The Physics of Space Plasmas

Auroral and Polar Cap Phenomenology

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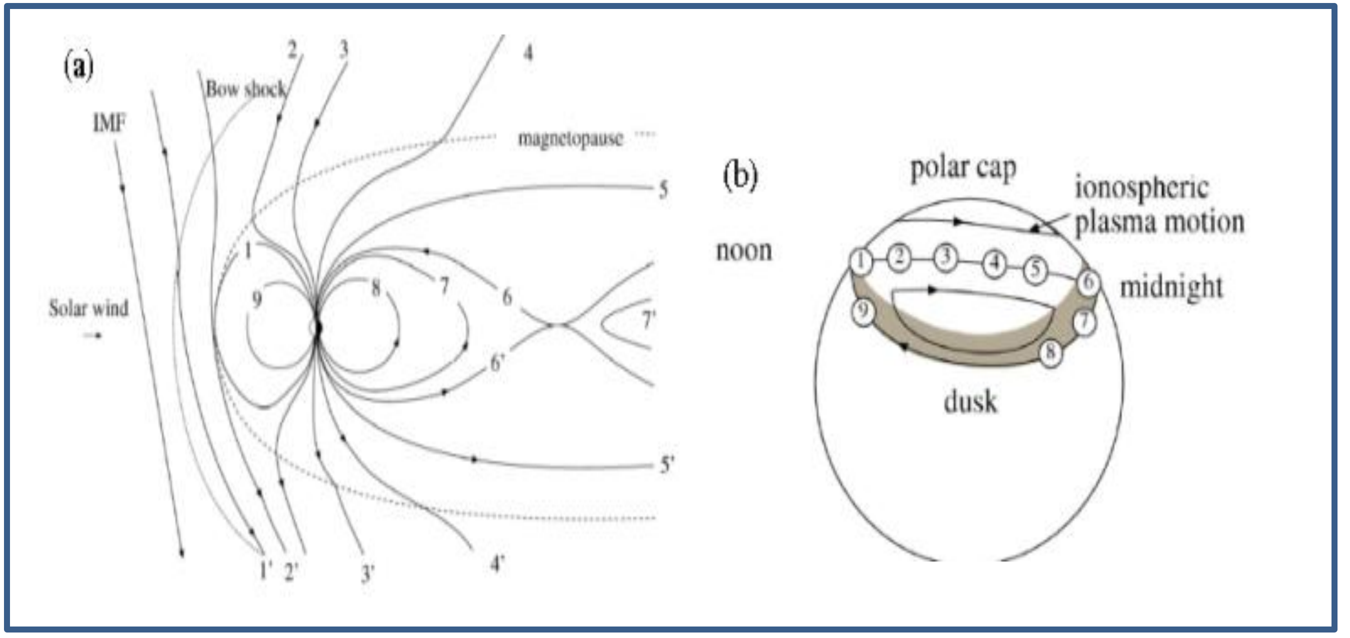
INSTITUTE FOR SCIENTIFIC RESEARCH

Lecture 3

- **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 (Φ_{PC})?**
  - **How does Φ_{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 BZ turns northward?**
- **How do electromagnetic forces couple the ionosphere and magnetosphere?**

Aurorae and Polar Cap

Dungey, Phys. Rev. 1961

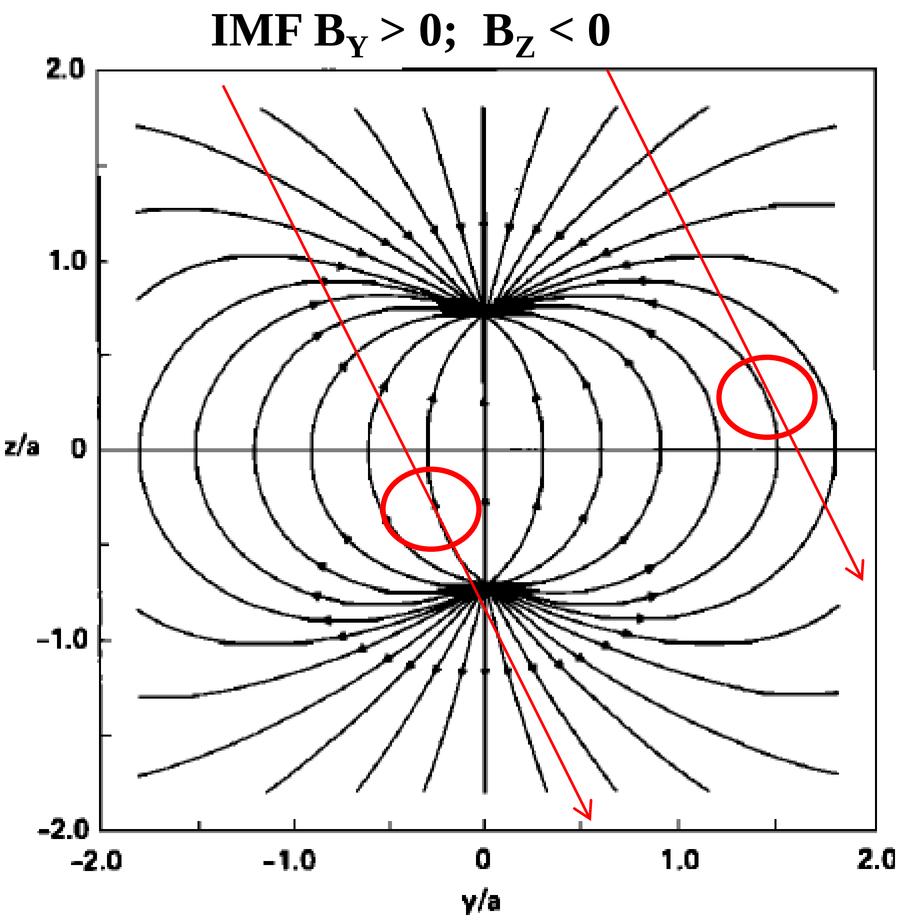


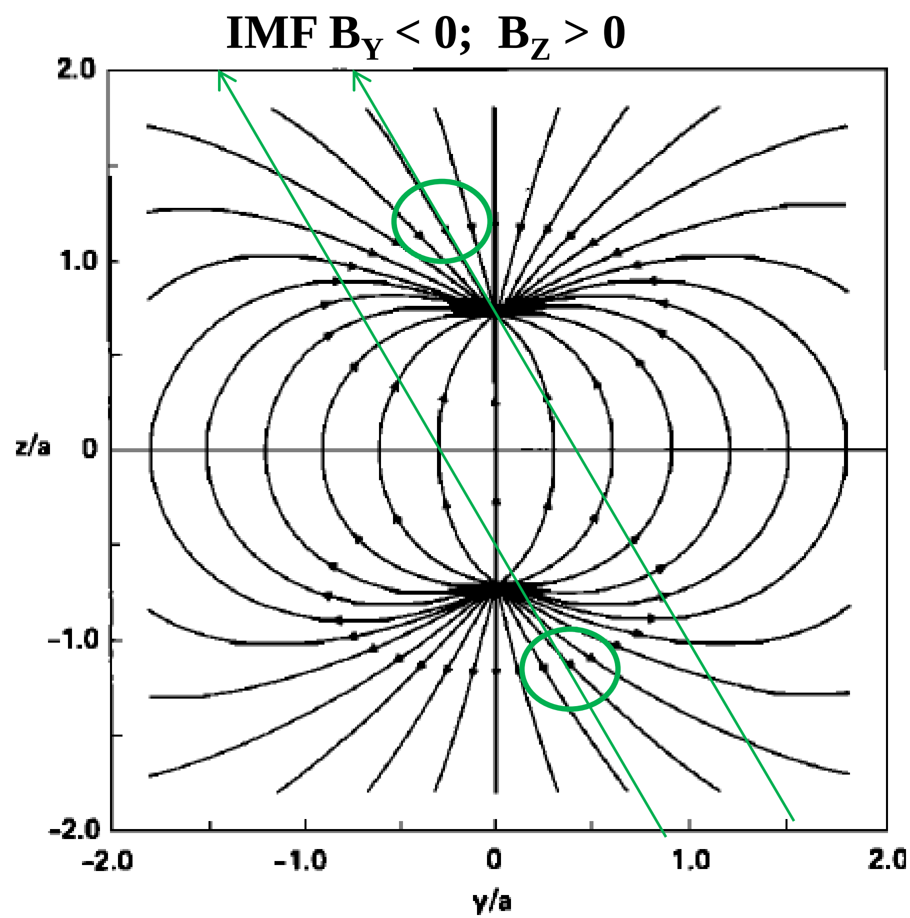
- While this 2-D model has heuristic value for pointing out how the Dungey magnetosphere works, it seemed to contain seeds of its own rejection.

