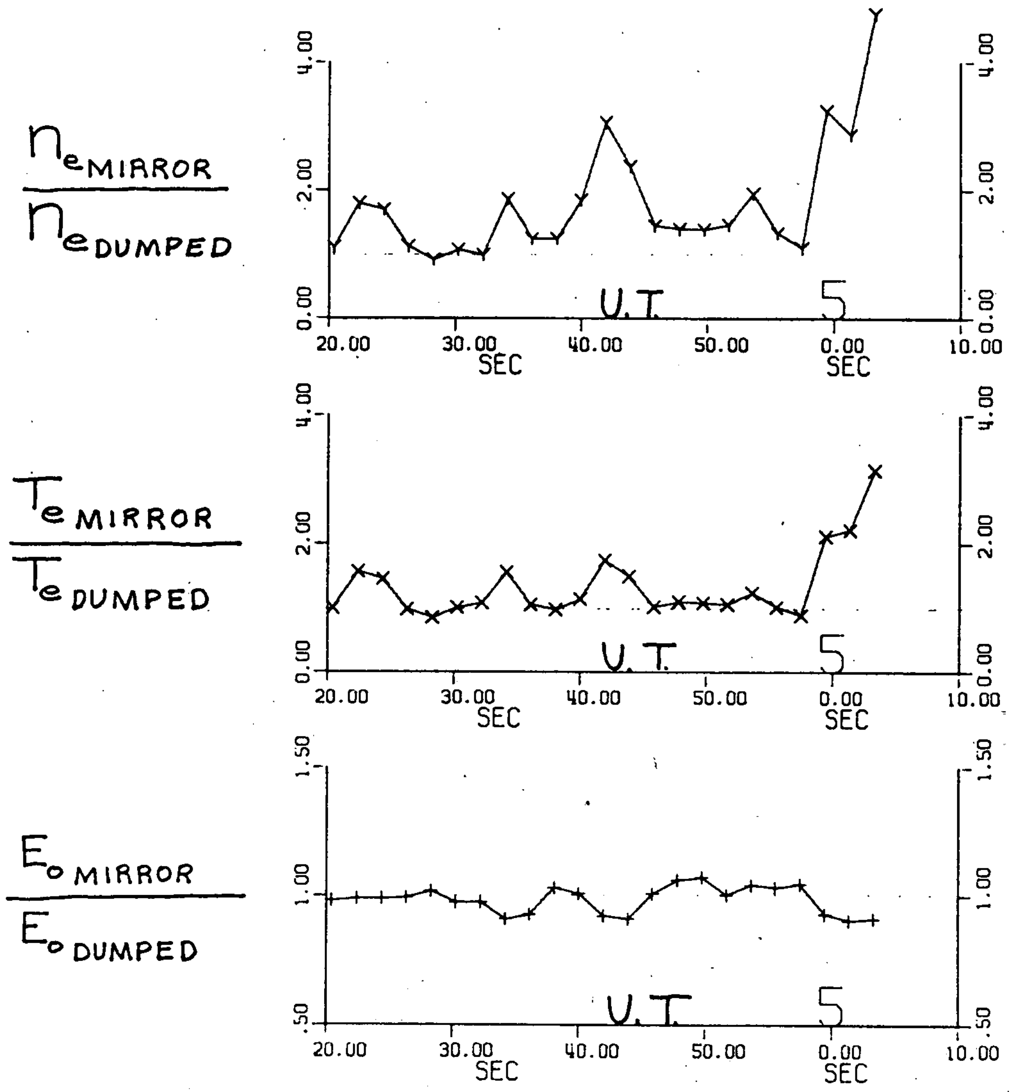
FIGURE 3



Adiabatic Compression of Drifting Maxwellian Electron Gas

$$T_e \sim n_e^{\gamma-1}$$

FIGURE 4



Deviations from Isotropy of Drifting Maxwellian Parameters E_o, T_e and n_e.

