Structured High Latitude Electrodynamics

New Analysis with the Combined Electric and Magnetic Field 16 s/sec data from the Dynamics Explorer-2 Satellite

CEDAR Workshop

GDC and Dynamic Science

Robert Pfaff

NASA/Goddard Space Flight Center

June 29, 2023

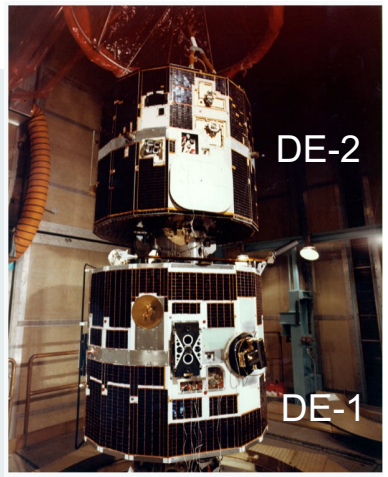
Dynamics Explorer-2

Launch: August 3, 1981

Re-enter: 19 February 1983

Initial Orbit:

310 km by 1010 km
90 deg inclination



Dynamics Explorer 1, 2

VEFI instrument included three-axis double probes, each 21.4 m sensor-to-sensor

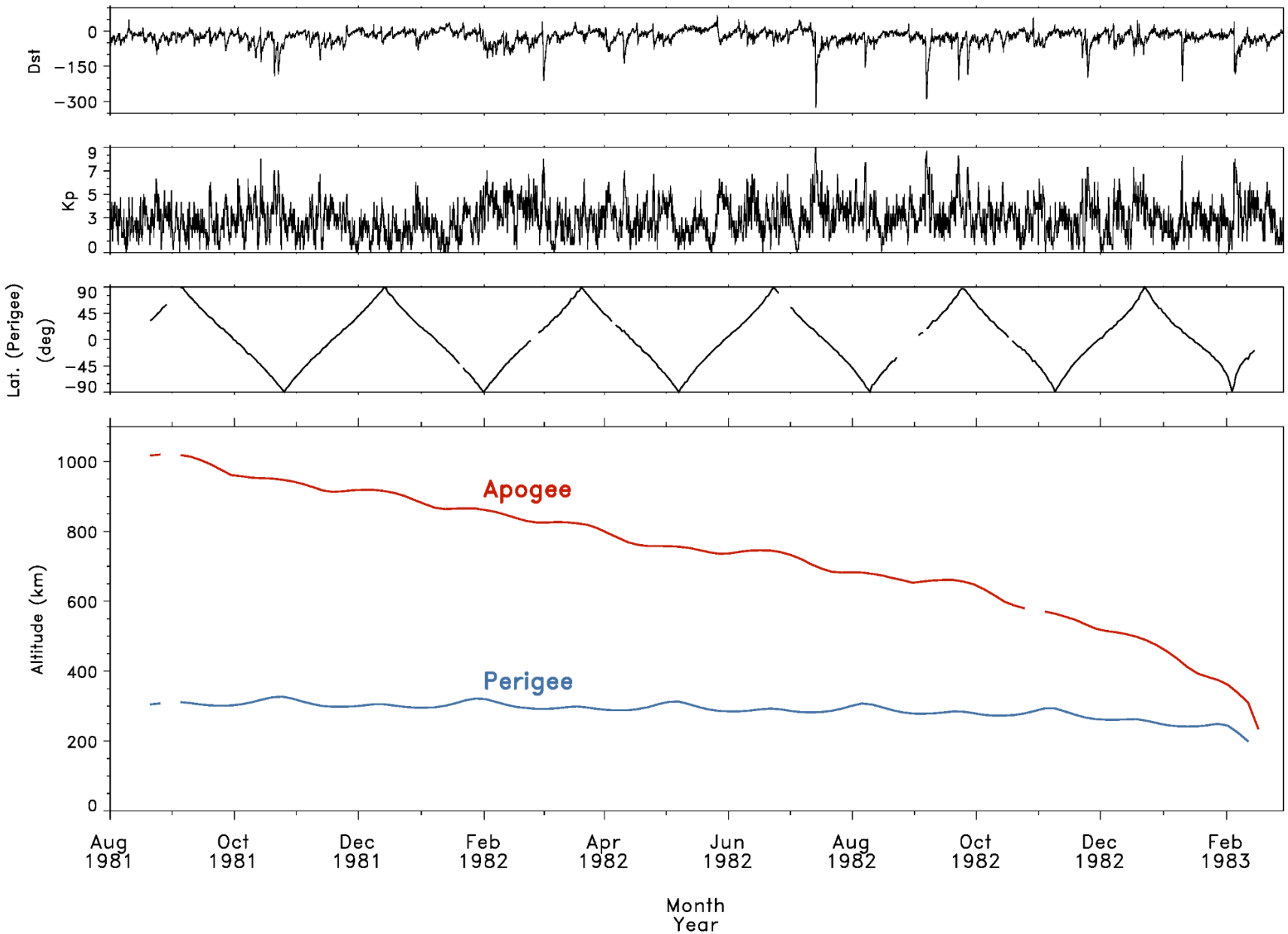
DC electric fields at 16 s/sec
AC Filter Bank data to 4 Hz - 500 kHz

MAG consisted of tri-axial fluxgate magnetometer at the end of a 6m boom

Magnetometer data sampled at 16 s/sec

DE−2 Orbit History & Dst, Kp Indices

August 15, 1981 to February 18, 1983



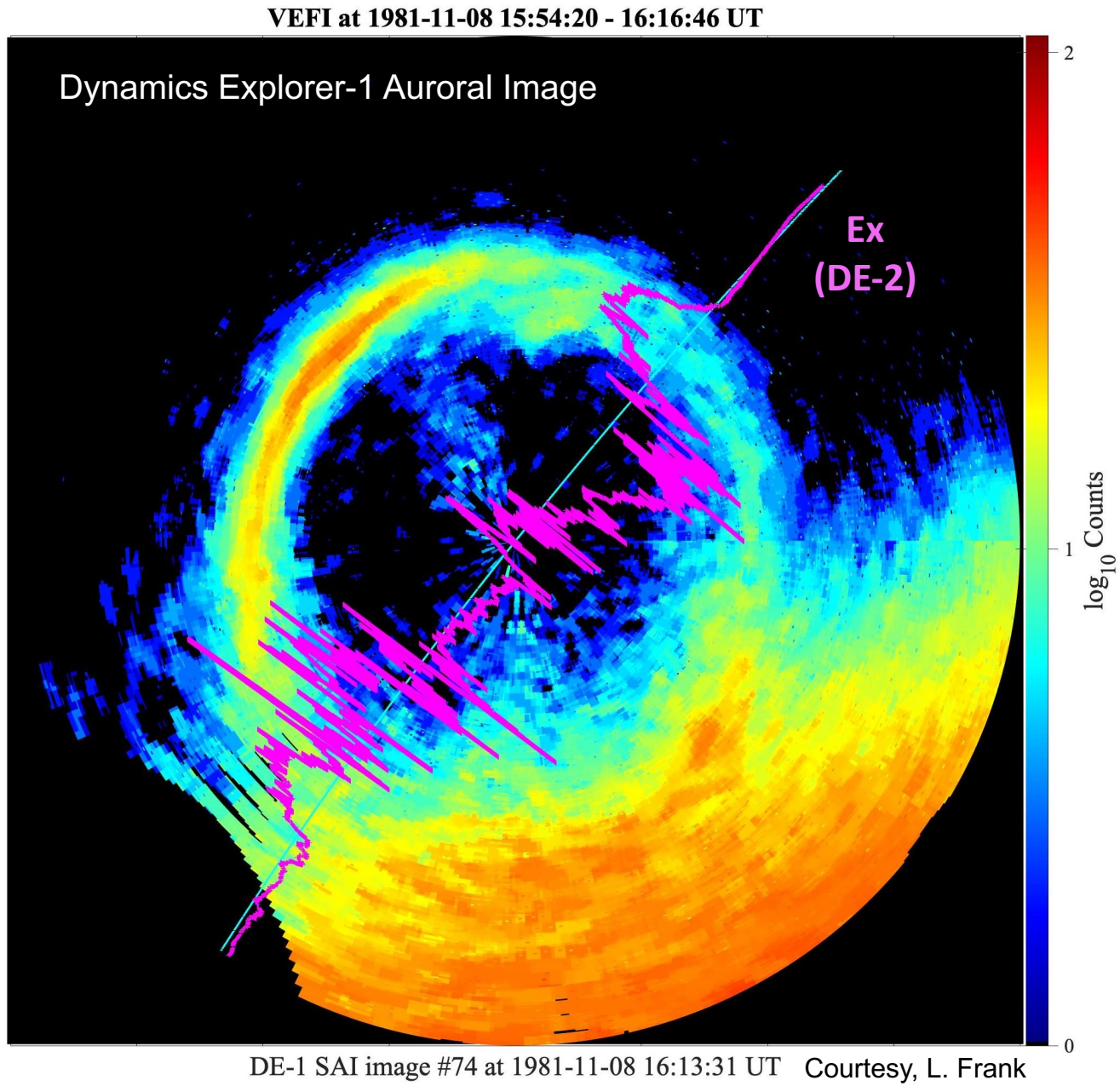
Key Point #1

High Latitude Electric Fields
(and hence **E** x **B** Plasma Flows)

→ Are Inherently Highly Structured

often Characterized by ”Peaks”, ”Flow Channels”, and “Shears”

Measured Electric Fields (DE-2) Superimposed on Theta Aurora Image (DE-1)

