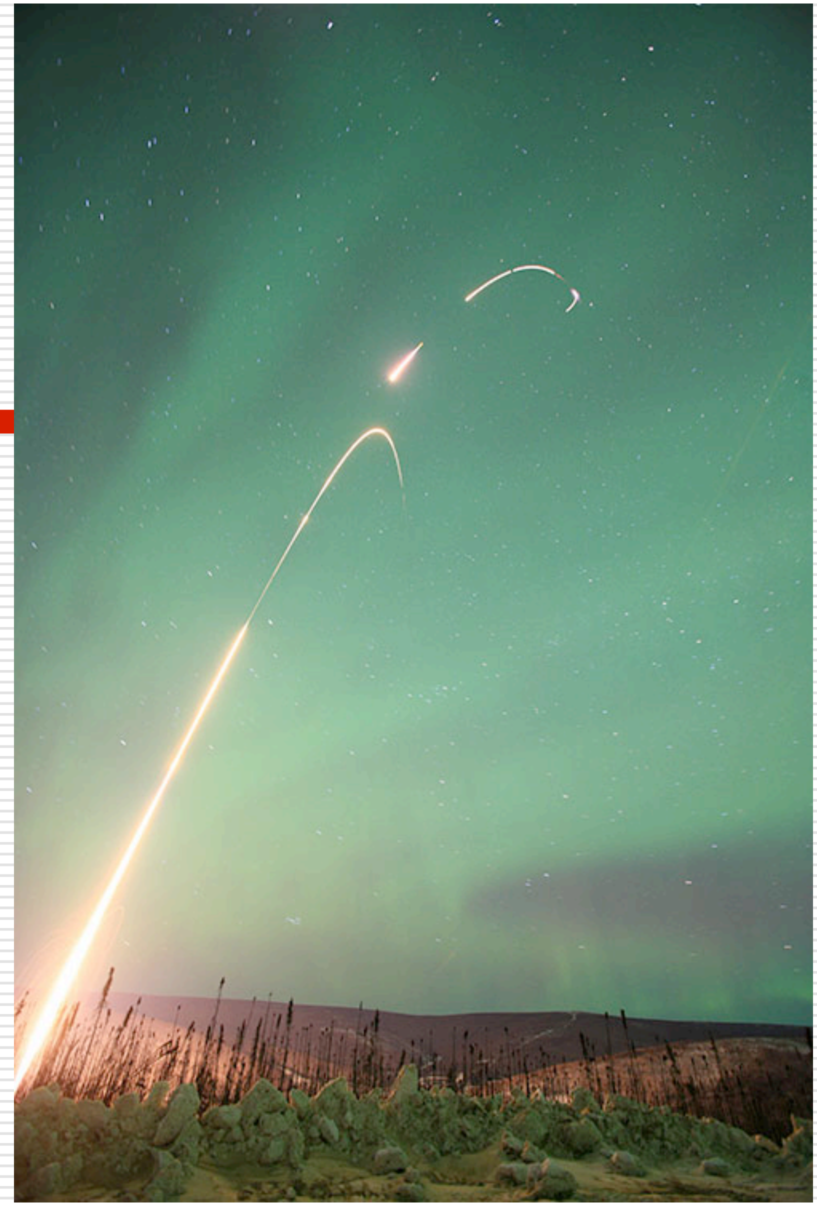
ROPA Launch, Fairbanks, AK. Feb.12 2007



GEM 2007 Student Tutorial

M-I Coupling

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Outline

- Magnetospheric currents
- Field-Aligned Currents (FACs)
  - R1/R2, mantle (cusp) currents, SCW
- Observation – FAST
- Alfven waves
- Examples – ground and satellite observations

What is M-I Coupling?

- Magnetosphere and ionosphere are closely linked together via magnetic field lines.
- Magnetospheric *electric fields* map down to the ionosphere, creating, e.g., plasma convection ($\mathbf{E} \times \mathbf{B}$ plasma drift), frictional heating and plasma instabilities.
- Auroral particle precipitation ionizes the high latitude atmosphere.
- Some of the cold ionospheric electrons and ions evaporate into the plasmasphere, plasma sheet and tail lobes: plasma outflow.

Magnetospheric Currents

Magnetopause current

Tail current

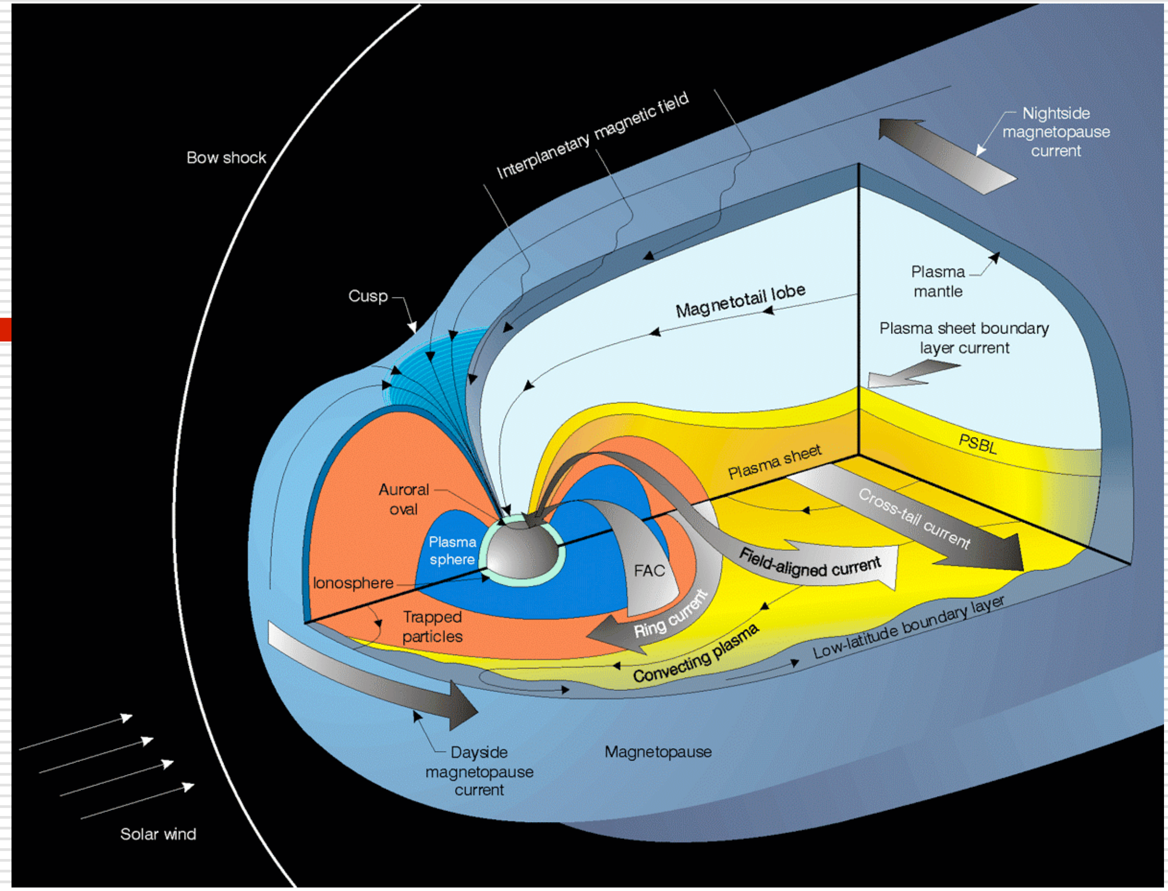
Neutral sheet current

Ring current

Auroral electrojets

Perp. currents

Field-aligned currents (FACs)