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

  <u>**"How can a load drive the magnetosphere?"**</u>

Aurorae and Polar Cap



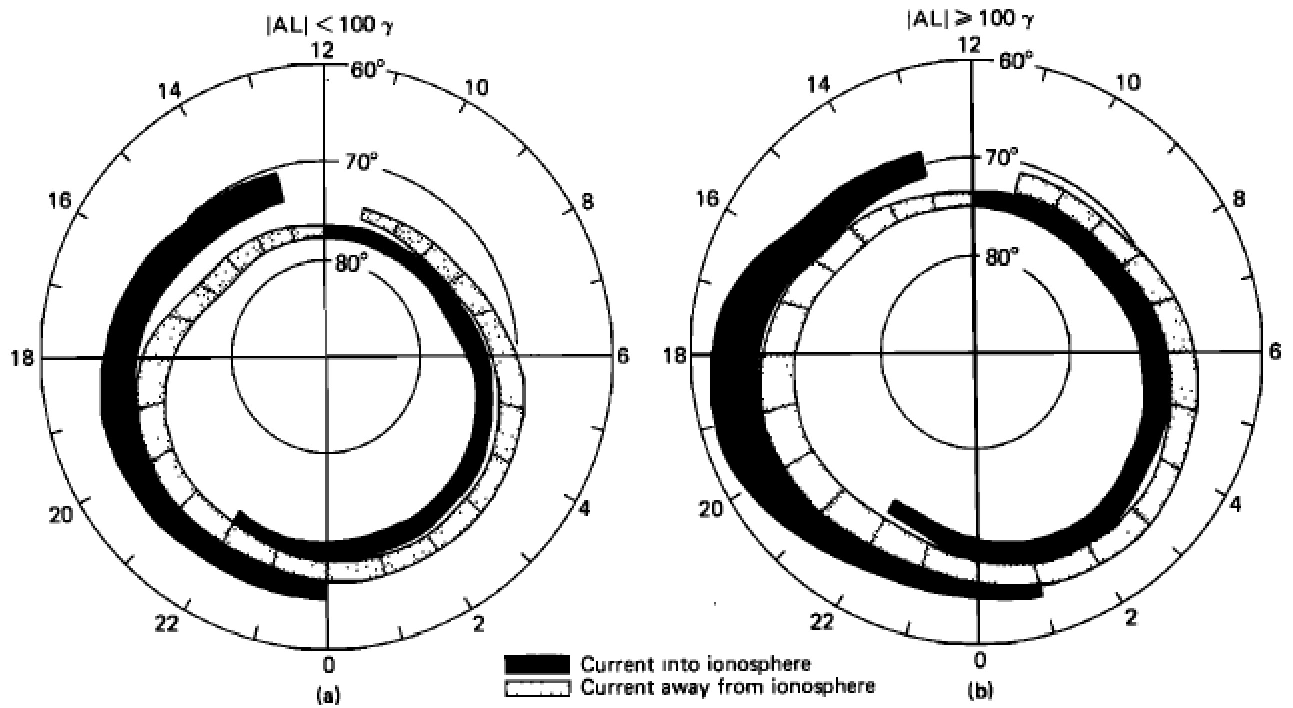


A second issue concerned the generalization of the *Dungey* model to 3D

- **Component merging hypothesis (*Bengt Sonnerup*)**
- **Anti-parallel merging hypothesis (*Nancy Crooker*)**

Aurorae and Polar Cap

***Iijima and Potemra*, JGR, 83, 599,1978**

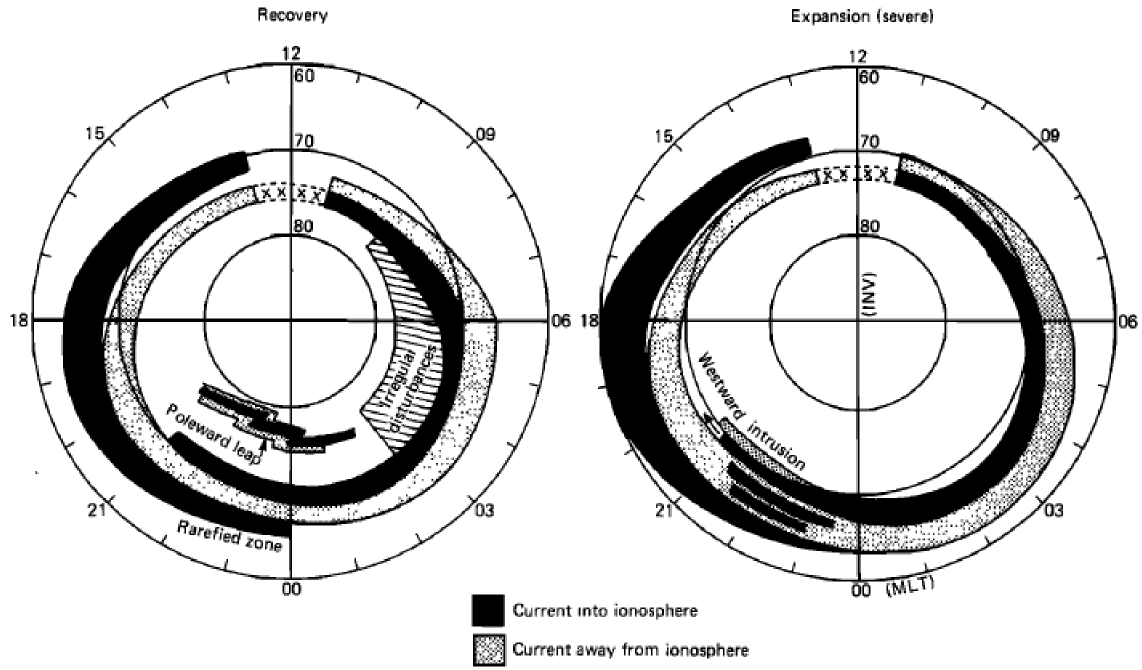


Large-scale system of FACs observed by TRIAD during relatively quiet (left) and disturbed (right) conditions

- **R1 and R2 expand colatitude ranges**
- **Cusp-related current system not yet identified**

Aurorae and Polar Cap

Iijima and Potemra, JGR, 83, 599,1978



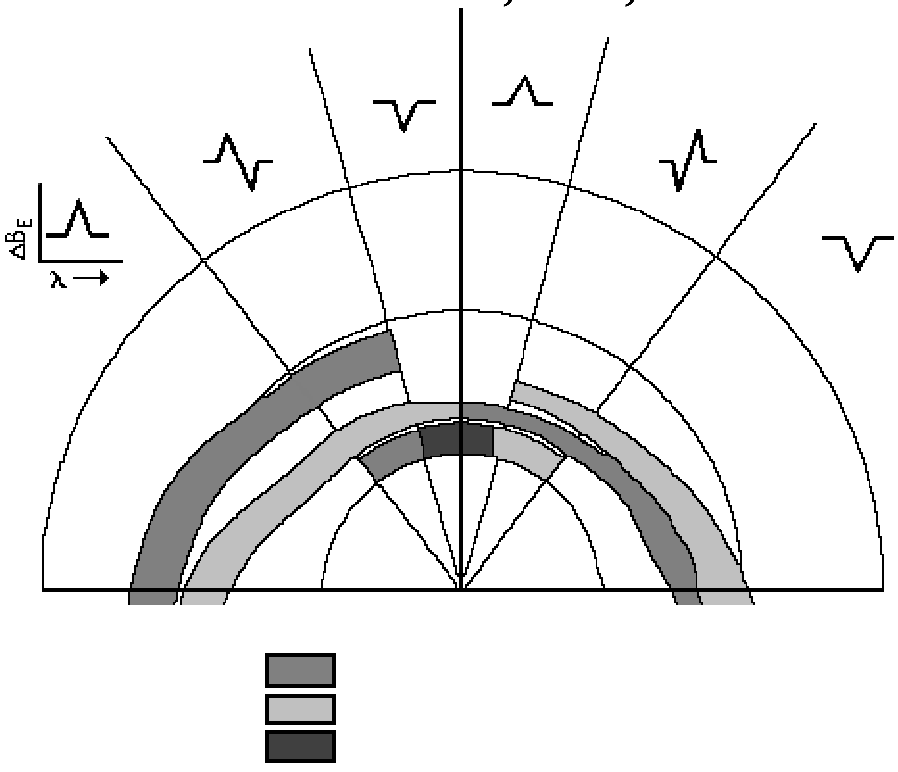
Large-scale system of FACs observed by TRIAD during the recovery (left) and expansion (right) phases of substorms

- **Small scale FACS associated with discrete auroral forms do not in this global-scale picture**
- **The infinite current sheet approximation**

Aurorae and Polar Cap

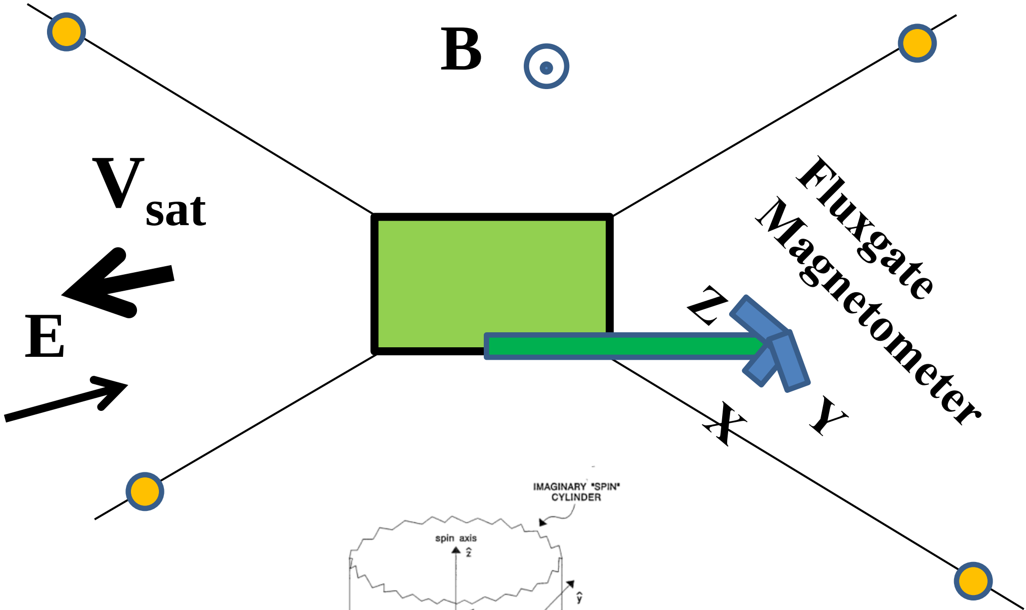
Dayside FAC System

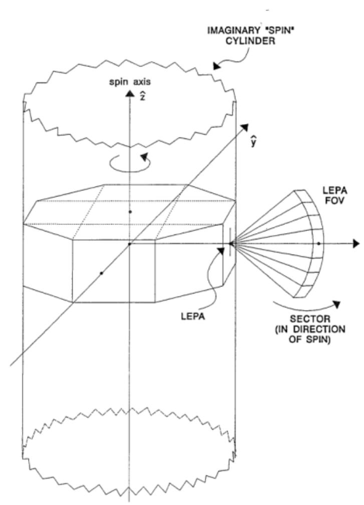
Erlandson et al., JGR, 1988



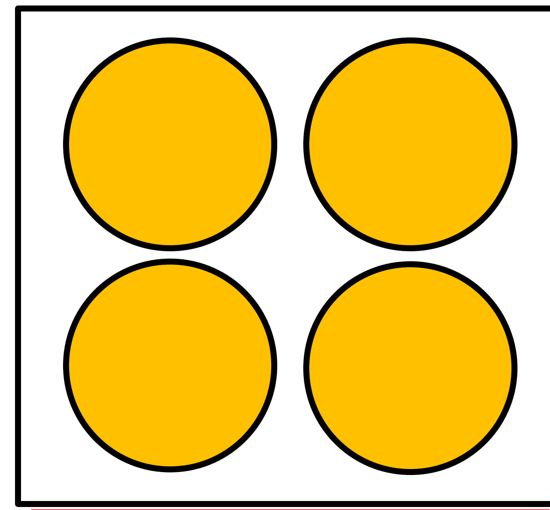
- From $\nabla \times B = \mu_0 j$ considerations, positive/ negative ΔB_E slopes indicate current into / out of ionosphere
- The existence / polarity of the cusp current system is IMF B_Y dependent
- *Erlandson* saw cusp currents as extensions of Region 1 past local noon.

