Ionospheric ELF/ULF Generation Without Needing Electrojets

Dennis Papadopoulos[1,2]

C.L. Chang[2], T. Wallace[2], I. Doxas[2]

B. Eliasson[1]

University of Maryland[1]

BAE Systems-AT[2]

Invited Presentation

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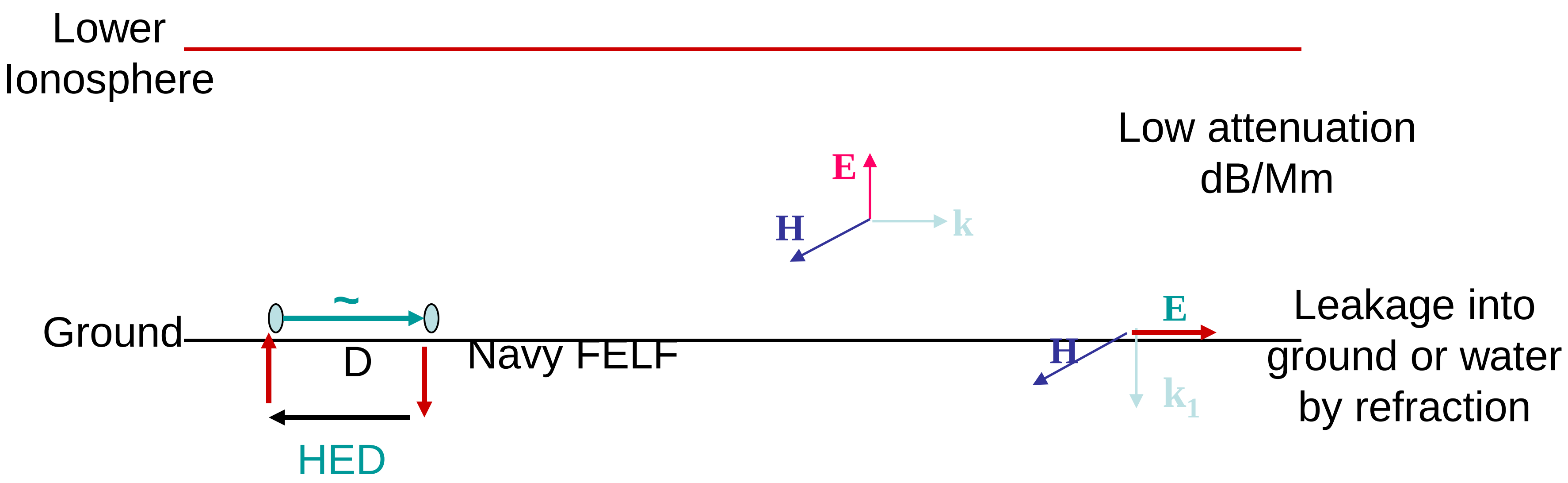
April 21, 2009

ELF/ULF – GROUND TRANSMITTER ISSUES

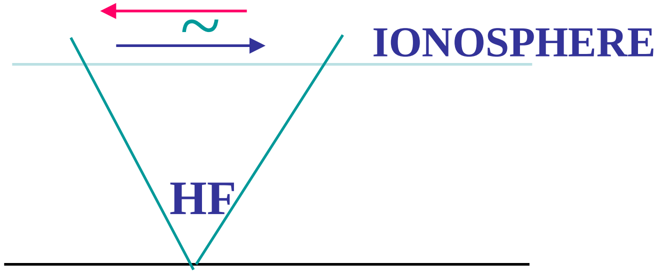
- **Why: Penetrate deep into the ground and seawater**
  Couple to the earth-ionosphere waveguide and propagate with small attenuation

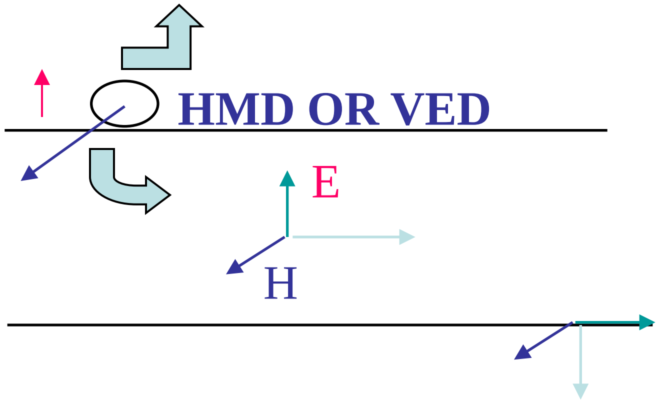


Problems : Low Efficiency Coupling $(D/\lambda)^2$; No tunability ; Limited Bandwidth

Cannot use VED

ALTERNATIVE IONOSPHERIC GENERATION –circa 1973





- **HF-PLASMA CURRENT DRIVE - USE ABSORPTION OF MODULATED HF POWER IN THE IONOSPHERE TO DRIVE LOW FREQUENCY AC CURRENTS IN THE IONOSPHERE**
- **EARLY (1973-1975) CONCEPT- PONDEROMOTIVE FORCE CURRENT DRIVE**
- **THRESHOLD - EITHER VERY OBLIQUE HEATERS OR TOO MUCH POWER**
- **ALTERNATIVE (1974) – MODULATE EJET CONDUCTIVITY**

- **PEJ ANTENNA DEMONSTRATED IN SURA, TROMSO, HIPAS, HAARP**

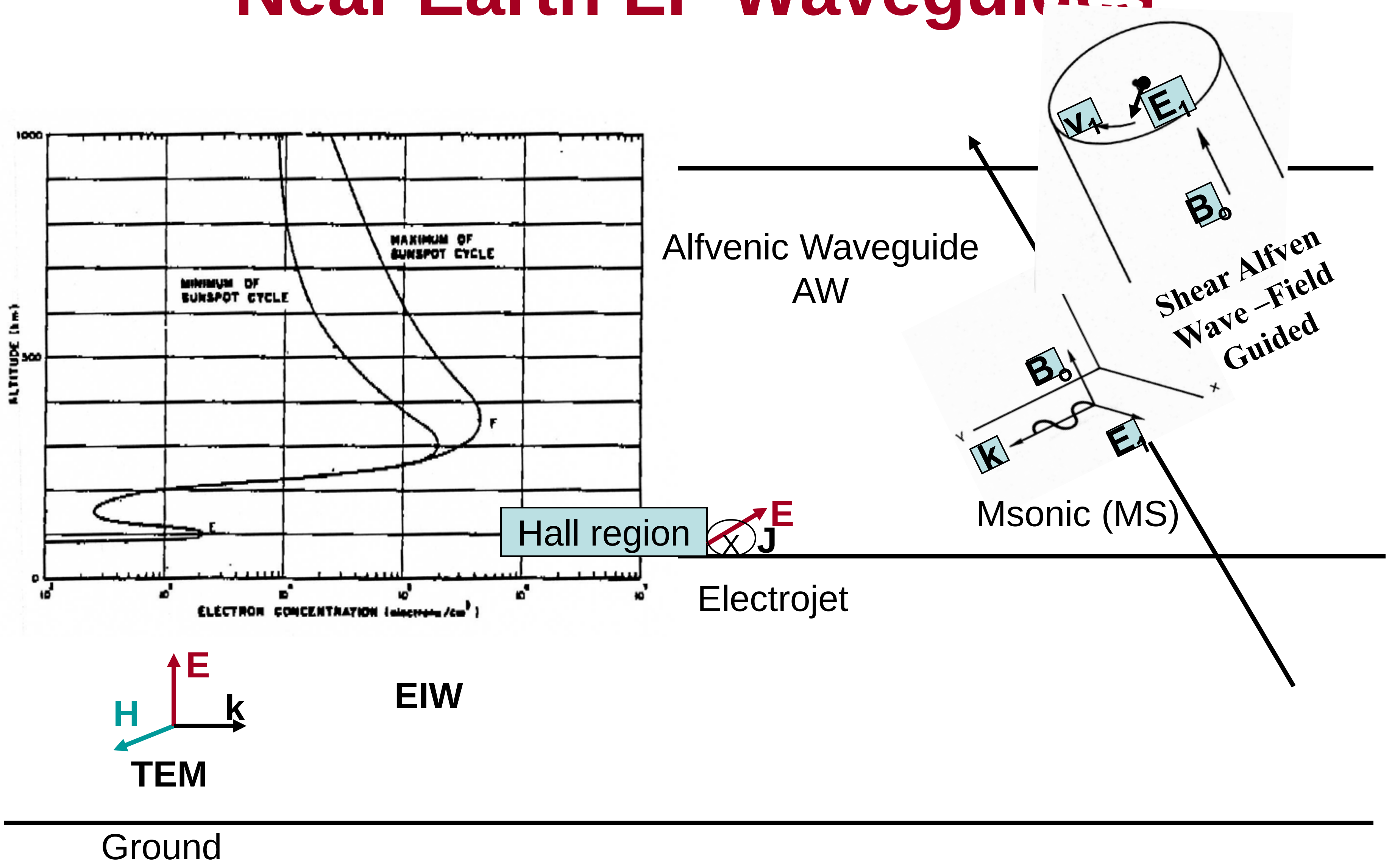
PEJ ANTENNA DRAWBACKS – **EJET AVAILABILITY , HEATER LOCATION, NEED FOR LONG PROPAGATION**

LOW FREQUENCY CURRENT DRIVE

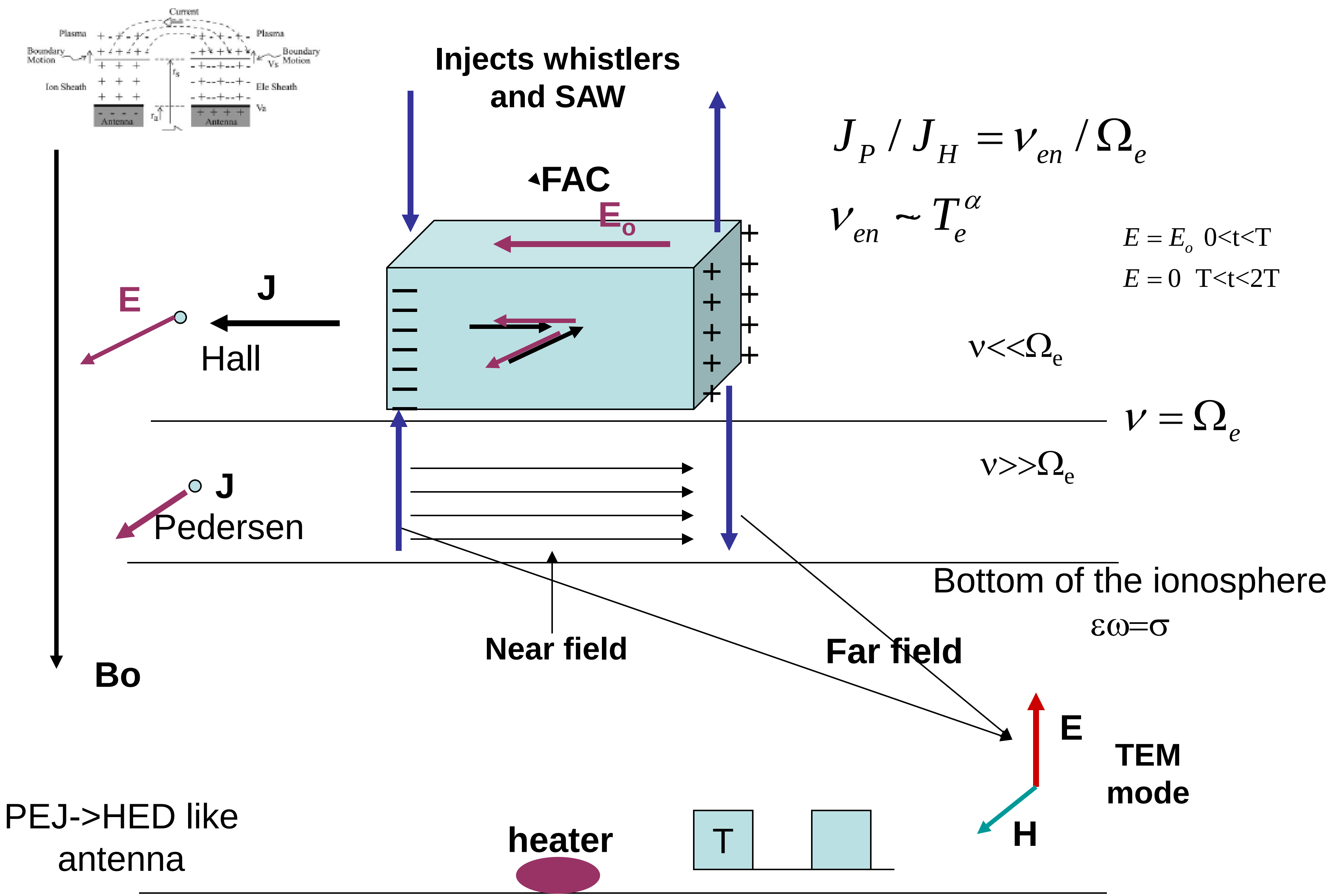
A REALITY

- THEORY AND HAARP EXPERIMENTS CONFIRMING GENERATION AND PROPAGATION OF LOW FREQUENCY WAVES (.1-20 Hz) BY COLLISIONLESS IONOSPHERIC CURRENT DRIVE
  - FUTURE TESTS AND CONCEPTS TO DETERMINE THE UPPER FREQUENCY
  - POSSIBLE TESTS IN ARECIBO (WHEN ?)
- THEORY AND SIMULATIONS OF NOVEL CONCEPT OF CURRENT DRIVE BY CONVENTIONAL HED
  - ARTIFICIALLY CONSTRUCTED ELECTROJET (ACE)
  - PULSED ARTIFICIALLY CONSTRUCTED ELECTROJET (PACE)

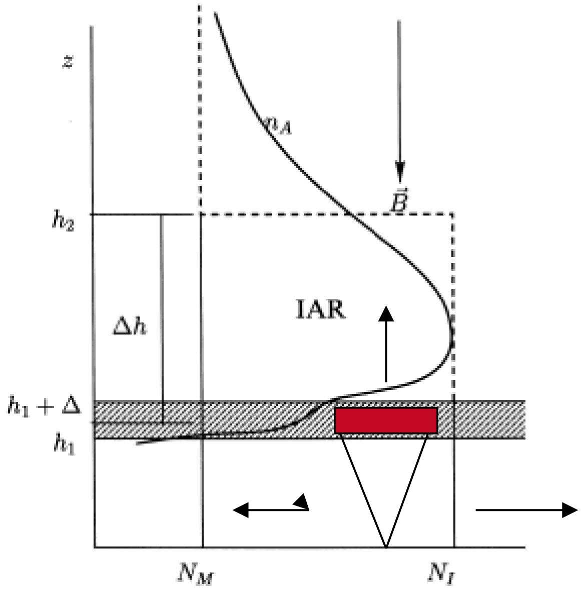
Near Earth LF Waveguides

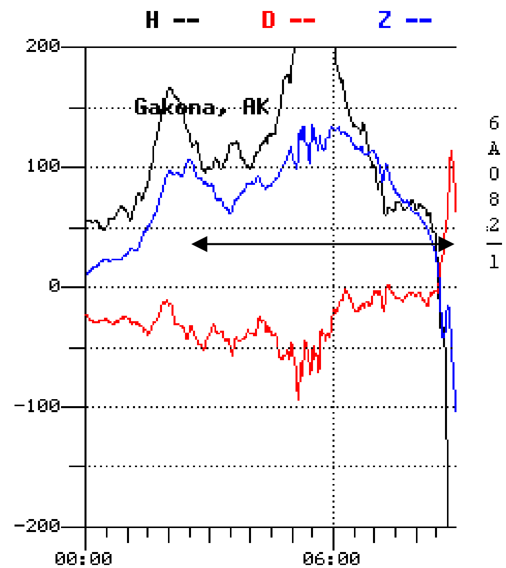


The Plasma Physics of the PEJ

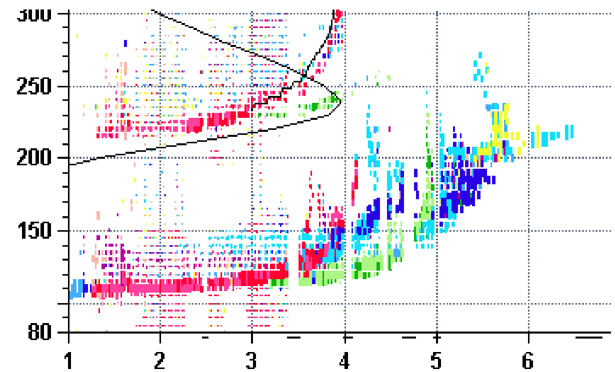


PEJ ELF/ULF Generation Tests

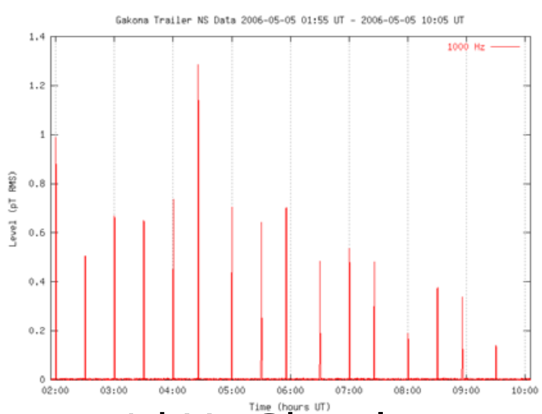




Magnetometer



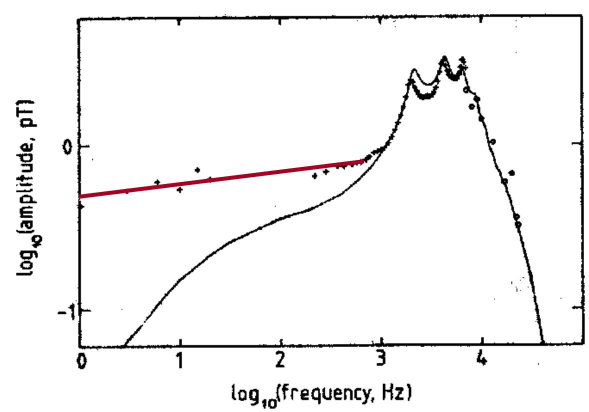
Ionosonde



1 kHz Signals

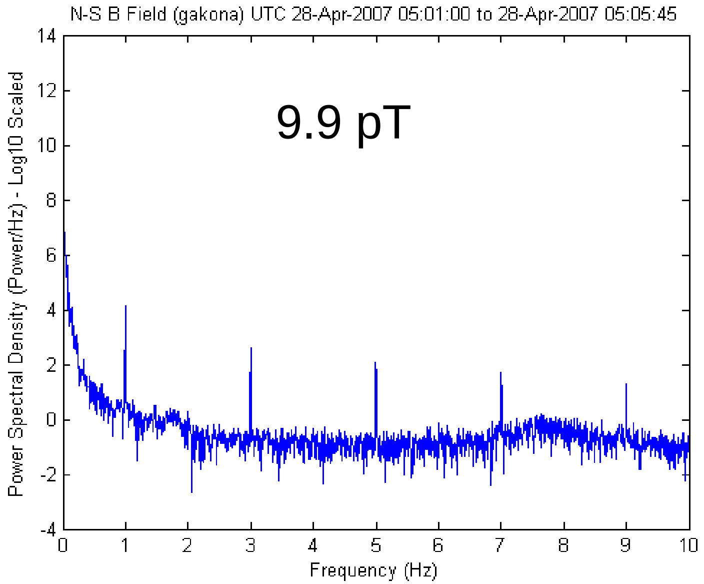
Marker of PEJ generation

$$B(F < 1kHz) / B(1kHz) \approx 1$$

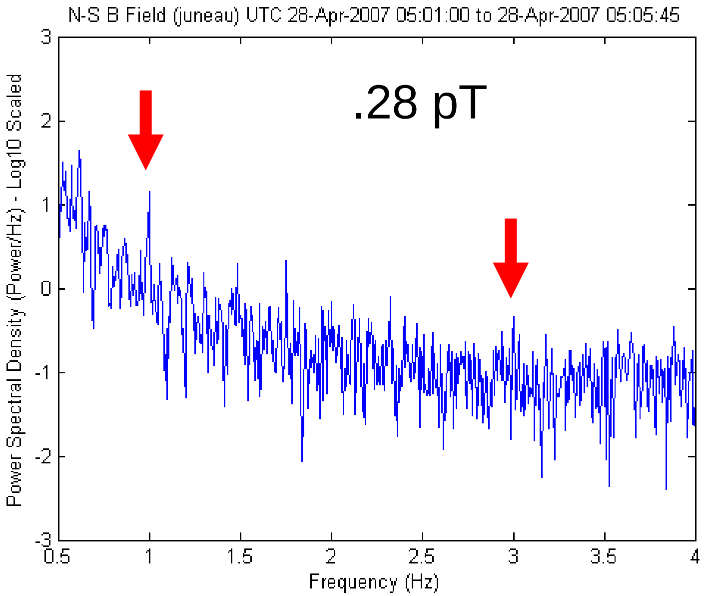


PEJ ULF Signal Propagation Evanescent Mode (1 Hz)

Gakona

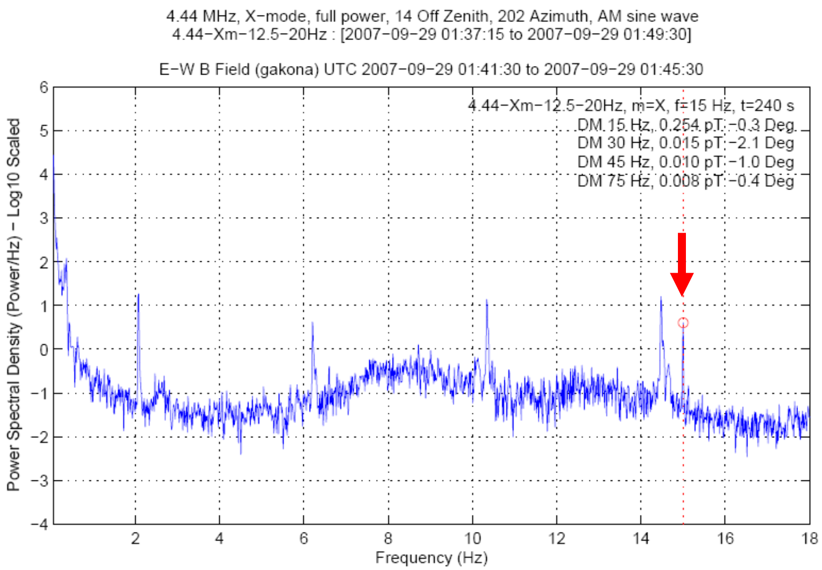


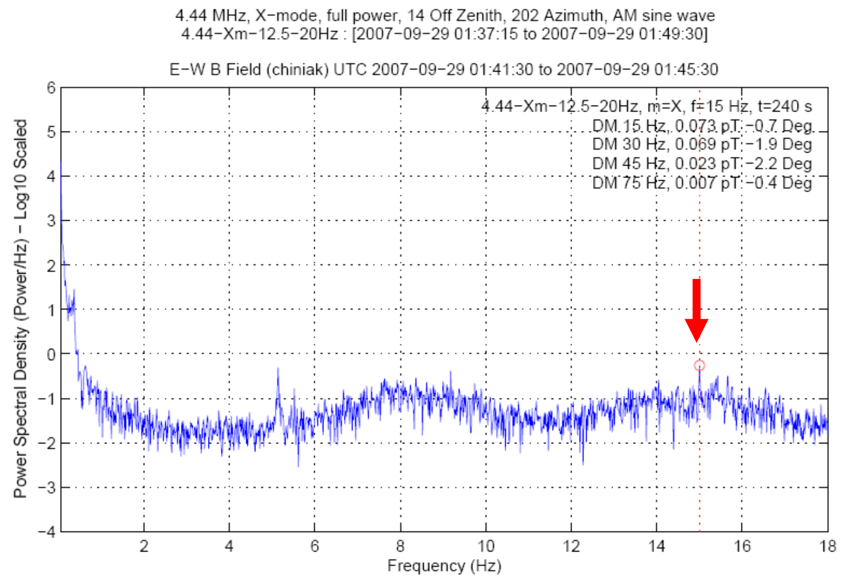
Juneau – 800 km



- 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 at Juneau – (30 dB loss)
- $B \sim 1/R^2$ wave evanescent (frequencies below few Hz)

PEJ ULF Signal Propagation Propagating Mode (15 Hz)





Gakona **Chiniak – 670 km**

Clear 15 Hz peak can be seen at both sites

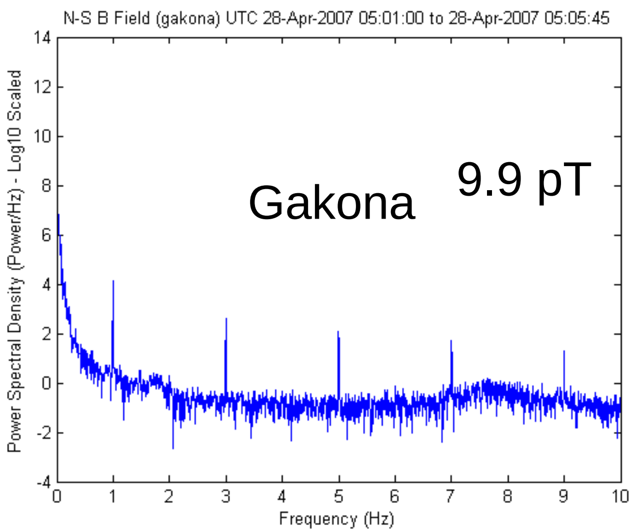
EW Amplitudes:

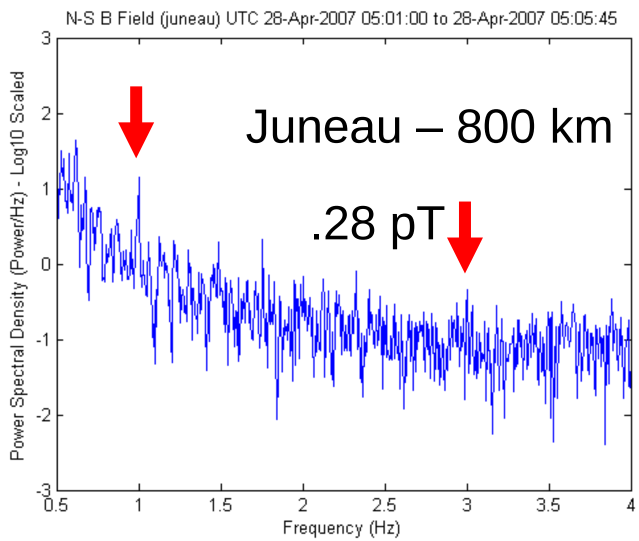
Gakona: 0.25 pT

Chiniak: 0.07 pT

Propagating mode
3 dB attenuation

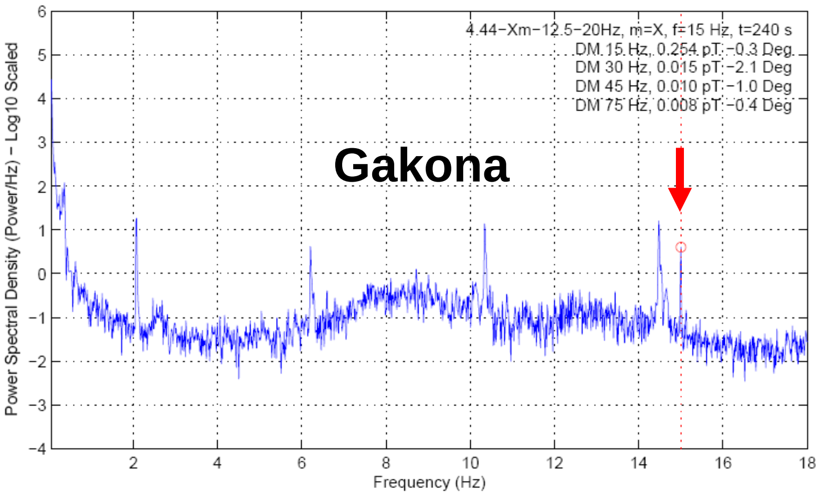
PEJ ULF Evanescent vs. Propagating Modes

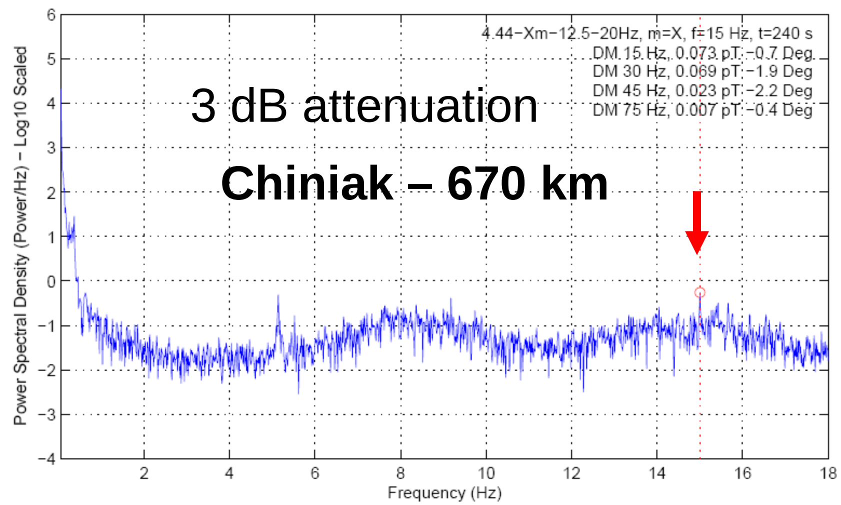




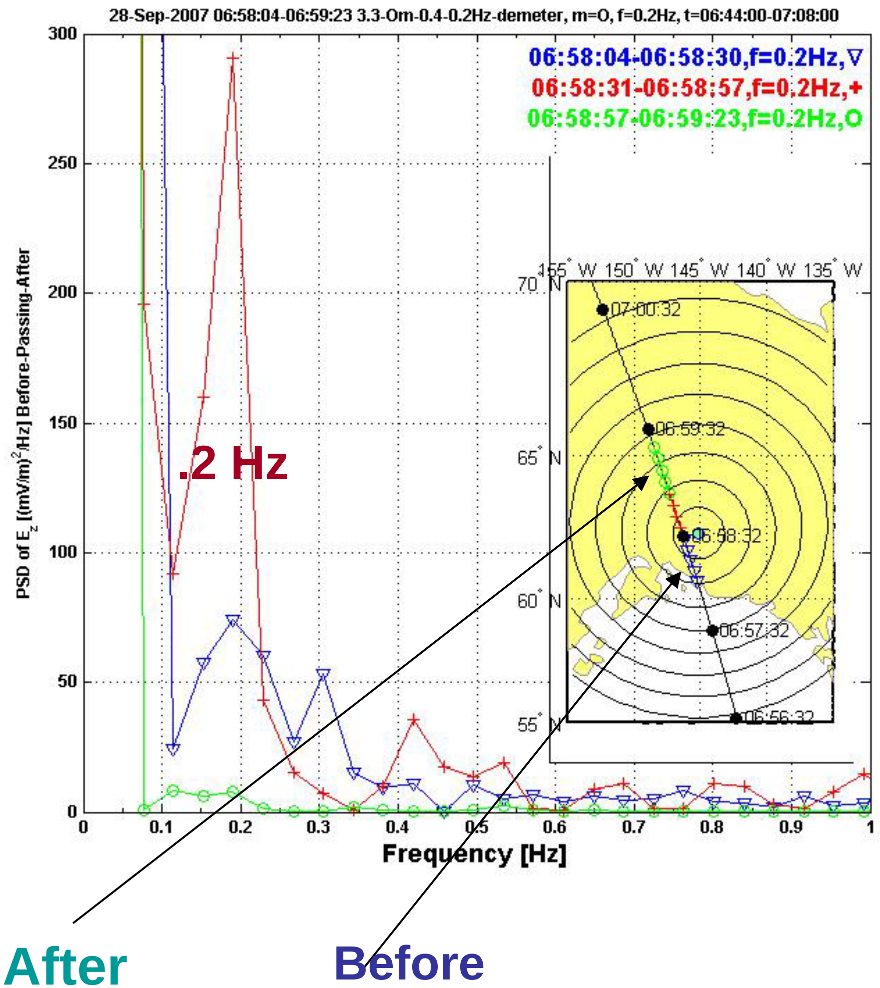
30 dB attenuation

$1/R^2$ Evanescent





SAW DEMETER Detection



Frequency .2 Hz

Closest distance 80 km

Detection time 25 sec

Detection distance 150 km

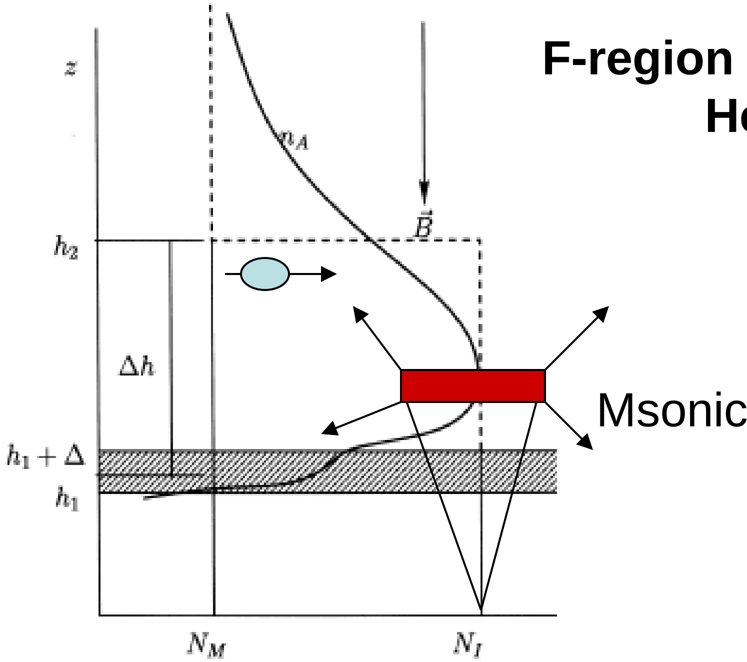
Maximum E □10 mV/m

Estimated power ~ kW

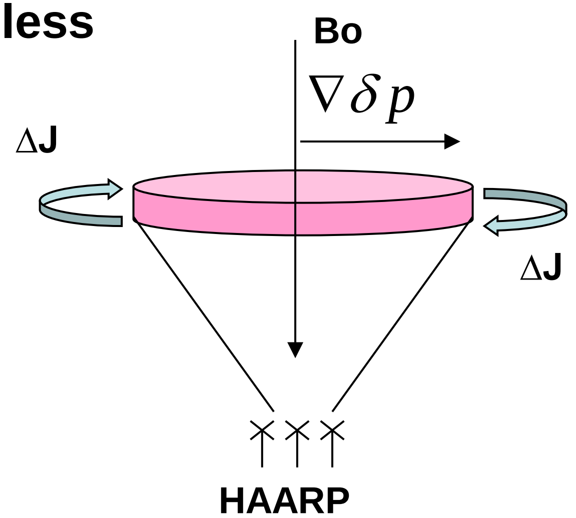
1.5 pT on the ground

SEPTEMBER 28, 2008

Ionospheric Current Drive (ICD)



