Using ISR to study ultra-low frequency (ULF) waves and their effects on the ionosphere

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ISR Workshop
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Outline

- Introduction to ULF waves
- Radar Observations of ULF waves
- ULF waves in the polar cap
- Using ISR to study ULF waves

ULF Waves

ULF = Ultra-Low-Frequency range from 1 mHz – 1 Hz

“Ultra” low → lower than natural plasma frequency

Geomagnetic ULF Pulsation classes (Jacobs et al. 1964)							
	Continuous pulsations					**Irregular pulsations**	
	Pc 1	**Pc 2**	**Pc 3**	**Pc 4**	**Pc 5**	**Pi 1**	**Pi 2**
T [s]	0.2-5	5-10	10-45	45-150	150-600	1-40	40-150
f	0.2-5 Hz	0.1-0.2 Hz	22-100 mHz	7-22 mHz	2-7 mHz	0.025-1 Hz	2-25 mHz

FLRs from 0.5- 5mHz

What is a Field Line Resonance (FLR)?

MHD Waves

One Fluid Ideal MHD Yields Three Wave Modes:

1. Alfven or Intermediate Mode $\omega^2=k_{||}^2 V_A^2$ $V_A^2=B^2/(\mu_o \rho)$

   -energy propagates along B field
   -non-compressional

2. Fast Mode $\omega^2=k^2\{(V_A^2+C_s^2)+[(V_A^2+C_s^2)^2-4C_s^2V_A^2\cos^2\theta]^{1/2}\}/2$

   - energy can propagate across B field
   - compressional

   $\omega^2=k^2V_A^2$ for cold plasma

2. Slow Mode $\omega^2=k^2\{(V_A^2+C_s^2)-[(V_A^2+C_s^2)^2-4C_s^2V_A^2\cos^2\theta]^{1/2}\}/2$

   - energy propagates ~along B field
   -compressional
   -doesn't propagate in cold plasma

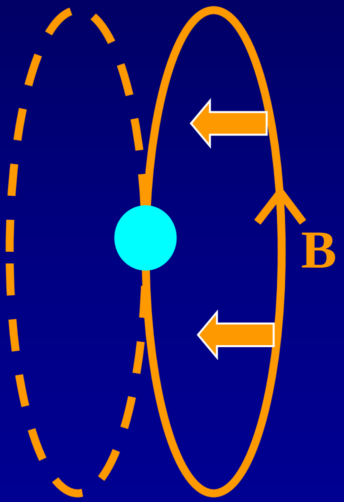
A field line resonance is a standing shear Alfven wave along a geomagnetic field line.

Two modes in a dipole field geometry:

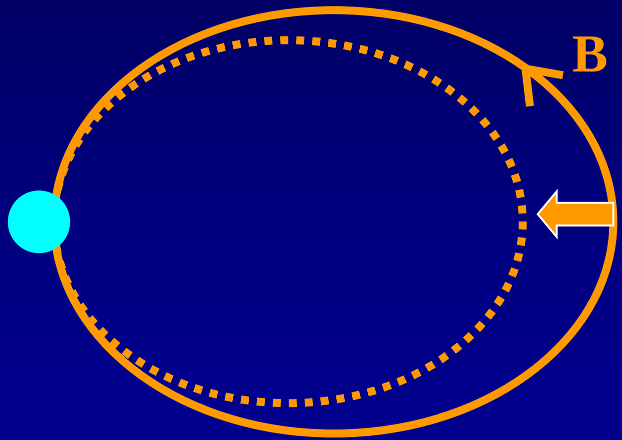
Toroidal Mode
(m = 0)

$m = 2\pi R/\lambda$

Poloidal Mode
(m→infinity)



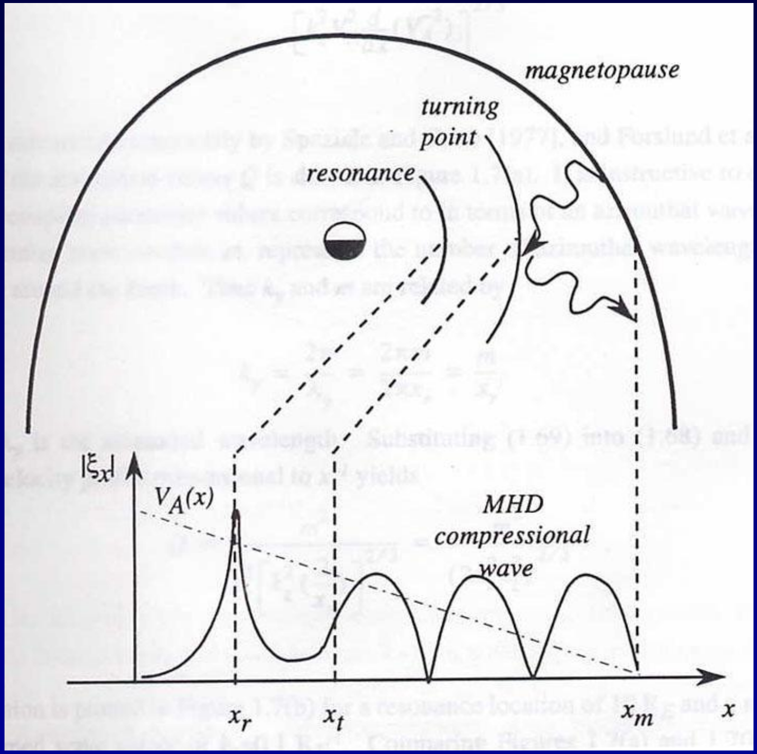
Looking radially towards earth



Looking azimuthally

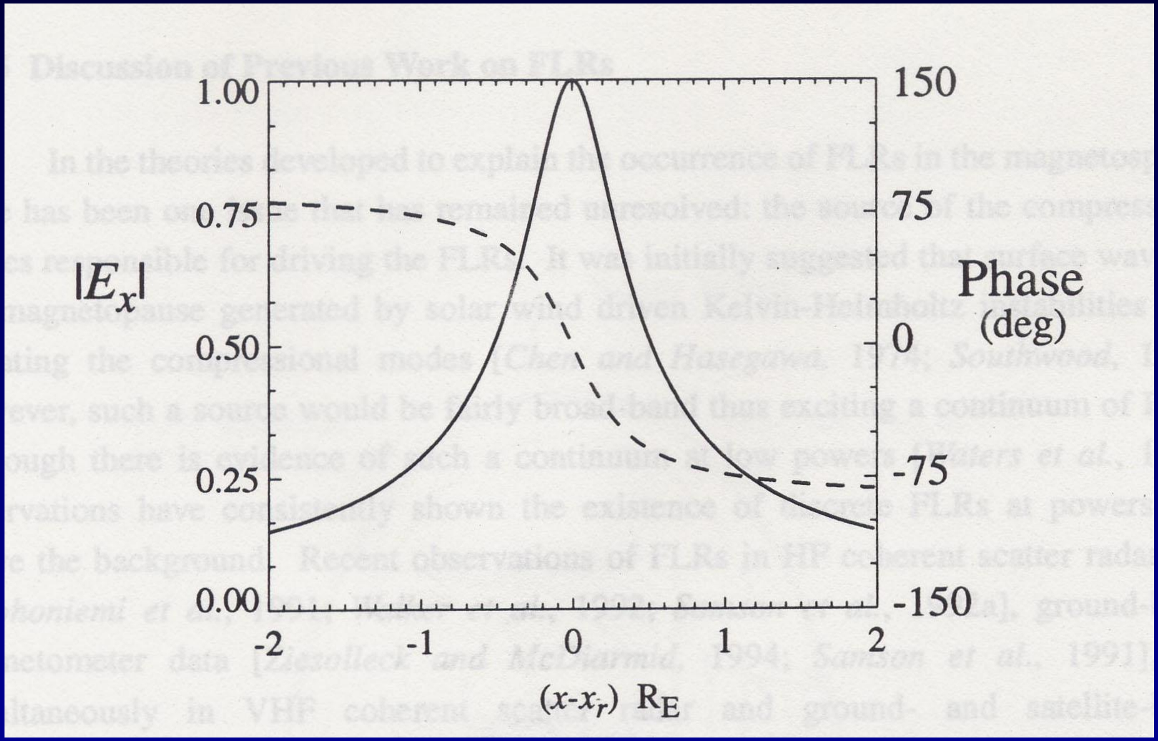
Observed m typically ranges from 1 to 100

Coupling of fast mode to shear Alfven mode → FLR



Distinguishing Characteristics of a FLR

Ionospheric
Pulsation
Amplitude



Magnetic Latitude

Decreasing phase with latitude ⇨ Poleward phase propagation

Why should we care about ULF waves and FLRs?

- ULF waves play a significant role in the coupling of energy from solar wind to magnetosphere and ionosphere.

