Testing Plasma Physics in the Ionosphere

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Invited Paper (D35)

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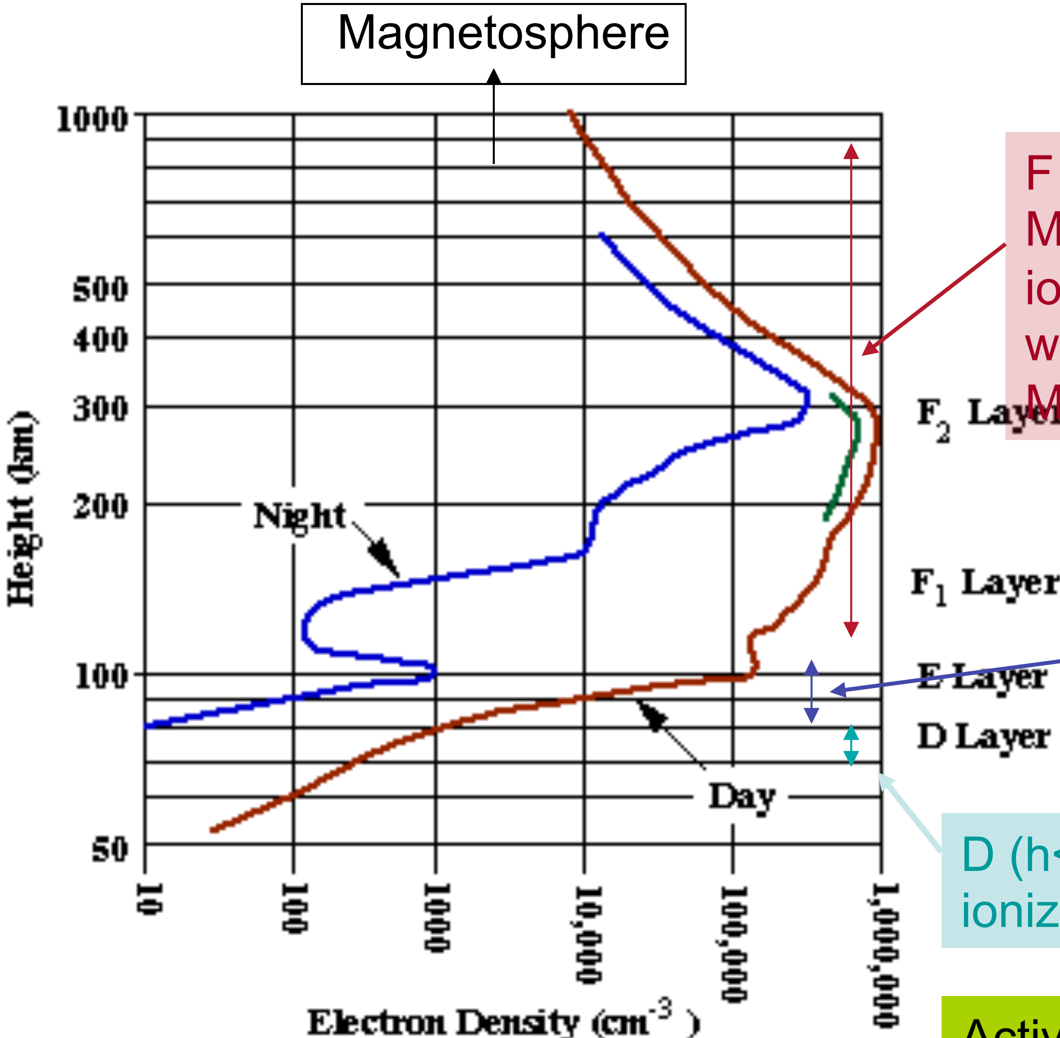
The Polar Ionosphere as Plasma



F (h> 120 km):Collisionless ($\nu<<\Omega$), Magnetized plasma – Electron and ion plasma waves, cyclotron waves, whistlers, MHD (Shear-Msonic) waves

E(70$<h<$120 km): $\omega_e,\Omega_e>\nu$, $\Omega_i<\nu$ EMHD plasma – Helicon waves – no Alfven or Ion Cyclotron waves

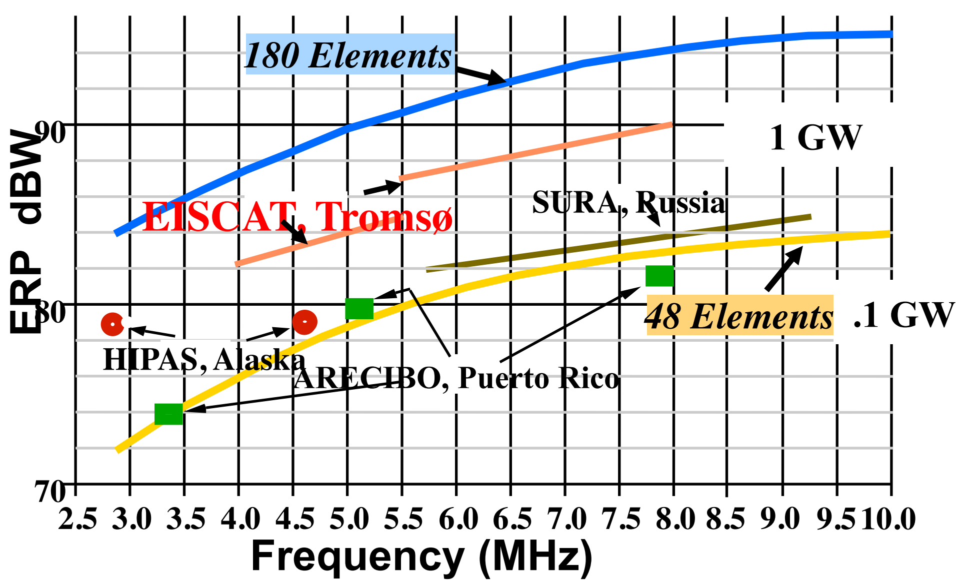
D (h$<$70 km): $\nu>\Omega_e,\omega_e$ weakly ionized gas – not plasma

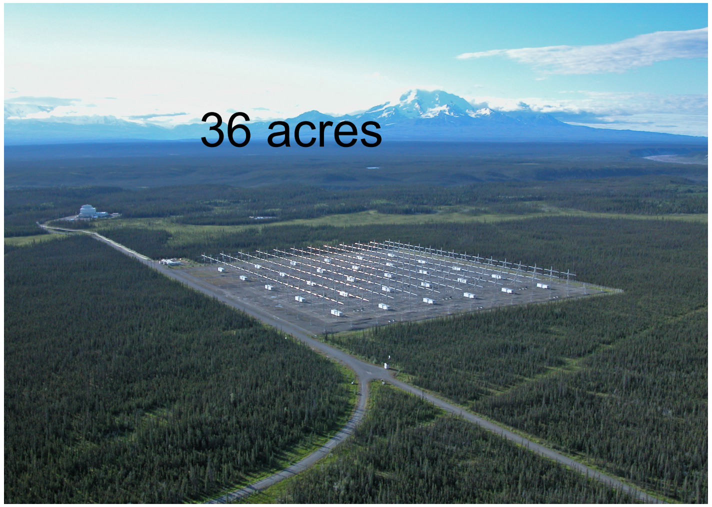
Active Regions (Plasmas with Free Energy): E-Electrojets, F- Density Gradient

Ionospheric Heaters – The HAARP Heater

- **Ionospheric heater** - **Powerful HF transmitter (2.8-10 MHz) that induces controlled temporary modification to the plasma temperature at desired altitude.**

- **Use in conjunction with diagnostics to study, in a cause and effect fashion:**
  - **EM propagation, plasma turbulence and instabilities**
  - **Response of magnetospheric plasma and Radiation Belts to controlled perturbations of the ionospheric plasma**



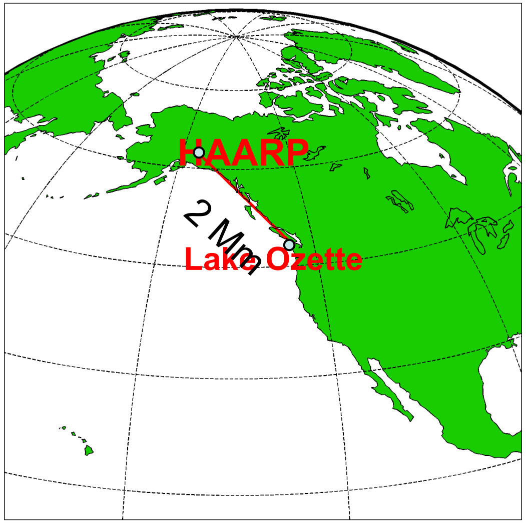


RESEARCH TOPICS

- Collisional Heating (D Region)
  - ULF/ELF generation by current modulation
    - Multiple site detection – Waveguide propagation
    - Shear Alfven Wave Injection – Satellite detection
    - Excitation of Ionospheric Alfven Resonator
    - Artificially Stimulated Emissions (ASE)
- F-Region Collisionless Heating (Anomalous Absorption) (and SE)
  - Magnetosonic Wave generation and Injection into the Alfvenic Waveguide
  - Generation and detection of artificial density ducts

- Langmuir turbulence - Parametric Instabilities
- Electron acceleration- Optical Emissions
- Field aligned striations - Scintillations
- Upper hybrid waves and conversion of lower hybrid waves to whistlers
- Artificially Stimulate emissions

Experiment Methodology

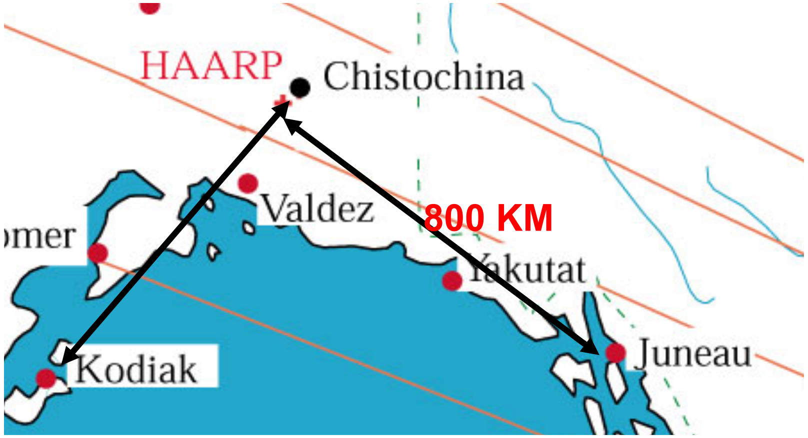


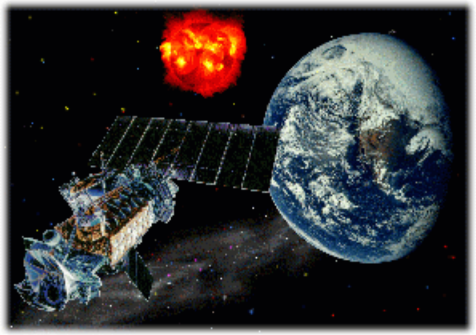
Ground Probes

DEMETER

HAARP

Satellite Probes 650-700 km





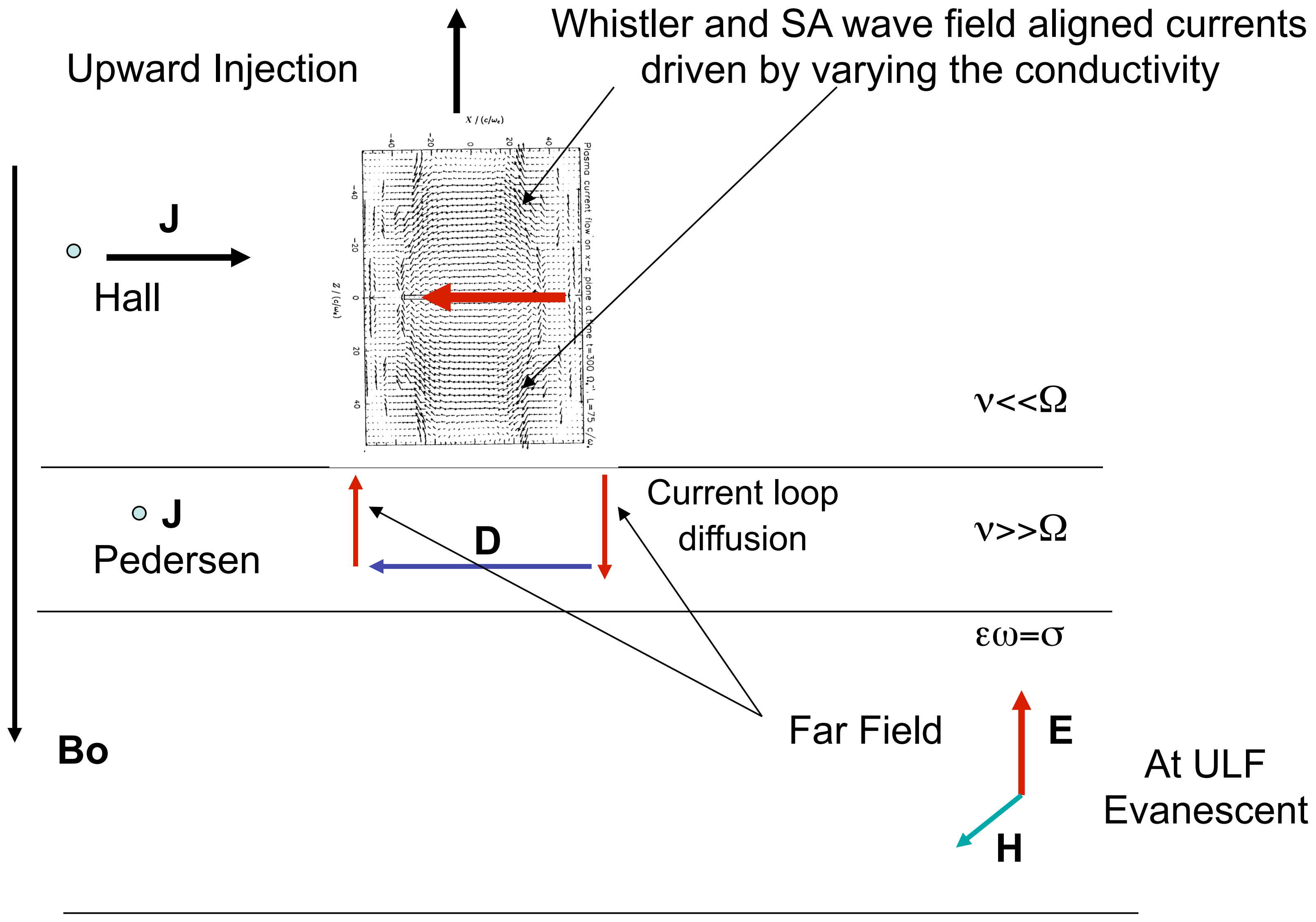
DMSP

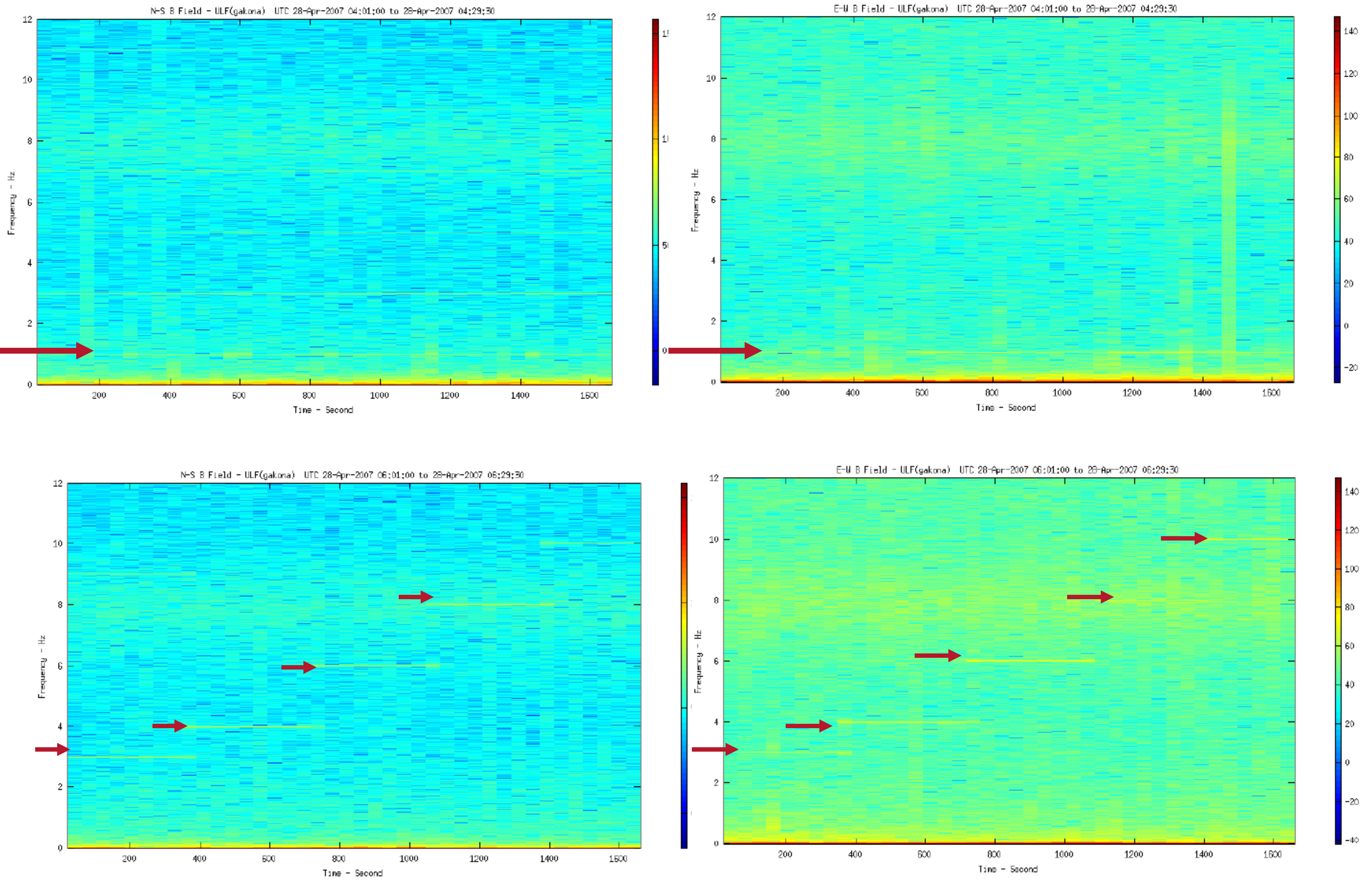
Current Modulation

- Basics – Physics-Conditions
- Gakona detection movie
- Near-Far detection
- SAW detection
- IAR Excitation

Collisional Heating

Conventional Electrojet Ionospheric ULF Generation

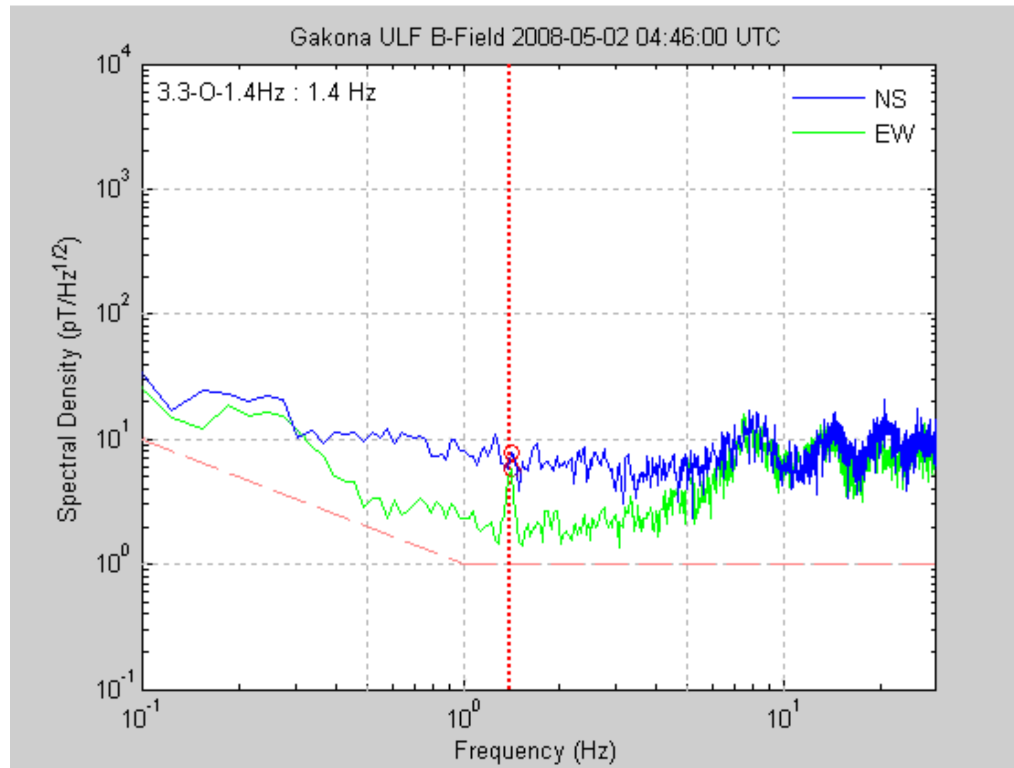




30 minute spectrograms of OX 1 Hz (upper) and O-mode 3, 4, 6, 8 and 10 Hz step up modulation

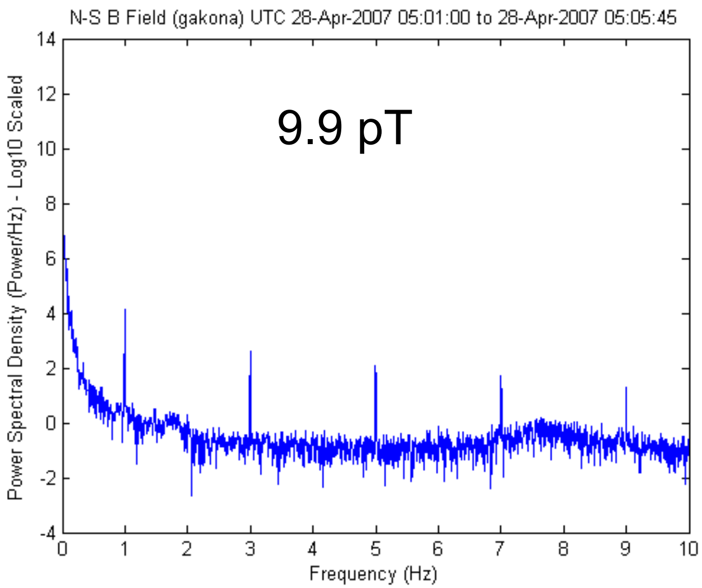
ULF at Gakona – Power Spectral Density (PSD)

- Frequency spectrum in a moving time window
- Clear Schumann resonances at 8, 14, .. Hz
- Signals emerge as freq. peaks in sync with HAARP ULF operation
- Greatly varying background below 1 Hz

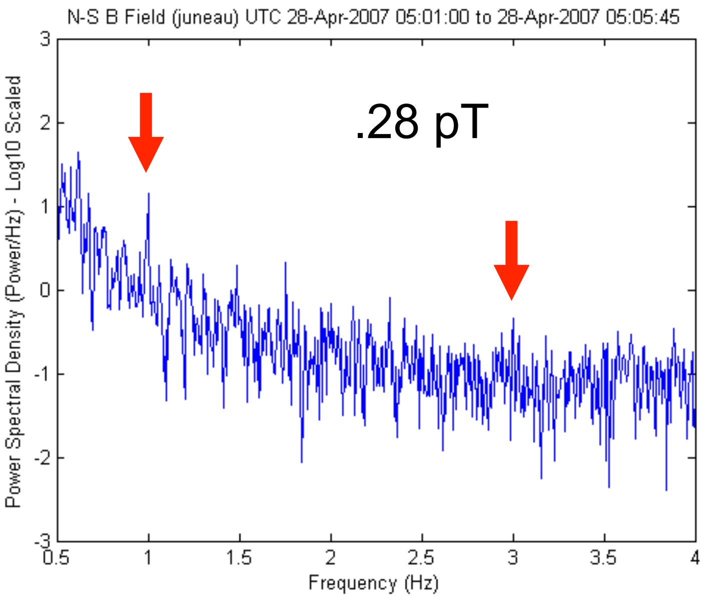


ULF Signal Propagation

Gakona

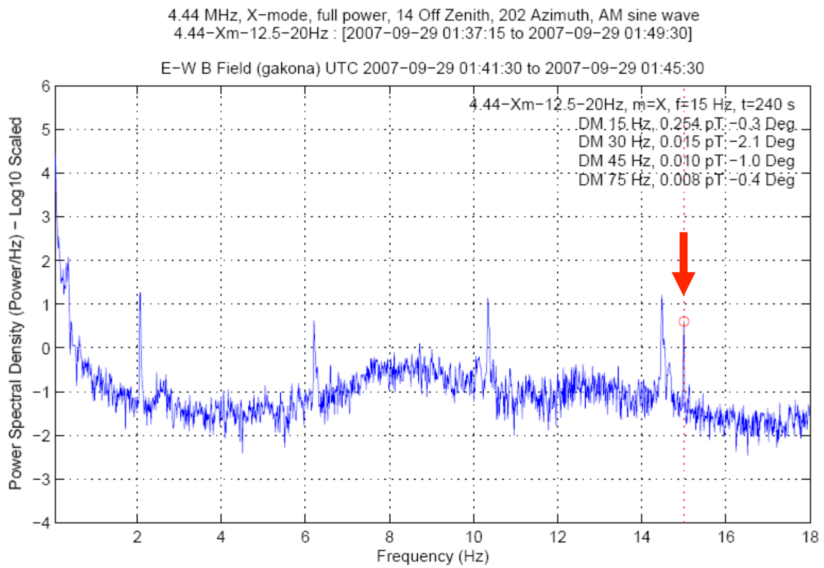


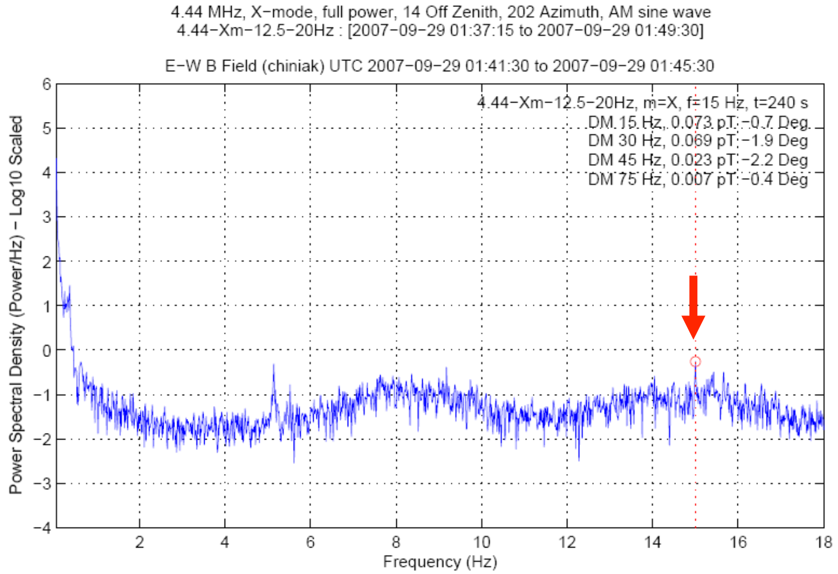
Juneau – 450 km



- 28 April, 2007 UTC 05:01:00 – 05:05:45
- HAARP at 2.88 MW and 3.3 MHz
- Detected 1 Hz & 3 Hz peaks
- $B \sim 1/R^2$ wave evanescent

ULF Signal Propagation





Gakona **Chiniak – 670 km**

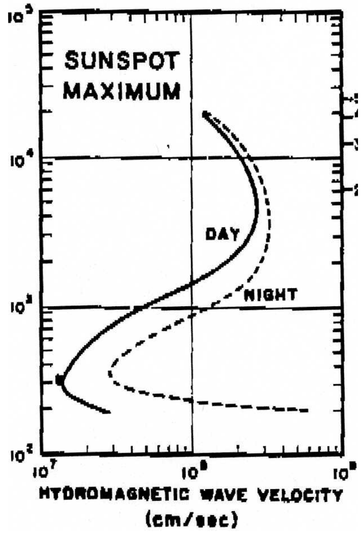
Clear 15 Hz peak can be seem at both sites