F-region Collisionless Heating



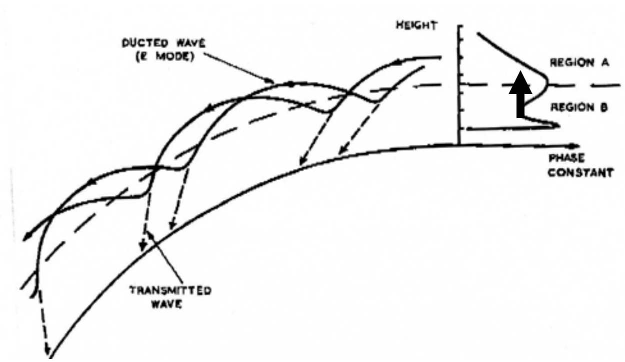
ICD Drives a Magnetic Loop – FAMD

Diamagnetic current

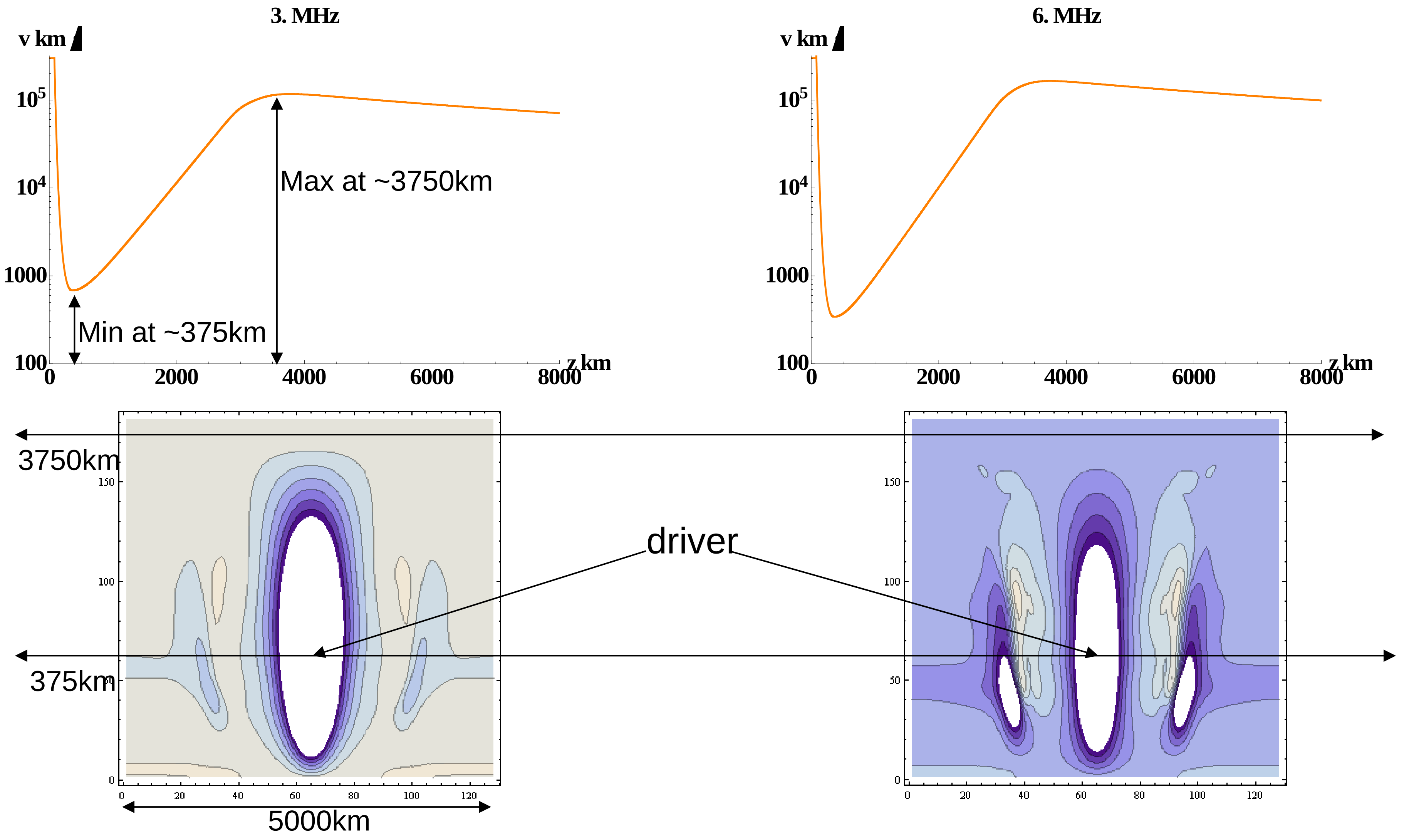
$$\Delta \vec{J} = \frac{\vec{B} \times \nabla \delta p}{B^2} \exp(i\omega t)$$

$$\vec{M} = \hat{b}(\Delta J L)\pi R^2$$

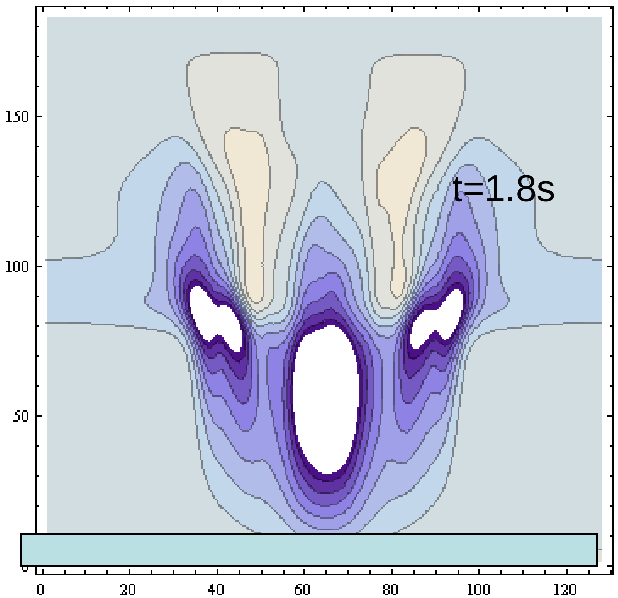
$$\vec{M} \approx \hat{b}(Volume)\Delta J \exp(i\omega t) \approx \hat{b} M_o \exp(i\omega t)$$



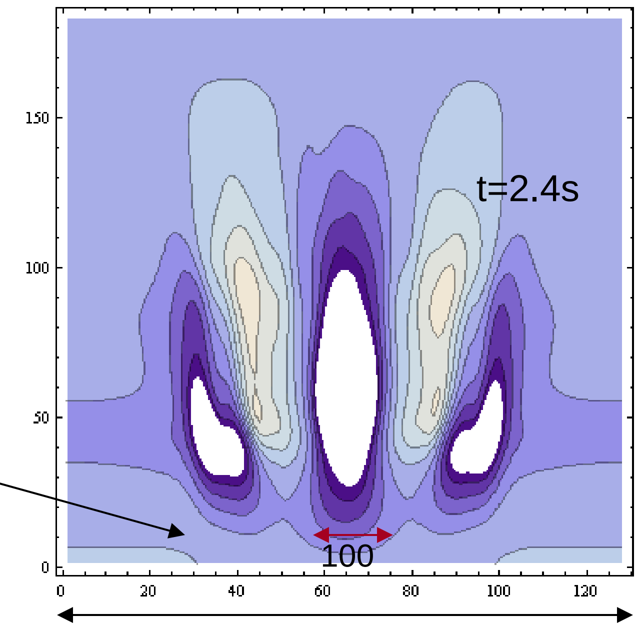
Weak F-Layer (FoF2 <~ 4.0 MHz) Results in Weaker Waves

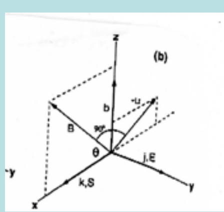


Propagation and Penetration to Ground

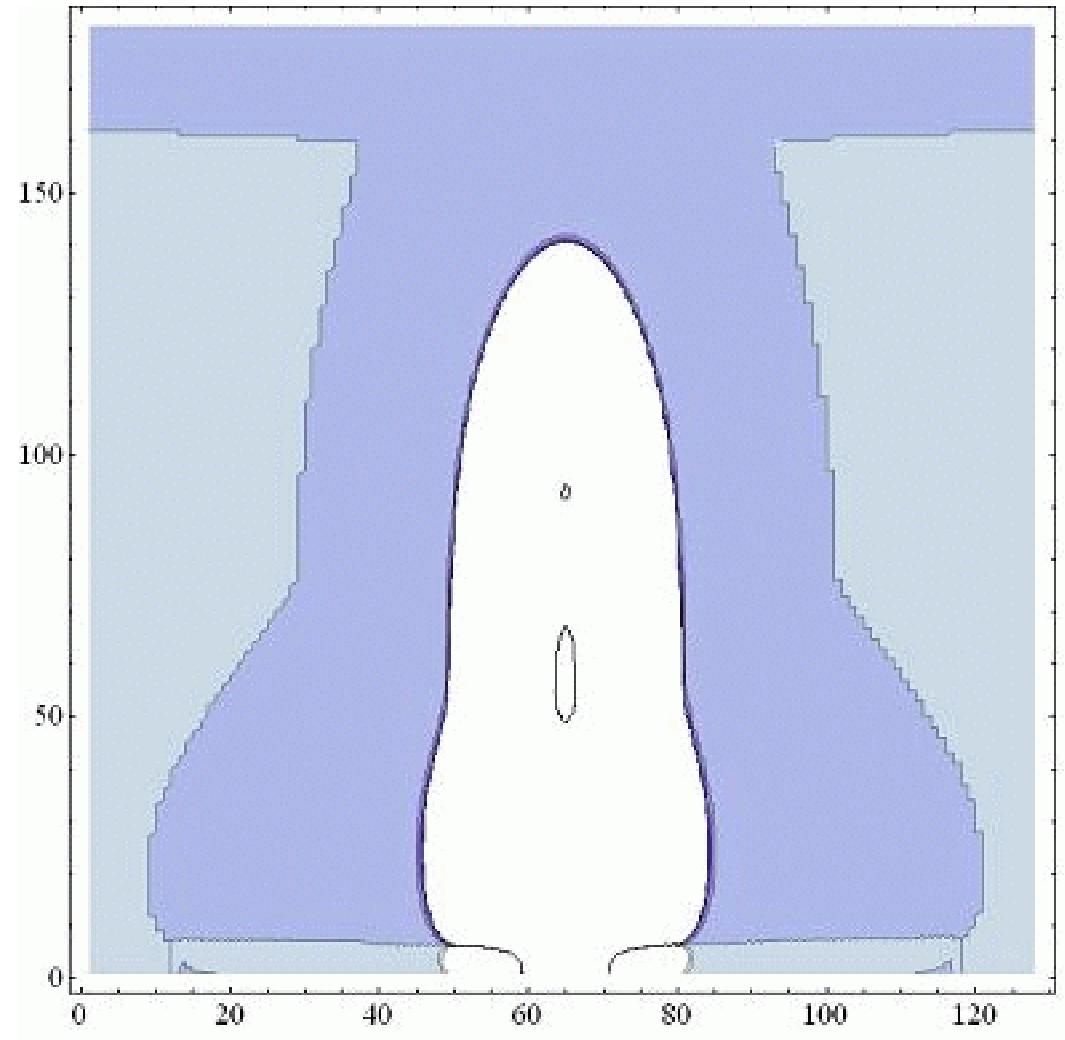


D/E region

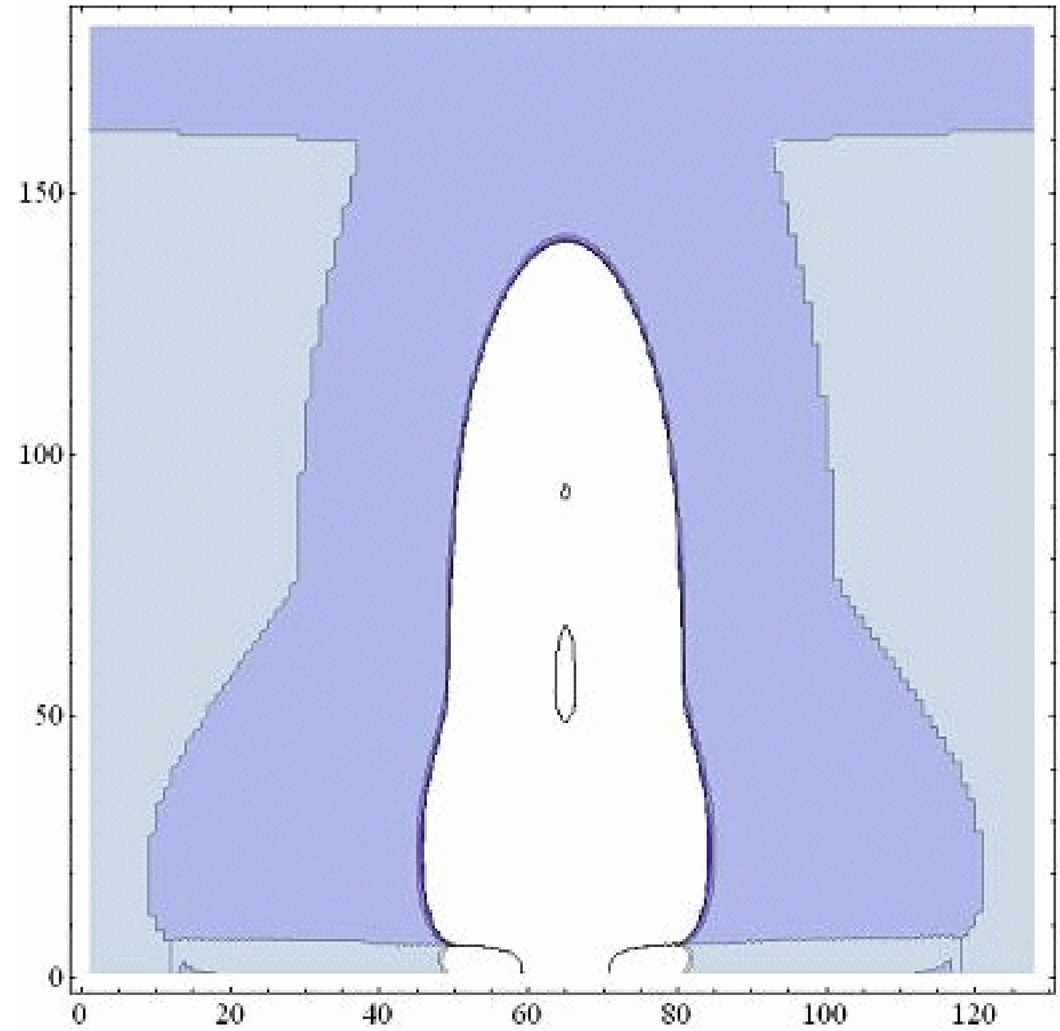




- Msonic wave imposes an oscillatory E field in the Hall region.
- It drives a Pedersen and a Hall current
- The Hall current generates B-field on the ground as well as injecting into the EI waveguide (Ejet like current)



150
100
50
0
0
20
40
60
80
100
120

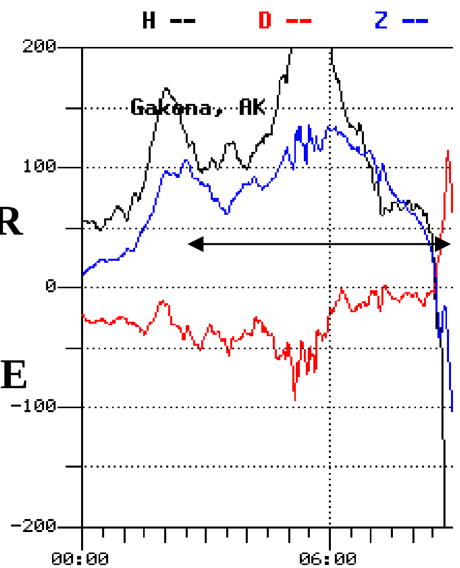

150
100
50
0
0
20
40
60
80
100
120

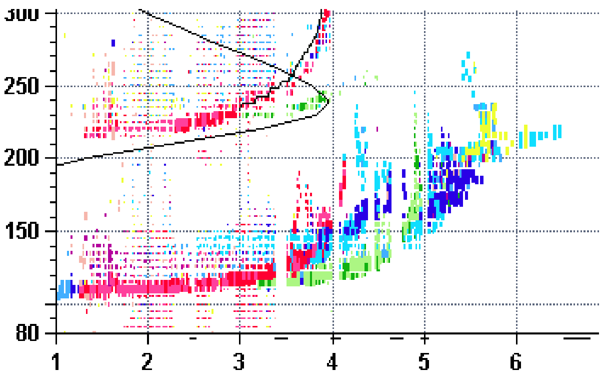
Optimal Conditions for ICD vs. PEJ

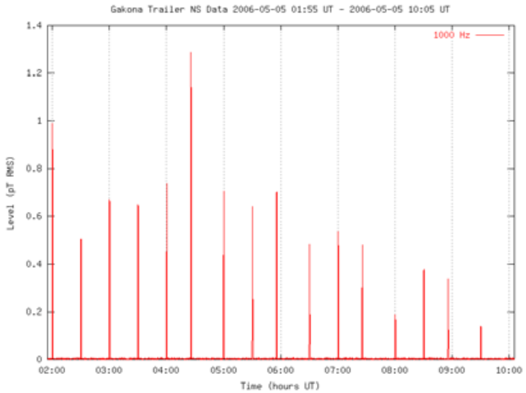
NEAR

X

MODE



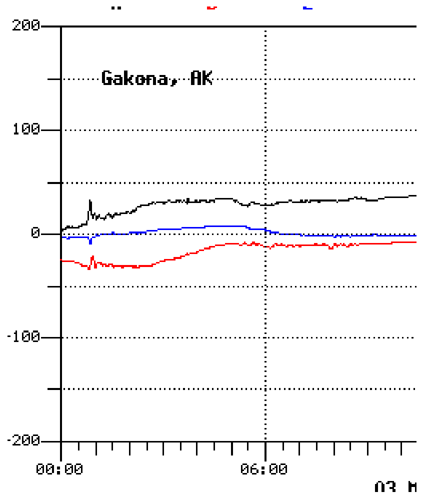


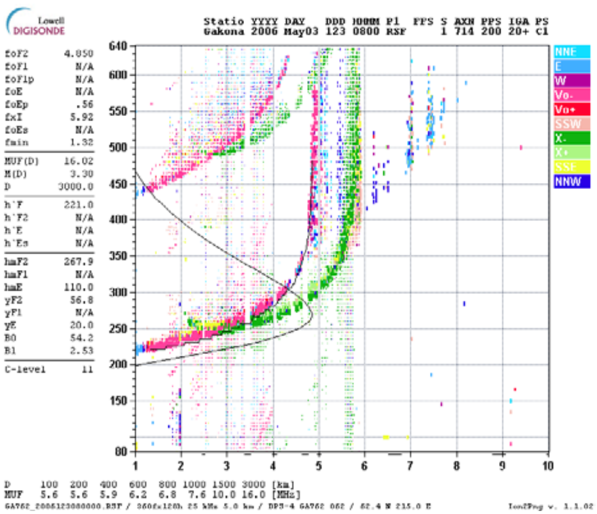


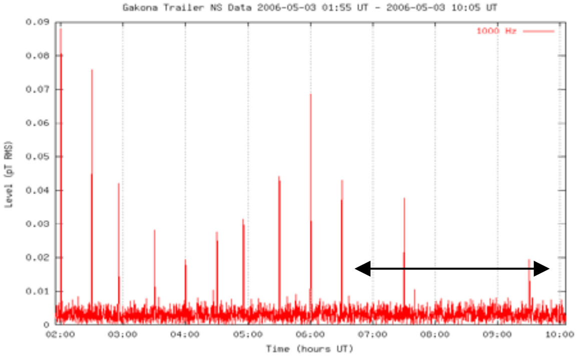
FAR

O

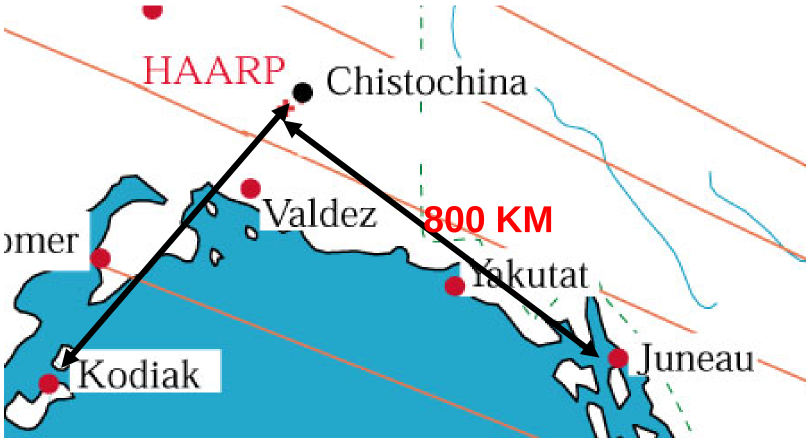
MODE



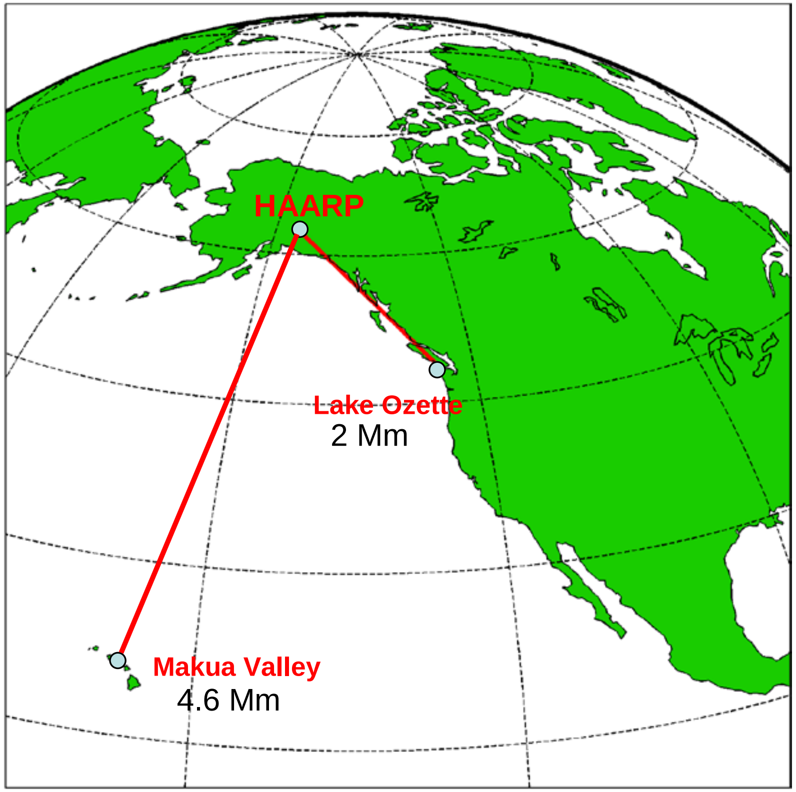




Far Measurement Sites

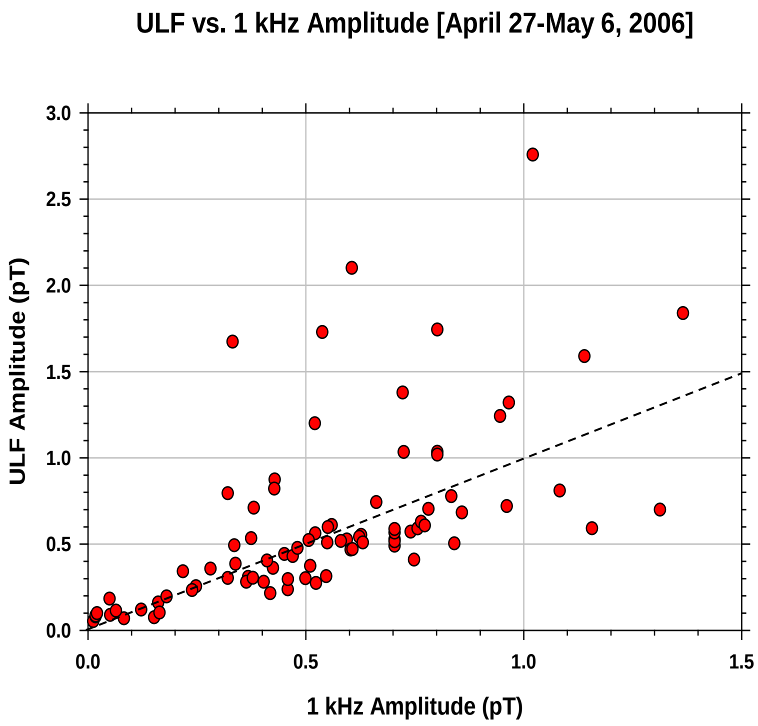


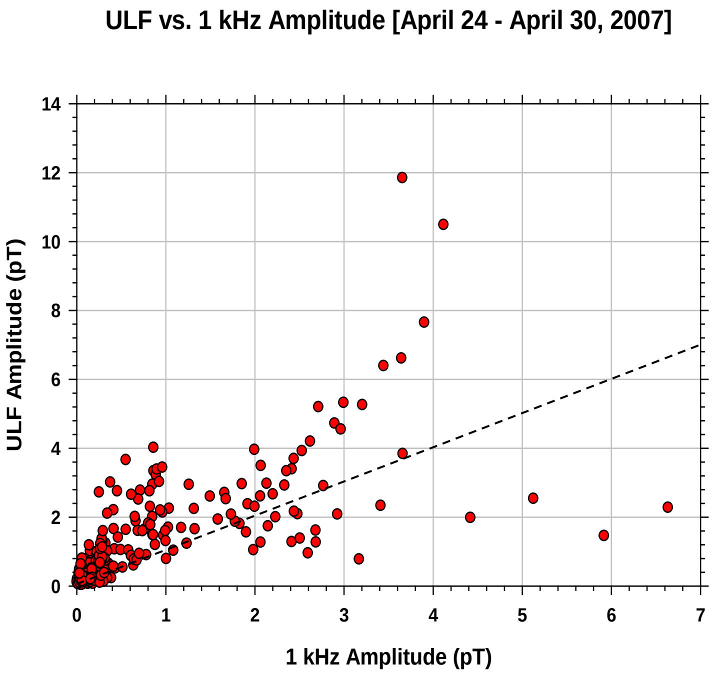
Early Experiments
(2006-2007)



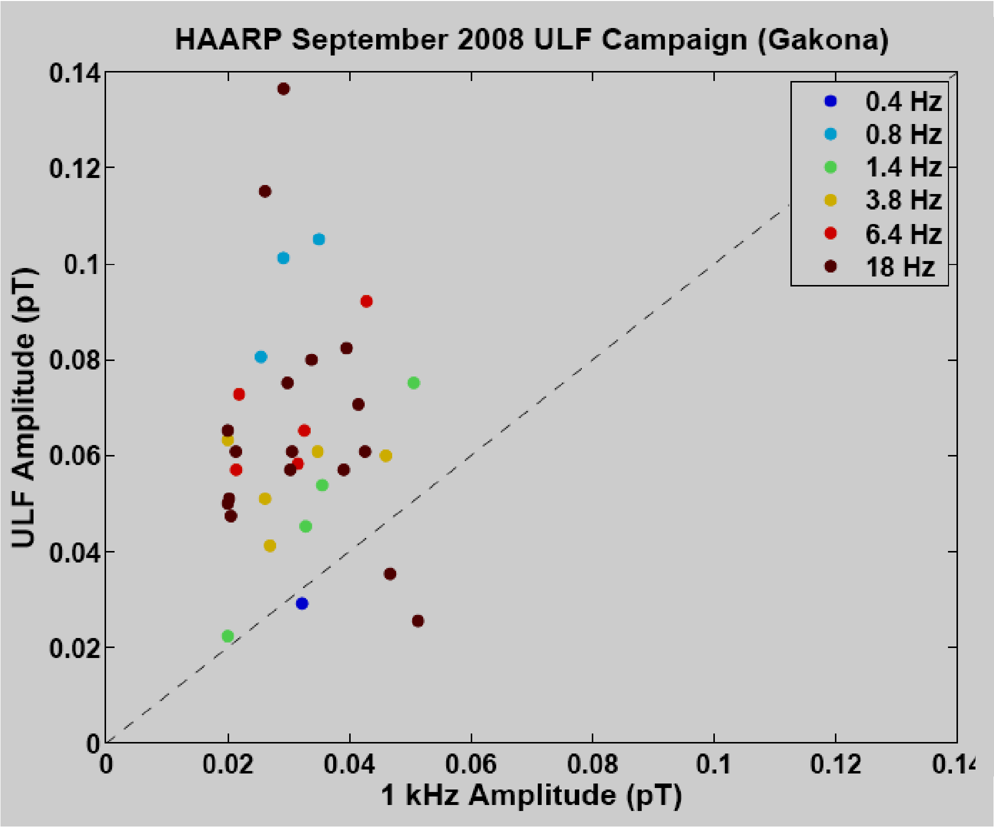
Recent Experiments (2008-2009)

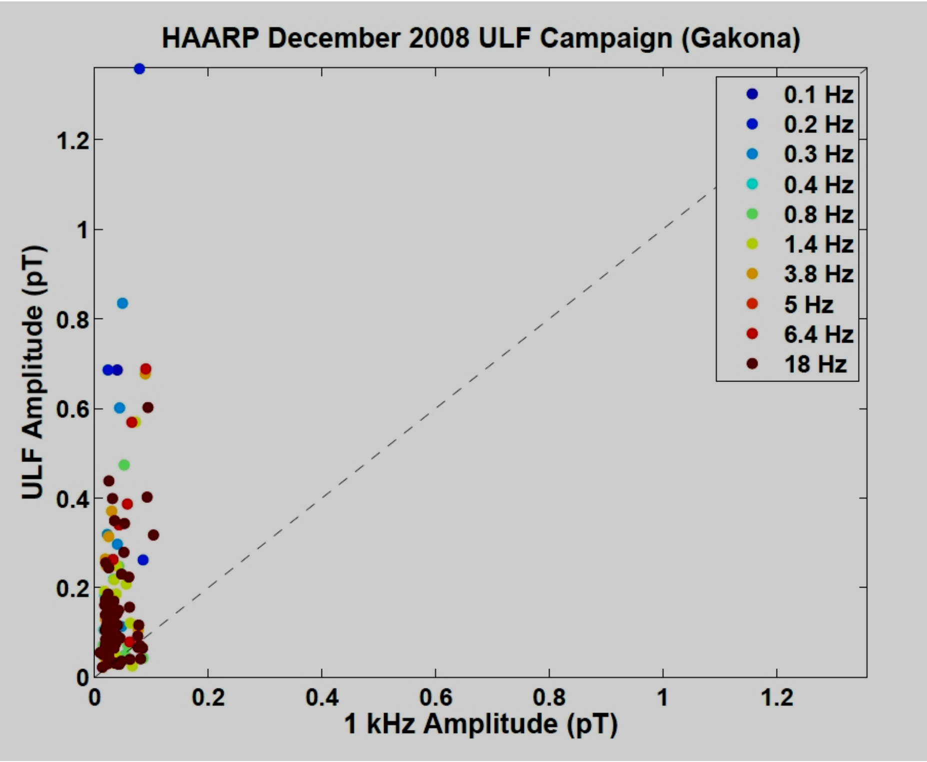
Early Tests

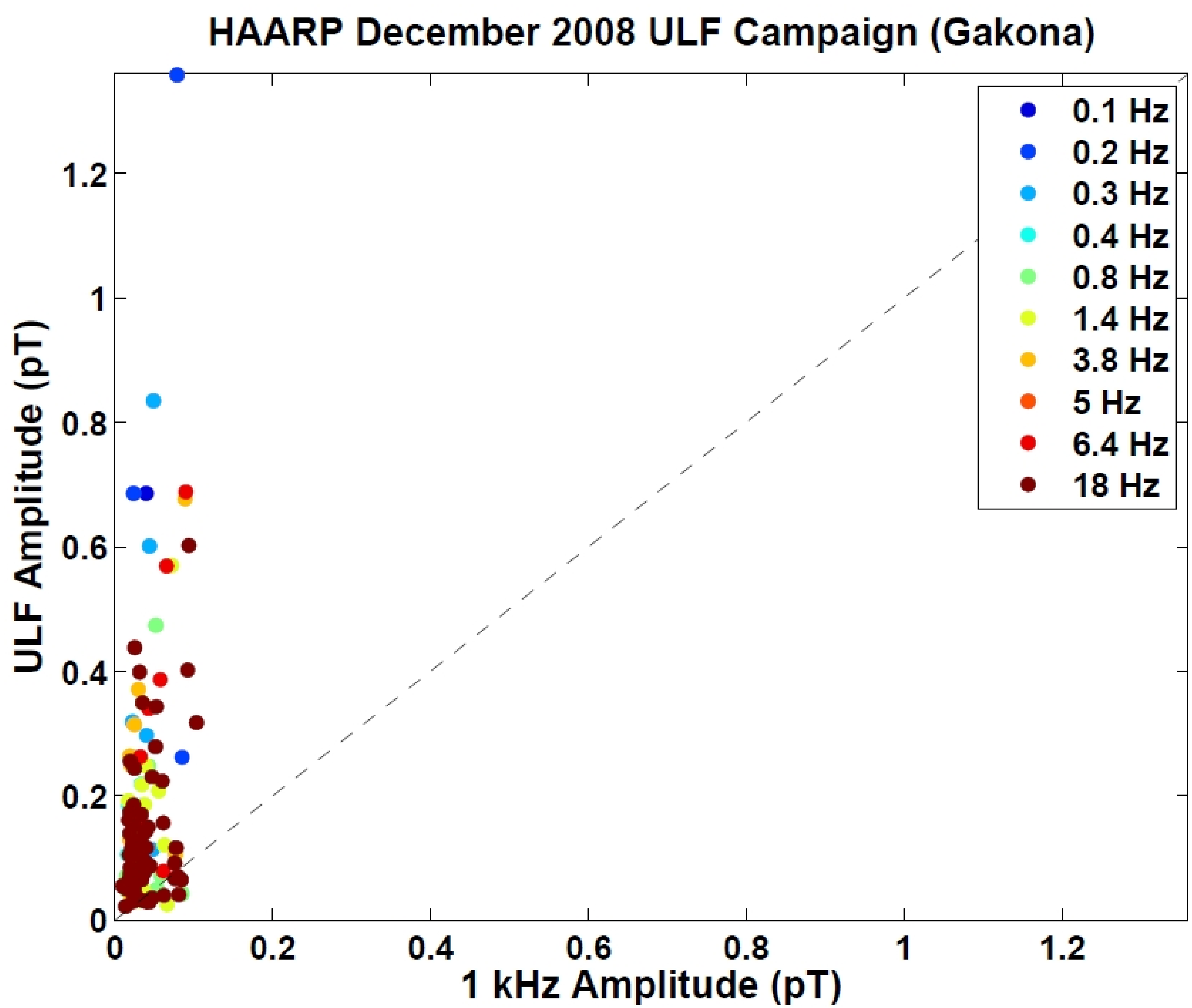

ULF vs. 1 kHz Amplitude [April 27-May 6, 2006]
ULF Amplitude (pT)
1 kHz Amplitude (pT)
0.0
0.5
1.0
1.5
2.0
2.5
3.0


ULF vs. 1 kHz Amplitude [April 24 - April 30, 2007]
ULF Amplitude (pT)
1 kHz Amplitude (pT)
0
1
2
3
4
5
6
7
8
10
12
14