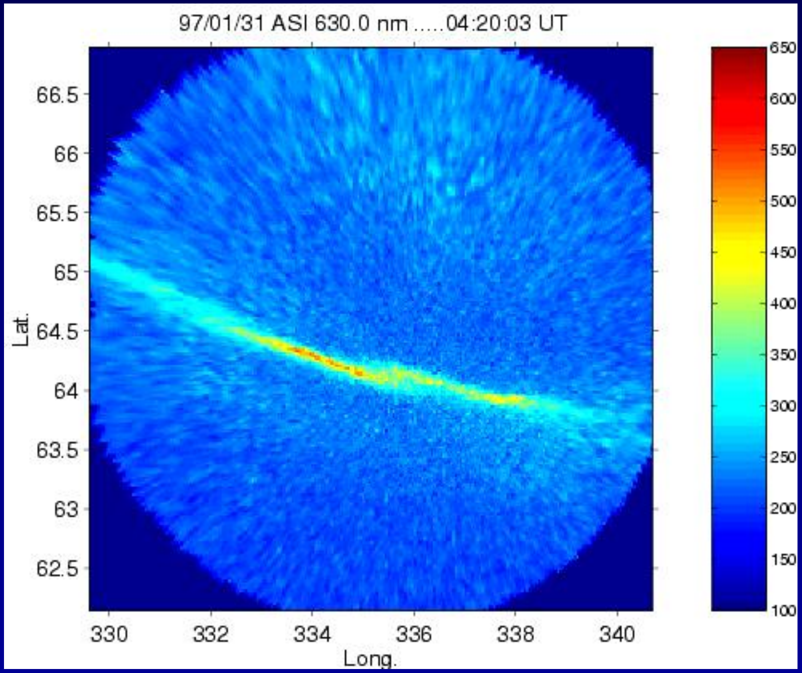
- ULF waves are associated with energetic electron acceleration in the radiation belt. (Elkington et al. GRL, 1999)

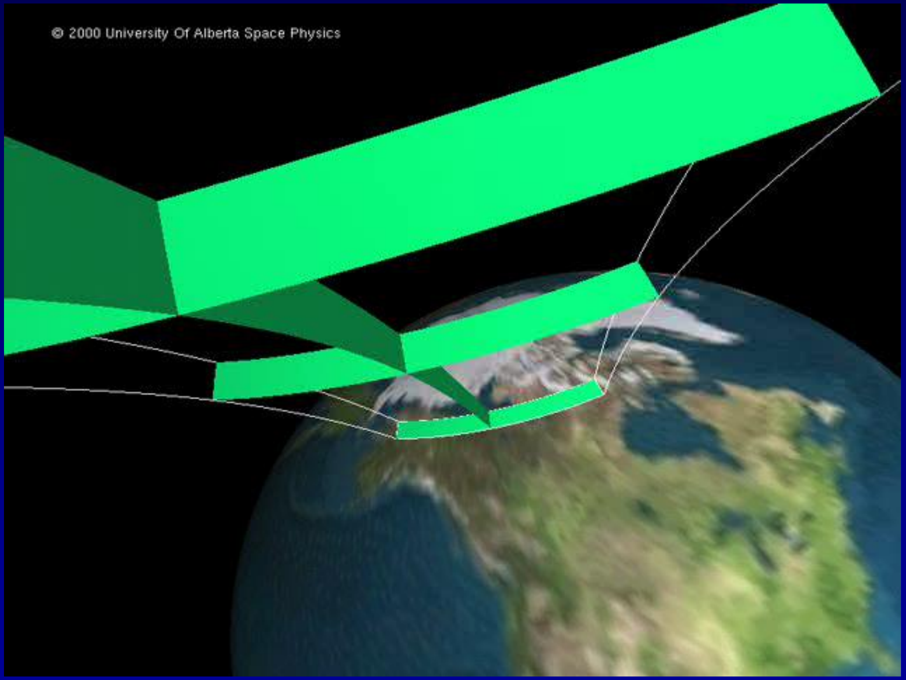
- FLRs can be used to infer equatorial plasma densities. (Waters et al. JGR, 1996)

- FLRs play a role in auroral arc generation and substorm onset. (Samson et al. JGR 1991; Samson et al. JGR, 1992)

FLRs are associated with auroral arcs

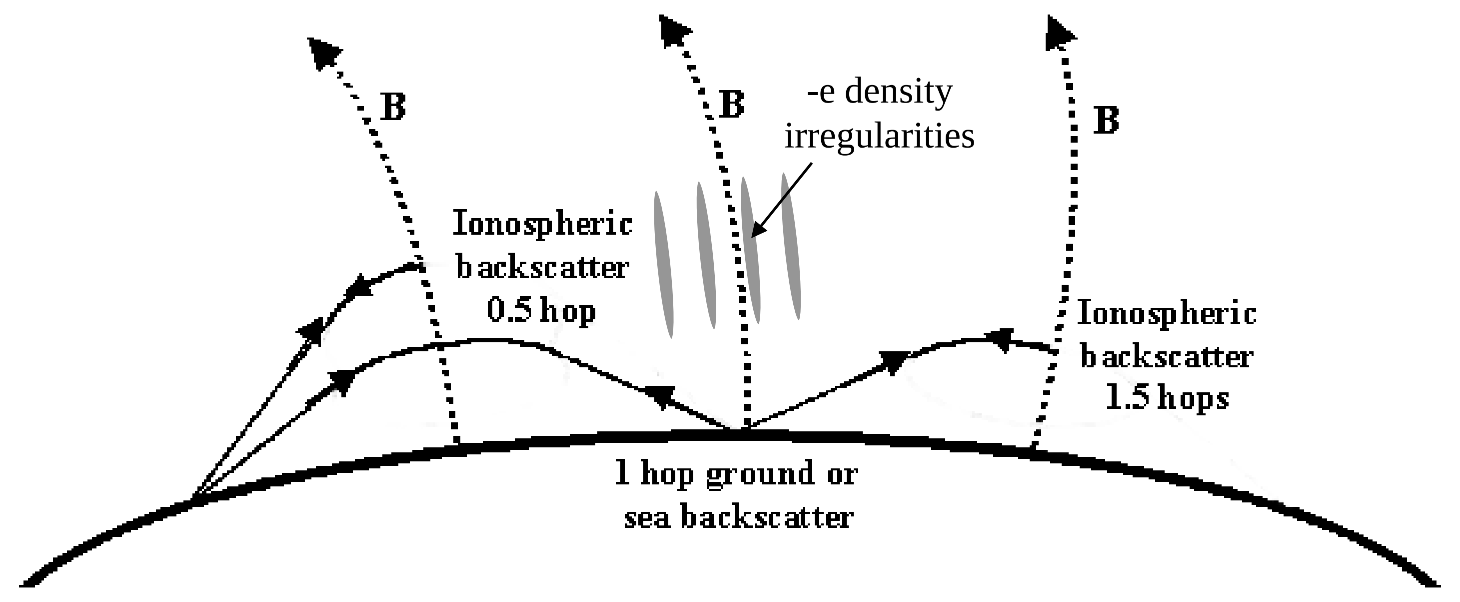
(Samson et al. JGR 1991; Samson et al. JGR, 1996; Lotko et al. GRL 1998; Rankin et al. GRL, 1999)





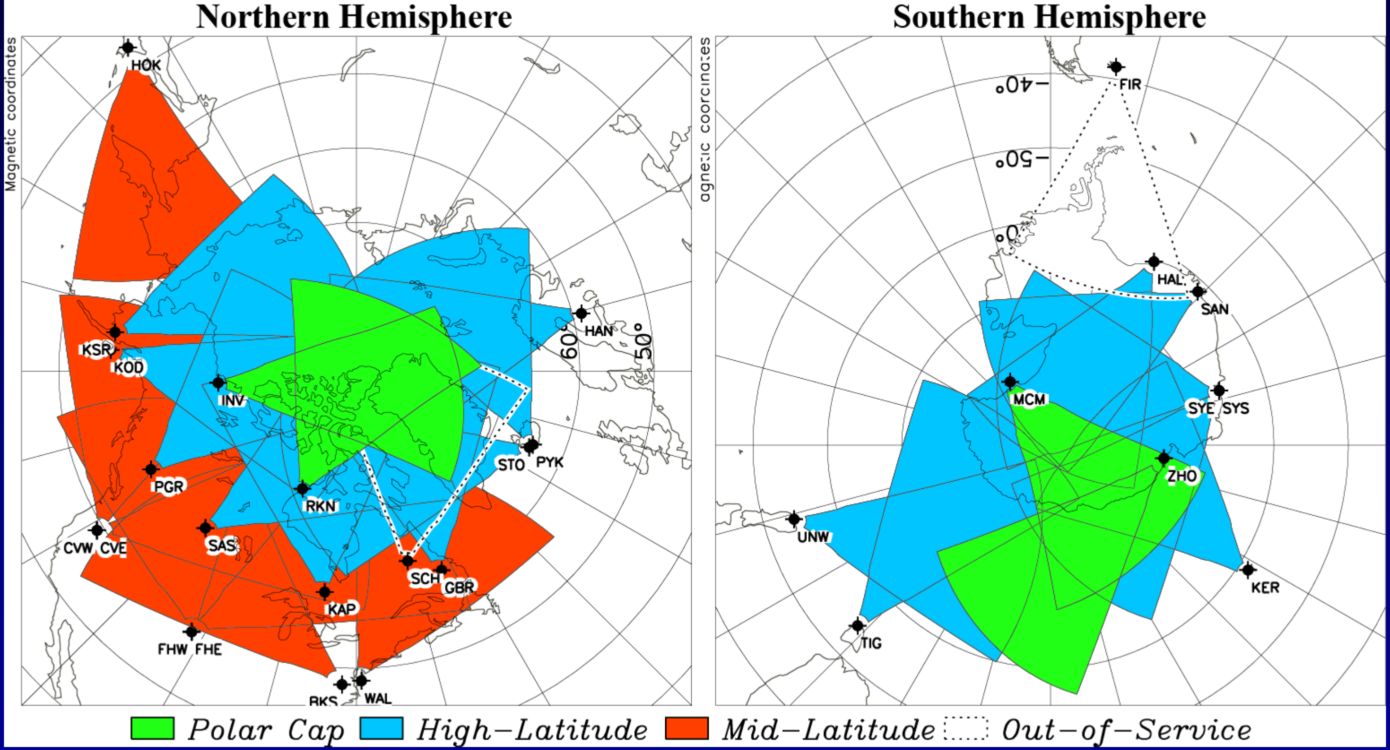
Observation of ULF FLRs in the Ionosphere with Radar