Particle Electric / Magnetic Field Measurements



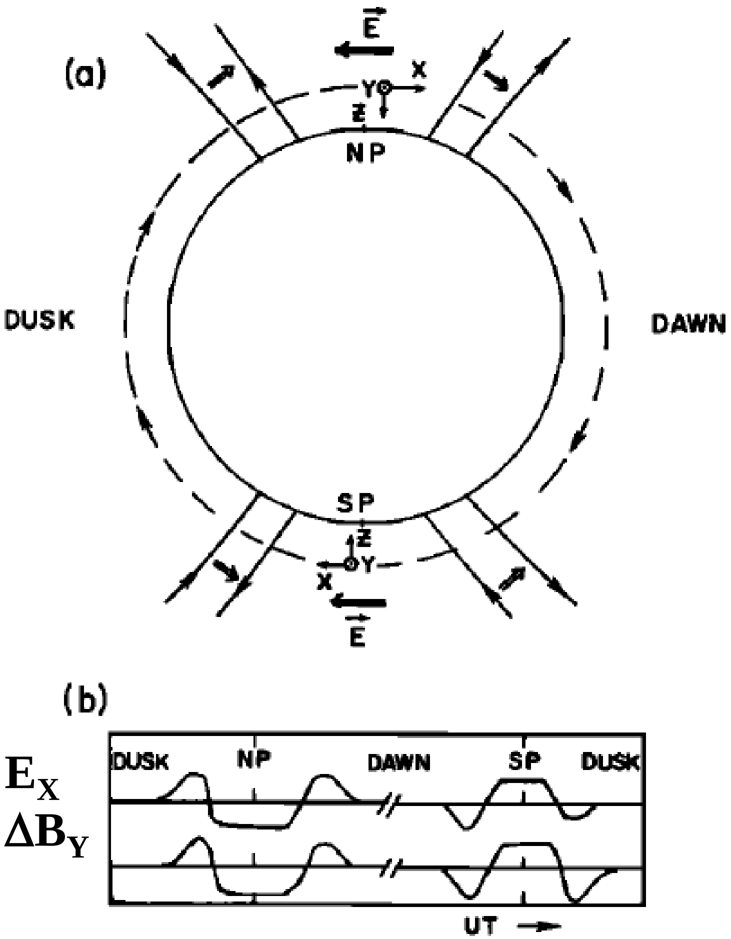


Electrostatic Analyzer



Ion Drift Meter
V_H, V_V

Aurorae and Polar Cap



E_X
ΔB_Y

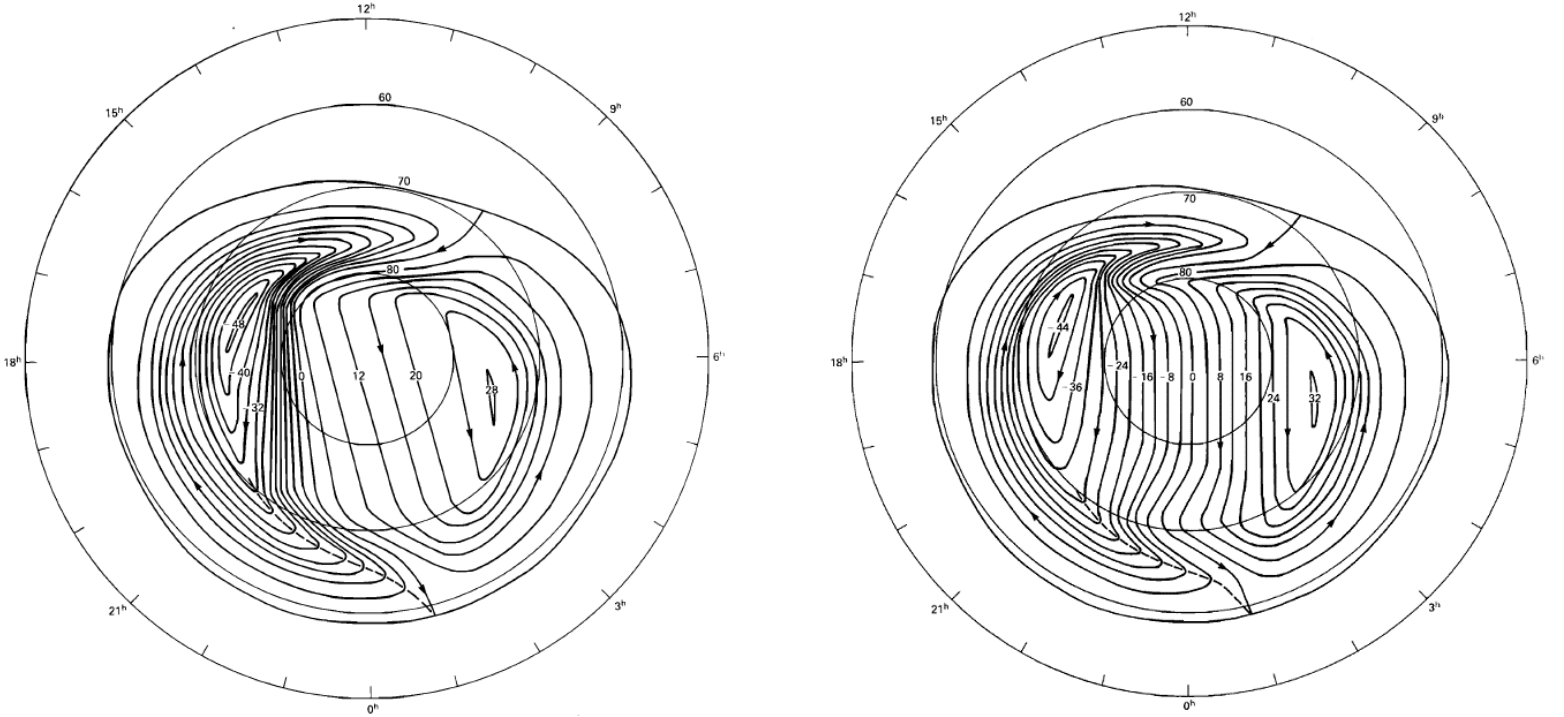
Earth cross section along the dawn-dusk meridian as viewed from the lunar surface

- **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
  ΔB_Y => positive in antisunward

Aurorae and Polar Cap

***Heppner-Maynard*, JGR, 1987**

Northern Hemisphere :
$B_Y < 0$, $B_Z < 0$

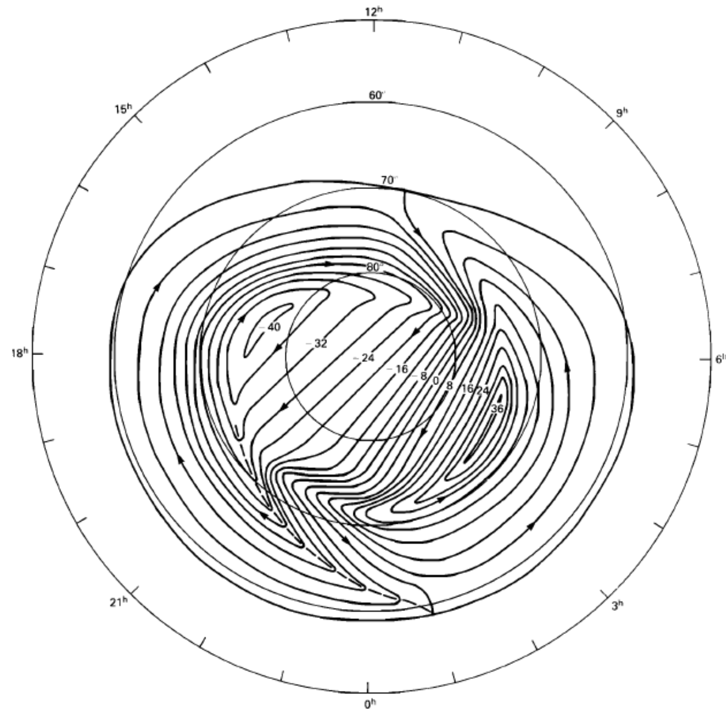


Southern Hemisphere :
$B_Y > 0$, $B_Z < 0$

Space Plasma & Field Sensors

Heppner-Maynard, JGR, 1987

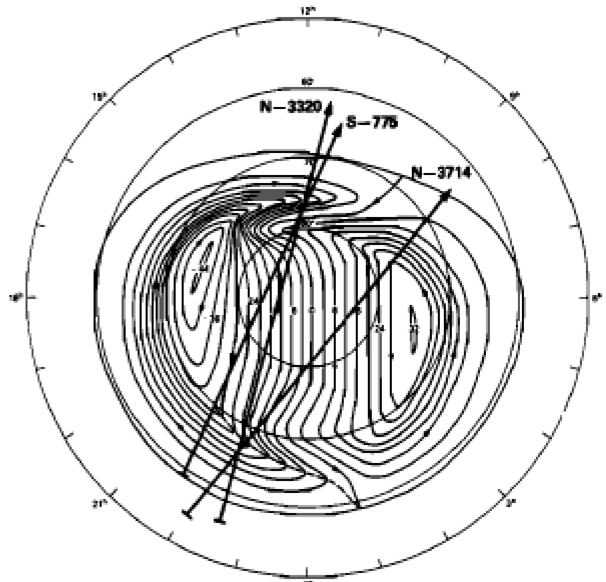
Northern Hemisphere:
$B_Y > 0$, $B_Z < 0$