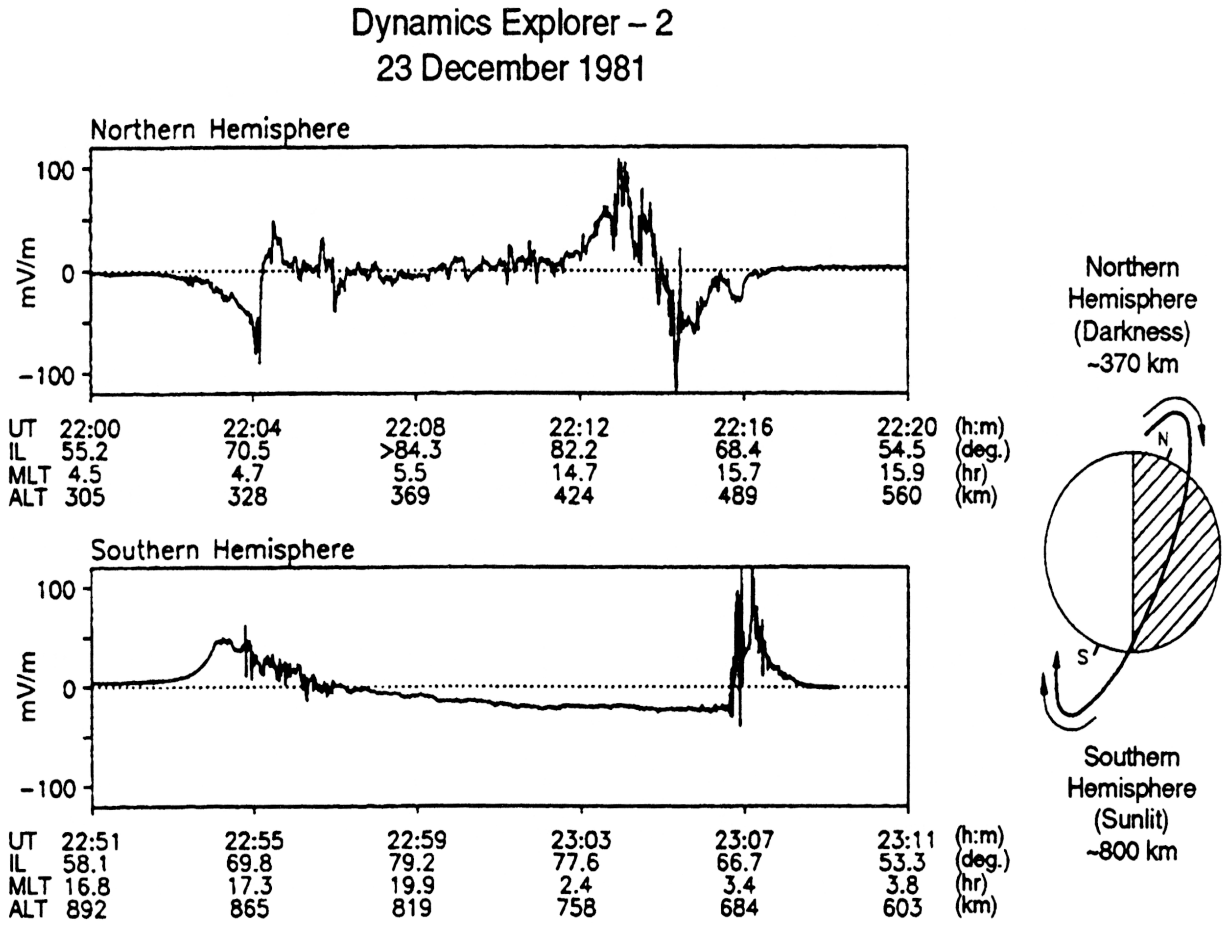


Courtesy, L. Frank

Electric Field Structures are Superimposed on Large Scale Patterns

Hemisphere in Darkness

Sunlit Hemisphere

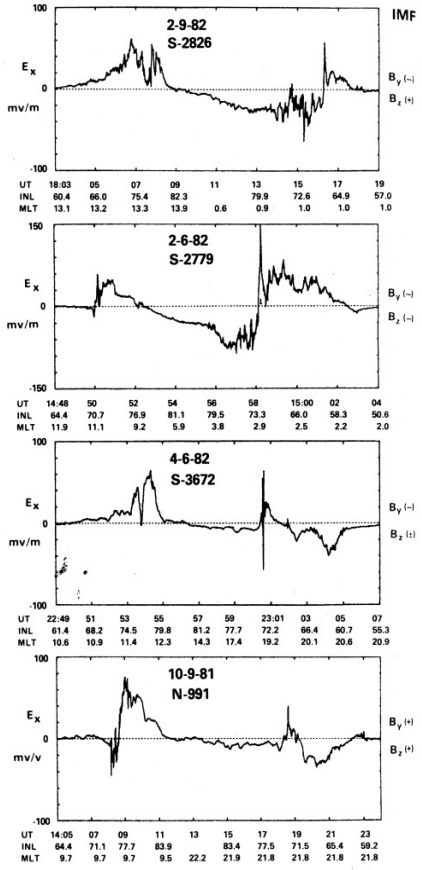


Pfaff et al., 1996

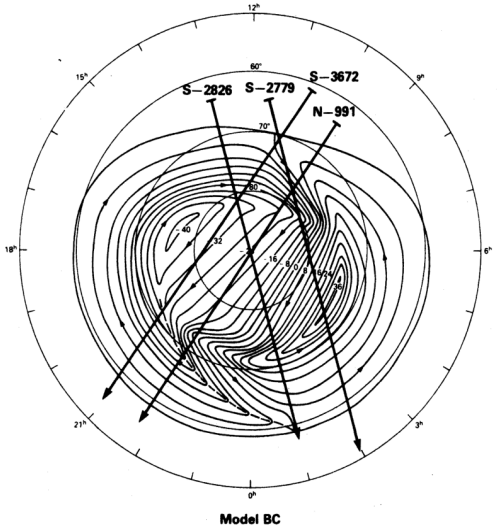
Are the Electric Field Structures imposed from the Magnetosphere or Locally Driven (or Both?)

Smoothed High Latitude Potential Patterns

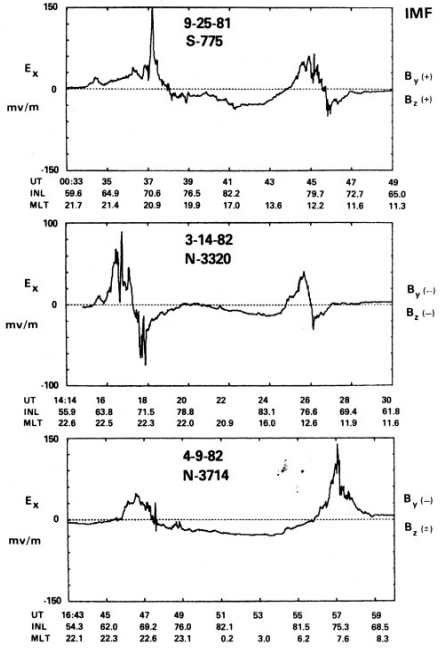
→ *Derived from Highly Structured Electric Fields*

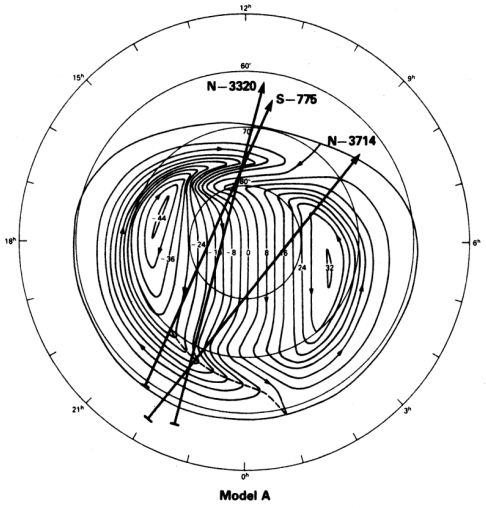


+ IMF By



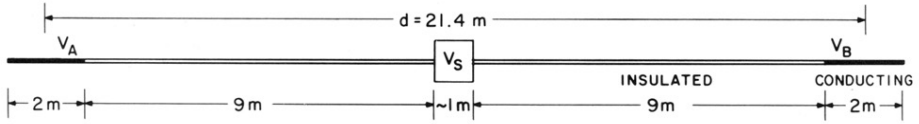
– IMF By





[Heppner and Maynard, 1987]

NASA/Dynamics Explorer-2 -- Vector Electric Field Field Instrument

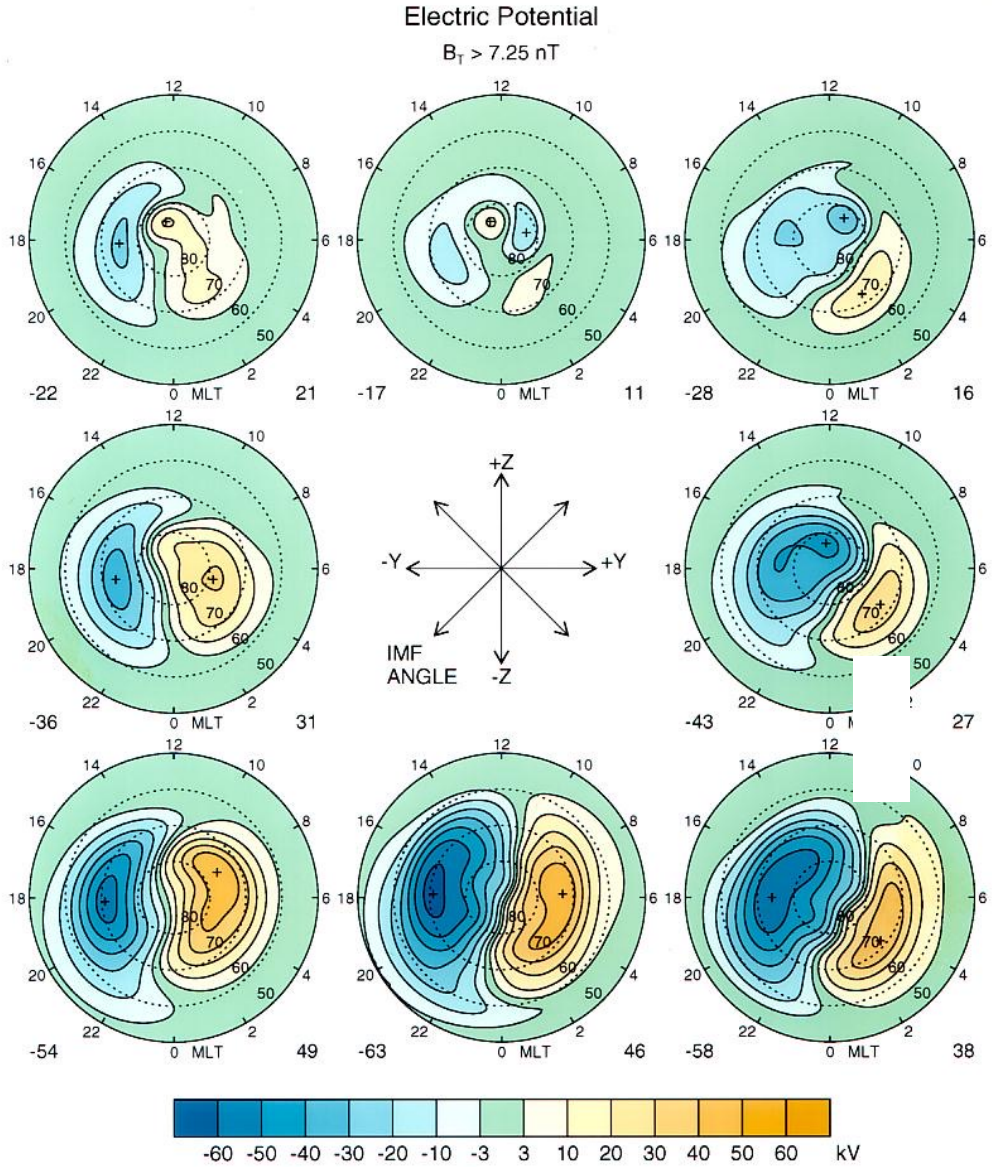


DE-2 Electric fields formed the basis of the Weimer Potential Model

- Weimer [1995] used least-square error fits of spherical harmonic coefficients to derive the potential patterns from individual orbits of DE-2 electric field (VEFI) measurements

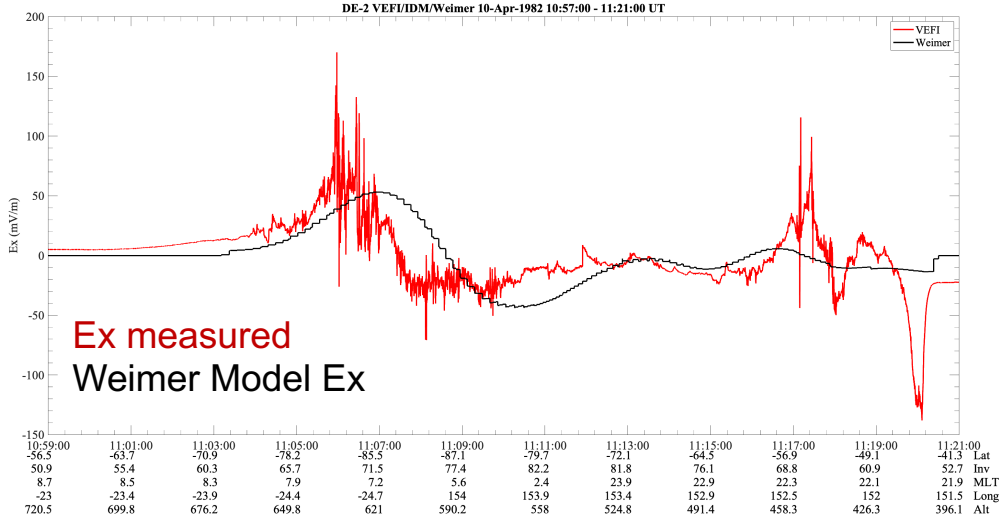
- The passes were sorted into “bins” by IMF magnitude, clock angle, and dipole tilt angle

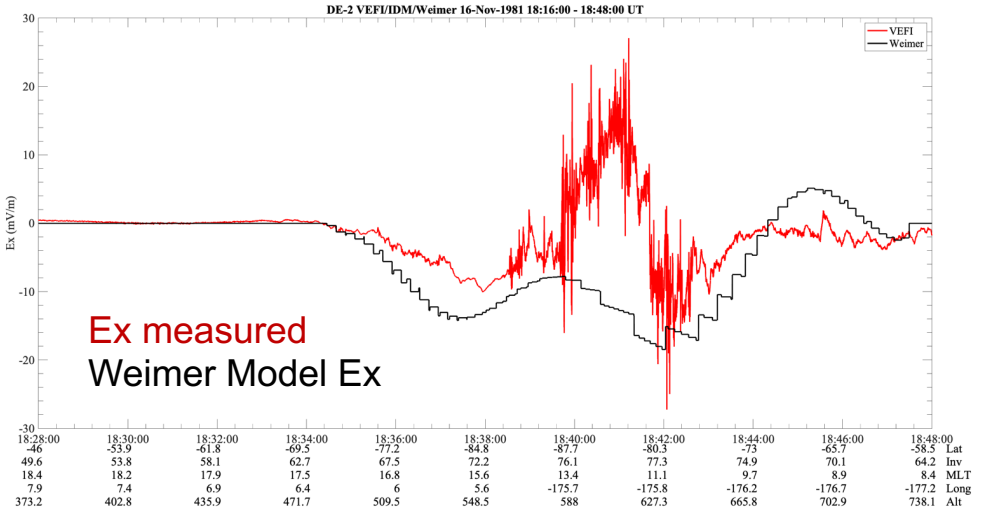
- Structured electric fields not characterized within the potential model