Coherent Radar

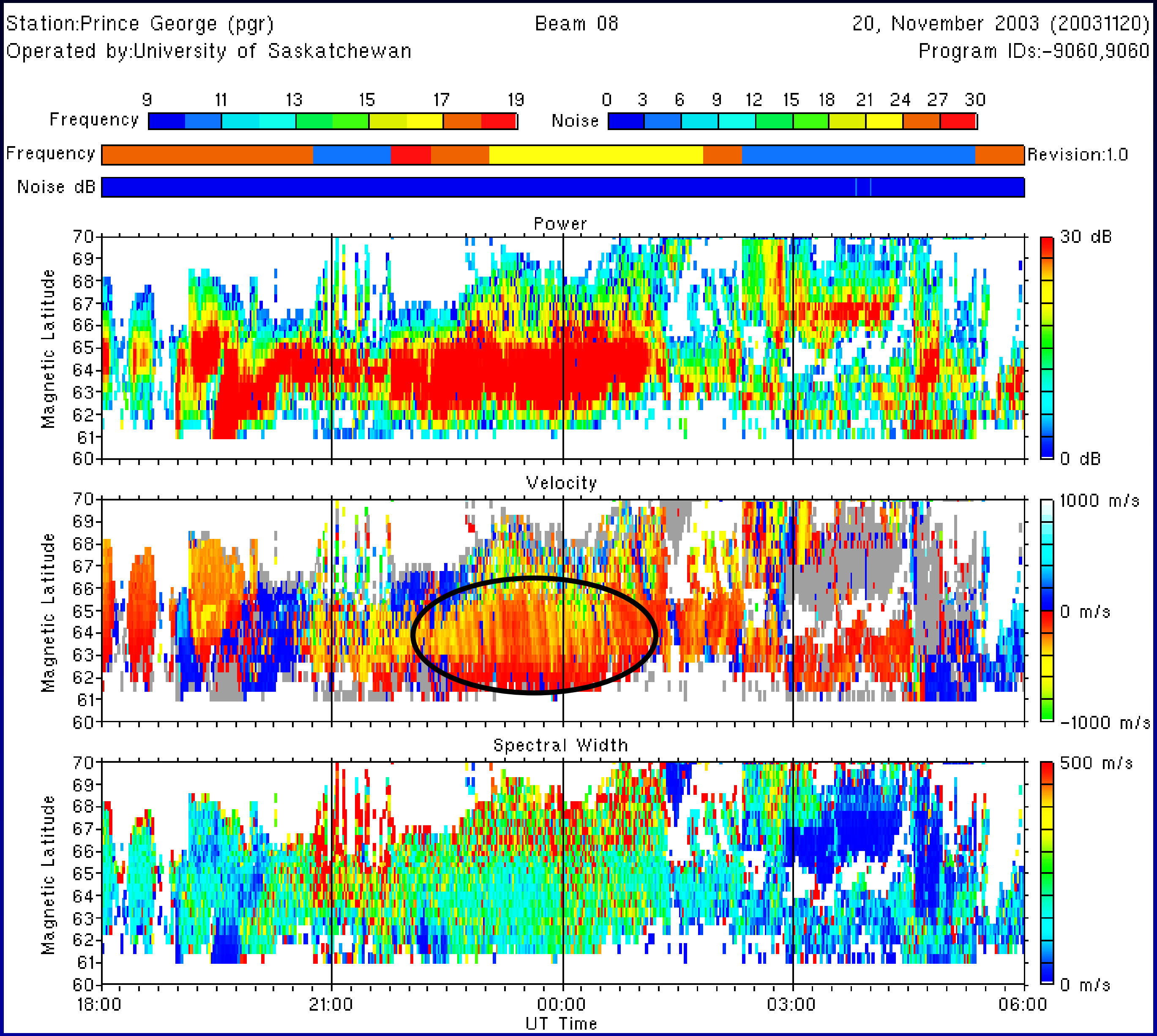


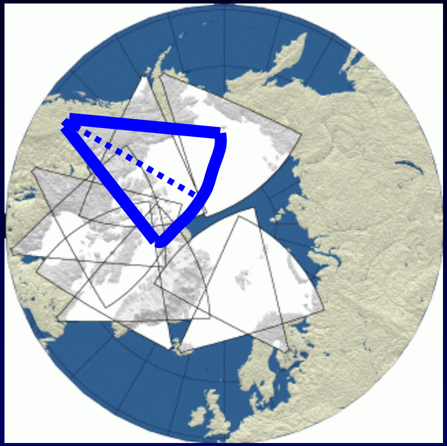
Backscatter is Doppler shifted by the line-of-sight speed of the ionospheric irregularities which flow with the background ionospheric convection.

Super Dual Auroral Radar Network



SuperDARN Time Series plot: Prince George



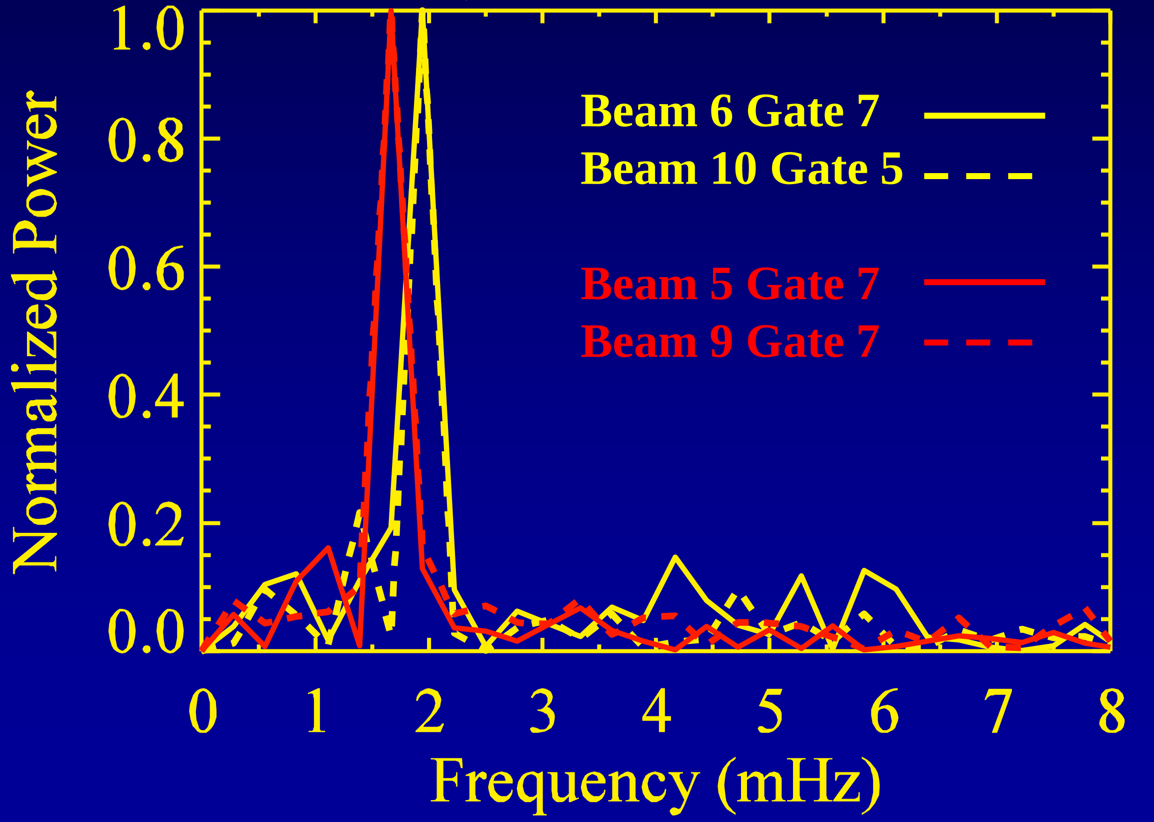


SuperDARN Power Spectra Nov. 20-21, 2003.