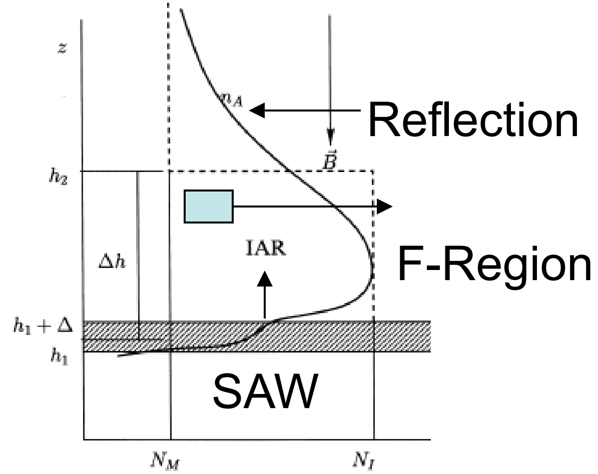
EW Amplitudes:

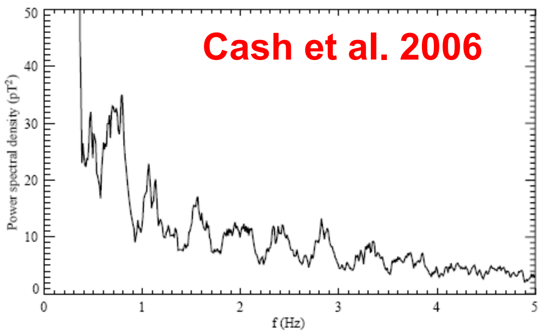
Gakona: 0.25 pT

Chiniak: 0.07 pT

IONOSPHERIC ALFVEN RESONATOR (IAR)

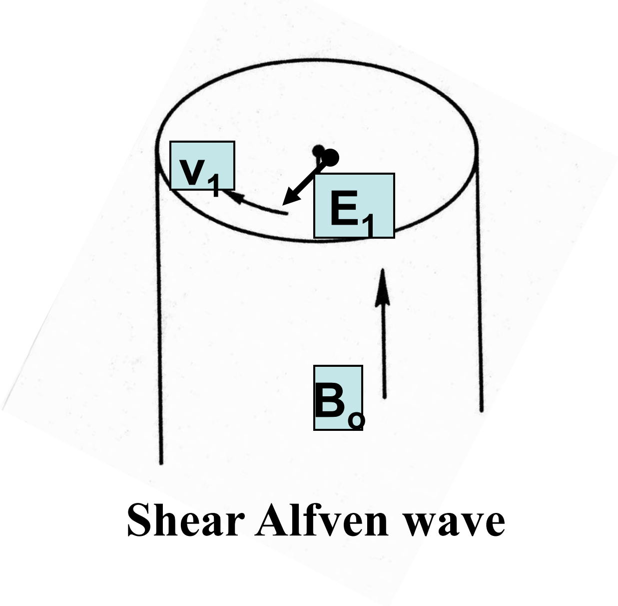






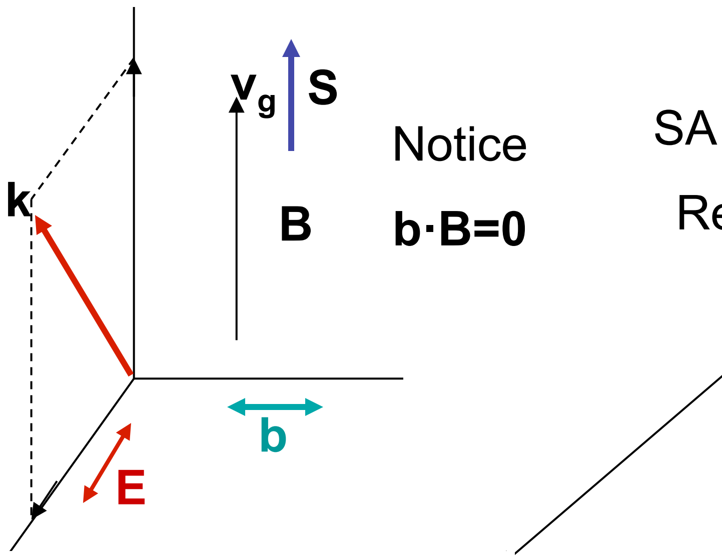
Fabry-Perot **like Resonator**

$$\omega_R \approx n \frac{\pi V_A}{(\Delta h)}$$



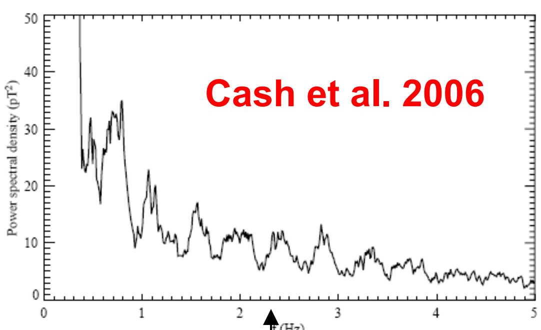
Shear Alfven wave

SA Waves – Ionospheric Alfven Resonator (IAR)



SA wave is guided along the B field

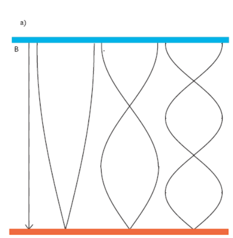
Reflections create standing wave structure

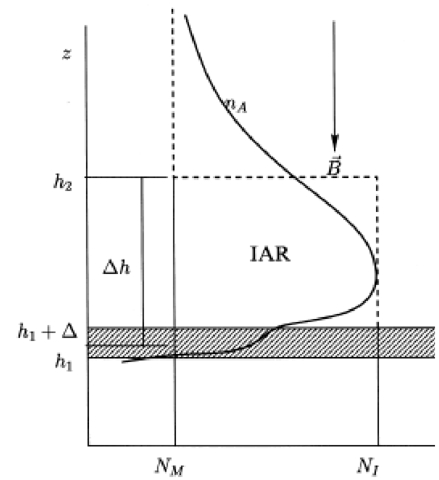


***Fabry-Perot* like Resonator**

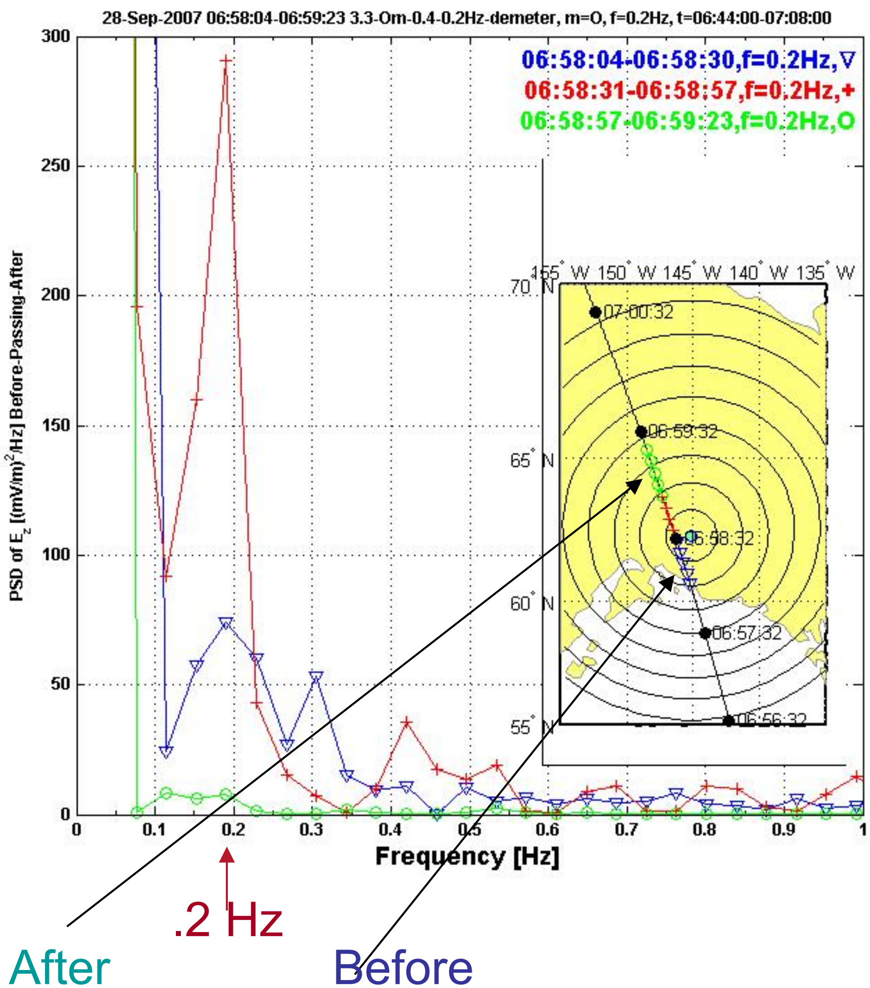
Natural SA waves

$$\omega_R \approx n \frac{\pi V_A}{(\Delta h)}$$





SAW DEMETER Detection



Frequency .2 Hz

Closest distance 80 km

Detection time 25 sec

Detection distance 150 km

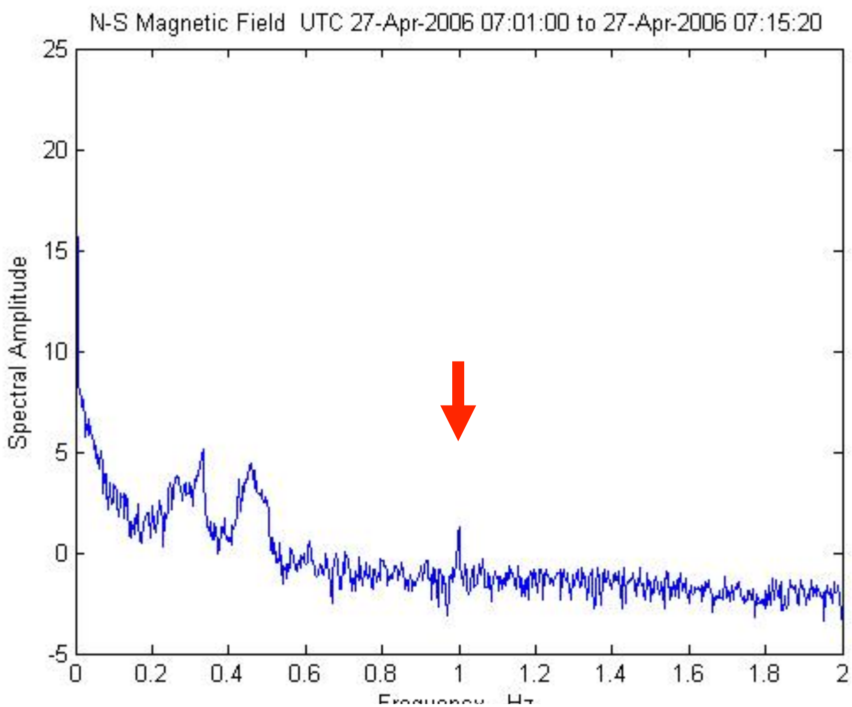
Maximum E ≈ 10 mV/m

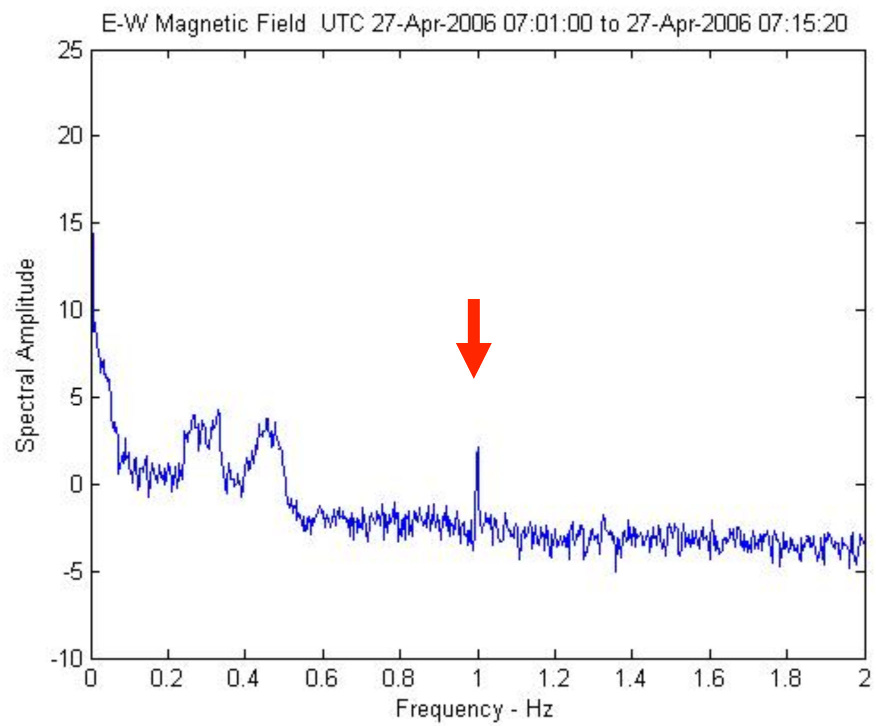
Estimated power ~ kW

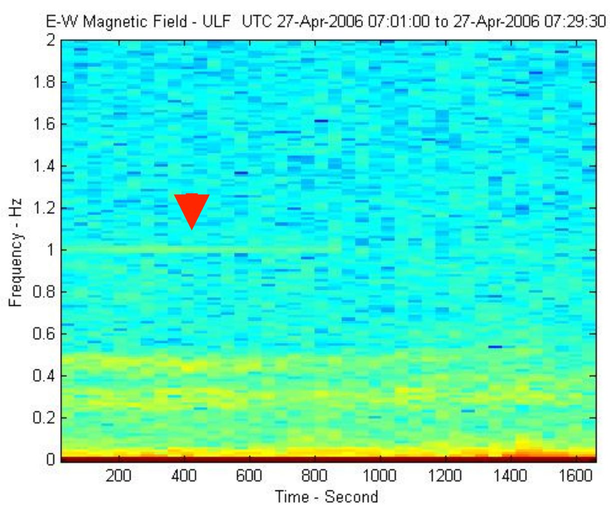
1.5 pT on the ground

SEPTEMBER 28, 2008

IAR Excitation

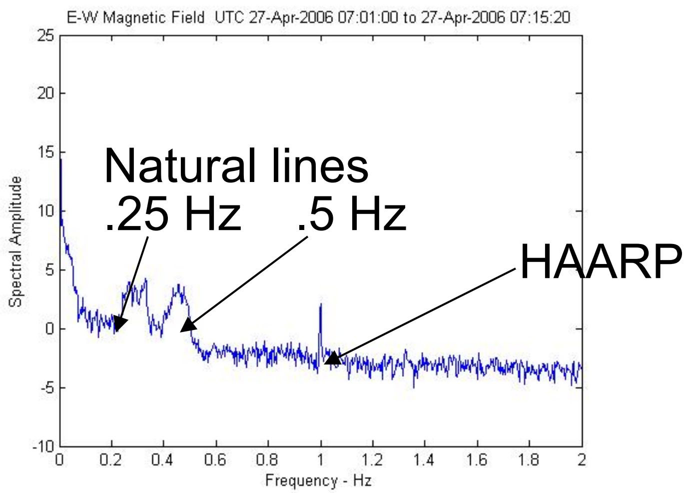




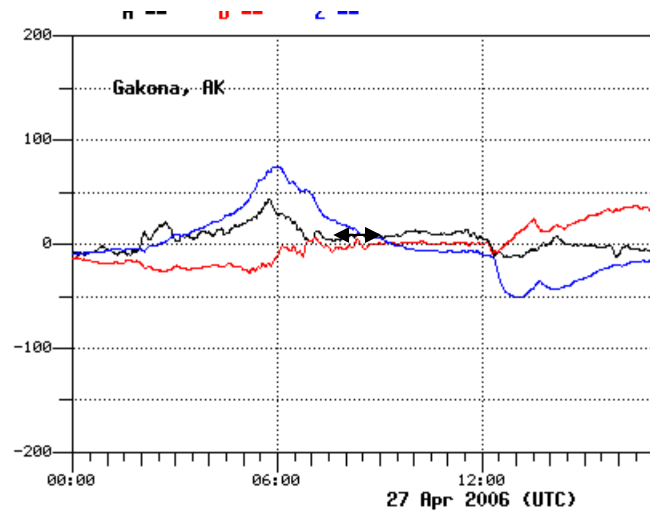


Excitation of the IAR due naturally excited waves at .25 Hz and .5 Hz and by HAARP generated shear (?) waves at 1.0 Hz. Notice the high quality of the artificial excitation despite the fact that it corresponds to the 4^{th} harmonic frequency.

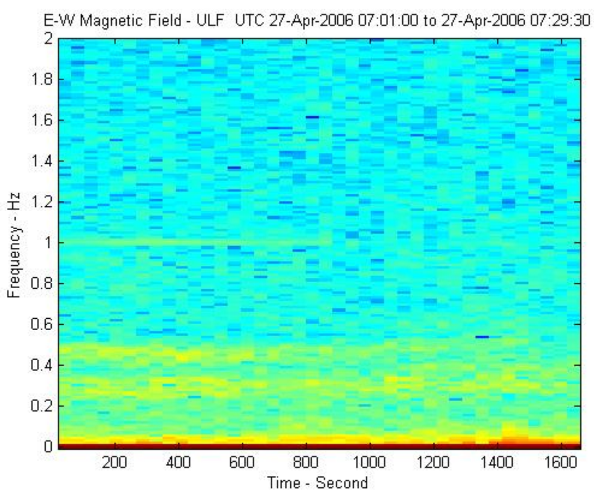
Paradox ?



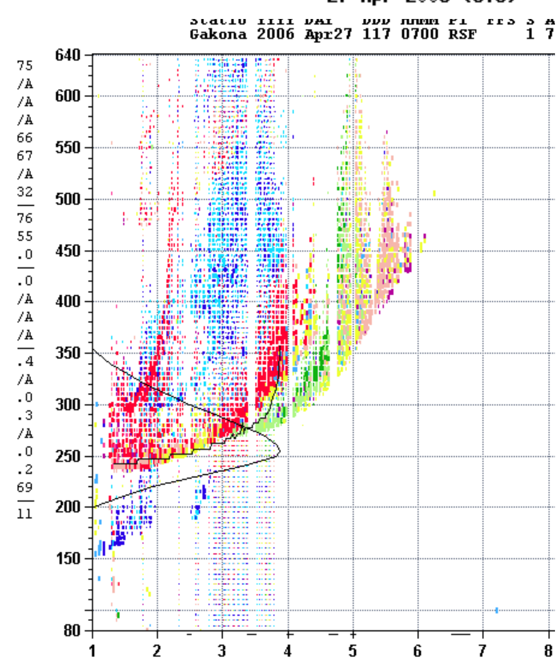
E-W Magnetic Field UTC 27-Apr-2006 07:01:00 to 27-Apr-2006 07:15:20
Spectral Amplitude
Frequency - Hz
Natural lines
.25 Hz
.5 Hz
HAARP



Gakona, AK
00:00
06:00
12:00
27 Apr 2006 (UTC)

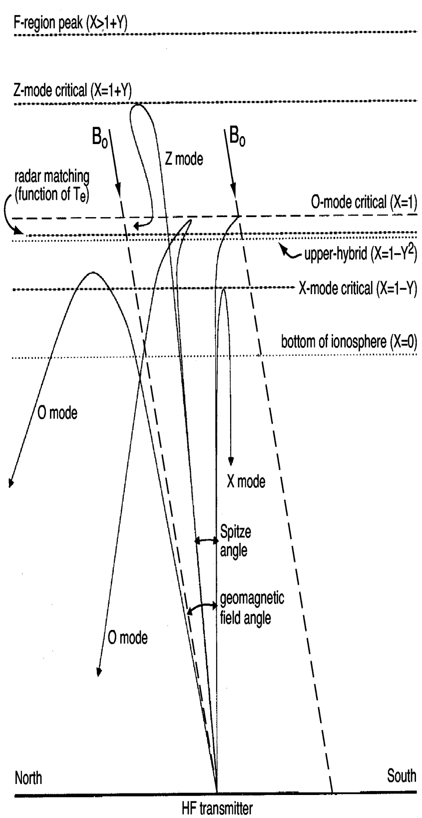


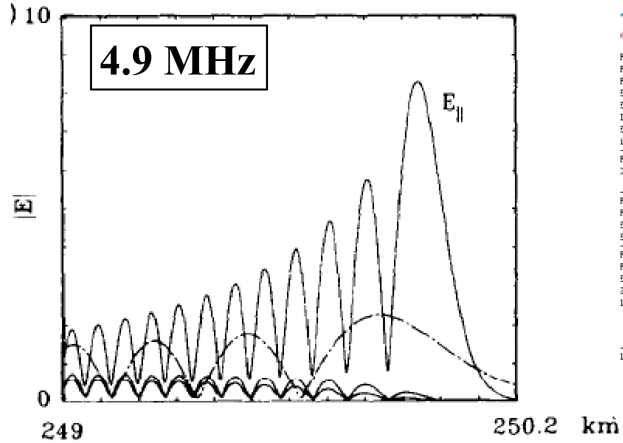
E-W Magnetic Field - ULF UTC 27-Apr-2006 07:01:00 to 27-Apr-2006 07:29:30
Frequency - Hz
Time - Second

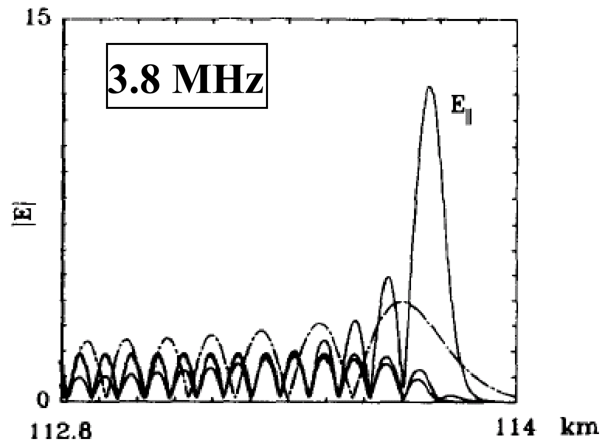


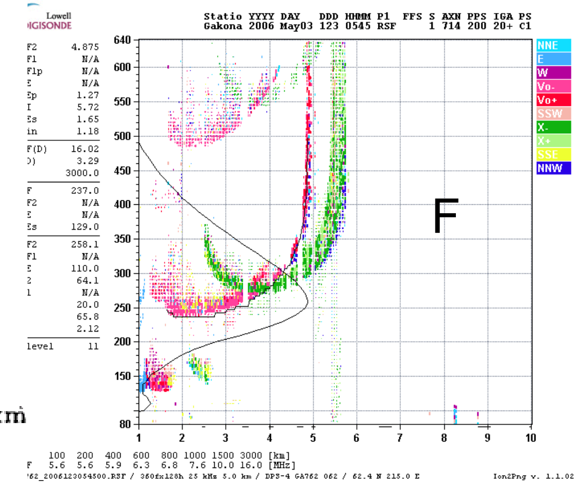
Gakona 2006 Apr27 117 0700 RSF 1 7

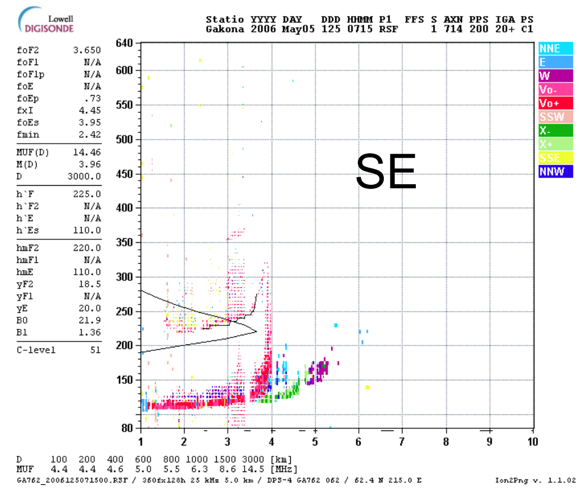
Collisionless Heating – Anomalous Absorption (F-Region; Sporadic E)









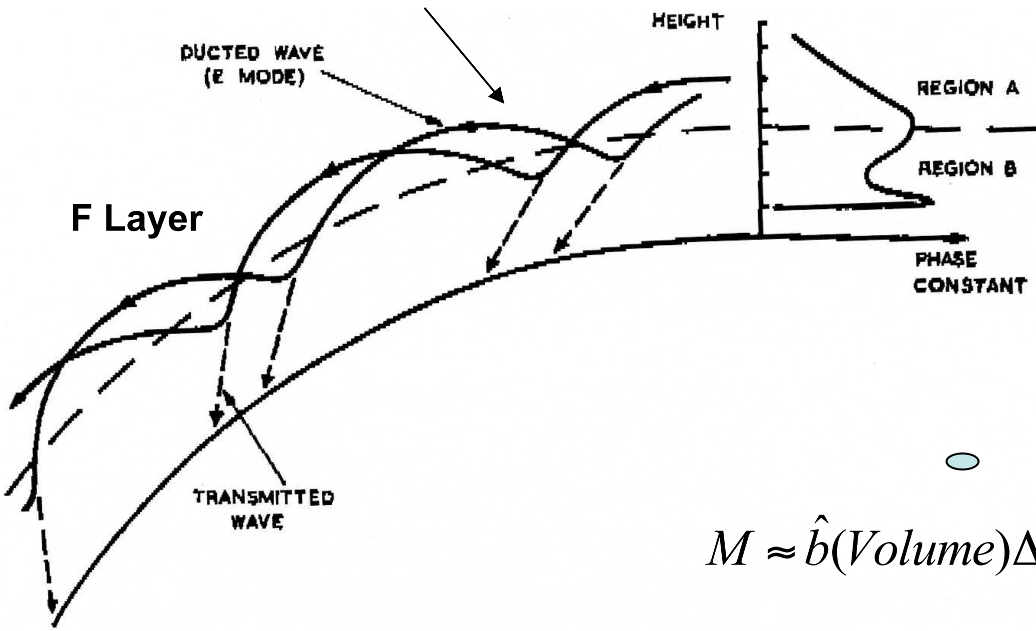


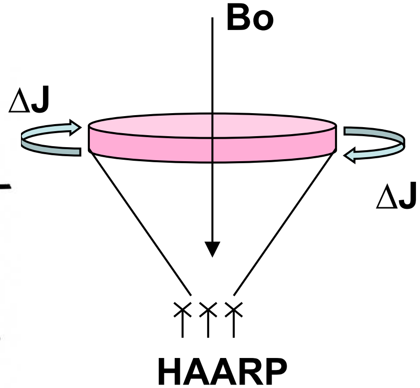
Lundborg and Thidé, 1986

Msonic Wave Generation

Ejet not needed

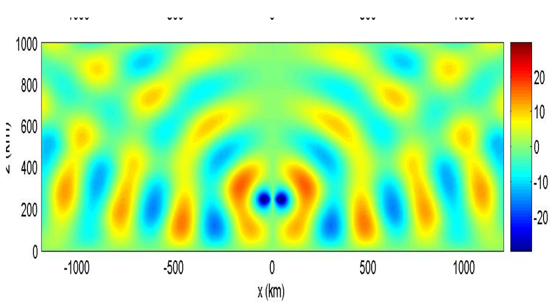
Ducted MS wave





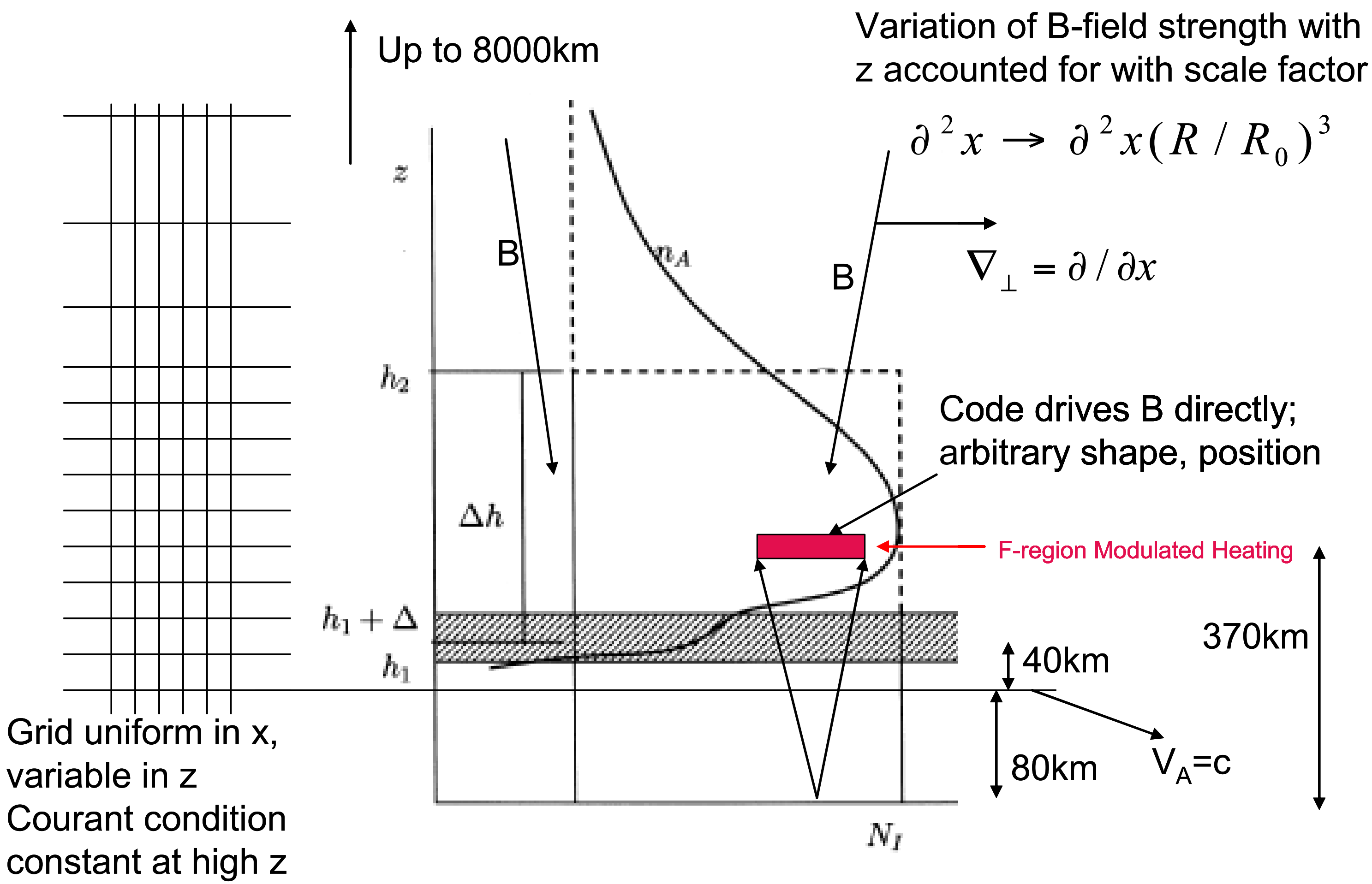
$$\Delta J = \frac{B \times \nabla \delta p}{B^2} \exp(i\omega t)$$

$$M \approx \hat{b}(Volume)\Delta J \exp(i\omega t) \approx \hat{b} M_o \exp(i\omega t)$$