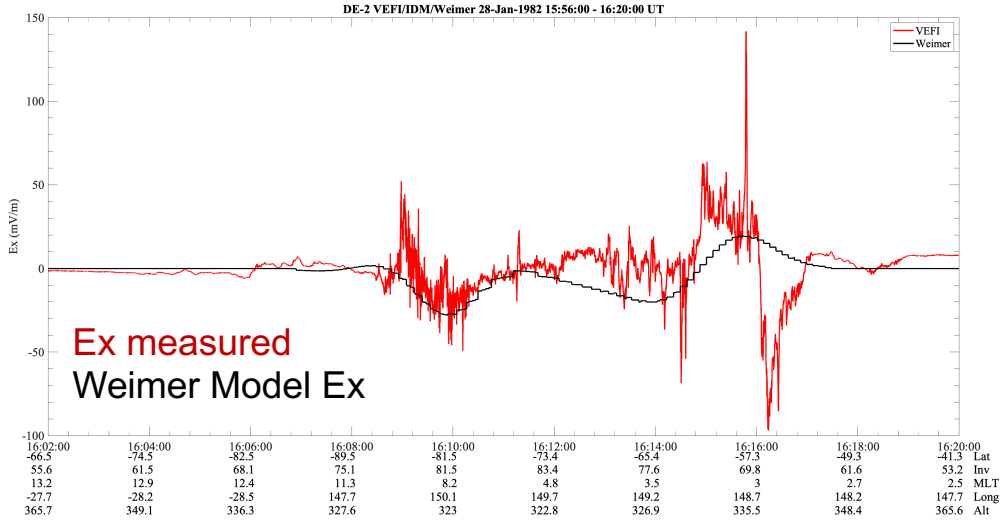


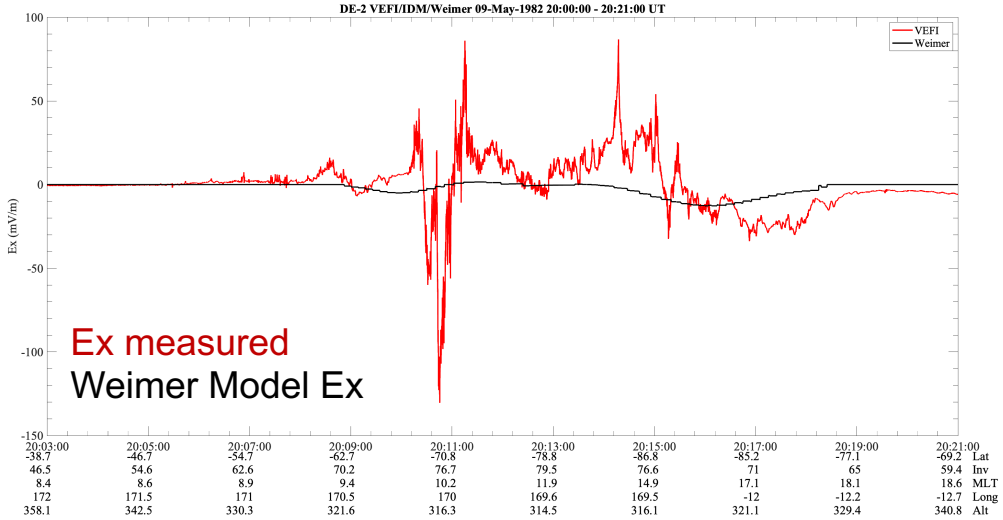
[Weimer, 1995]

Comparison: E-poleward "Predicted" by Weimer Model (**Black**) versus **Measured** VEFI E-poleward (**red**)









- Weimer Model Ex is in geomagnetic coordinates
- VEFI Ex is in geographical coordinates

GEOPHYSICAL RESEARCH LETTERS, VOL. 9, NO. 9, PAGES 981-984, SEPTEMBER 1982

INTENSE, VARIABLE ELECTRIC FIELDS AT IONOSPHERIC ALTITUDES IN THE HIGH LATITUDE REGIONS AS OBSERVED BY DE-2

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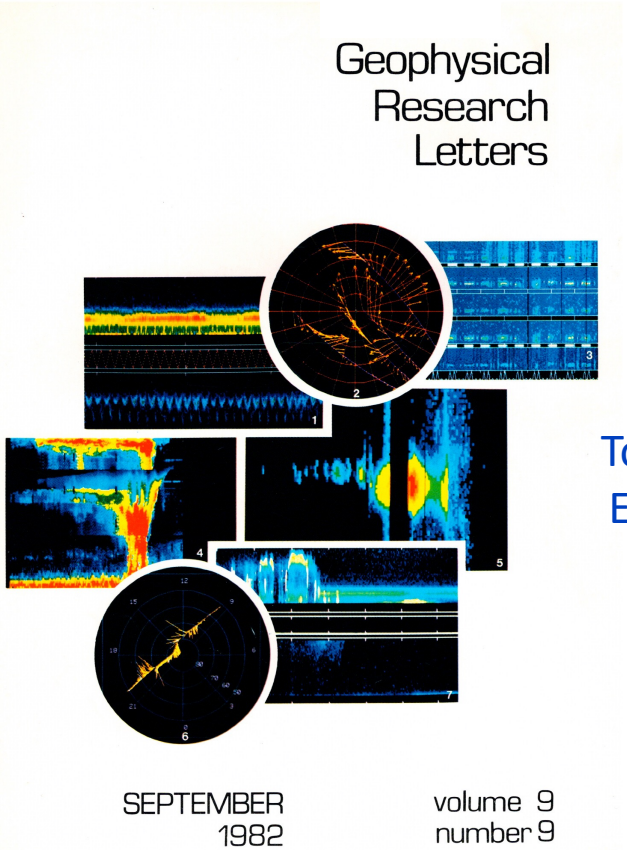
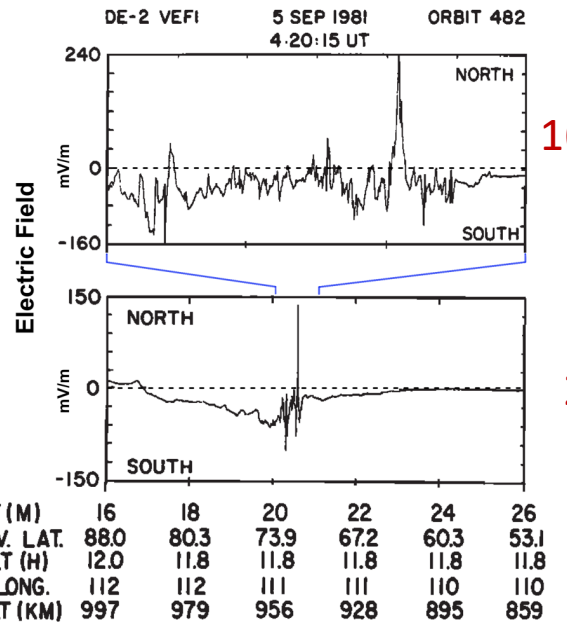
Laboratory for Extraterrestrial Physics, Goddard Space Flight Center, Greenbelt, MD 20771



Dynamics Explorer "First Results"
GRL Issue -- Maynard et al. report
Large Amplitude Structures in High
Latitude Electric Field Data

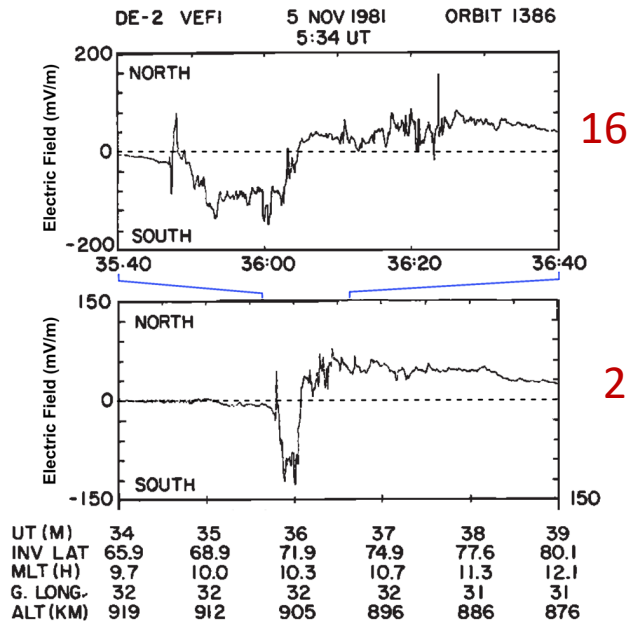
Top panels are Enlargements

Note: Increased Scales!



16 s/sec

2 s/sec



16 s/sec

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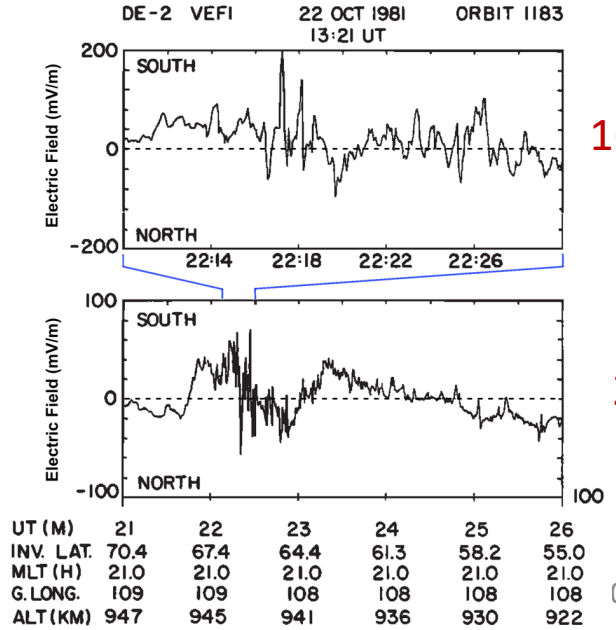
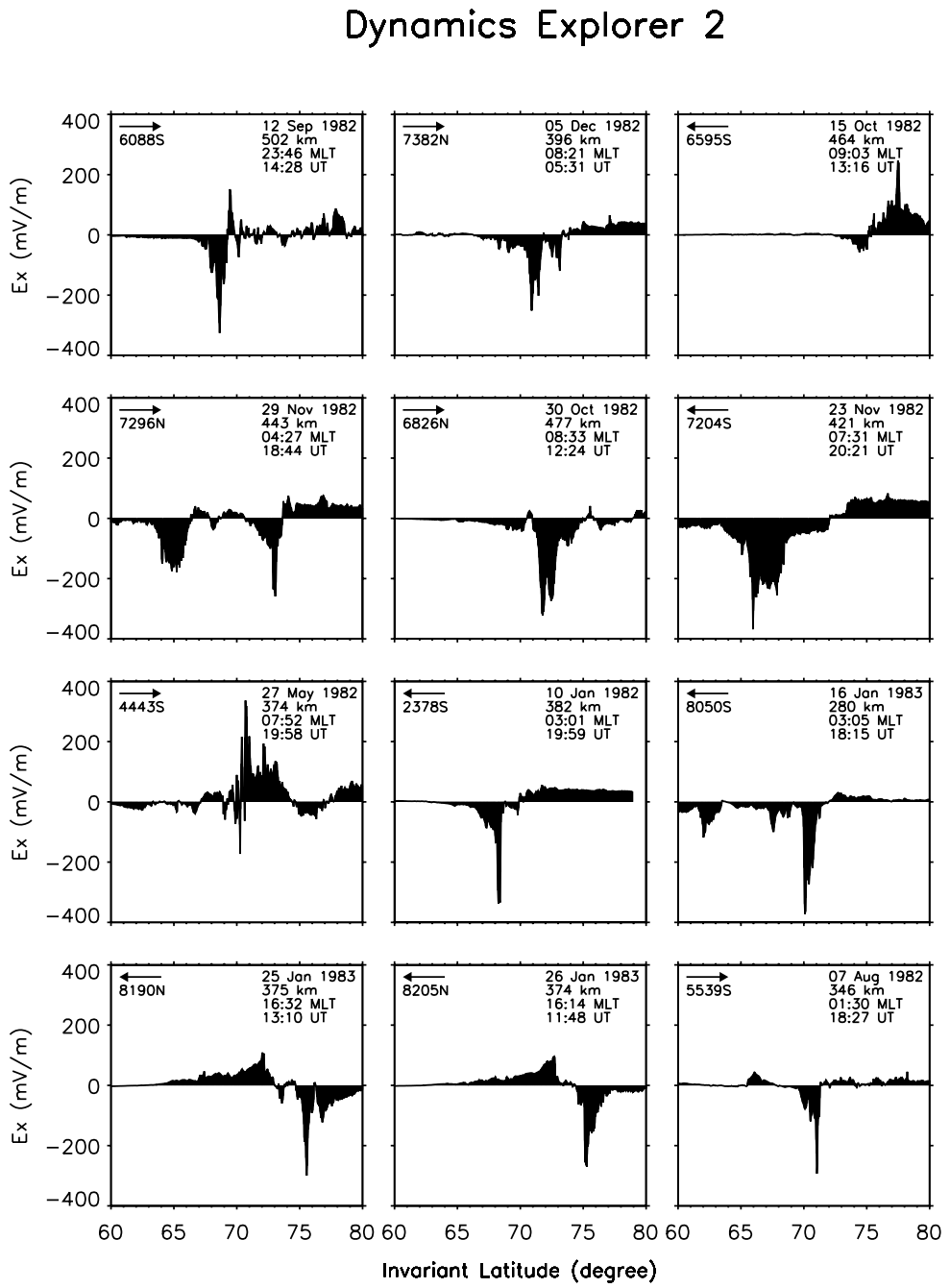


High Latitude Electric Field Structure is Typically Characterized by “Peaks” and/or “Flow Channels”, as well as Shears in the North-South Direction

Examples of peaked Ex fields that are not SAIDs, Corresponding to drifts of 6-8 km/s (or higher)