Prince George

Time Interval 2
23:45 – 00:45 UT
1.7mHz

Time Interval 1
22:30 – 23:30 UT
1.9 mHz



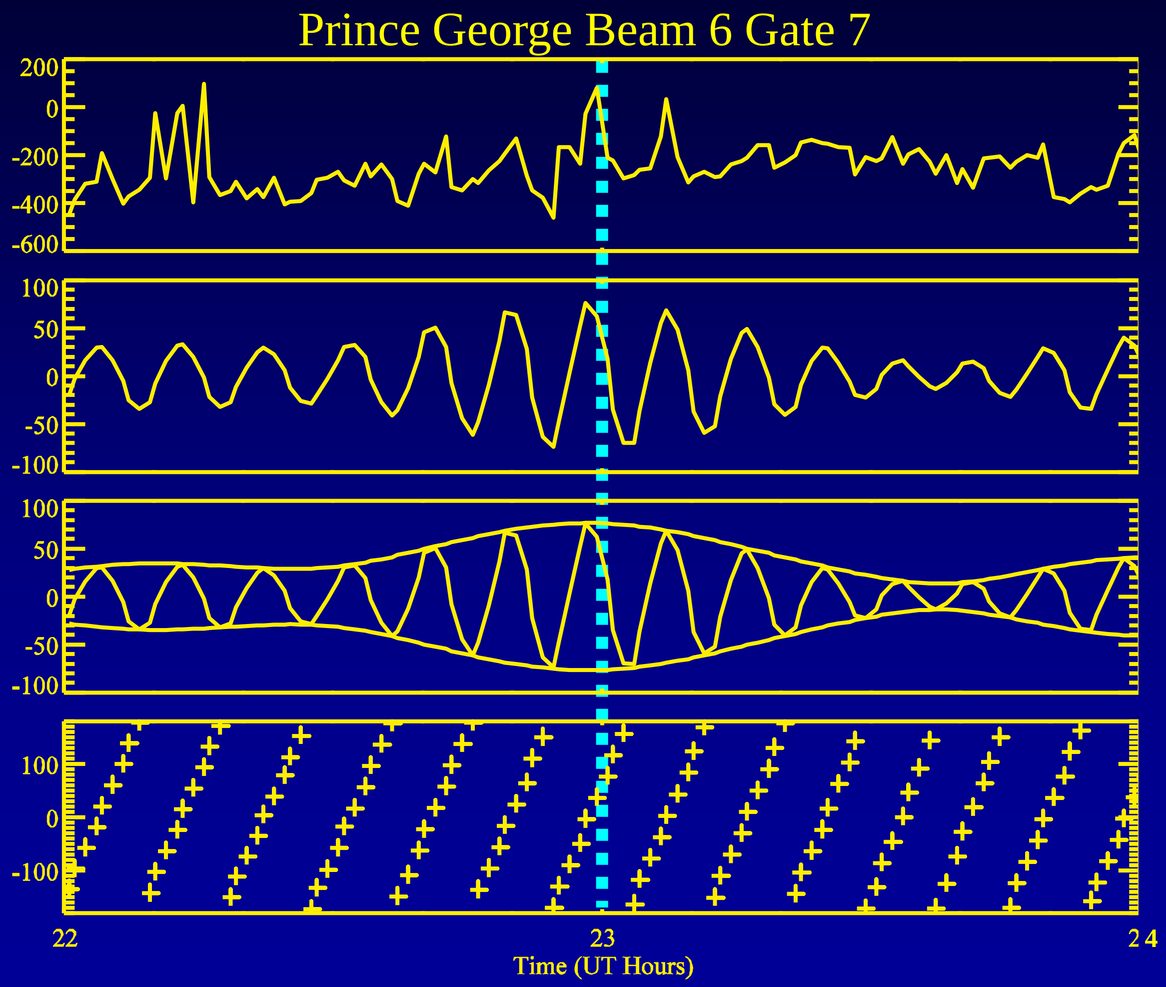
Interval 1
Bandpass at 1.7-2.1 mHz and
Calculate Analytic Signal Amplitude and Phase: $A(t) = f(t) - iH(t)$

Raw Interpolated Doppler Velocity Data *f(t)*

Bandpassed Data (1.7-2.1 mHz)