The wave propagates isotropically but is reflected at the D/E region and is much weaker on the ground under the heated region. It can be measured by satellites or at large lateral distances (skip zone)

Use Lysac 1997 Model

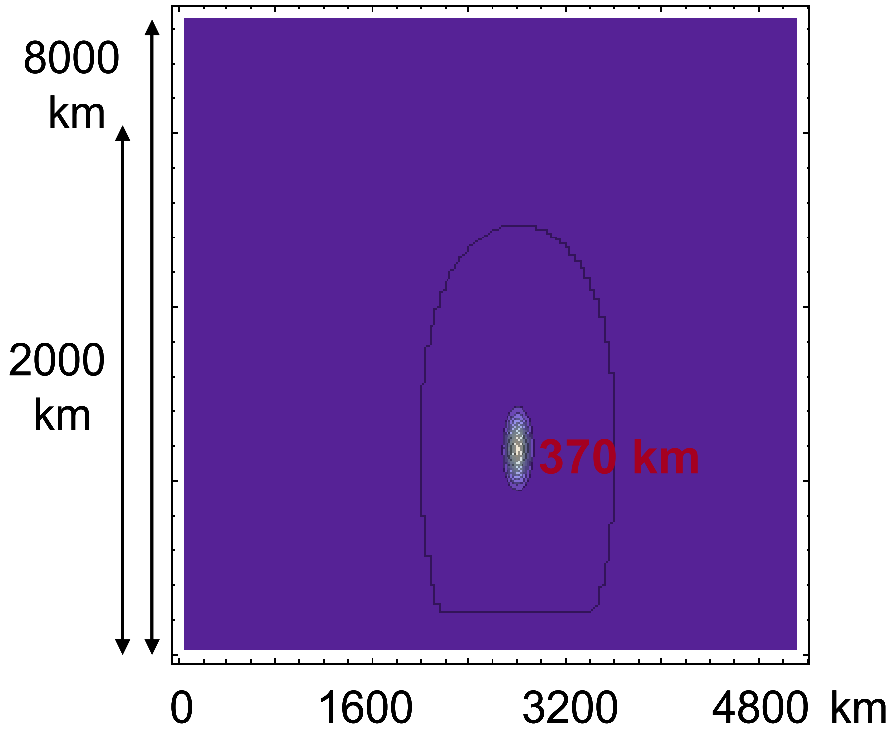


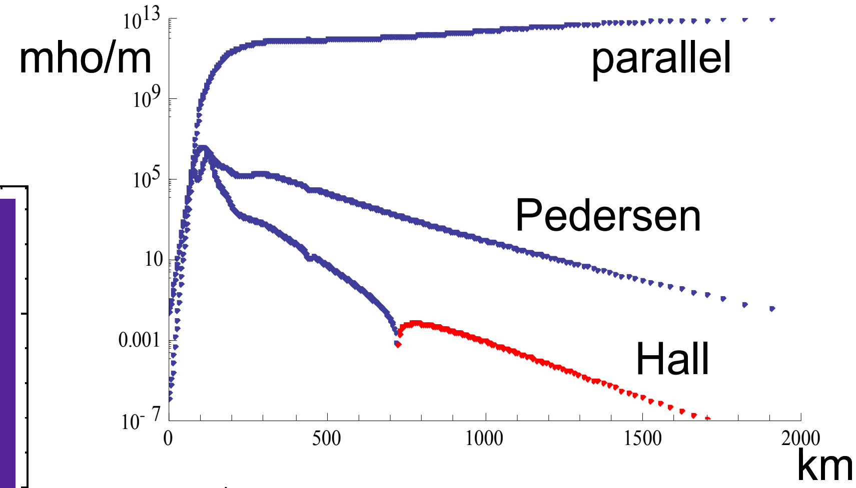
Simulations by I. Doxas

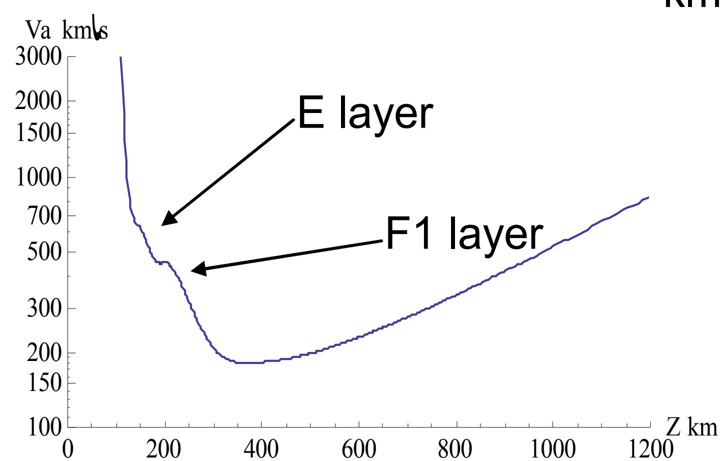
2D Simulations Show Skip Distance

Sawtooth/sine sweep

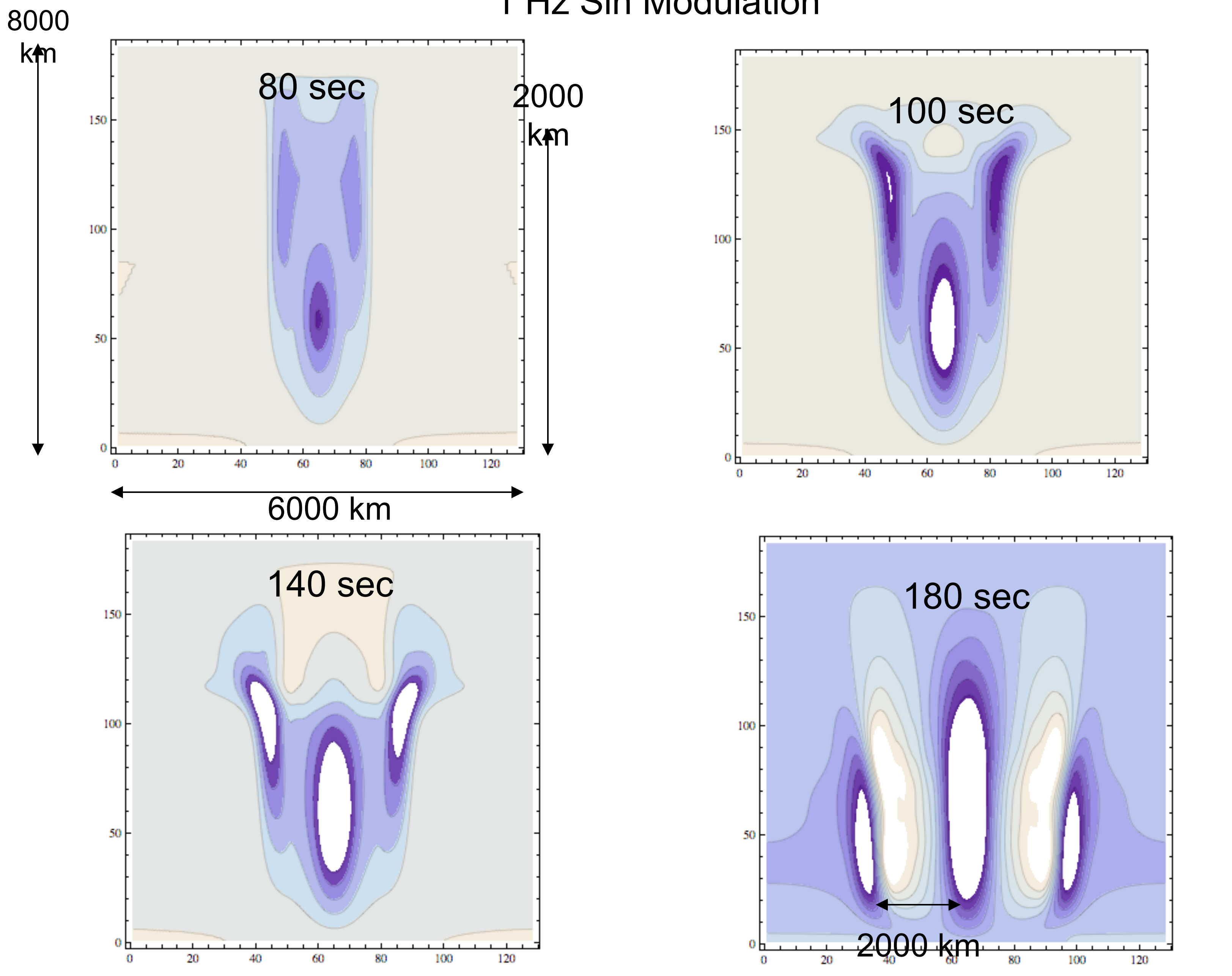
B-drive in x,z (units are grid points)



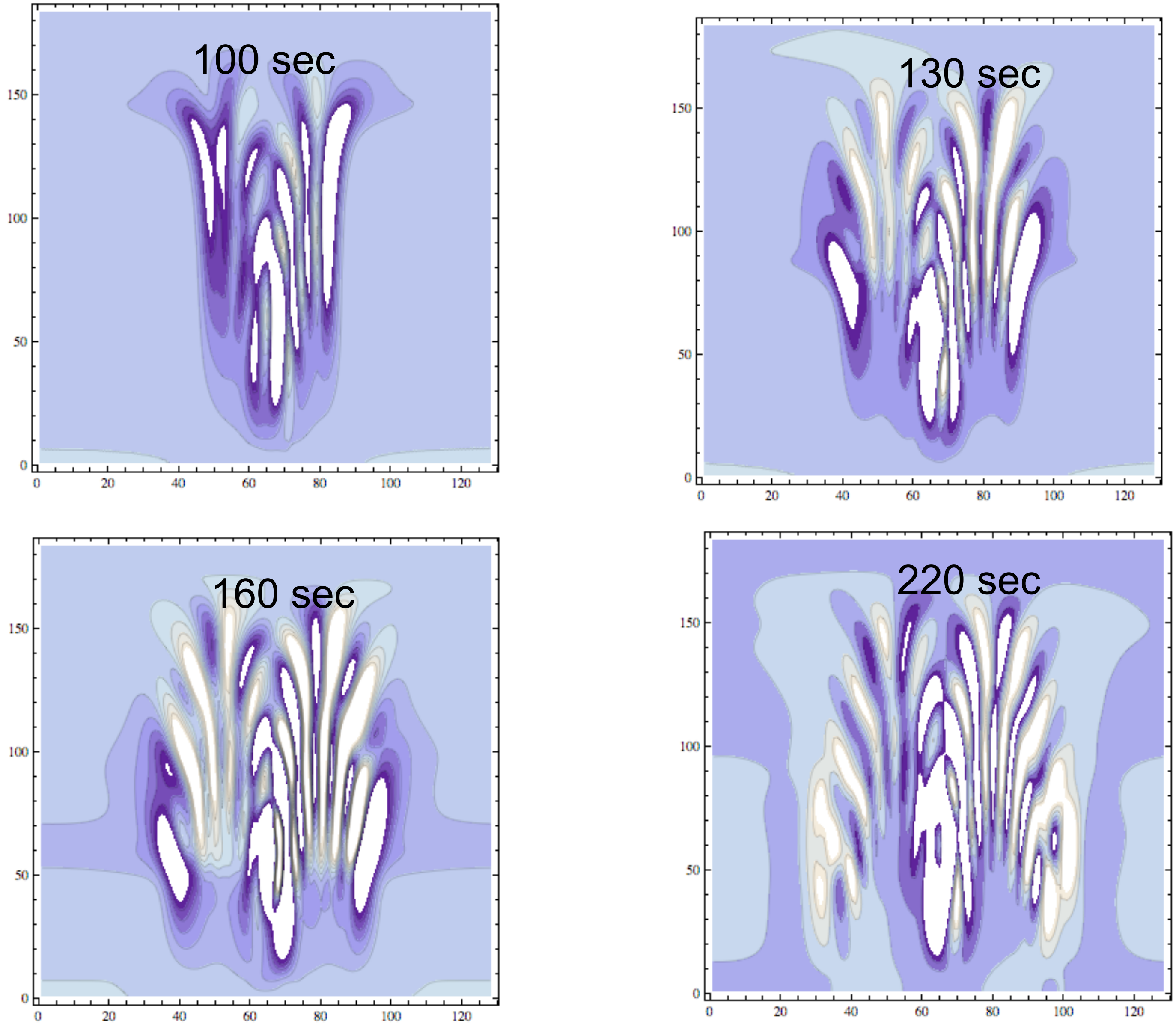




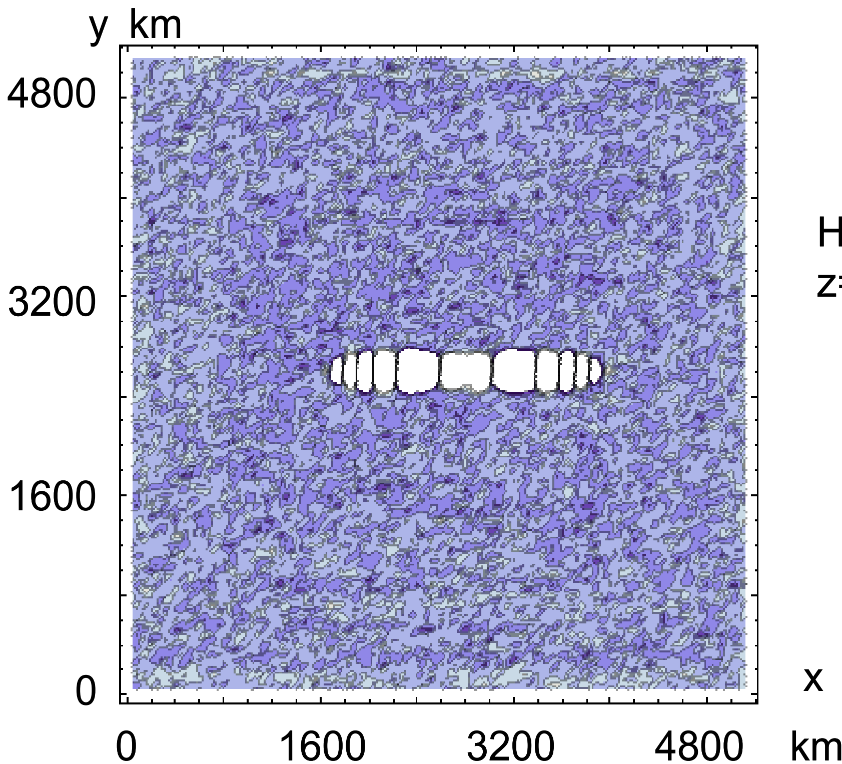
1 Hz Sin Modulation



1 Hz Sawtooth 100 m/sec



3D Simulations Show Beaming for Sawtooth Sweep

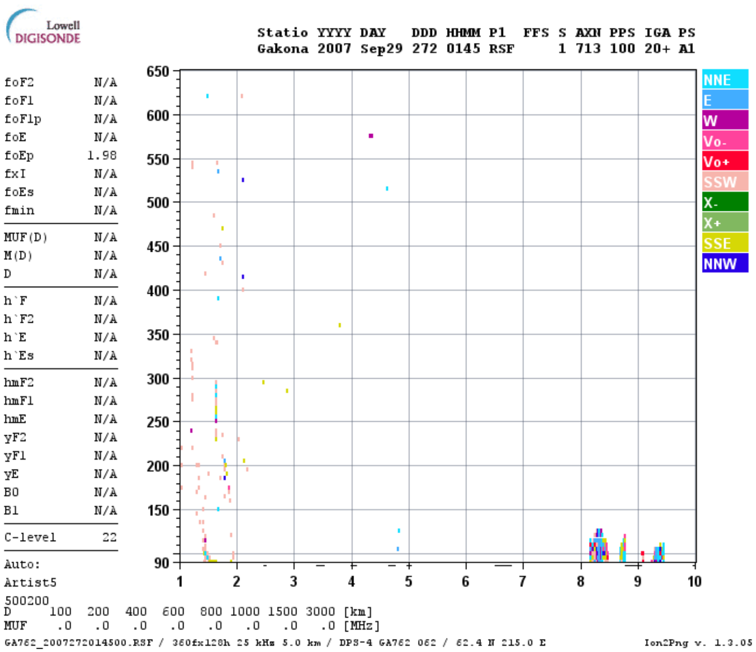


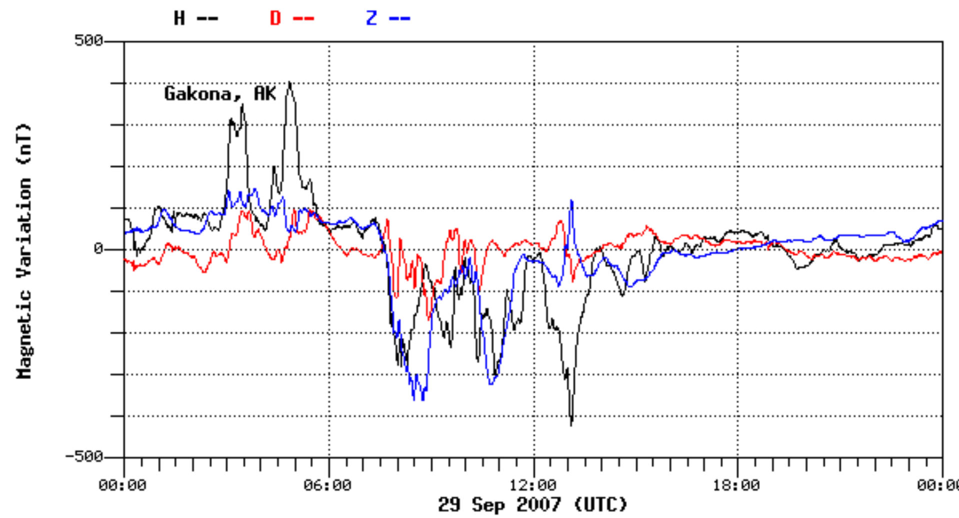
Contour plot of Bz

Horizontal slice at height of drive, z=370km (same as min of V_A)

Driver is swept in sawtooth in x-direction along a 100km track.
V_sweep=100km/s, repetition=1Hz

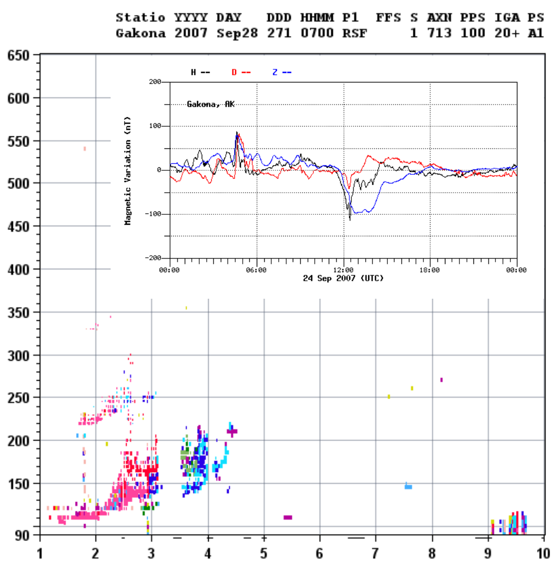
ULF Signal Propagation Conditions

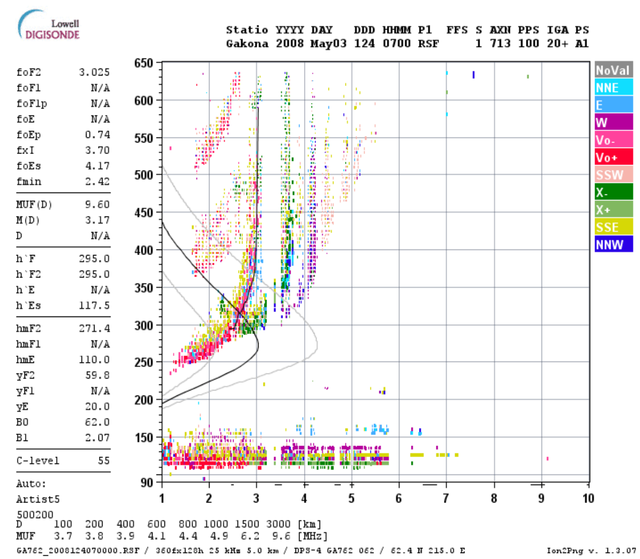




Ionogram does not show any profile due to high attenuation

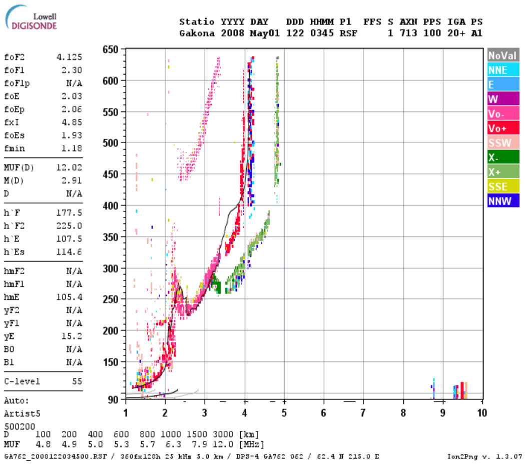
Gakona fluxgate B traces show that at 01:45:00 is in the build-up phase of moderate magnetic activities


Statio YYYY DAY DDD HHMM P1 FFS S AXN PPS IGA PS
Gakona 2007 Sep28 271 0700 RSF 1 713 100 20+ A1
Gakona, AK
Magnetic Variation (nT)
24 Sep 2007 (UTC)
H
D
Z

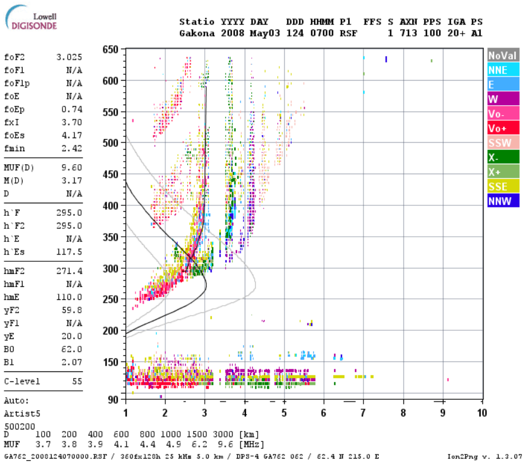

Lowell DIGISONDE
Statio YYYY DAY DDD HHMM P1 FFS S AXN PPS IGA PS
Gakona 2008 May03 124 0700 RSF 1 713 100 20+ A1
foF2 3.025
foF1 N/A
foF1p N/A
foE N/A
foEp 0.74
fxI 3.70
foEs 4.17
fmin 2.42
MUF(D) 9.60
M(D) 3.17
D N/A
h`F 295.0
h`F2 295.0
h`E N/A
h`Es 117.5
hmF2 271.4
hmF1 N/A
hmE 110.0
yF2 59.8
yF1 N/A
yE 20.0
B0 62.0
B1 2.07
C-level 55
Auto:
Artist5
500200
D 100 200 400 600 800 1000 1500 3000 [km]
MUF 3.7 3.8 3.9 4.1 4.4 4.9 6.2 9.6 [MHz]
NoVal
NNE
E
W
Vo-
Vo+
SSW
X-
X+
SSE
NNW
Ion2Png v. 1.3.07

HF Heating & Ionospheric Profile

- HF heating (max. mod. at F peak)
  - 3.6 MW along local B
  - O mode first, X mode secondary
  - Mainly at 3.3 MHz
    - 2.83 MHz: last hour of 5/4/2008
- Typical ionospheric condition
  - Weak F (foF2 < 4 MHz) for Alfven
    - Solar min.
- Two cases of diff. cond. at Gakona
  - <u>Example 1</u>: Enhanced F with D&E
    - With Ejet, D/E & F mod.
    - 20 Hz at Gakona & Ozette
  - <u>Example 2</u>: Weak F with Sporadic E
    - No Ejet, E layer mod.
    - 20 Hz at Ozette, not Gakona