Recent Tests





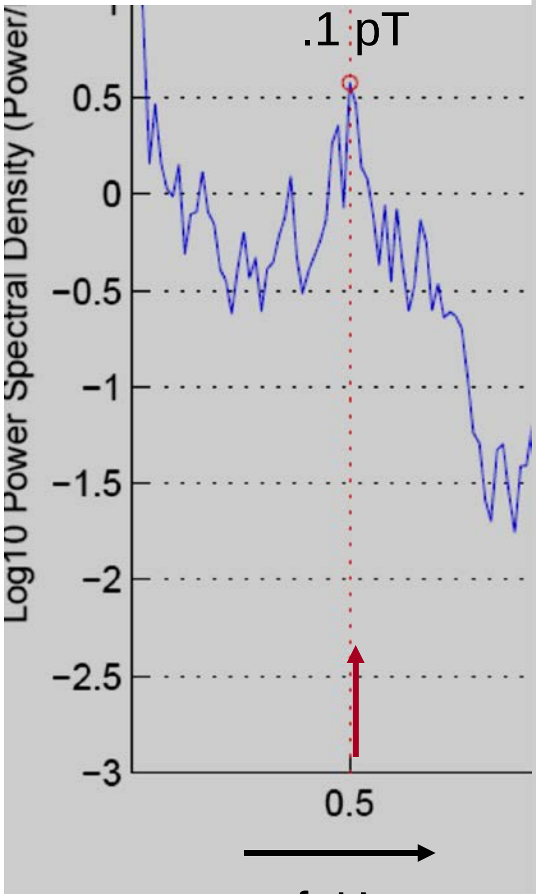


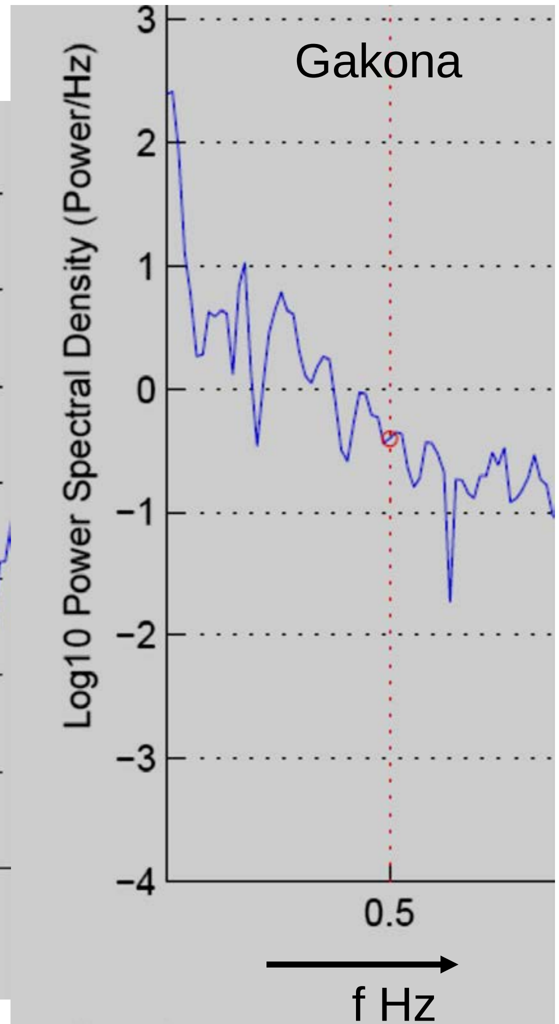
HAARP December 2008 ULF Campaign (Gakona)
ULF Amplitude (pT)
1 kHz Amplitude (pT)
0
0.2
0.4
0.6
0.8
1
1.2
0.1 Hz
0.2 Hz
0.3 Hz
0.4 Hz
0.8 Hz
1.4 Hz
3.8 Hz
5 Hz
6.4 Hz
18 Hz

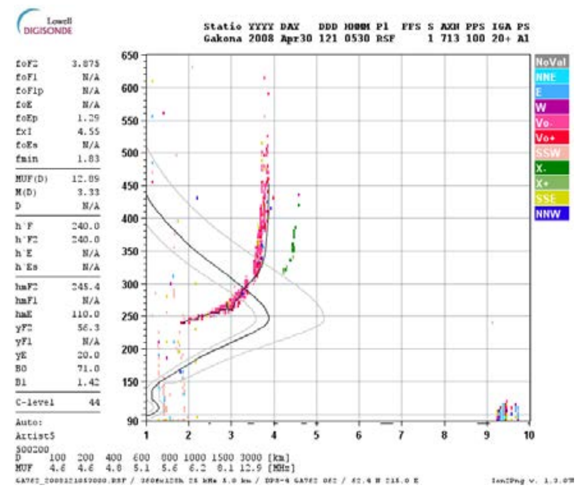
Lake Ozette vs. Gakona Detections

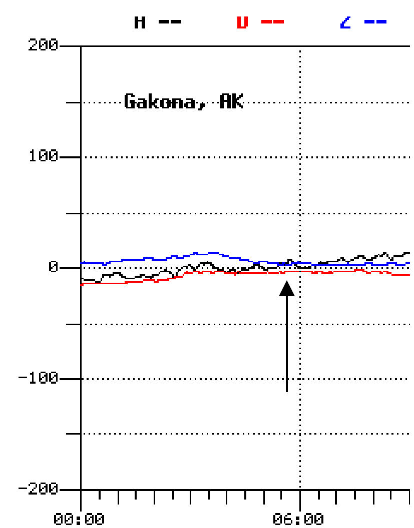
Example .5 Hz

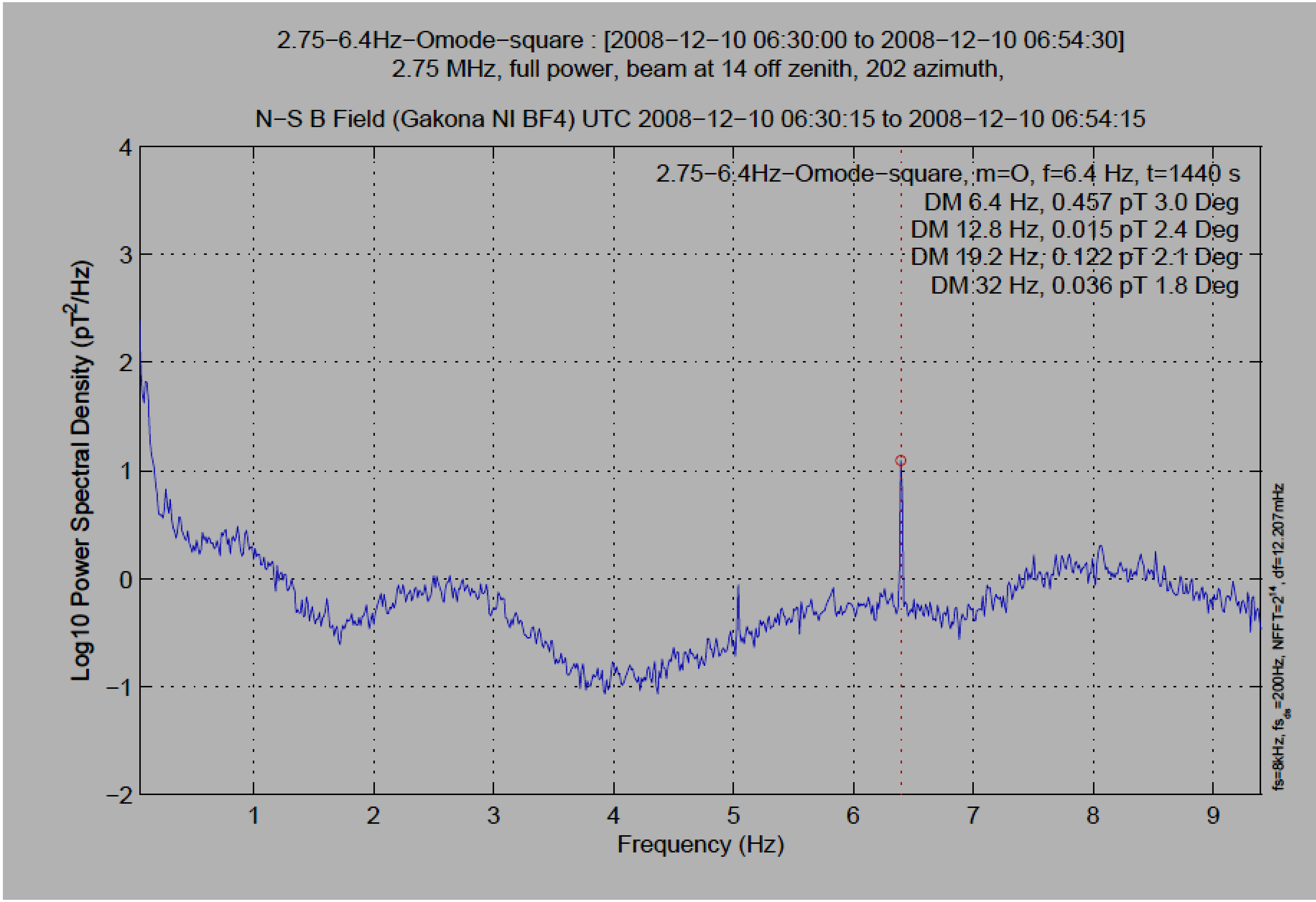
Ozette

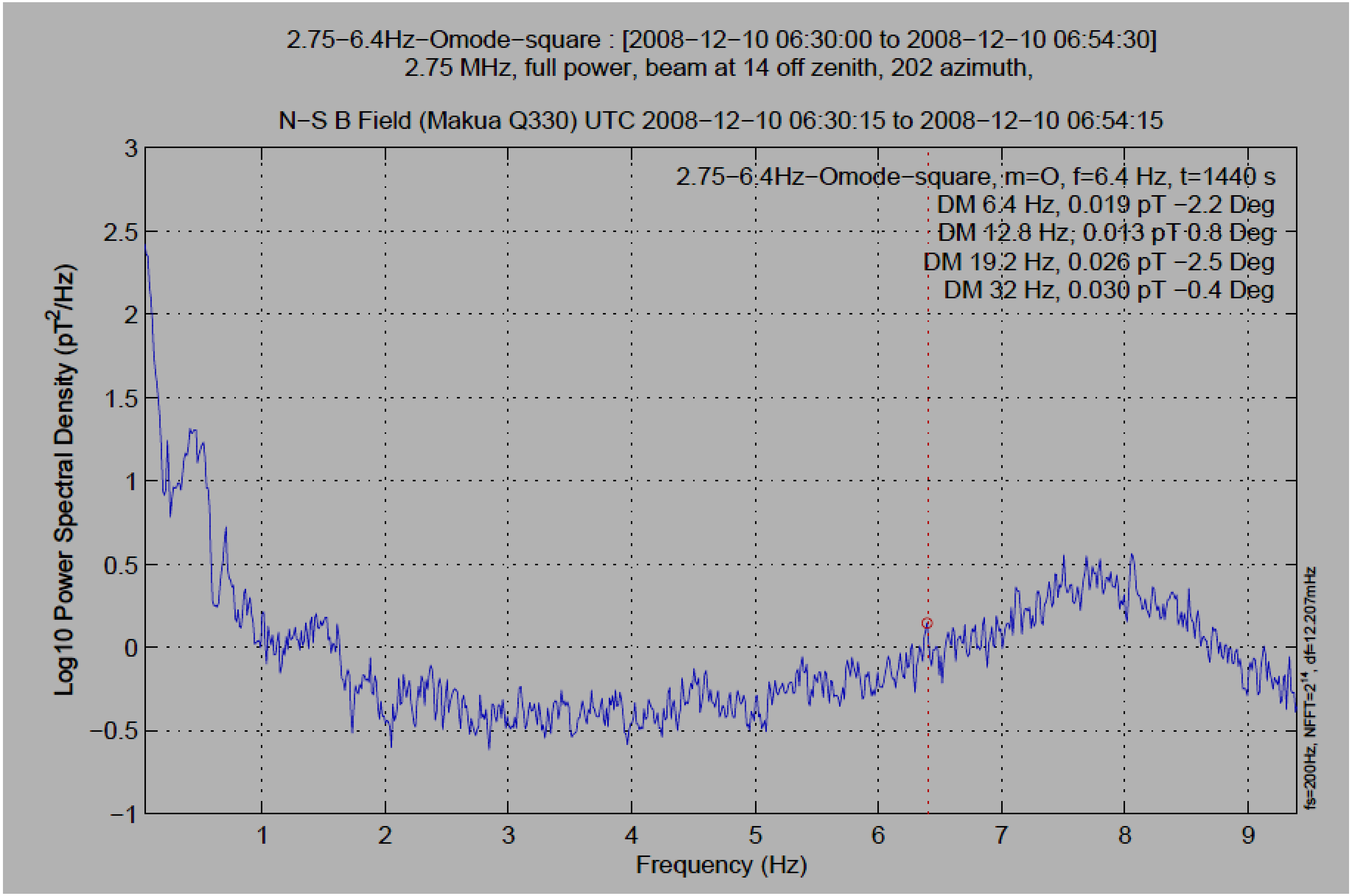




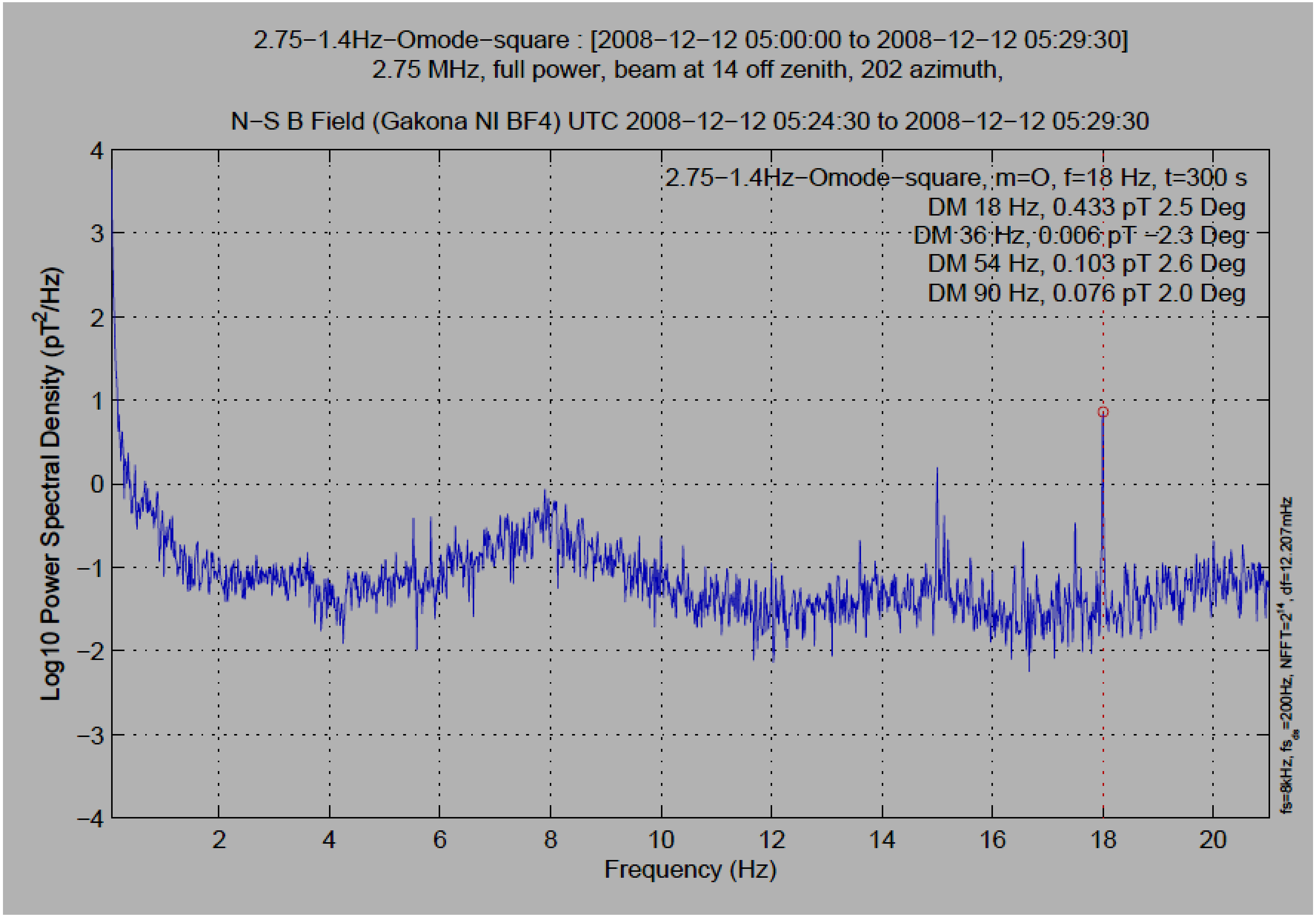


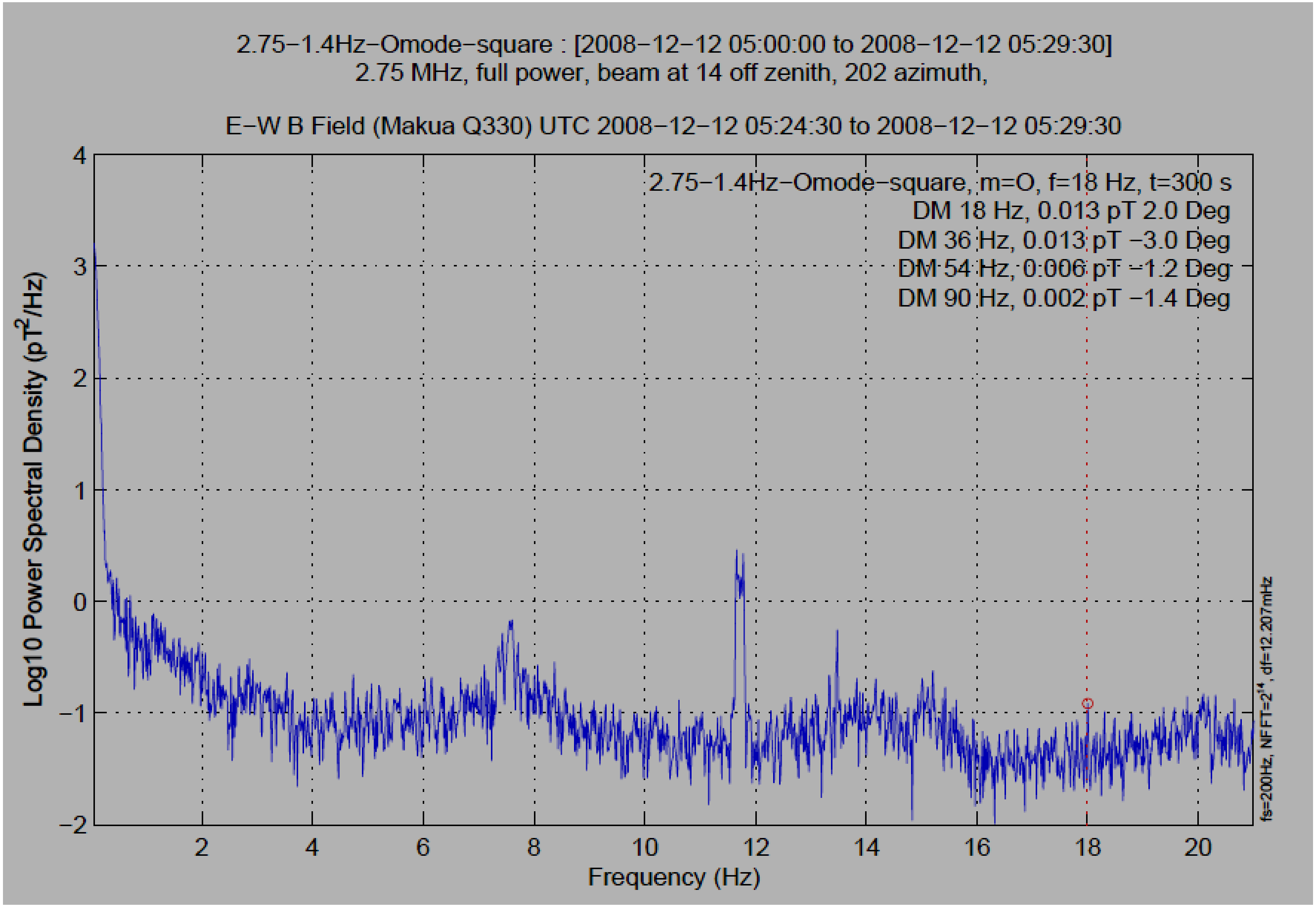



2.75−6.4Hz−Omode−square : [2008−12−10 06:30:00 to 2008−12−10 06:54:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
N−S B Field (Gakona NI BF4) UTC 2008−12−10 06:30:15 to 2008−12−10 06:54:15
2.75−6.4Hz−Omode−square, m=O, f=6.4 Hz, t=1440 s
DM 6.4 Hz, 0.457 pT 3.0 Deg
DM 12.8 Hz, 0.015 pT 2.4 Deg
DM 19.2 Hz, 0.122 pT 2.1 Deg
DM 32 Hz, 0.036 pT 1.8 Deg
Log10 Power Spectral Density (pT2/Hz)
Frequency (Hz)
fs=8kHz, fsds=200Hz, NFFT=214, df=12.207mHz
4
3
2
1
0
−1
−2
1
2
3
4
5
6
7
8
9

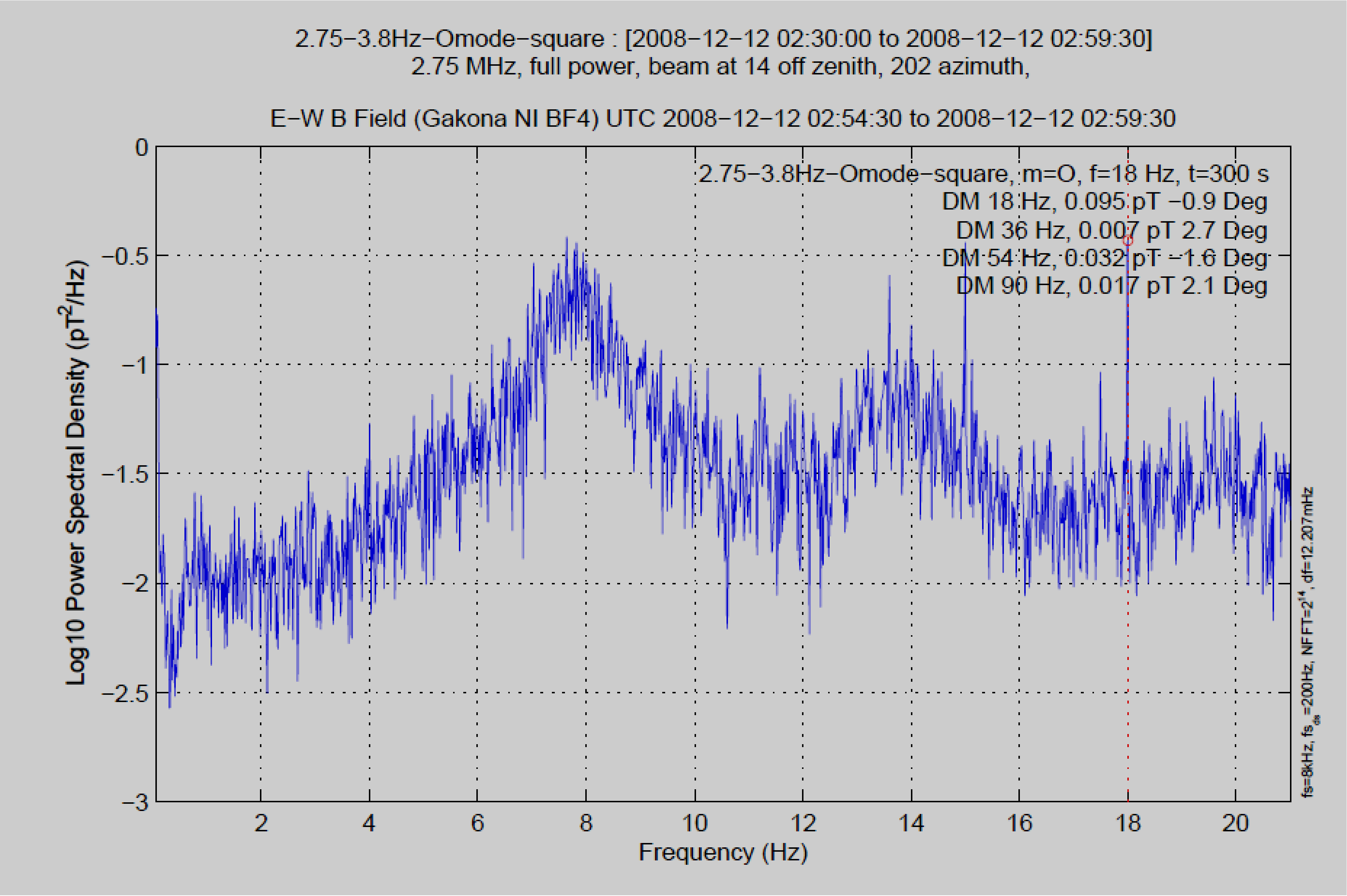


2.75−6.4Hz−Omode−square : [2008−12−10 06:30:00 to 2008−12−10 06:54:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
N−S B Field (Makua Q330) UTC 2008−12−10 06:30:15 to 2008−12−10 06:54:15
2.75−6.4Hz−Omode−square, m=O, f=6.4 Hz, t=1440 s
DM 6.4 Hz, 0.019 pT −2.2 Deg
DM 12.8 Hz, 0.013 pT 0.8 Deg
DM 19.2 Hz, 0.026 pT −2.5 Deg
DM 32 Hz, 0.030 pT −0.4 Deg
Log10 Power Spectral Density (pT²/Hz)
Frequency (Hz)
fs=200Hz, NFFT=2¹⁴, df=12.207mHz
3
2.5
2
1.5
1
0.5
0
−0.5
−1
1
2
3
4
5
6
7
8
9

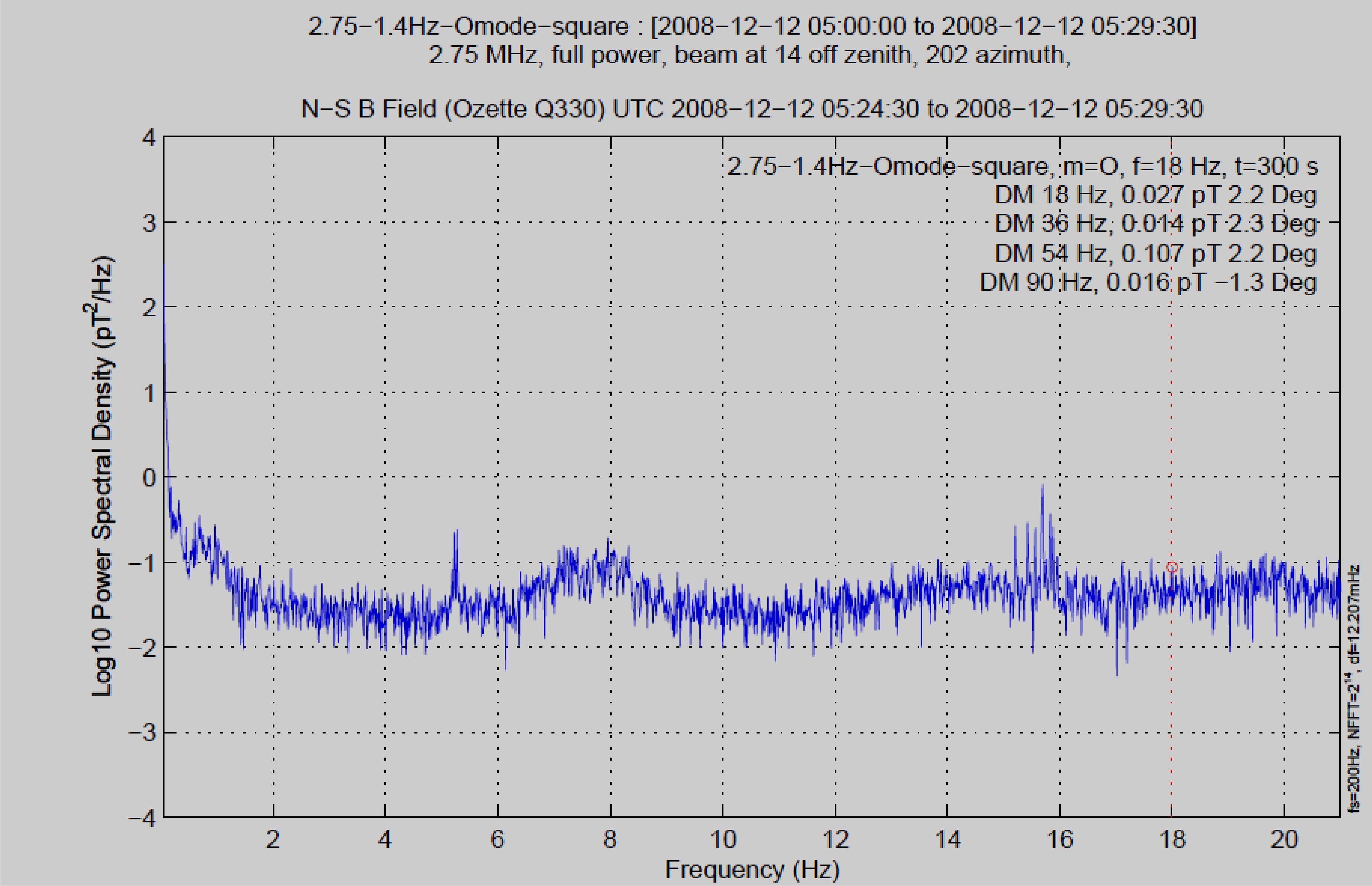

2.75−1.4Hz−Omode−square : [2008−12−12 05:00:00 to 2008−12−12 05:29:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
N−S B Field (Gakona NI BF4) UTC 2008−12−12 05:24:30 to 2008−12−12 05:29:30
2.75−1.4Hz−Omode−square, m=O, f=18 Hz, t=300 s
DM 18 Hz, 0.433 pT 2.5 Deg
DM 36 Hz, 0.006 pT −2.3 Deg
DM 54 Hz, 0.103 pT 2.6 Deg
DM 90 Hz, 0.076 pT 2.0 Deg
Log10 Power Spectral Density (pT2/Hz)
Frequency (Hz)
fs=8kHz, fsds=200Hz, NFFT=214, df=12.207mHz
4
3
2
1
0
−1
−2
−3
−4
2
4
6
8
10
12
14
16
18
20

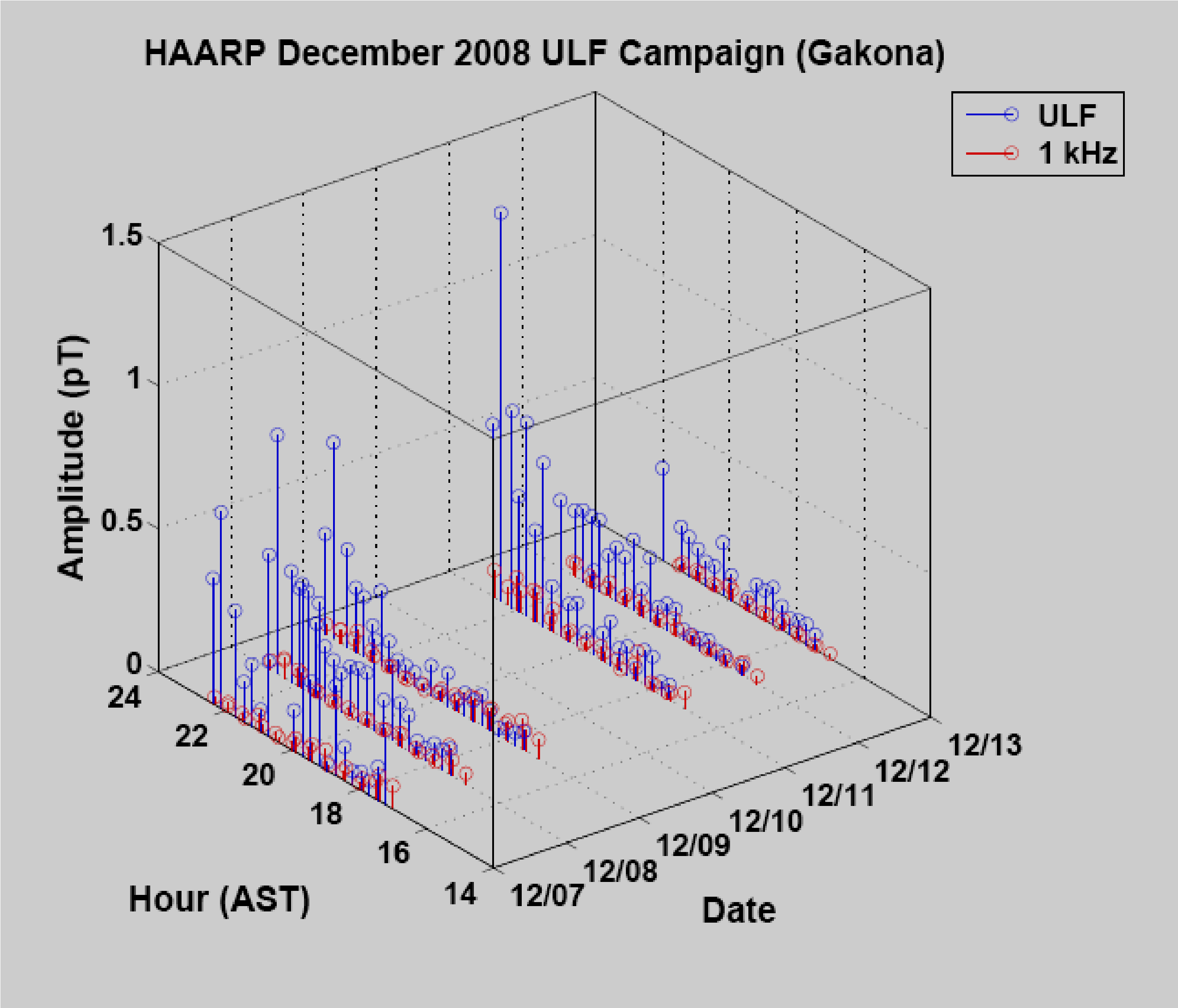


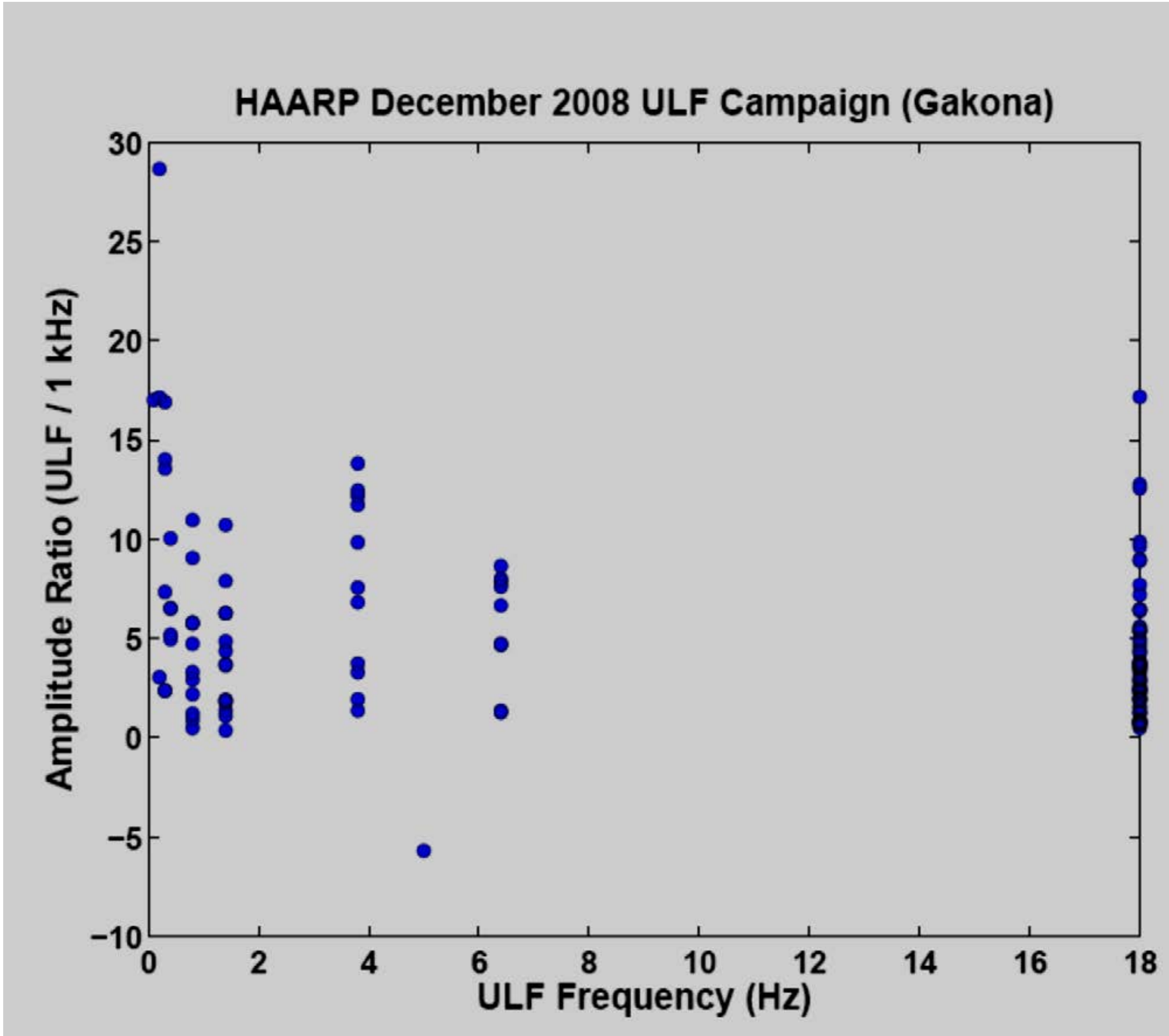
2.75−1.4Hz−Omode−square : [2008−12−12 05:00:00 to 2008−12−12 05:29:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
E−W B Field (Makua Q330) UTC 2008−12−12 05:24:30 to 2008−12−12 05:29:30
2.75−1.4Hz−Omode−square, m=O, f=18 Hz, t=300 s
DM 18 Hz, 0.013 pT 2.0 Deg
DM 36 Hz, 0.013 pT −3.0 Deg
DM 54 Hz, 0.006 pT −1.2 Deg
DM 90 Hz, 0.002 pT −1.4 Deg
Log10 Power Spectral Density (pT²/Hz)
Frequency (Hz)
fs=200Hz, NFFT=2¹⁴, df=12.207mHz
4
3
2
1
0
−1
−2
2
4
6
8
10
12
14
16
18
20