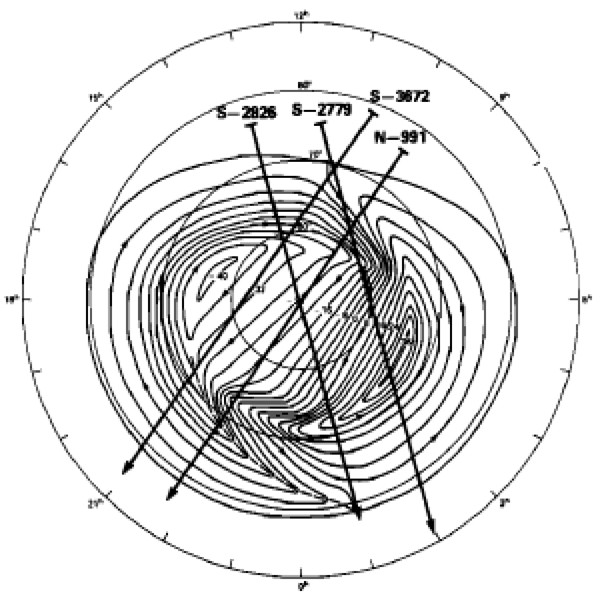
Southern Hemisphere:
$B_Y < 0$, $B_Z < 0$

Space Plasma & Field Sensors

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



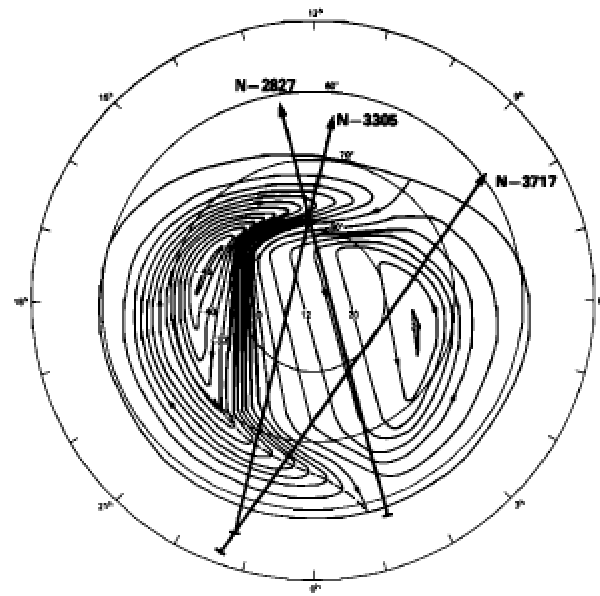
H-M "pattern recognition" technique later quantified by *Weimer* (JGR, 23,639, 1995)



Model BC

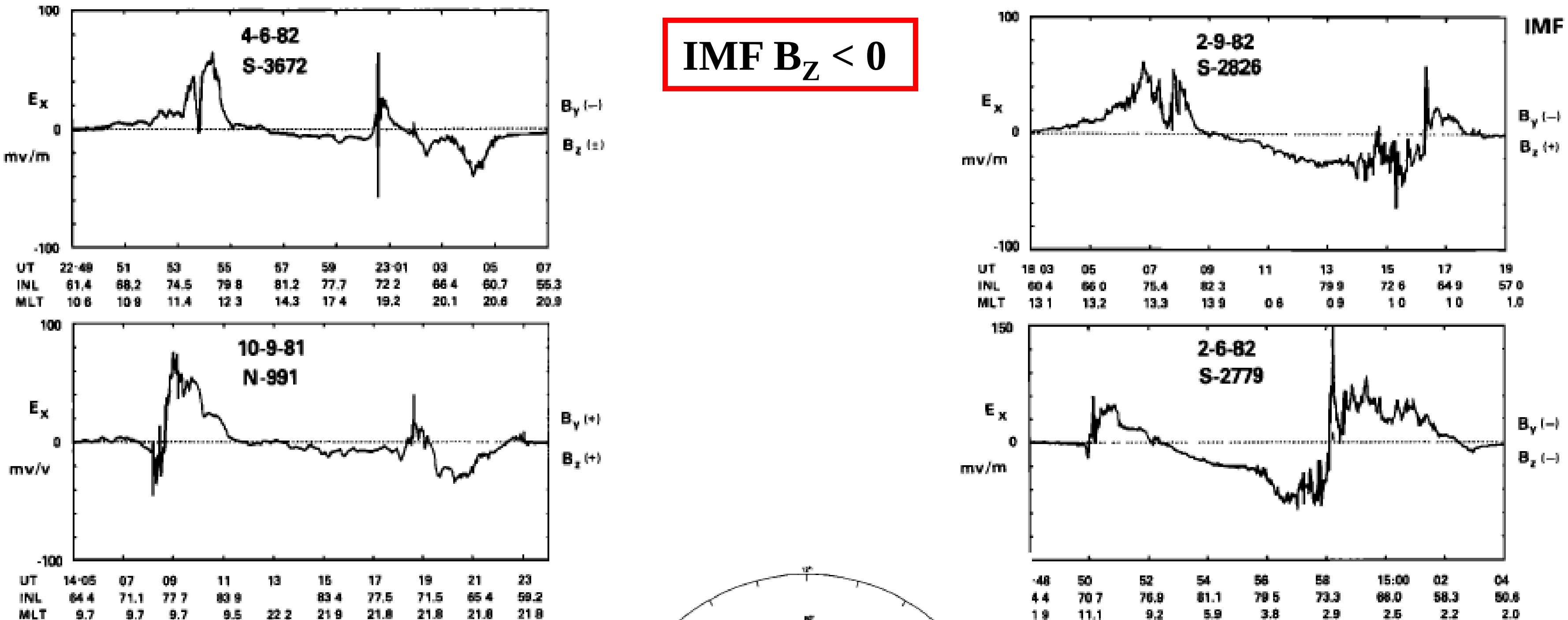
Model A

Appears in summer polar cap when IMF B_Y polarity would drive strong convection along dusk flank of polar cap