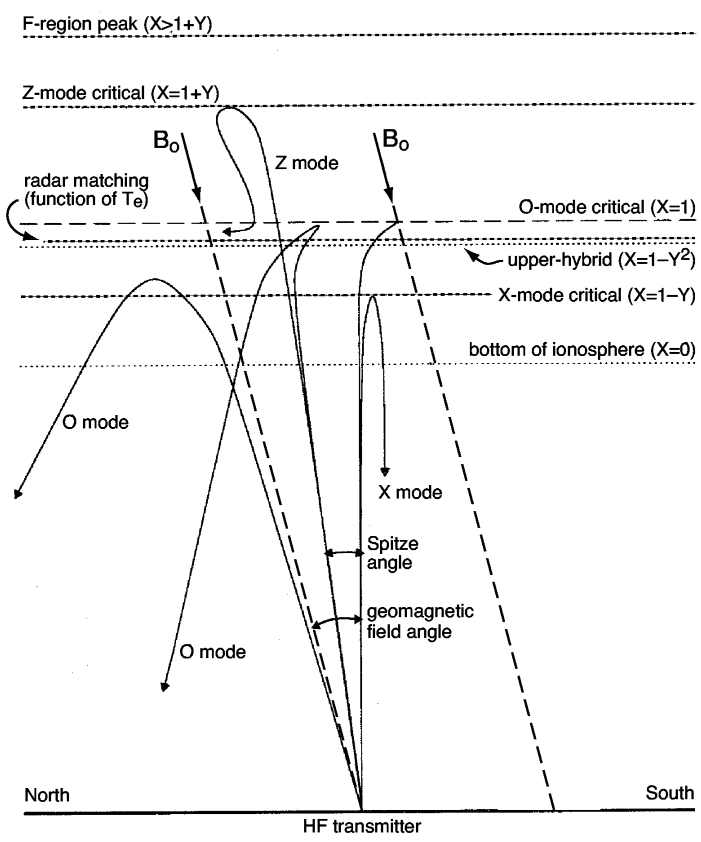


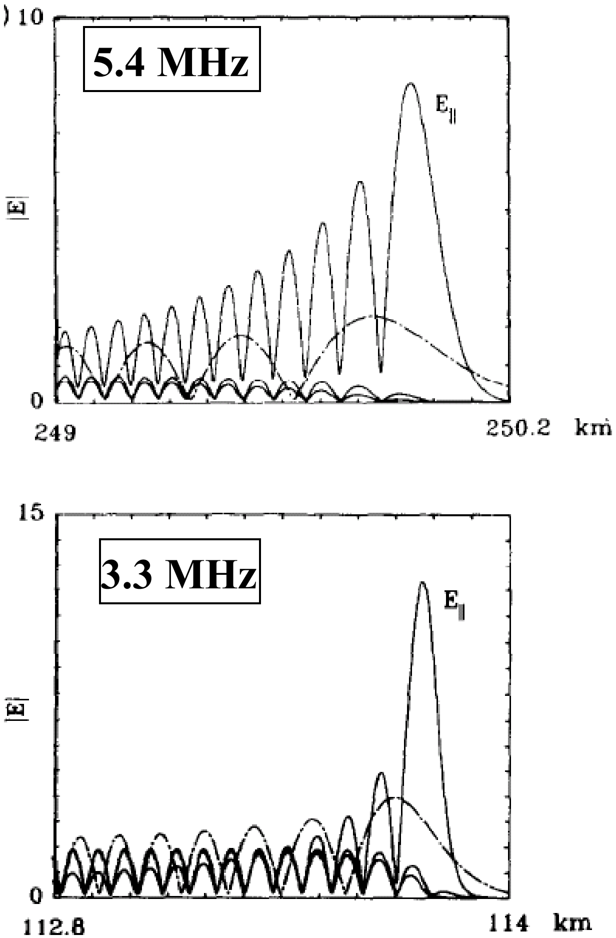
Example 1



Example 2

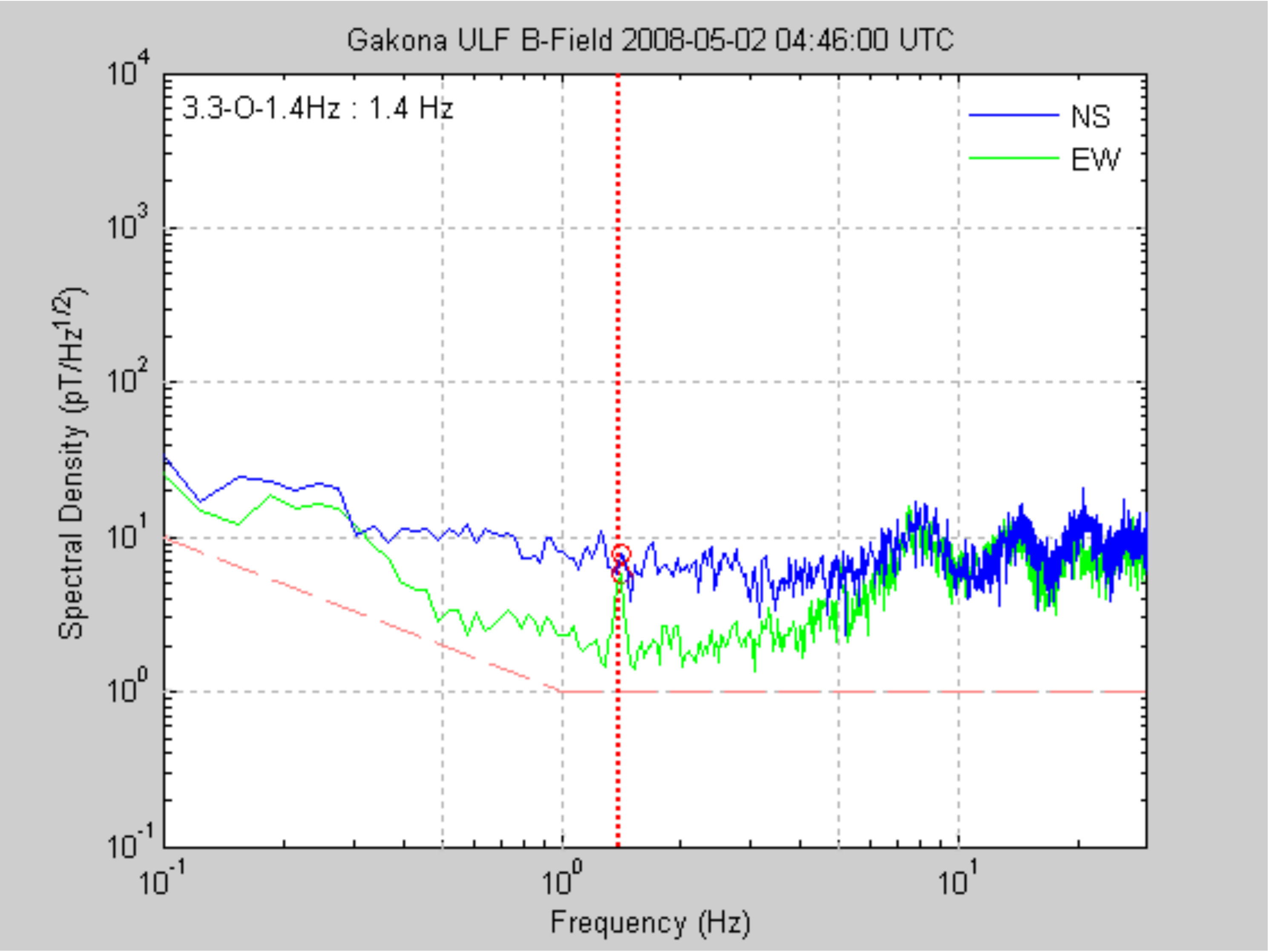
CONTROL OF MODIFICATION ALTITUDE



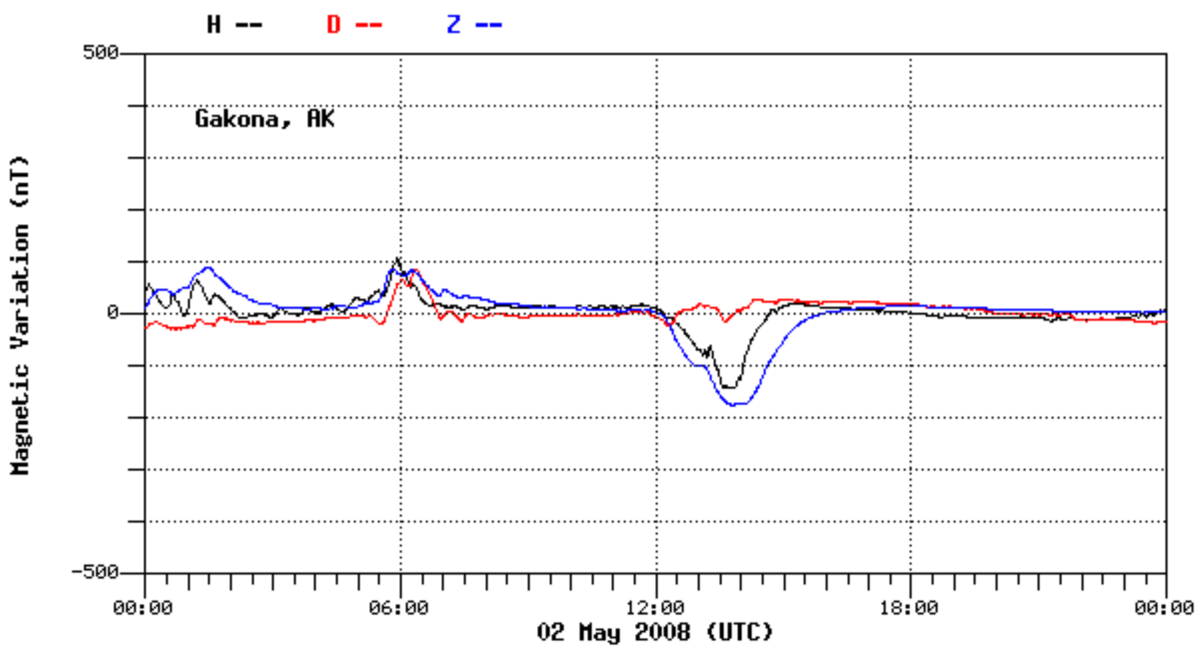


Lundborg and Thidé, 1986

ULF Measurements in Gakona




HAARP
2 Mm
Lake Ozette

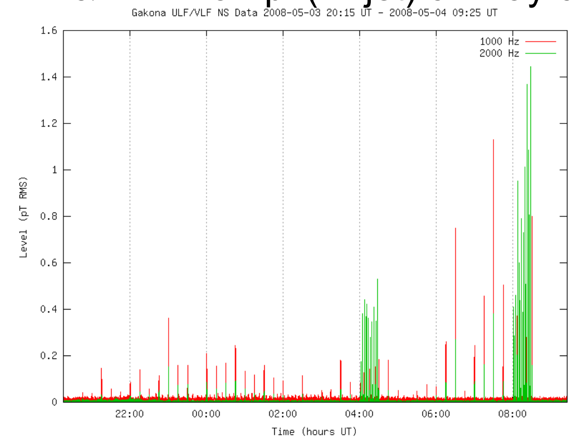


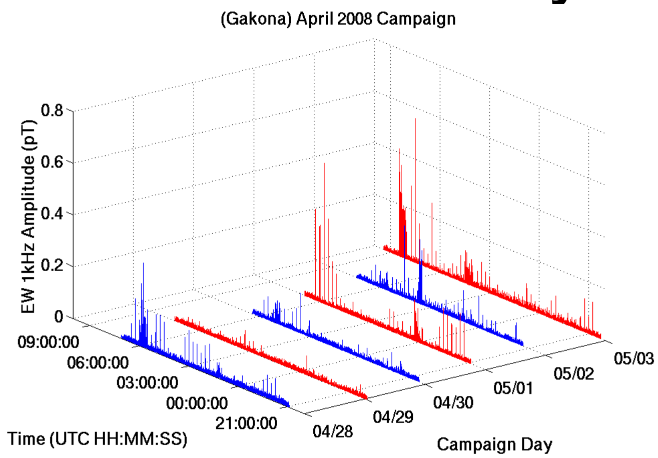
H --
D --
Z --
Gakona, AK
500
0
-500
Magnetic Variation (nT)
00:00
06:00
12:00
18:00
00:00
02 May 2008 (UTC)

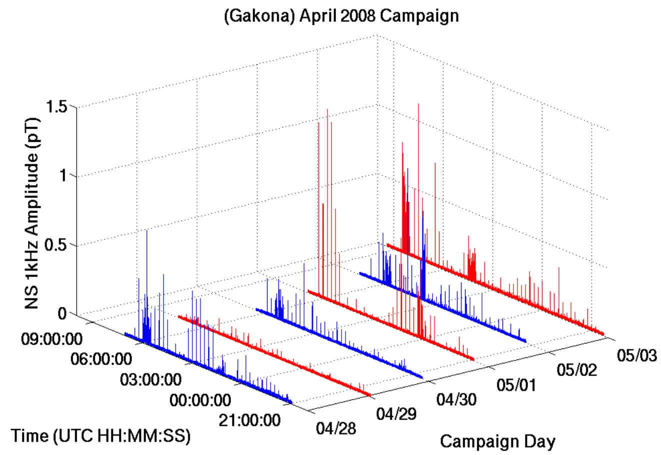
Electrojet Activity

- 1 kHz amp. can change in min.
- Low activity on Day 2 & 3
- Moderate activity on
-

1 & 2 kHz amp. (~Ejet) on Day 6





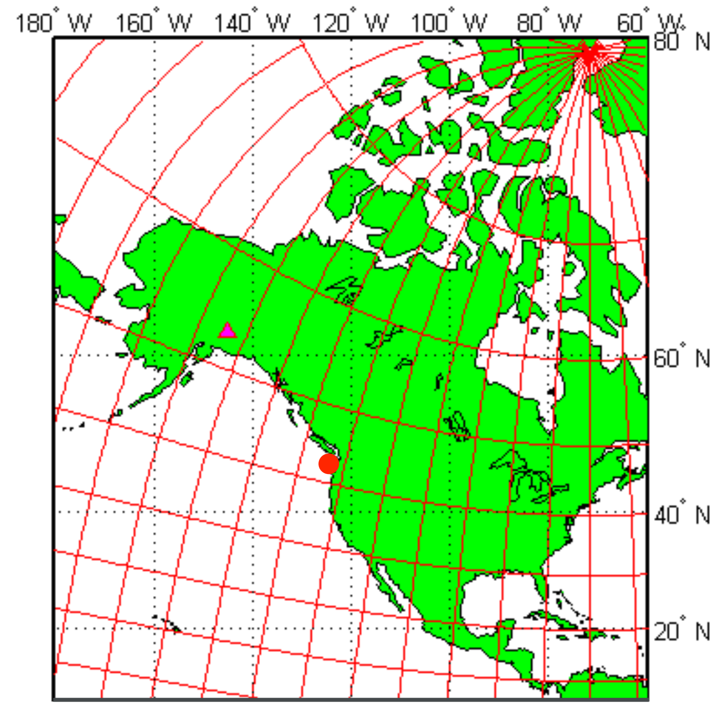


Ground Measurements – Gakona, AK

- Abundance of ULF signals recorded at Gakona
- Data analysis techniques
  - Power Spectral Density (PSD)
  - Rolling demodulation (RD)
  - Spectrogram
- Electrojet Correlation:
  - Over all ULF events vs. 1 kHz plot
  - Over all ULF events vs. freq. plot

ULF at Lake Ozette – Data Analysis Technique

- Distance to Gakona ~ 1370 miles
  - Dist. to Gakona is ~ 4 times longer than previous sites (Juneau/Kodiak)
- Only weak signals (≤ 0.1 pT) reach Lake Ozette (except 0.2 Hz events)
- RD and spectrogram yield no positive IDs (except some 20 Hz events)
- Use PSD & cross-correlation to find potential signals
  - Found 14 potential events



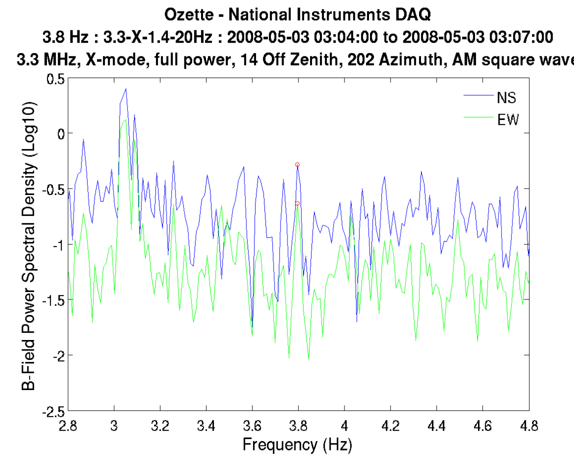
ULF at Lake Ozette – PSD & Cross Correlation - 3.8 Hz

- Cross correlation of NS & EW

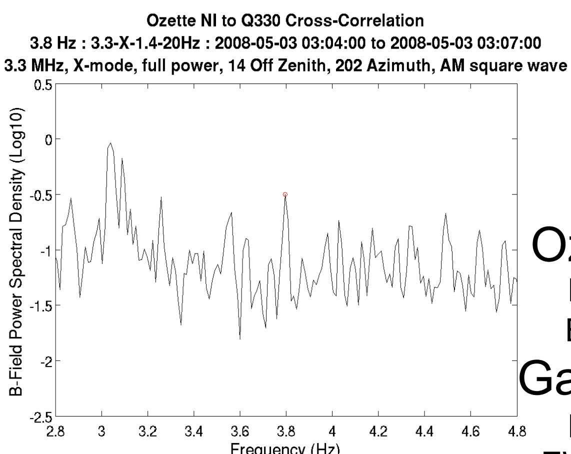
$$\mathcal{F}[B_{NS} * B_{EW}] = (\mathcal{F}[B_{NS}])^* \bullet (\mathcal{F}[B_{EW}])$$

- Enhance signal in NS & EW PSD; Suppress incoherent background
  - Location dependent cultural noise
    - Traffic/tree vibration etc.
  - Direction dependent background
- Will not eliminate coherent Pc1s

Ozette N.I.



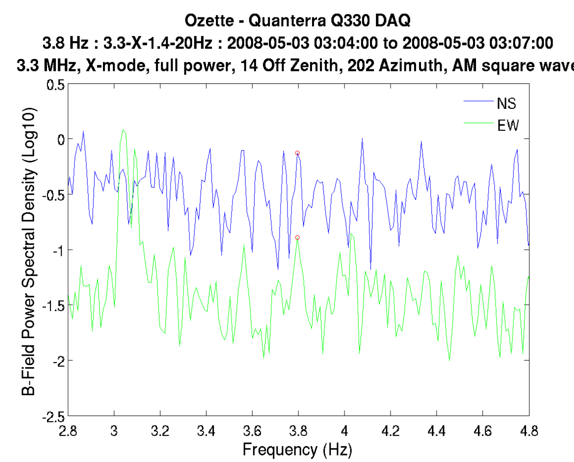
Cross Correlation



Ozette: Yes
NS: 0.06 pT
EW: 0.04 pT

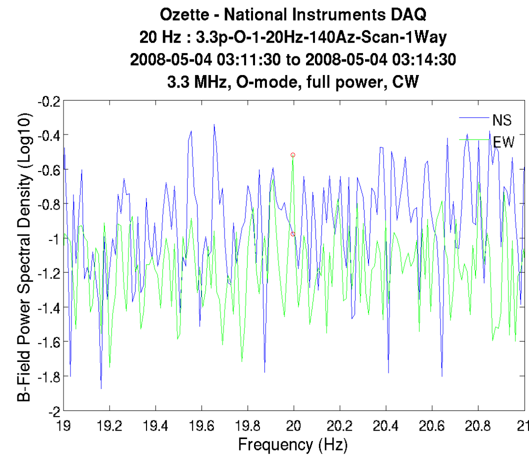
Gakona: Yes
NS: 0.29 pT
EW: 0.05 pT (≤)

Ozette Q-330

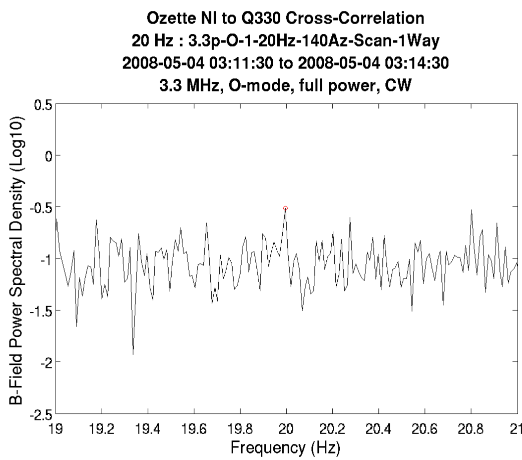


ELF at Lake Ozette – PSD & Cross Correlation – 20 Hz

- Many 20 Hz Lake Ozette events
- Example: 05-04-2008, 03:11:30 UT
- Low/no EJet
- Event at Ozette, but not Gakona

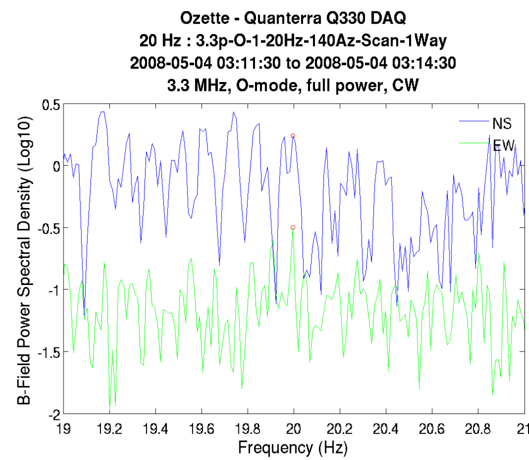


Ozette N.I.



Cross Correlation

Ozette: Yes
NS: 0.01 pT (≤)
EW: 0.04 pT
Gakona: No
NS: 0.02 pT (≤)
EW: 0.02 pT (≤)

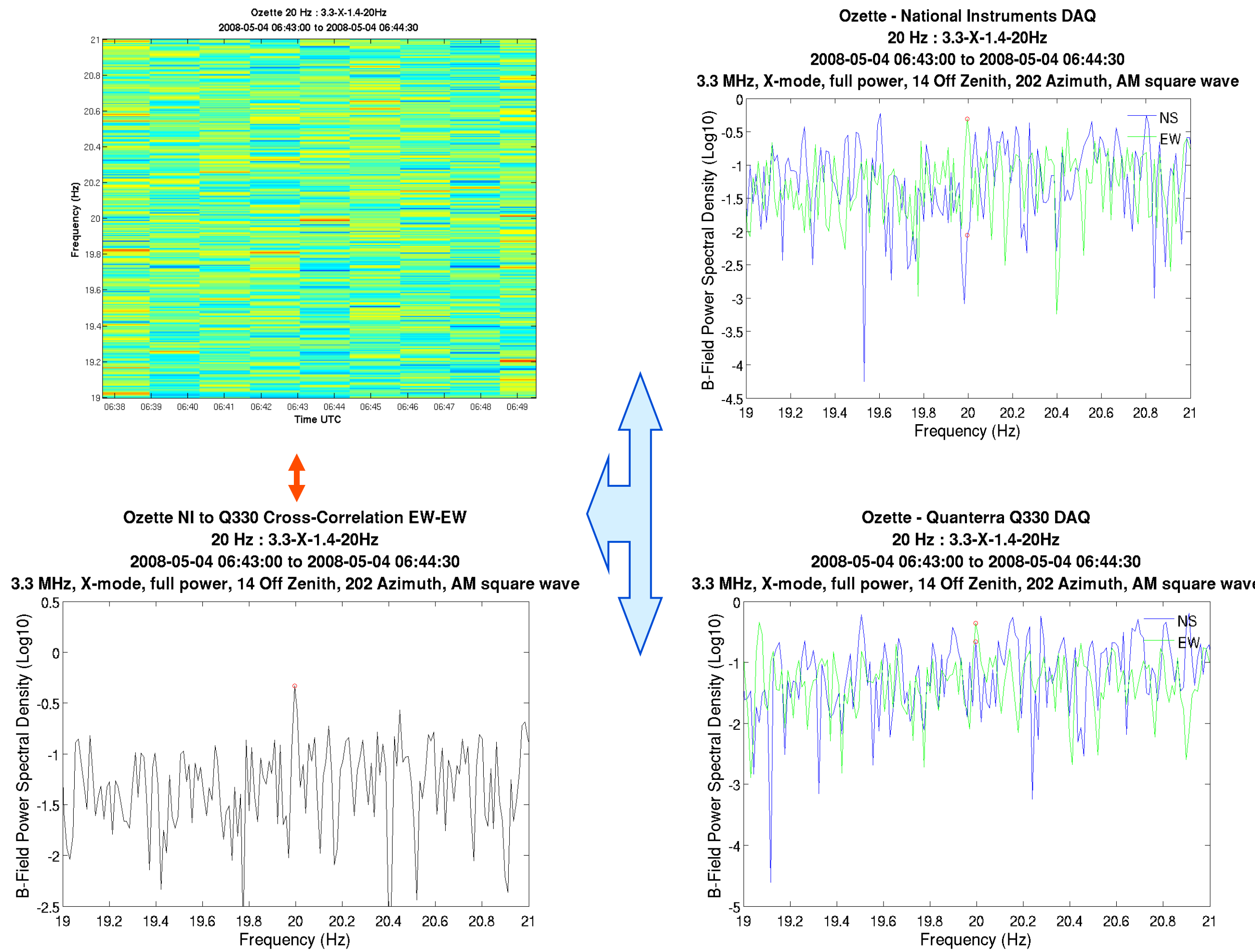


Ozette Q-330

ELF at Lake Ozette – PSD & Cross Correlation – 20 Hz

- Example: 05-04-2008
- 06:43:00 UT
- Moderate EJet
- Ozette: Yes
  - EW: 0.07 pT
  - NS: 0.01 pT (
  - Spectrogram
- Gakona: Yes
  - EW: 0.12 pT
  - NS: 0.06 pT ()

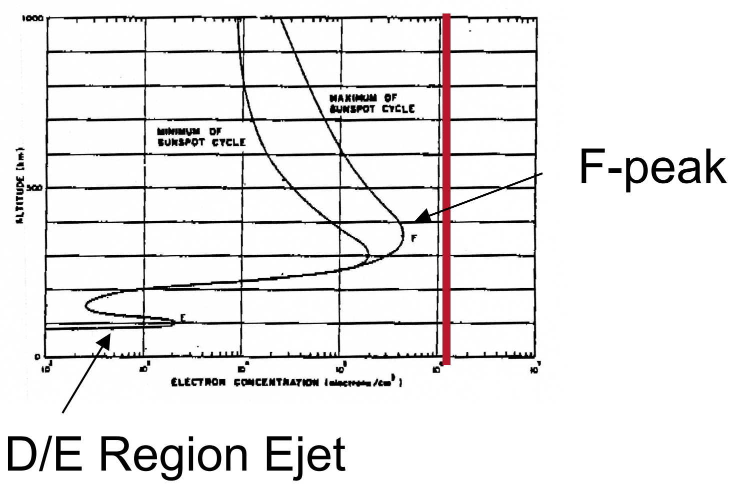
In Cross Correlation

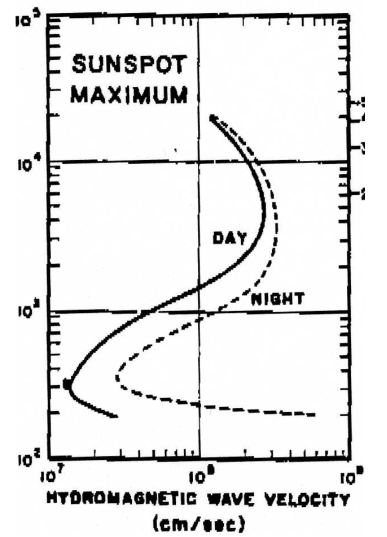


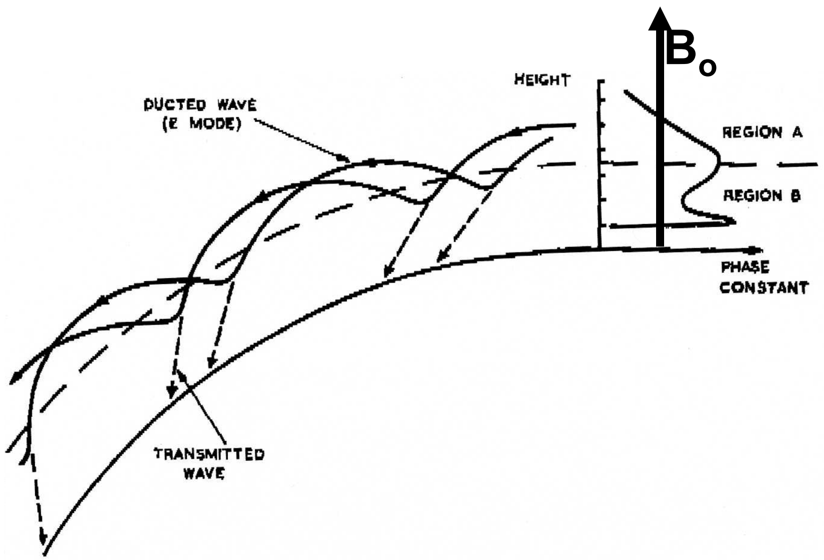
Ozette N.I.