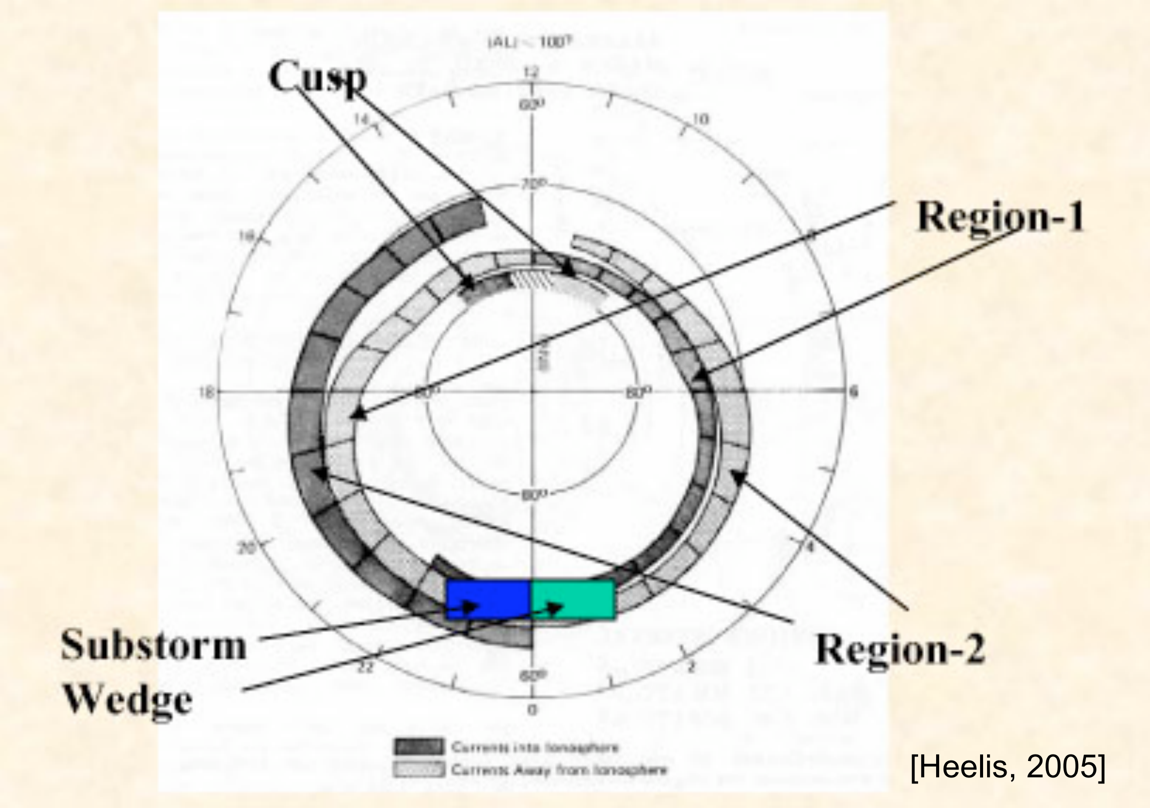


- Electric currents are very important for the dynamics of the Earth's plasma environment. They transport charge, mass, momentum and energy.
- The currents create magnetic fields, which may severely alter or distort any pre-existing fields.

Field-Aligned Currents (FACs)

- The field-aligned currents (called “Birkeland currents”) connect the magnetospheric current systems in the magnetosphere to those flowing in the polar ionosphere.
- The FACs are mainly carried by electrons and are essential for the exchange of energy and momentum between these regions.
- The ionosphere is itself a generator of current and the same principles apply; field-aligned currents flow into and out of the magnetosphere.
- Temporal changes are transmitted between the regions by Alfven waves.

FACs

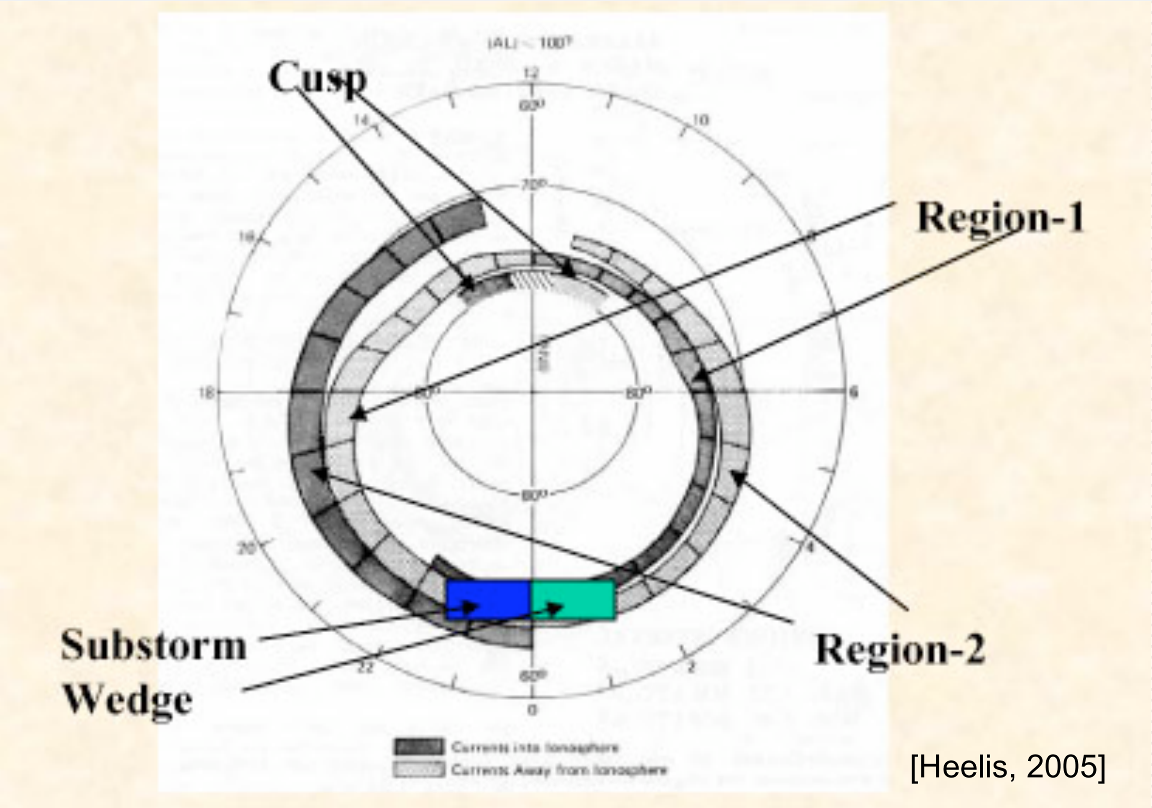


[Heelis, 2005]

1. Region1/2 currents: Expands to lower latitudes with increasing activity; current increase as the electric field associated with the solar wind/IMF increases.

- *Region 1 currents* – Near the poleward edge of the auroral zone, down into the ionosphere on the dawnside, up from the ionosphere on the duskside. Driver of ionospheric convection.
- *Region 2 currents* – equatorward part of the auroral zone. Flow up from the ionosphere on the dawnside, down into the ionosphere on the duskside.