Model DE

Aurorae and Polar Cap

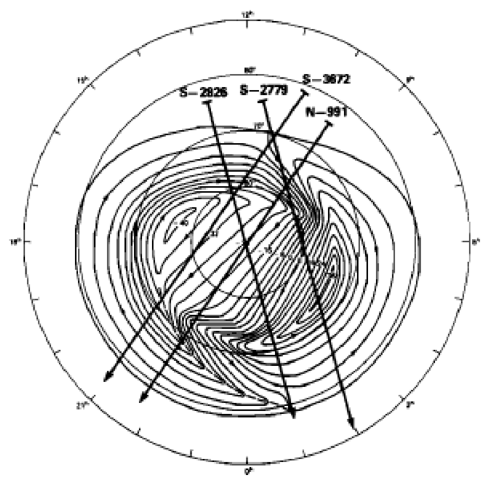


IMF $B_Z < 0$

Northern-hemisphere passes

IMF $B_Y > 0$

E_X is positive along direction of s/c motion



Model BC

Southern-hemisphere passes

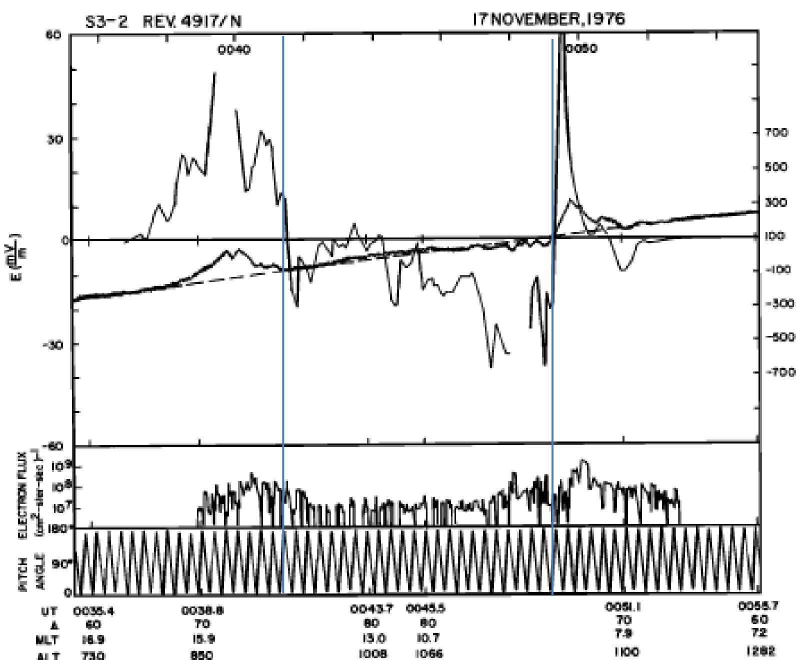
IMF $B_Y < 0$

Integrate E_X along trajectory, then connect equipotentials

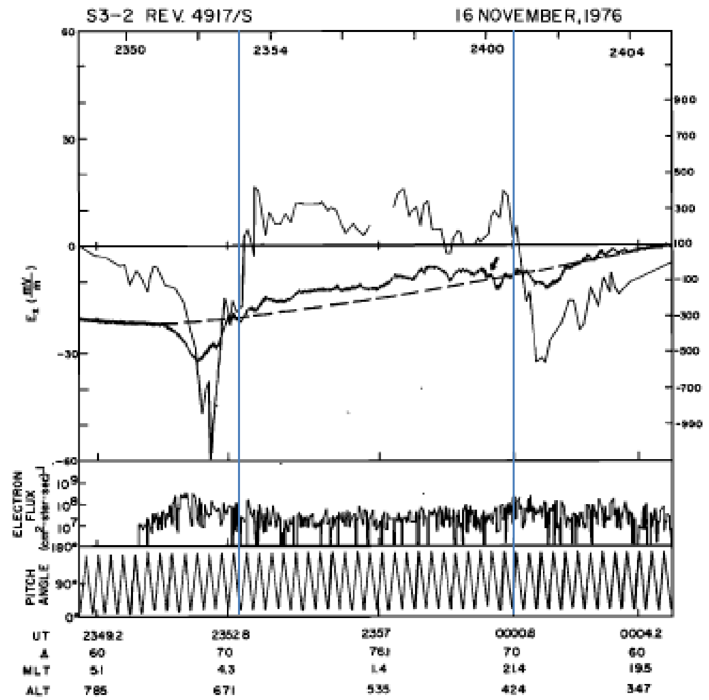
Aurorae and Polar Cap

Smiddy et al., JGR, 85, 6811 1980

Winter Hemisphere



Summer Hemisphere

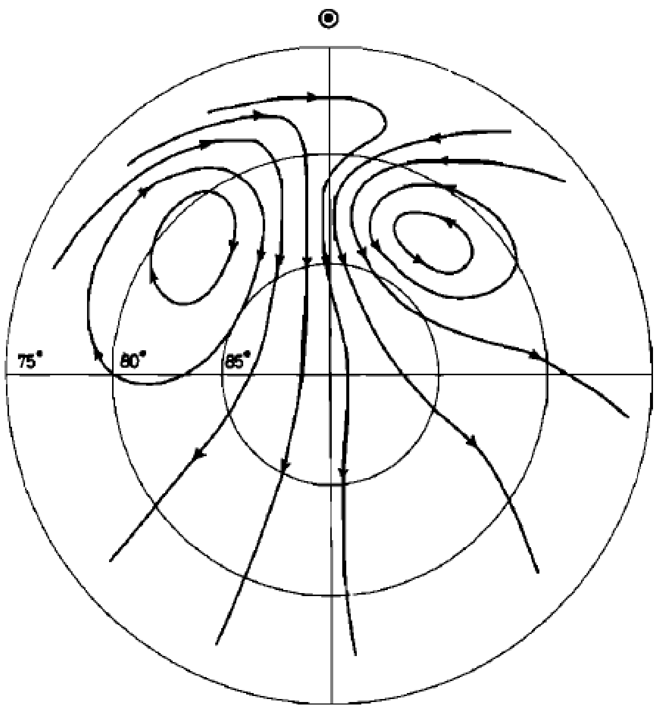


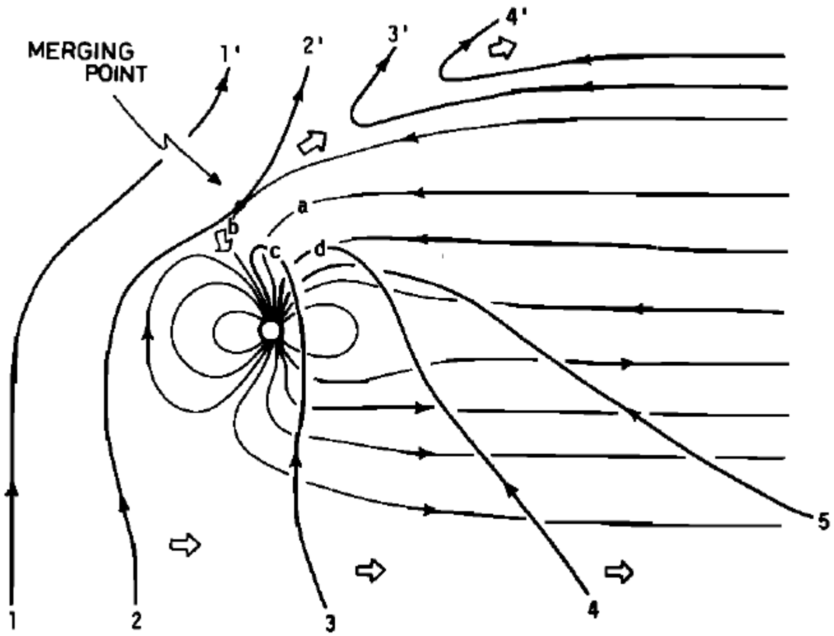
More current overcomes neutral drag on ion convection across summer polar cap

$$\vec{j} \times \vec{B} = \nu_{in}(\vec{V}_i - \vec{V}_n)$$

Aurorae and Polar Cap

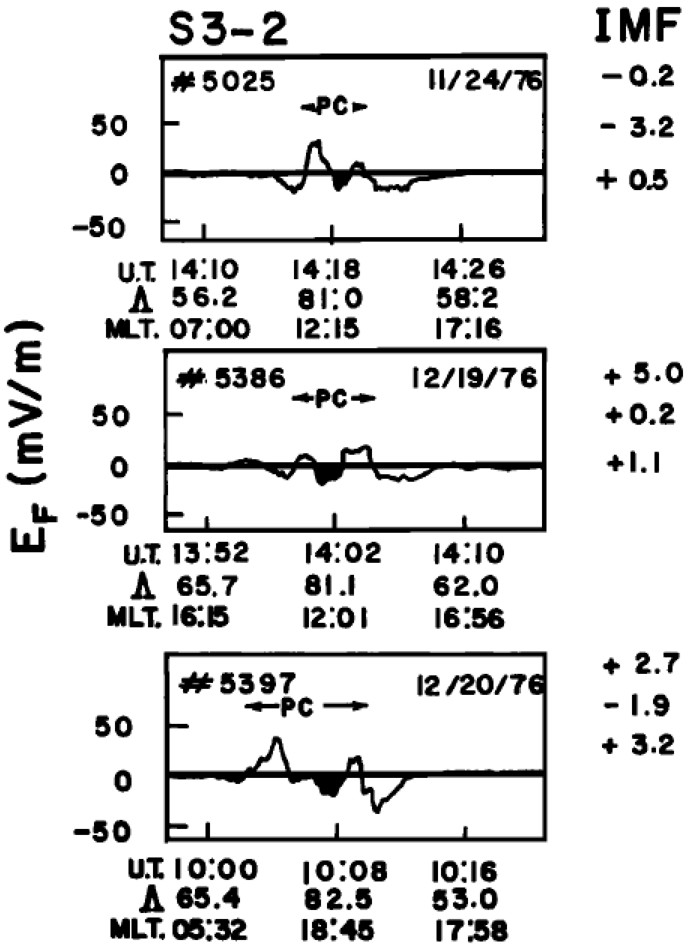
Equivalent current system and external driving with IMF $B_Z > 0$
***Maezawa*, JGR, 2289. 976**