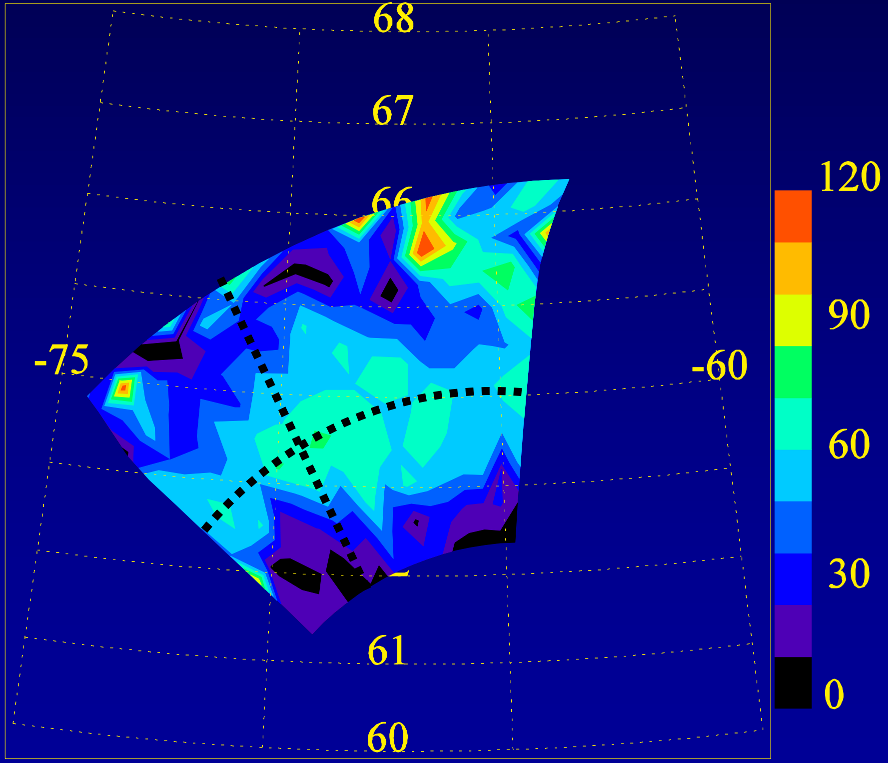
Analytic Signal Amplitude

Analytic Signal Phase

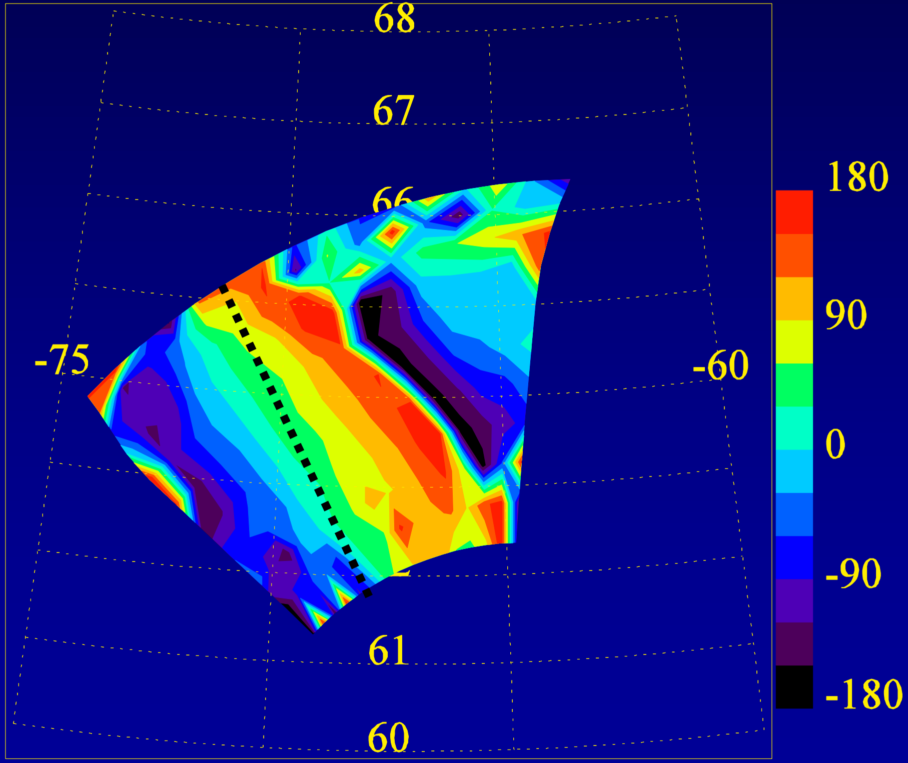


Prince George
Frequency Range: 1.7 – 2.1 mHz
Time: 23:00 UT Nov. 20 2003

Instantaneous Amplitude

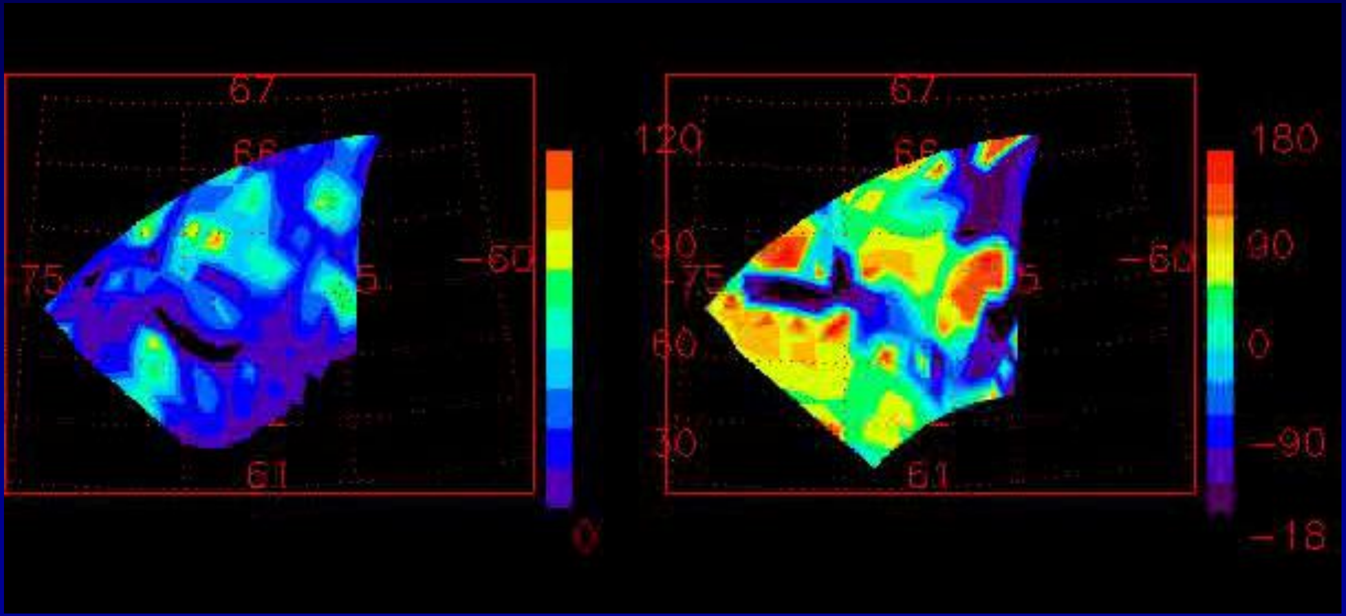


Instantaneous Phase

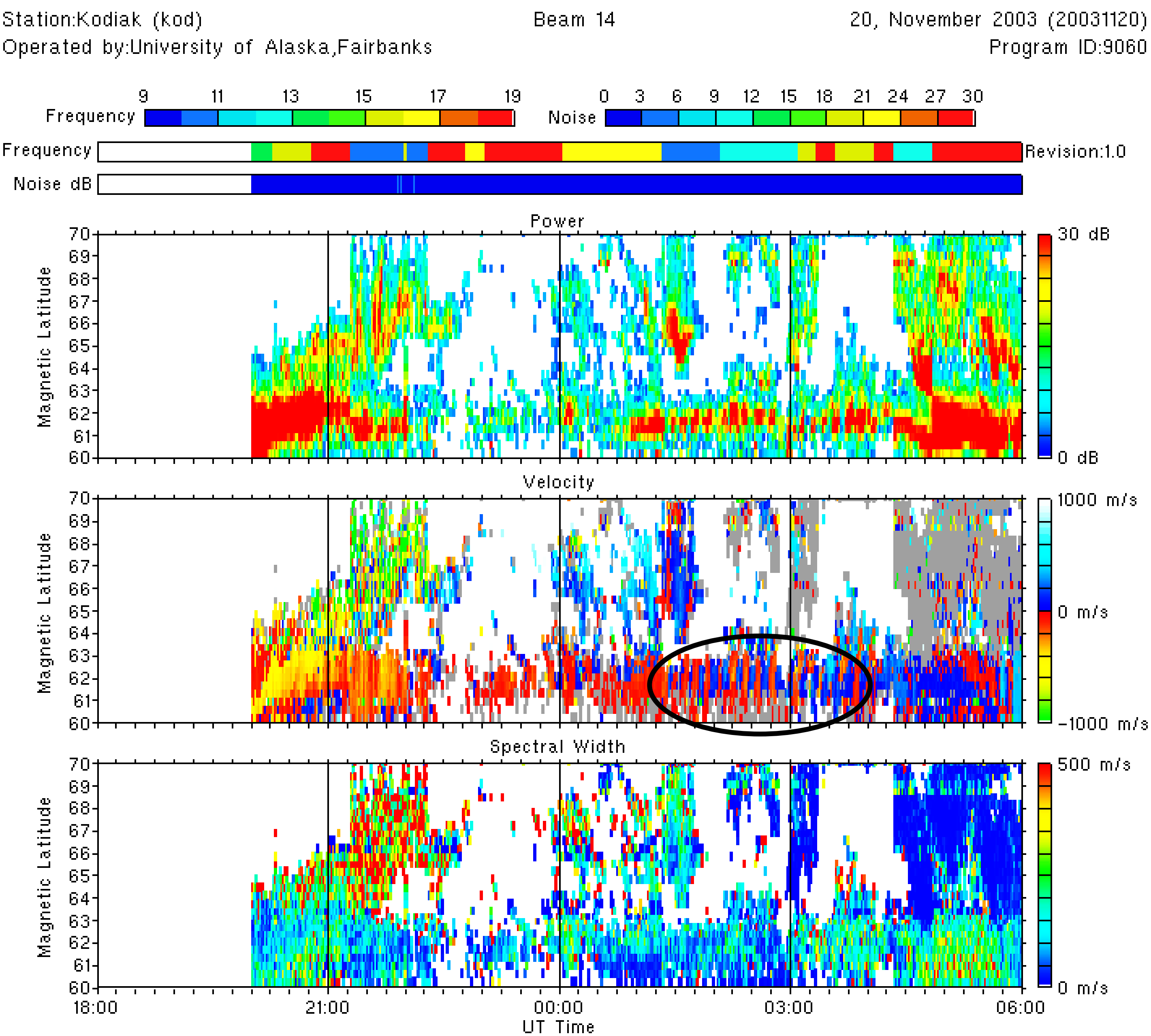


Prince George
Frequency Range: 1.7 – 2.1 mHz
Time: 22:30-23:30 UT Nov. 20 2003

Amplitude Phase



SuperDARN Range-Time plot: Kodiak

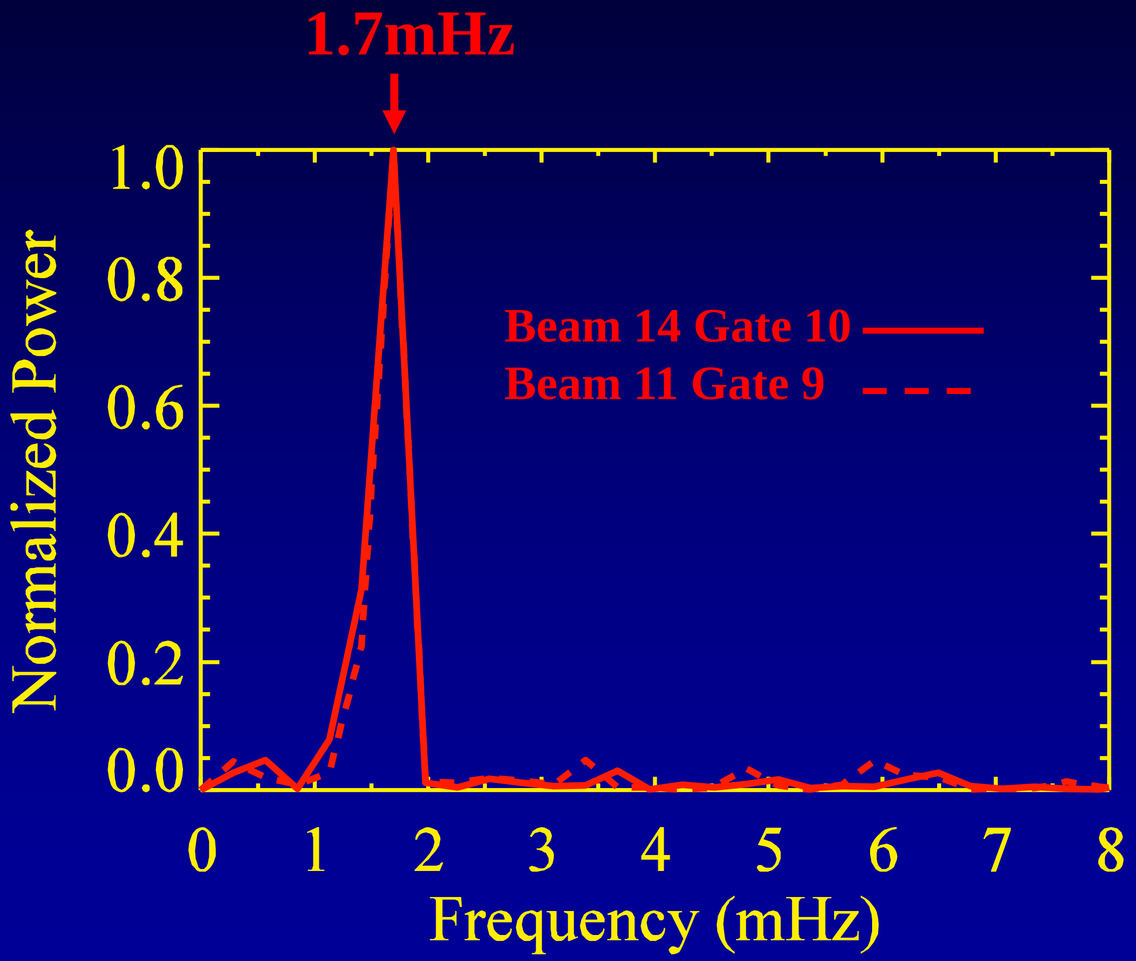

Station:Kodiak (kod)
Operated by:University of Alaska,Fairbanks

Beam 14

20, November 2003 (20031120)
Program ID:9060

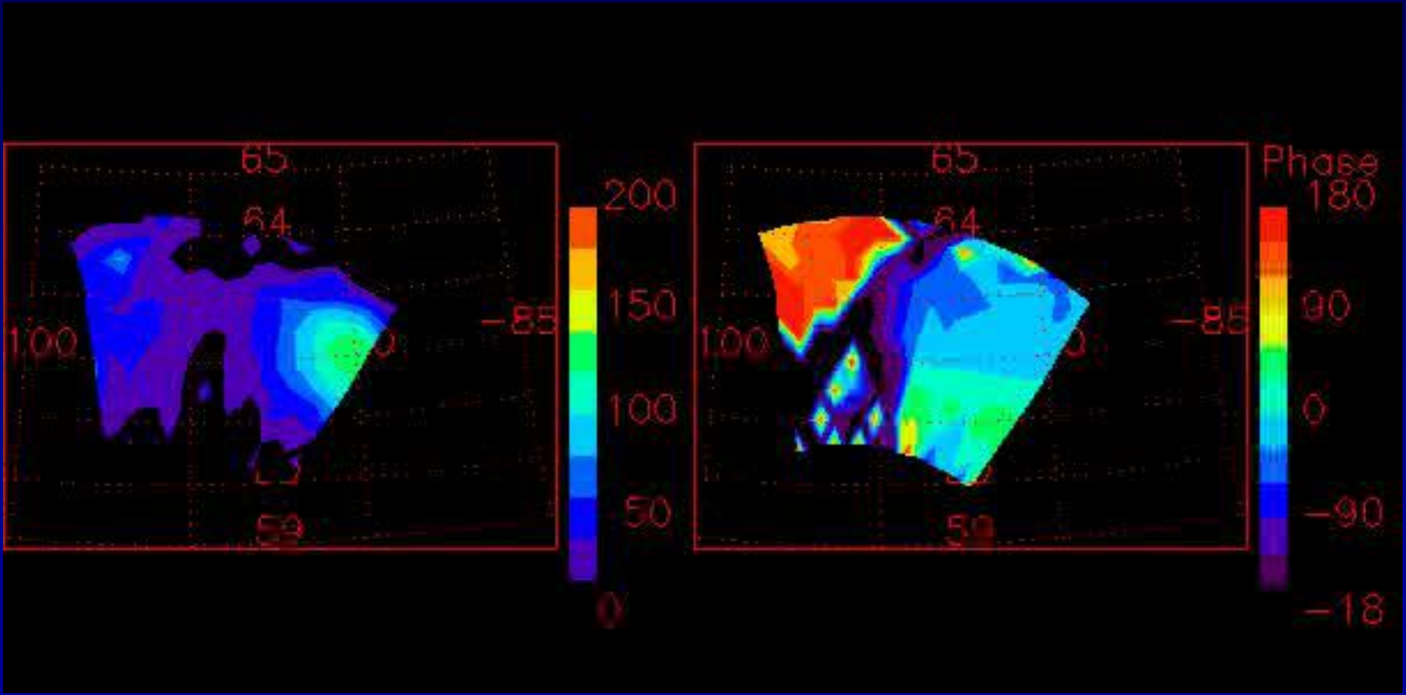
Revision:1.0