FACs

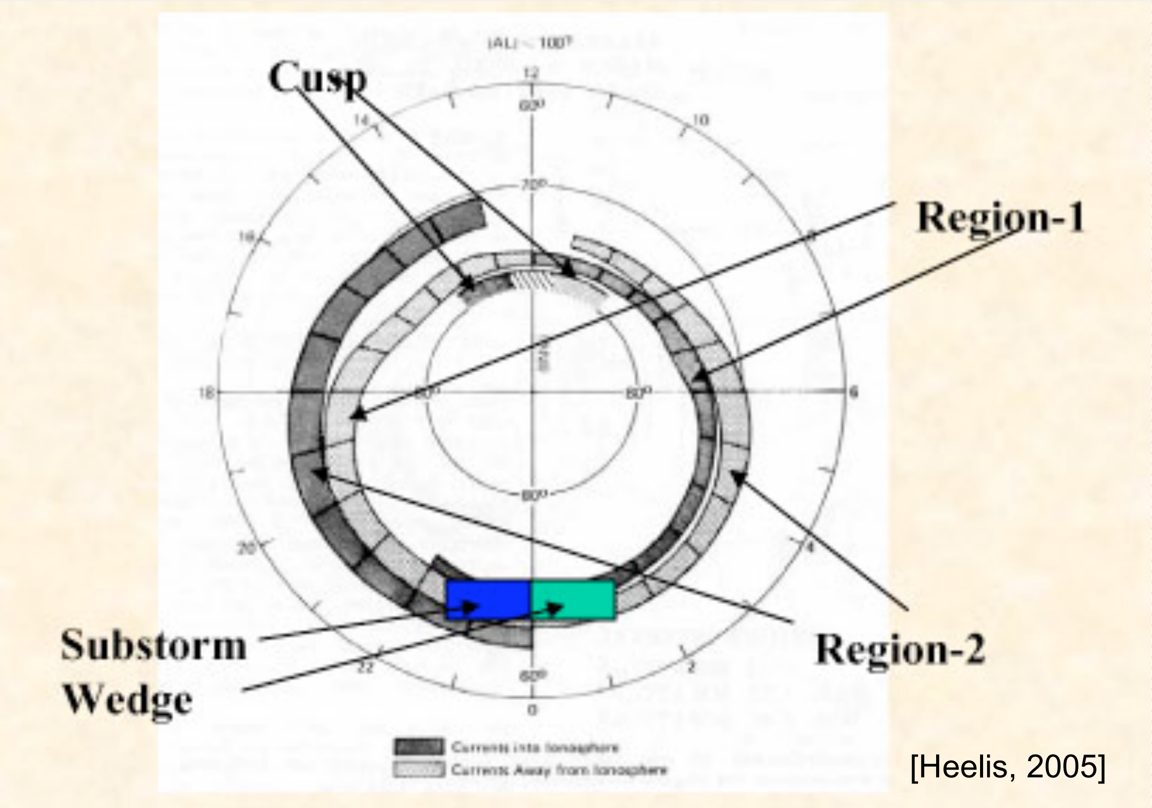


[Heelis, 2005]

2. Mantle(or called cusp currents)/NBZ (northward Bz) currents

- Poleward of the R1 near local noon, Current directions opposite to the adjacent R1 currents.
- Strong IMF By effect: for By > 0 predominantly upward in the northern hemisphere and downward in the southern, and the other way round for By < 0
- Strong IMF Bz effect
- Bz < 0: mantle currents - well localized, weak currents
- Bz > 0: NBZ currents - expand and become as strong as the weakened R1/R2 currents

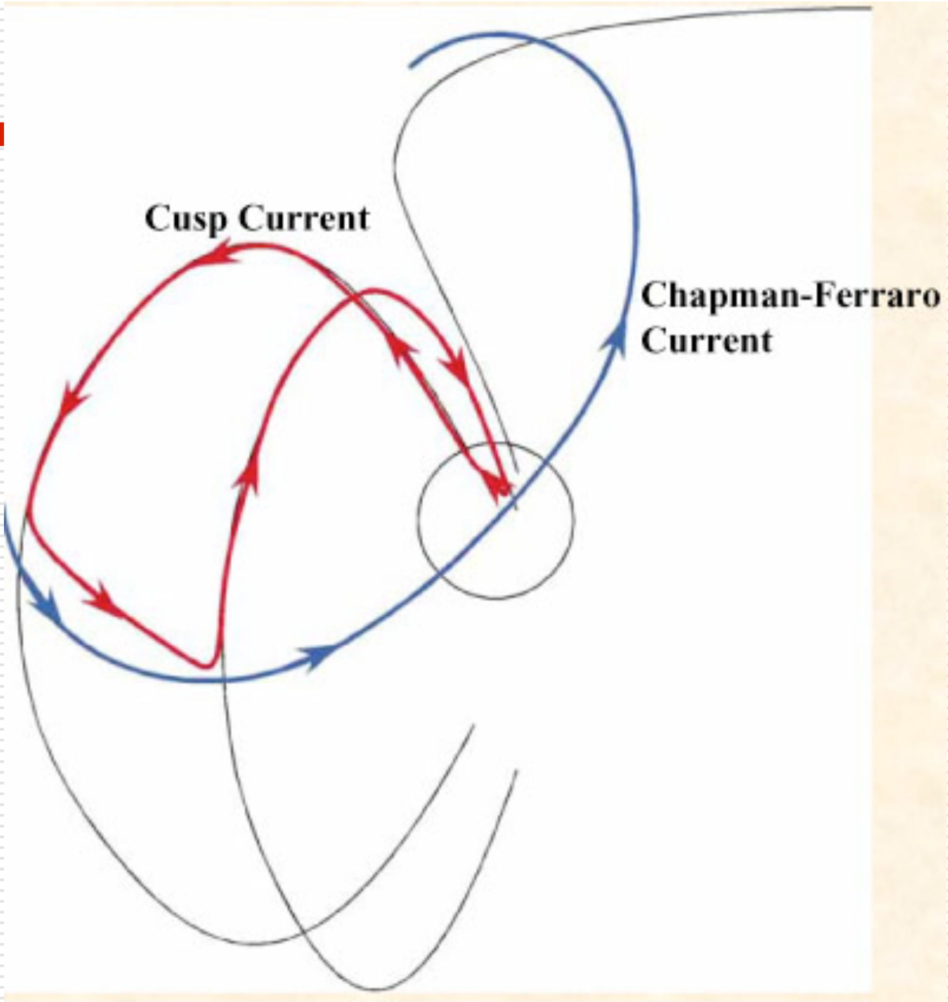
FACs



3. Substorm current wedge

Cusp Current

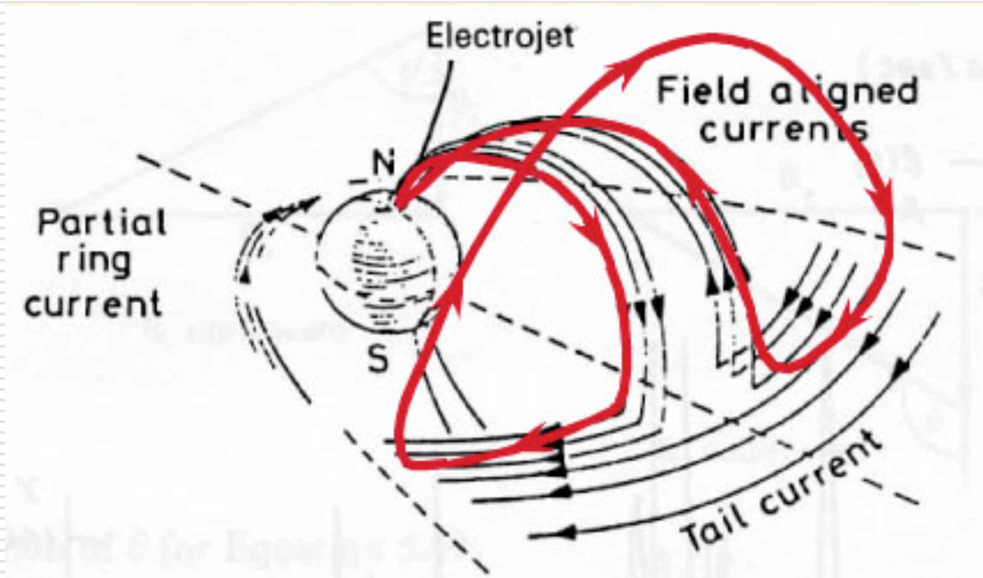
- The signature of the dayside interaction of the interplanetary magnetic field with the geomagnetic field.
- A variation in the configuration of the cusp currents is strongly dependent on IMF By.
- Cusp currents decrease the C-F current at high latitudes where it is replaced by the Region 1 current closure path.