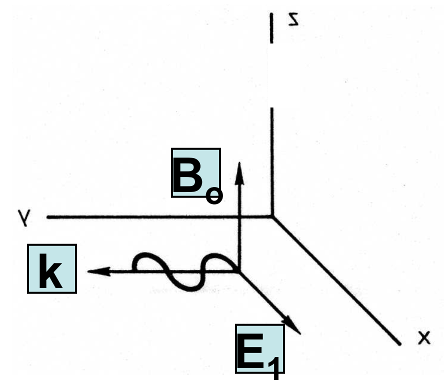
Ozette Q-330

ALFVENIC DUCT





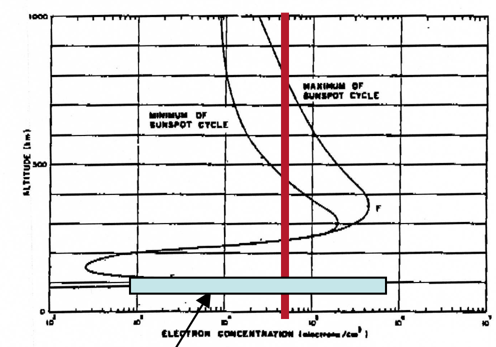


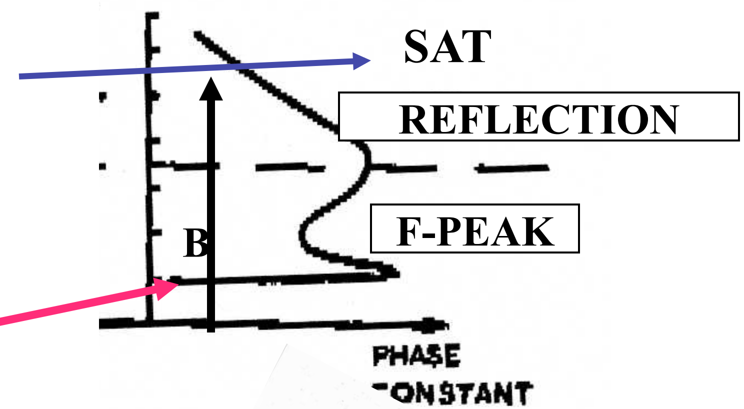


Magnetosonic Alfven Wave (compressional)

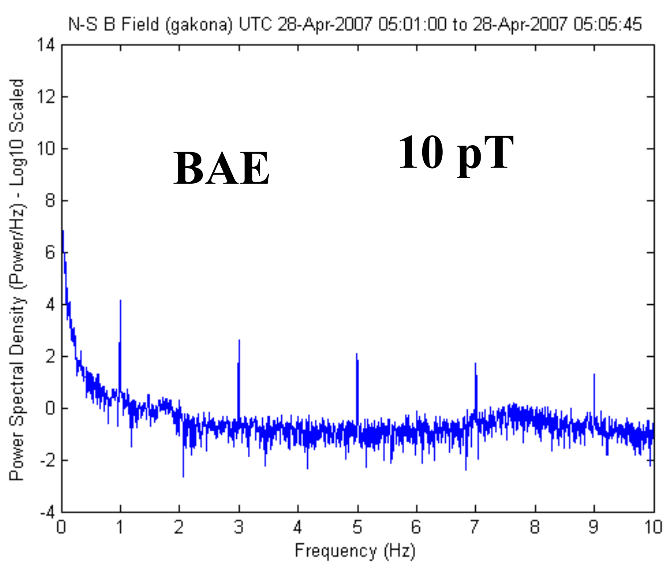
IONOSPHERIC ULF GENERATION

1. SAW – REQUIRES EJet AND D/E REGION X-MODE HEATING – OBSERVED ONLY IN NEAR ZONE, ALONG THE FLUX TUBE AND POSSIBLY CONJUGATE

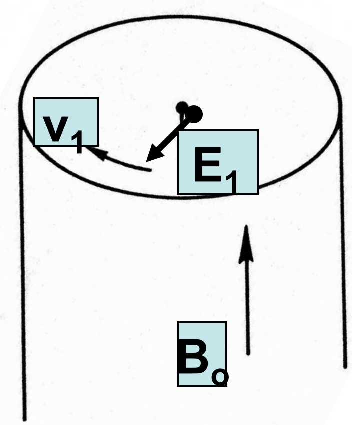




D/E Region heating+ Electrojet



BAE-UMCP



Shear Alfven wave

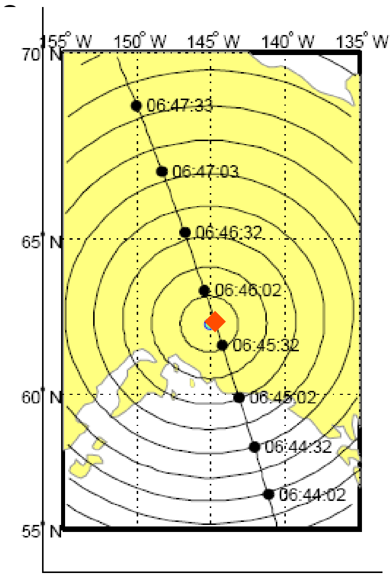
Lake Ozette - Highlights

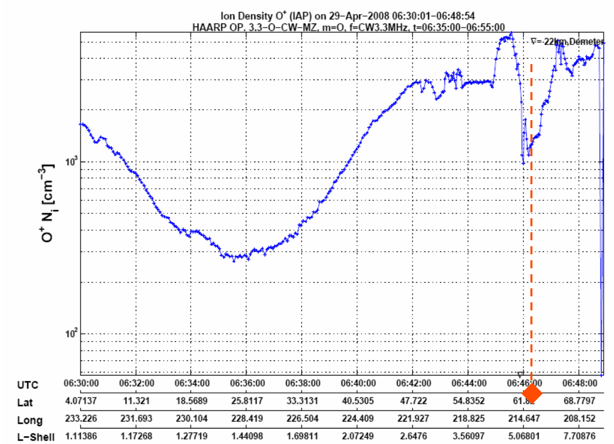
- Weak signals at best ($\leq$ 0.1 pT)
  - Except two 0.2 Hz events
- Total of 14 possible events found based on PSD-CC
- Far more 20 Hz events than ULF events (< 10 Hz)
- Most Lake Ozette events are in sync with low/no Gakona electrojet activity, thus in sync with non-event at Gakona
- No ELF/VLF sightings at and above 75 Hz

- Weak signals at Lake Ozette due to weak F layer?

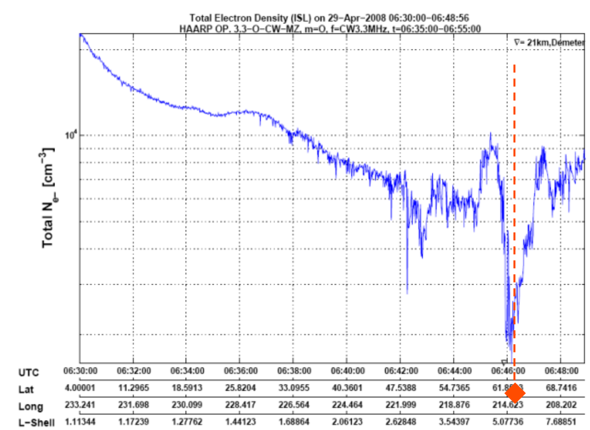
HAARP CW Op. - Duct Formation at Demeter Flyover

- April 29, 2008; 06:46:00 UTC
- O mode at 3.3 MHz - CW
- Electron & ion density cavity recorded during Demeter flyover
- Lateral size ~ 600 km at Demeter alt. of ~ 850 k
- 3 HAARP-CW Demete flyover events
  - Duct formation in all 3
- Artificial duct – ELF/VL propagation channel





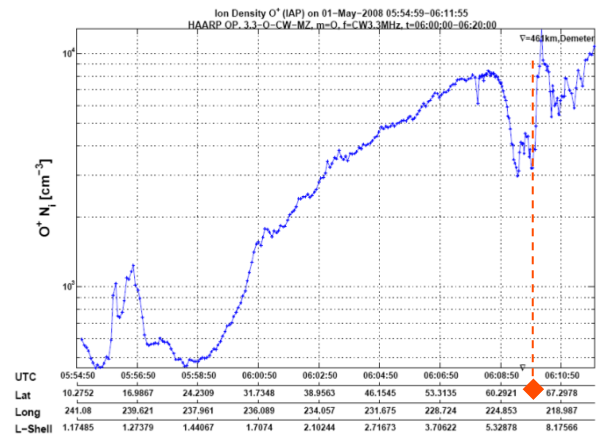
Ion Density



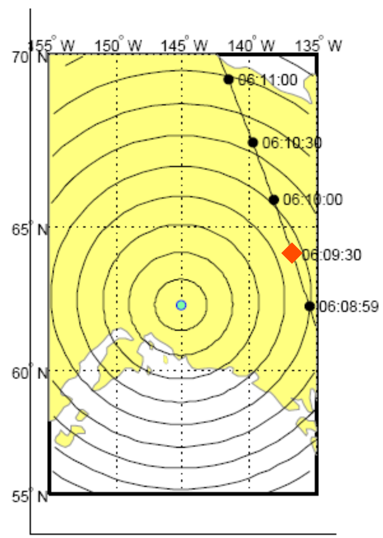
Electron Density

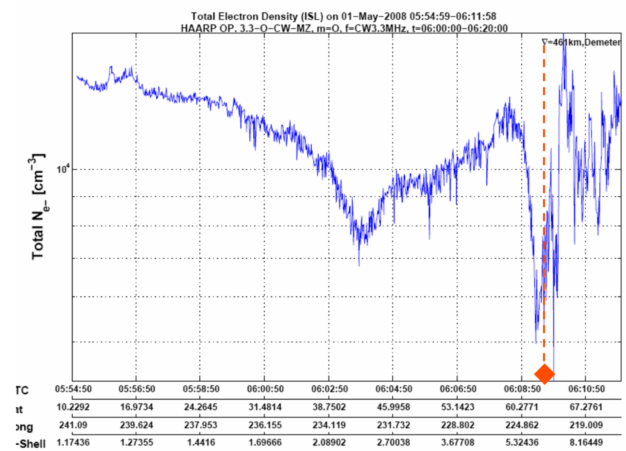
HAARP CW Op. - Duct Formation at Demeter Flyover

- May 1, 2008; 06:09:00 UTC
- Closest distance ~ 450 km



Ion Density

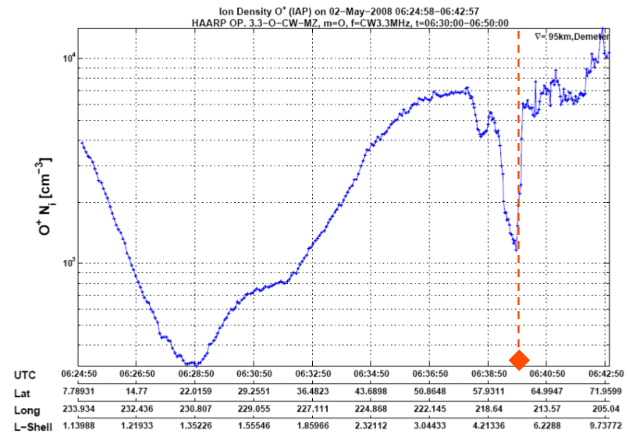




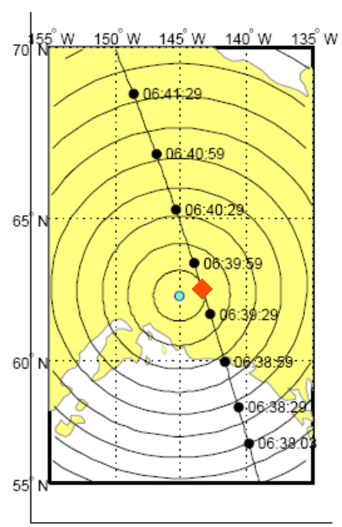
Electron Density

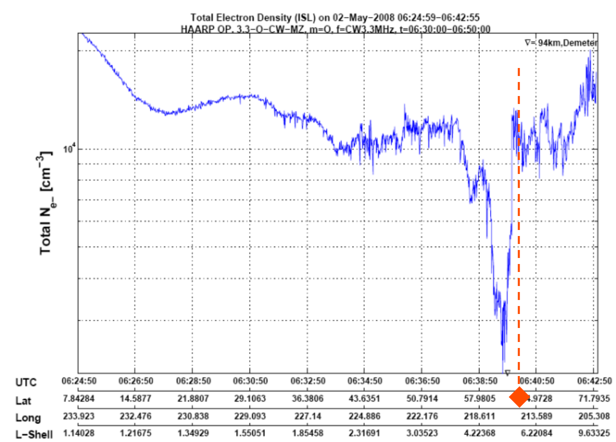
HAARP CW Op. - Duct Formation at Demeter Flyover

- May 2, 2008; 06:40:00 UTC



Ion Density

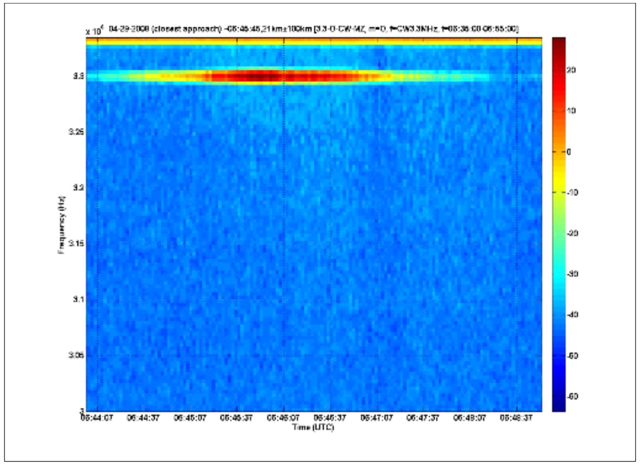




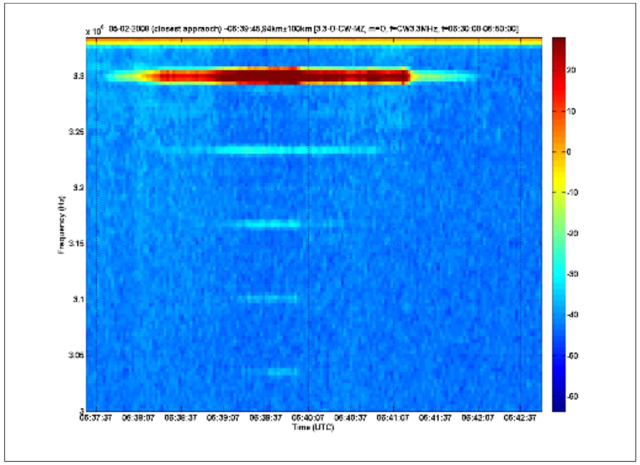
Electron Density

Demeter Detection of HAARP HF Power

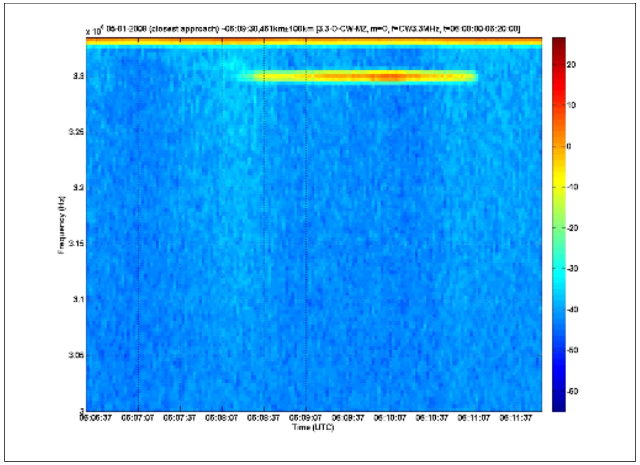
- HAARP HF was detected at all 3 duct formation events
- Peak HF field at Demeter level:
  – 4/29 case: 25 $(\mu V/m)^2/Hz$
  – 5/01 case: 2 $(\mu V/m)^2/Hz$
  – 5/02 case: 25 $(\mu V/m)^2/Hz$
- **Max. ~ 0.1% of HAARP HF power passing through F layer**



4/29 Case



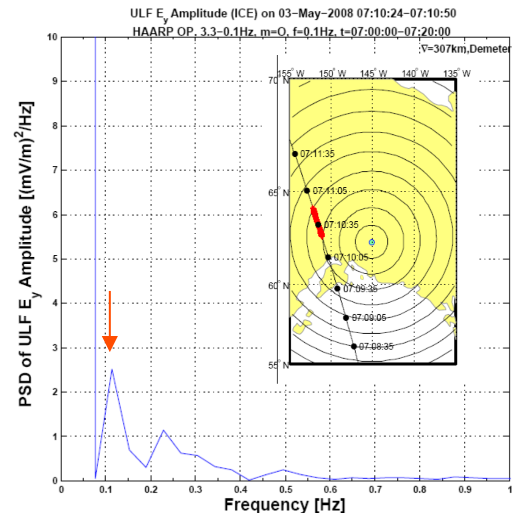
5/02 Case



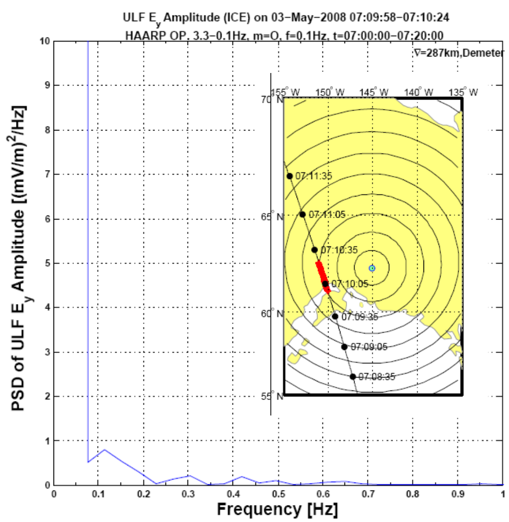
5/01 Case

Demeter Detection of HAARP ULF at 0.1 Hz

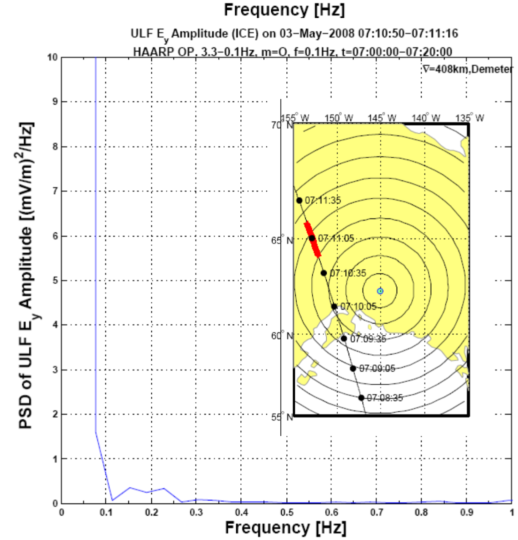
- May 3, 2008; 07:10:00 UTC
- Closest approach 287 km
- HAARP: 3.3 MHz, O mode, 0.1 Hz
- PSD shows 0.1 Hz in "during" plot, but not in "before" & "after" plot



During



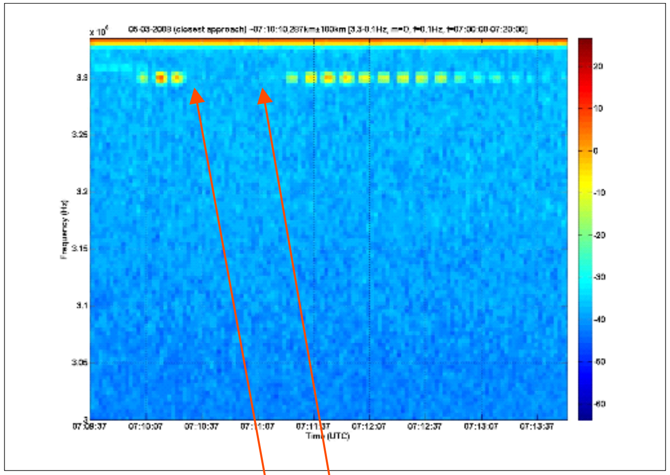
Before

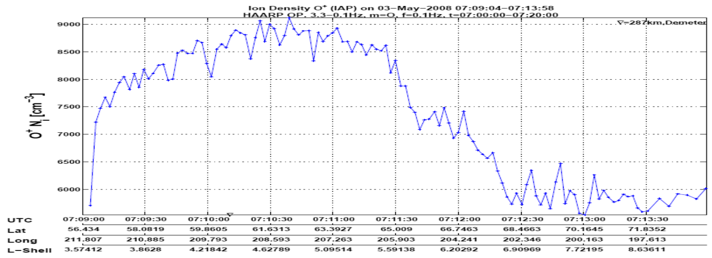


After

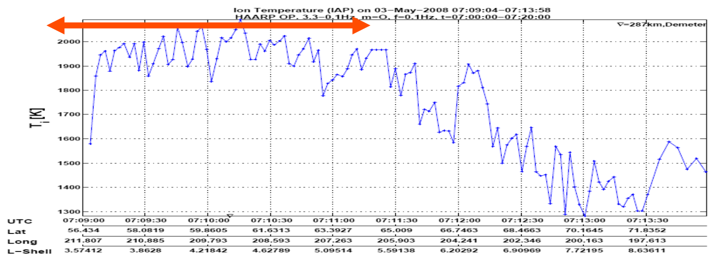
Demeter Detection of HAARP ULF at 0.1 Hz

- HAARP HF detected; on/off cycles are in series of dots
  - HF power ~ 1 (μV/m)^2/Hz
- Ion density and temp. increase during flyover
  - Ni: 6000/c.c. to 9000/c.c.
  - Ti: 1600^{o}K to 2000^{o}K

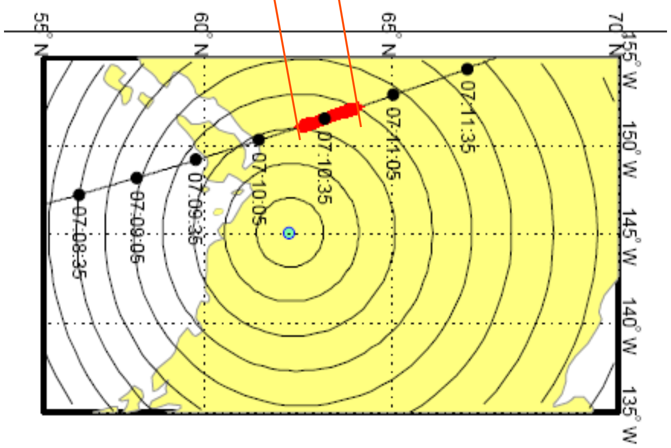




N_i

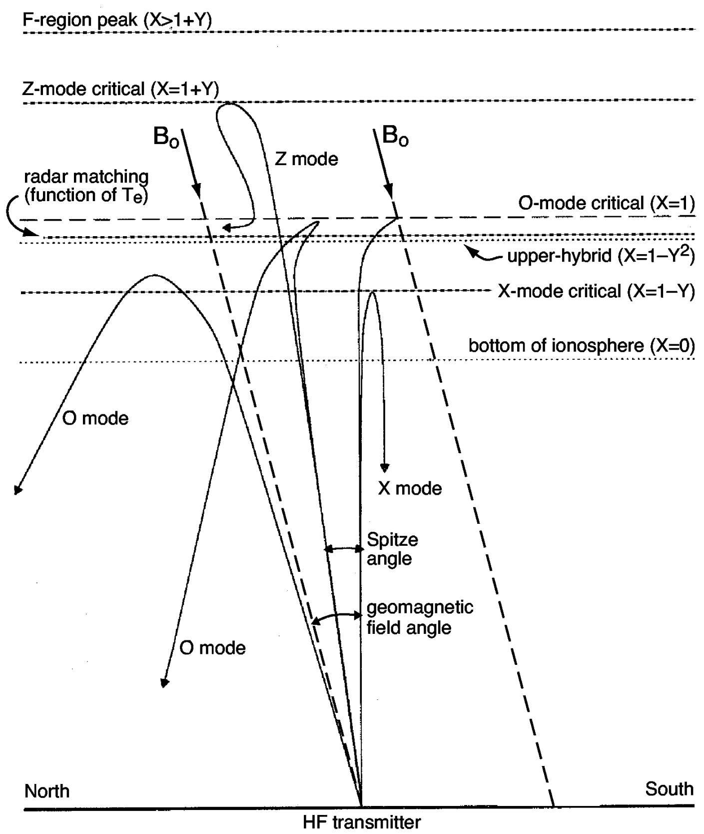


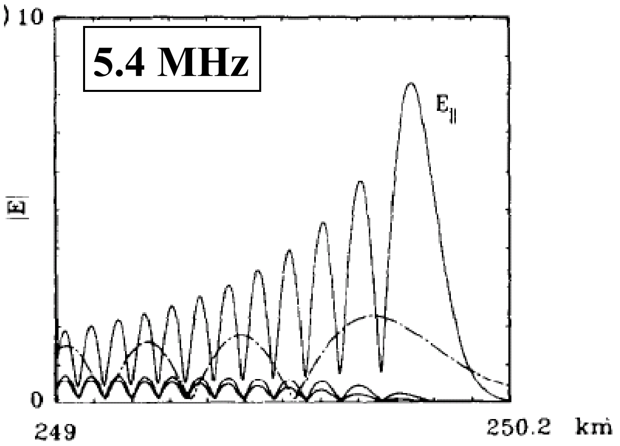
T_i

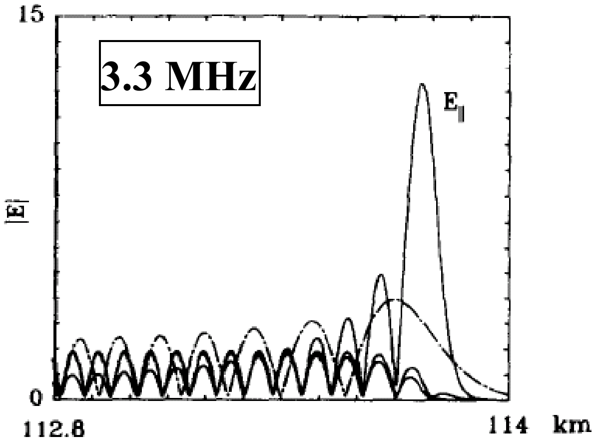


During

CONTROL OF MODIFICATION ALTITUDE





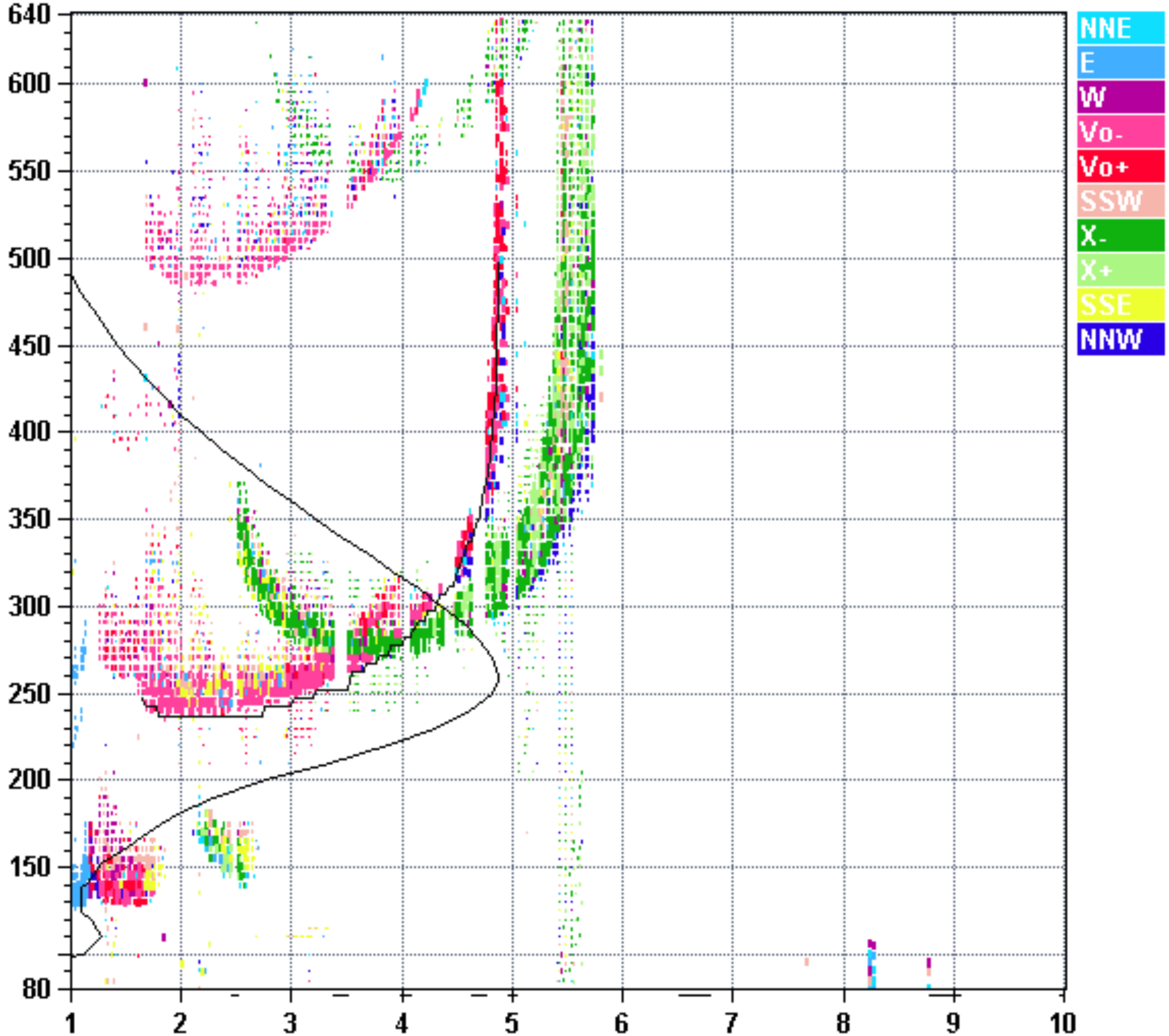


Lundborg and Thidé, 1986

Lowell DIGISONDE

Statio	YYYY	DAY	DDD	HHMM	P1	FFS	S	AXN	PPS	IGA	PS
Gakona	2006	May03	123	0545	RSF		1	714	200	20+	C1

foF2	4.875
foF1	N/A
foF1p	N/A
foE	N/A
foEp	1.27
fxI	5.72
foEs	1.65
fmin	1.18
MUF(D)	16.02
M(D)	3.29
D	3000.0
h\`F	237.0
h\`F2	N/A
h\`E	N/A
h\`Es	129.0
hmF2	258.1
hmF1	N/A
hmE	110.0
yF2	64.1
yF1	N/A
yE	20.0
B0	65.8
B1	2.12
C-level	11



