Ionospheric Plasma in the Magnetotail

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Outline

What have we leaned from previous investigations of ionospheric plasma in the magnetotail?

Sources | Losses | Structure | Dynamics

Why haven't we been able to answer "important" questions?

Where and how do substorms start?

Is there an undetected cold plasma component in the plasma sheet?

What kinds of questions should we be asking of the Cluster, Image, and Polar data sets?
Sources of plasma

• **Solar wind - the HELIOGENIC component**
  - \( \text{H}^+ \text{He}^{++} \text{O}^+ \text{O}^{5+} \)
  - Dominant during geomagnetically quiet intervals
  - Entry by **injection, diffusion, and convection**.
    - Only episodic investigations, no clear observational basis to support the dominance of any one picture of solar wind entry or their relative importance.

• **Ionosphere - the GEOGENIC component**
  - \( \text{H}^+ \text{He}^+ \text{O}^+ \text{N}^+ \text{O}^{++} \text{O}_2^+ \text{NO}^+ \text{N}_2^+ \)
  - Dominant during geomagnetically *very active* intervals
  - **Many processes are involved** in the energization and transport of geogenic ions from the ionosphere to the magnetotail
    - There are good, long term, calibrated data bases of ion outflow and plasma sheet composition available from ISEE/ICS, DE/EICS, Akebono/SMS, and Polar/TIMAS
Geogenic Source Processes

The ionosphere is not a thin conductor!

Relative flux and energy of $H^+, He^+, O^+, O^{++}, O_2^{++}, NO^+, and N_2^+$ are strong functions of position, as well as geomagnetic and solar activity.
Long term average source flux and plasma sheet density

Yau et al. from DE -1

Lennartsson from ISEE -1
Shelley [COSPAR, and AGU, 1986] combined these statistical studies and a simple, static, model of the plasma sheet volume to provide a first order estimate of the variation of the plasma sheet composition as a function of \textit{magnetic} and \textit{solar} activity.

Estimated fraction of the Plasma sheet of Geogenic origin

Chappell used basically the same DE outflow data and argued that the ionosphere was more than adequate to populate the plasma sheet at all times.
How much $O^+$ escapes down tail?

Seki et al. used Geotail data to estimate the flux of oxygen escaping down tail and found only about 10% of the flux expected from the DE -1 data.

Where is the missing oxygen? Did Geotail/LEP miss it or did it not escape?

From DE -1 data Yau estimated that the net outflow of Oxygen was $5 \times 10^7$ Kg/yr and concluded that the net escape was balanced by oxygen created by photodissociation of water in the atmosphere. Seki
et al. used the same data and estimated that the equivalent of 18% of the current atmospheric oxygen has escaped.
Structure of the plasma sheet

**Very Active Kp 6**

- Current Sheet
  - Thick
  - Thin
- < 100 eV O⁺
  - Yes
  - No
- Electrons
- Max Density
  - Data from:
    - Magnetometer (top)
    - TIMAS (next 2)
    - HYDRA (panel #4)

**Moderate Activity Kp 2**

- Data from:
  - POLAR October 9, 2001
  - Density max
  - ~ 0.5/cm³
  -~ 2/cm³

Equatorial, ~ 9.5 RE, 22:30 MLT

Equatorial, ~ 9.5 RE, 23:00 MLT
Dynamics of the magnetotail plasma

From Angelopoulos, GEM, 1999
Geotail observations that validated this interpretation were summarized by Terasawa this morning.
Polar observations demonstrated that the plasma sheet boundary layer (PSBL) is a temporal, not spatial structure.

New multi-point observations from...
Cluster confirm this.

W.K. Peterson, SM32-B, Spring, 2002, AGU Meeting
Substorm Questions: Where, When, How?

and What is the difference between a substorm and a Pseudobreakup?
Cluster/Polar/Image are now providing a multi-point picture of the plasma sheet.

Baker et al., showed Cluster, IMAGE, Polar, LANL, GOES and ground data this AM that demonstrate that reconnection inside Of 19 RE occurred several minutes before the current sheet was disrupted at ~04:08 on August 27, 2001.
Assume Cluster/Polar/Image spacecraft and ground based observations can answer the substorm Where? and When? questions.

**We are left with the How? Question**

What basic plasma physics processes or mechanism(s) are responsible for initiation of reconnection and current disruption?

Or does it make more sense to investigate the "How?" question in the framework of Self Organized Criticality?
How important is O\(^+\) initiation of the tearing mode plasma instability?

• Baker et al. [1982] noted that a "blob" of O\(^+\) in the plasma sheet would make it more unstable to the tearing mode described by Schindler.

• Cladis and Francis [1992] suggested that the pressure associated with O\(^+\) "blobs" in the plasma sheet modifies the magnetic field and drive
instabilities that lead to substorms
The observational evidence for O\(^+\) tearing mode association with substorm onset is not convincing

- Daglis and his colleagues in a series of papers have reported observations "suggesting" or "consistent with" but not "proof of" the O\(^+\) tearing mode occurring at or near substorm onset time (not position!)
- Lennartsson, on the basis of statistical evidence from ISEE-1 and AMPTE asserts that O\(^+\) blobs are not generally associated with substorm onset.
What kind of Evidence do we need?

- Schindler's analysis was 2-D
- Electrons stabilize the plasma against the tearing mode
- We need updated estimates of the ranges of parameters over which O⁺ "blobs" in the plasma sheet are unstable to the tearing mode?
  - Density Temperature Physical Size
Evidence?

The Daglis/Lennartsson disagreement comes down to:

Have the relevant observations been made at the right place at the right time?

The answer is no!

Best Candidates:

InterBall Tail beyond 15 $R_E$
Cluster
Questions we should address using Cluster/Polar/Image data sets

• What are the relative importance of the various solar wind entry mechanisms (injection/diffusion/convection)

• Structure and dynamics of the thin current sheet

• Substorm initiation
  - Current wedge and reconnection relative timing

• Evidence for O⁺ "blobs" in association with substorm onset.
Conclusions

- We still don't understand plasma sheet dynamics well at all!
- We know enough now to ask some more focused questions of the data.
- We have spectacular, new, data coming in from Cluster, Image, and Polar now that Polar apogee is near the equator.