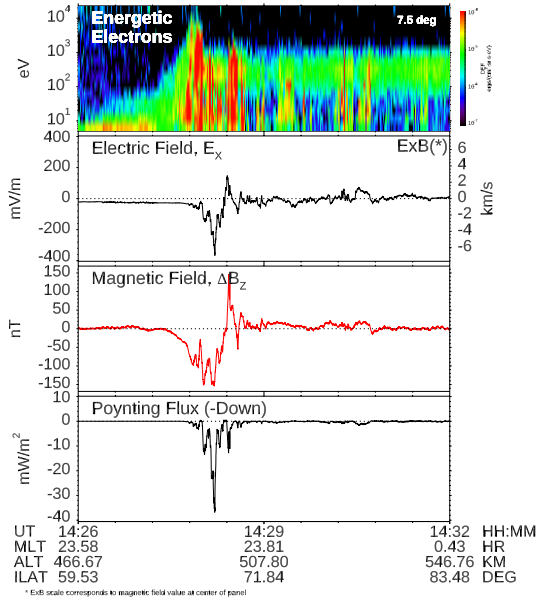
Key Point #2

High Latitude

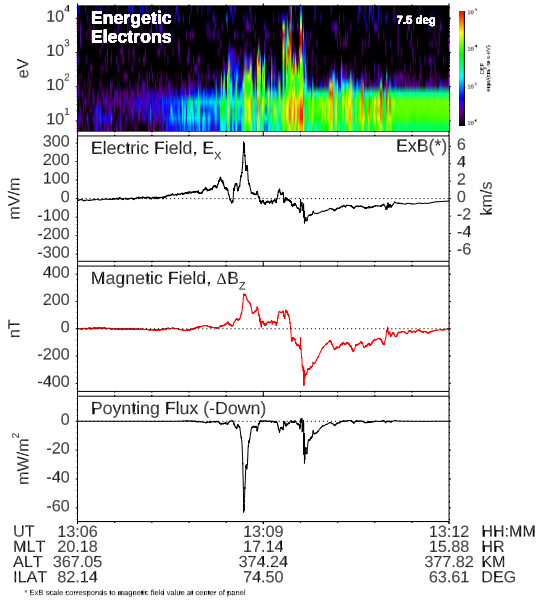
Electric Fields (Plasma Flows) and Magnetic Fields

- Are Correlated,
- Are (hence) *Both Intrinsically Structured*,
- Provide Poynting Flux

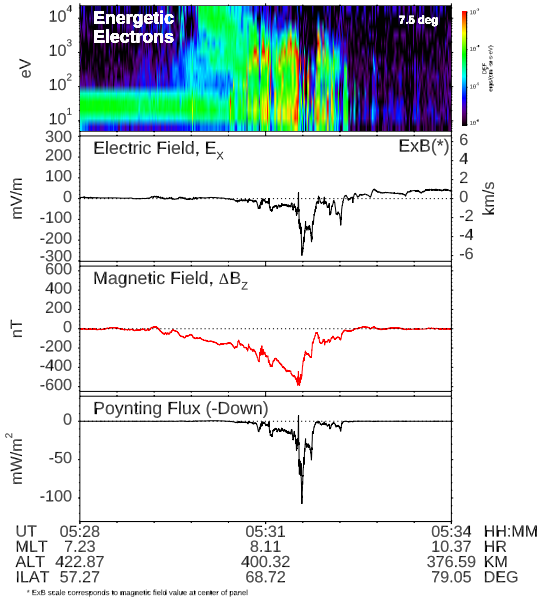
DE-2 Orbit 6088(S) – September 12, 1982(Day 255)



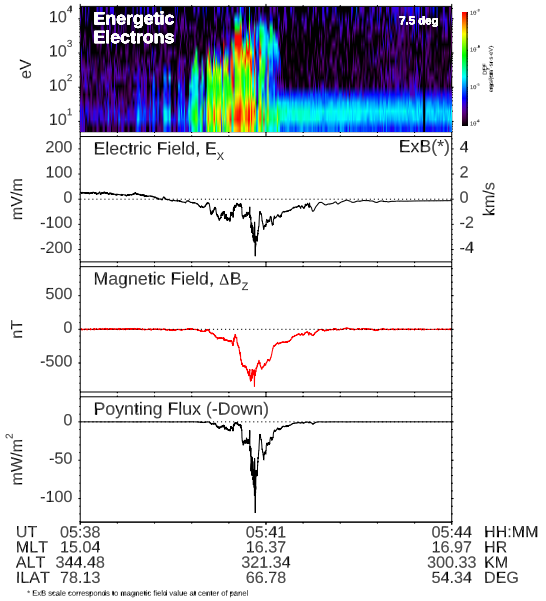
DE-2 Orbit 8190(N) – January 25, 1983(Day 025)



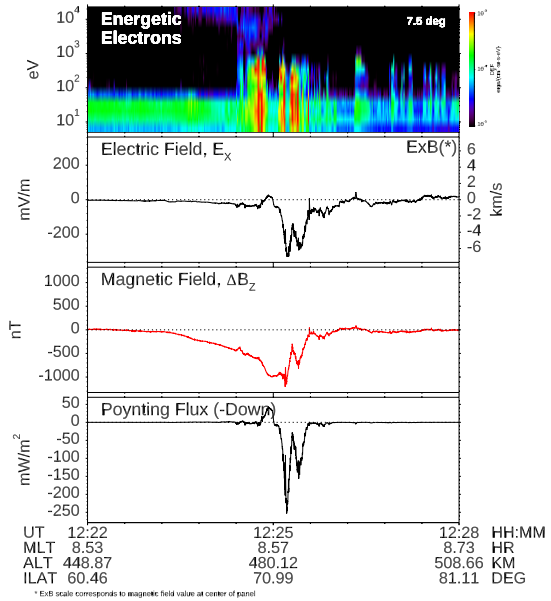
DE-2 Orbit 7382(N) – December 05, 1982(Day 339)



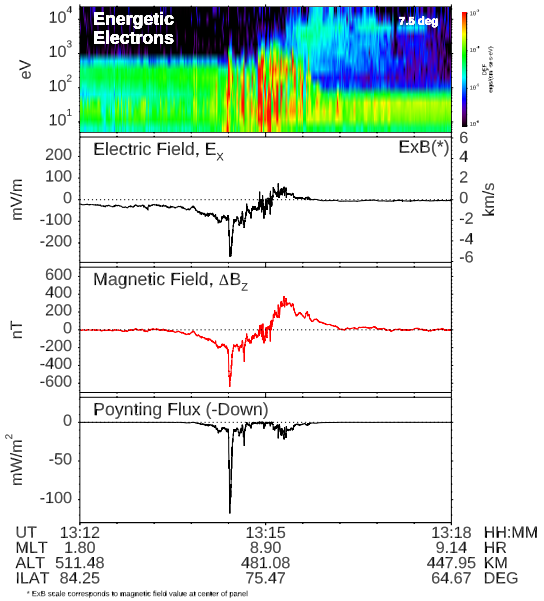
DE-2 Orbit 7382(N) – December 05, 1982(Day 339)



DE-2 Orbit 6826(N) – October 30, 1982(Day 303)

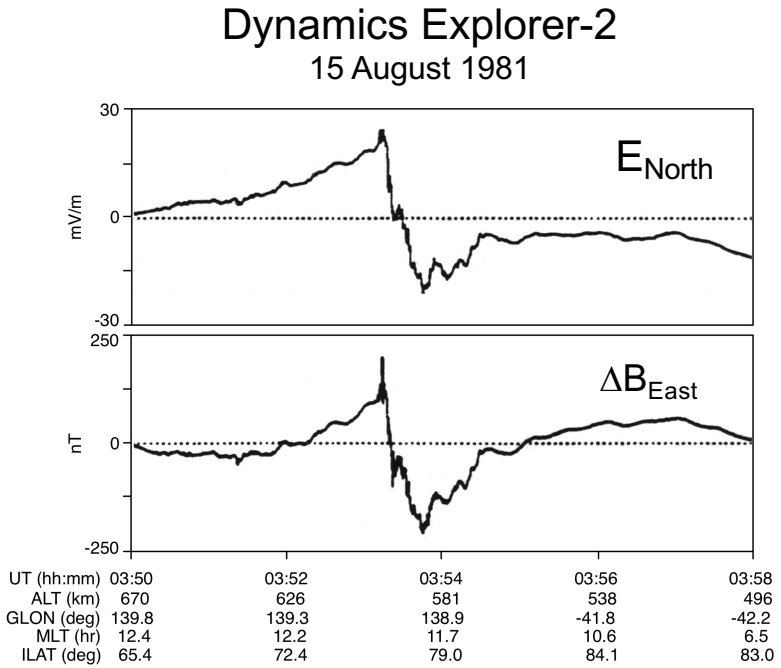


DE-2 Orbit 6595(S) – October 15, 1982(Day 288)



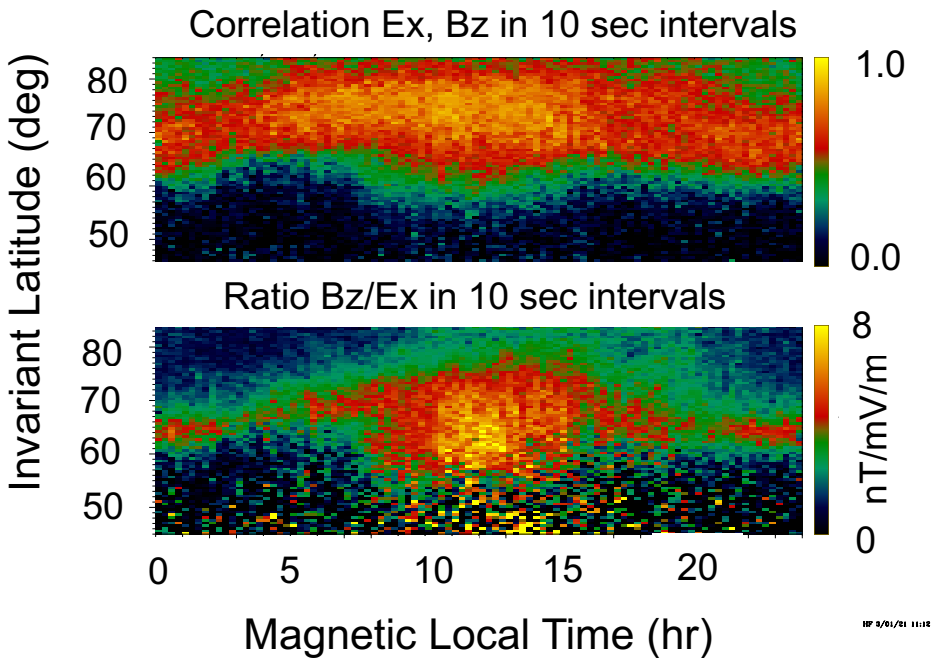
- Electric and Magnetic Fields highly correlated;
- Both are highly structured;
- Provide ready measure of magnetospheric energy input via Poynting Flux

Correlated E_{merid} and B_{zonal} signatures are commonly observed



Sugiura et al., *GRL*, 1982

Average Correlations and Ratios of Ex and ΔBz



Correlation of E_{merid} and B_{zonal} supports infinite current sheet approximation for field-aligned currents and provides a measured of the height-integrated Pedersen Conductivity

Key Point #3

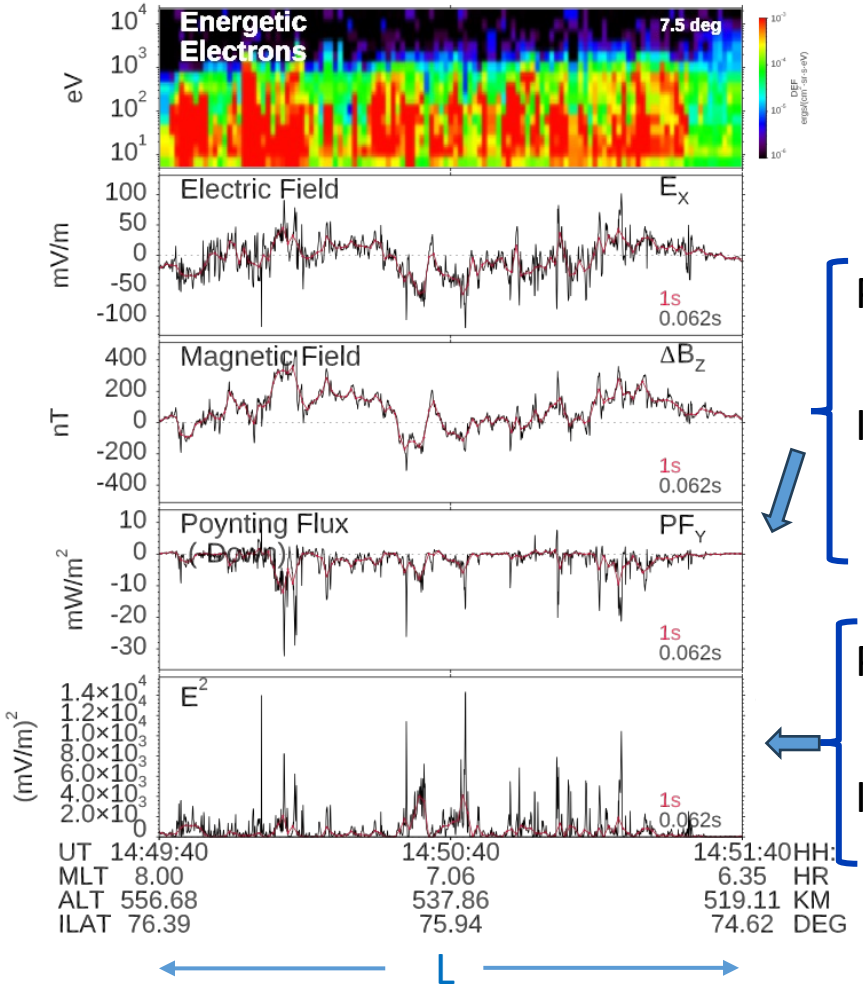
Higher resolution (16 s/sec) Electric and Magnetic Field data provide measurements at shorter scales (1 km instead of 10 km)