[Heelis, 2005]

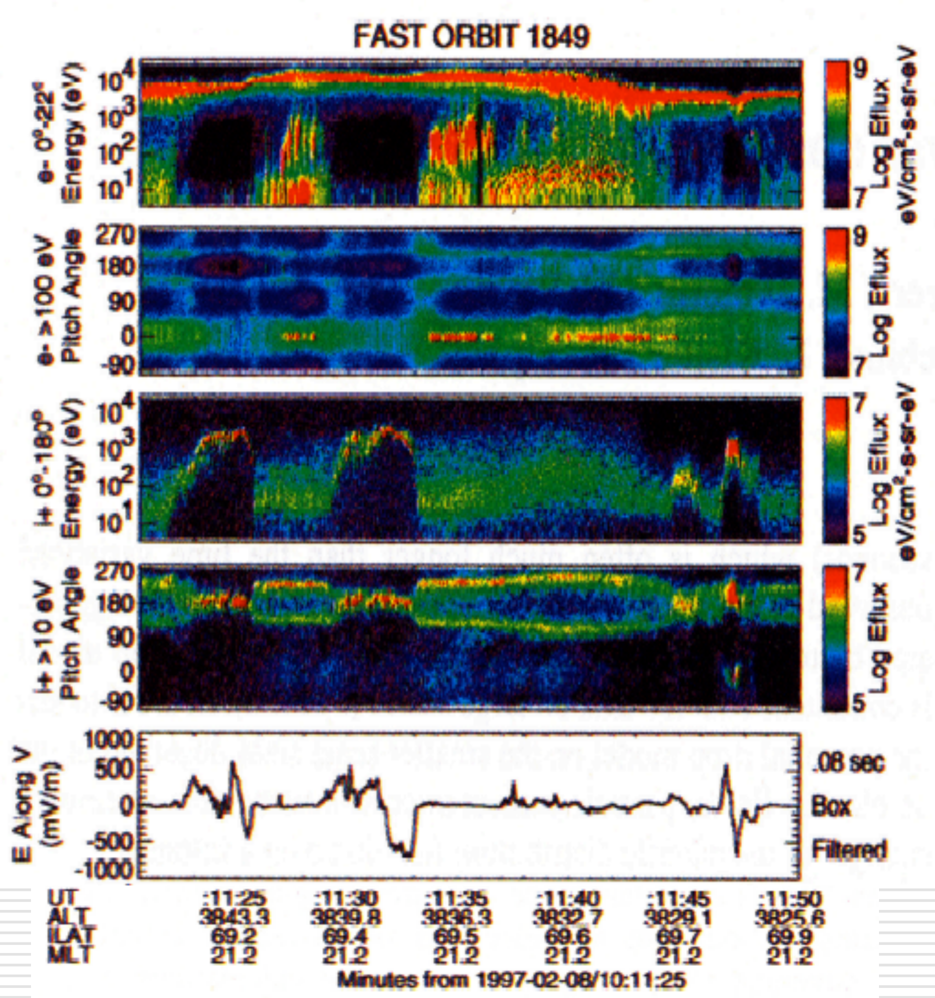
Substorm Current Wedge

- Plasma sheet thining can be associated with a diversion of some portion of the neutral sheet current through the ionosphere.
- This process occurs during a “magnetic substorm” and the current loop is called a “substorm current wedge”.



[Heelis, 2005]

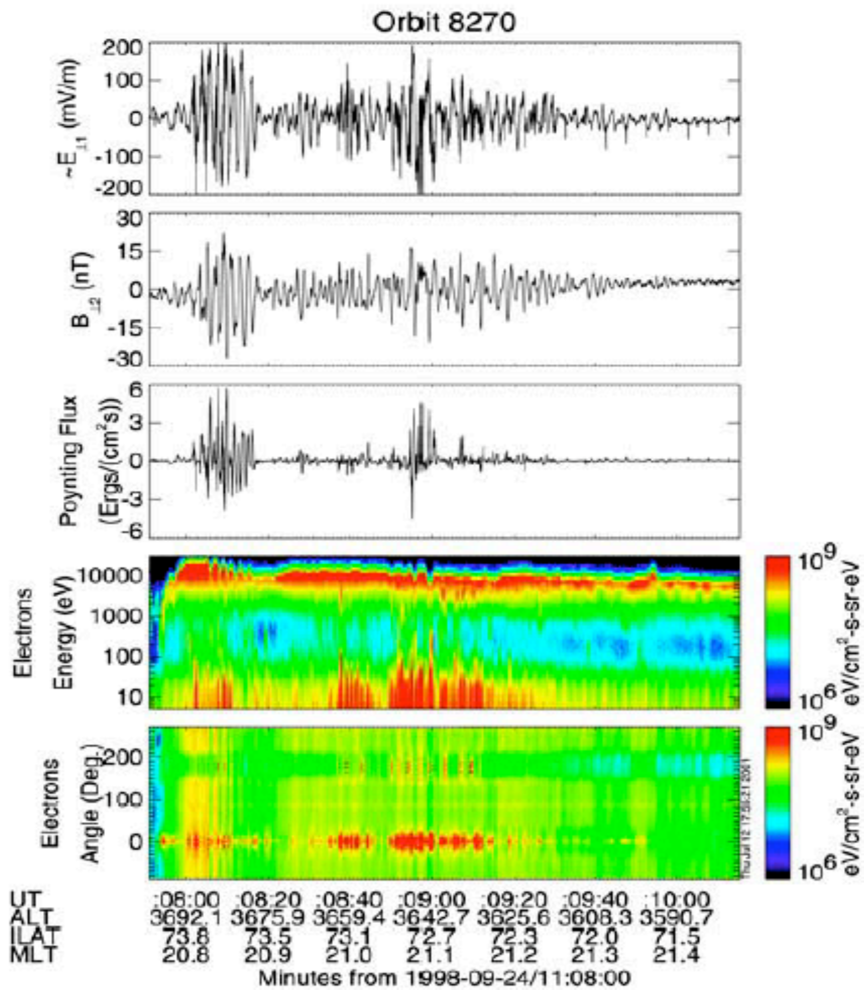
Recent Observations from FAST Satellite



- 30 seconds of data from the FAST (Fast Auroral SnapshoT) satellite.
- Top 4 panels give energy and pitch angle of electrons and ions (180 degrees is upward).
- Next is perpendicular electric field. Strong perpendicular fields always are seen in auroral zone.

[McFadden et al., 1998]

Field-Aligned Acceleration on FAST Satellite



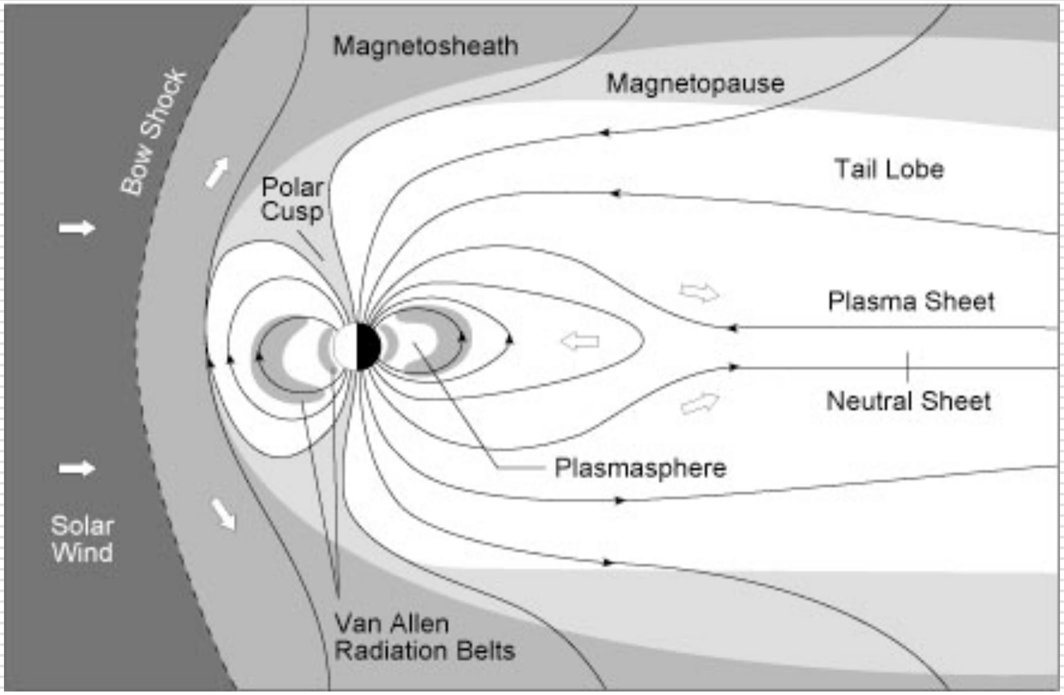
- Strong low energy electron fluxes (red regions at bottom of panel 4) which are field-aligned (0 degree pitch angle in panel 5). [Chaston et al., 1999].