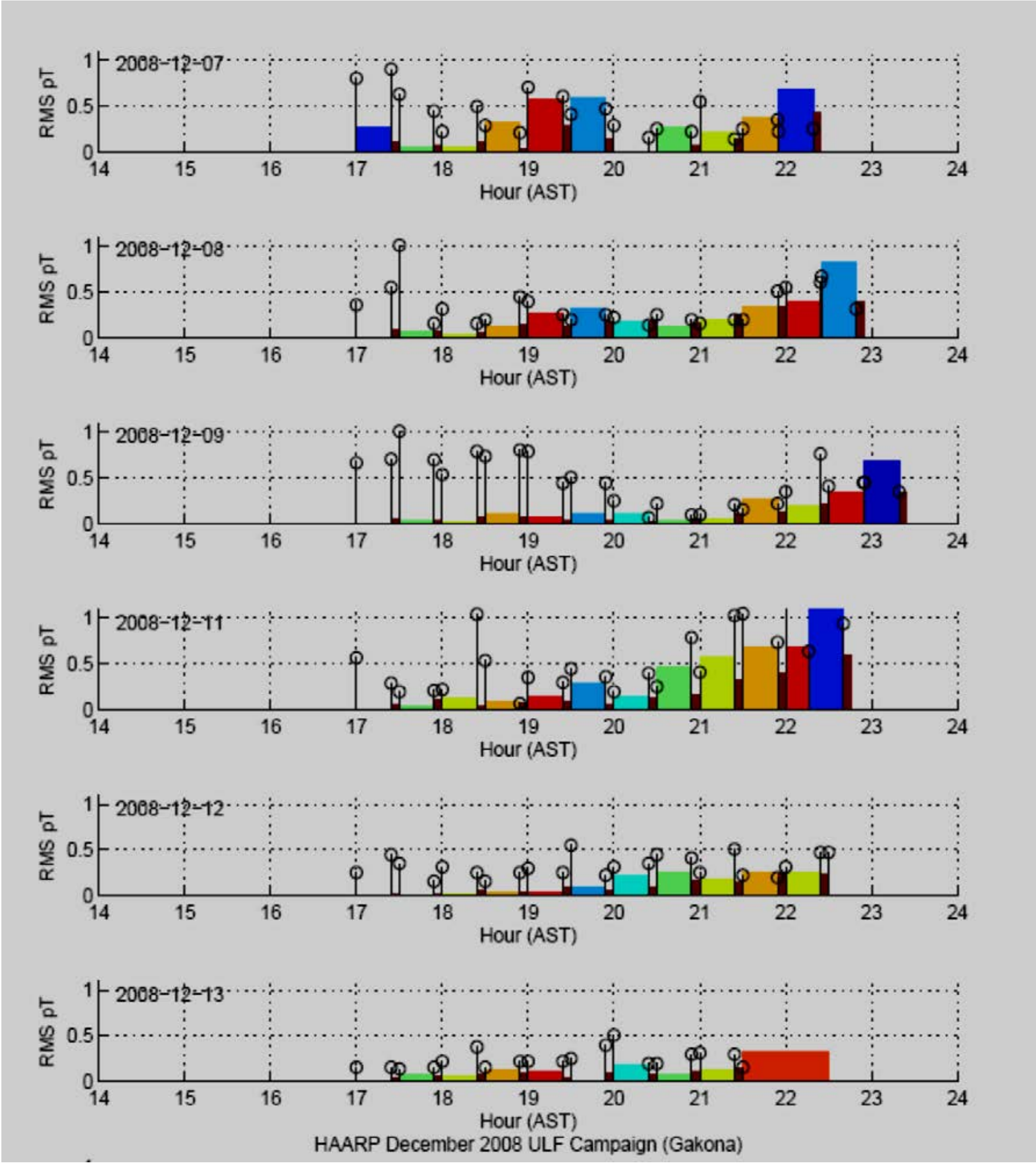
2.75−3.8Hz−Omode−square : [2008−12−12 02:30:00 to 2008−12−12 02:59:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
E−W B Field (Gakona NI BF4) UTC 2008−12−12 02:54:30 to 2008−12−12 02:59:30
2.75−3.8Hz−Omode−square, m=O, f=18 Hz, t=300 s
DM 18 Hz, 0.095 pT −0.9 Deg
DM 36 Hz, 0.007 pT 2.7 Deg
DM 54 Hz, 0.032 pT −1.6 Deg
DM 90 Hz, 0.017 pT 2.1 Deg
Log10 Power Spectral Density (pT²/Hz)
Frequency (Hz)
0
−0.5
−1
−1.5
−2
−2.5
−3
2
4
6
8
10
12
14
16
18
20
fs=8kHz, fs_ds=200Hz, NFFT=2^14, df=12.207mHz


2.75−1.4Hz−Omode−square : [2008−12−12 05:00:00 to 2008−12−12 05:29:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
N−S B Field (Ozette Q330) UTC 2008−12−12 05:24:30 to 2008−12−12 05:29:30
2.75−1.4Hz−Omode−square, m=O, f=18 Hz, t=300 s
DM 18 Hz, 0.027 pT 2.2 Deg
DM 36 Hz, 0.014 pT 2.3 Deg
DM 54 Hz, 0.107 pT 2.2 Deg
DM 90 Hz, 0.016 pT −1.3 Deg
Log10 Power Spectral Density (pT²/Hz)
Frequency (Hz)
fs=200Hz, NFFT=2¹⁴, df=12.207mHz


HAARP December 2008 ULF Campaign (Gakona)
ULF
1 kHz
Amplitude (pT)
1.5
1
0.5
0
24
22
20
18
16
14
Hour (AST)
12/07
12/08
12/09
12/10
12/11
12/12
12/13
Date

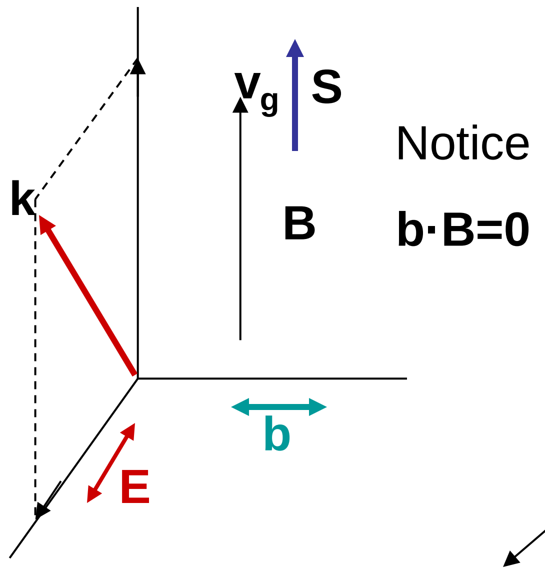


HAARP December 2008 ULF Campaign (Gakona)
Amplitude Ratio (ULF / 1 kHz)
ULF Frequency (Hz)
30
25
20
15
10
5
0
−5
−10
0
2
4
6
8
10
12
14
16
18



2008-12-07
2008-12-08
2008-12-09
2008-12-11
2008-12-12
2008-12-13
RMS pT
Hour (AST)
HAARP December 2008 ULF Campaign (Gakona)

SA Waves – Ionospheric Alfven Resonator (IAR)



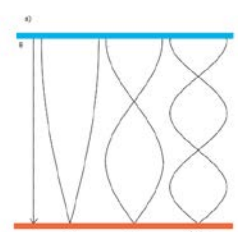
Notice

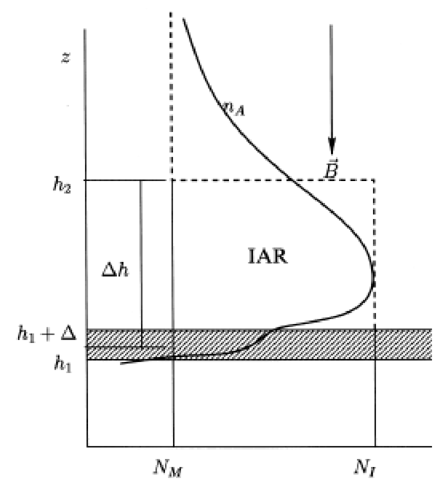
b·B=0

SA wave is guided along the B field

Reflections create standing wave structure

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



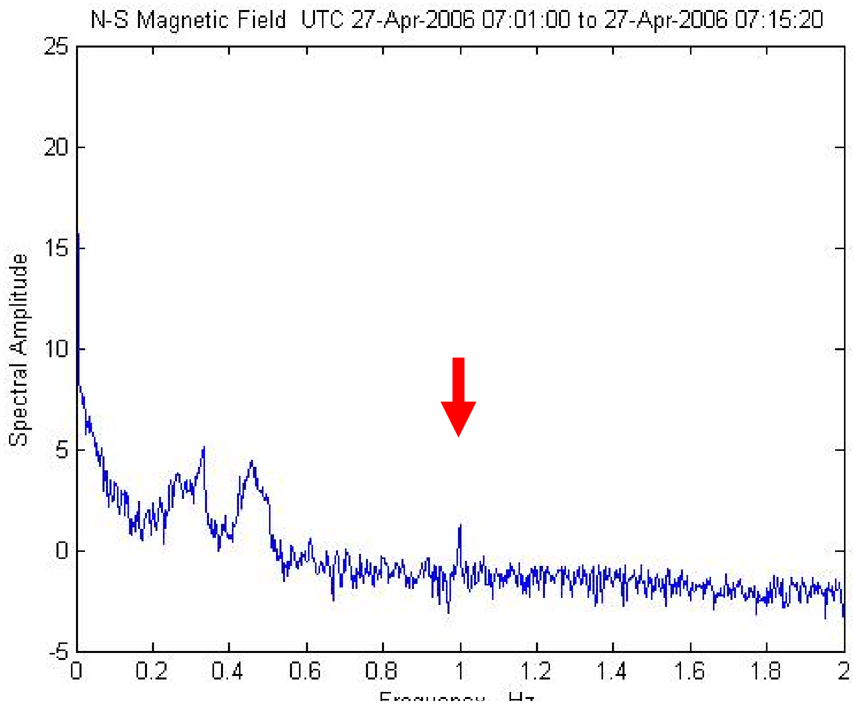


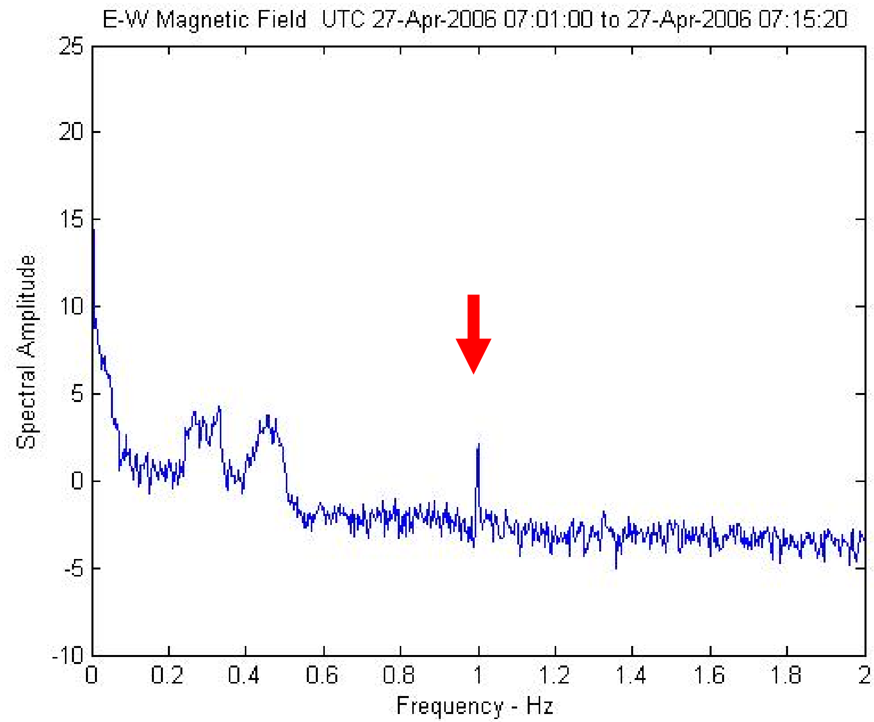
$\eta = c/V_A$

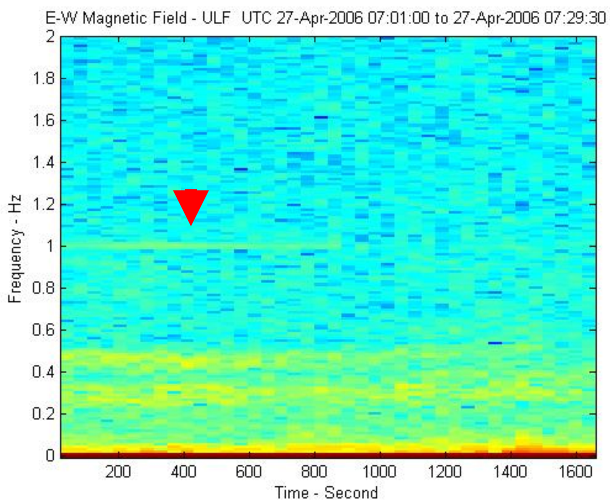
***Fabry-Perot* like Resonator**

Natural SA waves

IAR Excitation by ICD

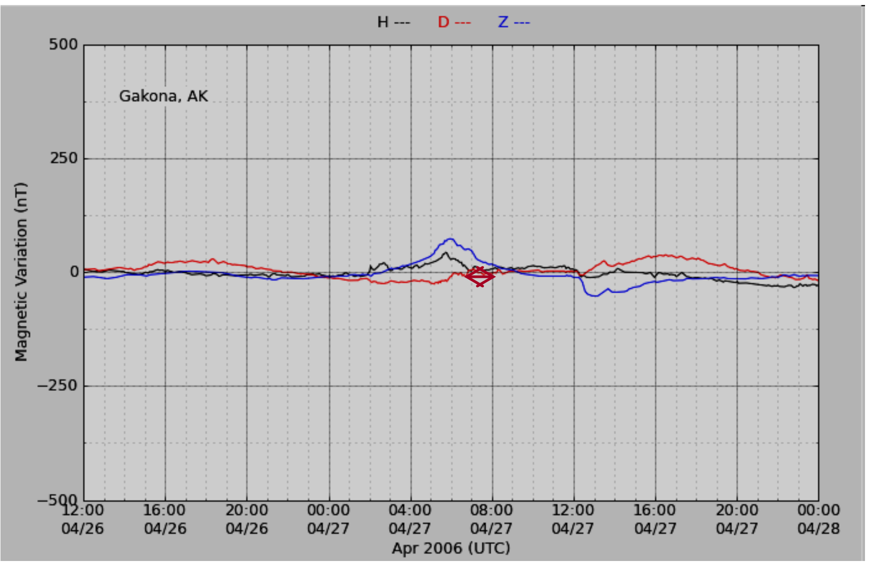


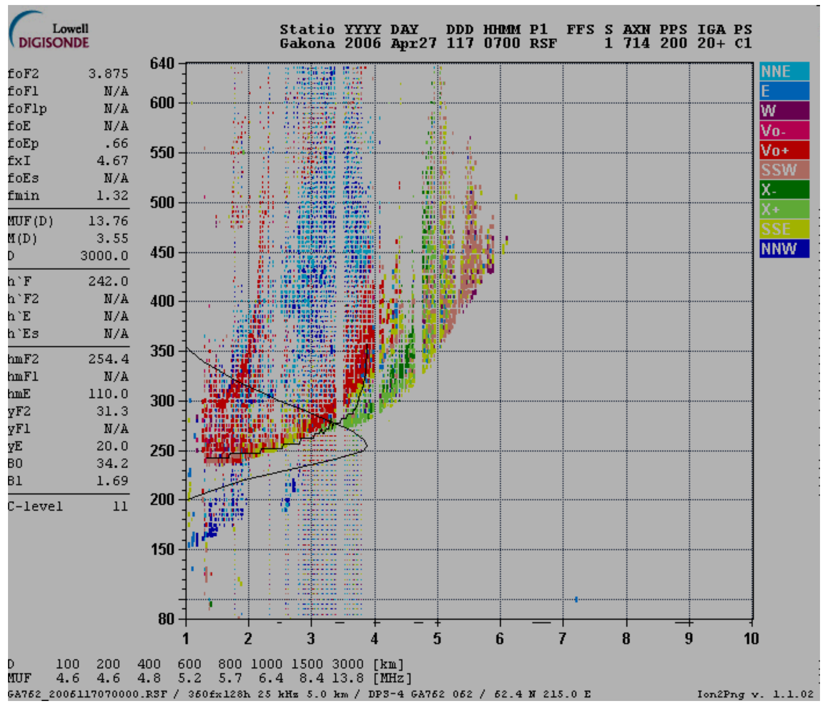




Excitation of the IAR due naturally excited waves at .25 Hz and .5 Hz and by HAARP at 1.0 Hz.

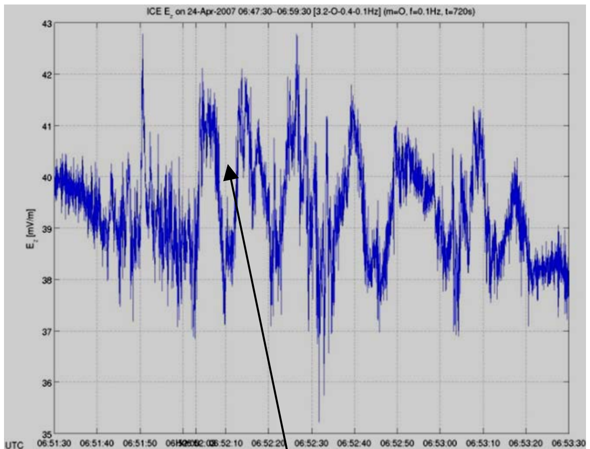
IAR Conditions

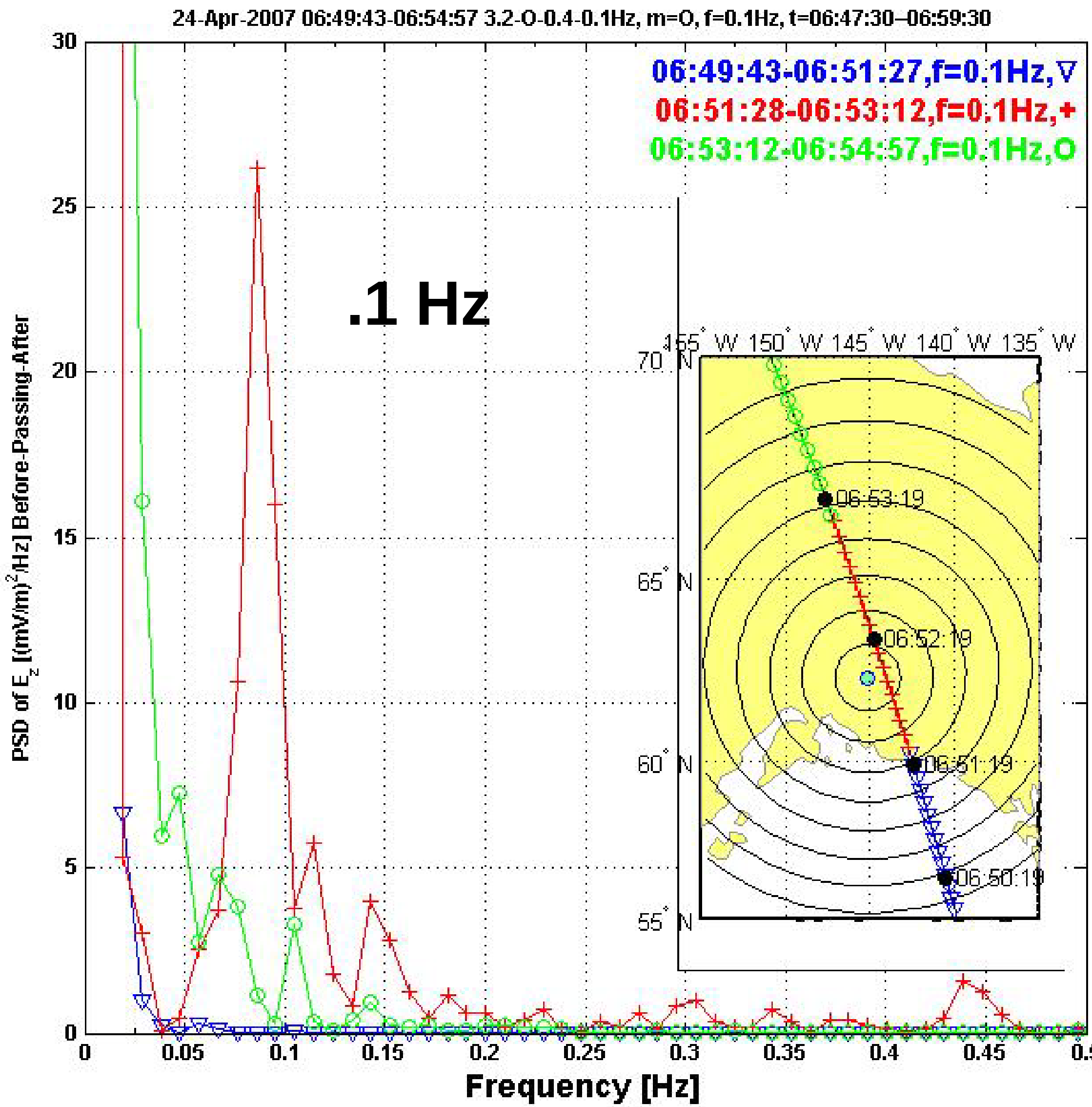




Msonic Wave Injection

DEMETER





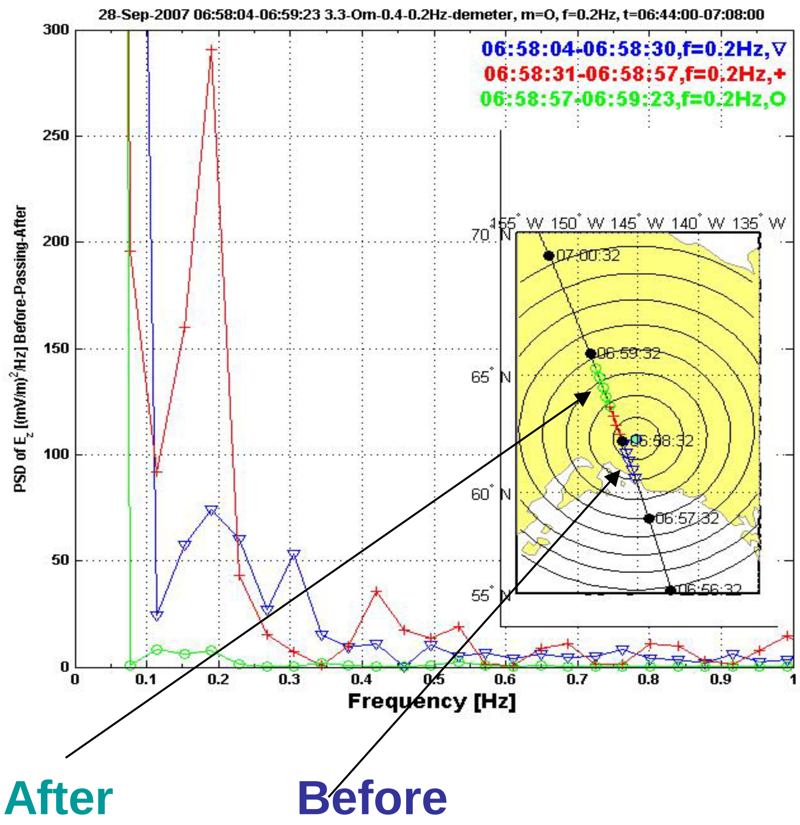
10 sec oscillations

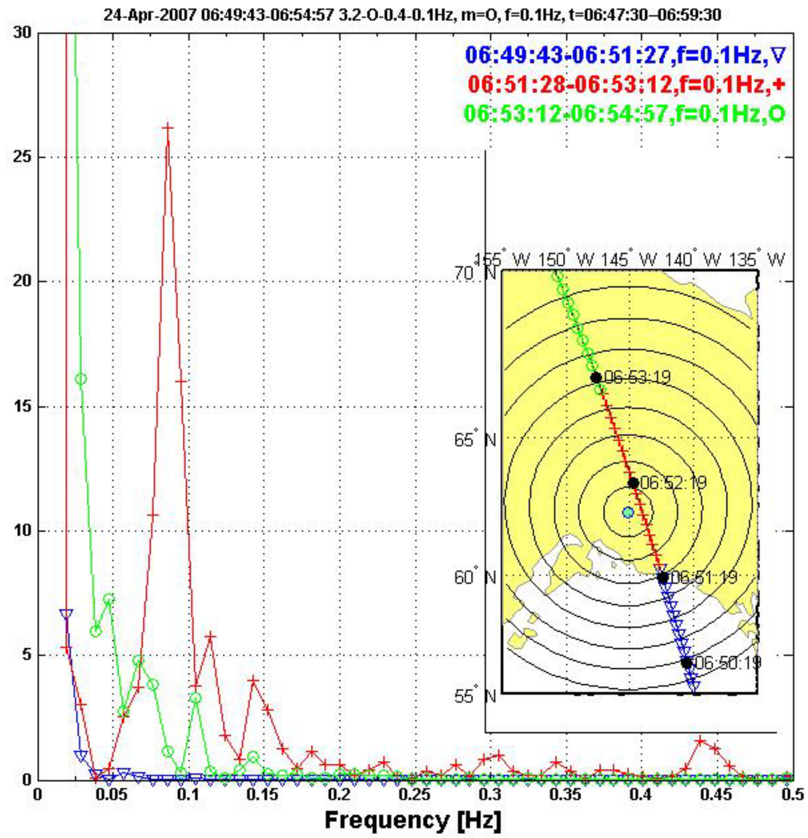
kW power

Demeter data – Inan and Pyddiachyi

SAW and Msonic Detection by DEMETER

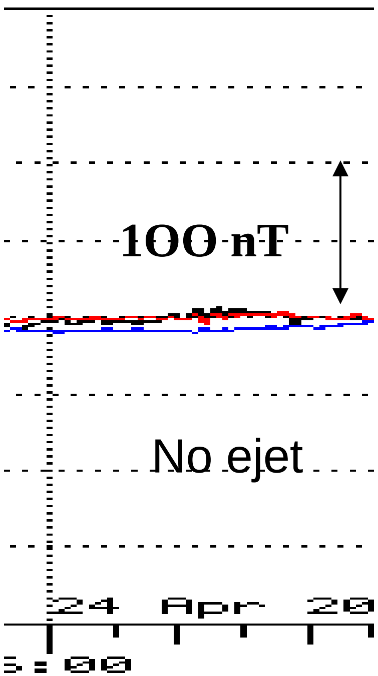
UMCP-Stanford-BAE

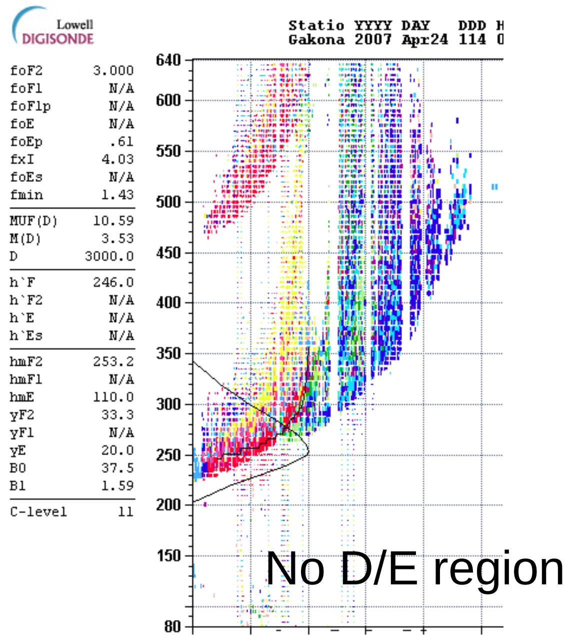


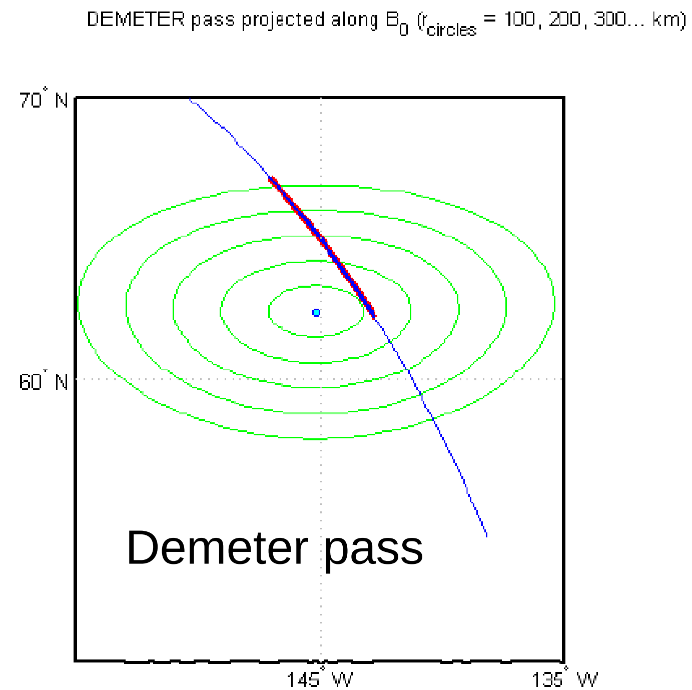


Example of F-Region Msonic Generation Detected by the Demeter satellite

O-mode at 4.4 MHz HAARP at 3.5 MW modulated at .1 Hz between 6:47:30 and 6:59:30 UT

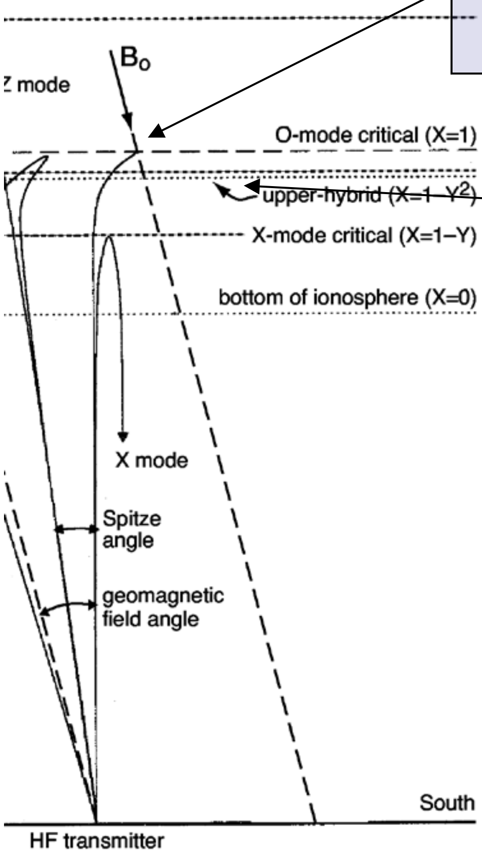






No ULF detection on the ground - .1 Hz detection at Demeter between 6:51:30 and 6:53:00

F Region Heating



Double resonance excitation
Langmuir+Ion Acoustic Instability -PDI -OTSI
Soliton+caviton pairs – Suprathermal tails

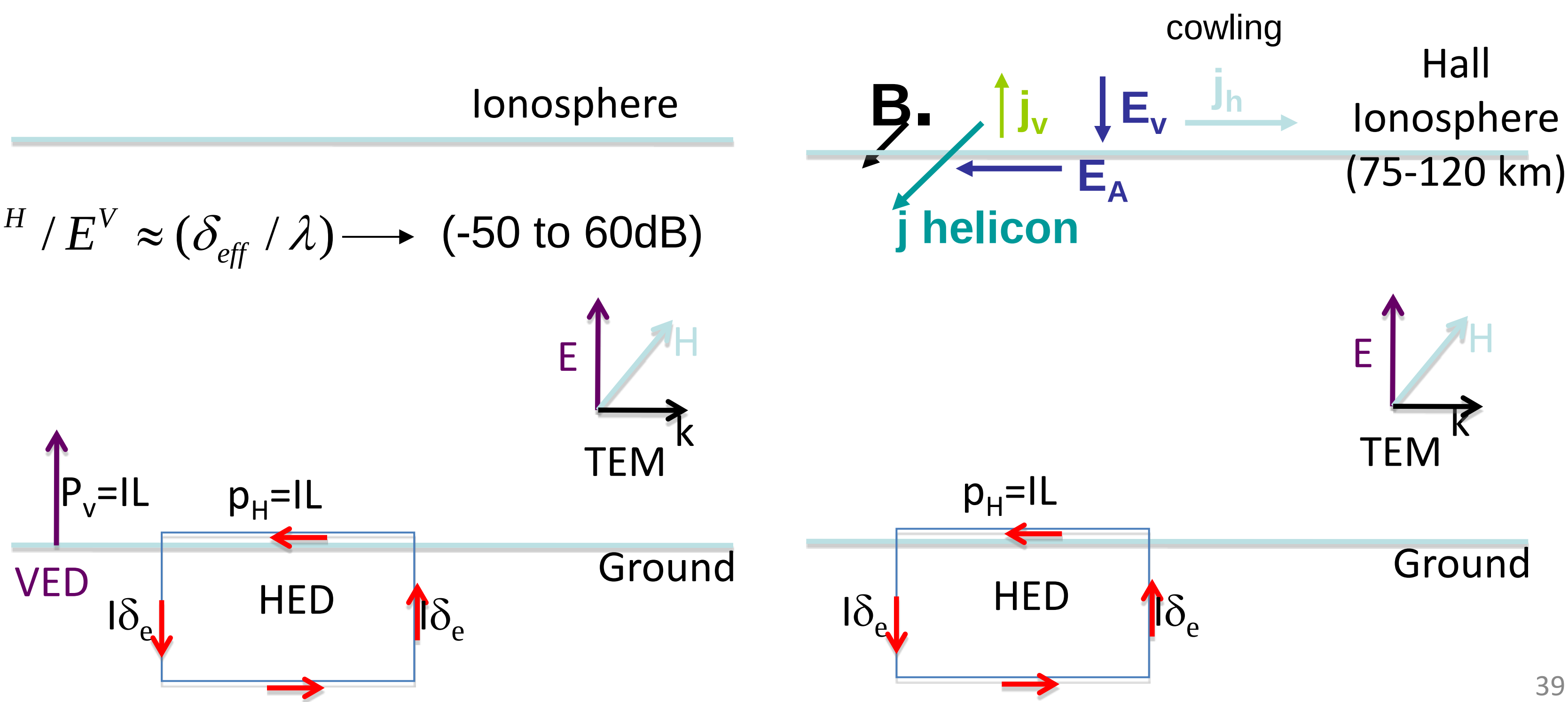
Upper hybrid turbulence – Striations – Electron Heating

MAXIMUM ACHIVABLE LOW FREQUENCY FOR ICD DEPENDS ON F-REGION COLLISIONLESS HEATING AND COOLING (ELECTRON HEAT FLUX DOMINATED). TESTS DURING NEXT SUMMER