→ Provide more accurate Poynting Flux and **E** * **E** energy input

→ Help account for the ”missing energy” in heating calculations (e.g., Codrescu et al., 1995)

Poynting Flux and E^2 using 16 s/sec data (black) can be significantly greater than 1 s/sec (red)

DE-2 Orbit 2330(S) – January 07, 1982(Day 007)



Using 16 s/sec:

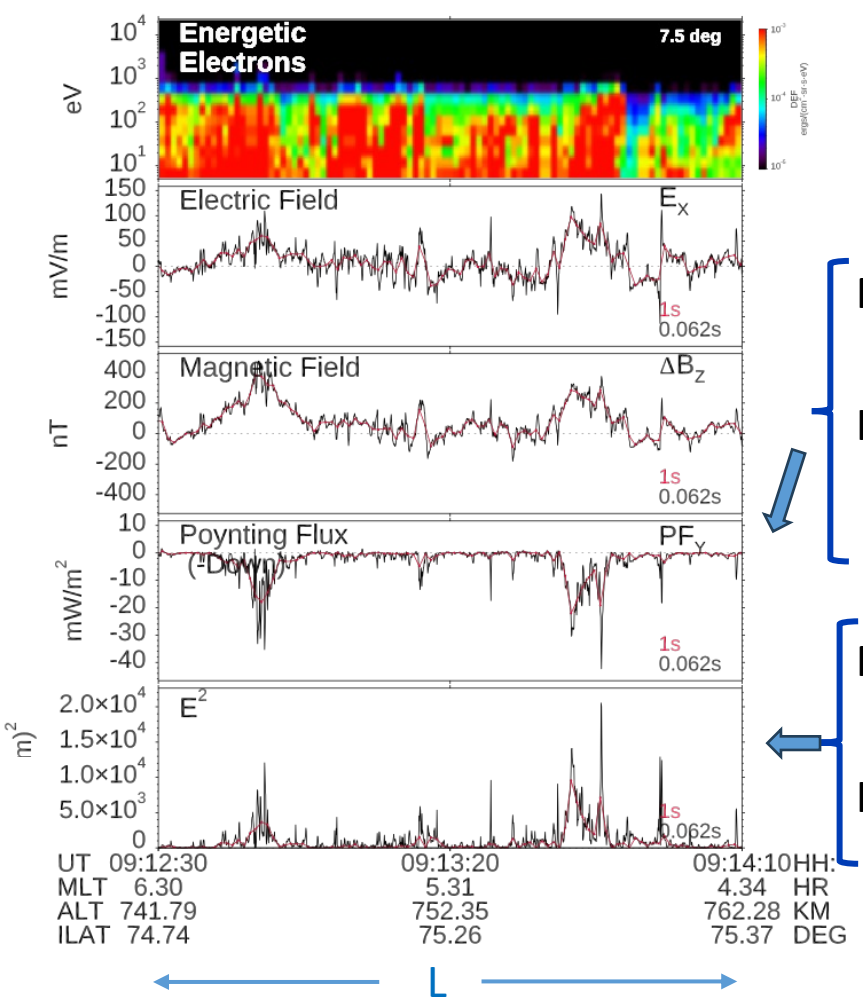
Peak Poynting Flux increases by **2.7**

Integrated over **L** Poynting Flux increases by **17%**

Peak **E * E** increases by **3.5**

Integrated **E * E** increases by **46%**

DE-2 Orbit 3241(S) – March 09, 1982(Day 068)



Using 16 s/sec:

Peak Poynting Flux increases by **2.2**

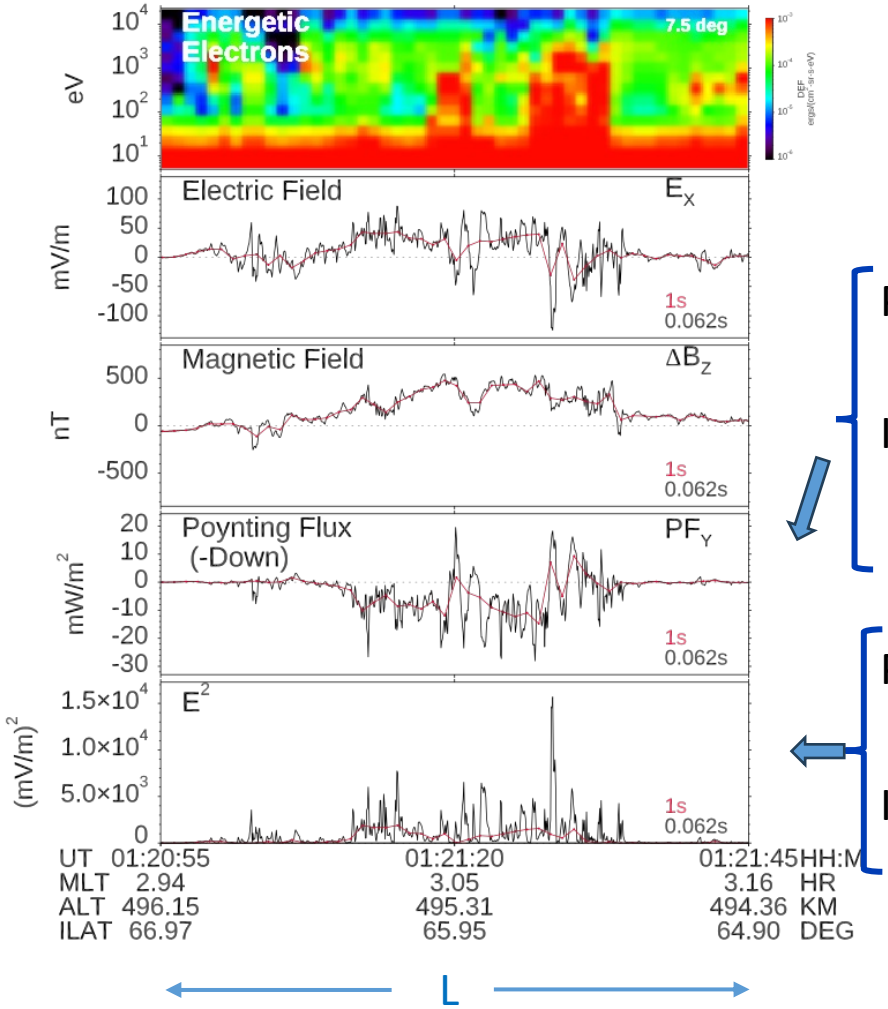
Integrated over **L** Poynting Flux increases by **17%**

Peak **E * E** increases by **2.9**

Integrated **E * E** increases by **35%**

Poynting Flux and E^2 using 16 s/sec data (black) can be significantly greater than 1 s/sec (red)

DE-2 Orbit 7582(S) – December 18, 1982(Day 352)



Using 16 s/sec:

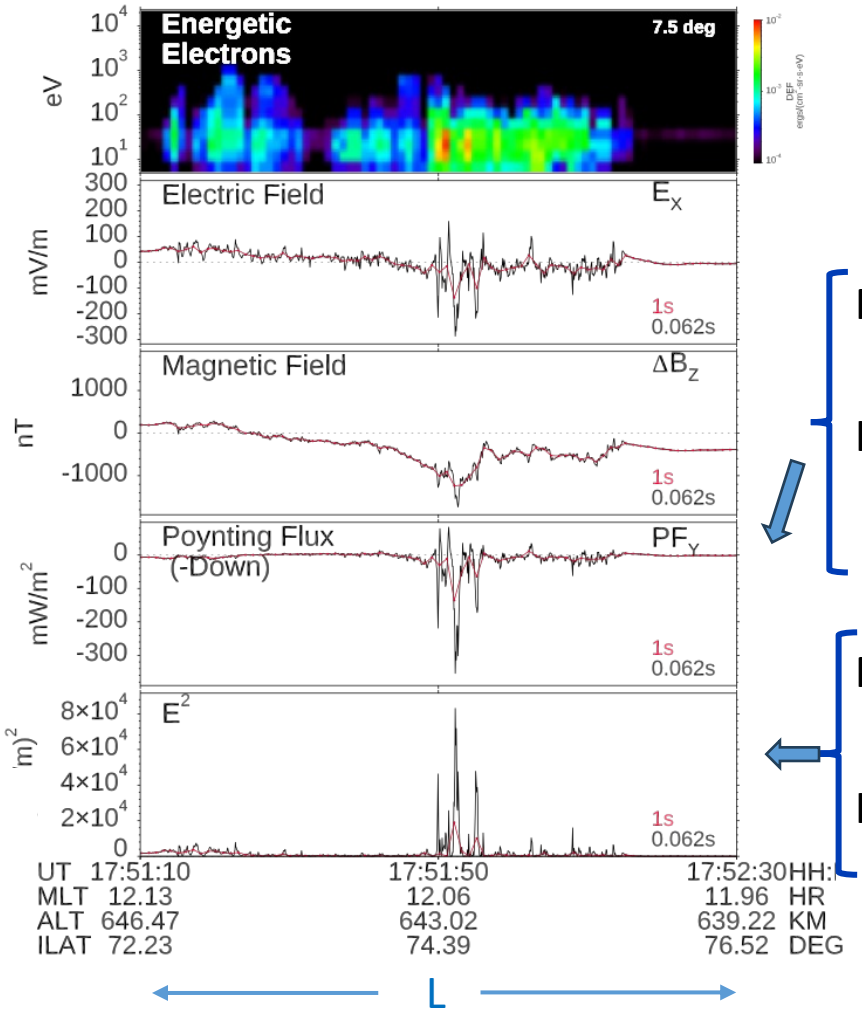
Peak Poynting Flux increases by **1.9**

Integrated over **L** Poynting Flux increases by **16%**

Peak **E * E** increases by **10.0**

Integrated **E * E** increases by **84%**

DE-2 Orbit 5784(N) – August 23, 1982(Day 235)



Using 16 s/sec:

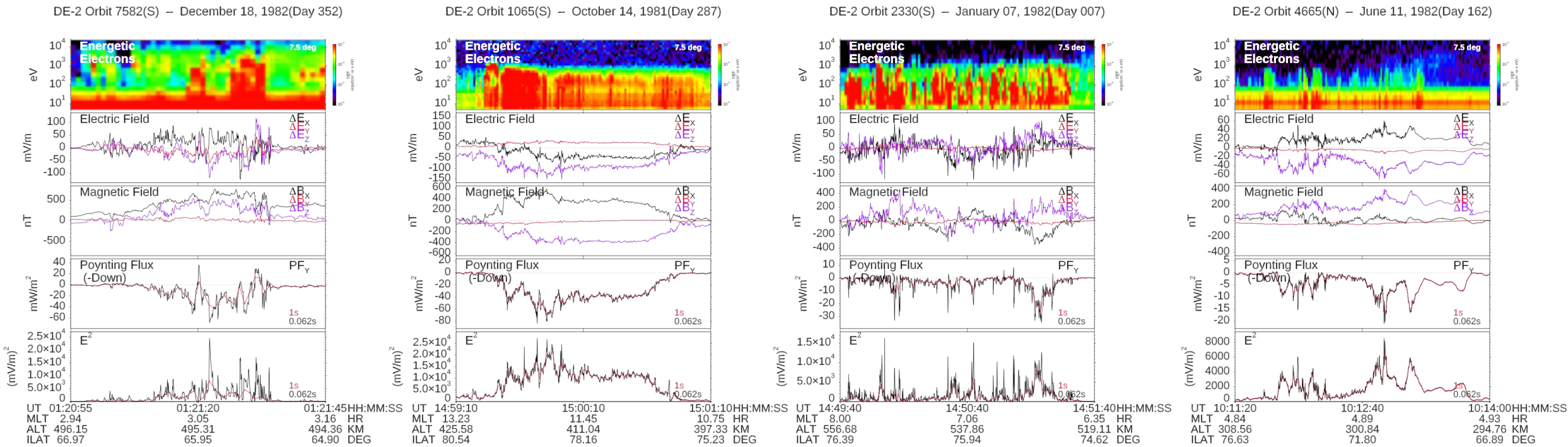
Peak Poynting Flux increases by **2.6**

Integrated over **L** Poynting Flux increases by **12%**

Peak **E * E** increases by **4.4**

Integrated **E * E** increases by **58%**

Vector Electric and Magnetic Field Measurements at 16 s/sec Provide More Accurate Measurements of Poynting Flux and **E** * **E**



Increase in **E** * **E** can be substantial when using vector Electric Field data!