- These particle fluxes are associated with strong Alfvén waves (top 3 panels: electric field, magnetic field, and Poynting flux), suggesting wave acceleration.

Instruments

- Electric field measurements – intensity (V/m)
- Magnetic field measurements – intensity (nT or nT/s)
- Particle measurements - energy (eV), pitch angle dist., etc.
- Imager (visible, X-ray, UV, IR…)

How are Alfven waves produced?

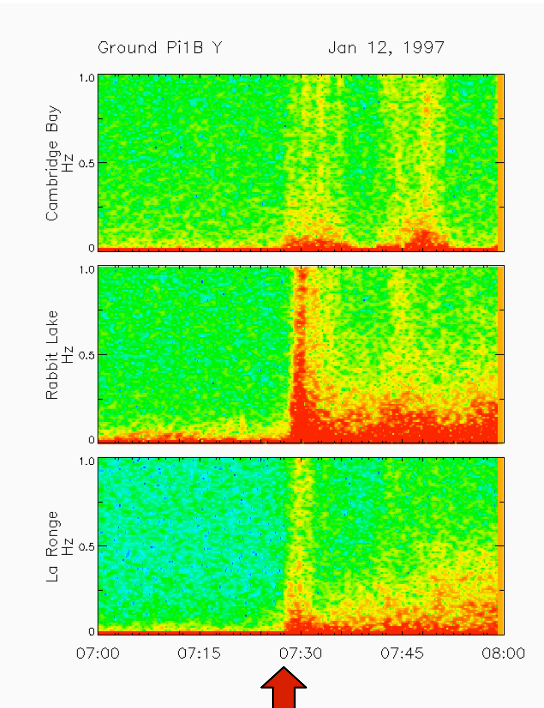


- Linear mode conversion
- Reconnection at distant neutral line
- Bursty Bulk Flows (BBF or fast flows) at substorm onset

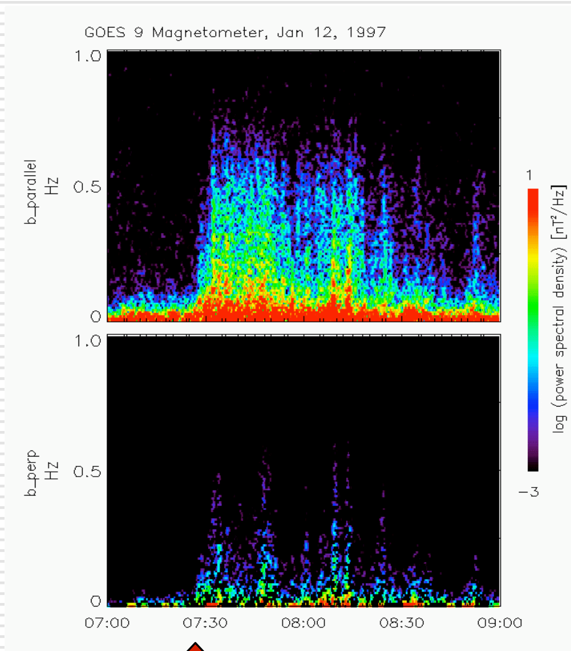
- Time-dependent transmission of electromagnetic energy is accomplished by Alfvén waves.
- Strong Alfvénic Poynting flux observed at plasma sheet boundary: leads to field-aligned acceleration of electrons [Lysak, 2003].

- **Observation #1**: Simultaneous observations of Pi1B pulsations (ULF broadband irregular bursts at 0.025 ~ 1 Hz) using ground-based and satellite-borne magnetometers (GOES and FAST) at substorm onset (magnetic reconnection) on Jan. 12. 1997 07:28 UT.