D	100	200	400	600	800	1000	1500	3000	[km]
MUF	5.6	5.6	5.9	6.3	6.8	7.6	10.0	16.0	[MHz]

GA762_2006123054500.RSF / 360fx128h 25 kHz 5.0 km / DPS-4 GA762 062 / 62.4 N 215.0 E   Ion2Png v. 1.1.02

Model Features & Limitations

- Linearized equations
- Advance B, J in ionosphere (80-140 km)

$$J = (\nabla_\perp \times B_\perp)\cdot \hat{z} \qquad M = c(\nabla_\perp \times E_\perp)\cdot \hat{z} \qquad Q = c\nabla_\perp \cdot E_\perp$$

- Add Q, M in magnetosphere
- Hall conductivity couples compressional (B,M) and shear (J,Q) modes

$$\left(\frac{\partial}{\partial t} + \frac{4\pi\sigma_P}{\varepsilon}\right)Q = \frac{c^2}{\varepsilon}\frac{\partial J}{\partial z} - \frac{4\pi\sigma_H}{\varepsilon}M \qquad \left(\frac{\partial}{\partial t} + \frac{4\pi\sigma_P}{\varepsilon}\right)M = \frac{c^2}{\varepsilon}\nabla_\perp^2 B_z + \frac{4\pi\sigma_H}{\varepsilon}Q$$

$$\frac{\partial}{\partial t}\left(1 - \lambda^2\nabla_\perp^2\right)J = -\frac{\partial Q}{\partial z} + \eta_{\|}\nabla_\perp^2 J \qquad \frac{\partial B_z}{\partial t} = -M$$

$\sigma_H \longrightarrow 0$ decouples left set from right set of equations

Model Features/Limitations

- 2D/3D

  Original 2D code provided by Lysac, 3D version developed since

- Background B-field parallel to g

  Variation of field strength with z accounted for with scale factor,

  $$\partial^2 x \rightarrow \partial^2 x (R / R_0)^3$$

  , but

  $$\nabla_\perp = \partial / \partial x$$

- Uses Chapman profile for E, F1, F2 layers

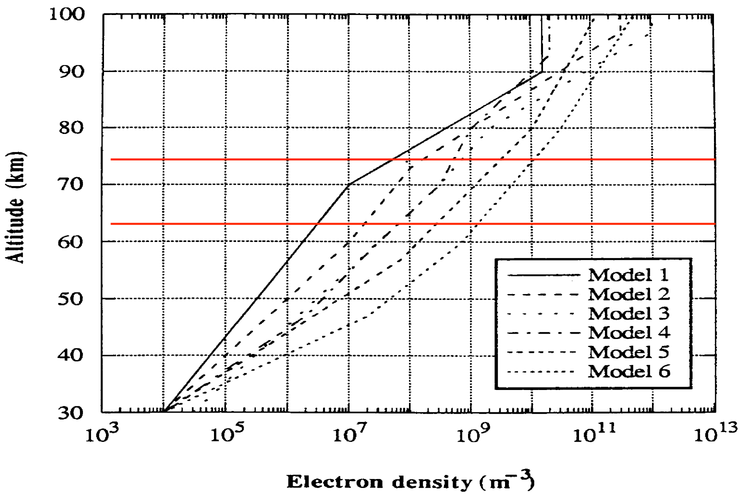
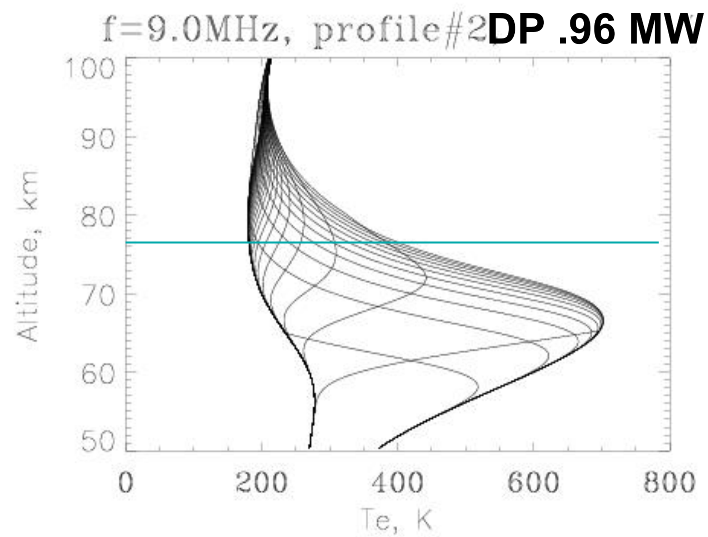
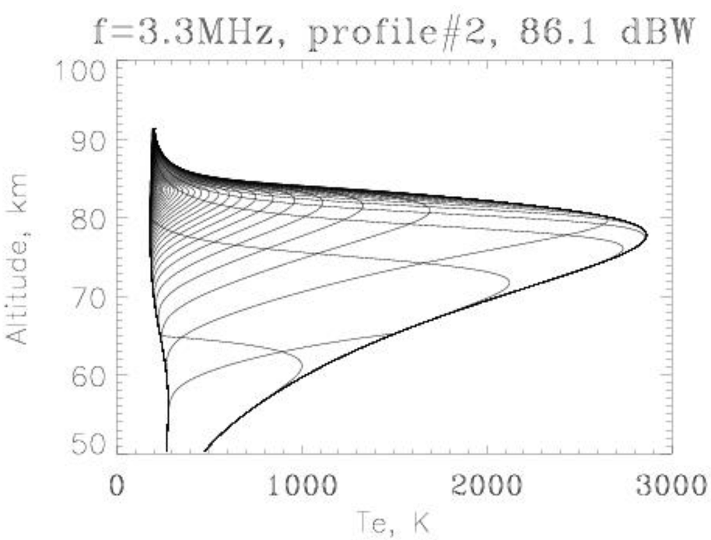
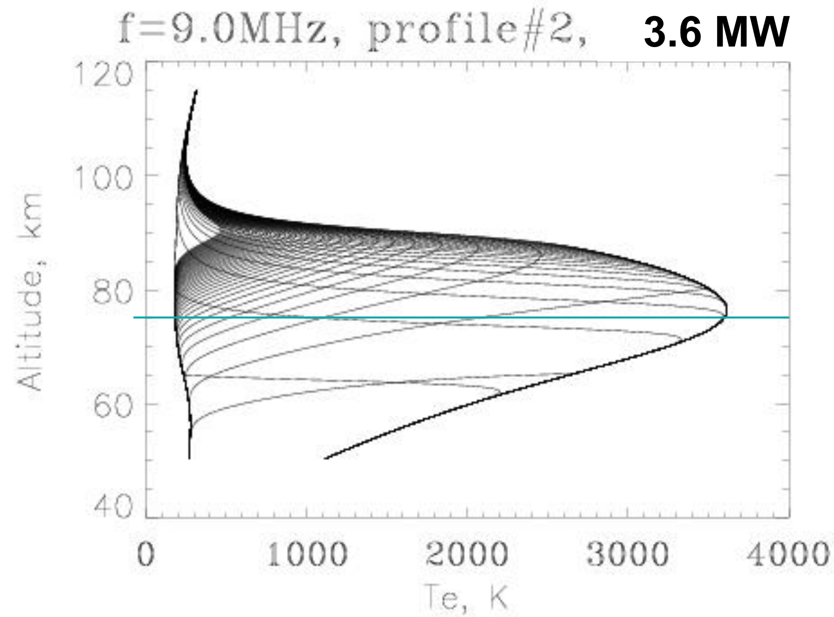


Figure 3-9 (U) Electron Density Profiles from [Barr and Stubbe, 1984]

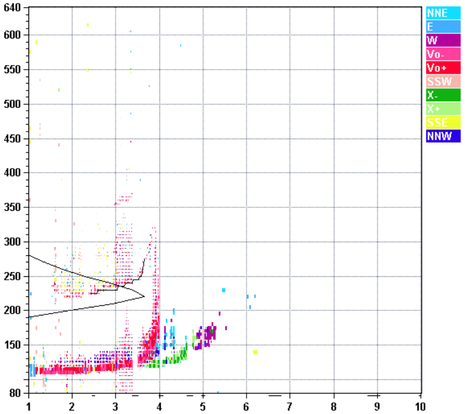






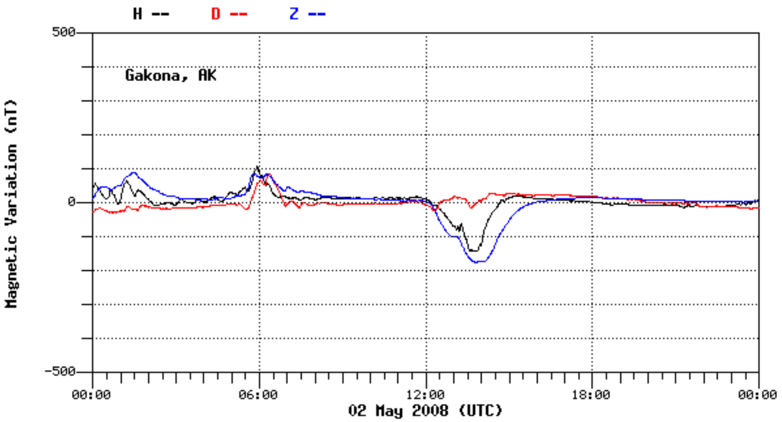
Statio	YYYY	DAY	DDD	HHMM	P1	FFS	S	AXN	PPS	IGA	PS
Gakona	2006	May05	125	0715	RSF		1	714	200	20+	C1

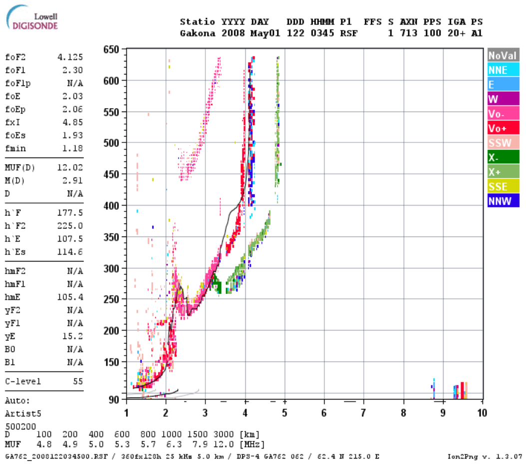
foF2	3.650
foF1	N/A
foF1p	N/A
foE	N/A
foEp	.73
fxI	4.45
foEs	3.95
fmin	2.42
MUF(D)	14.46
M(D)	3.96
D	3000.0
h\`F	225.0
h\`F2	N/A
h\`E	N/A
h\`Es	110.0
hmF2	220.0
hmF1	N/A
hmE	110.0
yF2	18.5
yF1	N/A
yE	20.0
B0	21.9
B1	1.36
C-level	51



D	100	200	400	600	800	1000	1500	3000	[km]
MUF	4.4	4.4	4.6	5.0	5.5	6.3	8.6	14.5	[MHz]

GA762_2006125071500.RSF / 360fx128h 25 kHz 5.0 km / DPS-4 GA762 062 / 62.4 N 215.0 E Ion2Png v. 1.1.02


H --
D --
Z --
Gakona, AK
Magnetic Variation (nT)
500
0
-500
00:00
06:00
12:00
18:00
00:00
02 May 2008 (UTC)


Lowell DIGISONDE
Statio YYYY DAY DDD HHMM P1 FFS S AXN PPS IGA PS
Gakona 2008 May01 122 0345 RSF 1 713 100 20+ A1
foF2 4.125
foF1 2.30
foF1p N/A
foE 2.03
foEp 2.06
fxI 4.85
foEs 1.93
fmin 1.18
MUF(D) 12.02
M(D) 2.91
D N/A
h`F 177.5
h`F2 225.0
h`E 107.5
h`Es 114.6
hmF2 N/A
hmF1 N/A
hmE 105.4
yF2 N/A
yF1 N/A
yE 15.2
B0 N/A
B1 N/A
C-level 55
Auto:
Artist5
500200
NoVal
NNE
E
W
Vo-
Vo+
SSW
X-
X+
SSE
NNW
D 100 200 400 600 800 1000 1500 3000 [km]
MUF 4.8 4.9 5.0 5.3 5.7 6.3 7.9 12.0 [MHz]
GA762_2008122034500.RSF / 360fx128h 25 kHz 5.0 km / DPS-4 GA762 062 / 62.4 N 215.0 E
Ion2Png v. 1.3.07

Sine sweep, 100km/s, 1Hz, at z=370km

scale in x is 50km/grid point

scale in z is variable; simulation covers 80km-8000km

Model Features/Limitations

- 2D/3D

  Original 2D code provided by Lysac, 3D version developed since

- Background B-field parallel to g

  Variation of field strength with z accounted for with scale factor,

  $$\partial^2 x \longrightarrow \partial^2 x (R / R_0)^3$$

  , but $\nabla_\perp = \partial / \partial x$

- Uses Chapman profile for E, F1, F2 layers

  Chapman profile uses different scale lengths above and below the peak.

Model Features/Limitations

- Variable grid in z, constant in x

  2.5km min z-grid size in ionosphere, up to 300km in magnetosphere (plots need care to interpret).

- B-drive at arbitrary (x, z)

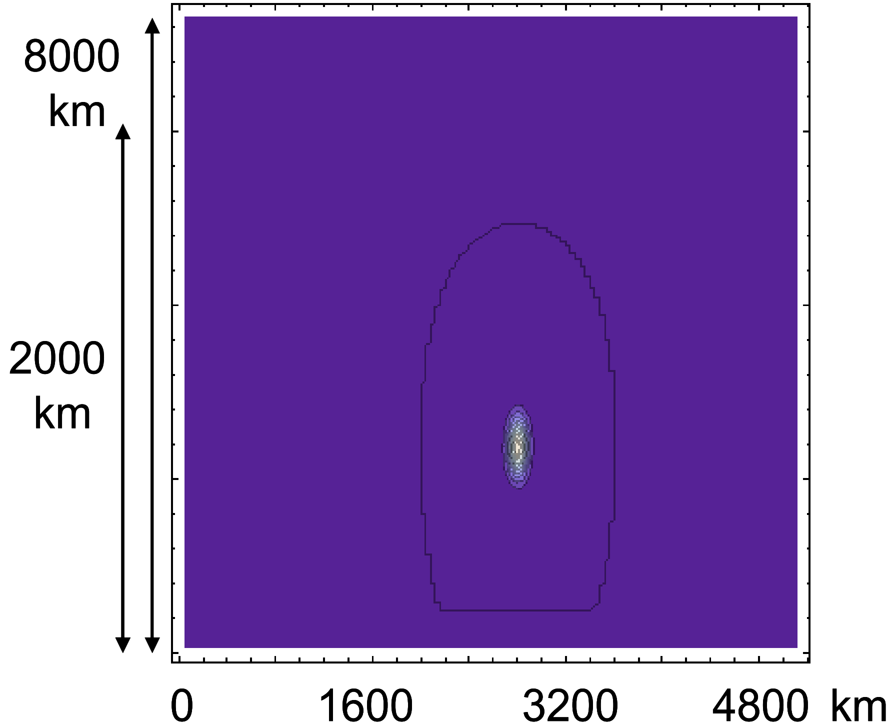
  We drive the system directly via the B equation by adding a drive term that is a gaussian in x, z

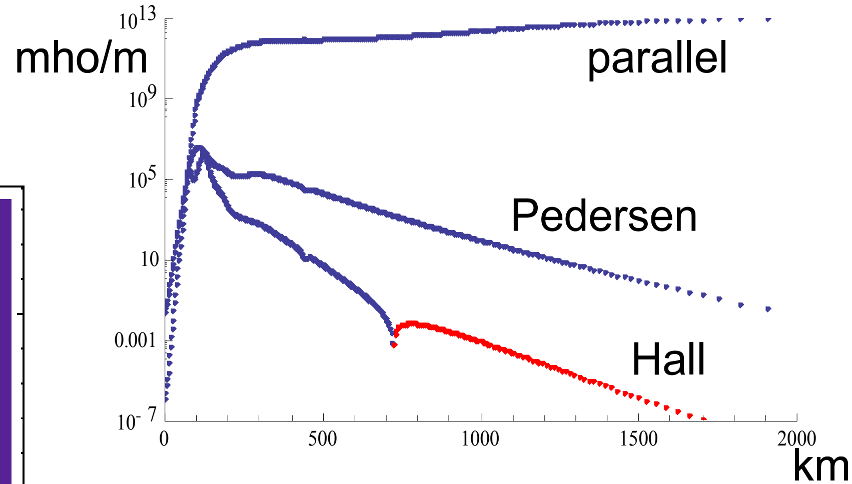
  We can modulate the driver at arbitrary frequency with either a sawtooth or a sinusoidal sweep. The sweep speed is also arbitrary.

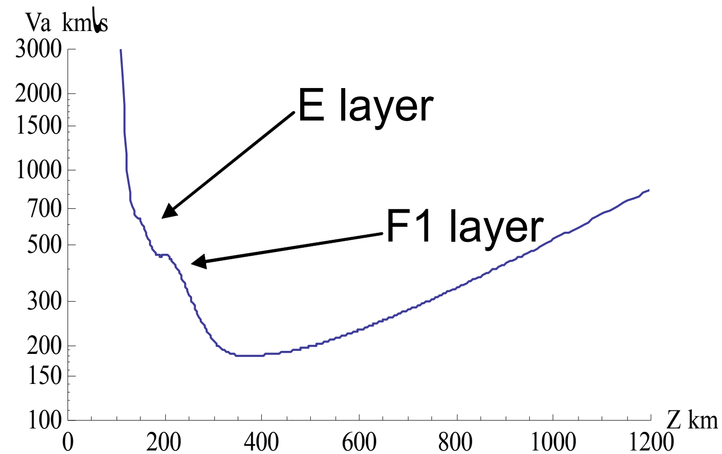
2D Simulations Show Skip Distance

Sawtooth/sine sweep

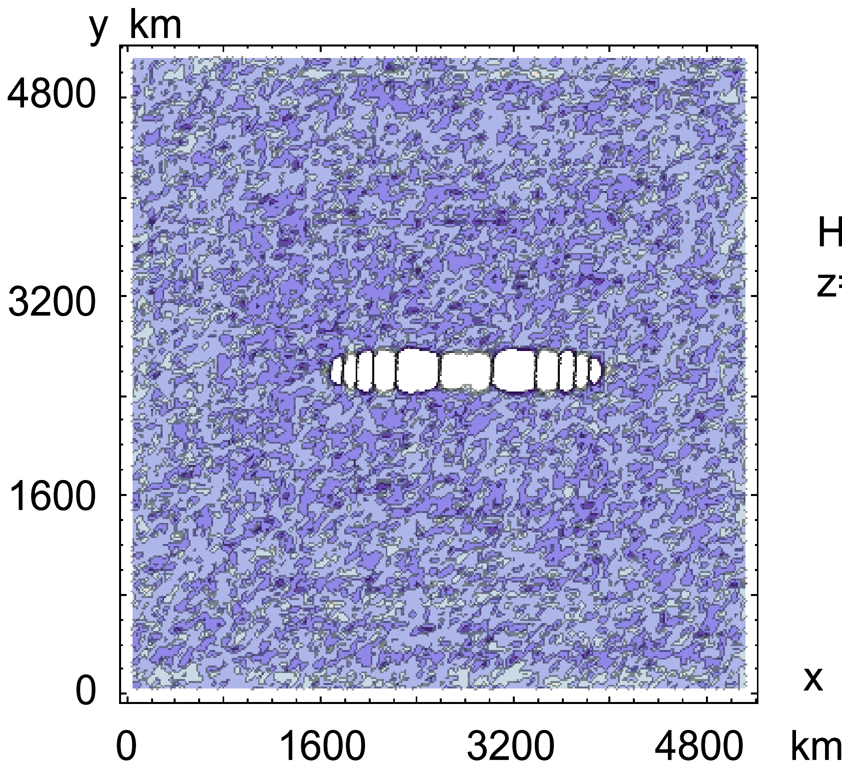
B-drive in x,z (units are grid points)







3D Simulations Show Beaming for Sawtooth Sweep



Contour plot of Bz

Horizontal slice at height of drive, z=370km (same as min of V_A)

Driver is swept in sawtooth in x-direction along a 100km track.
V_sweep=100km/s, repetition=1Hz

Remaining Issues, Future Plans

- Need B at arbitrary angle

  Simulations cover distances of ~5000km in x,y. At those scales B cannot be considered vertical. Need new code with arbitrary angle.

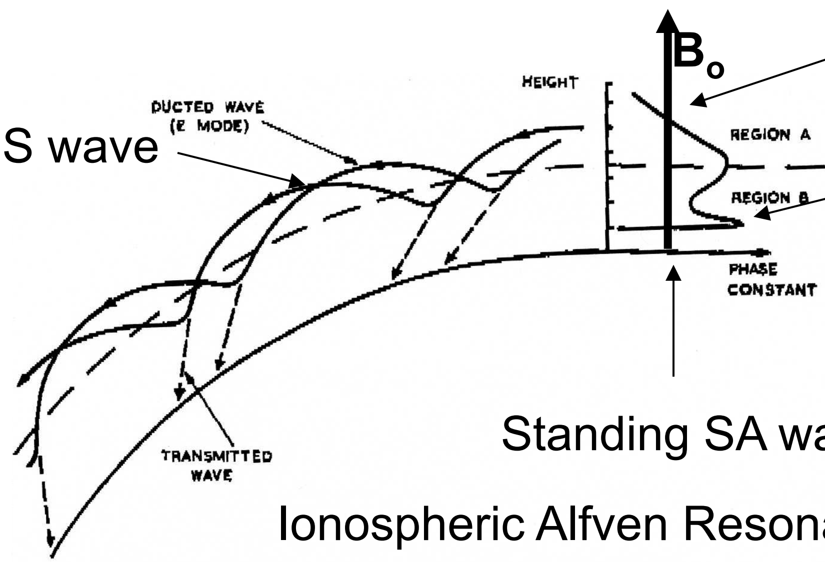
- Need parameter scan

  Need systematic study of propagation characteristics as a function of ionospheric conditions (strength of E layer, conductivity profiles, etc.).

Show Mathematica interactive model builder

The Fundamentals

- For Pc1 frequencies (.1-7 Hz) the ionosphere behaves as:
  - A resonator for Shear Alfven (SA) waves, confined along the B lines with an almost vertical structure at high latitudes
  - A waveguide for Magnetosonic (MS) waves propagating isotropically and ducted horizontally over long distances

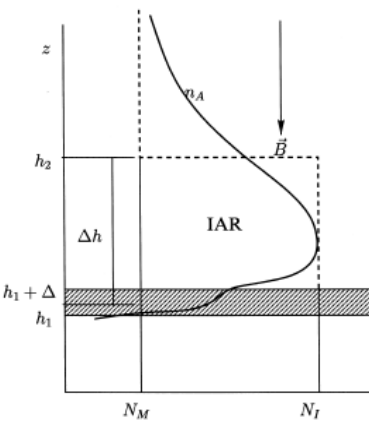


Reflection due to gradη at one to two thousand km

Partial reflection at E-region

Standing SA wave

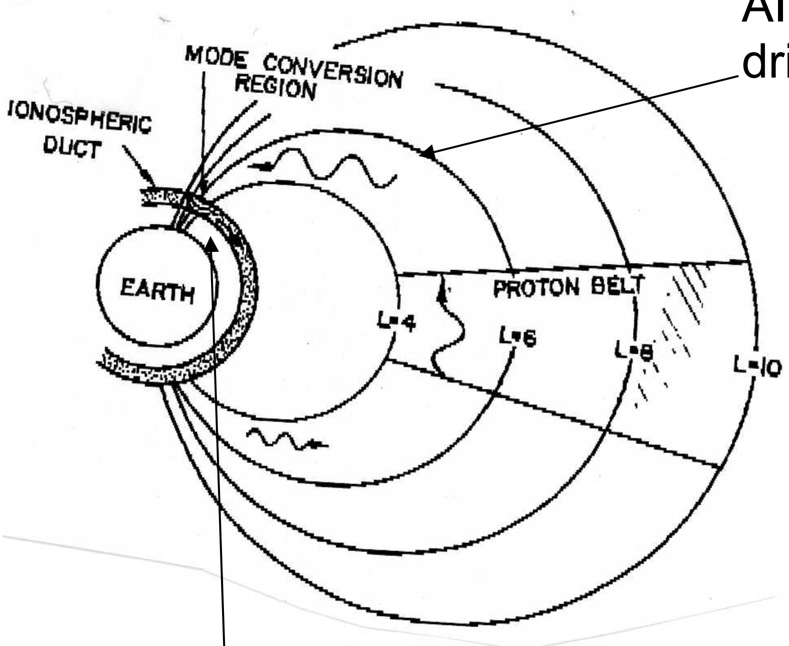
Ionospheric Alfven Resonator (IAR)



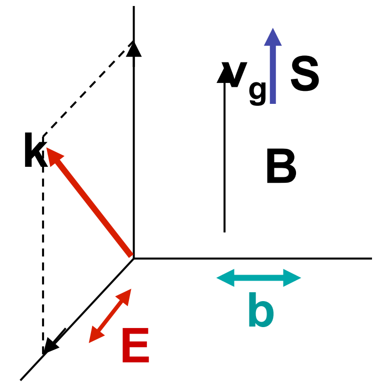
$V_A \sim B/\sqrt{n}$ $\eta = c/V_A$

Naturally Generated Pc1 Waves

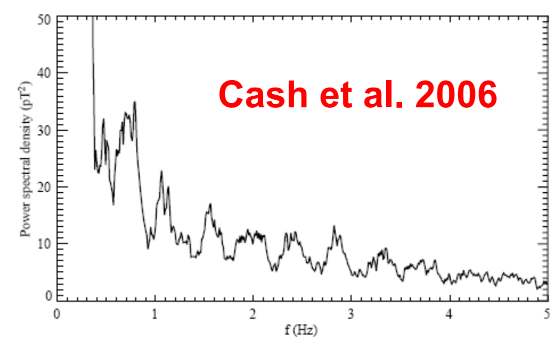
AIC instability due to proton anisotropy drives SA waves



SA waves mode converted at the boundary of duct and propagate laterally as MS waves over large distances