→ Peak values of vector **E** * **E** can be > 10 times that of single (Ex) component

→ **E** * **E** values integrated over 1000 km orbit segment typically twice as large

How Fast should sampling be?

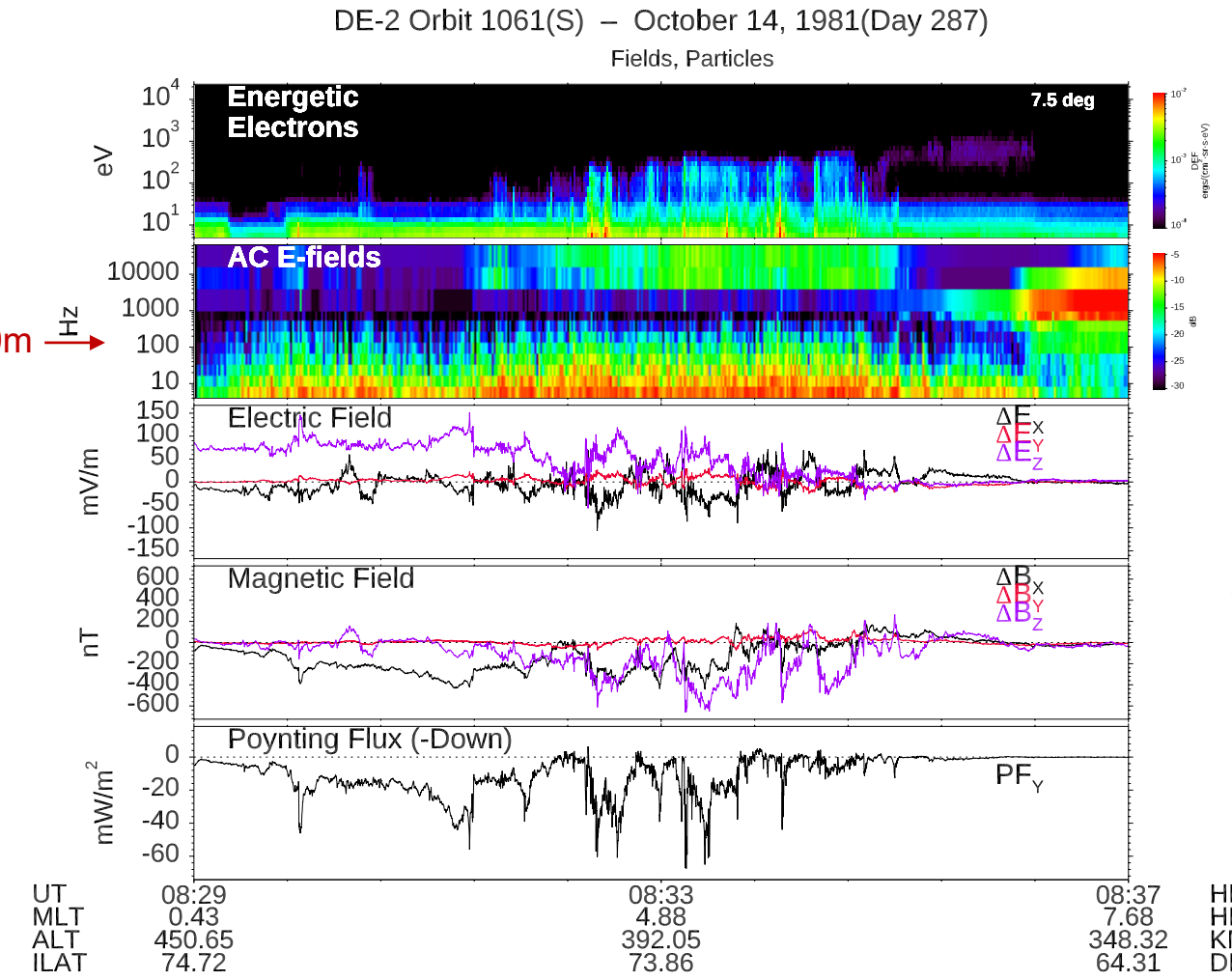
Key Question:

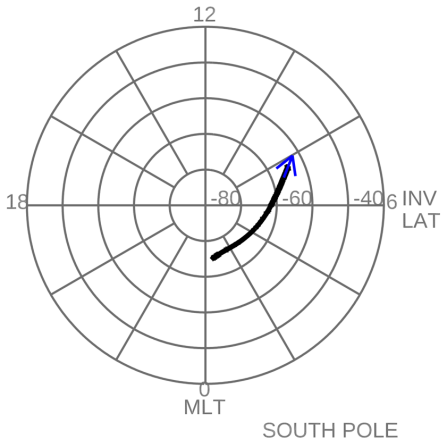
What are the shortest relevant scales?

Electric Field "Structure" is *Common* across Polar Cap

Amplitudes of 10-100 mV/m are common

Extends to scale lengths well shorter than 100 m





GDC mission requires vector Electric Fields to 100m scales

Poynting Flux from 16s/sec DC Electric and Magnetic Fields

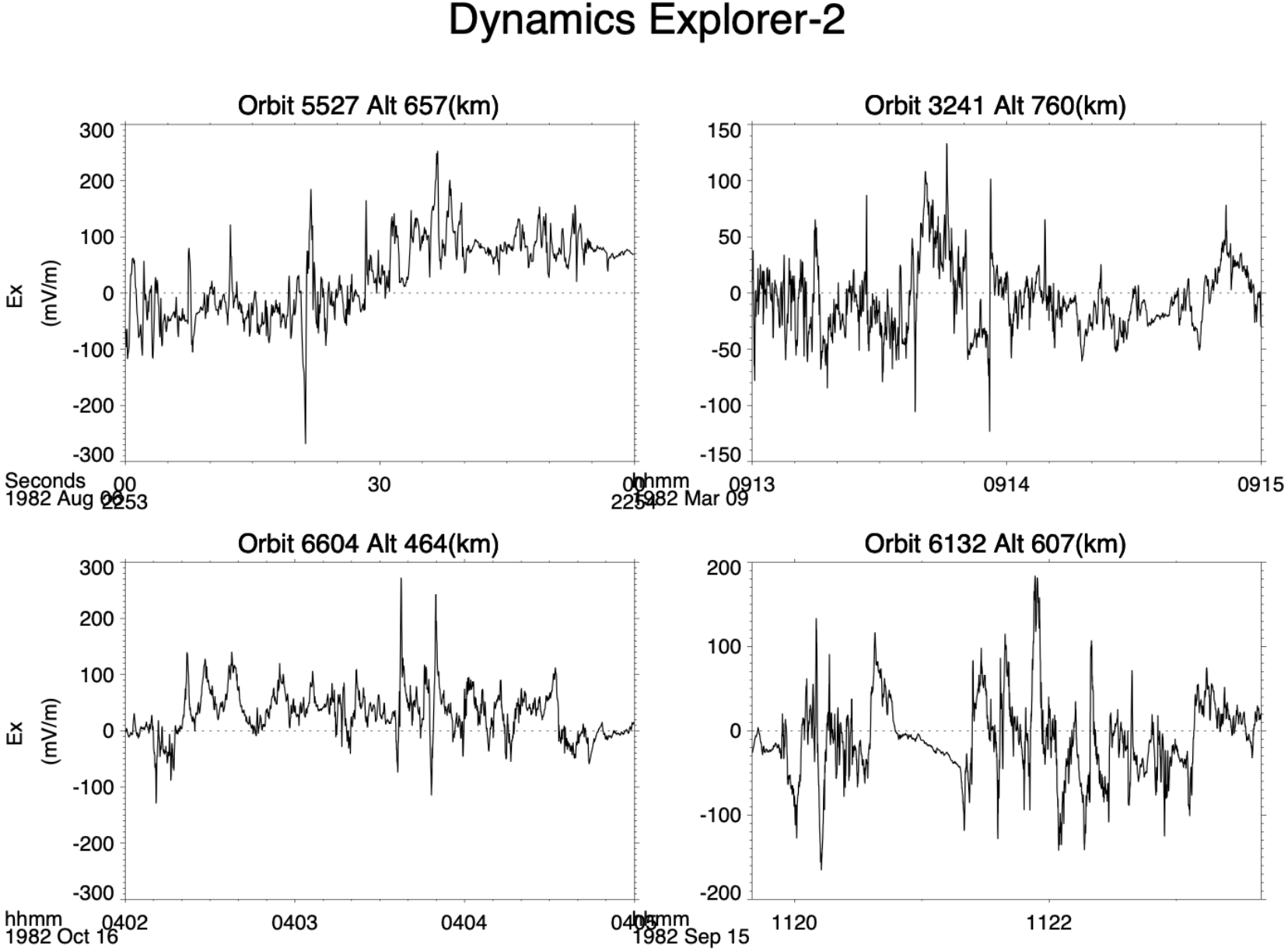
→ often several times higher than with 1 s/sec

Key Point #4

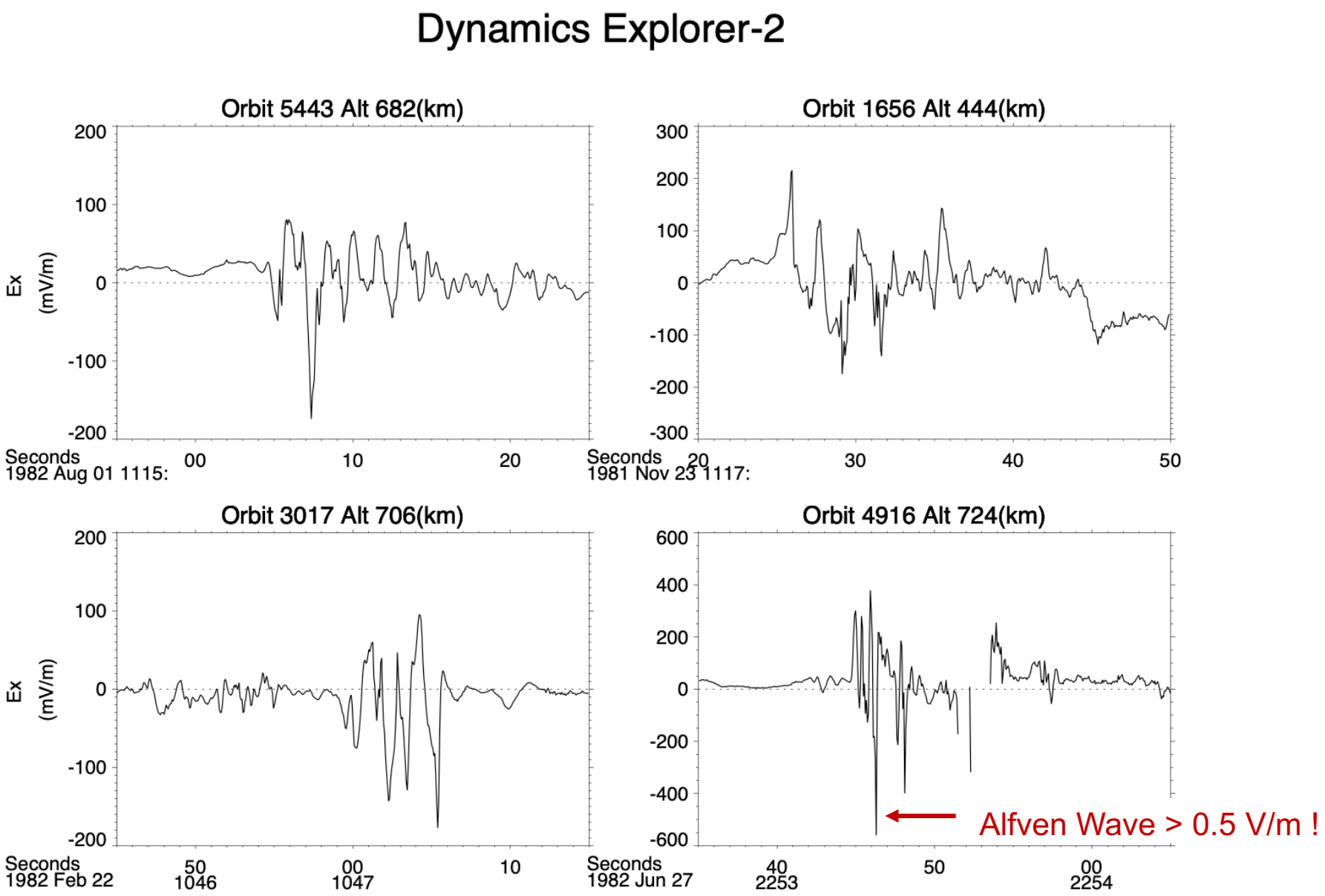
16 s/sec DE-2 Electric and Magnetic Field data reveal copious “packets” of high structured spikey fields and Alfven Waves, particularly in the cusp