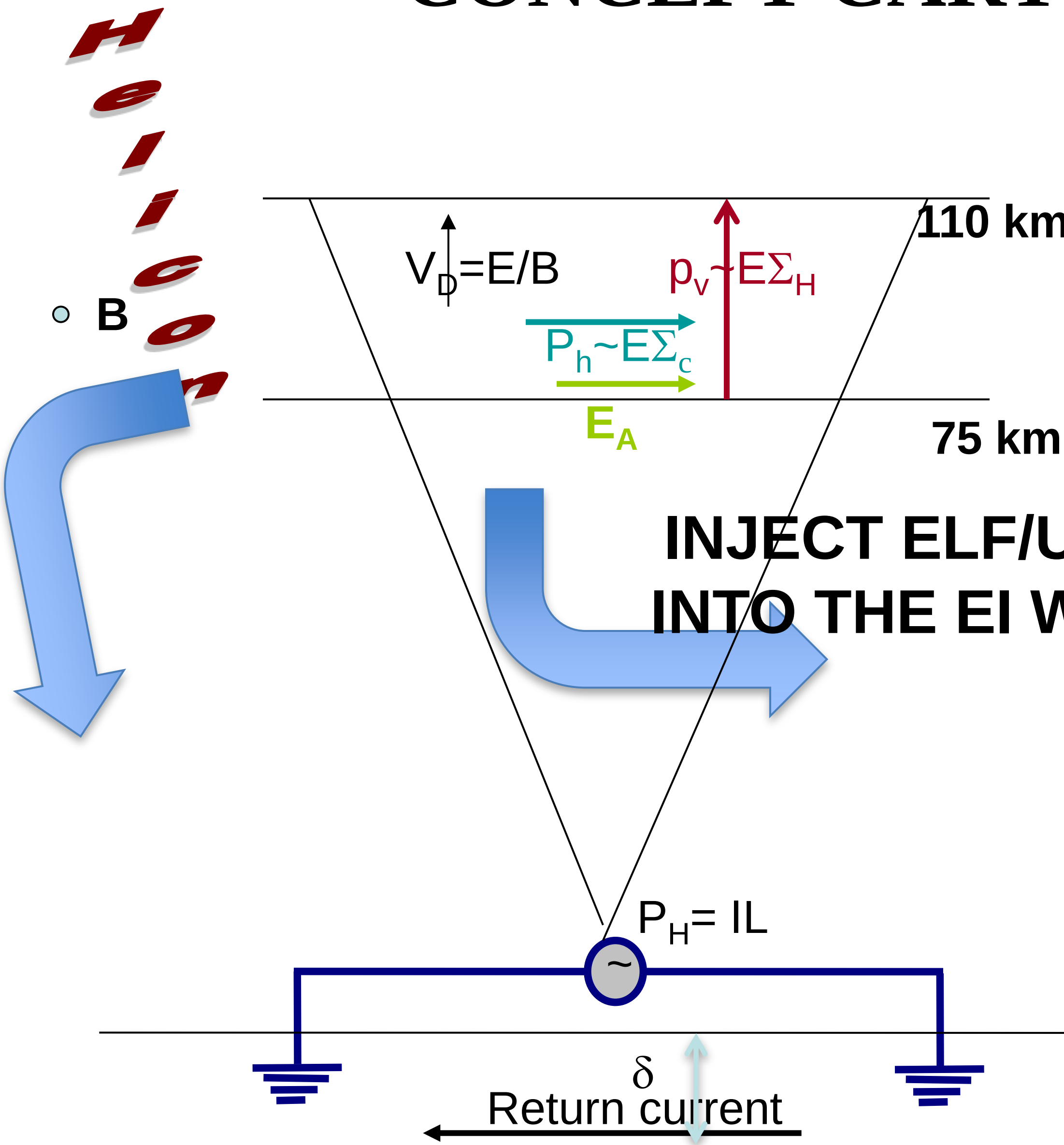
Artificially Created Electrojet (ACE)
Pulsed Artificially Created Ejet (PACE)

- **Spin-off of ICD HAARP Tests for ELF/ULF Generation**
- **Novel concept of efficient ELF/ULF generation for Navy and other applications –**

$$E^H / E^V \approx (\delta_{eff} / \lambda) \longrightarrow \text{(-50 to 60dB)}$$



CONCEPT CARTOON



Interaction of transmitted wave with E-region (Hall) plasma

E-region current spatio-temporal structure and re-radiation into EI waveguide

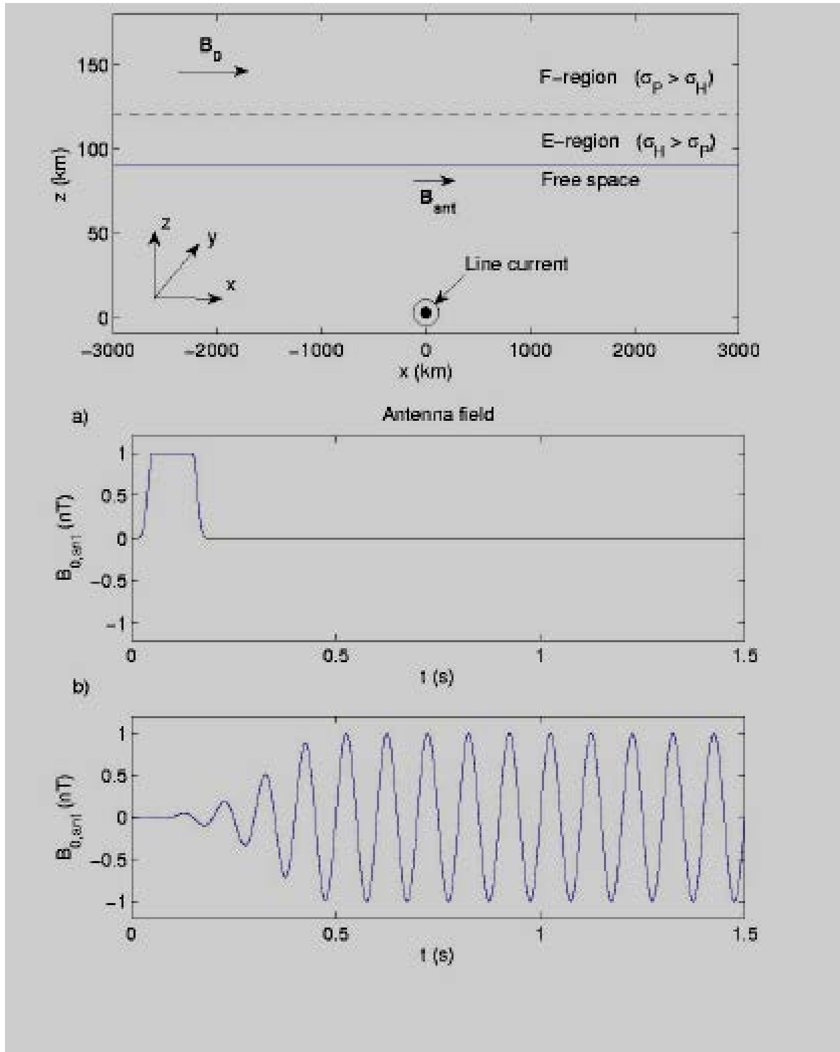
B. Eliason

INJECT ELF/ULF WAVES INTO THE EI WAVEGUIDE

Improve HED Efficiency

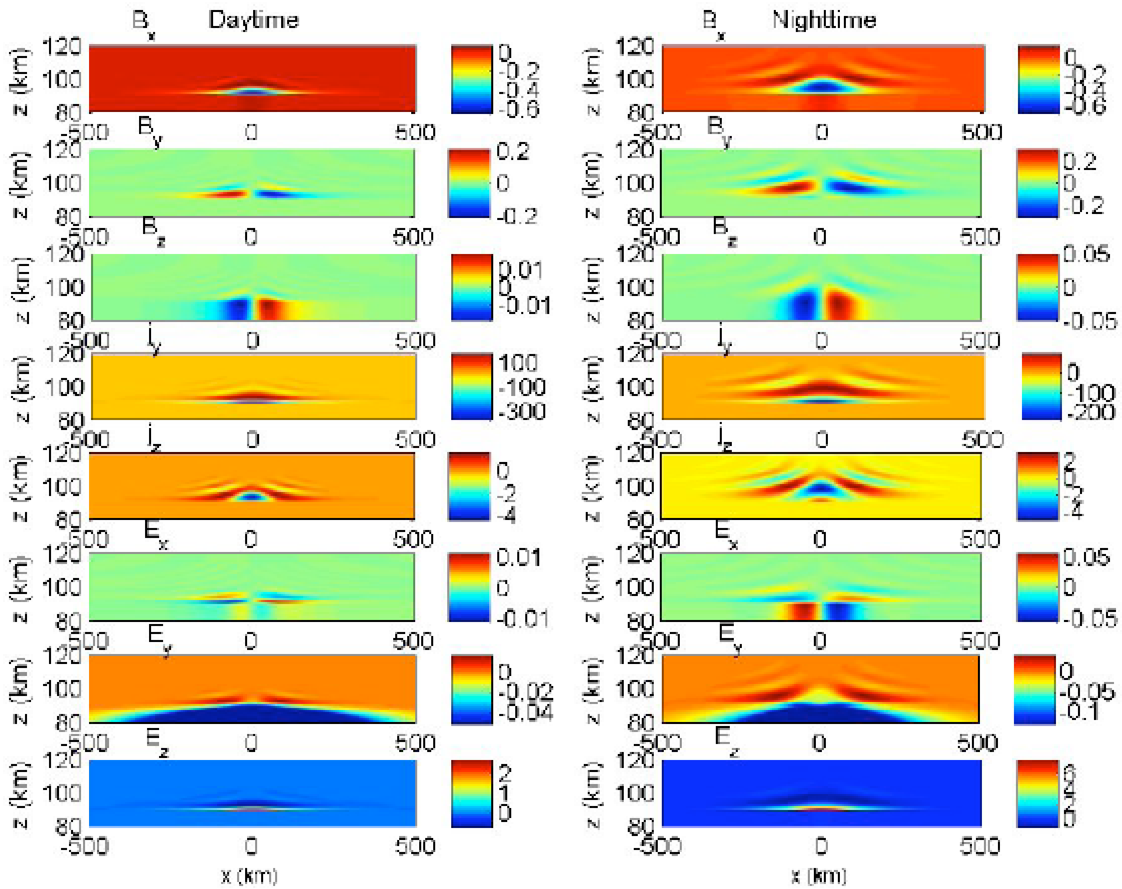
Sneak-Through

$E_T \approx (IL/h^2)(\delta/h)$

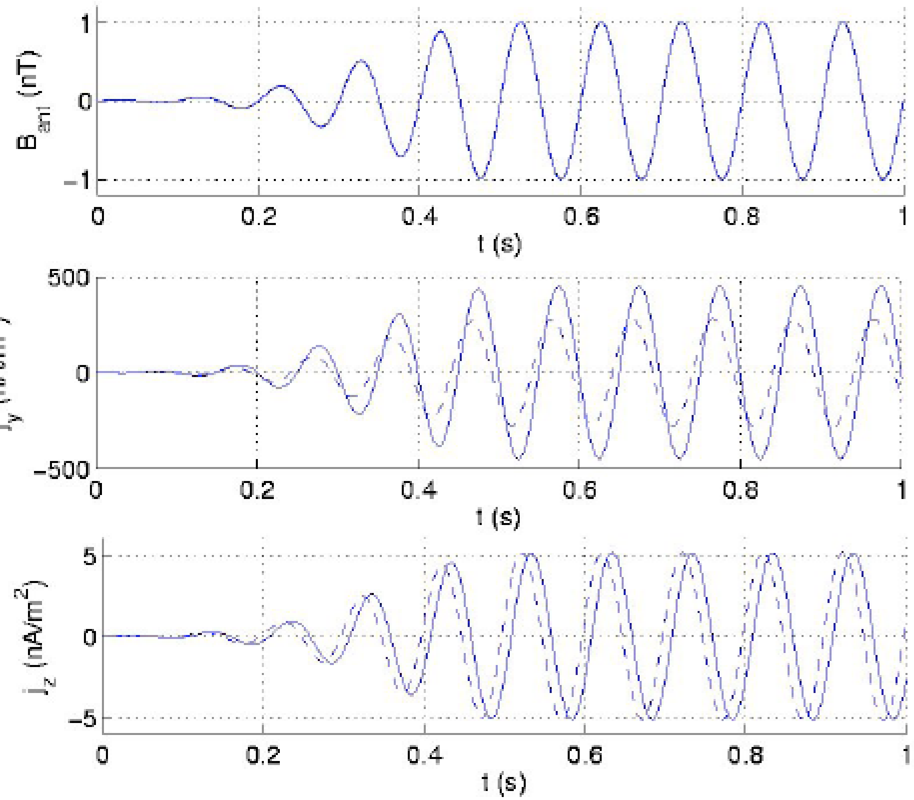

B0
F–region (σP > σH)
E–region (σH > σP)
Free space
Bant
Line current
z (km)
x (km)
a)
Antenna field
B0,ant (nT)
t (s)
b)
B0,ant (nT)
t (s)

CW antenna field, day and nighttime conditions

Profiles of B (nT), j $(\mathrm{nA/m^2})$ and E $(\mathrm{mV/m})$

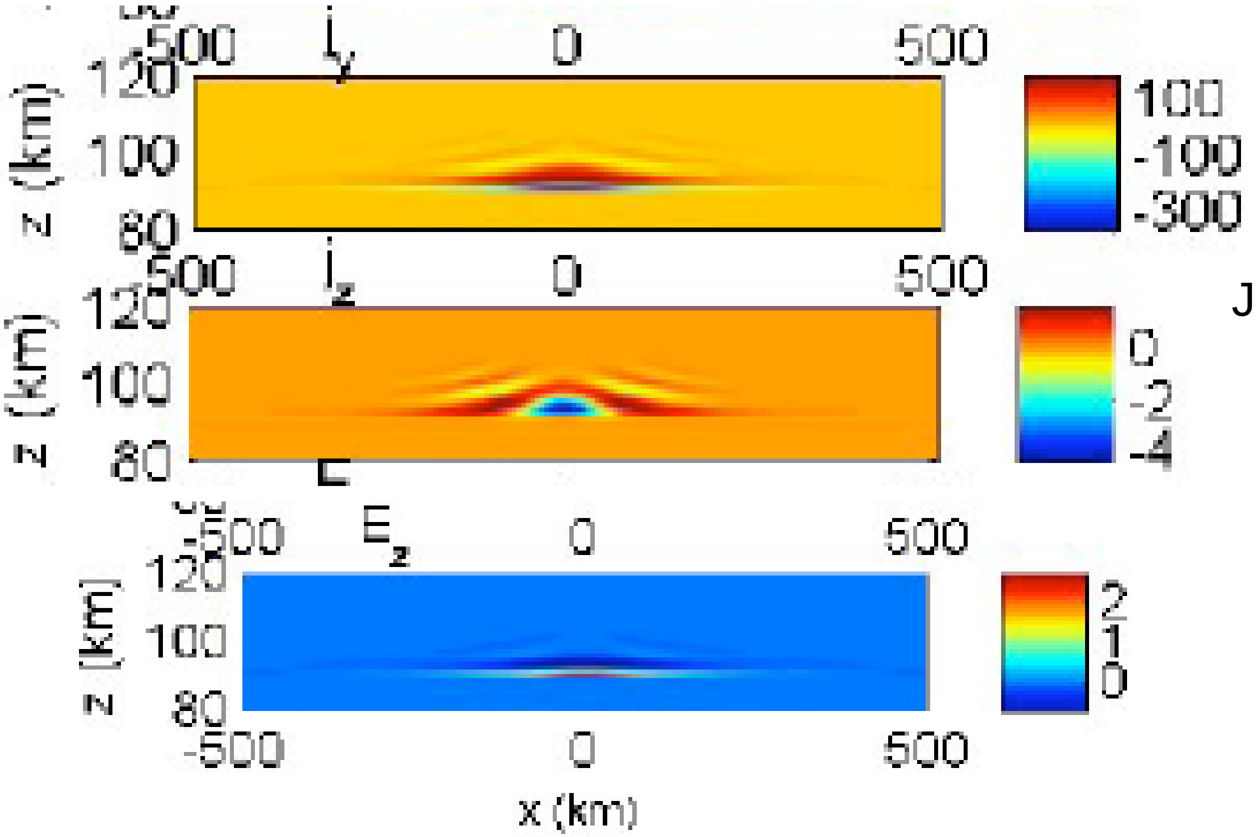


Currents at $z = 92$ km, CW antenna field



—— Daytime, - - - Nighttime

Induced currents in the lower ionosphere



J in nA/m^2

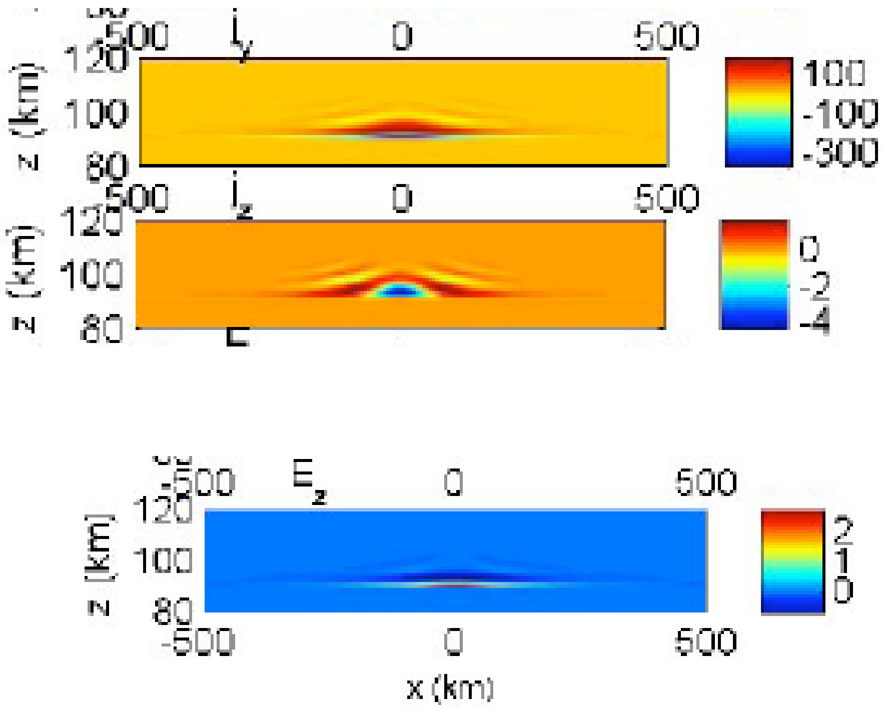
E in mV/m

Estimates: Assume $\Delta y \approx 100$ km -> I_v**≈60 A**, **$I_vL \approx 6 \times 10^5$ A-m**, **$I_H \approx 400$ A**, **$I_HL \approx 4 \times 10^7$ A-m**

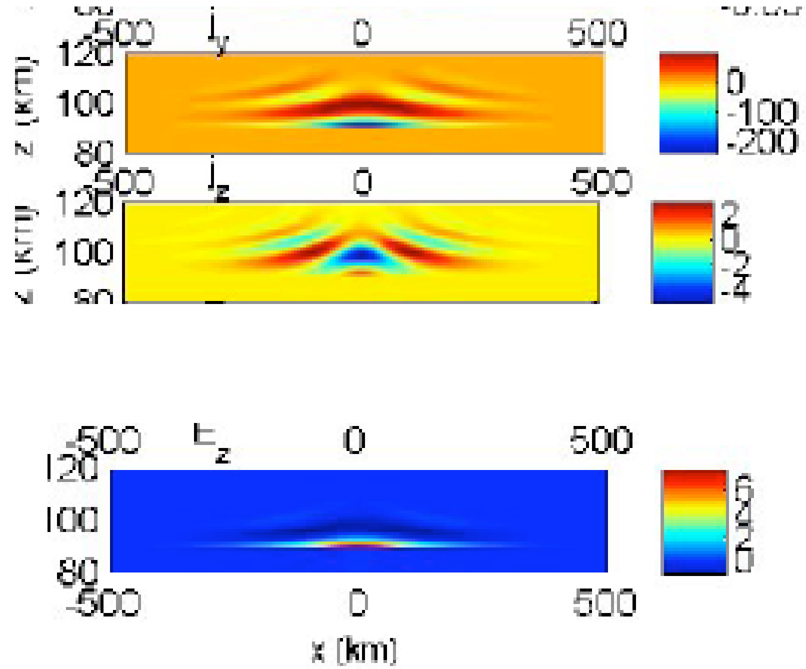
Current closure through field aligned currents carried by helicons

Get .1 nT fields at Mm distance

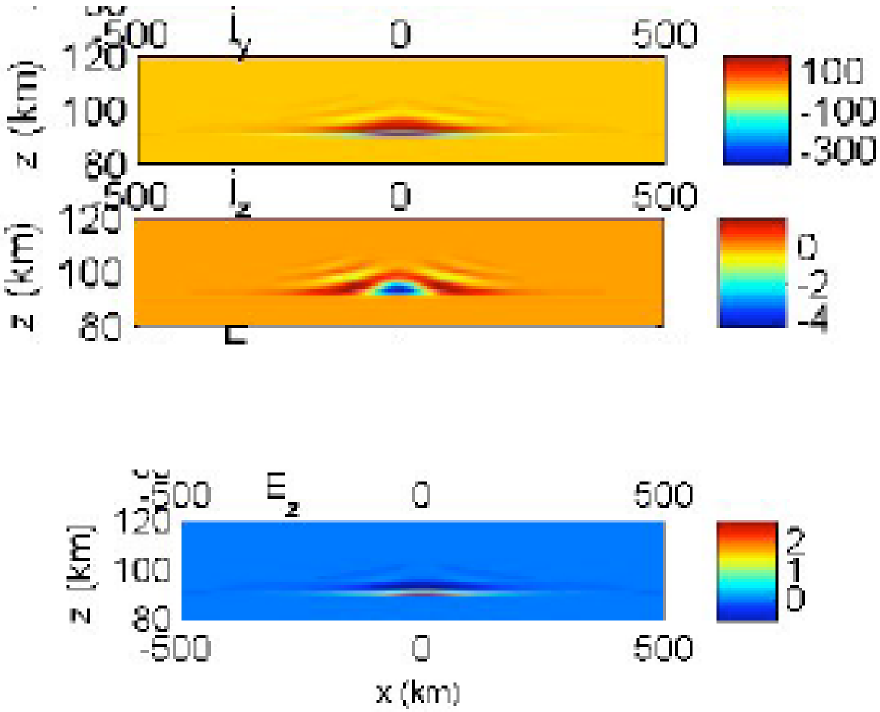
Daytime



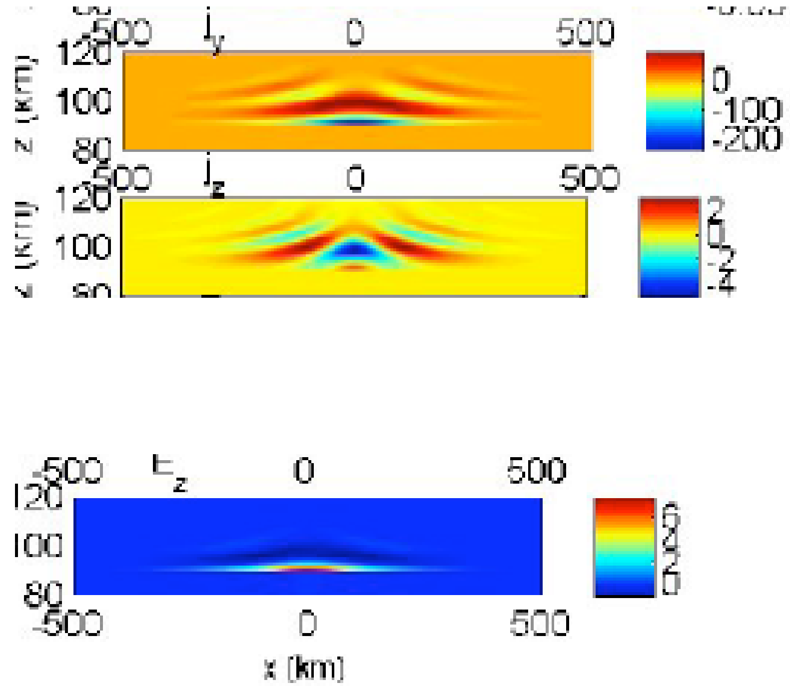
Nighttime



Daytime

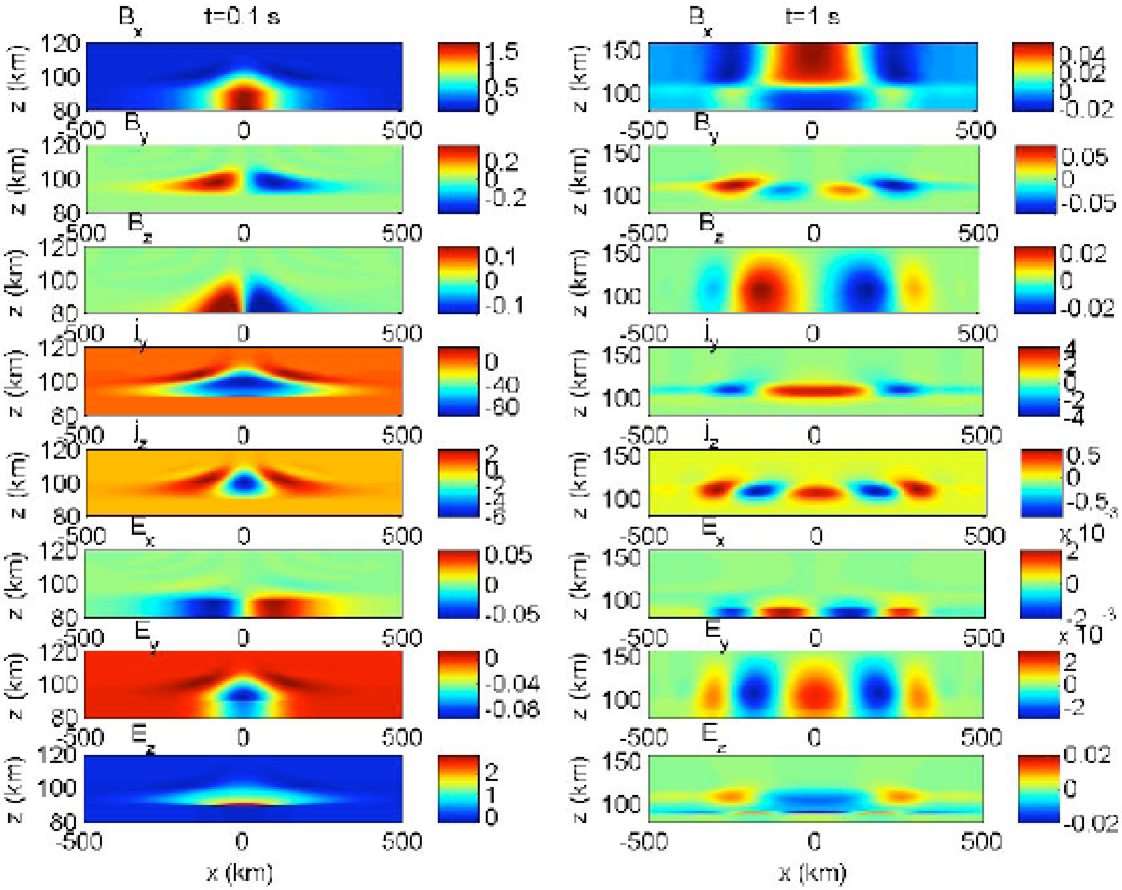


Nighttime

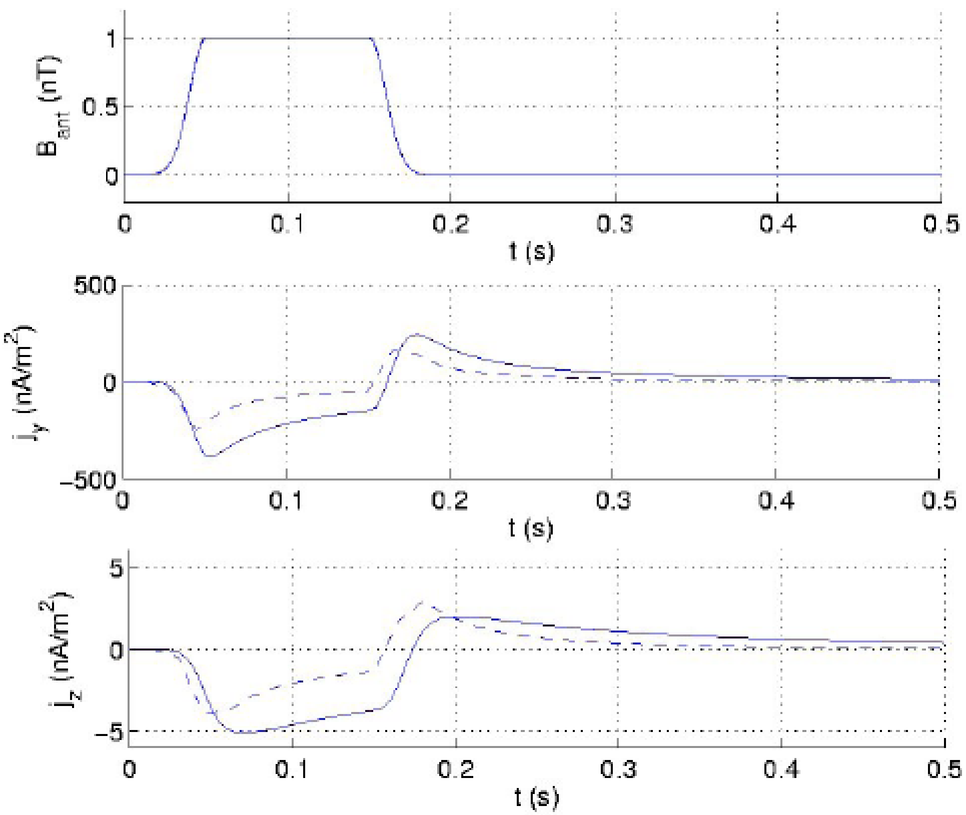


Pulsed antenna field, nighttime conditions

Profiles of $\mathbf{B}$ (nT), $\mathbf{j}$ $(\mathrm{nA/m^2})$ and $\mathbf{E}$ $(\mathrm{mV/m})$

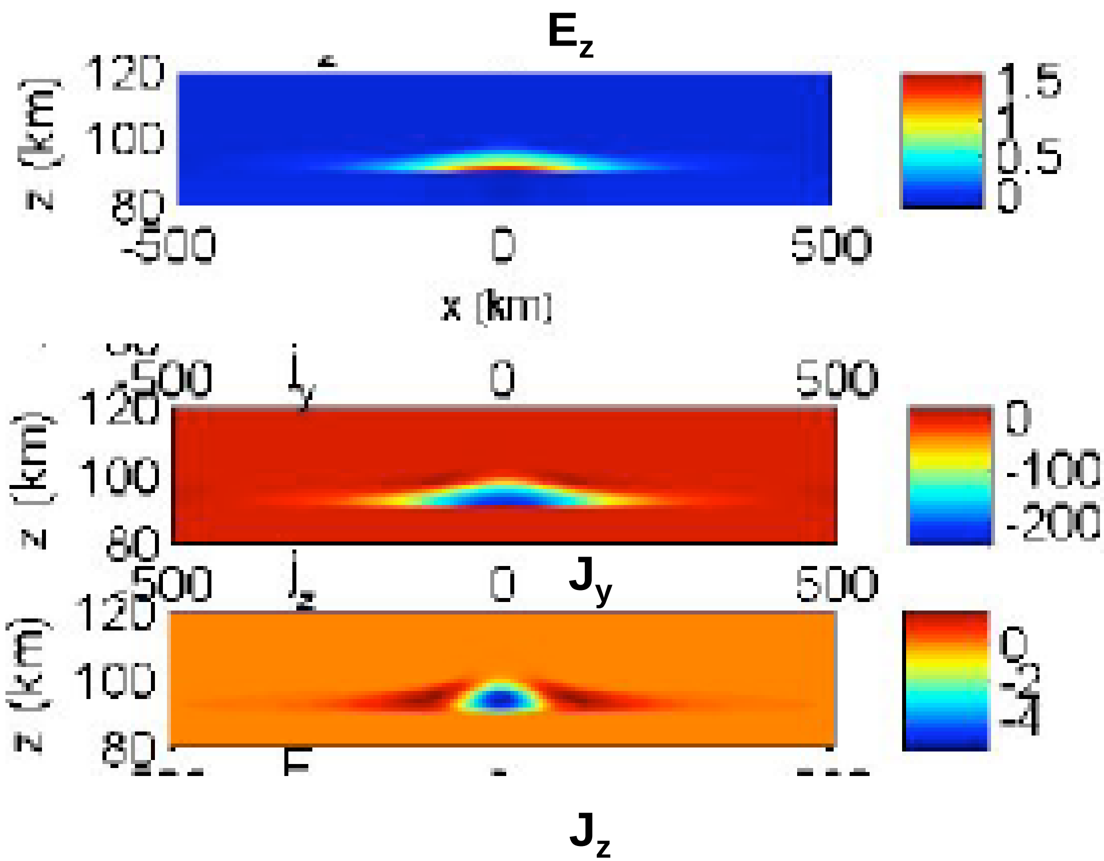


Currents at $z = 92$ km, pulsed antenna field



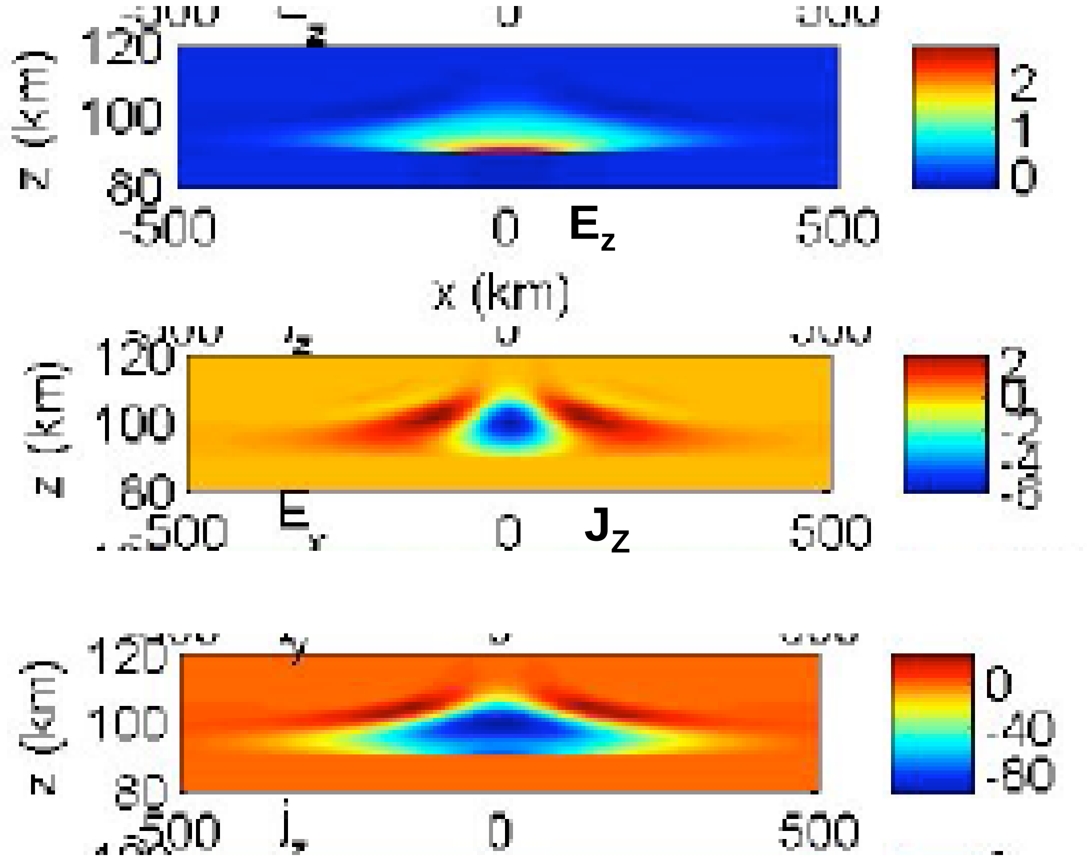
—— Daytime, - - - Nighttime

Induced Pulsed Ionospheric Current



Day time
Pulse

Induced Pulsed Ionospheric Current



Nighttime
Pulsed

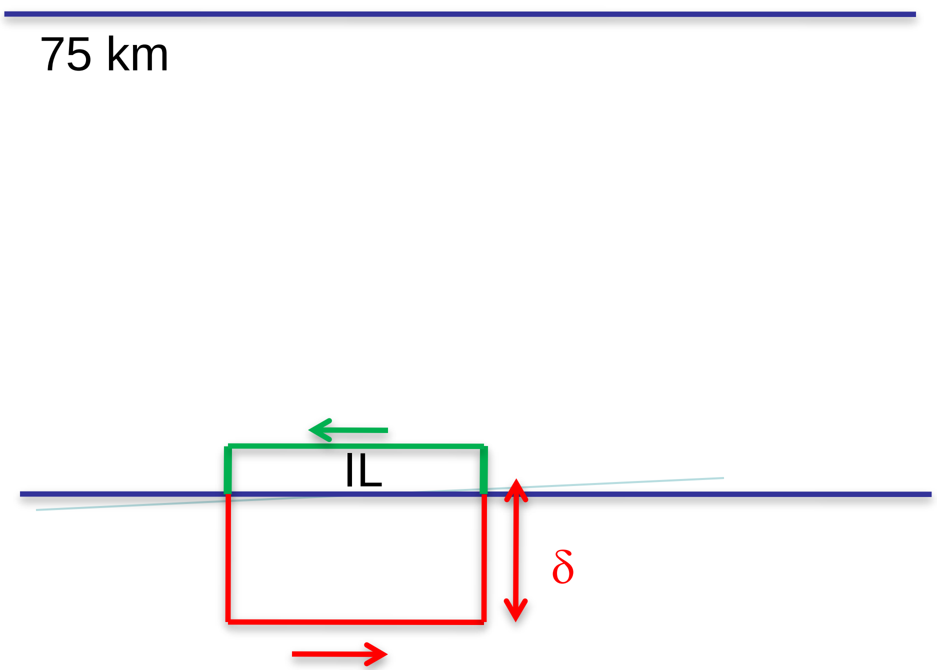
Getting nT field at 75 km

$$B(75km) = (IL/5\times10^{6}A - m)(\delta/75km)$$

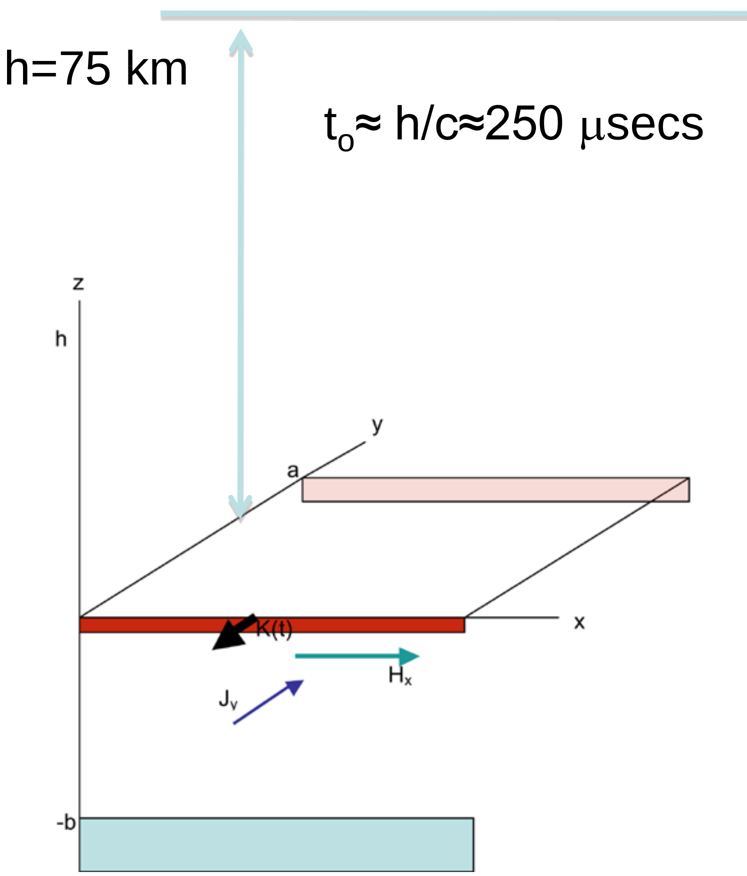
Skin depth km like
Conductivity dependent