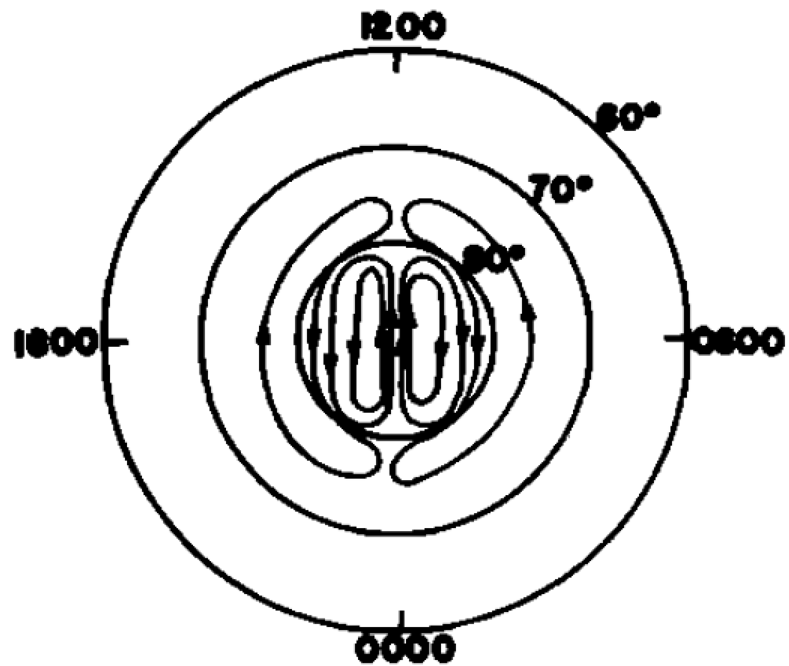




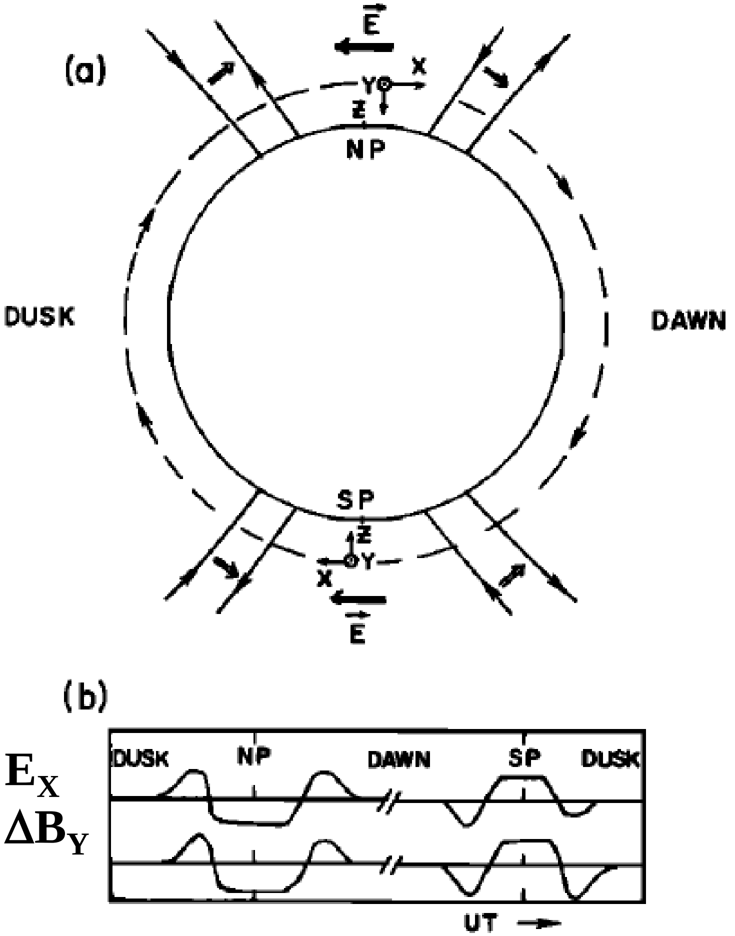
The NASA Explorer Series

***Burke et al.*, GRL, 21, 1979**





Aurorae and Polar Cap



Earth viewed from lunar surface

- **Before examining *E* and *B* data**

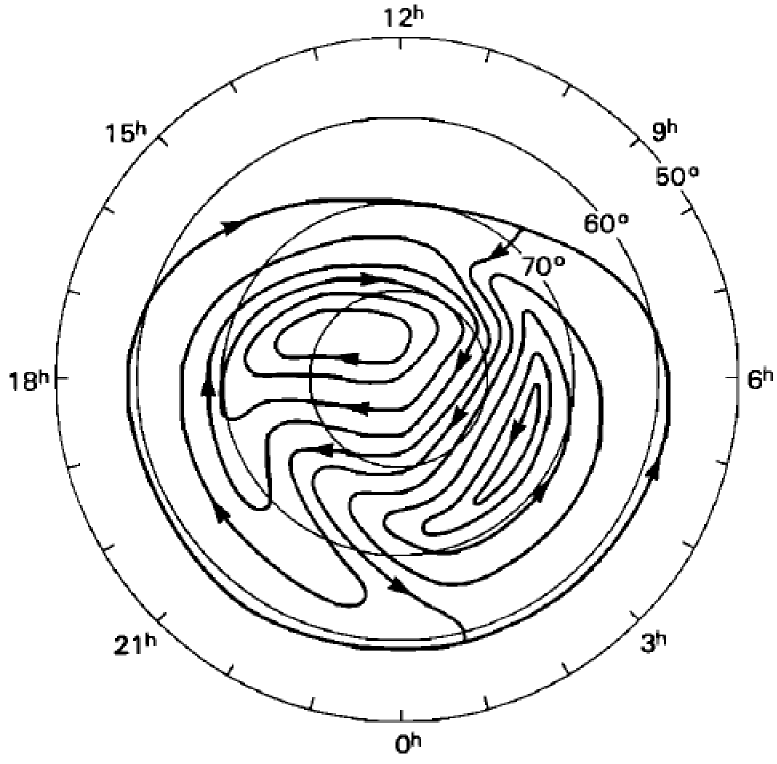
It is useful as a guide to think a bit about what we might expect to see in the measurements

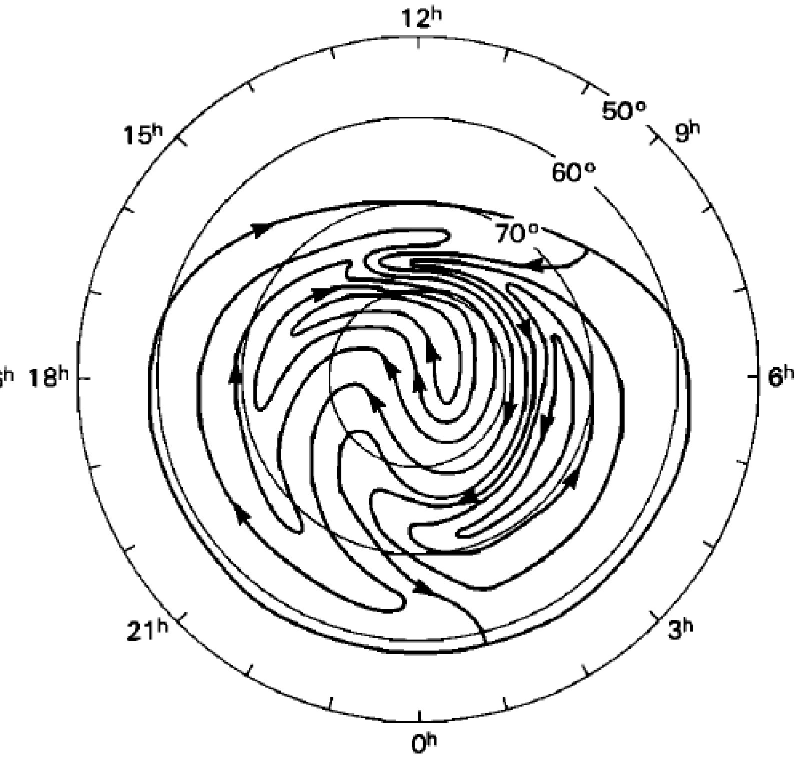
- **We consider a satellite in circular polar orbit**
- **That carries an electric field sensor and a magnetometer**

- **We assume that in the polar cap *E* is directed dawn to dusk**

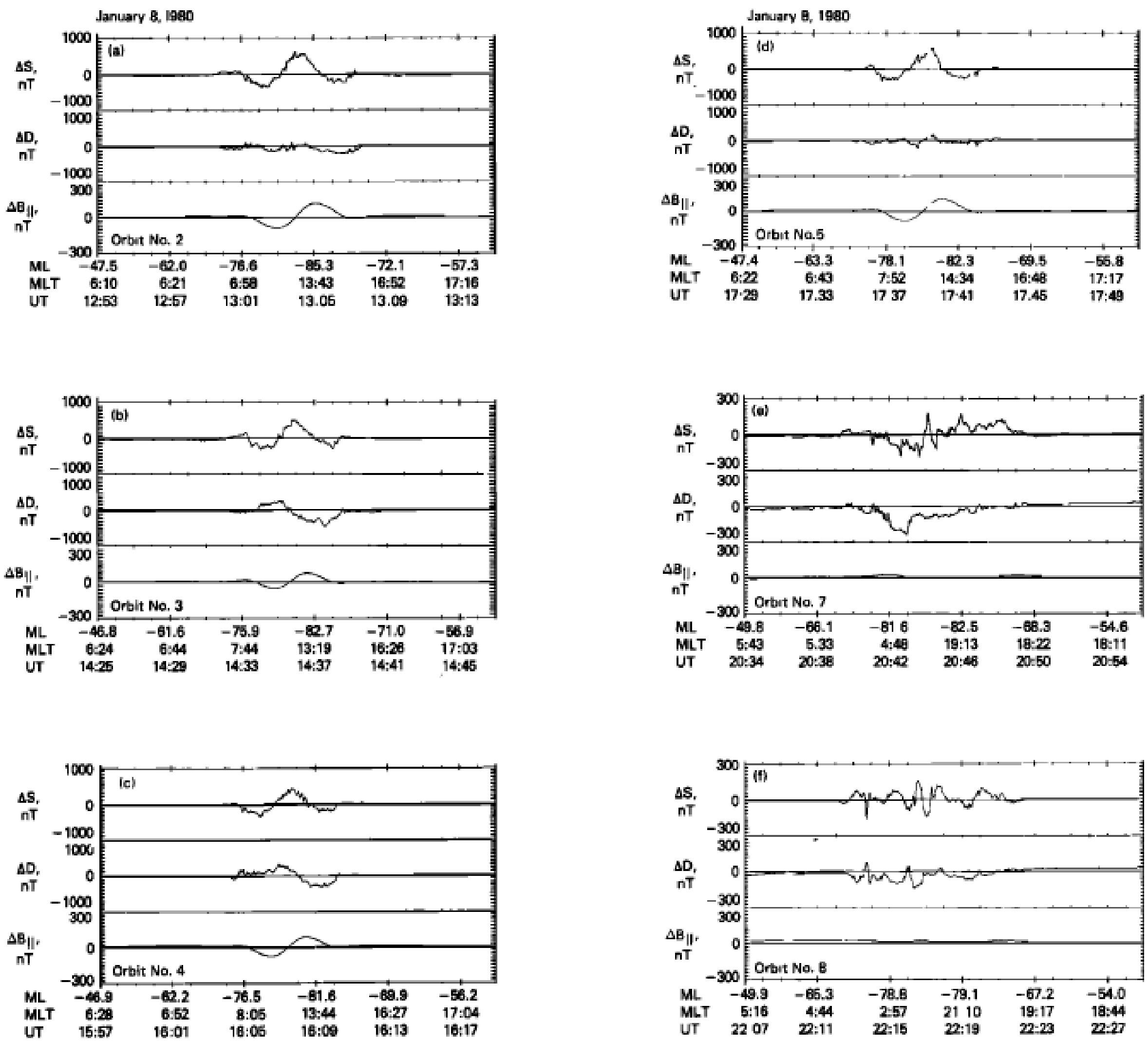
- **In the specified satellite centered coordinate system**
  E_X => positive along s/c velocity
  ΔB_Y => positive in antisunward

Distorted BC potential/convection patterns with IMF BZ "weakly" (left) and "strongly" (right) positive

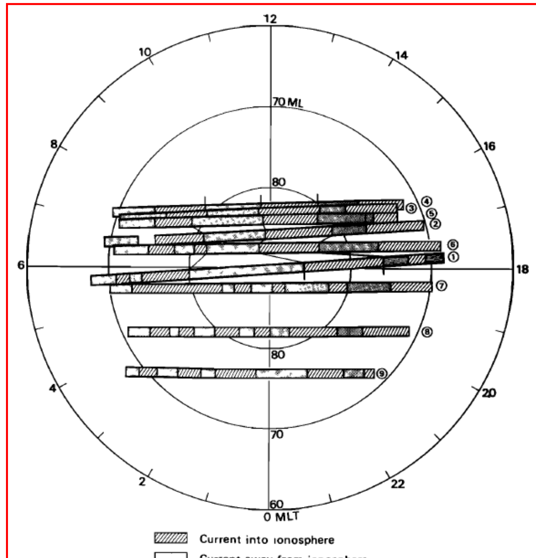




Aurorae and Polar Cap

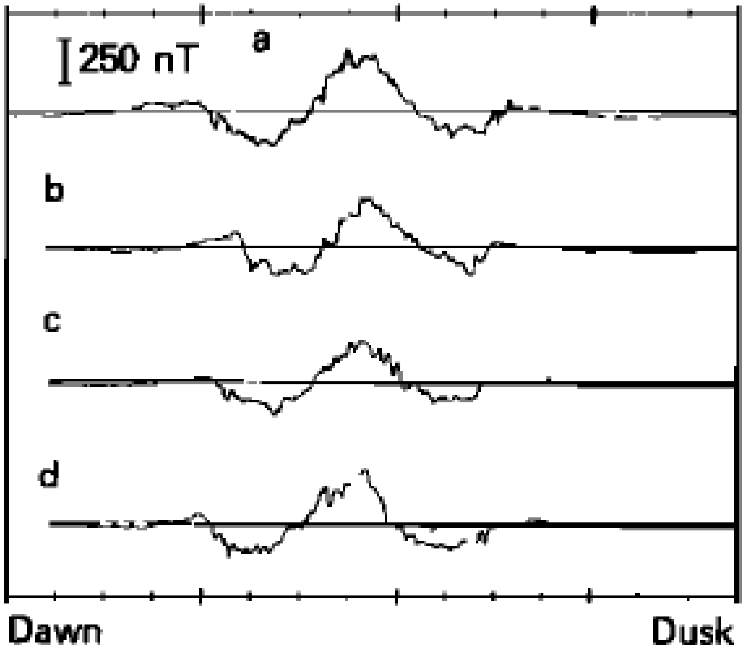


MAGSAT measurements acquired during six consecutive southern hemisphere passes on 8 January 1980 while IMF B_Z was strongly positive.
***Iijima et al.*, 7774, 1984**