FIGURE 5

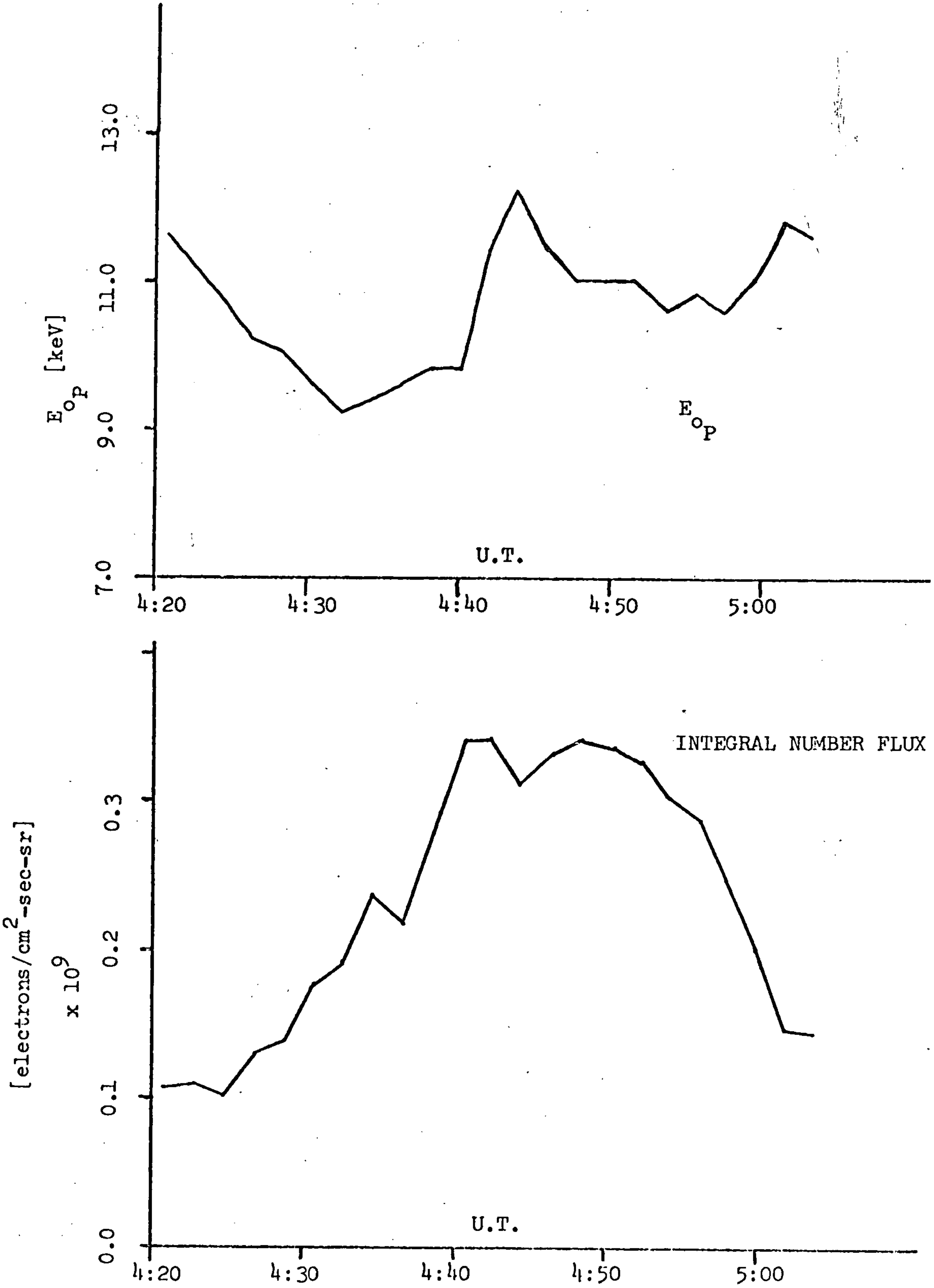


Figure 6.33. Comparision of time profiles of E_{o_p} and integral number flux in drifting Maxwellian

FIGURE 6