Electron Acceleration in the Near Earth Plasma Sheet

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Outline

- Introduction
  - Electron spectra in the plasma sheet
  - Electron spectral changes in the plasma sheet

- Data
  - Rapid (~ 1 second) spectral change from Wind/3DP

- Analysis
  - In-situ acceleration → non-adiabatic
  - Spatial boundary motion

- Conclusion
  - Inconclusive, but leaning toward boundary motion
Electron Spectra in the Plasma Sheet

• From 10s of eV to several 100 keV, electron spectra can be well characterized by a Kappa function [Vasyliunas, 1968]
  \[ f \sim [1 + E/\kappa E_0]^{-\kappa-1} \]
  \[ j \sim E[1 + E/\kappa E_0]^{-\kappa-1} \]
  where \( \kappa \) is a constant (spectral slope at large \( E \)),
  \( E_0 \) is the energy of peak flux, and
  \( E_0 = kT[1 – 3/2\kappa] \)

• Maxwellian for \( E < \kappa E_0 \)
• Power law for \( E >> \kappa E_0 \)
• Maxwellian as \( \kappa \to \infty \)

• During active (and quiet) times, electron spectra have multiple components [e.g., Christon et al., 1991]
Electron Spectral Changes in the PS

Example from Christon et al. [1988]
- Slow transition in temperature ($E_o$) $\kappa \sim$ constant (in this case)
- Lower $kT$, higher $\kappa$ during quiet intervals ($AE < 100$ nT);
- Higher $kT$, lower(?) $\kappa$ during active intervals ($AE > 100$ nT)
  [Christon et al., 1991]

Ambiguity: Spatial or temporal?
Instrumentation

Wind 3DP
- EESA-High
  - Energy range: 100 eV – 30 keV
  - Time resolution: 3 sec (1 s/c spin) every ~ 100 seconds
- SST-Foil
  - Energy range: 25 keV – 600 keV (> 1 MeV)
  - Time resolution: 12.5 sec for 25 keV; 50 sec for 600 keV

At 06 UT on 1997-07-26, Wind was located in the plasma sheet at [-11, 3, 0] R_E GSM
Overview of PS Electron Observations

During intervals of auroral brightening, large $B$ fluctuation, high ion velocity;

- $n_e$ decreases,

- $kT_e$ increases

$\Rightarrow$ electron spectral change
Electron Spectra

05:42:43 UT
smooth \( B \),
isotropic ions,
cold, isotropic \( e^- \)

05:46:04 UT
fluctuating \( B \),
hot ions, hot \( e^- \)

05:44:24
fluctuating \( B \),
dynamic ions
??? \( e^- \)
Sub-Spin (200 ms) Resolution

1 keV flux decreases (in all directions),
3 keV flux \(\sim\) constant,
9 keV flux increases,
in \(\sim\) 1 second;

\(\mathbf{B}\) increases from 1.5 to
40 nT in \(\sim\) 2 sec (\(\geq 20x\))

2005 Joint Assembly
Spectral Fits: Before and After

\[
\begin{align*}
n &= 0.85 \text{ cm}^{-3} \\
kT &= 0.37 \text{ keV} \\
\kappa &= 4.2
\end{align*}
\]

\[
\begin{align*}
n_1 &= 0.78 \text{ cm}^{-3} \\
n_2 &= 0.16 \text{ cm}^{-3} \\
kT_1 &= 0.75 \text{ keV} \\
kT_2 &= 3.50 \text{ keV} \\
\kappa_1 &= 4.6 \\
\kappa_2 &= 7.0
\end{align*}
\]

\[
\begin{align*}
n &= 0.16 \text{ cm}^{-3} \\
kT &= 3.00 \text{ keV} \\
\kappa &= 7.0
\end{align*}
\]
**In-situ Acceleration?**

Non-adiabatic in fluid sense:

\[ P = \alpha n^\gamma, \quad P = nkT \]

\[ \Rightarrow kT = \alpha n^{\gamma-1} \]

- \( \alpha \) = specific entropy
- \( \gamma \) = polytropic index
- \( \gamma = 5/3 \Rightarrow \text{adiabatic} \)

Non-adiabatic in kinetic sense:

- \( \mu = E_\perp / B = \text{constant} \Rightarrow \delta E_\perp / E_\perp = \delta B / B \) (e.g., betatron)
- Expect translation in energy with constant spectral index (slope)
- Not observed; \( \kappa = 4.2 \to 7.0 \)
- Also, \( B_{\text{initial}} \) (05:42) and \( B_{\text{final}} \) (05:46) approx. equal (~ 20 nT)
Propagating particle boundary?

- $\rho_e \sim 100 \sqrt{E_\perp [\text{keV}]/B [\text{nT}]} \text{ km}$
  - For $B = 10 \text{ nT}, \ E_\perp = 25 \text{ keV}, \ \rho_e \sim 50 \text{ km}$
  - $E_\perp = 600 \text{ keV}, \ \rho_e \sim 250 \text{ km}$
  - For $B = 40 \text{ nT}, \ E_\perp = 25 \text{ keV}, \ \rho_e \sim 12.5 \text{ km}$
  - $E_\perp = 600 \text{ keV}, \ \rho_e \sim 62.5 \text{ km}$

- $\langle v_i \rangle \sim 300 \text{ km/s}$

- In 1 second, traverse few $\rho_e$ for $E_\perp \sim 600 \text{ keV}$
  - few 10s of $\rho_e$ for $E_\perp \sim 25 \text{ keV}$
  - $\sim 100 \rho_e$ for $E_\perp \sim 1 \text{ keV}$ (thermal $e^-$)

- In this case, don’t expect adiabatic behavior:
  - $\Rightarrow$ not following plasma element; inhomogeneities in $\alpha$
  - [cf., Baumjohann and Paschmann, 1989]
Summary

We have presented high-time resolution (200 ms) observations of a rapid (~ 1 second) electron spectral change in the plasma sheet during an “active” period (aurora, large $\Delta B$, large $<v_i>$) → $n_e$ decrease, $kT_e$ increase, $\kappa$ increase (softening of spectrum)

Inconsistent with *local* adiabatic (fluid or kinetic) acceleration
Consistent with crossing a boundary several energetic $\rho_e$ thick

Ambiguity remains:
- local non-adiabatic process (temporal), or
- sampling different plasma populations (spatial)
  (simplest interpretation)