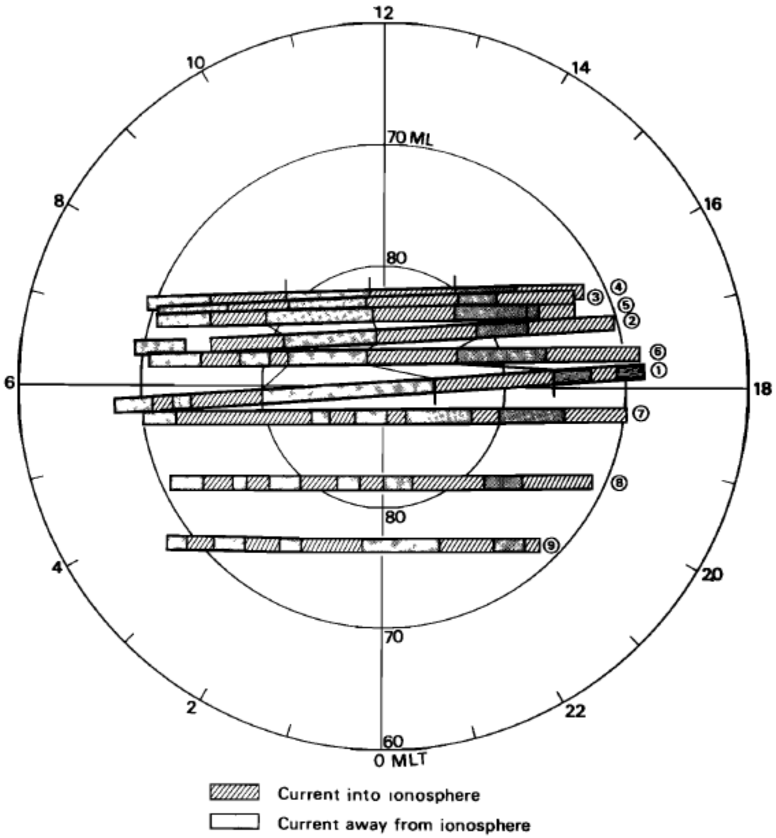


NBZ current system

Aurorae and Polar Cap



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

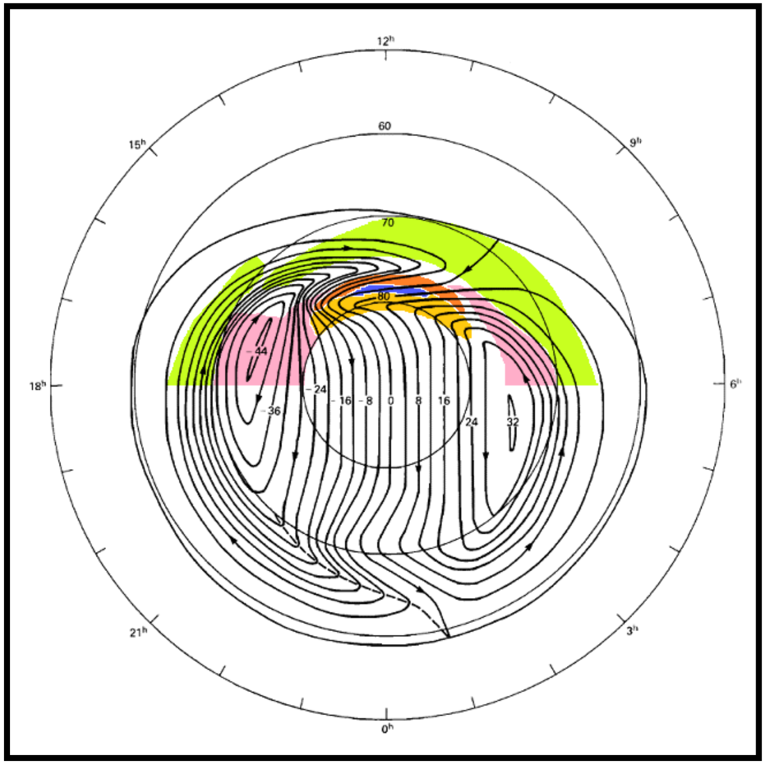


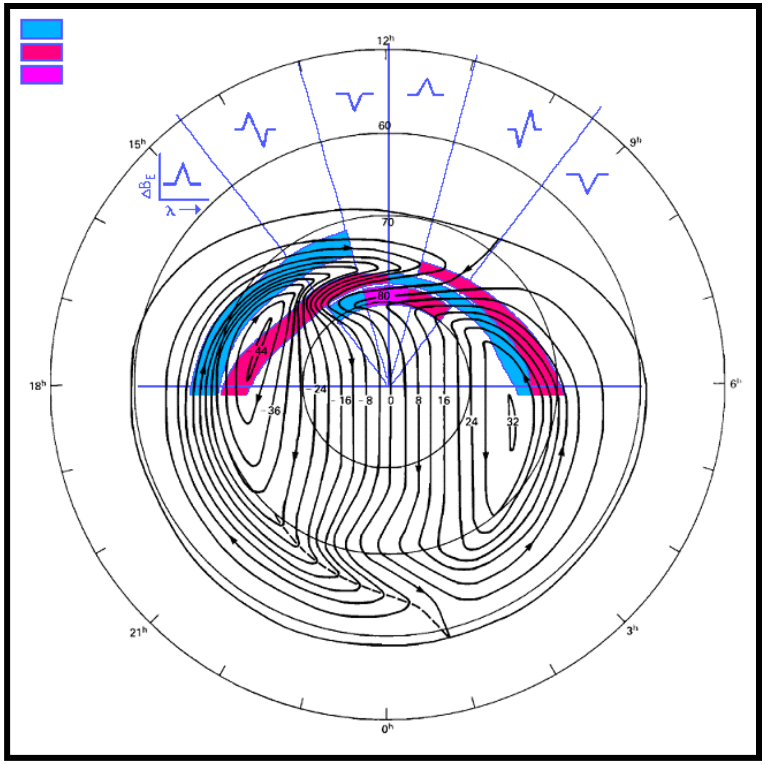
NBZ current system

Aurorae and Polar Cap

Dayside Precipitation Pattern
***Newell and Meng*, GRL, 1992**

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

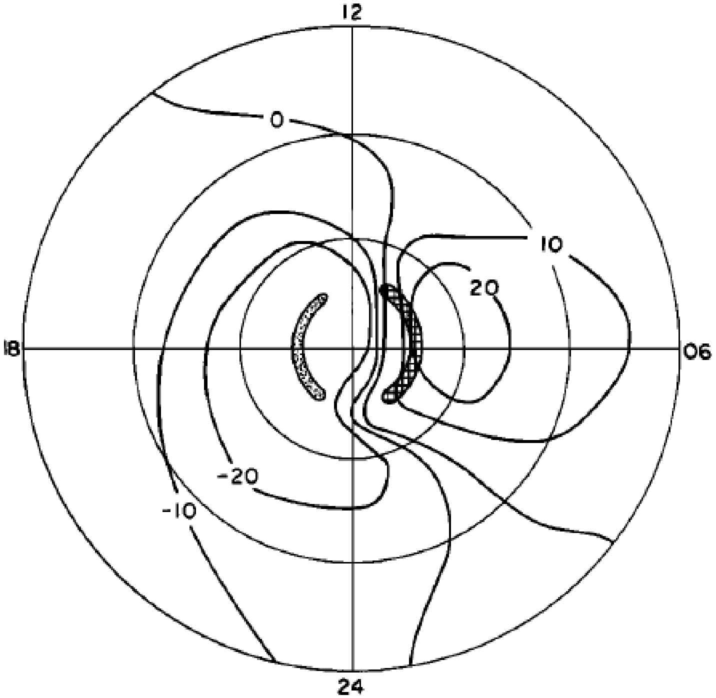




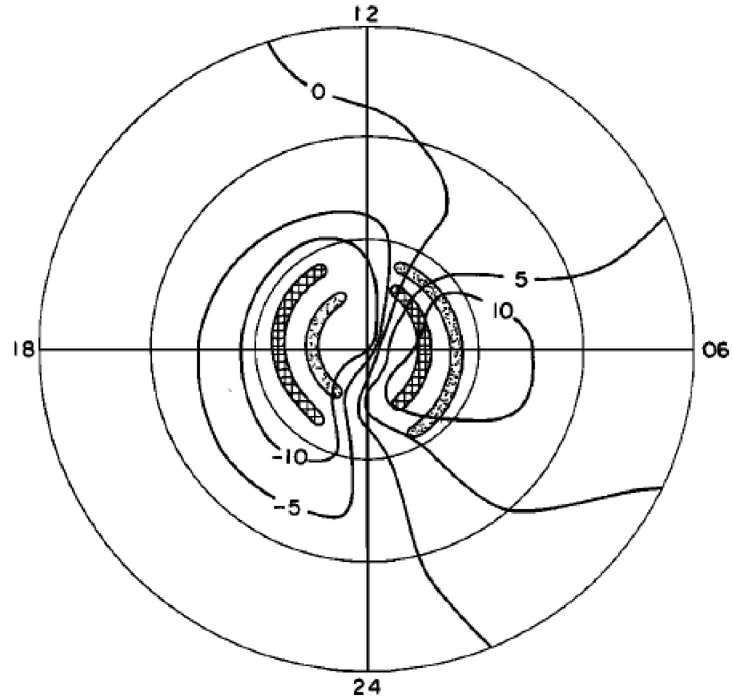
Heppner - Maynard Convection Patterns (JGR, 1987)

Aurorae and Polar Cap

Nopper and Carovillano, GRL 699, 1978



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



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

Wolf, R. A., Effects of Ionospheric Conductivity on Convective Flow of Plasma in the Magnetosphere, JGR, 75, 4677, 1970.