Provide an important measure of Energy Input

Large Amplitude Electric Field Time Domain "Spikey" Structures are Common in the High Latitude Ionosphere in 16 s/sec data



Large Amplitude Alfven Waves are Common in the High Latitude Ionosphere in 16 s/sec data

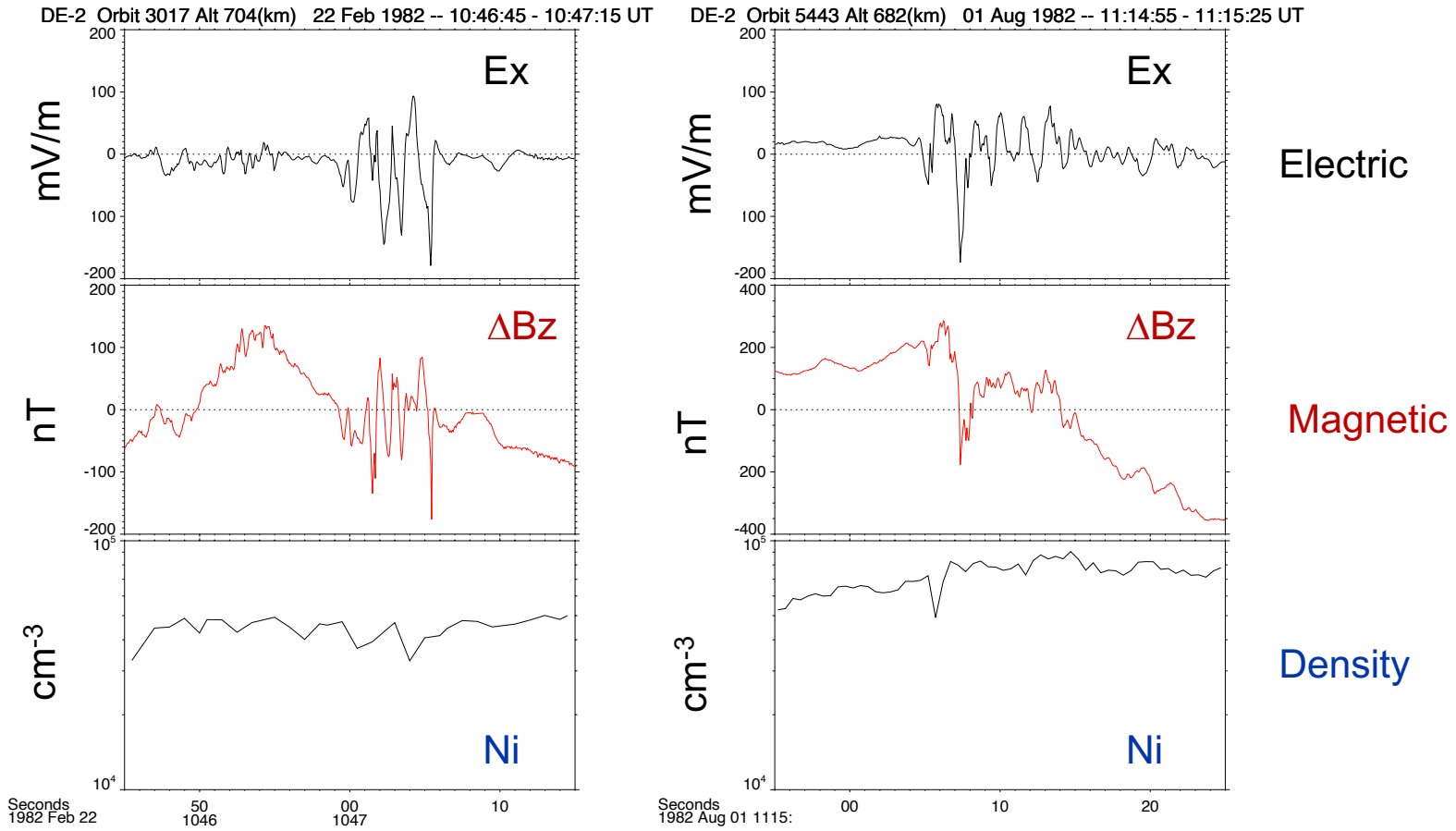


DE-2 Alfven Waves Observed in Orthogonal E and B data

Electric

Magnetic

Density



Electric

Magnetic

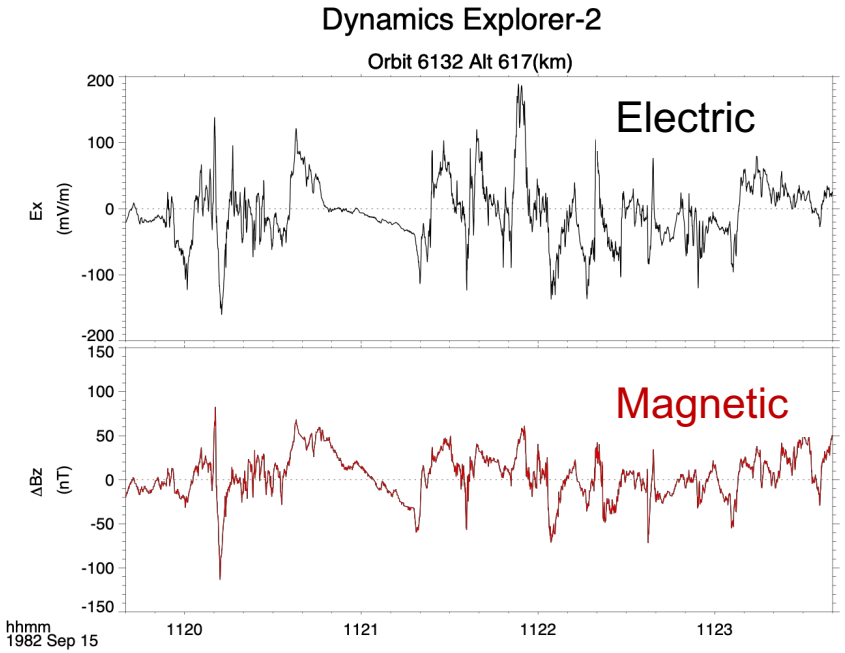
Density

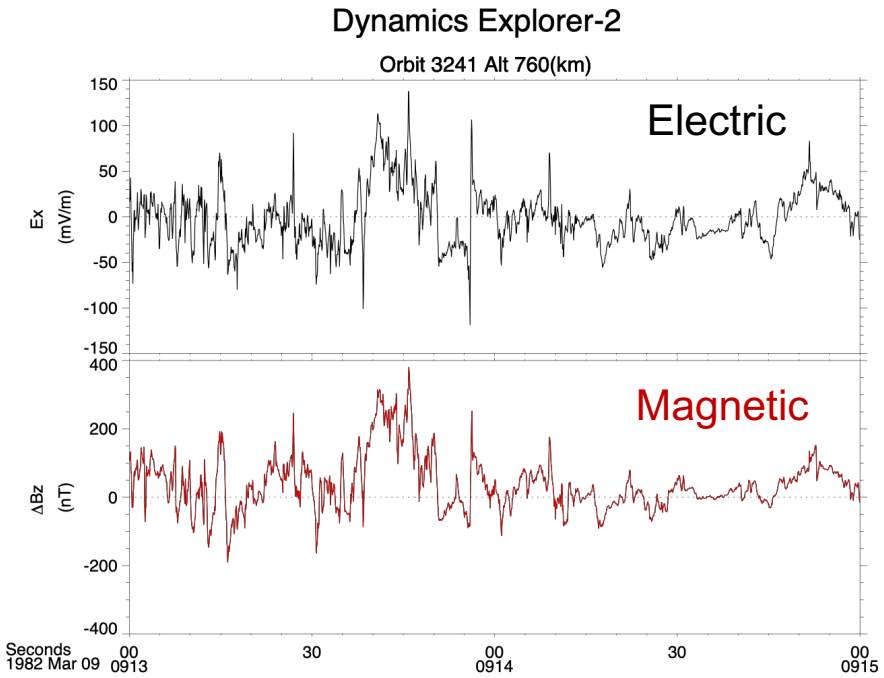
Alfven wave velocity:

E/B → 100 mV/m/100 nT = 1000 km/s

$V_A = B/(\mathrm{Sqrt}(\mu_o \rho)) \sim 1350$ km/s for $5 \times 10^4/cm^3$, B= 0.4G, 50% O+, H+

DE-2 16 s/sec electric and magnetic field data reveal large amplitude and "spikey" time domain structures

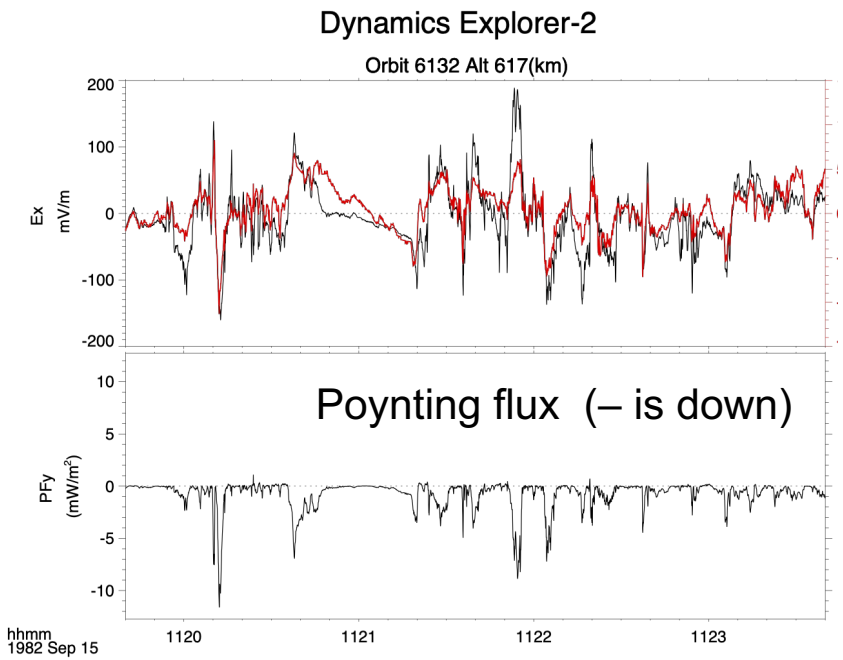


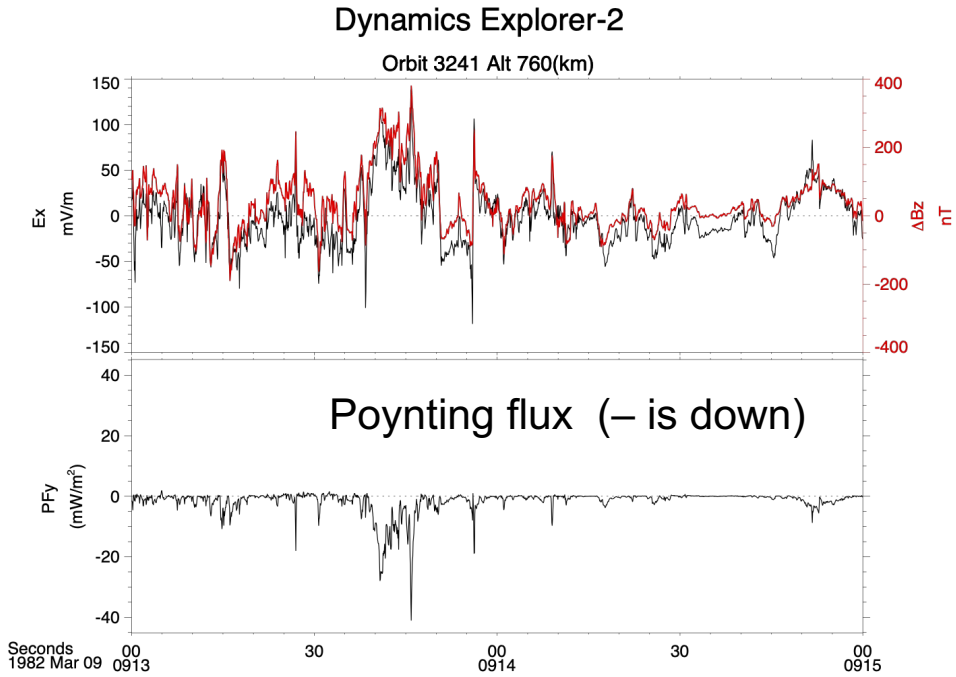


Large Amplitude Alfven Waves

Structured Time-domain Electric and Magnetic Fields

DE-2 16 s/sec electric and magnetic field data reveal large amplitude and "spikey" time domain structures