Kodiak FFT Spectra
02:00-03:00 UT Nov. 21, 2003.



Kodiak Alaska
Frequency Range: 1.5 – 1.9 mHz
Time: 02:00-03:00 UT Nov. 21 2003

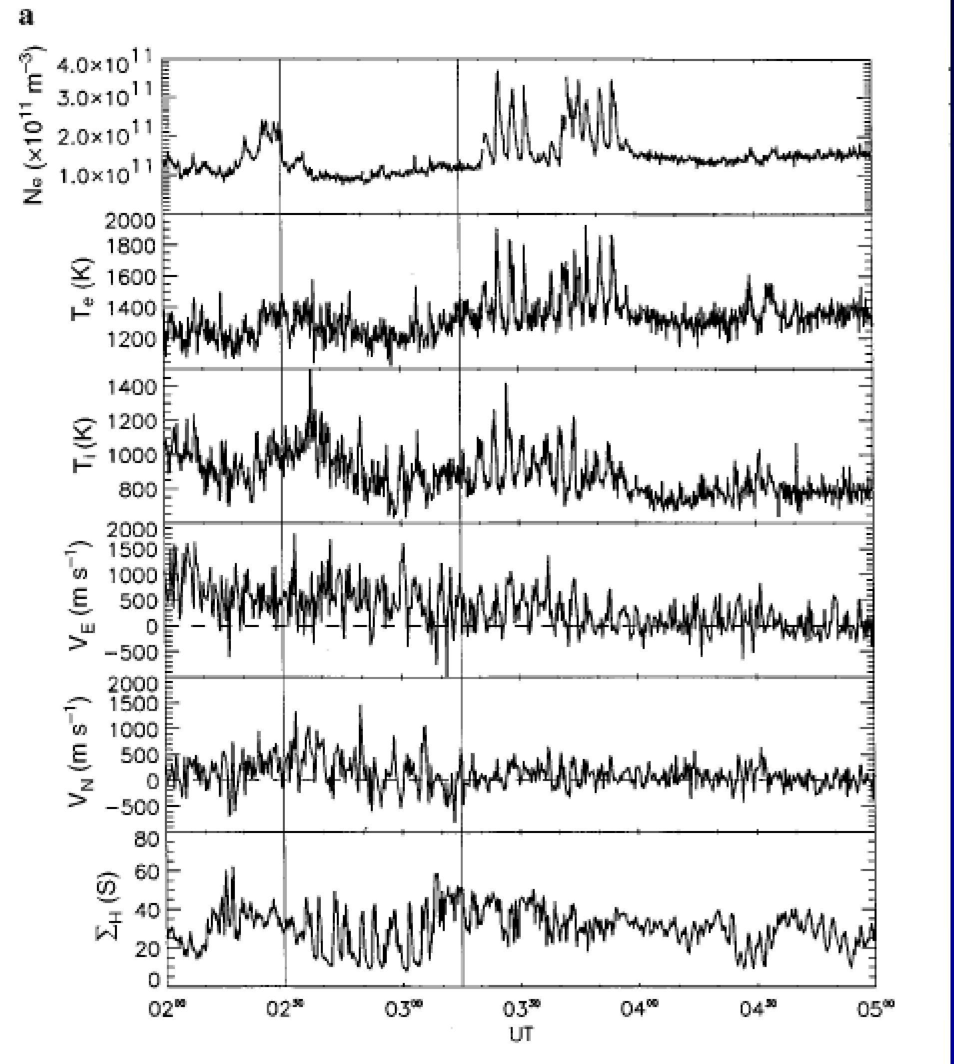
Amplitude Phase



Incoherent Scatter Radar Observations of ULF Waves at Auroral Latitudes

Eiscat Incoherent Radar Observations of Pc5 Waves

Lester et al., Annales Geophysicae, 2000

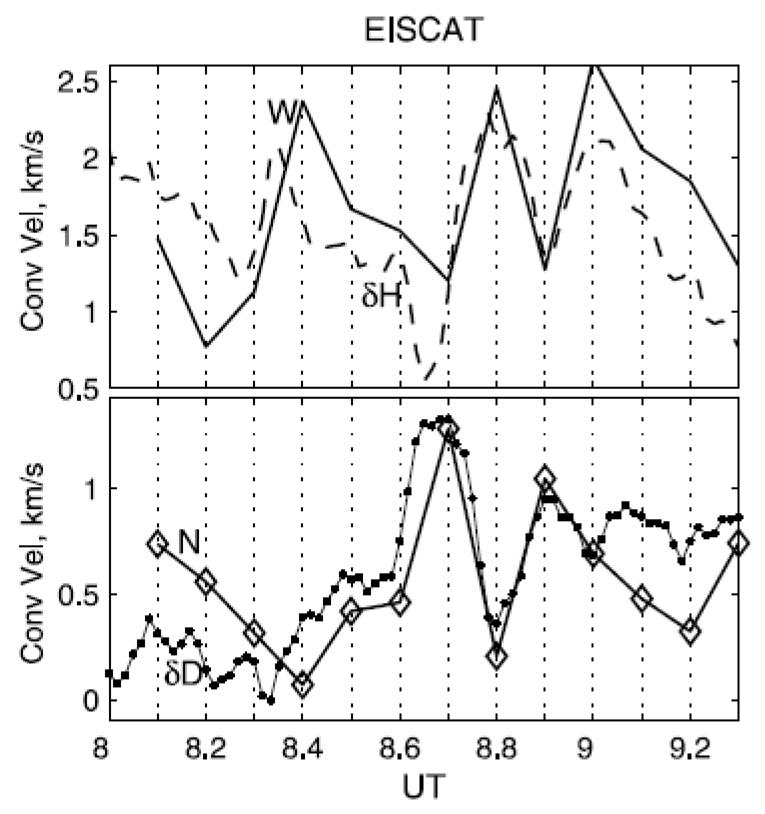


- Eiscat observes oscillations in electron density, electron and ion temperature, flow velocities, conductivities associated with Pc5 FLRs.

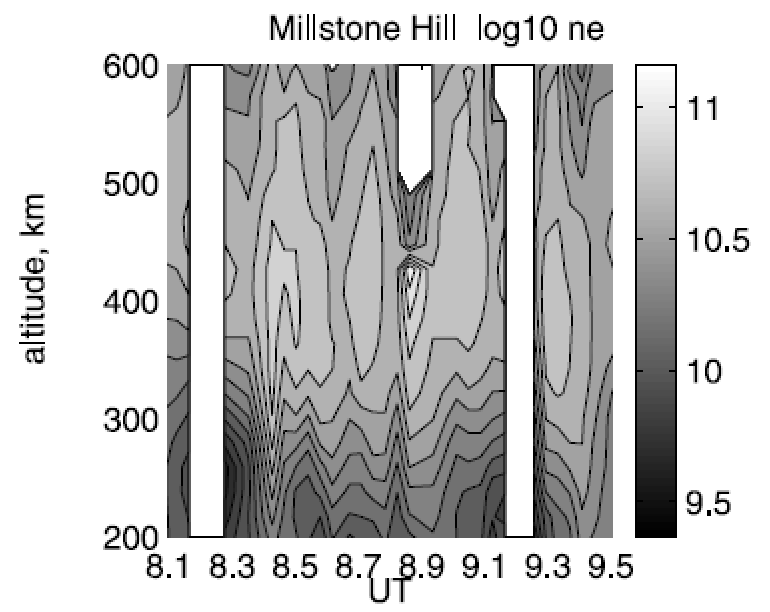
- The ionospheric plasma response to ULF waves varies with local time, azimuthal wave number and altitude.