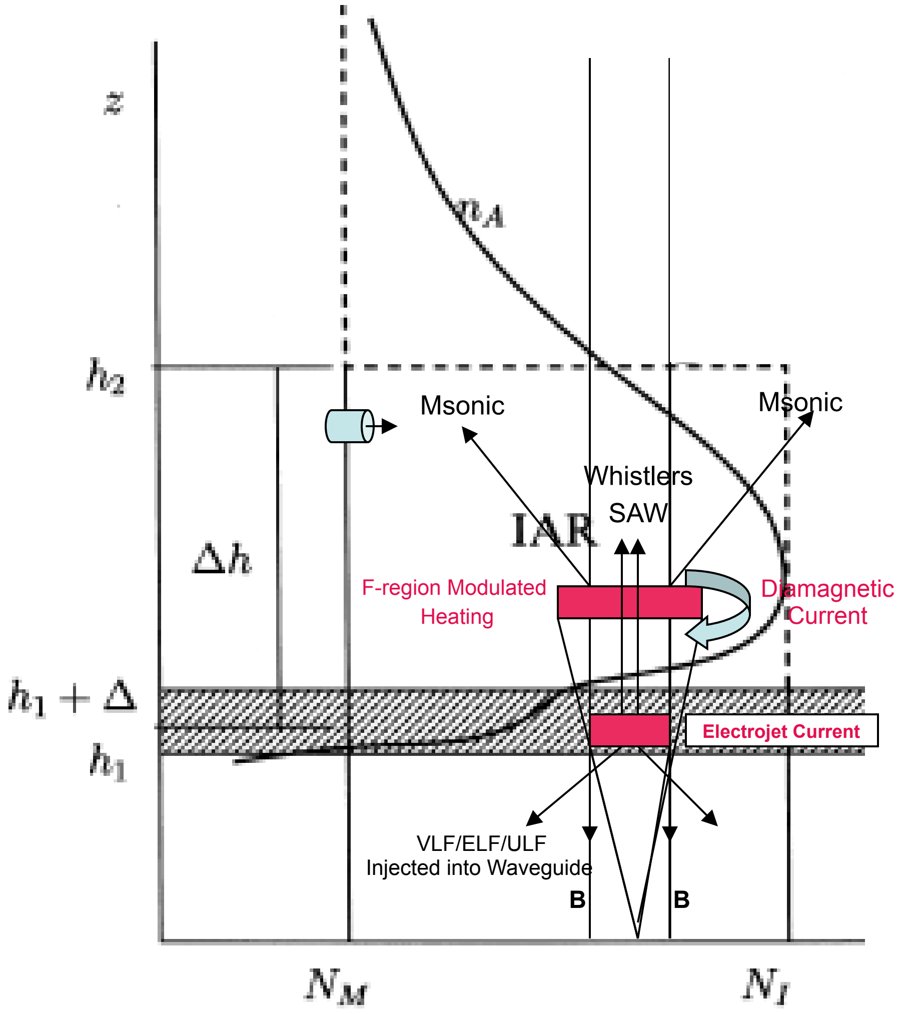


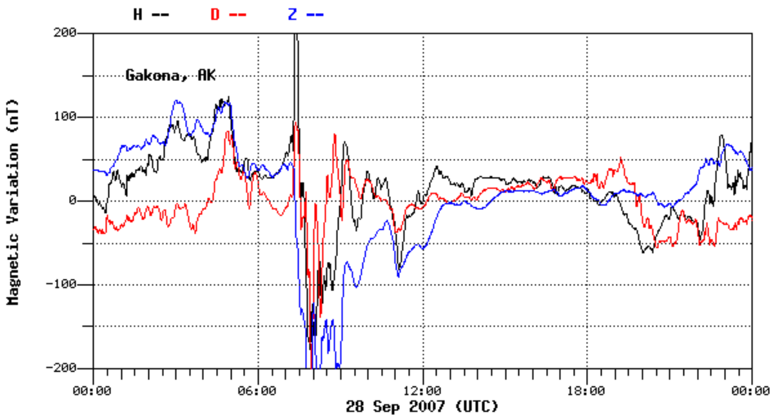
IAR

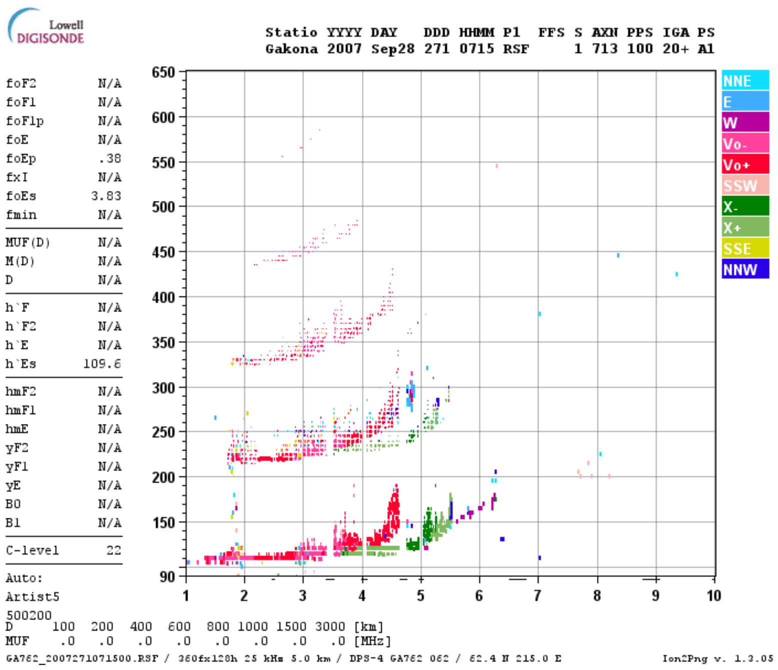


***Fabry-Perot* like Resonator**

D/E vs F-Region ULF

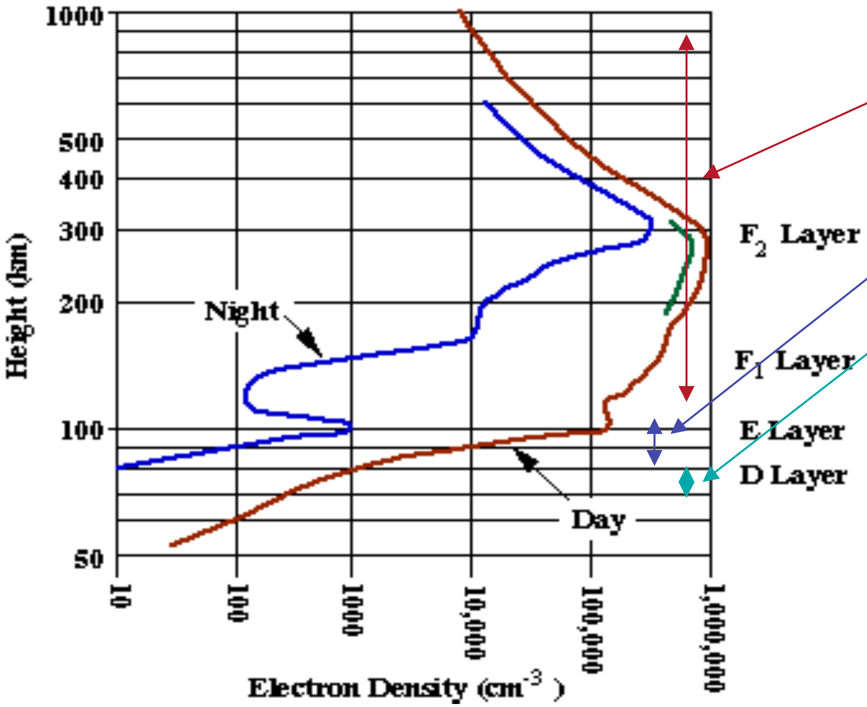






Conditions favoring D/E region ULF generation

PLASMA RESEARCH USING THE IONOSPHERE



PLASMA REGIONS

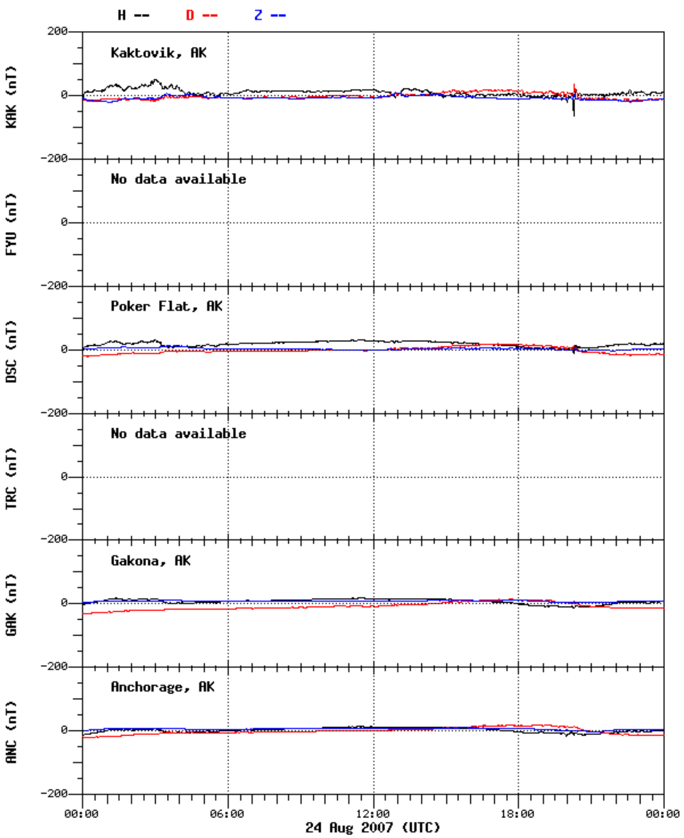
1. Collisionless magnetized - MHD, Whistlers, Electron and ion Plasma Waves
2. Helicon or Hall - Like solid plasma
3. Plain conducting weakly ionized gas

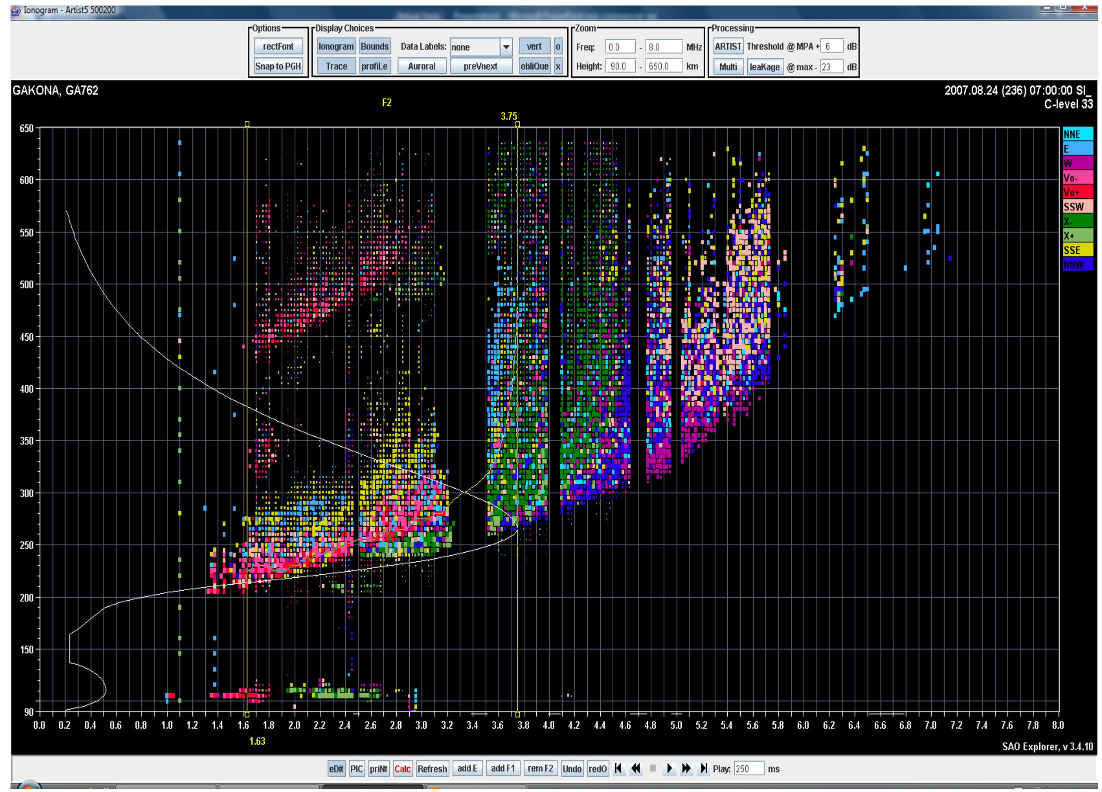
ACTIVE PLASMA REGIONS

(Regions with free energy)

1. Electrojets (Polar- Equatorial) D/E
2. Inverse density gradient F/Region

- **Ionospheric heater - Powerful HF transmitter that induces controlled temporary modification to the plasma temperature at desired altitude. Use in conjunction with diagnostics to study, in a cause and effect fashion:**
  - **EM propagation, plasma turbulence and instabilities**
  - **Response of magnetospheric plasma and Radiation Belts to controlled perturbations of the ionospheric plasma**

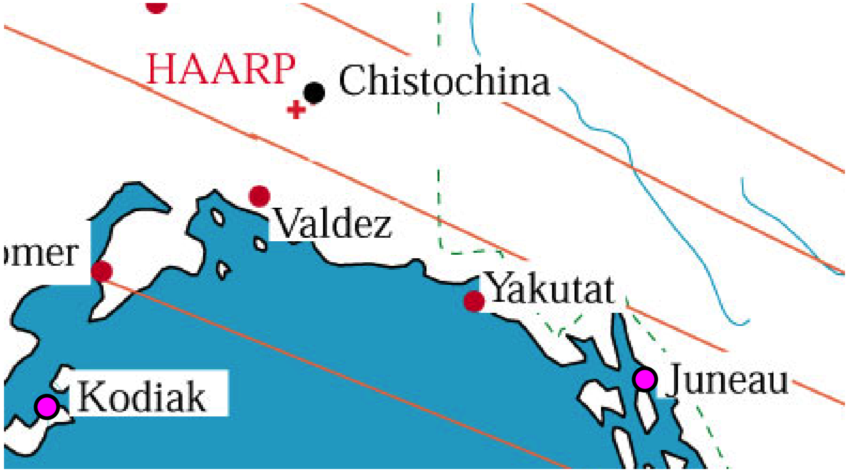




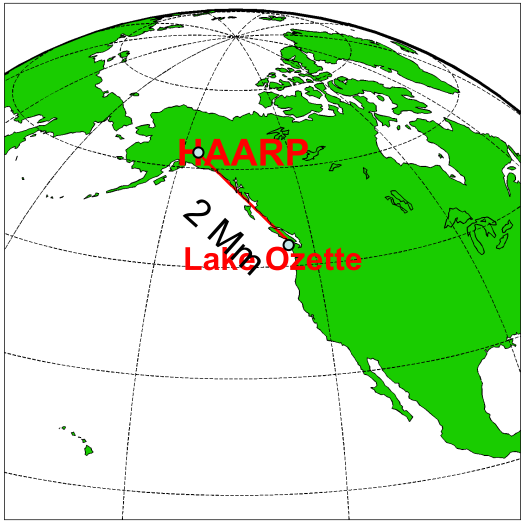
Conditions favoring F-region ULF generation

Experiments

ULF Experiment	Date of Experiment		ULF Measurements		
	Start	End	Onsite	Distant	Satellite
1	Apr. 25, 2006	May 6, 2006	Yes	N/A	DEMETER
2	Apr. 24, 2007	Apr. 30, 2007	Yes	Juneau, AK	DEMETER
3	Jul. 30, 2007	Aug. 2, 2007	Yes	N/A	DEMETER
4	Aug. 20, 2007	Aug. 26, 2007	Yes	N/A	DEMETER
5	Sep. 24, 2007	Sep. 30, 2007	Yes	Kodiak, AK	DEMETER



Measurement Sites

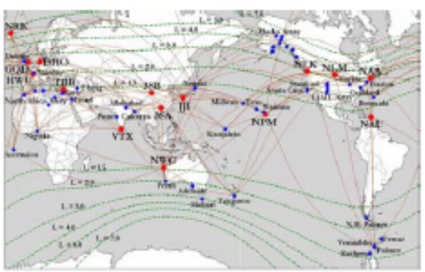


INTEGRATED RESEARCH METHODOLOGY

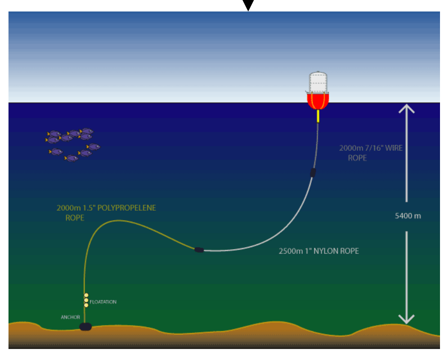
LAPD

HAARP

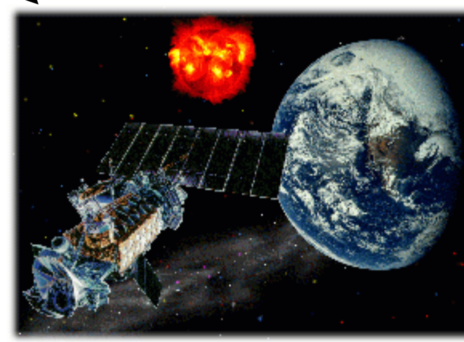
DEMETER



Worldwide SU-Deployed VLF Receiver in support of IHY/UNBSS Program



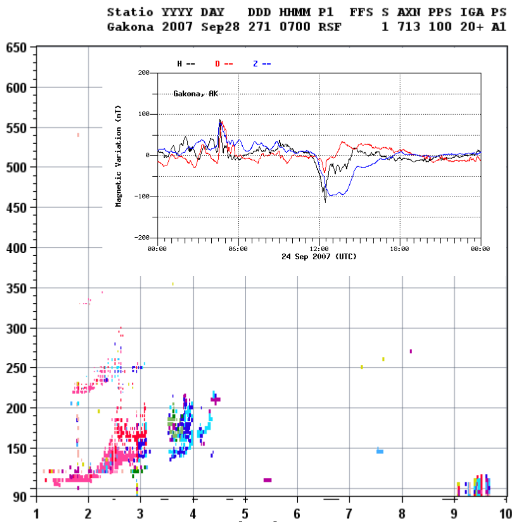
CONJUGATE BUOYS



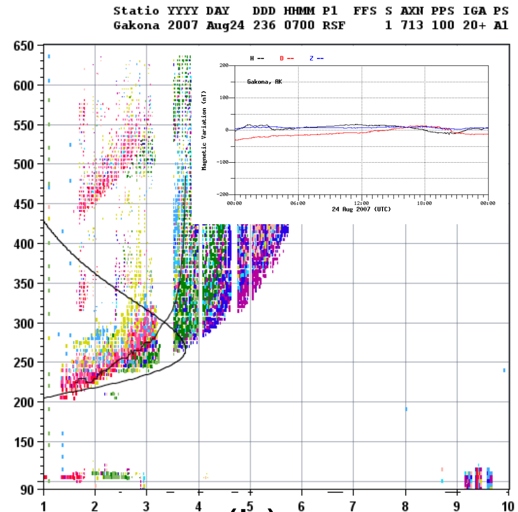
DMSP

WIDE RANGE OF CODES THAT COUPLE TO THE ABOVE EXPERIMENTS

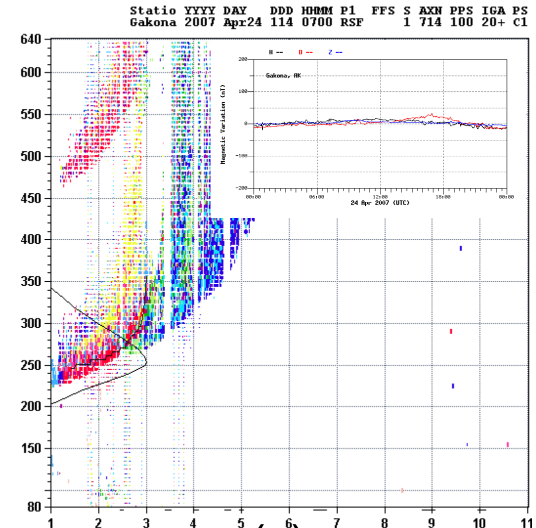
DEMETER DETECTIONS



(a)

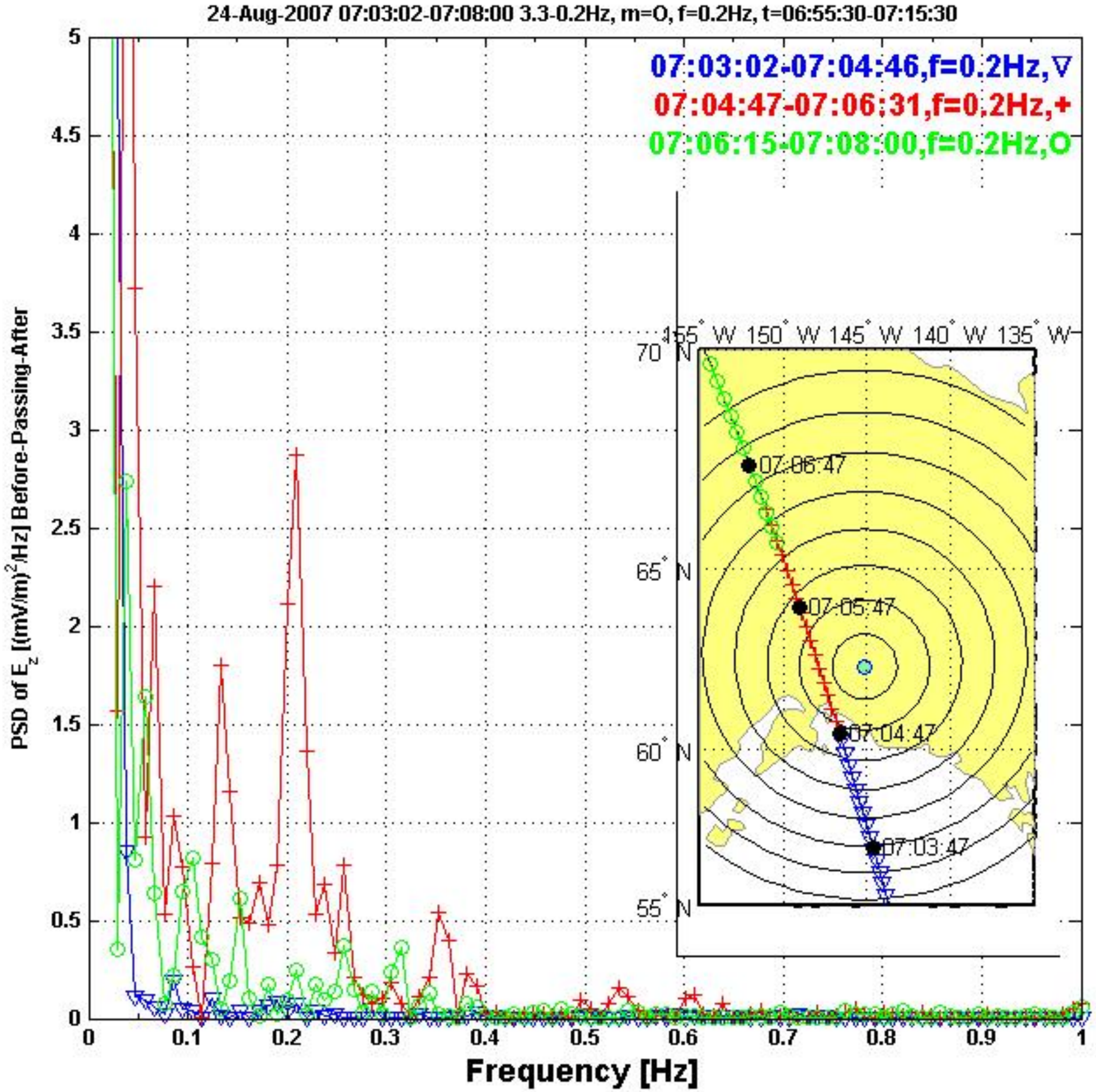


(b)



(c)

Ionogram and Magnetometer (insert) traces for cases #1 (a), #2 (b) and #3 (c) discussed next. Notice the presence of strong electrojets and D region for case #1 and the opposite for cases #2 and #3