Ground magnetometer



GOES 9 satellite magnetometer



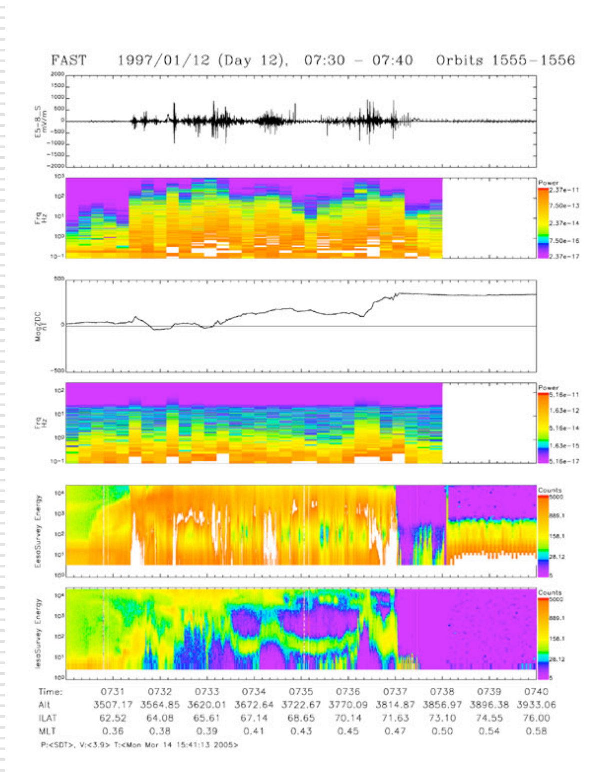
FAST satellite magnetometer

E

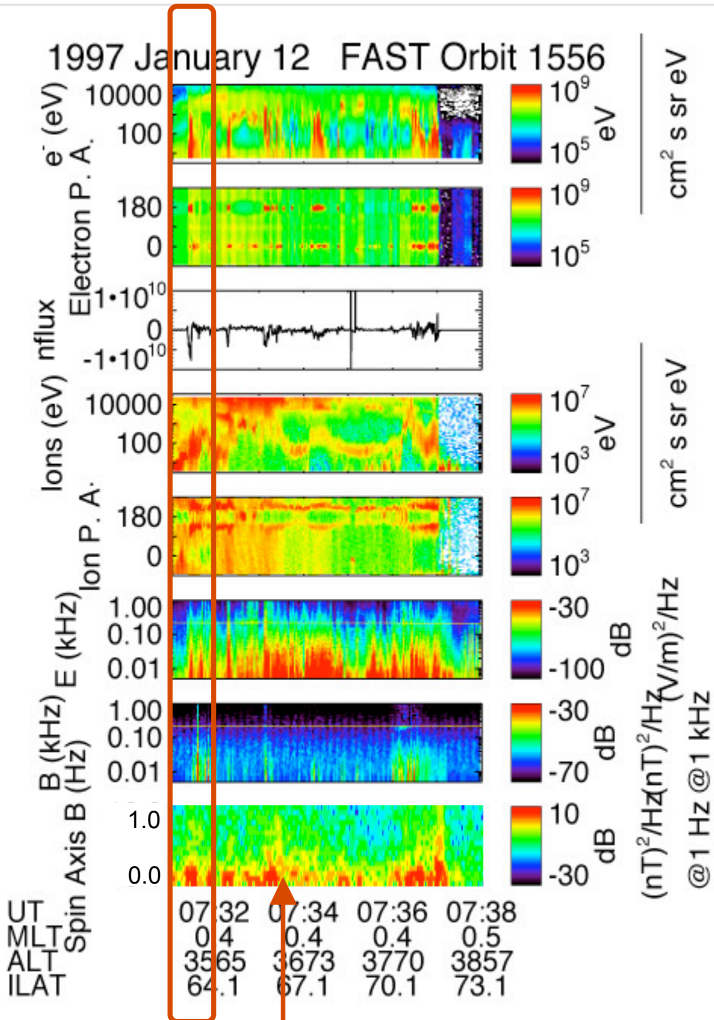
B_Z

e^-

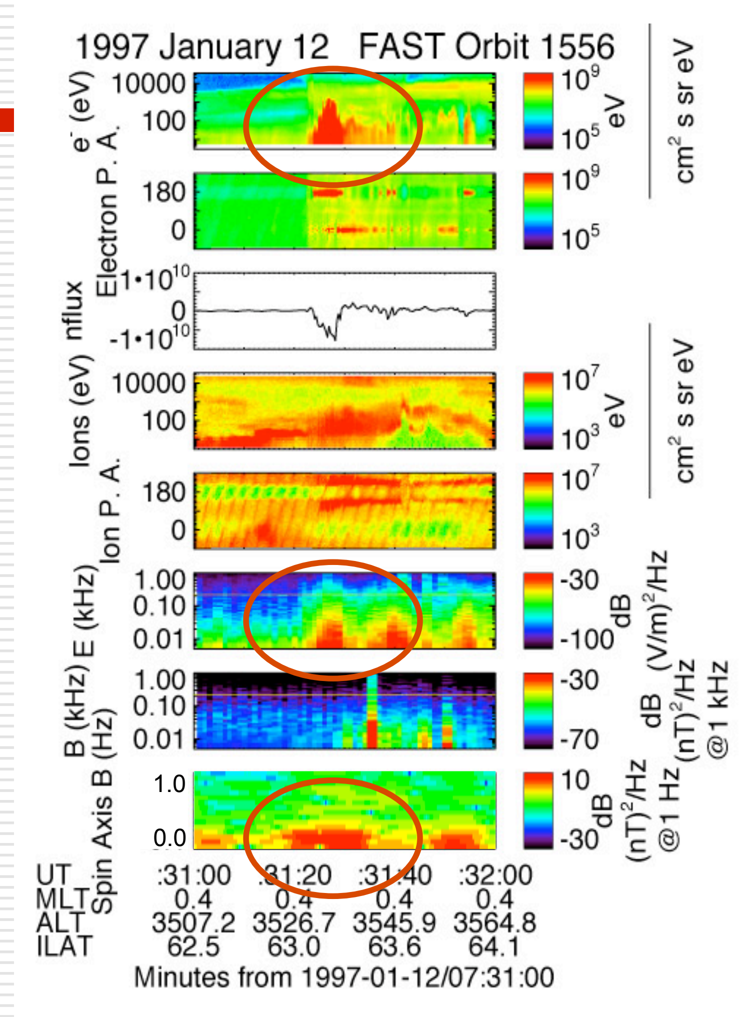
Ion



- **Observation #1**: Simultaneous observations of Pi1B pulsations using ground-based and satellite-borne magnetometers (GOES and FAST) at substorm onset (magnetic reconnection) on Jan. 12. 1997 07:28 UT.

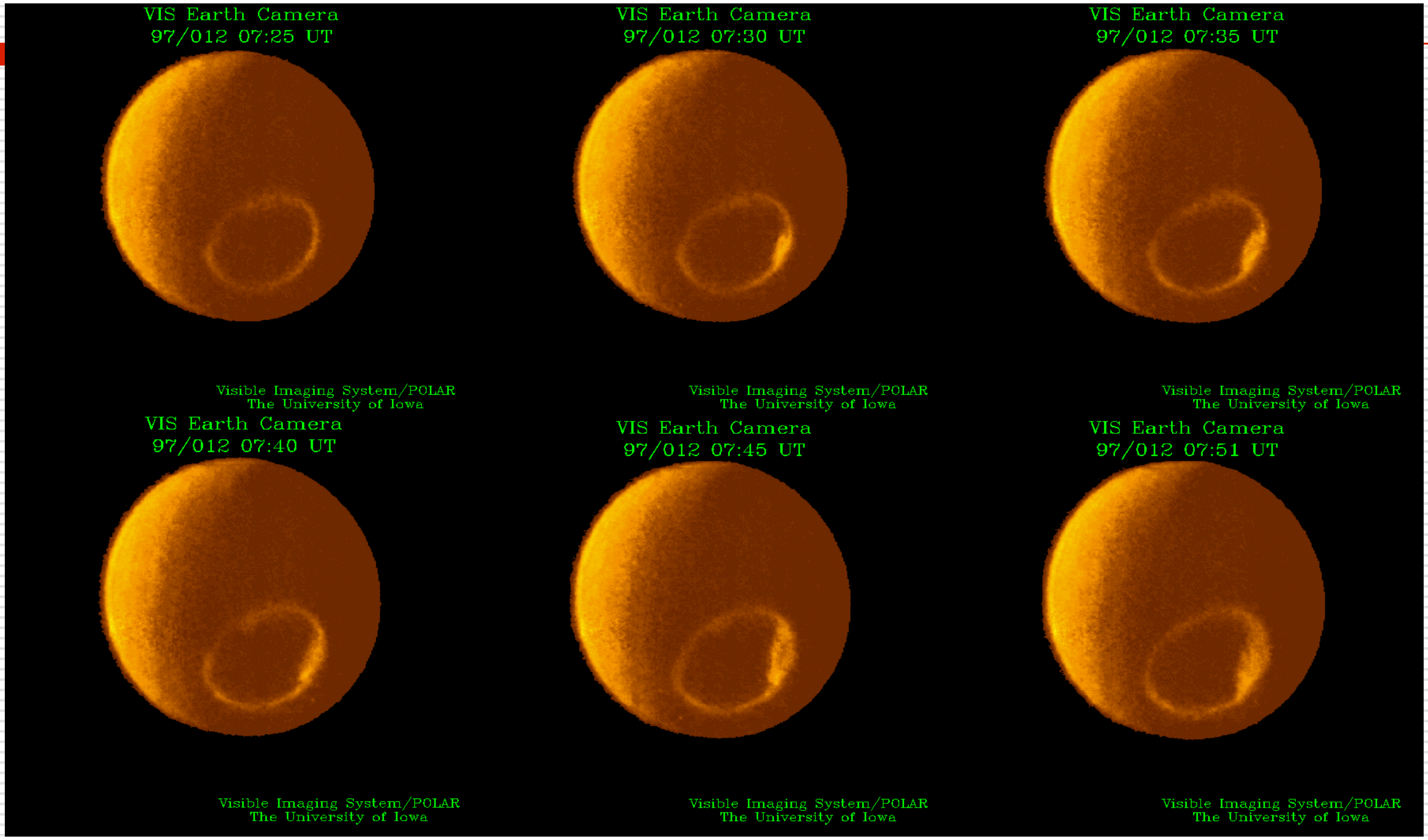


Rabbit Lake crossing



La Ronge crossing

- **Observation #1**: Simultaneous observations of Pi1B pulsations (ULF broadband irregular bursts at 0.025 ~ 1 Hz) using ground-based and satellite-borne magnetometers (GOES and FAST) at substorm onset (magnetic reconnection) on Jan. 12. 1997 07:28 UT.