ISR Observations of a Global ULF Wave

Mishin et al., J. Geophys. Res.,, 2002



ISR Convection velocities and IMAGE ground magnetic fields associated with FLR



F-layer plasma densities attributed to gravity waves generated by ULF electric fields.

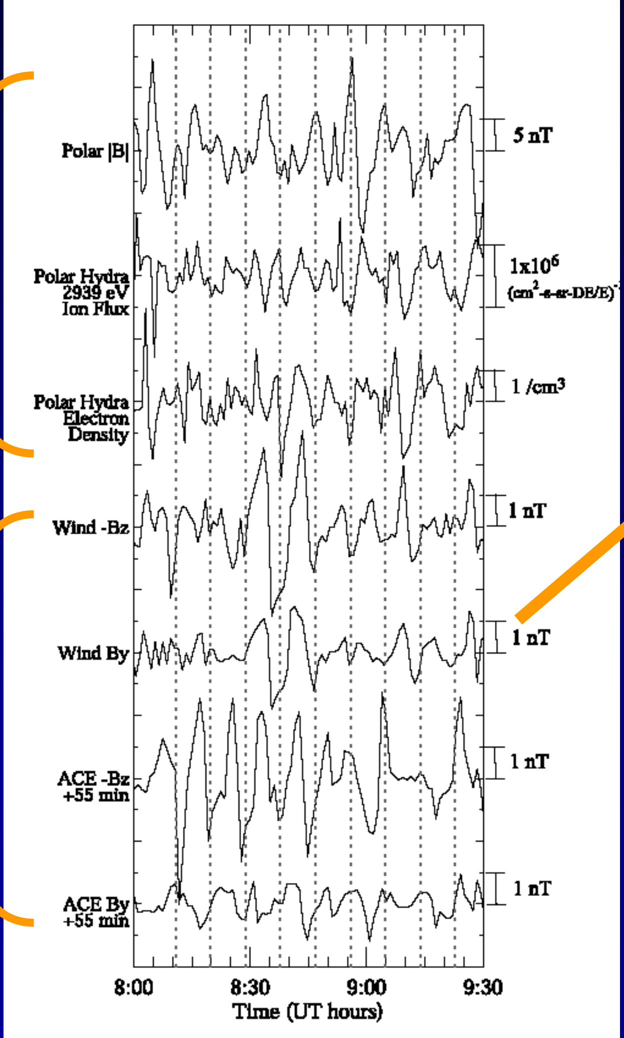
Observation of ULF Waves in the Polar CAP

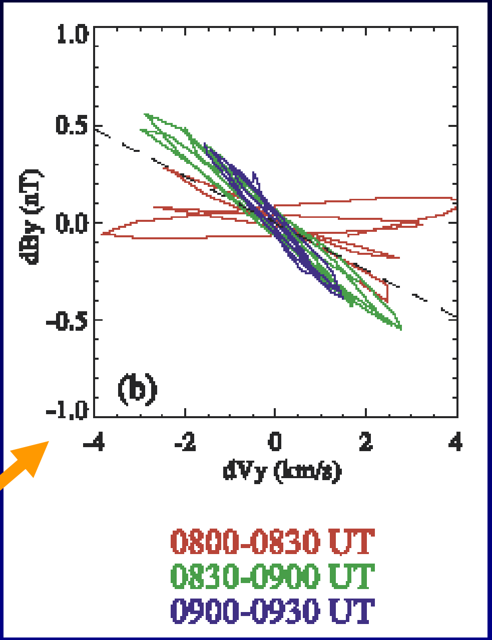
Evidence for Solar Wind Solar Wind Driven ULF Cusp Pulsations

Rae et al., JGR 2004

Polar Cusp

Solar Wind





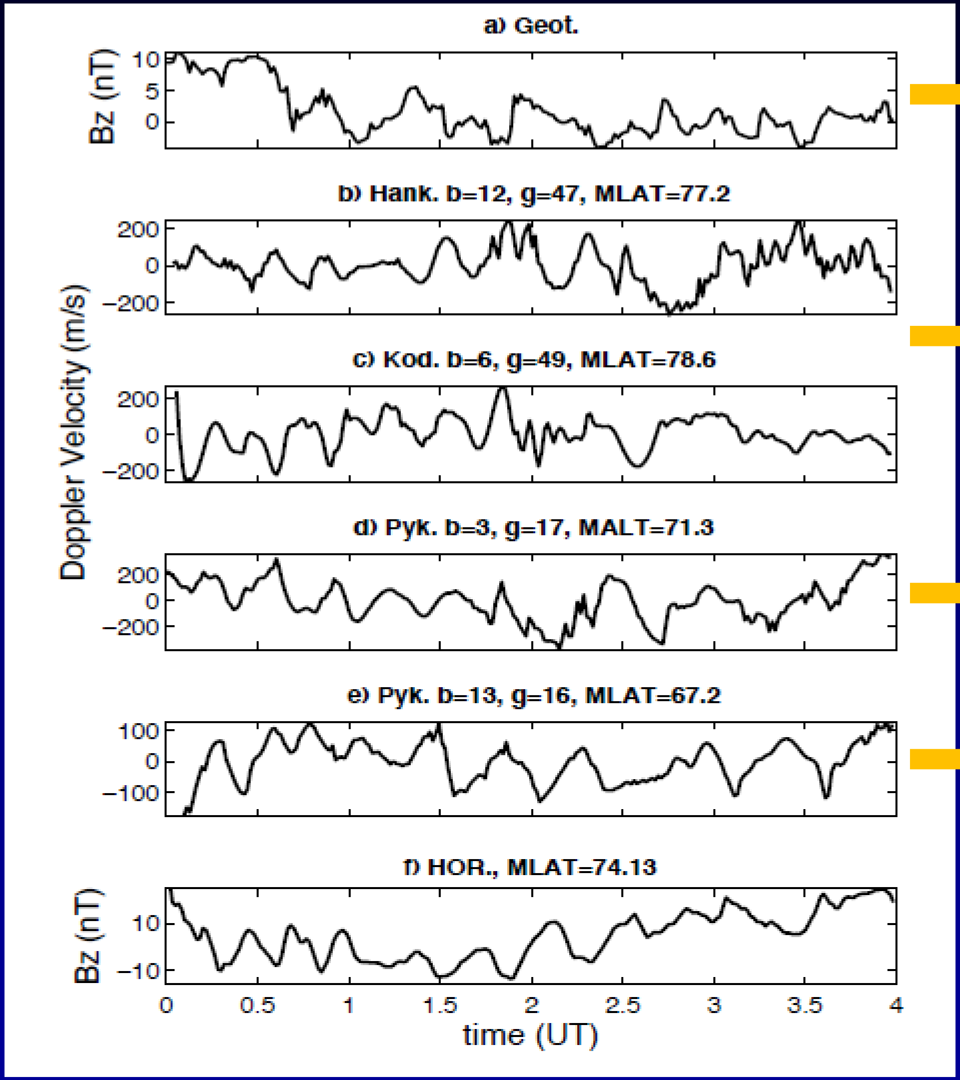
$dB/dV = -u_o m_p (N_p + 4N_\alpha)^{1/2}$

Solar wind Alfven wave at 1.9 mhz drives 1.9 mhz pulsed particle and ionospheric flow signatures in cusp.

Similar results by Prikryl et al., 1998, 1999, 2002

SuperDARN observation of the driver wave associated with fLRs

A.Z. Nedie, R. Rankin and F.R. Fenrich, J. Geophys. Res., 2012



Dec. 26, 2000

Solar wind source of 0.8 mHz wave.

