The Physics of Space Plasmas

Auroral and Polar Cap Phenomenology

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This lecture deals primarily with electromagnetic coupling between the interplanetary medium and the high-latitude ionosphere.

What do high-latitude convection / potential distributions look like?
- How do they vary with the IMF’s orientation?
- What is the polar cap potential ($\Phi_{PC}$)?
- How does $\Phi_{PC}$ depend on the IMF?
- What happens when IMF $B_Z$ turns northward?

We have all seen schematics of the Region 1 – Region 2 system
- How do they come about?
- What are their relationships with particle precipitation electric field patterns?
- What happens when IMF $B_Z$ turns northward?

How do electromagnetic forces couple the ionosphere and magnetosphere?
While this 2-D model has heuristic value for pointing out how the Dungey magnetosphere works, it seemed to contain seeds of its own rejection.

Walter Heikkila often pointed out that along the sub-solar merging line the electric field and currents were in the same direction!

“How can a load drive the magnetosphere?”
A second issue concerned the generalization of the Dungey model to 3D:

- Component merging hypothesis (Bengt Sonnerup)
- Anti-parallel merging hypothesis (Nancy Crooker)
Large-scale system of FACs observed by TRIAD during relatively quiet (left) and disturbed (right) conditions

- R1 and R2 expand colatitude ranges
- Cusp-related current system not yet identified
Large-scale system of FACs observed by TRIAD during the recovery (left) and expansion (right) phases of substorms

- Small scale FACS associated with discrete auroral forms do not in this global-scale picture
- The infinite current sheet approximation
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**Dayside FAC System**  
*Erlandson et al., JGR, 1988*

- From $\nabla \times B = \mu_0 j$ considerations, positive/ negative $\Delta B_E$ slopes indicate current into / out of ionosphere.
- The existence / polarity of the cusp current system is IMF $B_Y$ dependent.
- *Erlandson* saw cusp currents as extensions of Region 1 past local noon.
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Particle Electric / Magnetic Field Measurements

\[ E \]
\[ B \]
\[ V_{\text{sat}} \]

Fluxgate Magnetometer

Ion Drift Meter
\[ V_H, V_V \]

Electrostatic Analyzer
Before examining $E$ and $B$ data, as a guide it is useful to reflect on what to expect in measurements.

We consider a satellite in circular polar orbit that carries an electric field sensor and a magnetometer.

We assume that in the polar cap $E$ is directed dawn to dusk.

In the specified satellite centered coordinate system

$E_X$ => positive along s/c velocity

$\Delta B_Y$ => positive in antisunward

Earth cross section along the dawn-dusk meridian as viewed from the lunar surface.
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Heppner-Maynard, JGR, 1987

Northern Hemisphere:
\[ B_Y < 0, \ B_Z < 0 \]

Southern Hemisphere:
\[ B_Y > 0, \ B_Z < 0 \]
Northern Hemisphere:
\[B_Y > 0, \quad B_Z < 0\]

Southern Hemisphere:
\[B_Y < 0, \quad B_Z < 0\]
Space Plasma & Field Sensors

Methodology used by Heppner and Maynard (JGR, 4467, 1987) to construct Potential / convection patterns.

Model A appears in summer polar cap when IMF $B_Y$ polarity would drive strong convection along dusk flank of polar cap.


Model BC

Model DE
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**Model BC**

**IMF** $B_Z < 0$

Northern-hemisphere passes

\[ IMF\ B_Y > 0 \]

\[ E_X \text{ is positive along direction of s/c motion} \]

Southern-hemisphere passes

\[ IMF\ B_Y < 0 \]

Integrate $E_X$ along trajectory, then connect equipotentials

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*Image 33x478 to 176x519*

*Image 618x480 to 672x534*

*Image 0x29 to 720x452*
More current overcomes neutral drag on ion convection across summer polar cap

\[ \mathbf{j} \times \mathbf{B} = \nu_n (\mathbf{V}_i - \mathbf{V}_n) \]
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Equivalent current system and external driving with IMF $B_Z > 0$

Maezawa, JGR, 2289. 976
The NASA Explorer Series

Burke et al., GRL, 21, 1979

[Diagram showing solar wind data and magnetic field readings]
Before examining $E$ and $B$ data, it is useful as a guide to think a bit about what we might expect to see in the measurements:

- We consider a satellite in circular polar orbit.
- That carries an electric field sensor and a magnetometer.
- We assume that in the polar cap $E$ is directed dawn to dusk.
- In the specified satellite centered coordinate system, $E_X$ is positive along s/c velocity, and $\Delta B_Y$ is positive in antisunward.
Distorted BC potential/convection patterns with IMF BZ “weakly” (left) and “strongly” (right) positive
MAGSAT measurements acquired during six consecutive southern hemisphere passes on 8 January 1980 while IMF $B_z$ was strongly positive. Iijima et al., 7774, 1984

NBZ current system
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MAGSAT ΔS measurements from four southern high-latitude passes on 8 Jan. 1980

NBZ current system
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Dayside Precipitation Pattern
*Newell and Meng, GRL, 1992*

Dayside FAC System
*Erlandson et al., JGR, 1988*

Heppner - Maynard Convection Patterns  *(JGR, 1987)*
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Nopper and Carovillano, GRL 699, 1978

Region 1 = $10^6$ A
Region 2 = 0 A

Region 1 = $10^6$ A
Region 2 = $3 \times 10^5$ A

Independent studies using AE-C, S3.2 and DE-2 measurements of $\Phi_{PC}$ all showed that the highest correlation was obtained with

$$\Phi_{PC}(kV) = \Phi_0(kV) + \alpha V_{SW} B_T \sin^2(\theta / 2)$$

$$B_T = \sqrt{B_Y^2 + B_Z^2}$$

$$\theta = B_Z / B_T$$

Interplanetary electric field given in mV/m. Since 1 mV/m $\approx 6.4$ kV/ $R_E$

$L_G =$ width of the gate in solar wind ($\sim 3.5$ $R_E$) through which geoeffective streamlines (equipotential) flow.

**Burke, Weimer and Maynard,**

*JGR, 104, 9989, 1999.*
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Dynamics Explorer 1
135.6 nm image of
auroral oval and Theta aurora

*Frank et al.*, JGR, 1986
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Reiff and Burch, JGR 1595, 1985
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