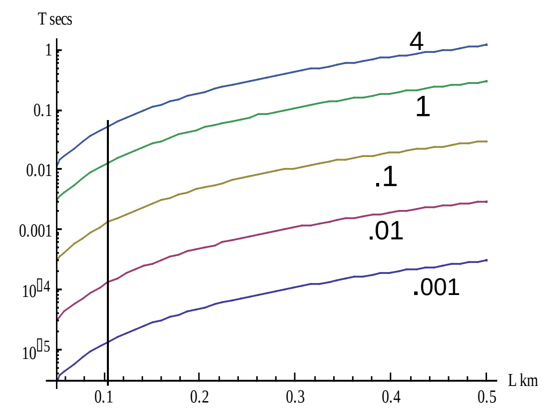
↓

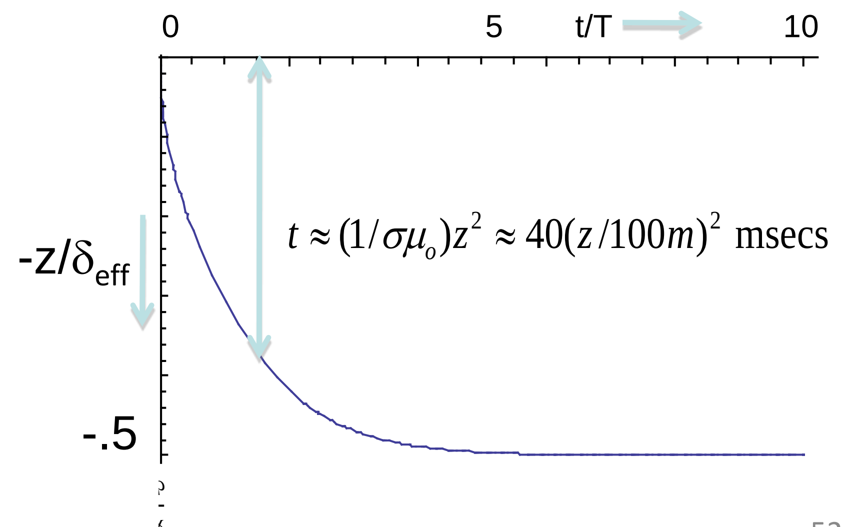
Use pulsed antenna
sneak-through concept



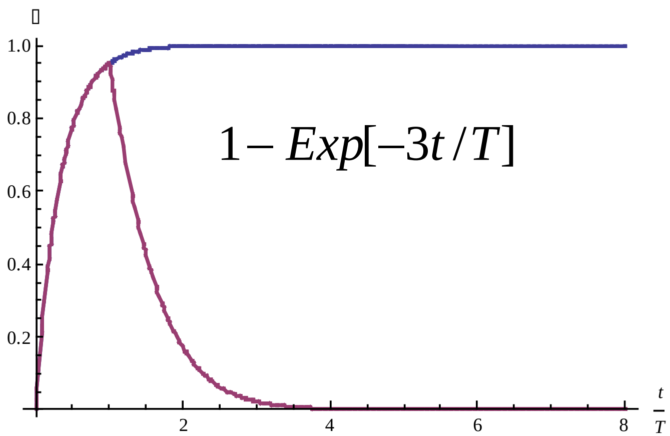
Sneak-through Concept

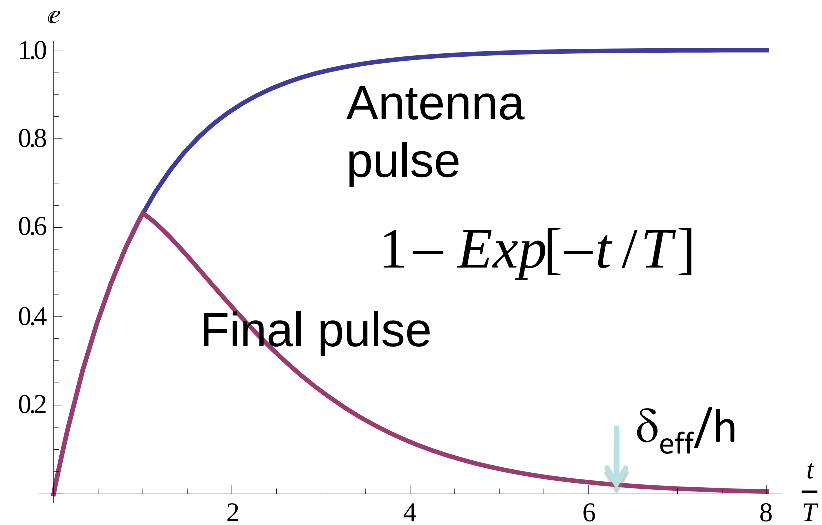






Sneak-through Concept

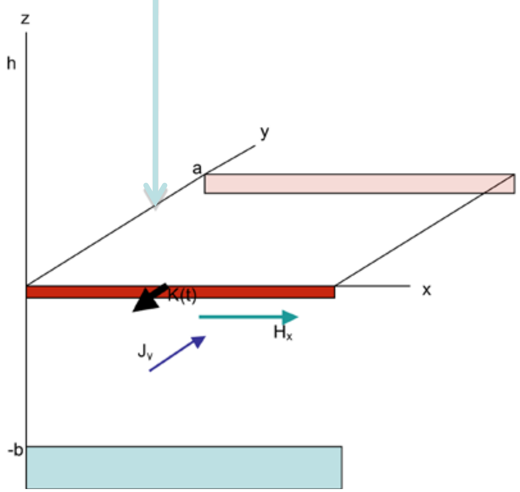


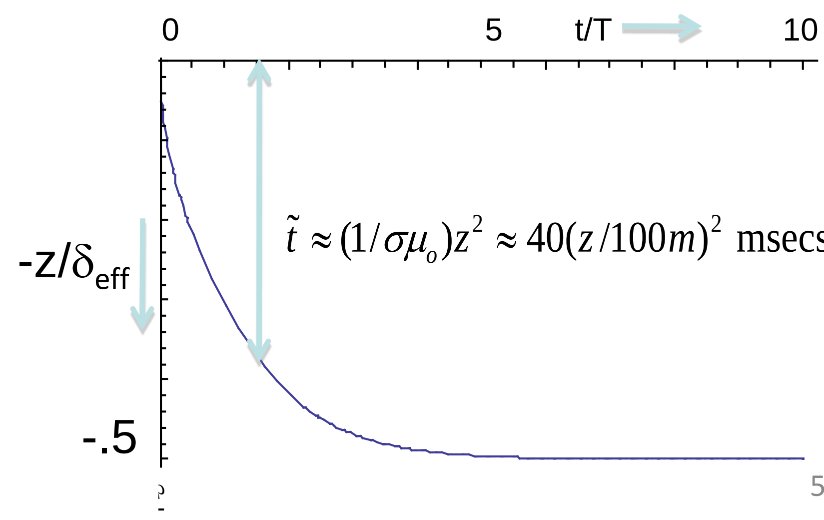


h=75 km

$t_o \approx h/c \approx 250$ μsecs

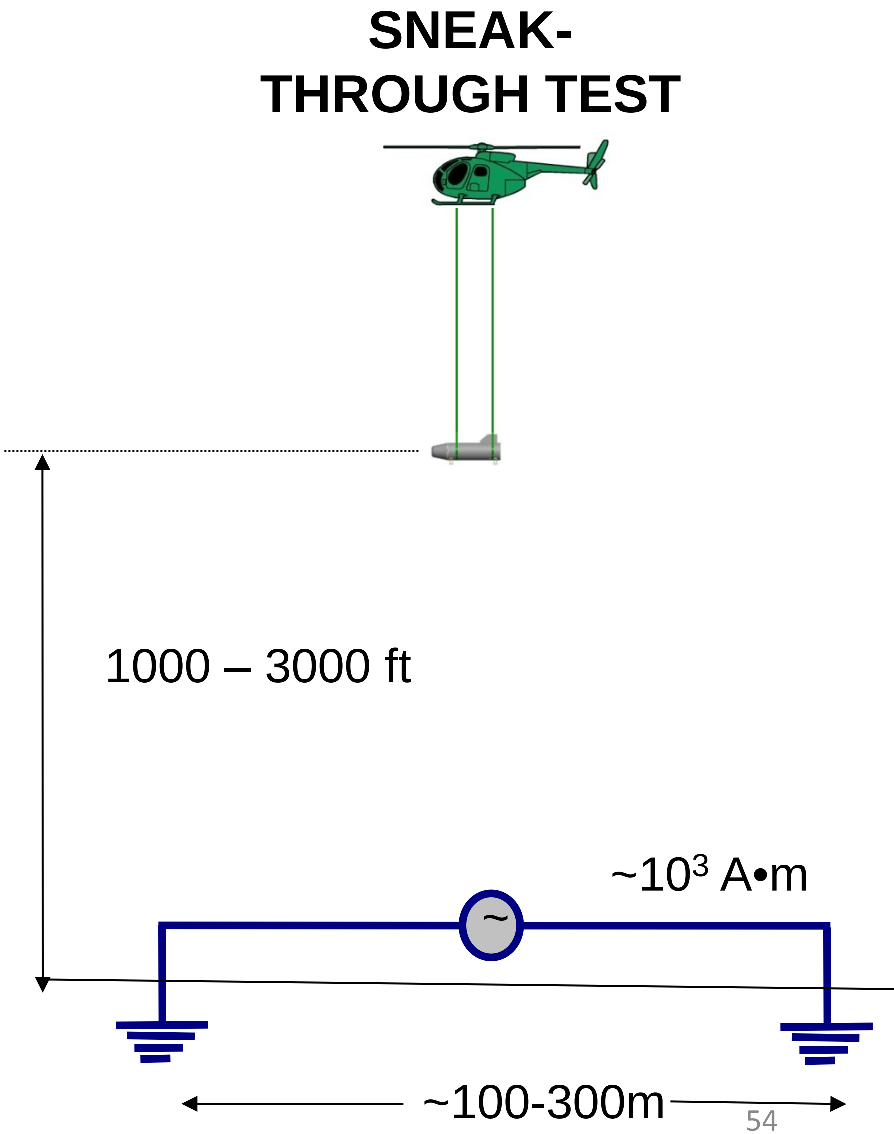
$$H(z,t) \propto K(t-t_o) - K(t-t_o-\tilde{t}) \approx \tilde{t}K'(t-t_o)$$



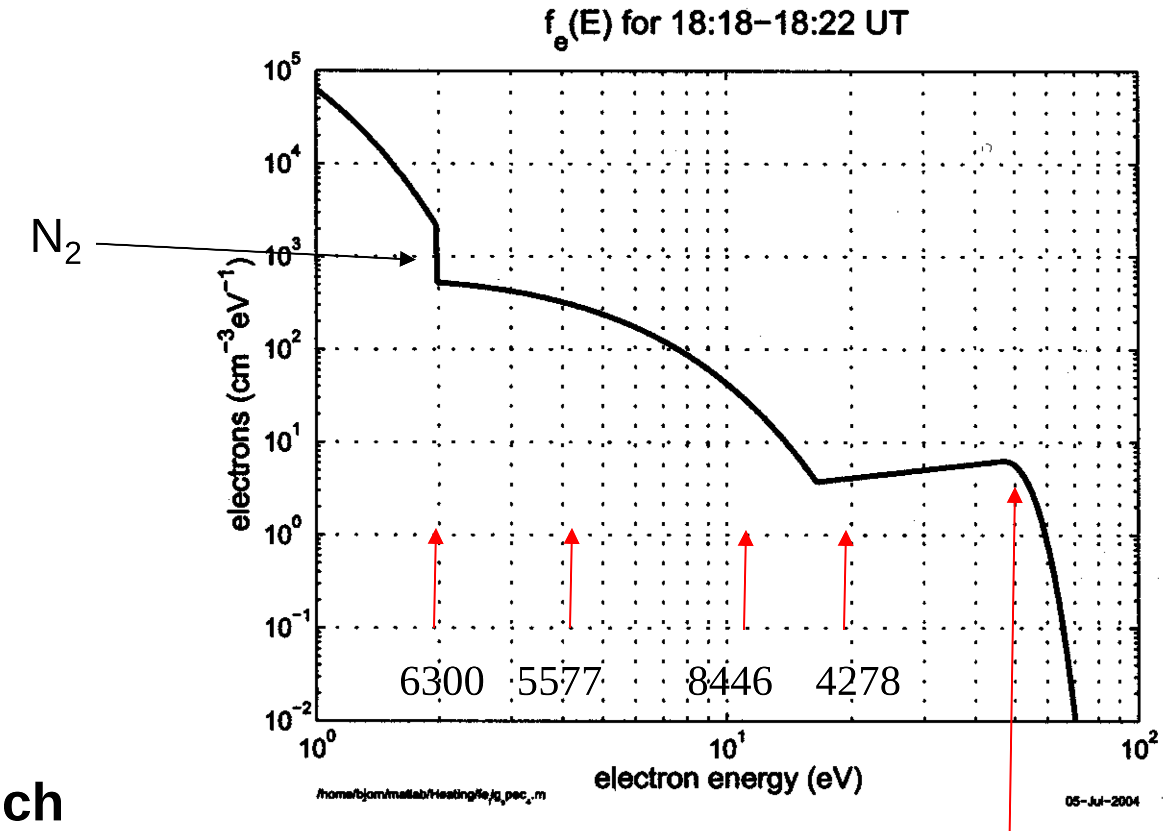


PACE – SUMMARY STATUS

DARPA Seedling awarded for Sneak-through test . Probably May.



Reconstruction of the EDF

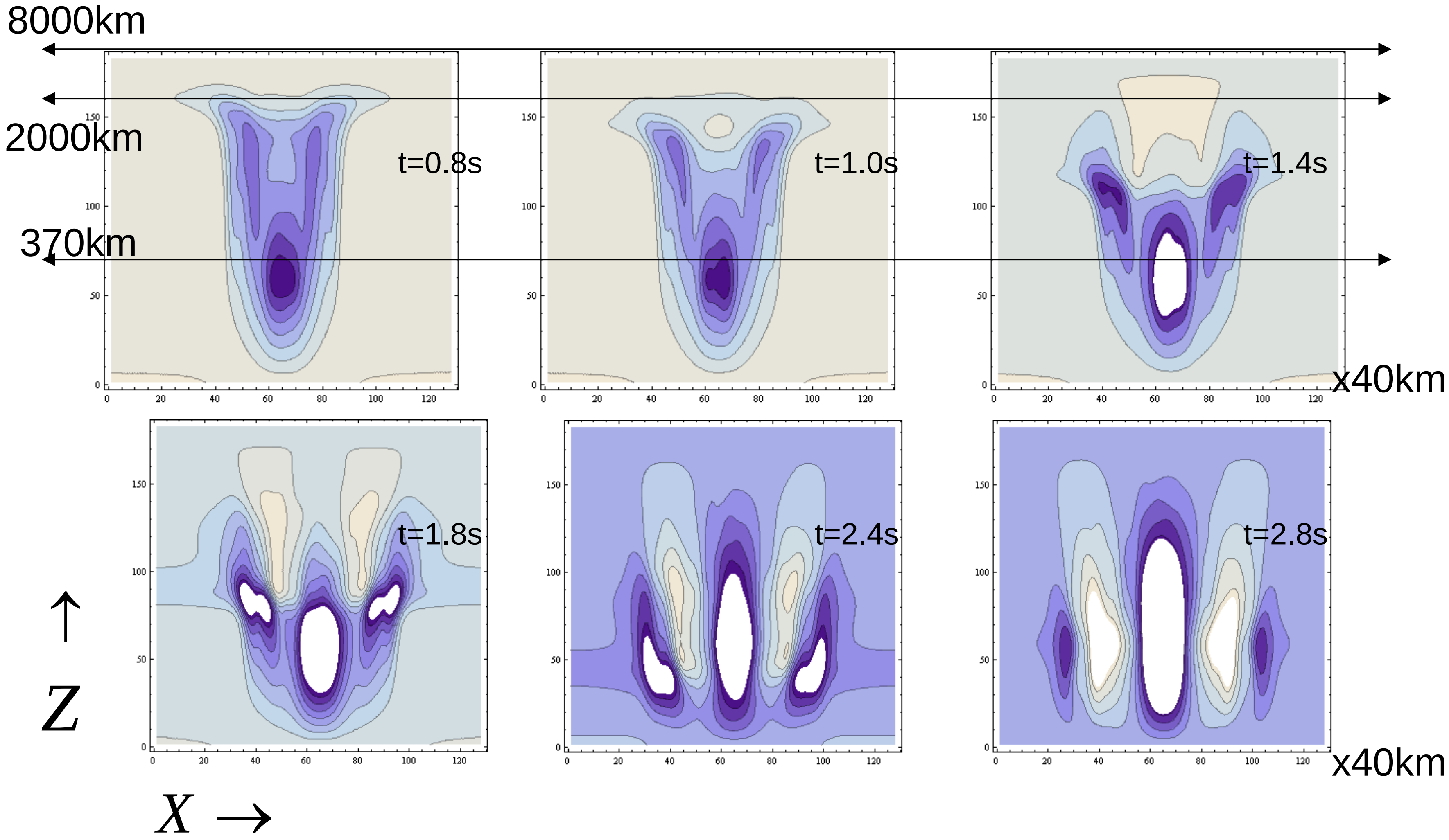


M. Kosch

~ 0.5 million Kelvin

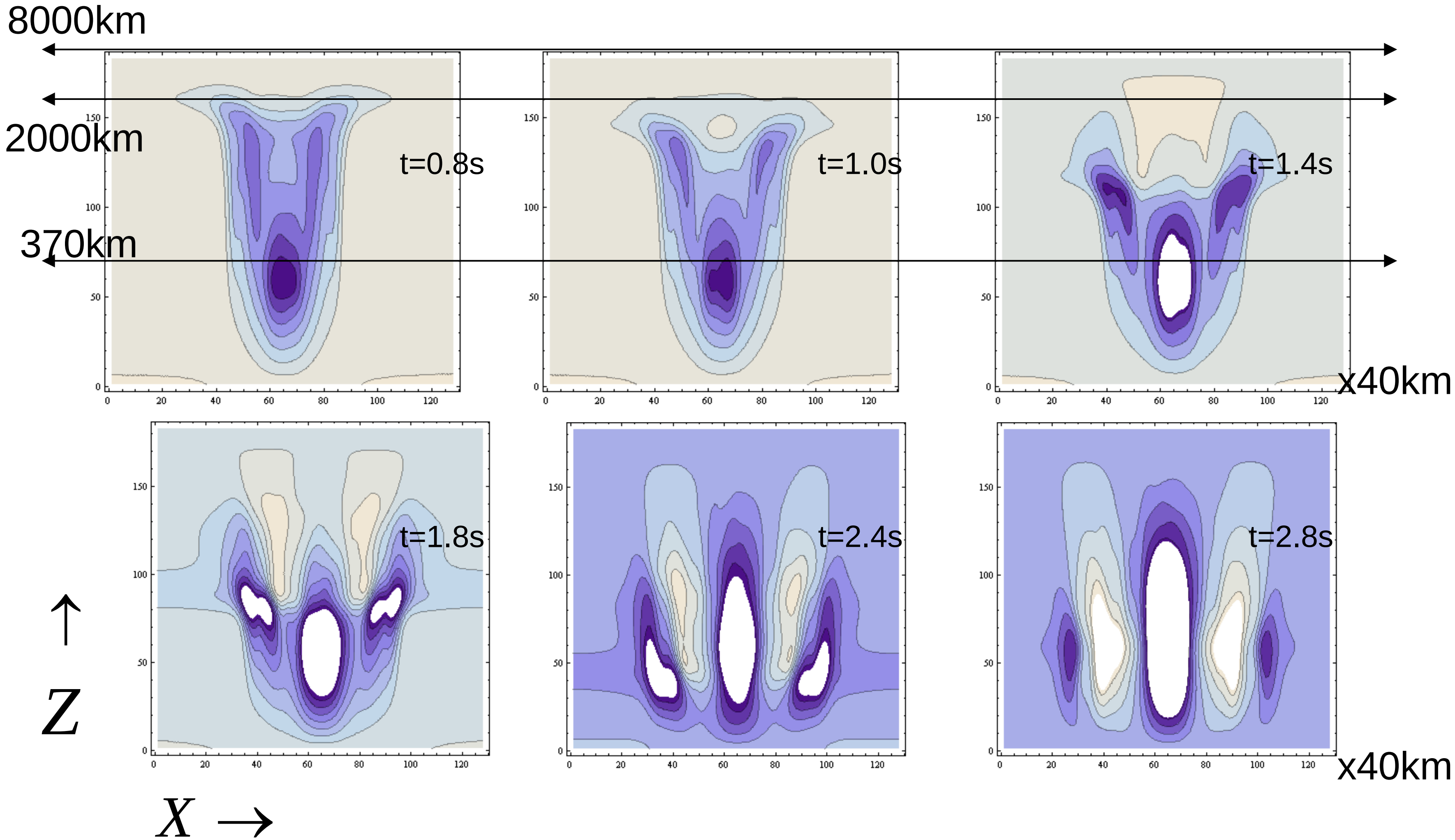
Electron temperature <3500 K ➔ Bulk electron energy <0.3 eV

2D Simulations Show Far Lateral Propagation



Sinusoidal sweep

2D Simulations
Show Far Lateral Propagation



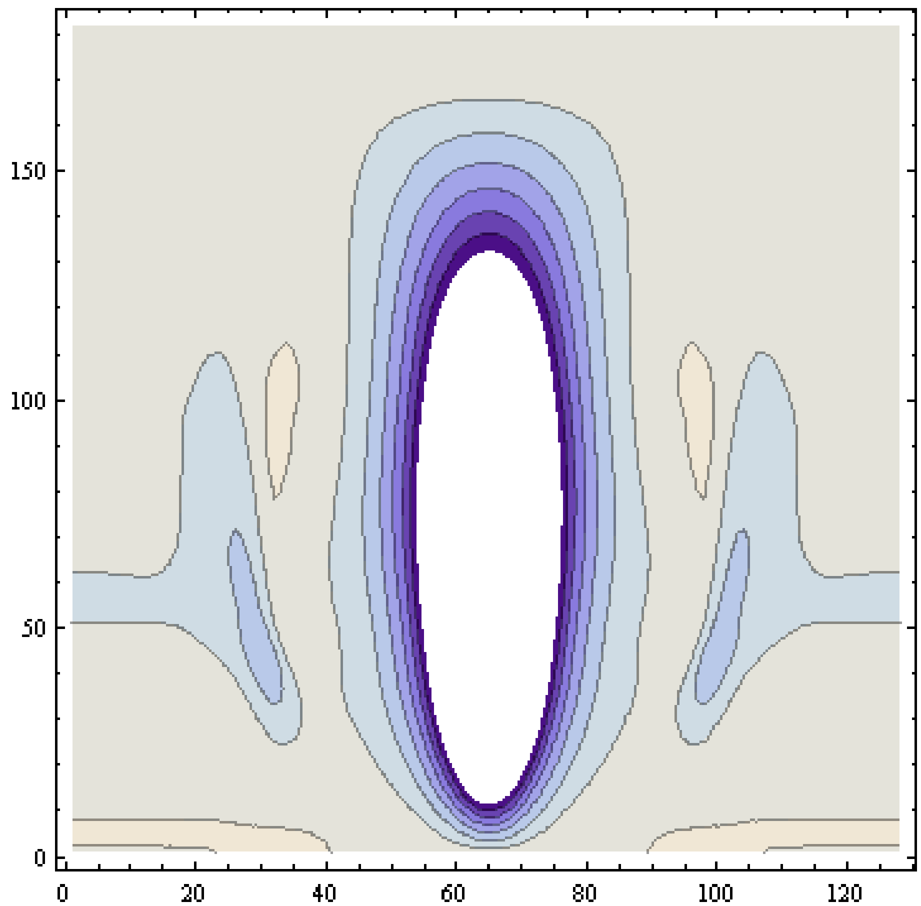
Sinusoidal sweep

Parameter Study
Shows that Strong F-layer
is Critical for Far Propagation

- Four frequencies: 3.0, 4.0, 6.0 and 8.0 MHz.
- For FoF2 >= 6MHz strong waves in far field