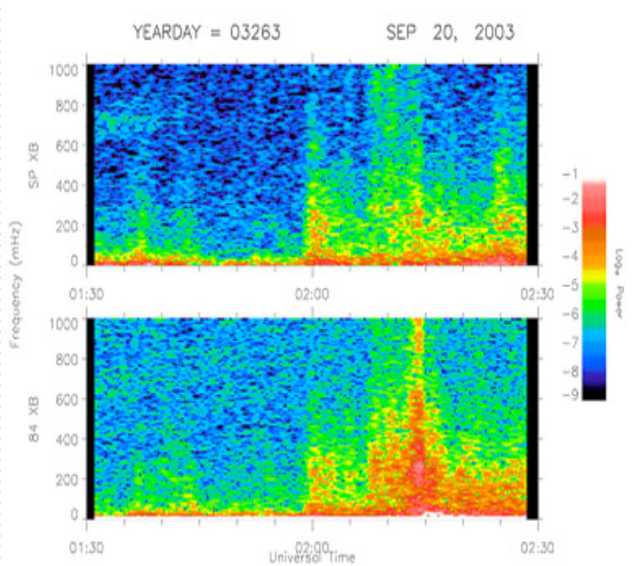
POLAR VIS images, showing initial brightening between 7:25 and 7:30, compares well with other estimates of 7:28

- **Observation #2**: Simultaneous observations of Pi1B pulsations using ground-based and satellite-borne magnetometer (Cluster and Polar) at substorm onset (magnetic reconnection) on Sep. 20. 2003 02:00 UT.

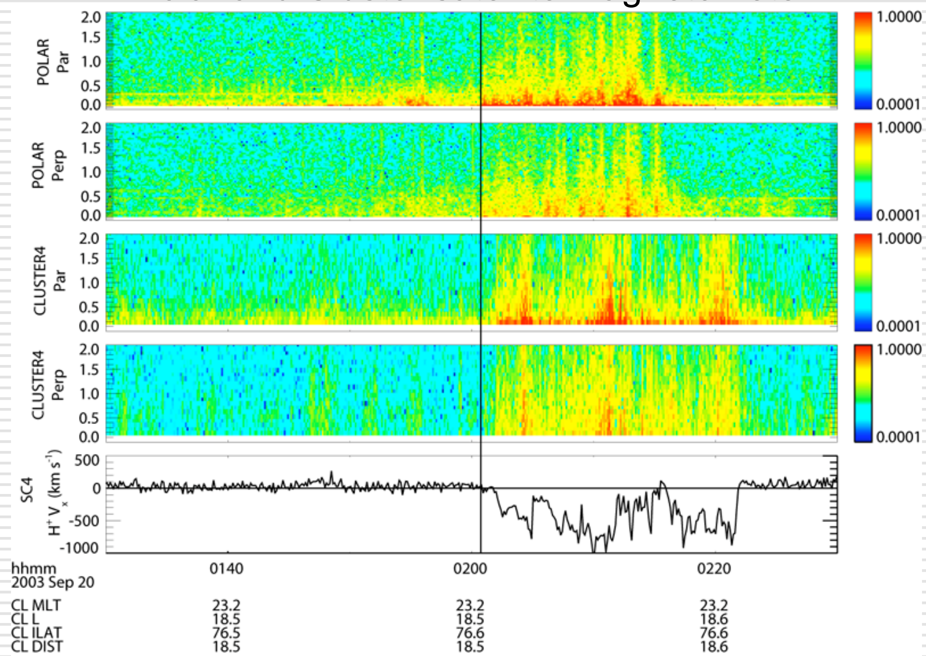
Ground magnetometer

South Pole

A80

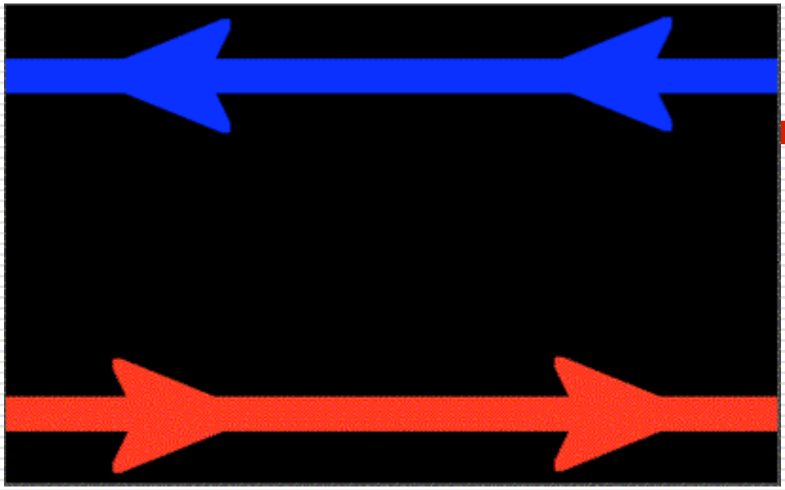


Polar and Cluster satellite magnetometer

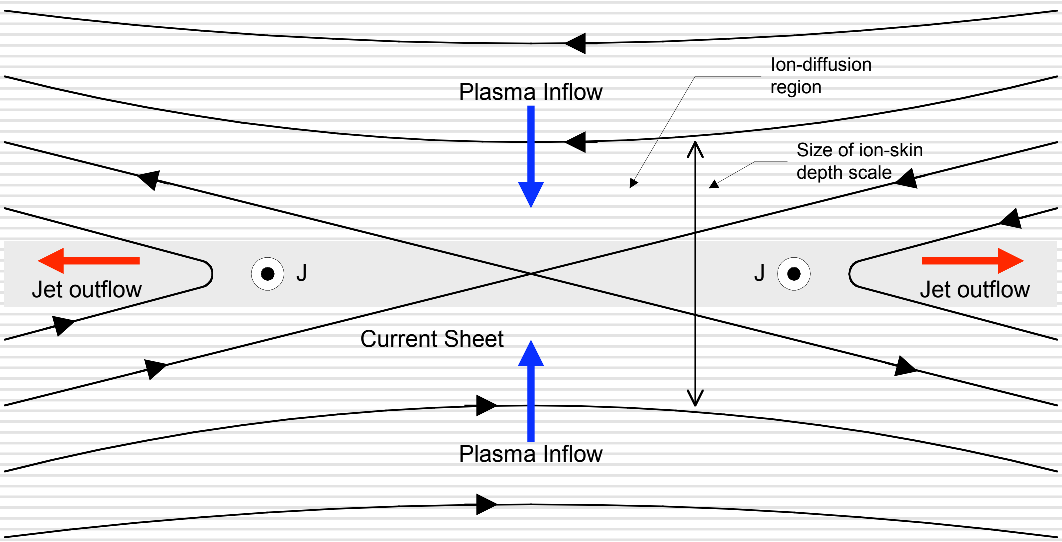


- Polar (upper two panels, *right*) and Cluster (3rd and 4th panels, *right*) observations of PI1B pulsations at substorm onset (magnetic reconnection). The bottom panel shows Cluster me asures the ion flow propagating tailward (fast flows or bursty bulky flows: BBF).