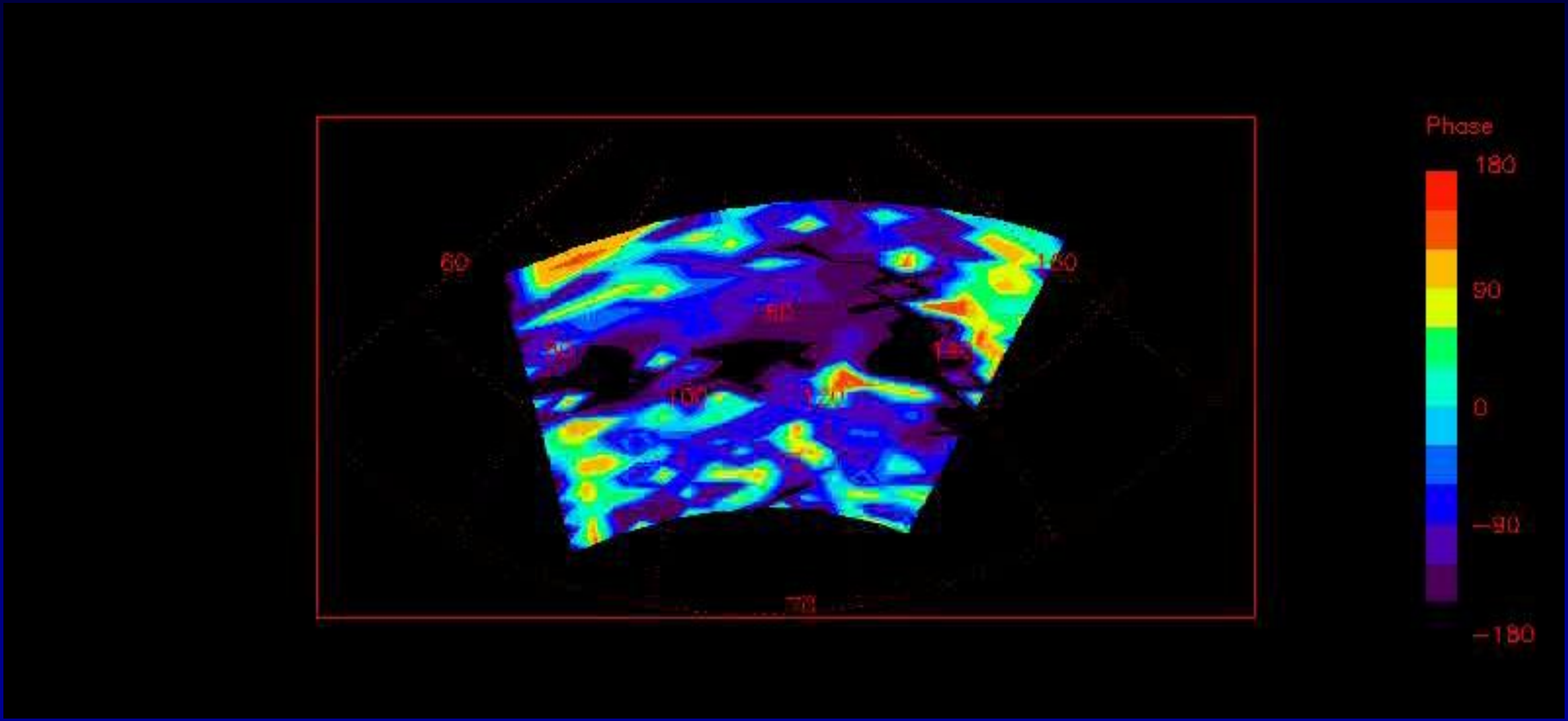
0.8 mHz driver wave observed on open field lines.

Second harmonic FLR at 0.8 mHz

Fundamental mode FLR at 0.8 mHz

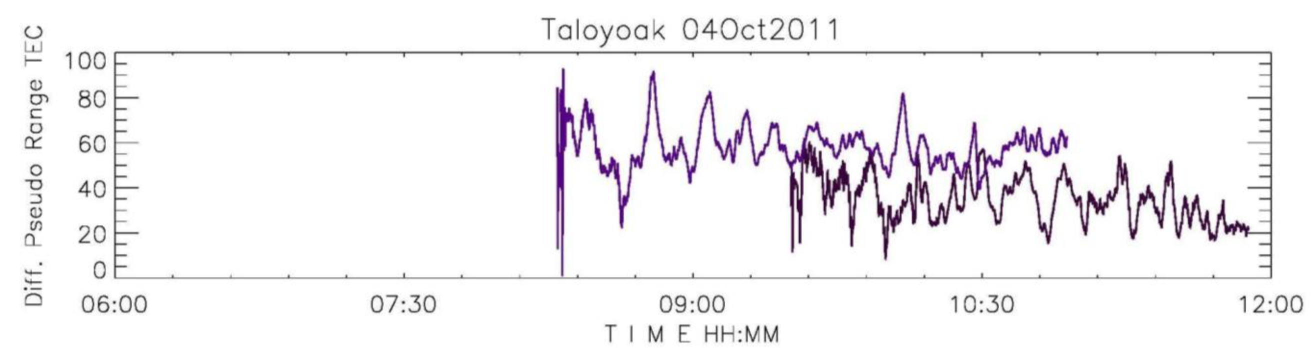
Hankasalmi radar observation of coherent phase on open field lines

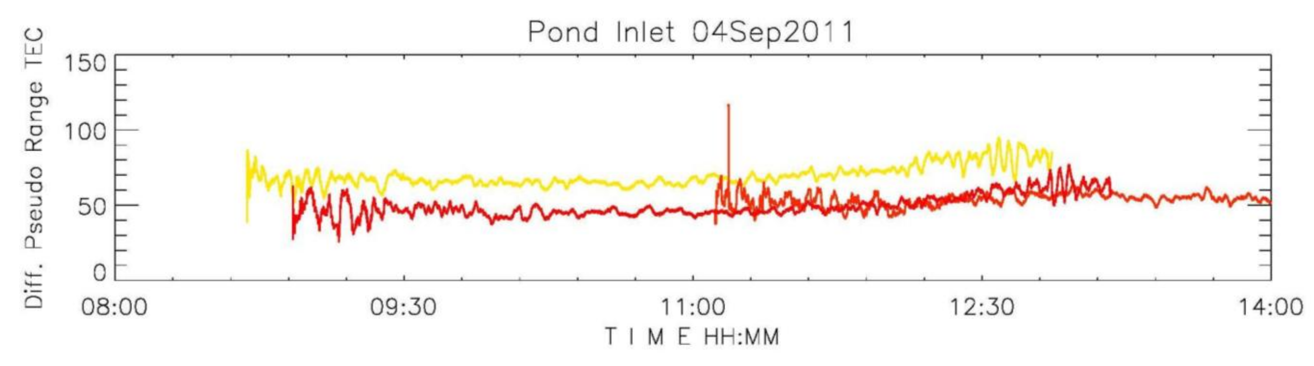
Dec 26, 2000, 00:00-02:30 UT at 0.8 mHz



A.Z. Nedie, R. Rankin and F.R. Fenrich, J. Geophys. Res., 2012

CHAIN GPS TEC observation of ULF waves in polar cap



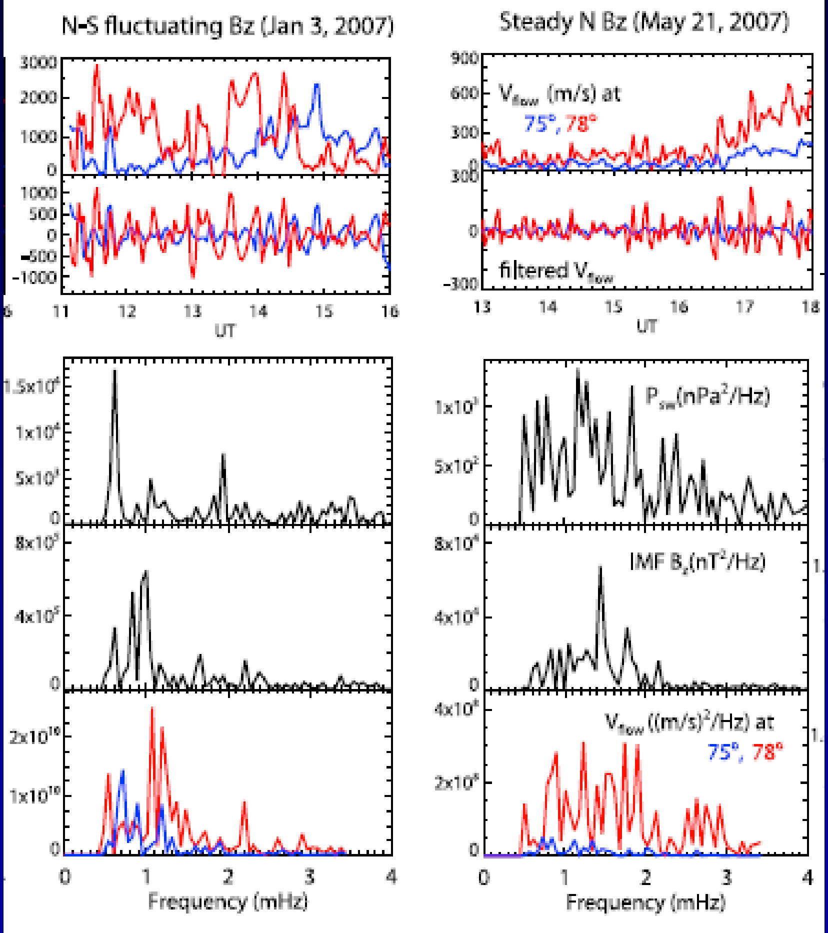


Courtesy Dr. P.T. Jayachandran
Infrastructure funding for CHAIN is provided by the Canada Foundation for Innovation and the New Brunswick Innovation Foundation. CHAIN operation is conducted in collaboration with the Canadian Space Agency.

Using ISR to Study ULF Waves in the Polar CAP

Sondrestrom ISR observations of ionospheric convection in the polar cap associated with solar wind ULF fluctuations

Kim et al., J. Geophys. Res.,, 2009



Solar wind ULF fluctuations drive

- ➢ enhanced convection
- ➢ ULF fluctuations in convection
- ➢ ionospheric heating
- ➢ atmospheric gravity waves which couple ionosphere to neutral atmosphere

Some questions one could address with ISR:

- What effect do ULF waves have on the ionospheric plasma?

- How do these effects vary with latitude, local time, altitude and azimuthal wave number?

- Is ionospheric heating associated with solar wind ULF wave activity?

- Do ULF waves couple ionosphere to neutral atmosphere via gravity waves?

- What are the dominant ULF wave sources? Are they different at polar cap and auroral latitudes?

Conclusions

- ULF waves are important in coupling between solar wind, magnetosphere and ionosphere.

- ULF waves cause oscillations in ionospheric density, electron and ion temperature, convection flow and electric field.

- Lots of potential for ISR studies of ULF waves.