Aurorae and Polar Cap

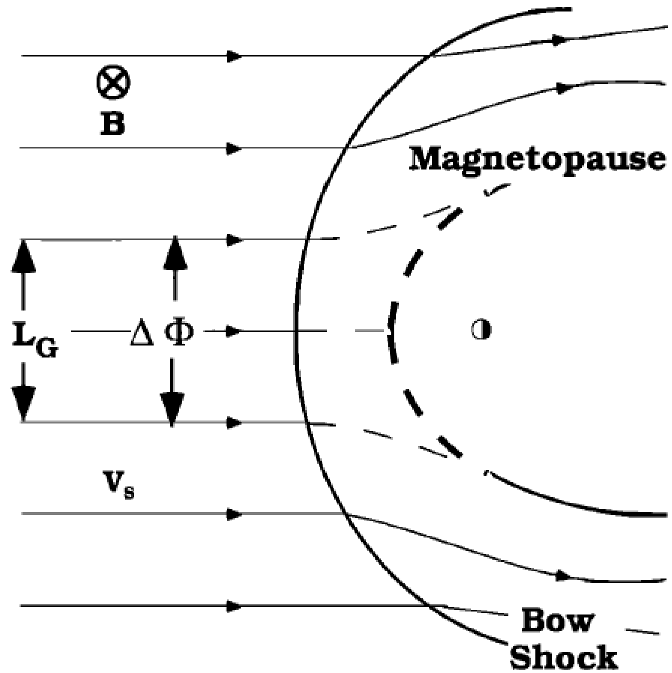
Burke, Weimer and Maynard,
JGR, 104, 9989, 1999.

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

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

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

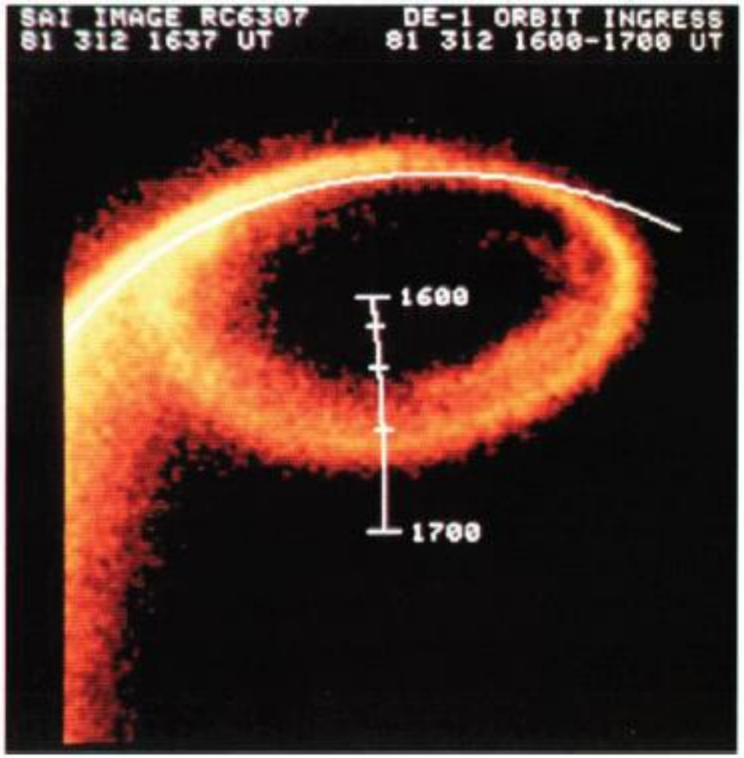
$$\theta = B_Z / B_T$$

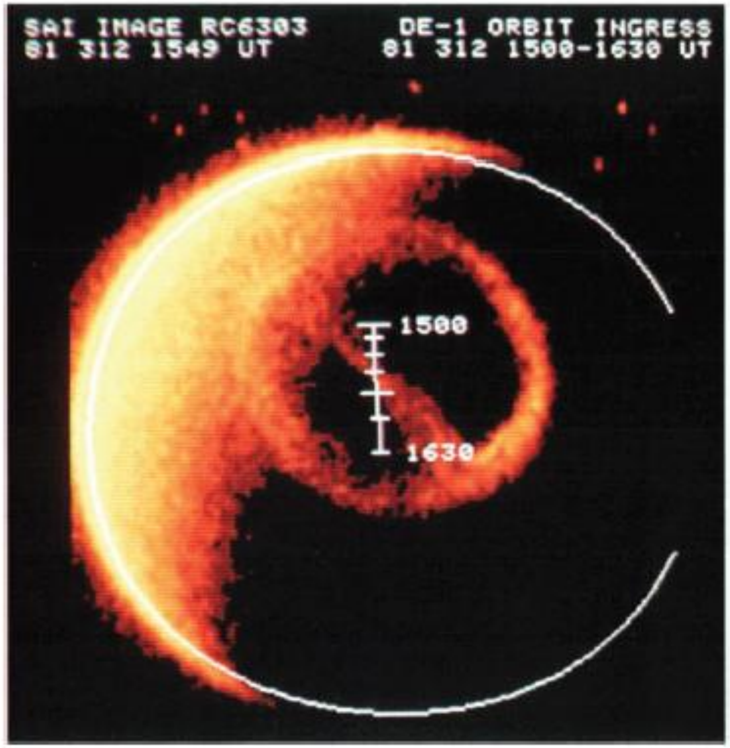


Interplanetary electric field given in mV/m.
Since 1 mV/m $\approx$ 6.4 kV/ R_E
L_G = width of the gate in solar wind (~ 3.5 R_E) through which geoeffective streamlines (equipotential) flow.

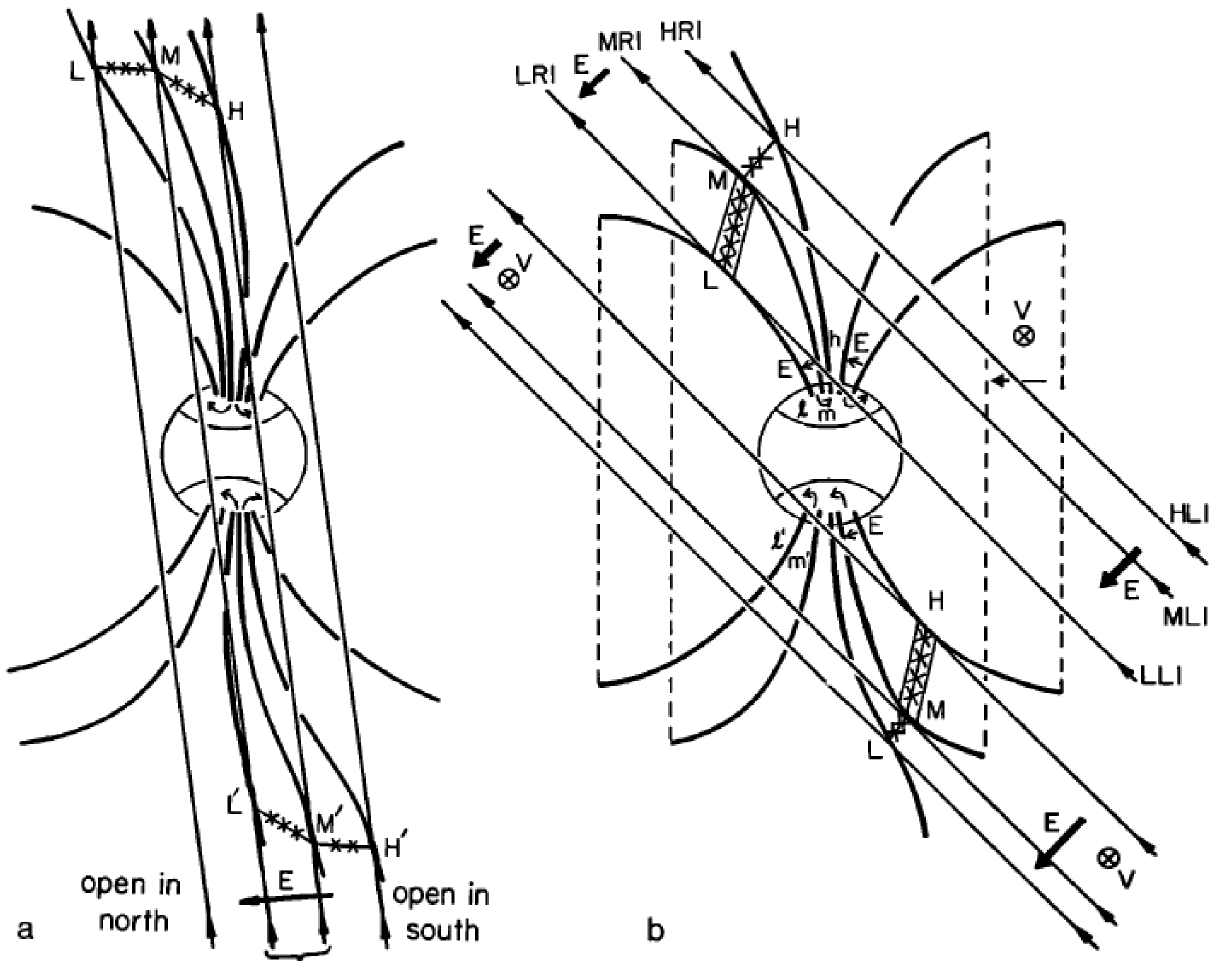
Aurorae and Polar Cap

Dynamics Explorer 1
135.6 nm image of
auroral oval and Theta aurora
***Frank et al.*, JGR, 1986**





Aurorae and Polar Cap



Reiff and Burch, **JGR 1595, 1985**

Aurorae and Polar Cap