Reconnection model – possible relation to Pi1B generation

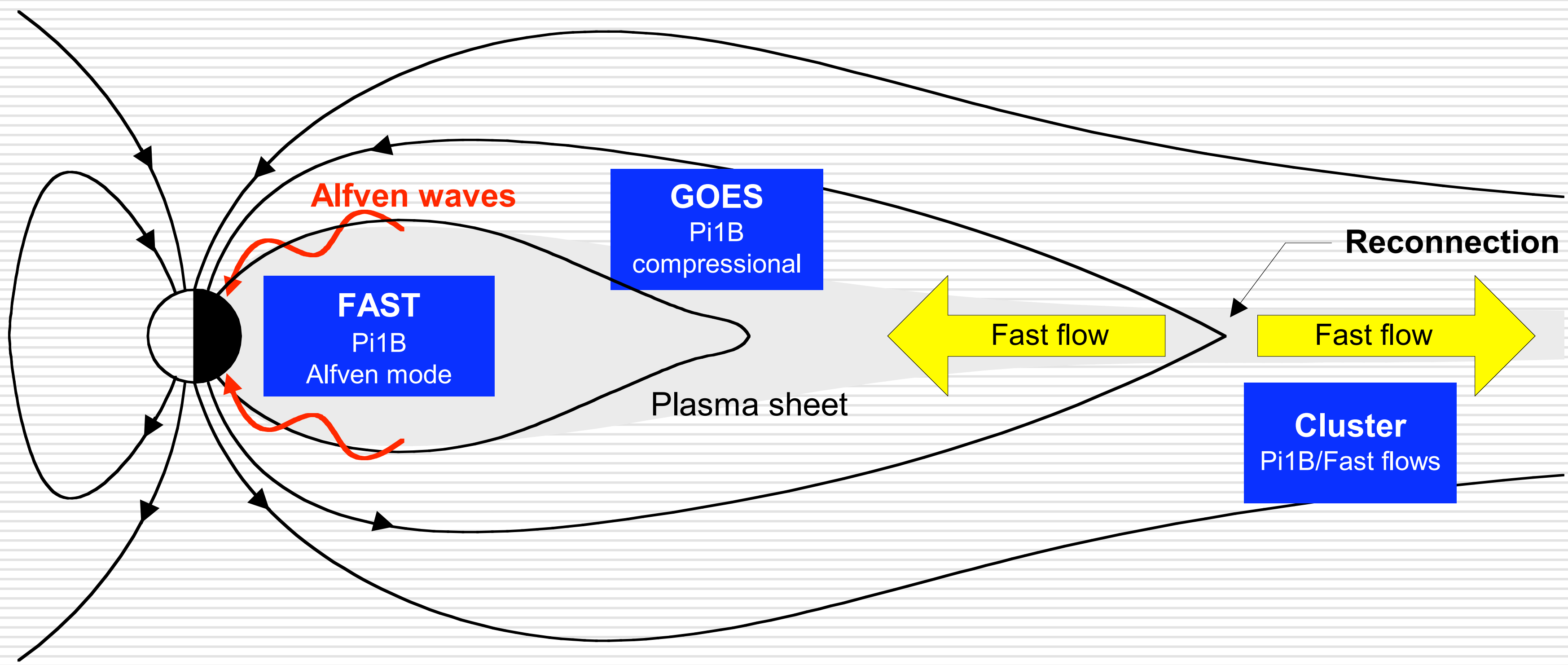


Animation showing how magnetic field lines of opposite direction break and reconnect. Such reconnection events in space create jets of high-speed particles.



Overview/Scenario

- Pi1B signatures, which are observed with burst bulky flows (fast flows) by Cluster (~ 20 RE) at substorm onset (reconnection), are seen as compressional waves at geosynchronous orbit by GOES. Then, as the flows propagate earthward, they become increasingly parallel to the background field, eventually undergoing a mode conversion to Alfven waves, which propagate parallel to the background field. FAST satellite observes the Alfven waves and auroras were observed on the ground.



GEM 2007 Focus Group - MIC

- FG6 – MICET (MIC Electrodynamics and Transport): MIC gap region, cross-latitude coupling (Mon)
- FG7 – Global MIC: Dayside Global Ionospheric Electrodynamics, Reconnection (Tue)
- FG10 – Diffuse Aurora (Wed)
- And MIC tutorials (Mon, Thu)

Q?

A polar bear shown up at Polish Polar Station, Hornsund, Svalbard. Courtesy of Piotr Modzel.

Field-Aligned Currents vs. Alfvén Waves

- Field-aligned current is often quoted as energy source for aurora.
- But, the kinetic energy of electrons is negligible: Poynting flux associated with FAC is responsible.
- FAC closed by conductivity in ionosphere; electric and magnetic fields related by

[illegible]

Σ_P is usually > 1 mho, so ratio is less than 800 km/s

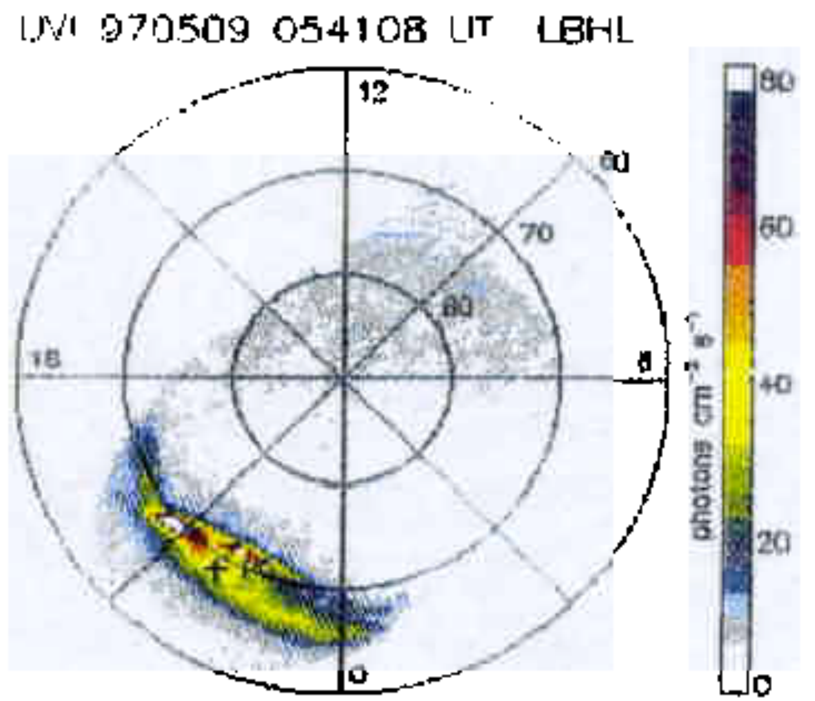
- Alfvén waves have a similar electric and magnetic field signature, but for these waves

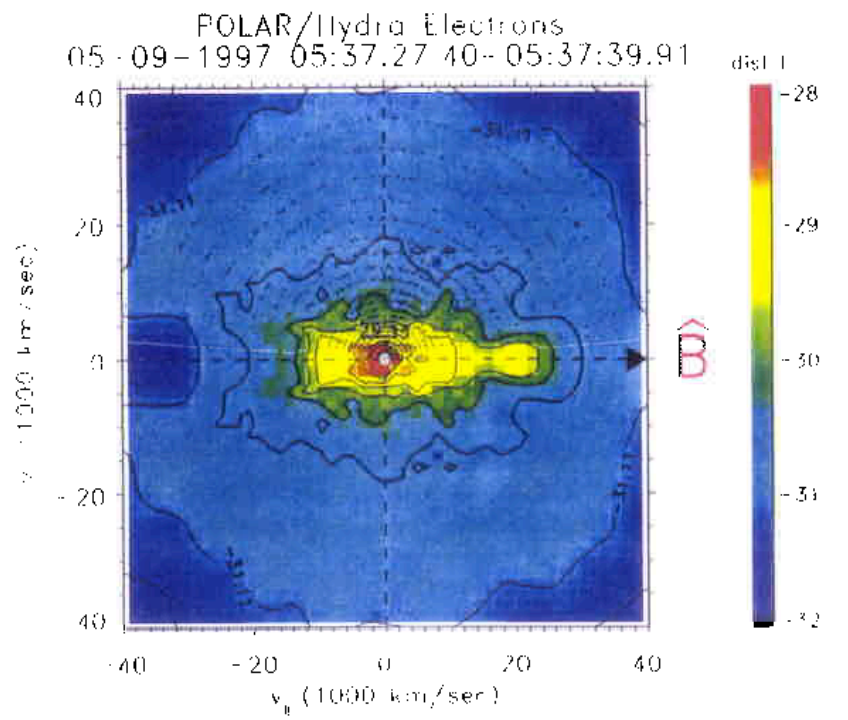
$$\frac{E_x}{B_y} = V_A = \frac{B_0}{\sqrt{\mu_0 \rho}}$$

V_A is usually much greater than 1000 km/s, can be up to speed of light

- Thus, large E/B ratios indicate Alfvén waves, smaller ratios static currents
- Oversimplified picture! Wave reflections, parallel electric fields, kinetic effects all affect this ratio.

Alfvén Waves on Polar Map to Aurora and Accelerate Electrons





Left: Ultra-violet image of aurora taken from Polar satellite. Cross indicates footpoint of field line of Polar (Wygant et al., 2000)

Right: Electron distribution function measured on Polar. Horizontal direction is direction of magnetic field. Scale is ±40,000 km/s is both directions (Wygant et al., 2002)