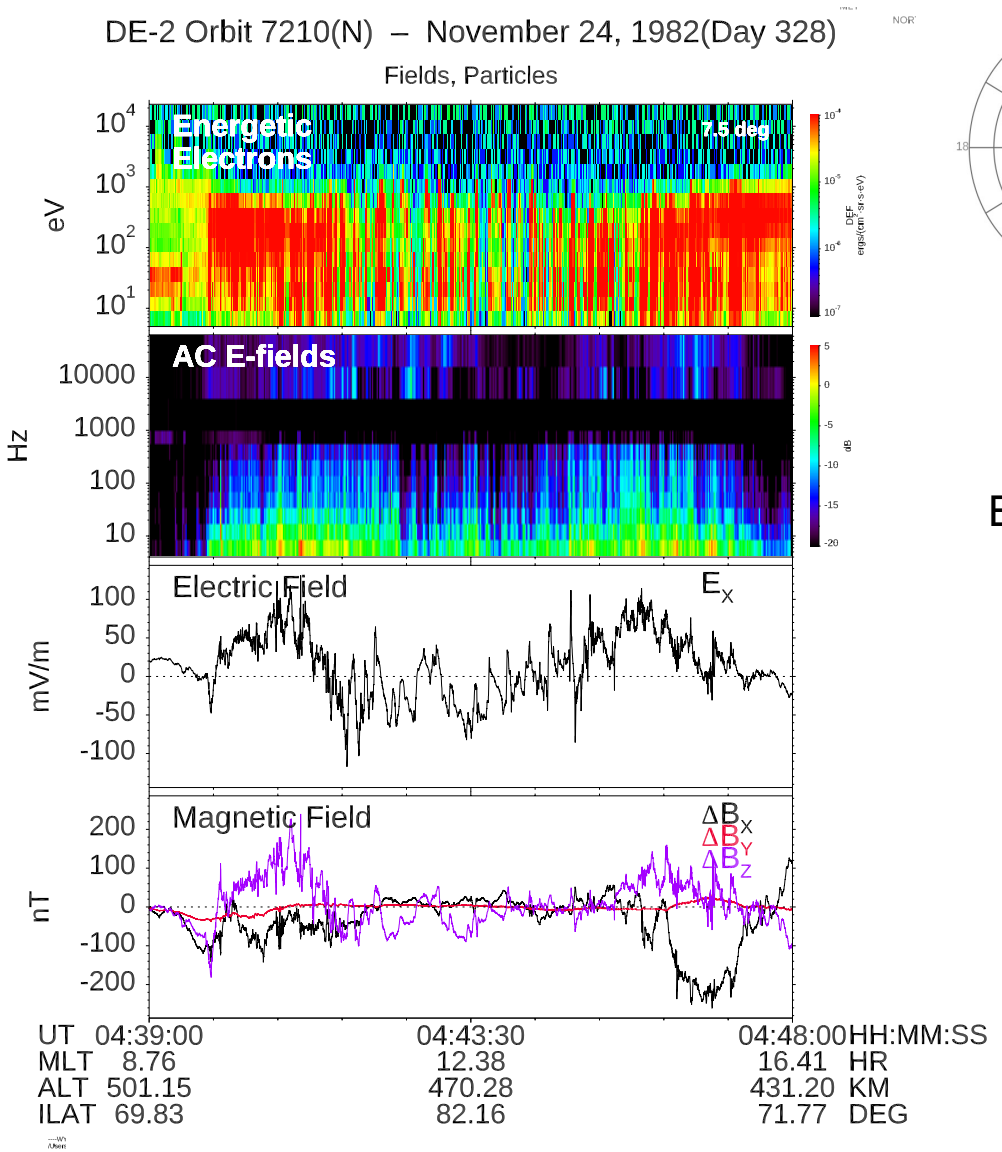


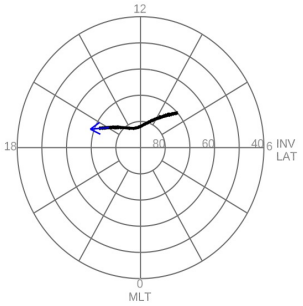


Large Amplitude Alfven Waves

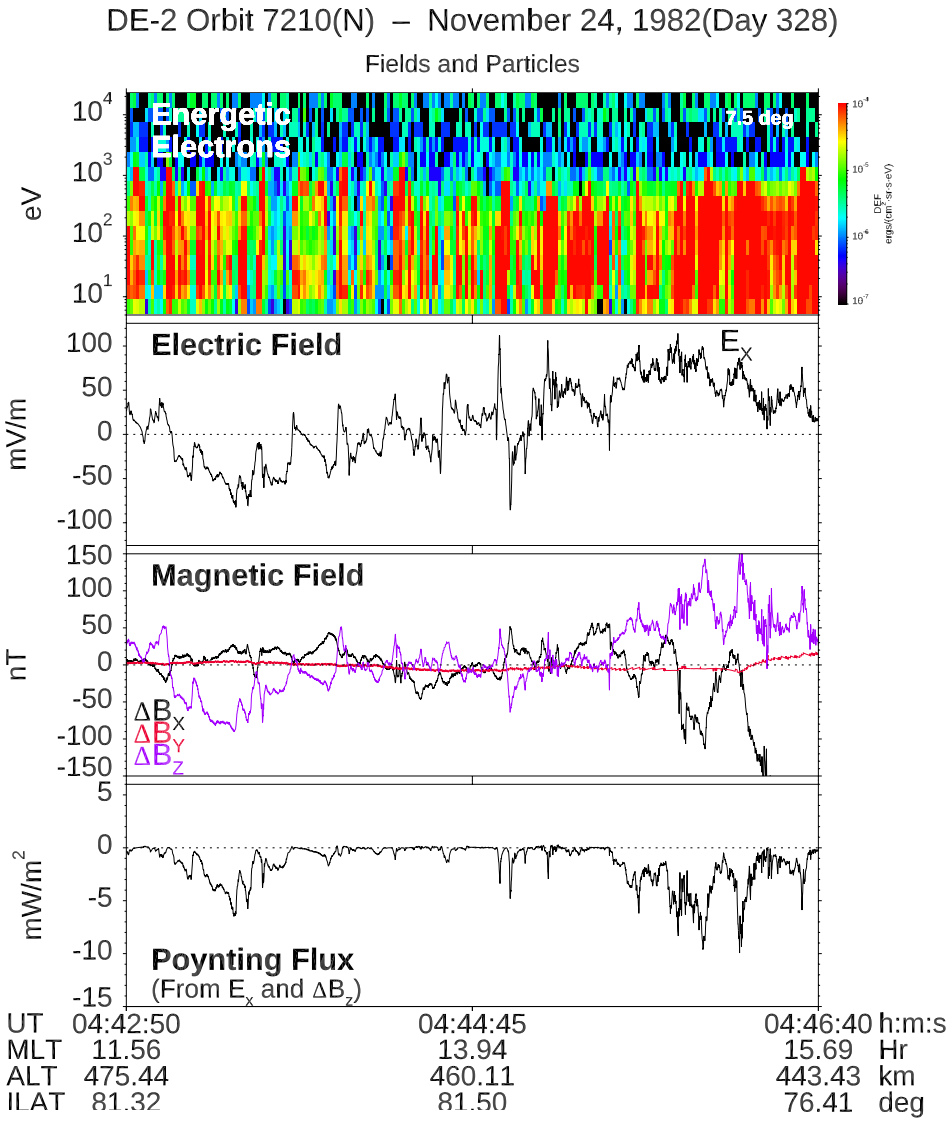
Structured Time-domain Electric and Magnetic Fields

Alfven waves/spikes correlate with low energy, field-aligned electrons





Enlargement



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Theory and simulation of low-frequency plasma waves and comparison to Freja satellite observations

C. E. Seyler and J.-E. Wahlund[1]
School of Electrical Engineering, Cornell University, Ithaca, New York

B. Holback
Swedish Institute of Space Physics, Uppsala Division, Uppsala

Freja Satellite show steepening of E and B waveforms

Simulation showing steepening of initially sinusoidal waveform

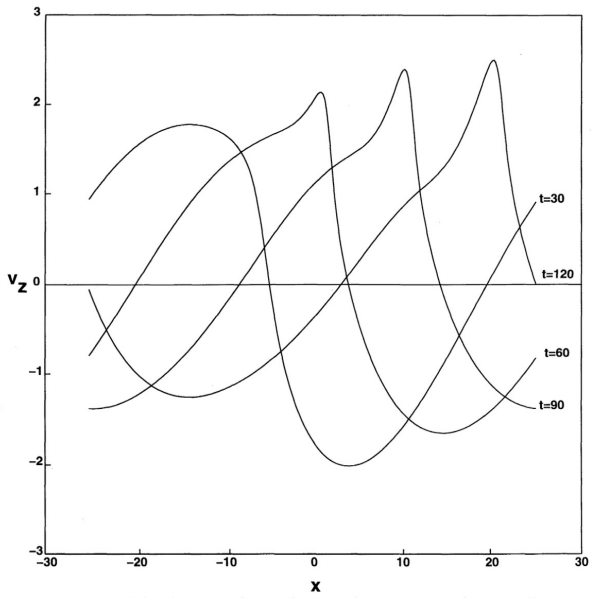

Figure 6. Time sequence of the electron velocity showing the steepening of an initially sinusoidal waveform corresponding to a normal mode with an initial density perturbation of 20%.

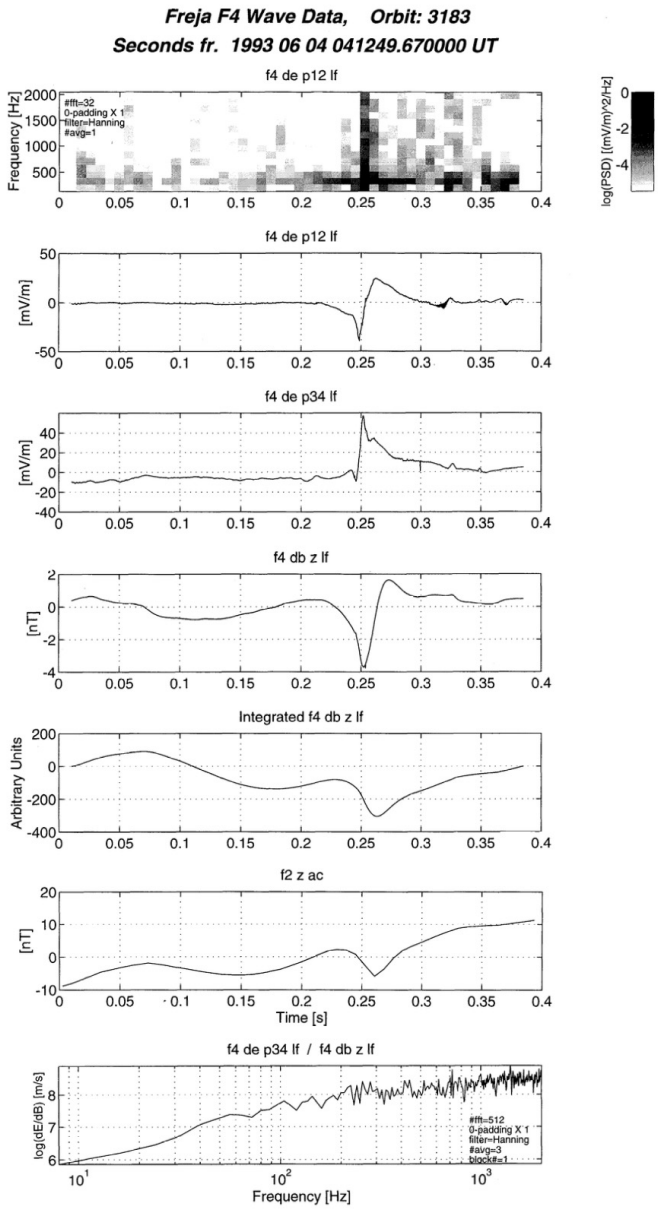

Figure 4. A SKAW having an electric field signature often encountered for larger amplitude events. The antenna P12 was near parallel to B_0, and if we assume the electric field was purely perpendicular it would become several hundred millivolts per meter. The orientation of the antennas with respect to the plane of the wave is not known.

Summary (1/2)

Recent analysis of the DE-2 16 s/sec electric and magnetic field data highlights several key features of high latitude ionosphere electrodynamics:

- Plasma flow (**E** x **B** or **V**i) at high latitudes is highly structured, often characterized by peaks, flow channels, and shears, not by smooth flows reflected by models

- Electric and magnetic fields are highly correlated; Both are highly structured, characterized by peaks and shears,

- Combined electric and magnetic fields readily provide a measure of magnetospheric energy input, showing large downwards Poynting flux

- Poynting Flux “peak” calculations using 16 s/sec **E** and **B** data can be several times higher compared to the 1 s/sec; Together with increased $\mathbf{E}^2$ from vector data provides a measure of ”missing energy”

Summary (2/2)

- High time resolution electric and magnetic field data suggest Alfven waves are copious in the high latitude ionosphere, particularly in the cusp.

- Such Alfven wave amplitudes may be 100's of mV/m and 100's of nT appearing in packets that extend for horizontal distances (along the s/c track) of 100-500 km with pronounced "spikes" in E and B, similar to Freja measurements

DE-2 analysis with 16 s/sec E and B data presents a new perspective on magnetosphere-ionosphere coupling at high latitudes, including energy deposition and momentum exchange at different spatial and temporal scales during both quiet and disturbed conditions.

→ It is hoped that a way can be found for the GDC mission to meet its stated requirements in the AO of measuring vector, structured electric fields from 25 km to 100m (160 s/sec)