Sources of Electron Pitch Angle Anisotropy in the Magnetotail Plasma Sheet

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The Magnetotail Plasma Sheet
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This green bit

\[ n \sim 0.1-1 \text{ cm}^{-3} \]
\[ T_i \sim 10^7 \text{ K} \]
\[ T_e \sim 10^6 \text{ K} \]

Plasma thought to be isotropic
Ring Current
Pitch angle tells us how a particle is moving with respect to the local magnetic field.

- $0 = \text{parallel}$
- $90 = \text{perpendicular}$
- $180 = \text{antiparallel}$

Different physical processes produce particles with different pitch angles.

Comparing the flux of particles with different pitch angles we can learn about the processes that have acted on them.
Plasma Sheet Electron Pitch Angle Distributions

- Are the electrons in the plasma sheet really isotropic?
- Survey of Cluster data.
- \(\sim 10^6\) electron spectra.
- Examine average electron flux at different pitch angles as a function of distance from the centre of the plasma sheet.
- Examine ratio between average field-aligned flux and average perpendicular flux.

\[
\frac{\langle E \rangle}{\langle T \rangle}
\]

\[
\frac{\langle E \rangle}{\langle P \rangle}
\]

\[
\frac{\langle \| \rangle }{\langle P \rangle}
\]

\[
\beta
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\beta
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\beta
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Electron Anisotropy

Field-Aligned electron fluxes are balanced almost everywhere.

Instrument effect at high energy, low $\beta$: Sunlight entering the aperture.

Net field-aligned, tailward flux at low energy, low $\beta$: Mirrored polar rain & ionospheric outflow?

Bidirectional electrons dominate at all energies, moderate $\beta$: An “electron PSBL”.

Trapped, perpendicular population at high energies; bidirectional at low energies.
What is the source of the anisotropy?

• There is, on average, an excess flux of field-aligned electrons at sub-KeV energies.

• Is it simply an aliasing effect?
  • Is the electron plasma sheet sometimes colder and more strongly field-aligned?
  • Is it sometimes hotter and more isotropic?
  • Is this controlled by IMF BZ?

• Are there two coexisting components of plasma sheet electrons, similar to the two component proton plasma sheet?
  • If so, what are the sources of these components?
Northward vs Southward IMF

Northward IMF
- Earthward Field-Aligned
- Perpendicular
- Tailward Field-Aligned
- Earthward Tailward
- Field-Aligned Perpendicular

Southward IMF
- Earthward Field-Aligned
- Perpendicular
- Tailward Field-Aligned
- Earthward Tailward
- Field-Aligned Perpendicular
The Kappa Distribution

- Widely used in space plasmas in place of a Maxwellian.
- Models the suprathermal tails of observed particle distributions.
- Can simply sum $n$ kappa functions with different parameters to represent an $n$ component distribution.

\[ J(E) = A_c E \frac{\Gamma(\kappa_c + 1)}{\Gamma(\kappa_c - \frac{1}{2})} \left( 1 + \frac{E}{\kappa_c E_0c} \right)^{-\kappa_c - 1} + A_h E \frac{\Gamma(\kappa_h + 1)}{\Gamma(\kappa_h - \frac{1}{2})} \left( 1 + \frac{E}{\kappa_h E_{0h}} \right)^{-\kappa_h - 1} \]

(Haaland et al., 2010)
An Ionospheric Source?

• Using an empirical magnetic field model (Tsyganenko et al., 1989) we can estimate the location in the ionosphere magnetically conjugate to the Cluster spacecraft at any given time.

• We can then determine if there’s a pattern to the locations in the ionosphere conjugate to where the cold electrons are most often observed.

(Adapted from Forsyth et al., 2012)
An Ionospheric Source?

Cold electrons more likely
Cold electrons less likely
Electrons are pulled from the ionosphere into the magnetosphere by the downward Birkeland currents that connect the two regimes.
Conclusions

• The electron plasma sheet is not isotropic as commonly thought.
• The anisotropy is driven by the presence of an additional cold component of electrons.
• Evidence suggests that the cold electrons come from the ionosphere and are transported via field aligned currents.
• This has been postulated in the past and seen in case studies (e.g. Kletzing & Scudder, 1999; Wright et al., 2008), but we’ve shown it is persistent and significant.
• Walsh et al., GRL, 2011; Walsh et al., JGR, 2013