  For FoF2 <= 4MHz far field very weak

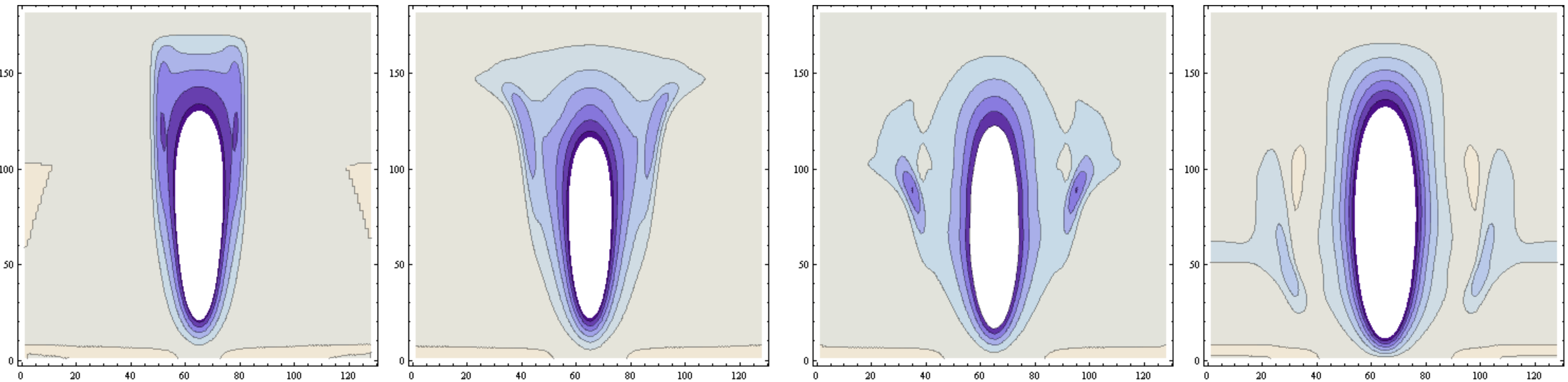
- Limit experiments to FoF2 > 4.0MHz



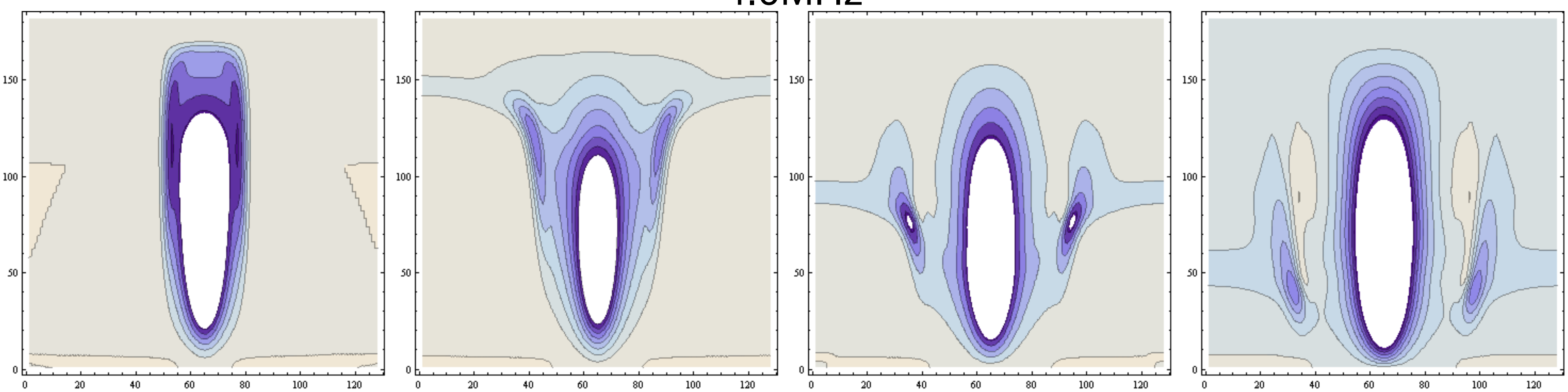
150
100
50
0
0
20
40
60
80
100
120

Weaker F-Layer Gives Weaker Waves

3.0MHz

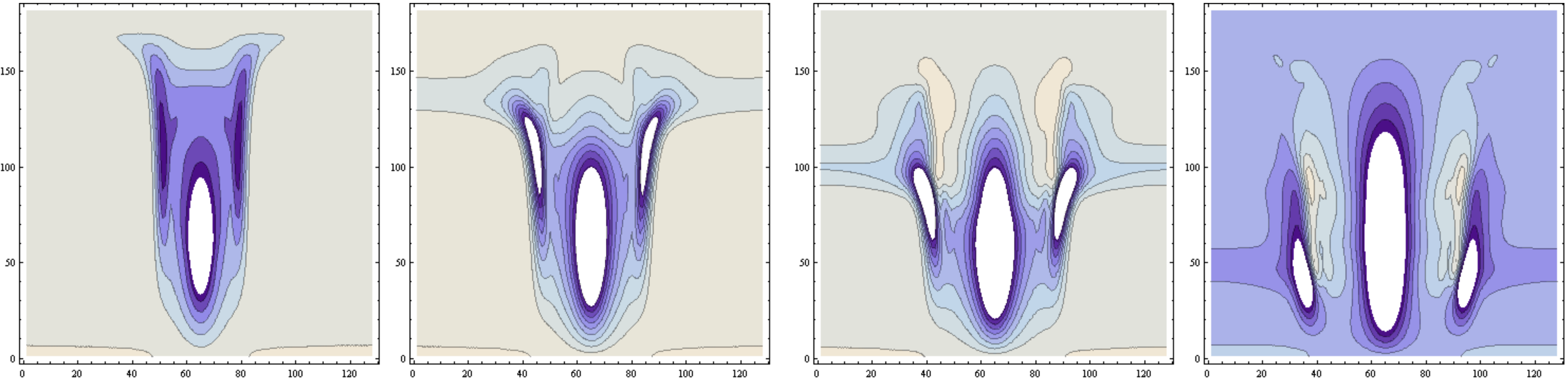


4.0MHz

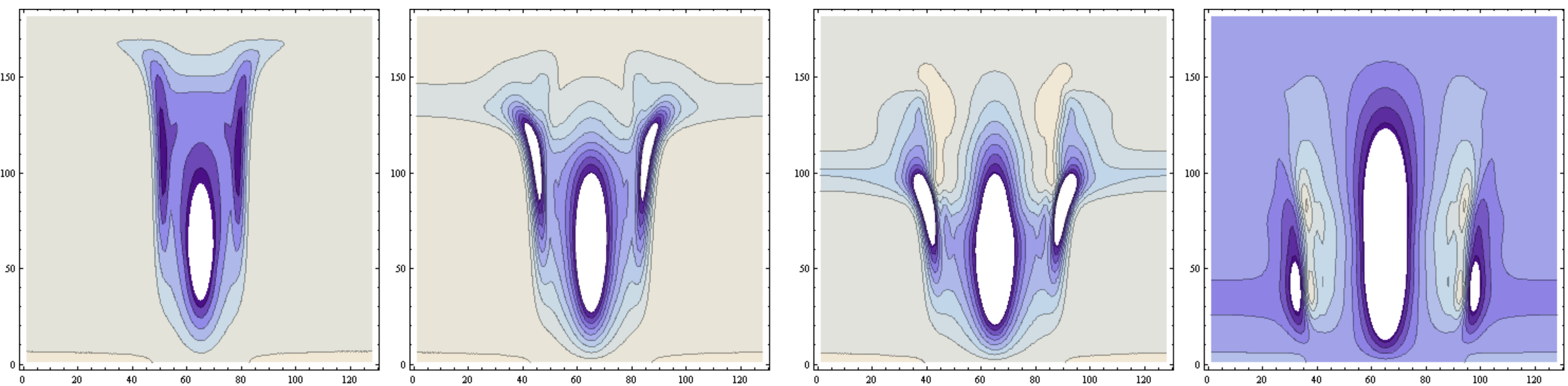


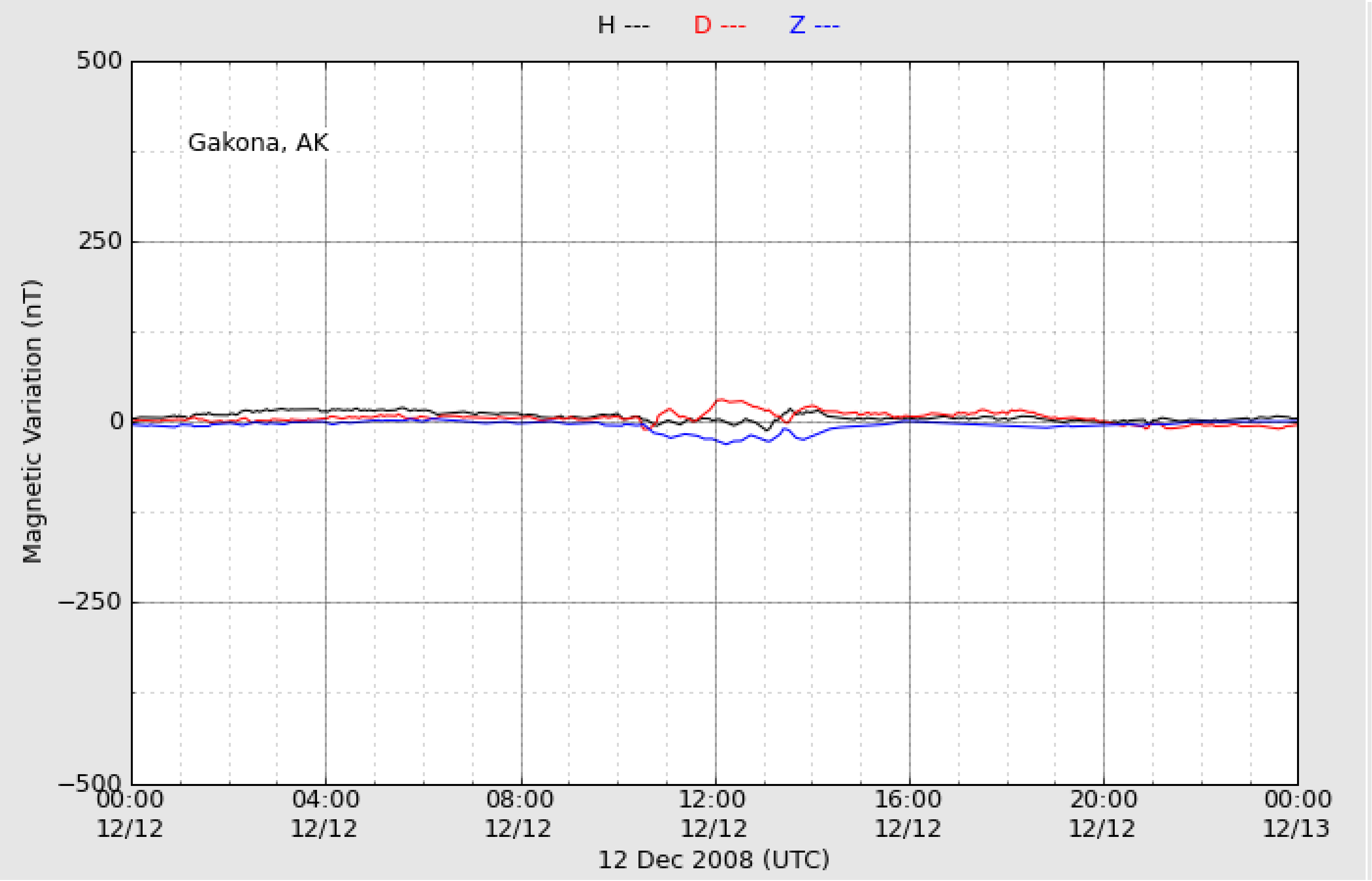
Weaker F-Layer Gives Weaker Waves

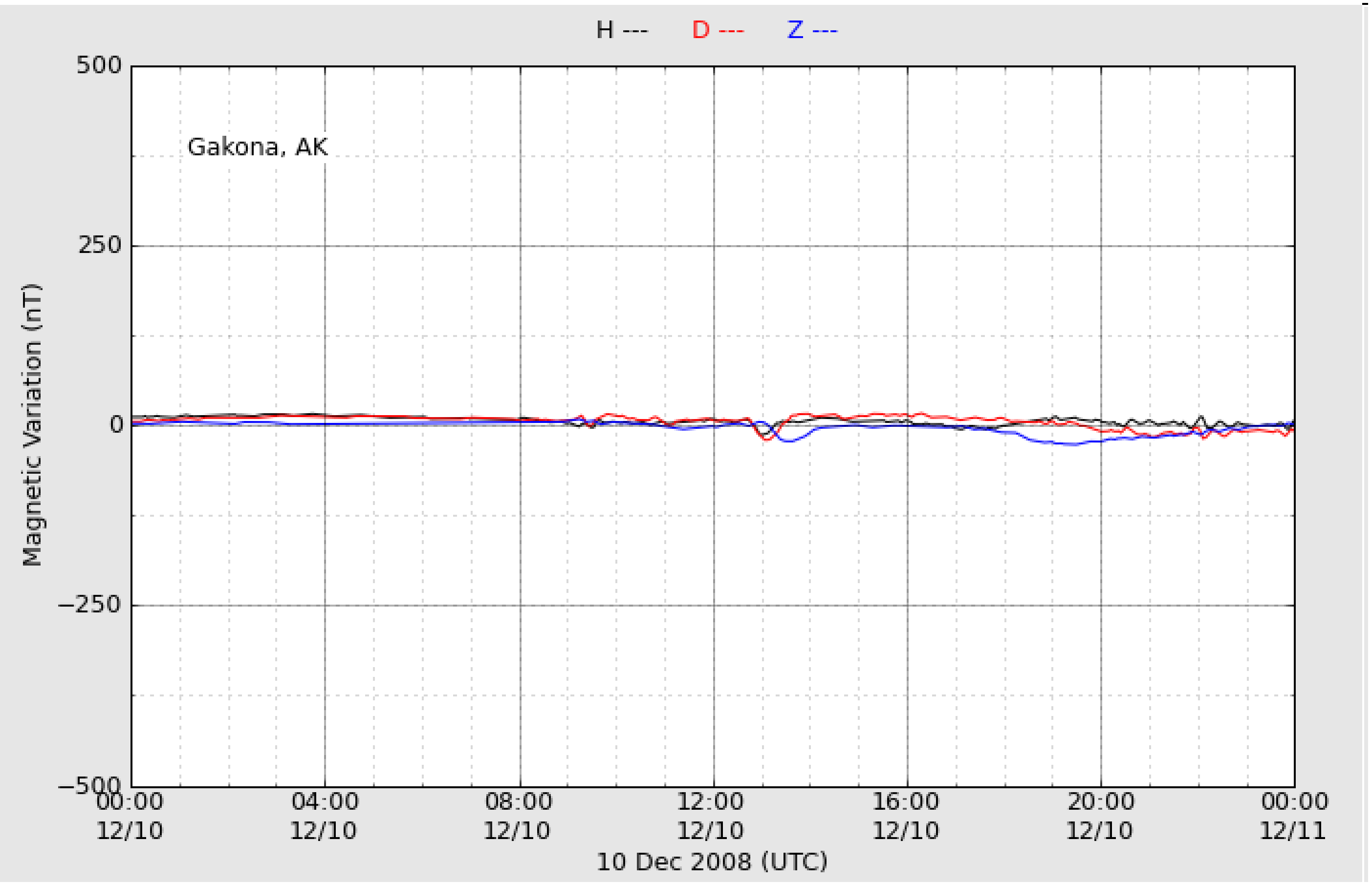
6.0MHz



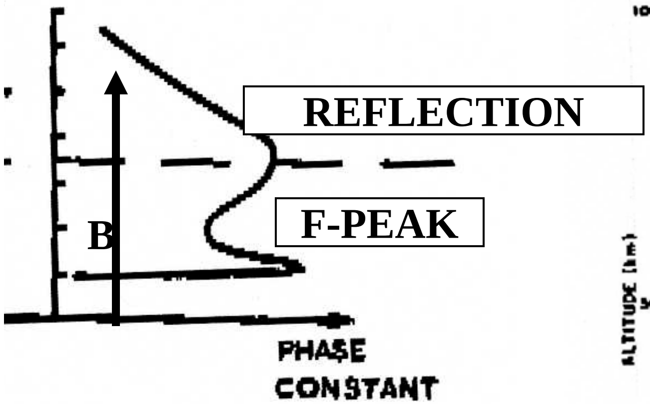
8.0MHz

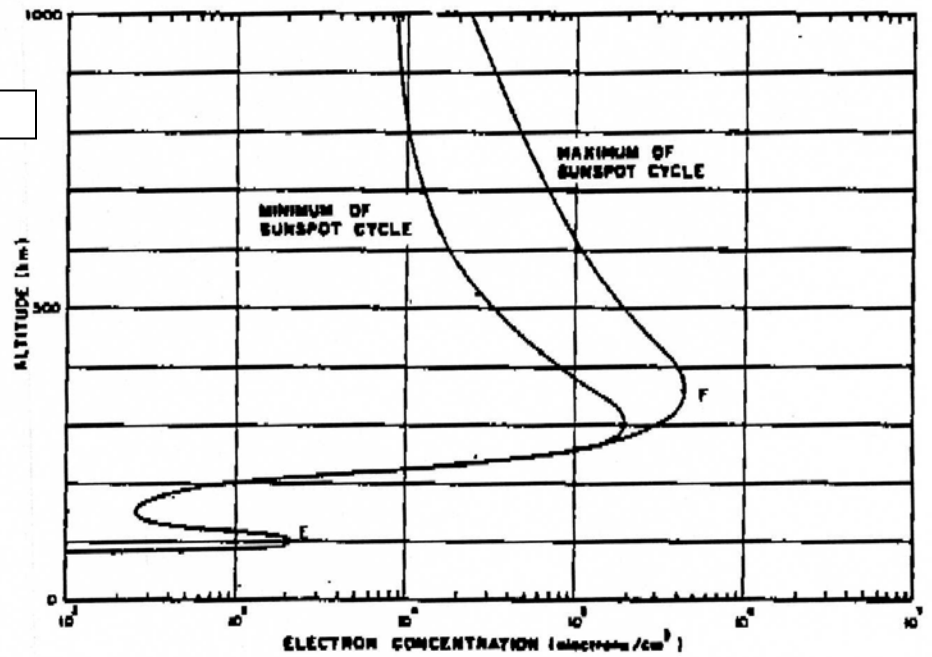


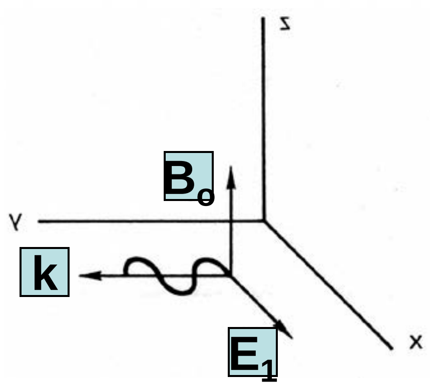

H ---
D ---
Z ---
500
250
0
−250
−500
Gakona, AK
Magnetic Variation (nT)
00:00
12/12
04:00
12/12
08:00
12/12
12:00
12/12
16:00
12/12
20:00
12/12
00:00
12/13
12 Dec 2008 (UTC)


H ---
D ---
Z ---
Gakona, AK
Magnetic Variation (nT)
500
250
0
−250
−500
00:00
12/10
04:00
12/10
08:00
12/10
12:00
12/10
16:00
12/10
20:00
12/10
00:00
12/11
10 Dec 2008 (UTC)

Near Earth LF Waveguides





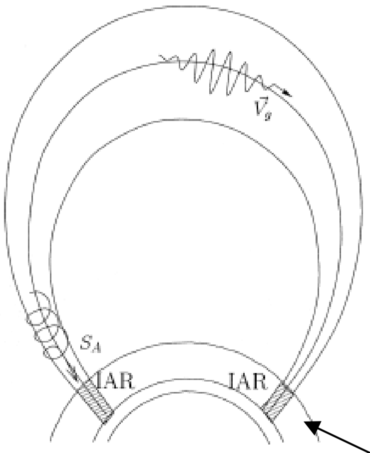


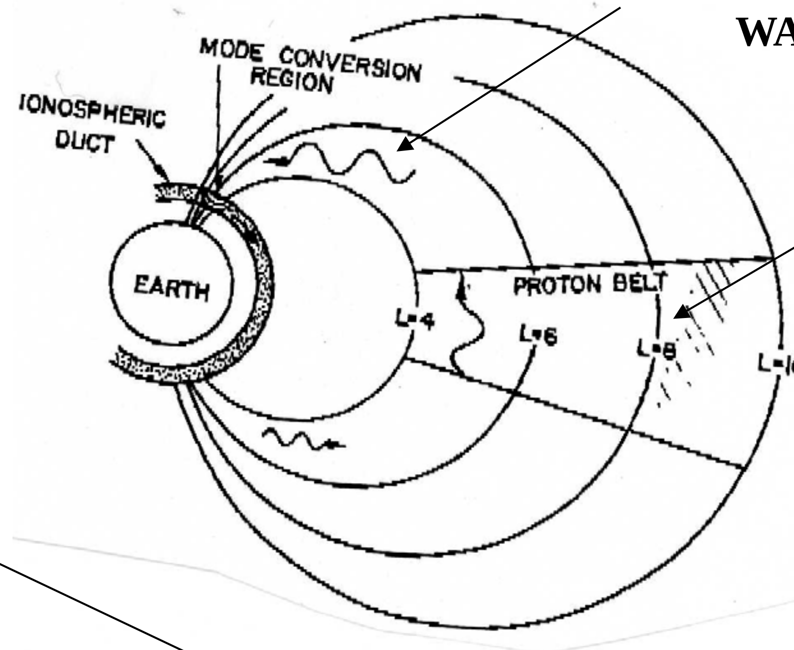
Magnetosonic Alfven
Wave (compressional)

PHYSICS – TRIGGERED ULF

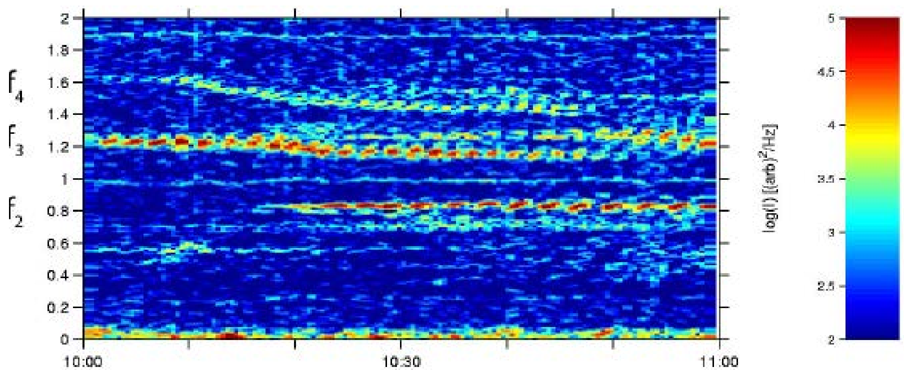
SHEAR ALFVEN WAVE

Ion Cyclotron Instability

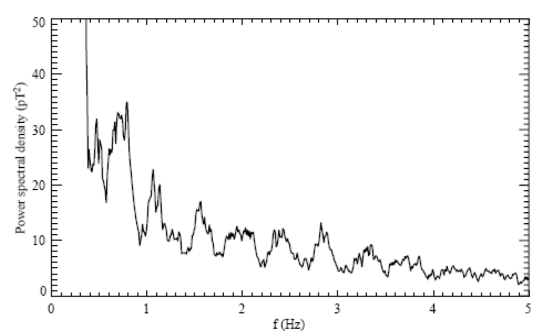




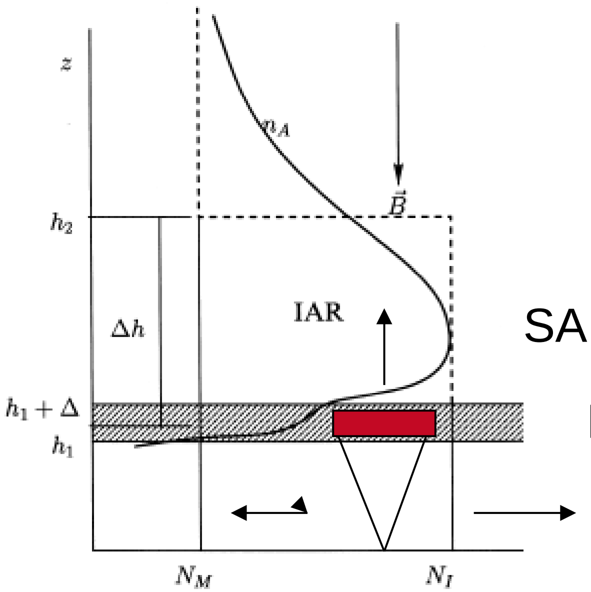
BOUNCING WAVE-PACKET



BANDPASS FILTER



ULF Generation by Ejet Modulation



SA waves do not Excite Ionospheric Duct

D/E region heating + Electrojet

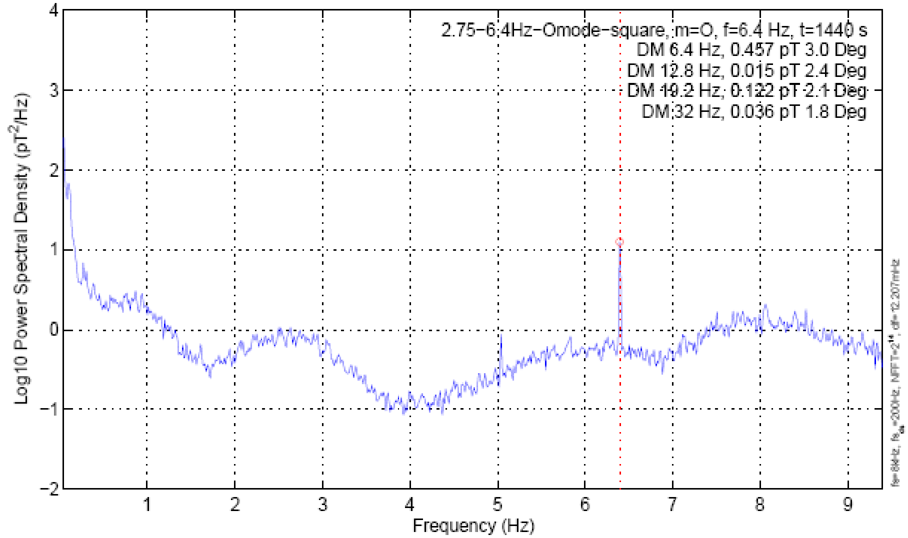
Evanescent in EI Waveguide

- 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.

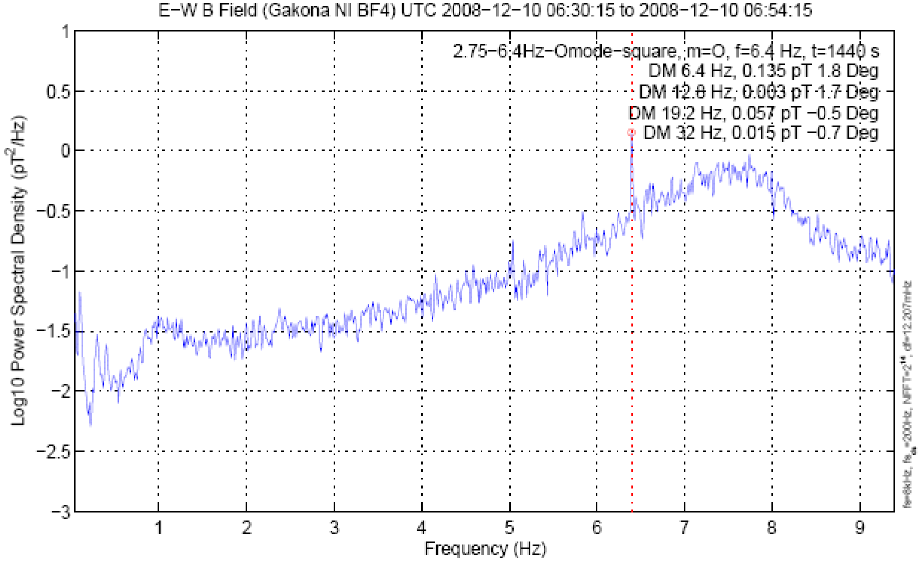
2.75−6.4Hz−Omode−square : [2008−12−10 06:30:00 to 2008−12−10 06:54:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,

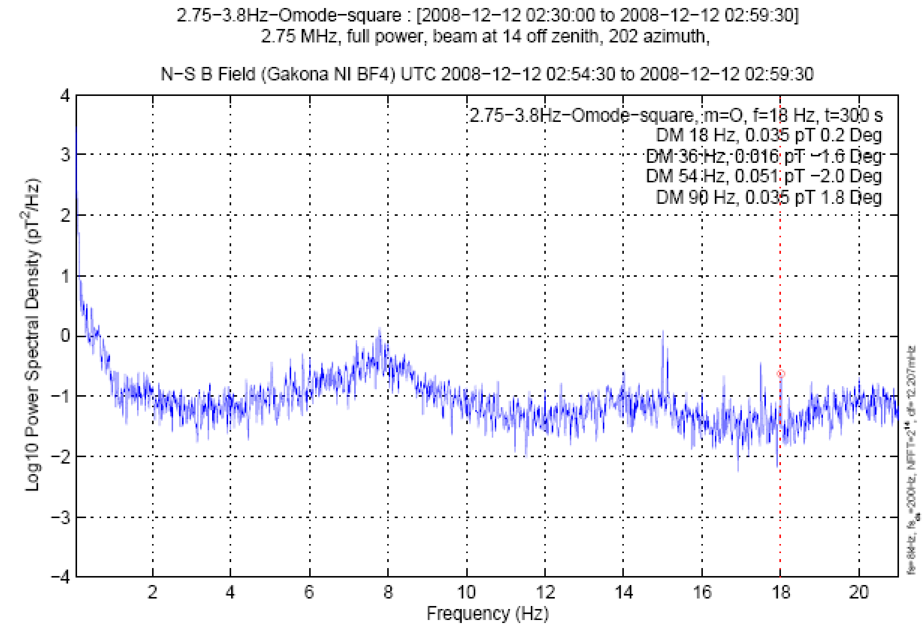
N−S B Field (Gakona NI BF4) UTC 2008−12−10 06:30:15 to 2008−12−10 06:54:15

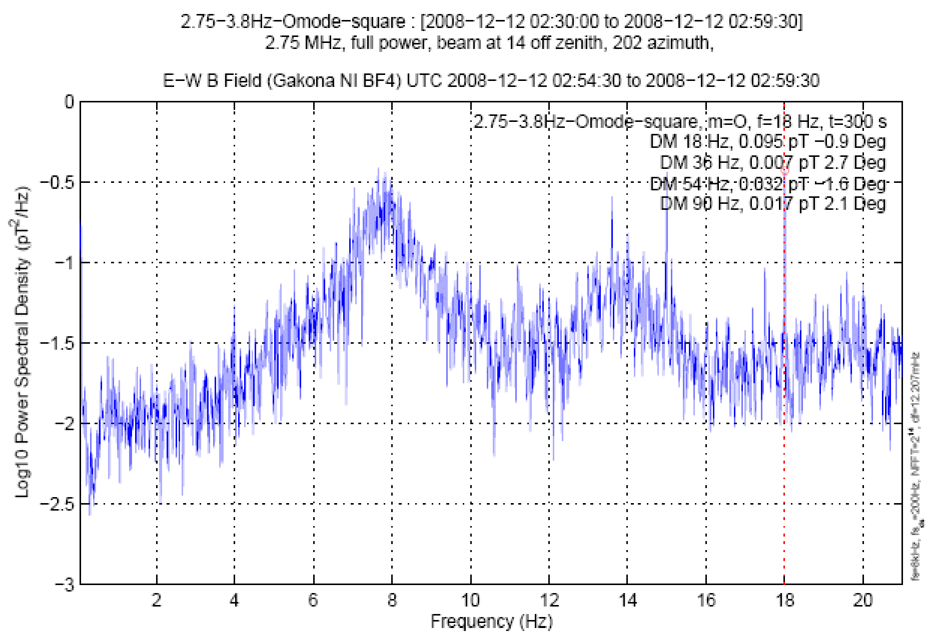


2.75−6.4Hz−Omode−square : [2008−12−10 06:30:00 to 2008−12−10 06:54:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,

E−W B Field (Gakona NI BF4) UTC 2008−12−10 06:30:15 to 2008−12−10 06:54:15

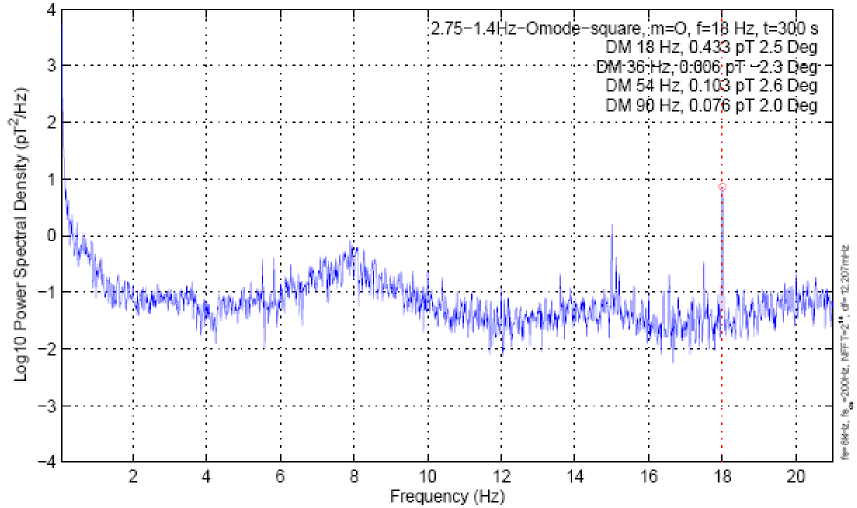



2.75−3.8Hz−Omode−square : [2008−12−12 02:30:00 to 2008−12−12 02:59:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
N−S B Field (Gakona NI BF4) UTC 2008−12−12 02:54:30 to 2008−12−12 02:59:30
2.75−3.8Hz−Omode−square, m=O, f=18 Hz, t=300 s
DM 18 Hz, 0.035 pT 0.2 Deg
DM 36 Hz, 0.016 pT −1.6 Deg
DM 54 Hz, 0.051 pT −2.0 Deg
DM 90 Hz, 0.035 pT 1.8 Deg
Log10 Power Spectral Density (pT²/Hz)
Frequency (Hz)


2.75−3.8Hz−Omode−square : [2008−12−12 02:30:00 to 2008−12−12 02:59:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
E−W B Field (Gakona NI BF4) UTC 2008−12−12 02:54:30 to 2008−12−12 02:59:30
2.75−3.8Hz−Omode−square, m=O, f=18 Hz, t=300 s
DM 18 Hz, 0.095 pT −0.9 Deg
DM 36 Hz, 0.007 pT 2.7 Deg
DM 54 Hz, 0.032 pT −1.6 Deg
DM 90 Hz, 0.017 pT 2.1 Deg
Log10 Power Spectral Density (pT²/Hz)
Frequency (Hz)

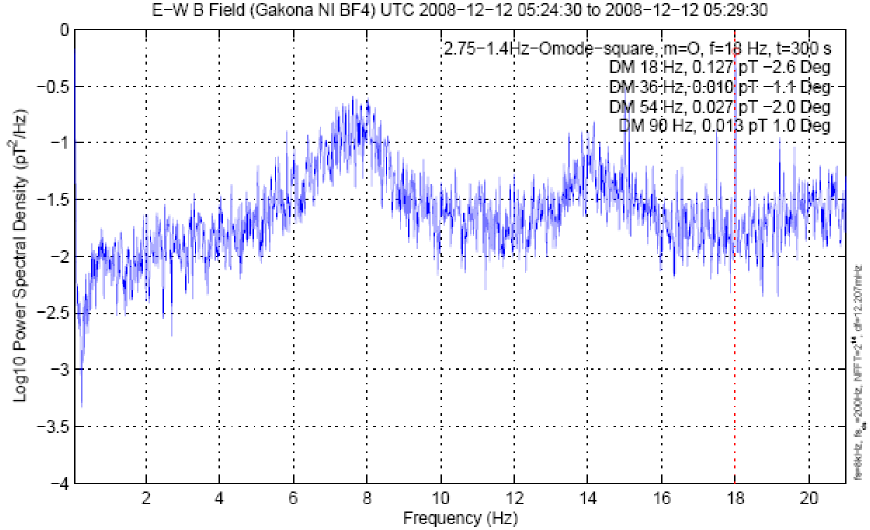
2.75−1.4Hz−Omode−square : [2008−12−12 05:00:00 to 2008−12−12 05:29:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,

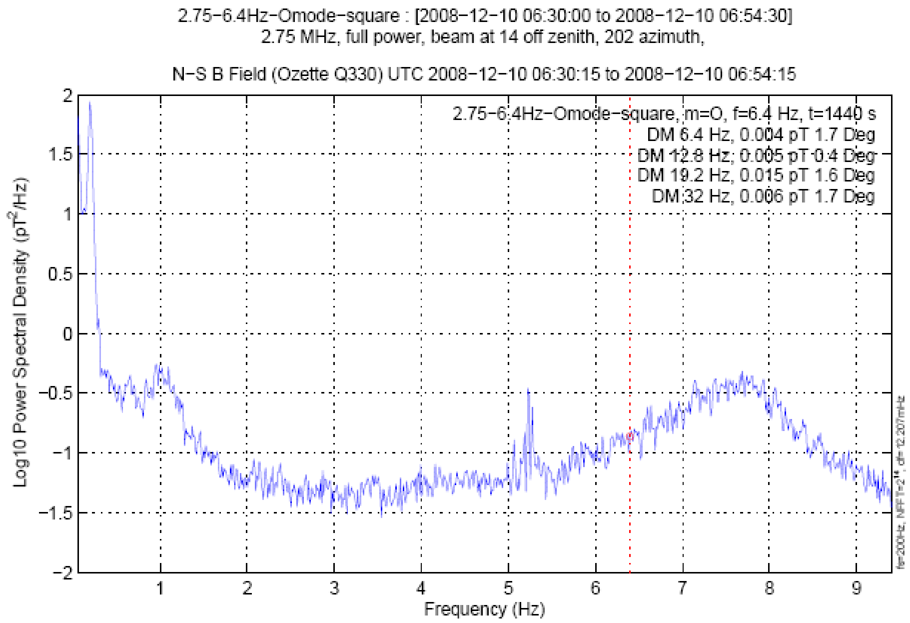
N−S B Field (Gakona NI BF4) UTC 2008−12−12 05:24:30 to 2008−12−12 05:29:30

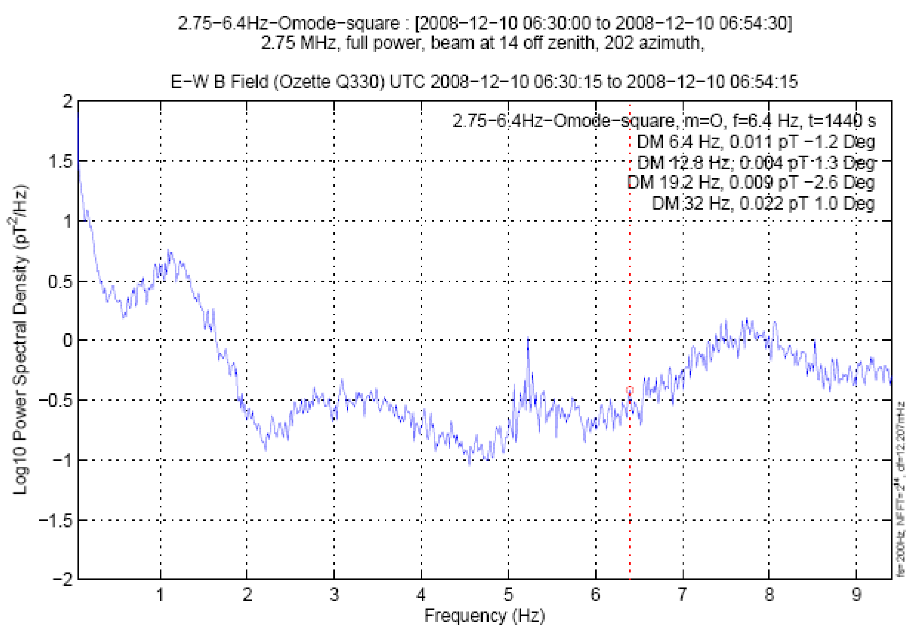


2.75−1.4Hz−Omode−square : [2008−12−12 05:00:00 to 2008−12−12 05:29:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,

E−W B Field (Gakona NI BF4) UTC 2008−12−12 05:24:30 to 2008−12−12 05:29:30

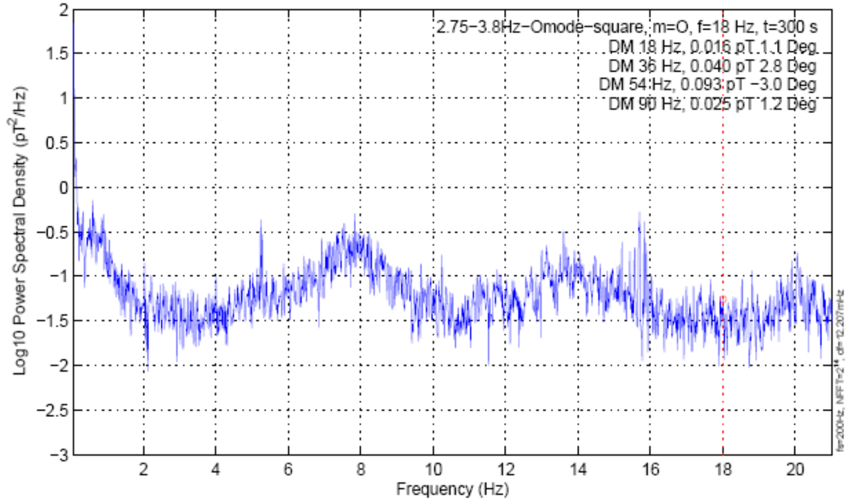



2.75−6.4Hz−Omode−square : [2008−12−10 06:30:00 to 2008−12−10 06:54:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
N−S B Field (Ozette Q330) UTC 2008−12−10 06:30:15 to 2008−12−10 06:54:15
2.75−6.4Hz−Omode−square, m=O, f=6.4 Hz, t=1440 s
DM 6.4 Hz, 0.004 pT 1.7 Deg
DM 12.8 Hz, 0.005 pT 0.4 Deg
DM 19.2 Hz, 0.015 pT 1.6 Deg
DM 32 Hz, 0.006 pT 1.7 Deg
Log10 Power Spectral Density (pT^2/Hz)
Frequency (Hz)
fs=200Hz, NFFT=2^14, df=12.207mHz


2.75−6.4Hz−Omode−square : [2008−12−10 06:30:00 to 2008−12−10 06:54:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
E−W B Field (Ozette Q330) UTC 2008−12−10 06:30:15 to 2008−12−10 06:54:15
2.75−6.4Hz−Omode−square, m=O, f=6.4 Hz, t=1440 s
DM 6.4 Hz, 0.011 pT −1.2 Deg
DM 12.8 Hz, 0.004 pT 1.3 Deg
DM 19.2 Hz, 0.009 pT −2.6 Deg
DM 32 Hz, 0.022 pT 1.0 Deg
Log10 Power Spectral Density (pT^2/Hz)
Frequency (Hz)
fs=200Hz, NFFT=2^14, df=12.207mHz