August 24, 2008

Closest distance 120 km

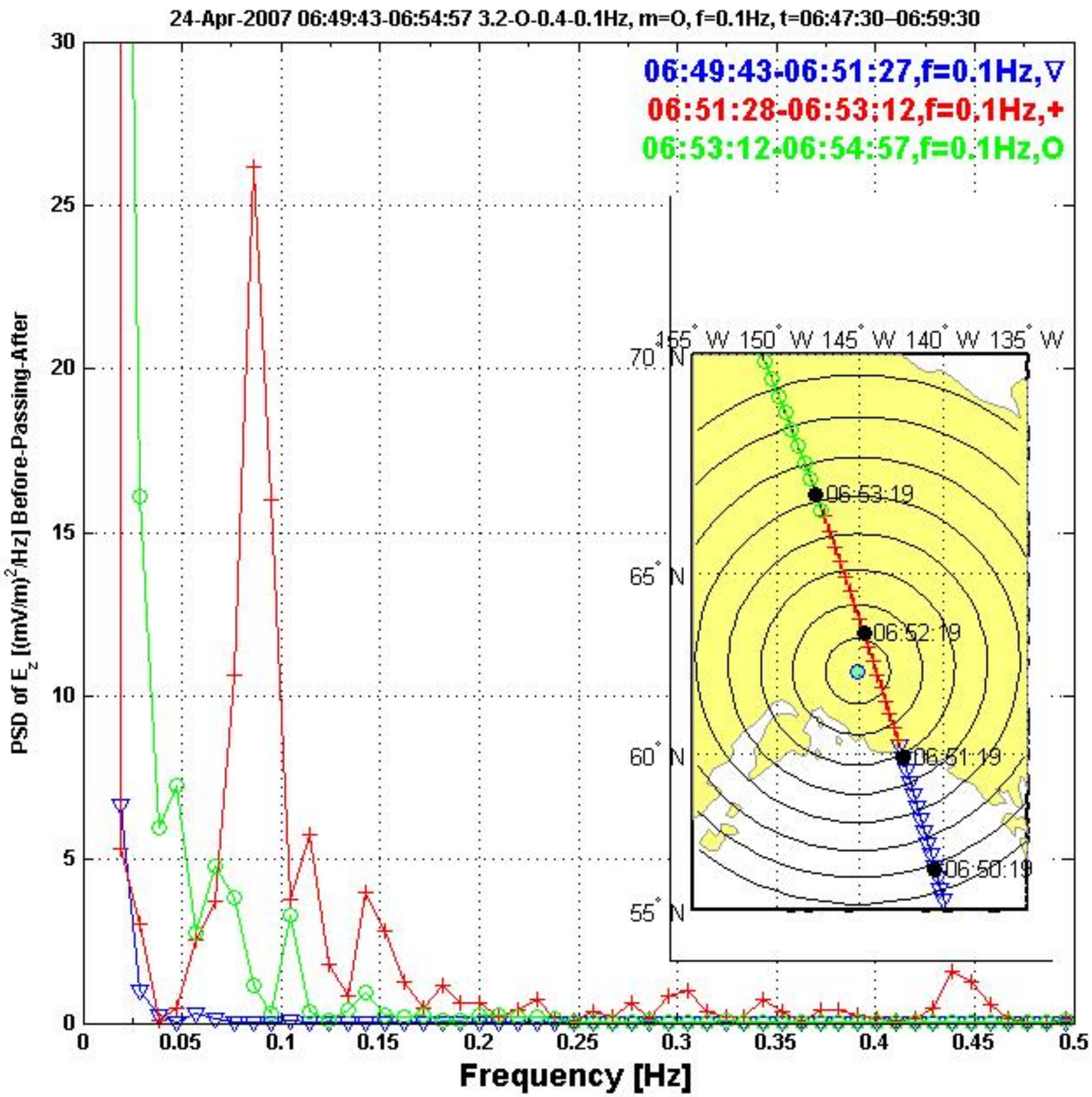
Detection time 110 sec

Detection distance 700-800 km

Maximum E [illegible] .1 mV/m

Estimated power < 1 kW

No field on the ground



APRIL 24, 2008

Closest distance 50 km

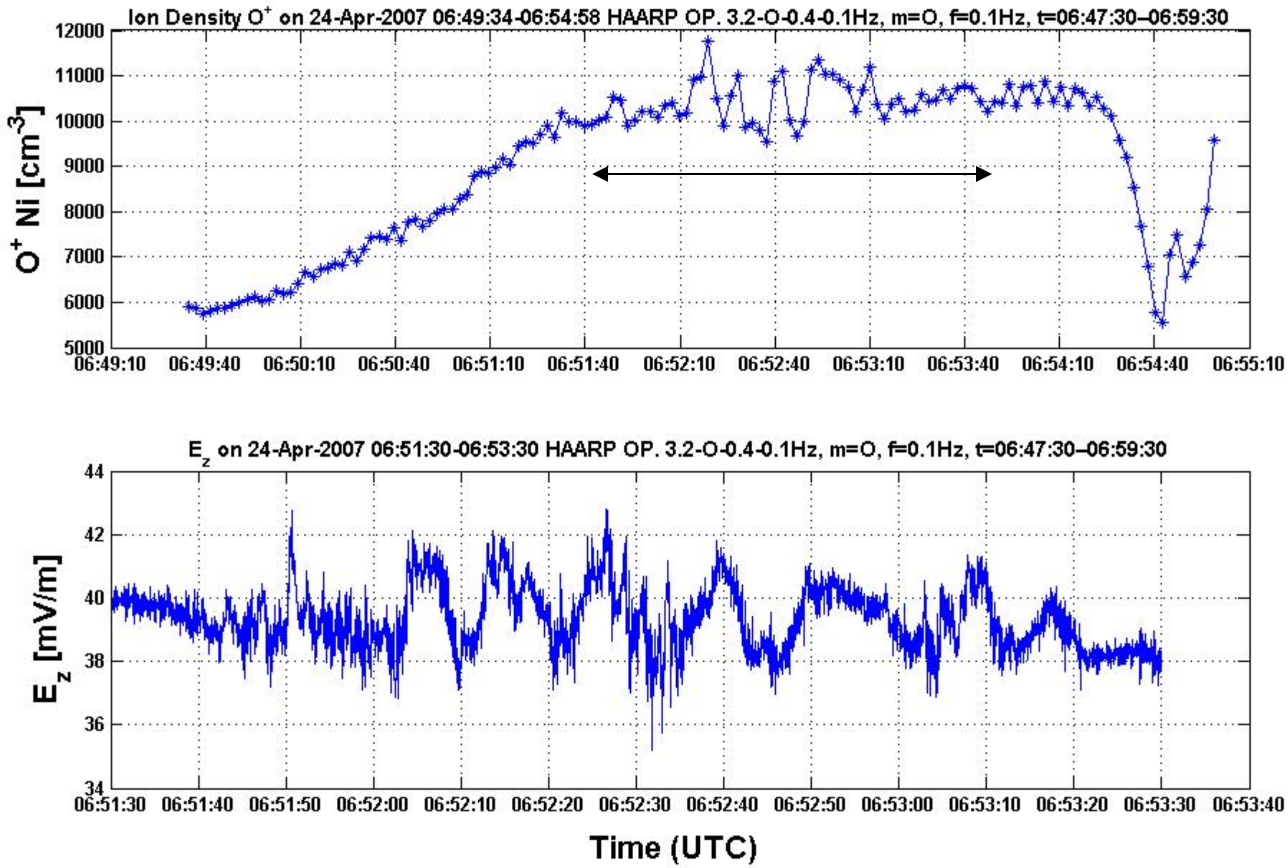
Detection time 120 sec

Detection distance 700-800 km

Maximum E 3 mV/m

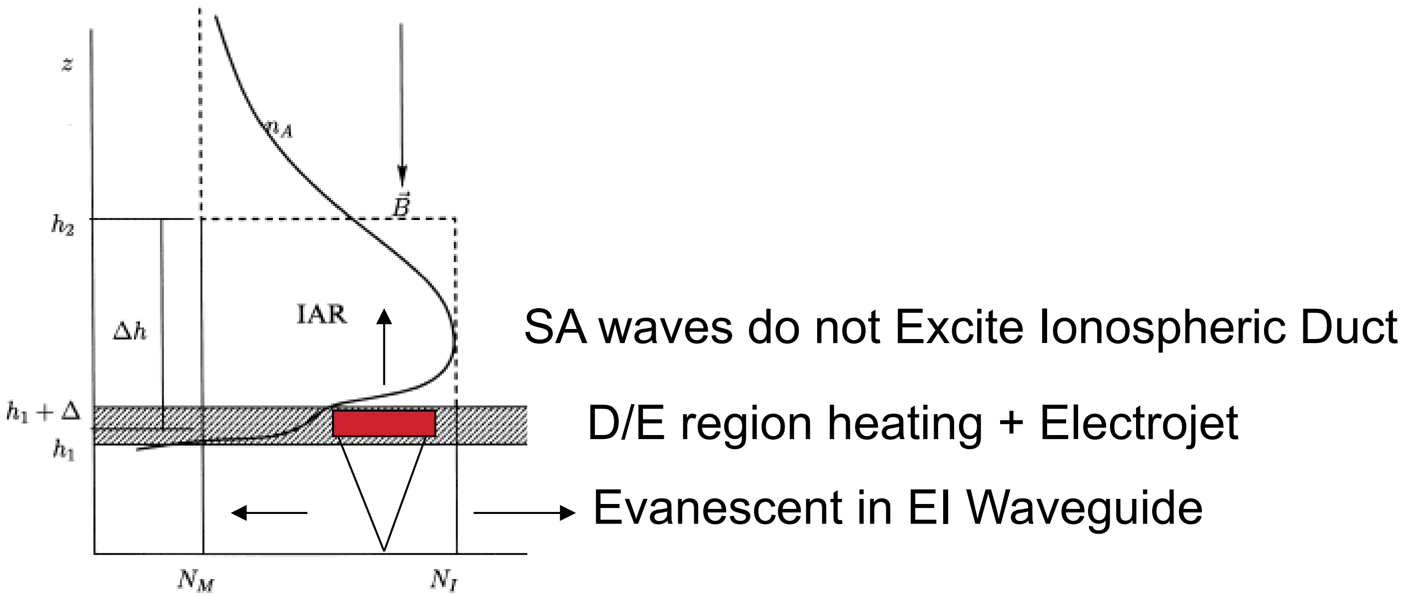
Estimated power ~ 5-10 kW

No field on the ground at Gakona or Juneau



Simultaneous profile of density and electric field fluctuations measured by DEMETER for case #2.

ULF Generation by Ejet Modulation

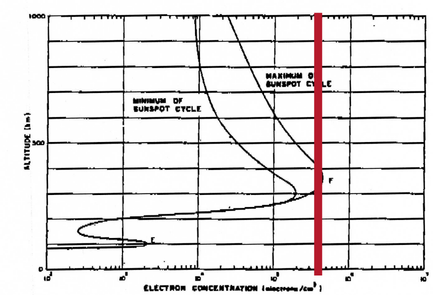


• Ejet modulation cannot drive **b** field parallel to ambient **B**. This type of modulation can create only SA waves. The waves cannot propagate laterally since they are evanescent in the Earth-Ionosphere Waveguide and do not couple to the Alfvenic Duct

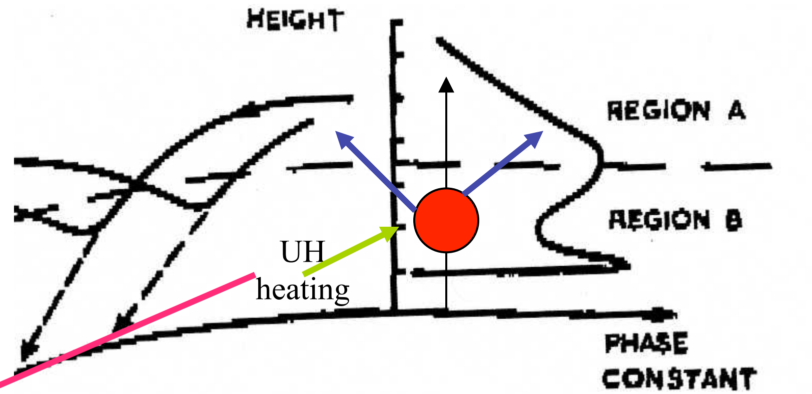
• SA waves can be detected: (a) In the near zone below the heated spot and (b) By satellites over-flying the heated spot but confined to the magnetic flux tube that spans the heated spot.

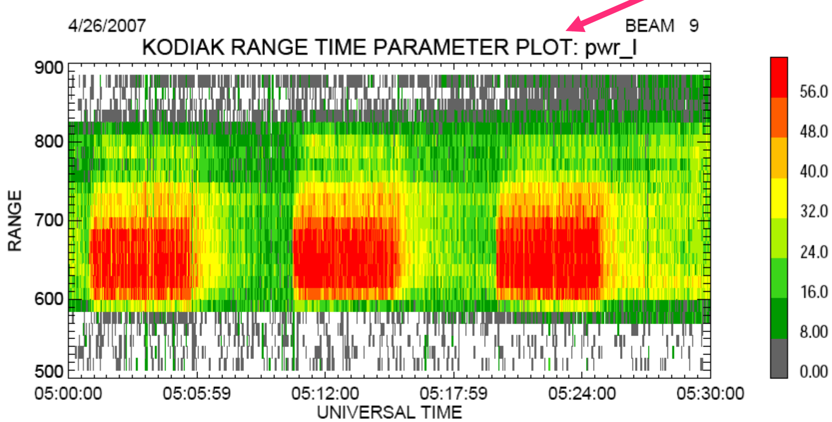
IONOSPHERIC ULF GENERATION

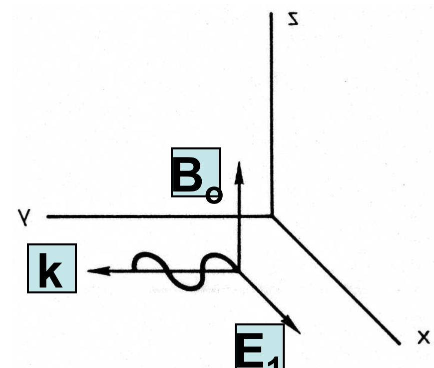
2. **MSONIC WAVE** – REQUIRES F-REGION O-MODE, UPPER HYBRID HEATING; INDEPENDENT OF EJet – WEAK OR NO NEAR FIELD



$$\delta B / B \approx \beta$$







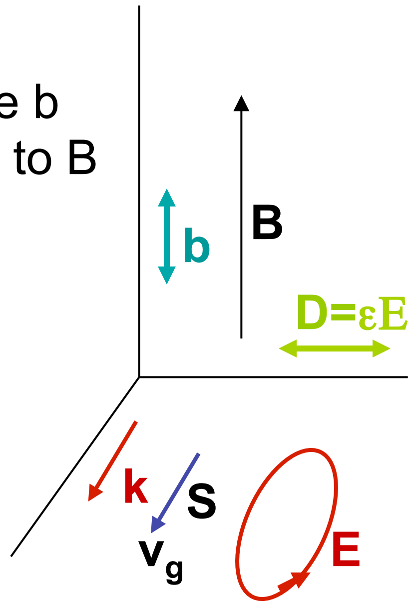
Bill Bristow UAL

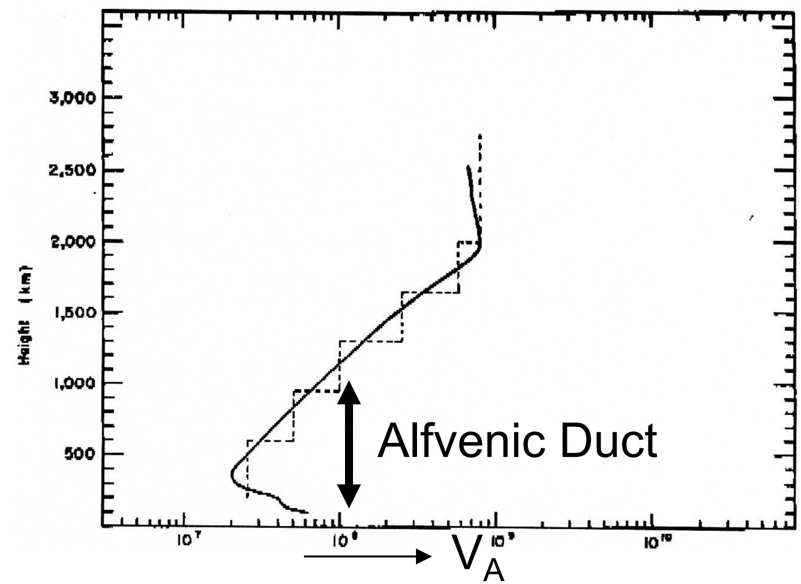
Magnetosonic Alfven Wave (compressional)

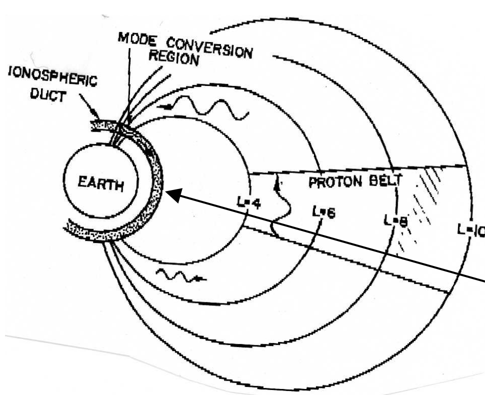
MS (Compressional) Waves
Alfvenic Duct

Isotropic Mode

Notice b parallel to B



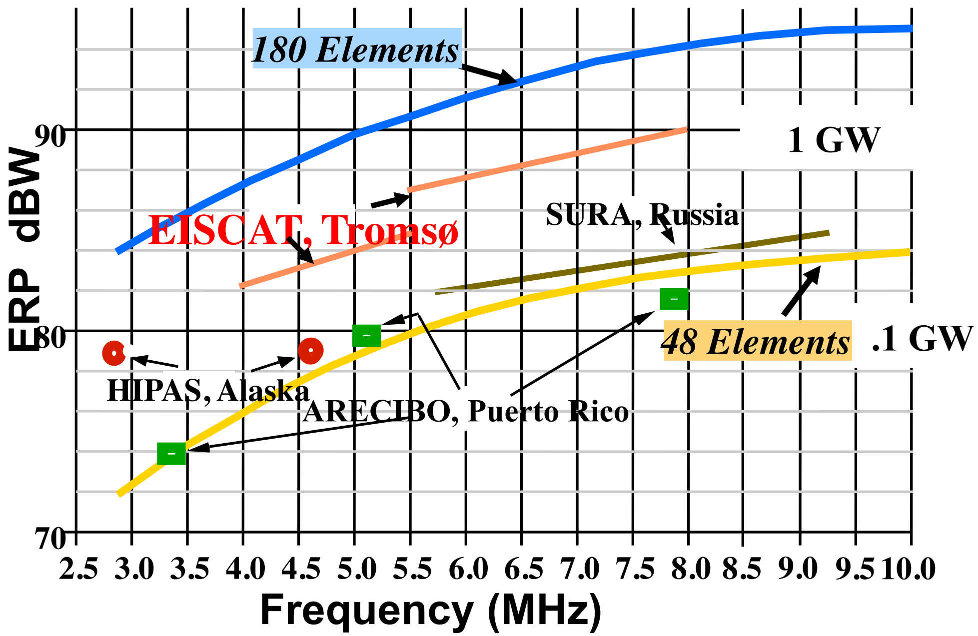




Natural generation and ducting of MS waves

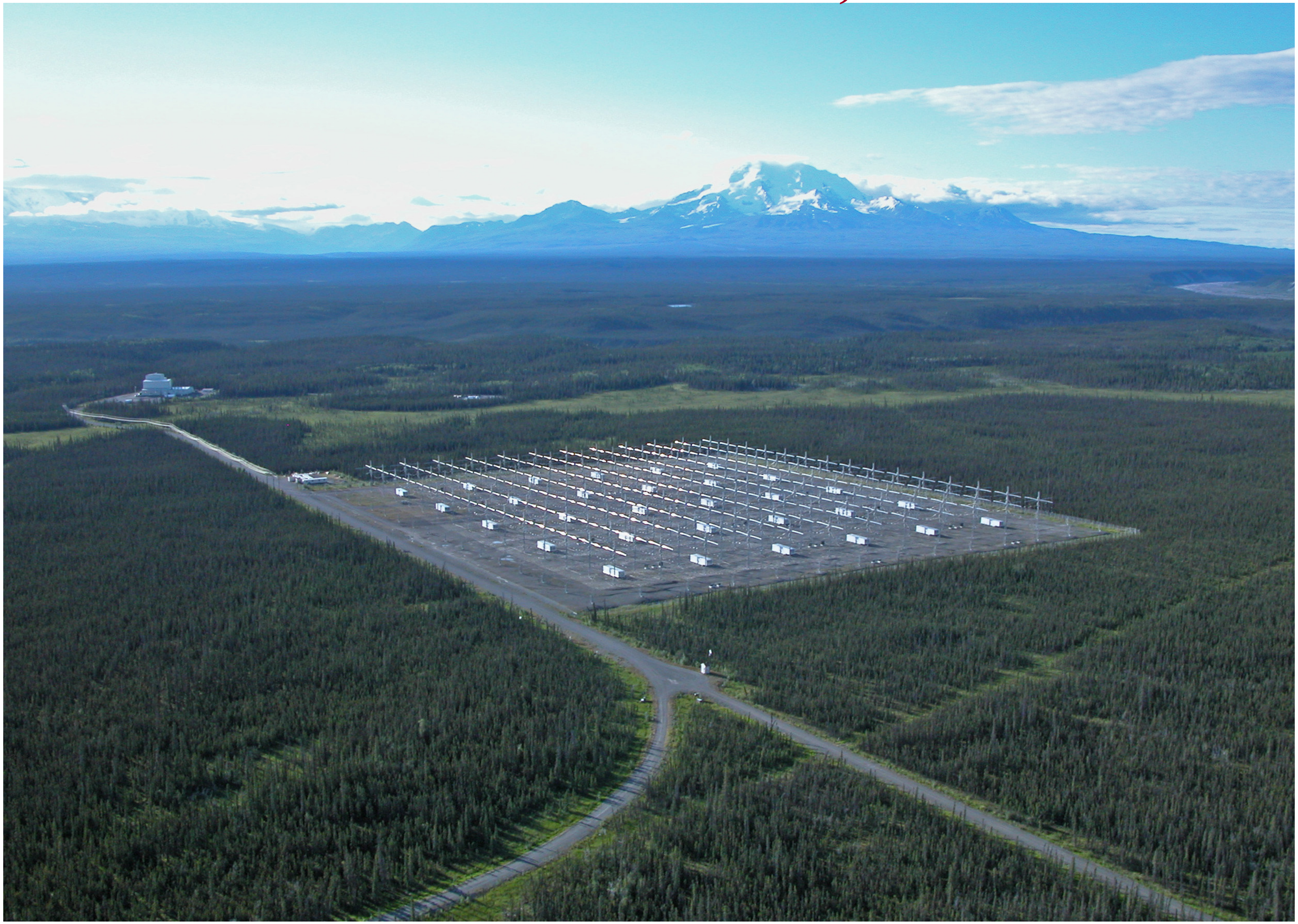
AIC instability drives SA waves

SA waves mode converted at the boundary of duct and propagate laterally as MS waves over large distances



180 Elements
1 GW
SURA, Russia
EISCAT, Tromsø
48 Elements
.1 GW
HIPAS, Alaska
ARECIBO, Puerto Rico
90
80
70
ERP dBW
2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0
Frequency (MHz)

HAARP – JULY 1, 2007



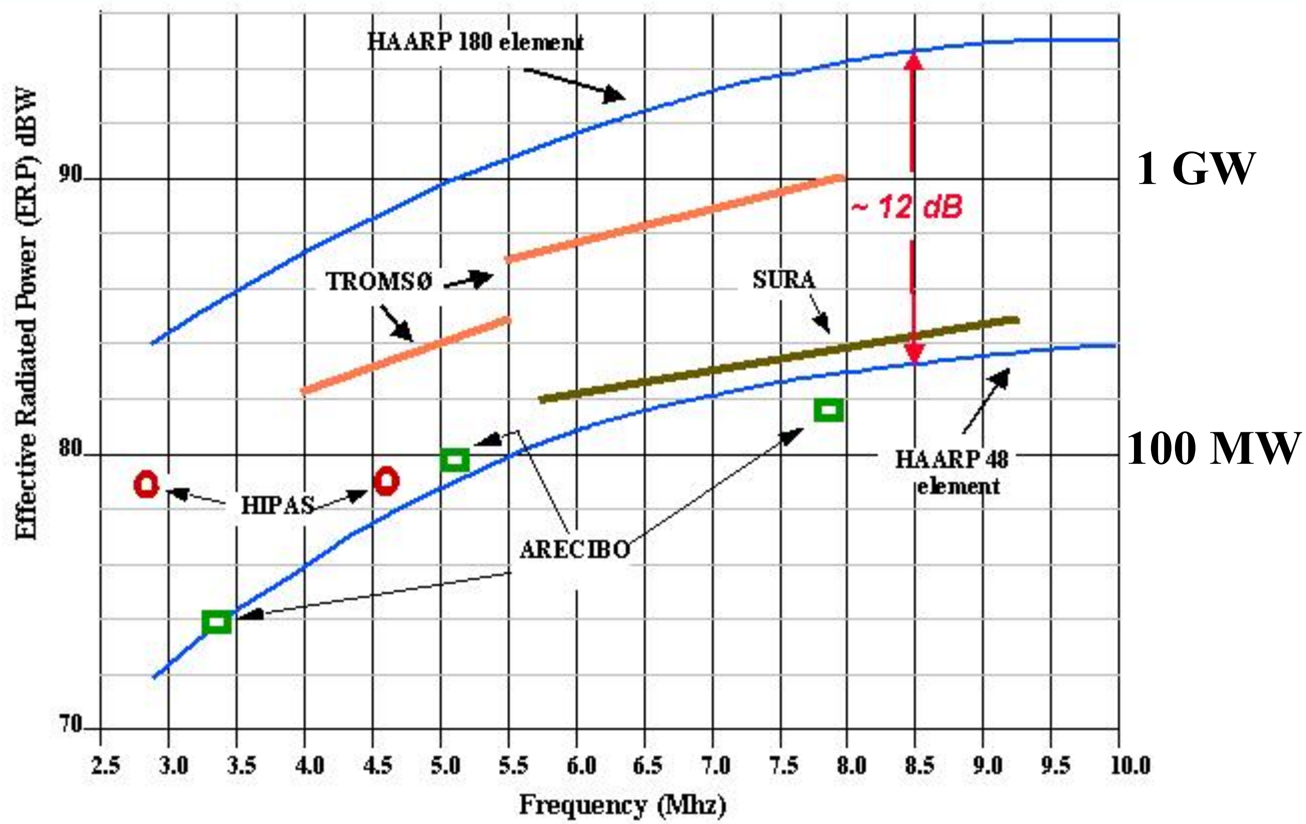
30.6 acres

- 180 Element (12x15) Phased Array
- 360 Nested Crossed Dipoles
  - Low Band Dipole - 2.8 to 8.4 MHz
  - High Band Dipole - 7to 10 MHz
- 3.6 MW Radiated from 360 10 kW Transmitters
- Instantaneous Bandwidth
  - 200 kHz (2.8 MHZ)
  - 500 kHz (10 MHz)
- ERP 84 to 95 dBW
- Beam width
  - 20°x16° (2.8 MHz)
  - 5.7°x4.5° (10 MHz)

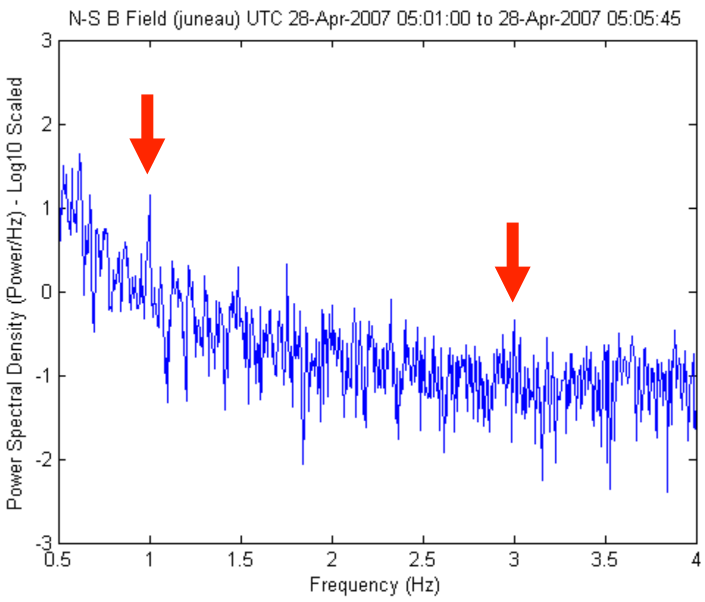
- Beam can be Slued 30° off Zenith in any Azimuth 2.8 to 8 MHz (15° at 10 MHz)
- Rapid Scanning of +/- 15°
- FM, AM and Pulse Modulation to 30 kHz
- Dual Frequency Operation (Split Array)
- Linear, Left and Right Circular Polarization

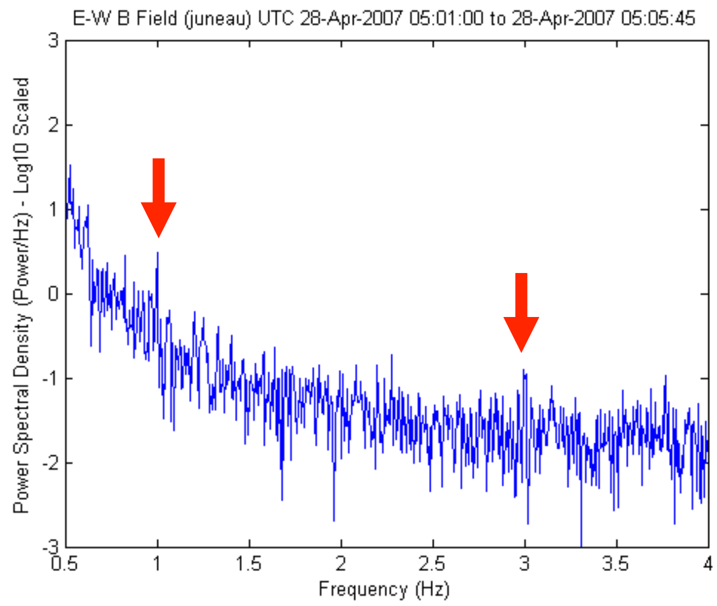
Diagnostics: Riometer, Ionosonde, Magnetometers, Optics, VHF and UHF radars, ELF/VLF/ULF receivers, HF to UHF Spectrum Monitor, etc

THRESHOLDS - ERP- QUIVER ENERGY



ULF Signals at Juneau





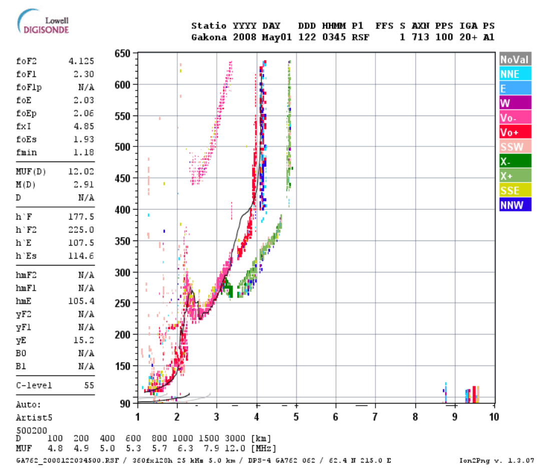
- 28 April, 2007 UTC 05:01:00 – 05:05:45
- Detected 1 Hz & 3 Hz peaks
- Amplitudes at 1 Hz: 0.28 pT NS; 0.23 pT EW

$$b \sim 1/R^2$$

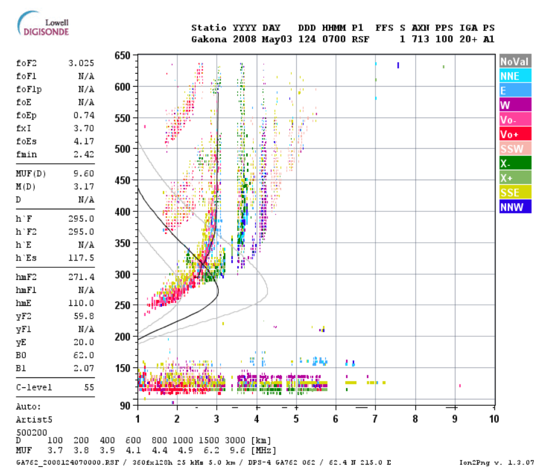
EVANESCENT

HF Heating & Ionospheric Profile

- HF heating (max. mod. at F peak)
  - 3.6 MW along local B
  - O mode first, X mode secondary
  - Mainly at 3.3 MHz
    - 2.83 MHz: last hour of 5/4/2008
- Typical ionospheric condition
  - Weak F (foF2 < 4 MHz) for Alfven
    - Solar min.
- Two cases of diff. cond. at Gakona
  - <u>Example 1</u>: Enhanced F with D&E
    - With Ejet, D/E & F mod.
    - 20 Hz at Gakona & Ozette
  - <u>Example 2</u>: Weak F with Sporadic E
    - No Ejet, E layer mod.
    - 20 Hz at Ozette, not Gakona



Example 1



Example 2