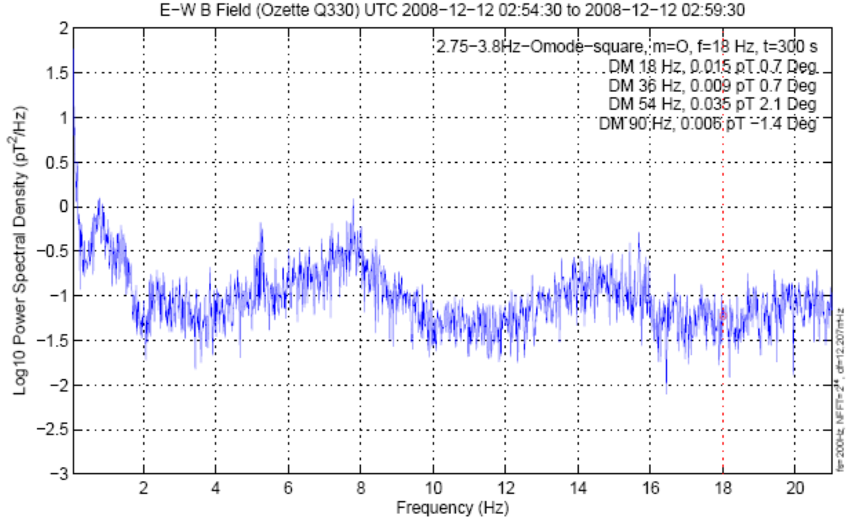
2.75−3.8Hz−Omode−square : [2008−12−12 02:30:00 to 2008−12−12 02:59:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,

N−S B Field (Ozette Q330) UTC 2008−12−12 02:54:30 to 2008−12−12 02:59:30



2.75−3.8Hz−Omode−square : [2008−12−12 02:30:00 to 2008−12−12 02:59:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,

E−W B Field (Ozette Q330) UTC 2008−12−12 02:54:30 to 2008−12−12 02:59:30



2.75−1.4Hz−Omode−square : [2008−12−12 05:00:00 to 2008−12−12 05:29:30]
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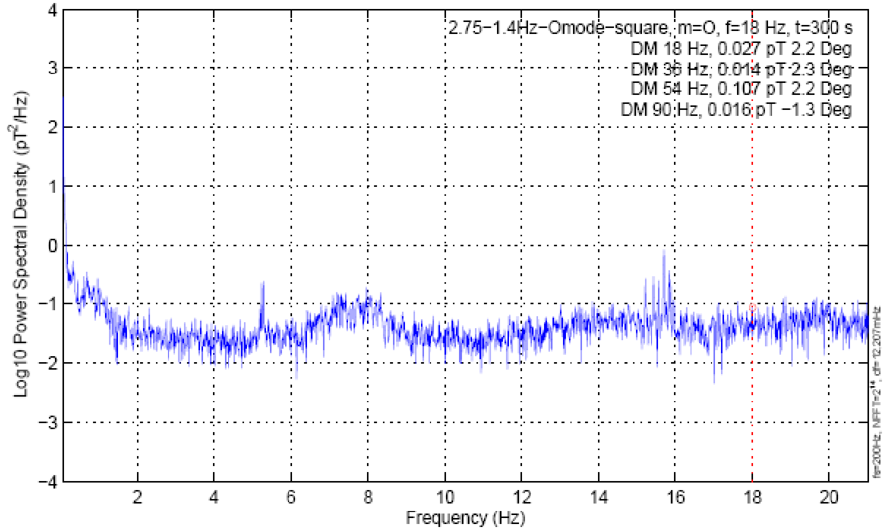
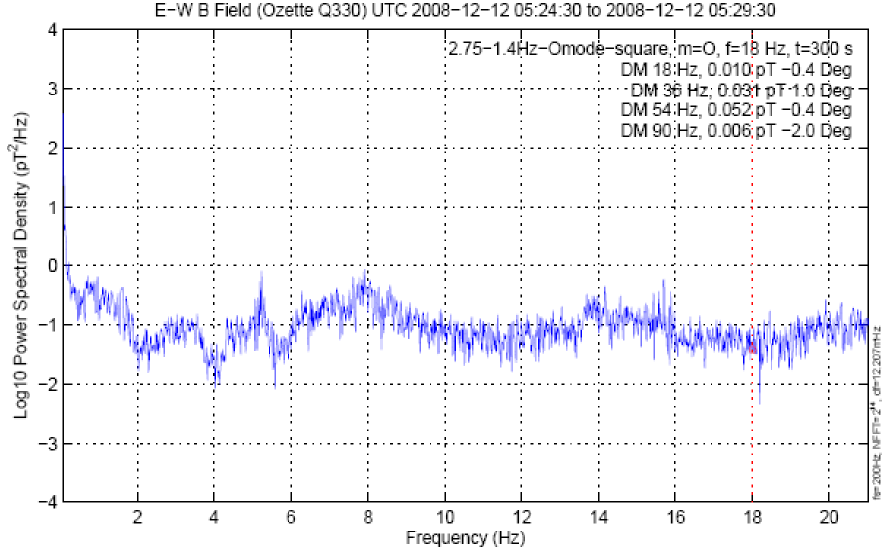
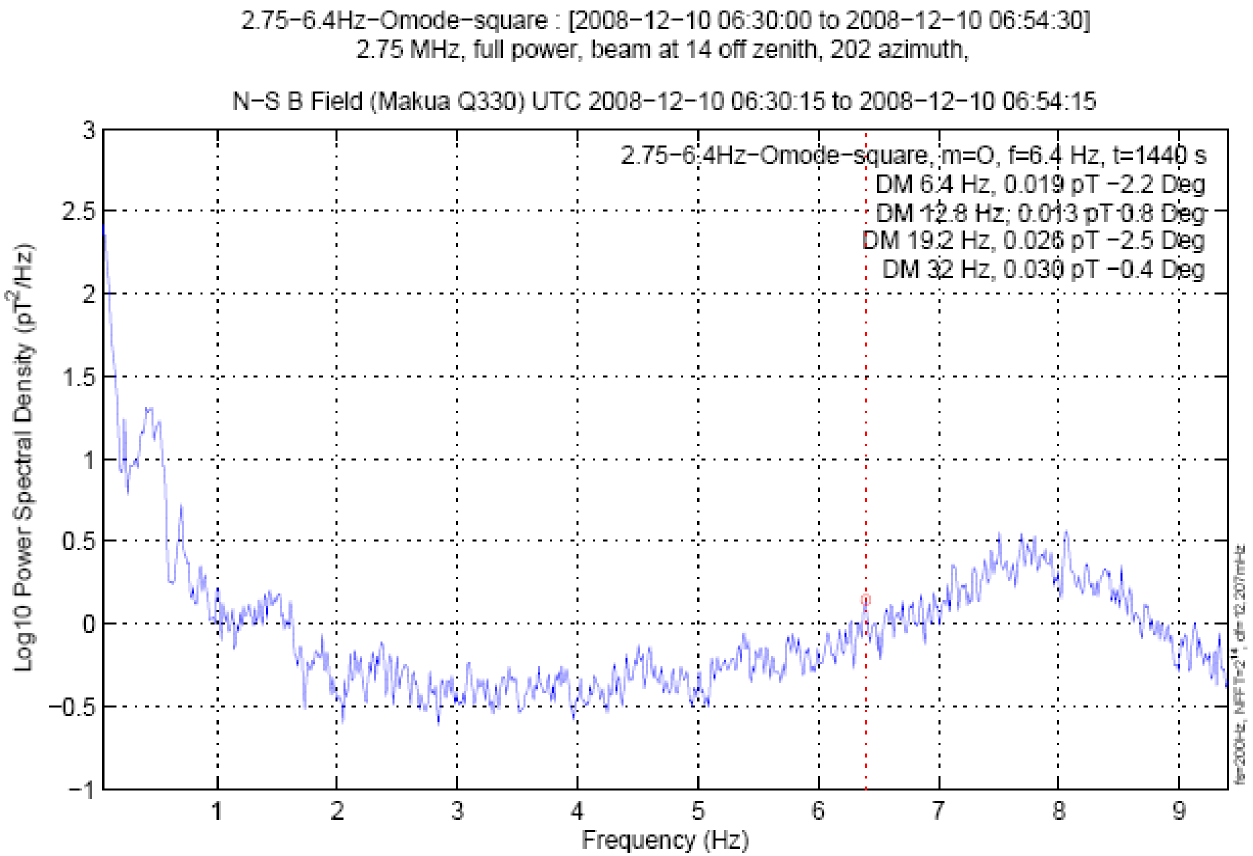
N−S B Field (Ozette Q330) UTC 2008−12−12 05:24:30 to 2008−12−12 05:29:30



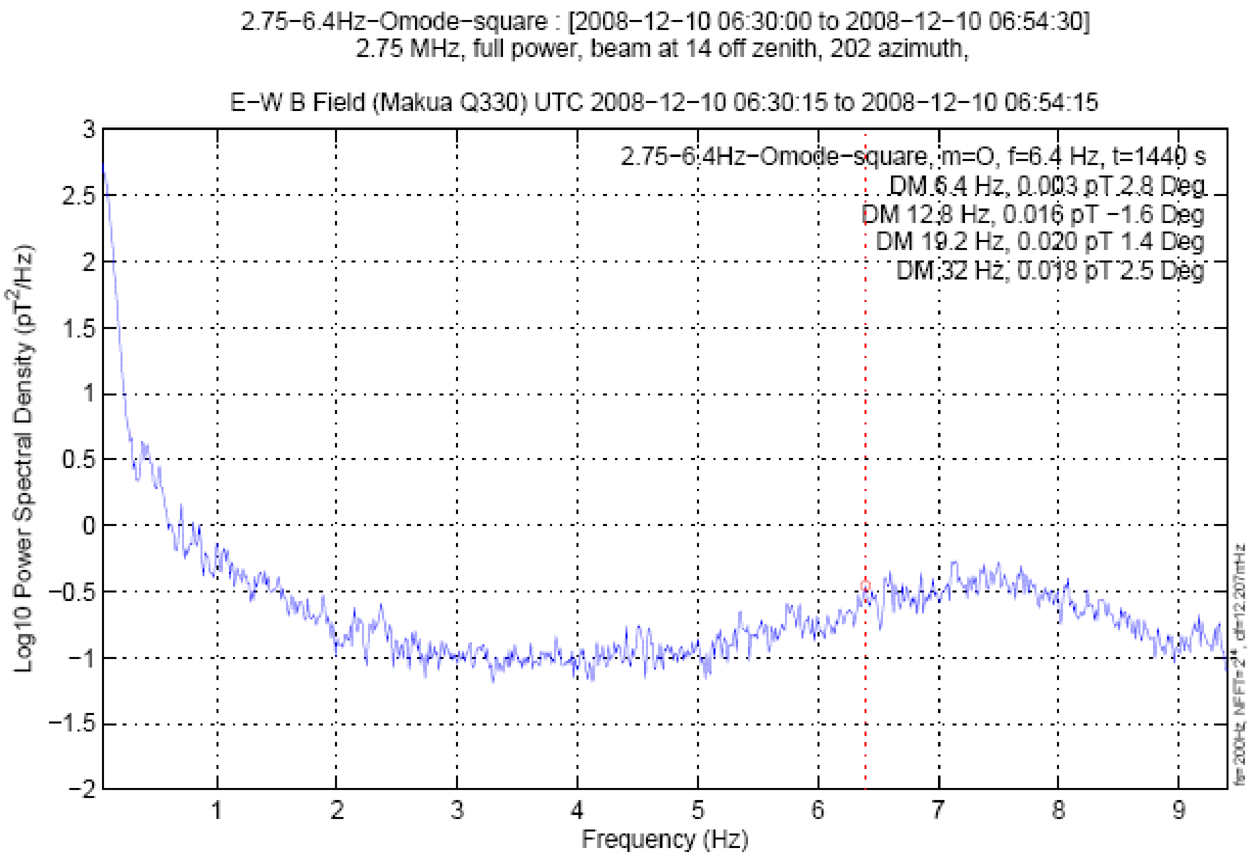
2.75−1.4Hz−Omode−square : [2008−12−12 05:00:00 to 2008−12−12 05:29:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,

E−W B Field (Ozette Q330) UTC 2008−12−12 05:24:30 to 2008−12−12 05:29:30

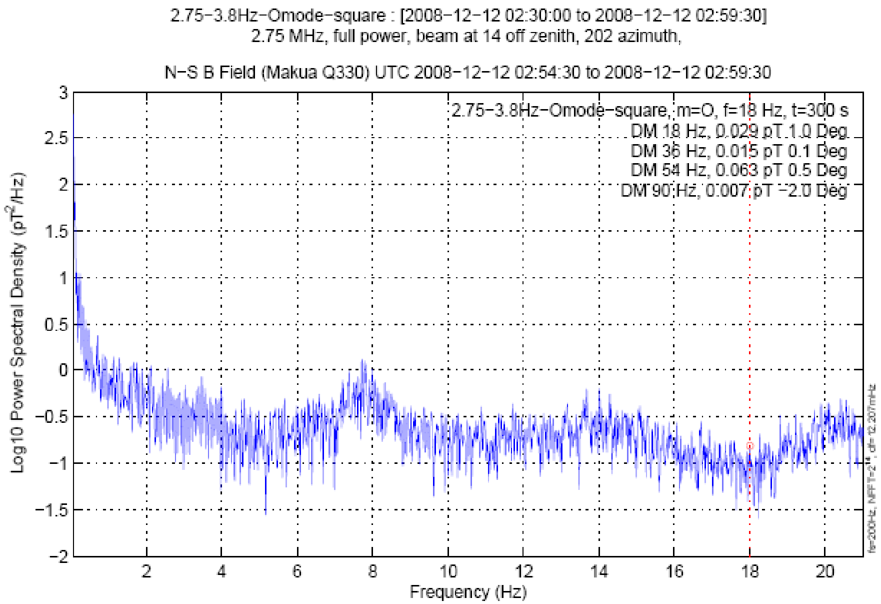


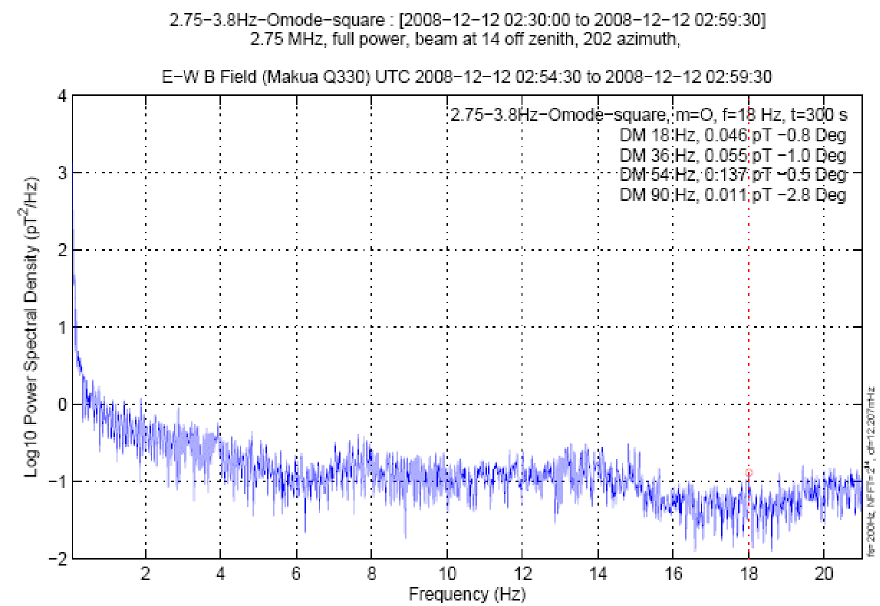


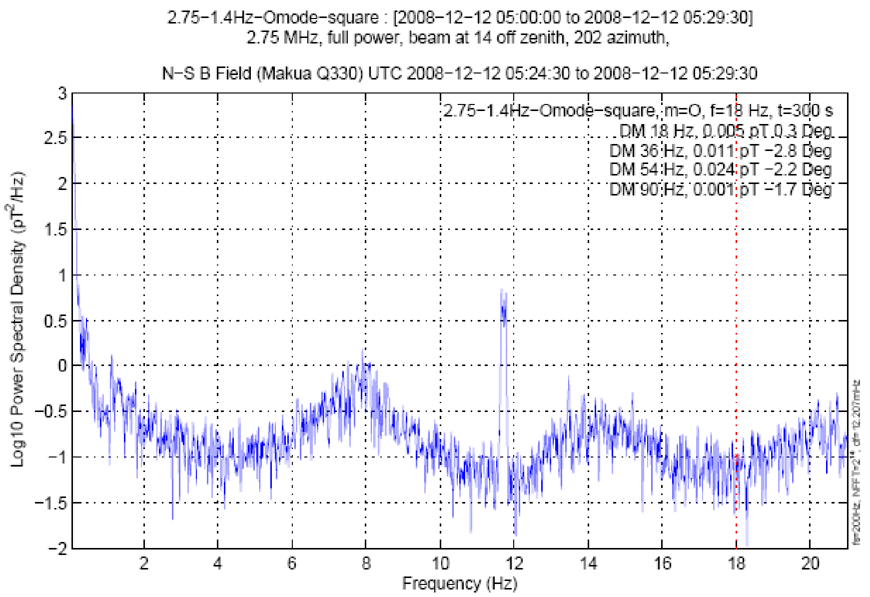
2.75−6.4Hz−Omode−square : [2008−12−10 06:30:00 to 2008−12−10 06:54:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
N−S B Field (Makua Q330) UTC 2008−12−10 06:30:15 to 2008−12−10 06:54:15
2.75−6.4Hz−Omode−square, m=O, f=6.4 Hz, t=1440 s
DM 6.4 Hz, 0.019 pT −2.2 Deg
DM 12.8 Hz, 0.013 pT 0.8 Deg
DM 19.2 Hz, 0.026 pT −2.5 Deg
DM 32 Hz, 0.030 pT −0.4 Deg
Log10 Power Spectral Density (pT^2/Hz)
Frequency (Hz)

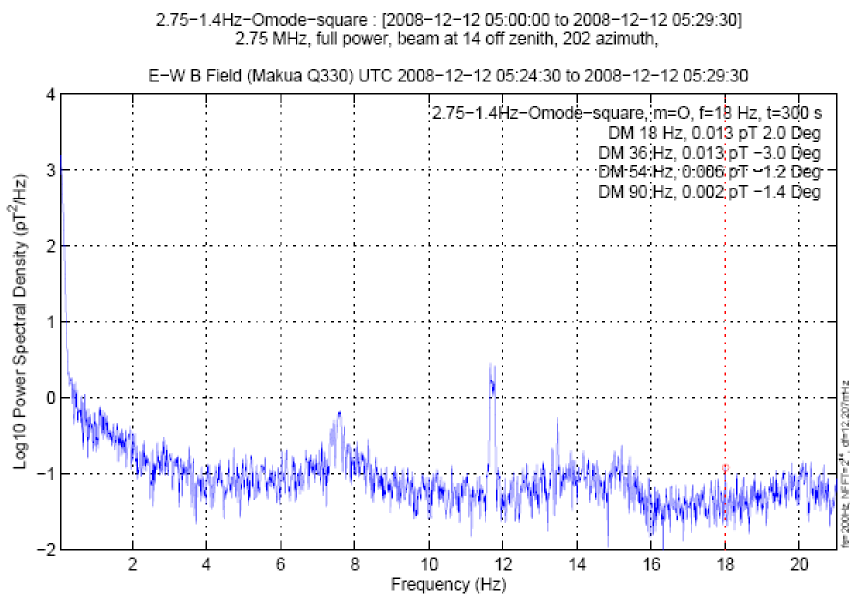


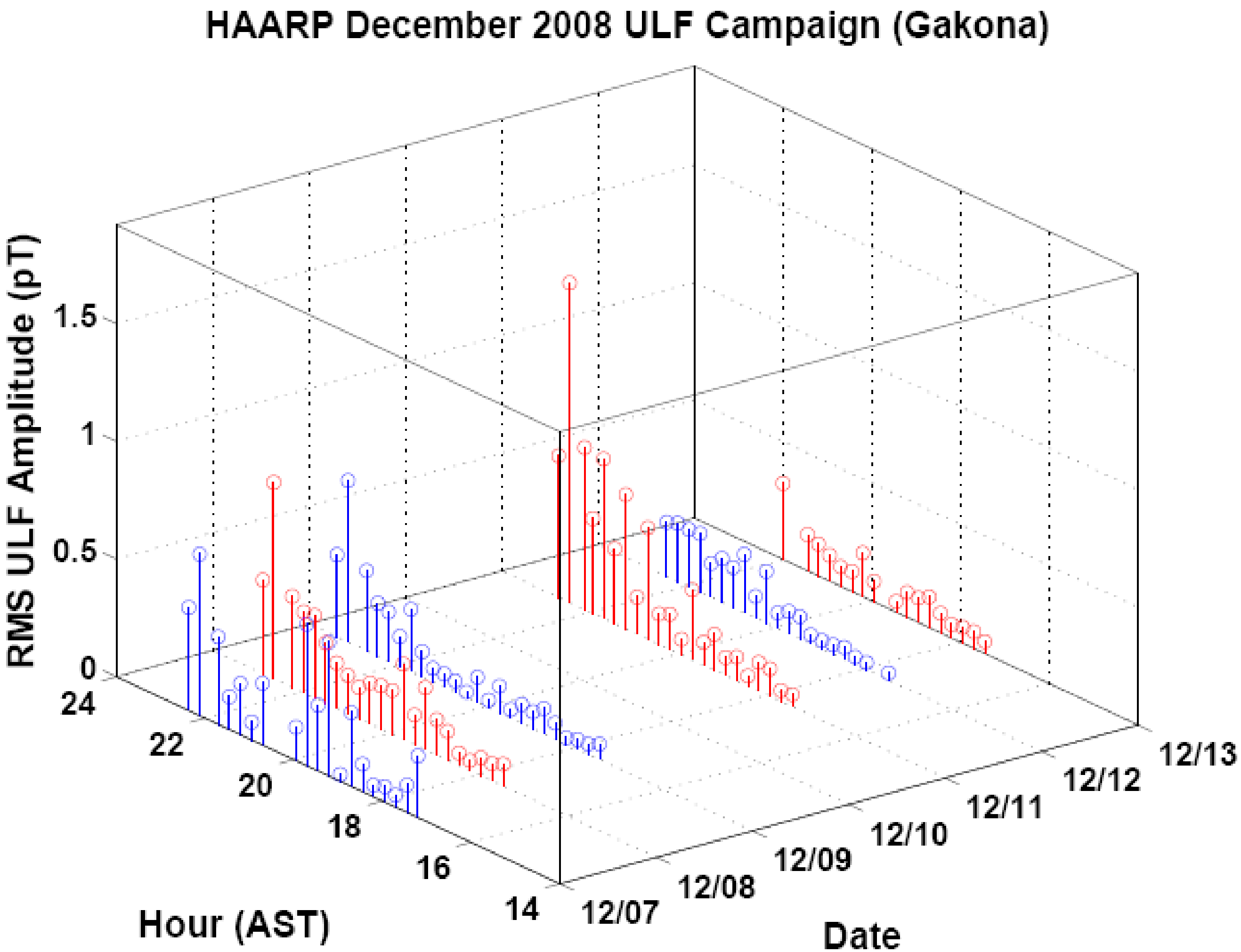
2.75−6.4Hz−Omode−square : [2008−12−10 06:30:00 to 2008−12−10 06:54:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
E−W B Field (Makua Q330) UTC 2008−12−10 06:30:15 to 2008−12−10 06:54:15
2.75−6.4Hz−Omode−square, m=O, f=6.4 Hz, t=1440 s
DM 6.4 Hz, 0.003 pT 2.8 Deg
DM 12.8 Hz, 0.016 pT −1.6 Deg
DM 19.2 Hz, 0.020 pT 1.4 Deg
DM 32 Hz, 0.018 pT 2.5 Deg
Log10 Power Spectral Density (pT²/Hz)
Frequency (Hz)

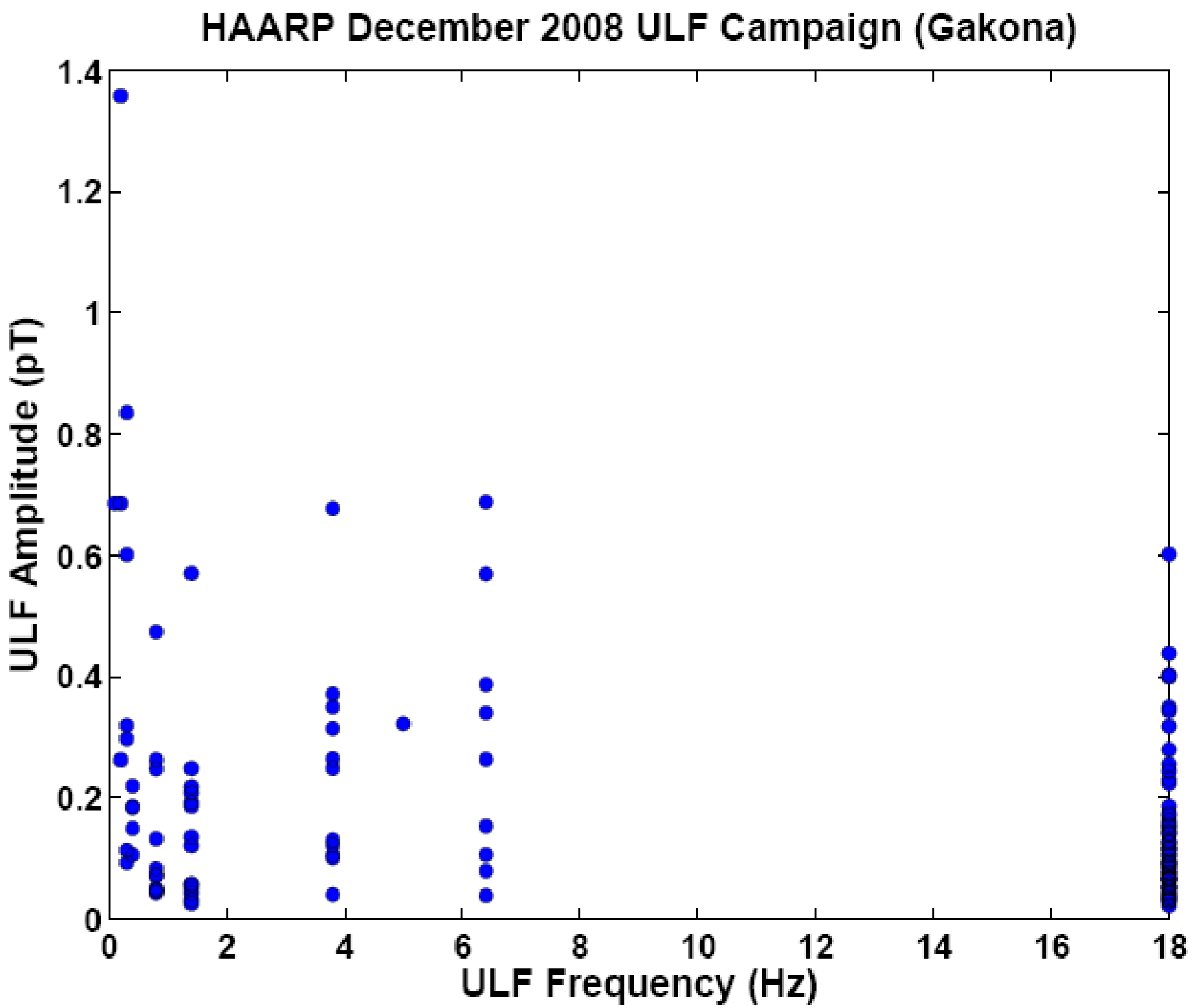

2.75−3.8Hz−Omode−square : [2008−12−12 02:30:00 to 2008−12−12 02:59:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
N−S B Field (Makua Q330) UTC 2008−12−12 02:54:30 to 2008−12−12 02:59:30
2.75−3.8Hz−Omode−square, m=O, f=18 Hz, t=300 s
DM 18 Hz, 0.029 pT 1.0 Deg
DM 36 Hz, 0.015 pT 0.1 Deg
DM 54 Hz, 0.063 pT 0.5 Deg
DM 90 Hz, 0.007 pT −2.0 Deg
Log10 Power Spectral Density (pT^2/Hz)
Frequency (Hz)


2.75−3.8Hz−Omode−square : [2008−12−12 02:30:00 to 2008−12−12 02:59:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
E−W B Field (Makua Q330) UTC 2008−12−12 02:54:30 to 2008−12−12 02:59:30
2.75−3.8Hz−Omode−square, m=O, f=18 Hz, t=300 s
DM 18 Hz, 0.046 pT −0.8 Deg
DM 36 Hz, 0.055 pT −1.0 Deg
DM 54 Hz, 0.137 pT −0.5 Deg
DM 90 Hz, 0.011 pT −2.8 Deg
Log10 Power Spectral Density (pT^2/Hz)
Frequency (Hz)

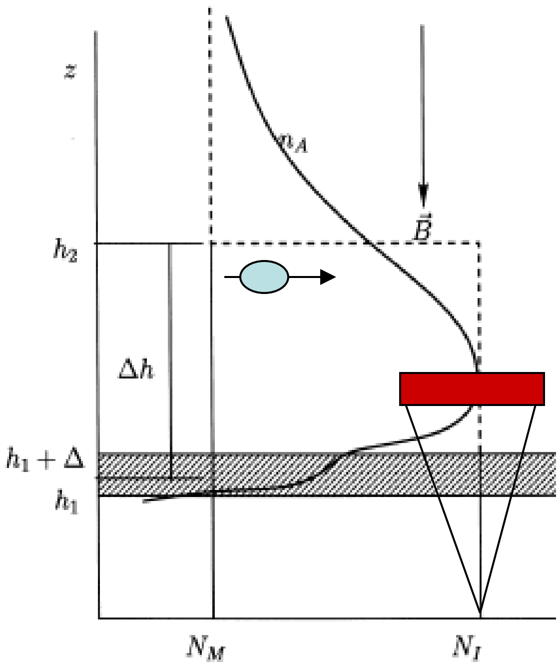

2.75−1.4Hz−Omode−square : [2008−12−12 05:00:00 to 2008−12−12 05:29:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
N−S B Field (Makua Q330) UTC 2008−12−12 05:24:30 to 2008−12−12 05:29:30
2.75−1.4Hz−Omode−square, m=O, f=18 Hz, t=300 s
DM 18 Hz, 0.005 pT 0.3 Deg
DM 36 Hz, 0.011 pT −2.8 Deg
DM 54 Hz, 0.024 pT −2.2 Deg
DM 90 Hz, 0.001 pT −1.7 Deg
Log10 Power Spectral Density (pT²/Hz)
Frequency (Hz)


2.75−1.4Hz−Omode−square : [2008−12−12 05:00:00 to 2008−12−12 05:29:30]
2.75 MHz, full power, beam at 14 off zenith, 202 azimuth,
E−W B Field (Makua Q330) UTC 2008−12−12 05:24:30 to 2008−12−12 05:29:30
2.75−1.4Hz−Omode−square, m=O, f=18 Hz, t=300 s
DM 18 Hz, 0.013 pT 2.0 Deg
DM 36 Hz, 0.013 pT −3.0 Deg
DM 54 Hz, 0.006 pT −1.2 Deg
DM 90 Hz, 0.002 pT −1.4 Deg
Log10 Power Spectral Density (pT²/Hz)
Frequency (Hz)

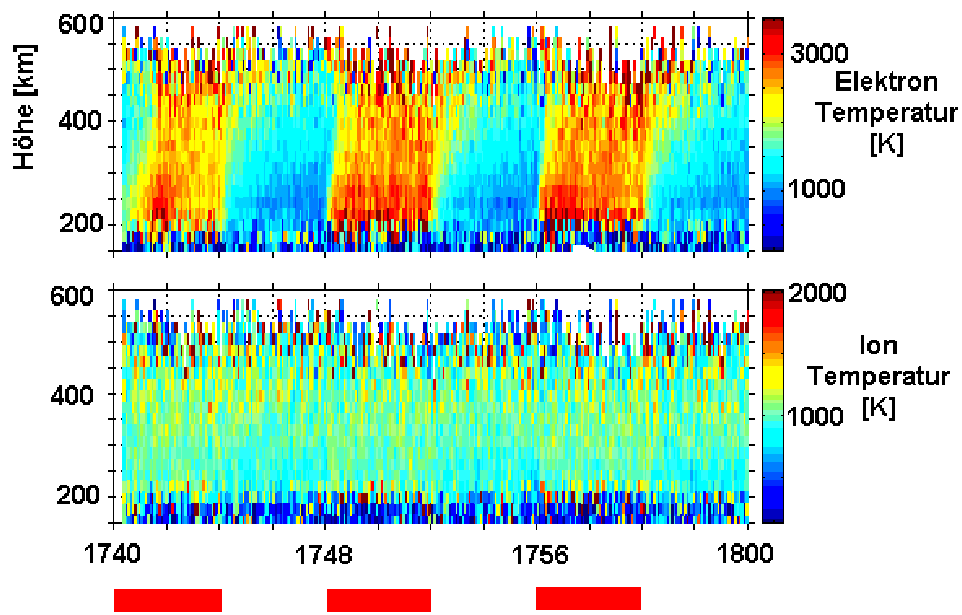

HAARP December 2008 ULF Campaign (Gakona)
RMS ULF Amplitude (pT)
0
0.5
1
1.5
24
22
20
18
16
14
Hour (AST)
12/07
12/08
12/09
12/10
12/11
12/12
12/13
Date


HAARP December 2008 ULF Campaign (Gakona)
ULF Amplitude (pT)
ULF Frequency (Hz)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
2
4
6
8
10
12
14
16
18

F-Region Heating-Current Drive



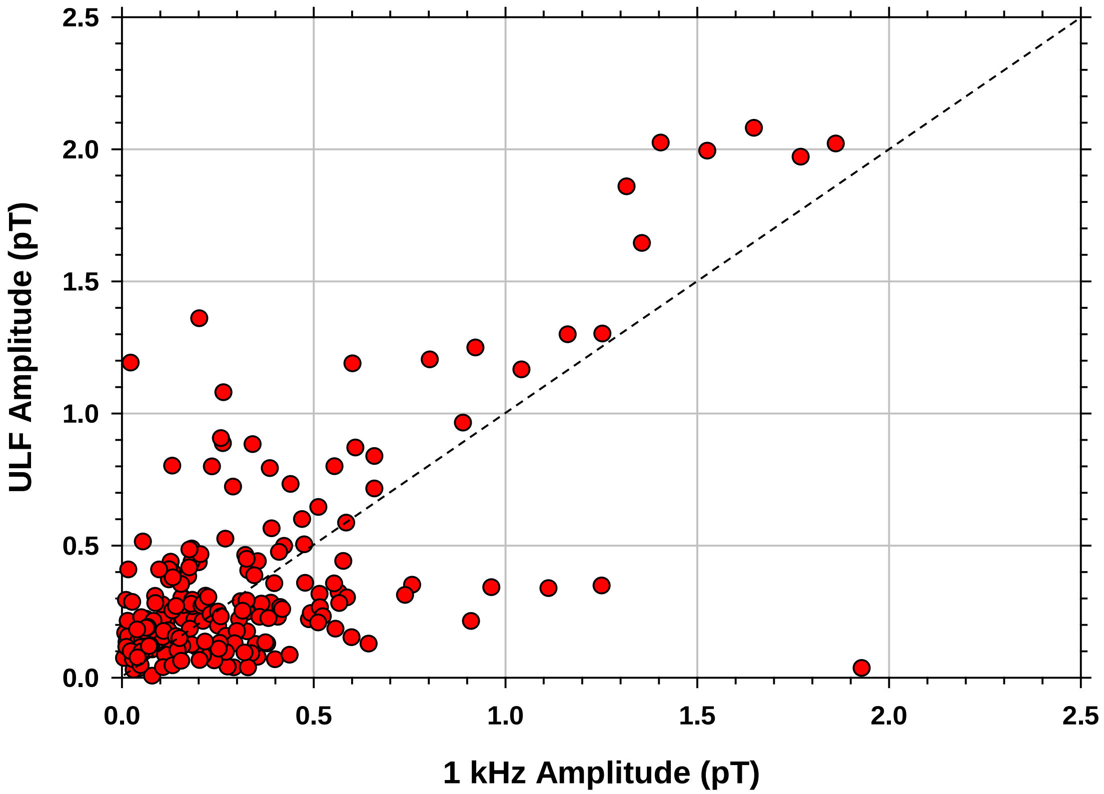
Drive AC Diamagnetic Current Loop



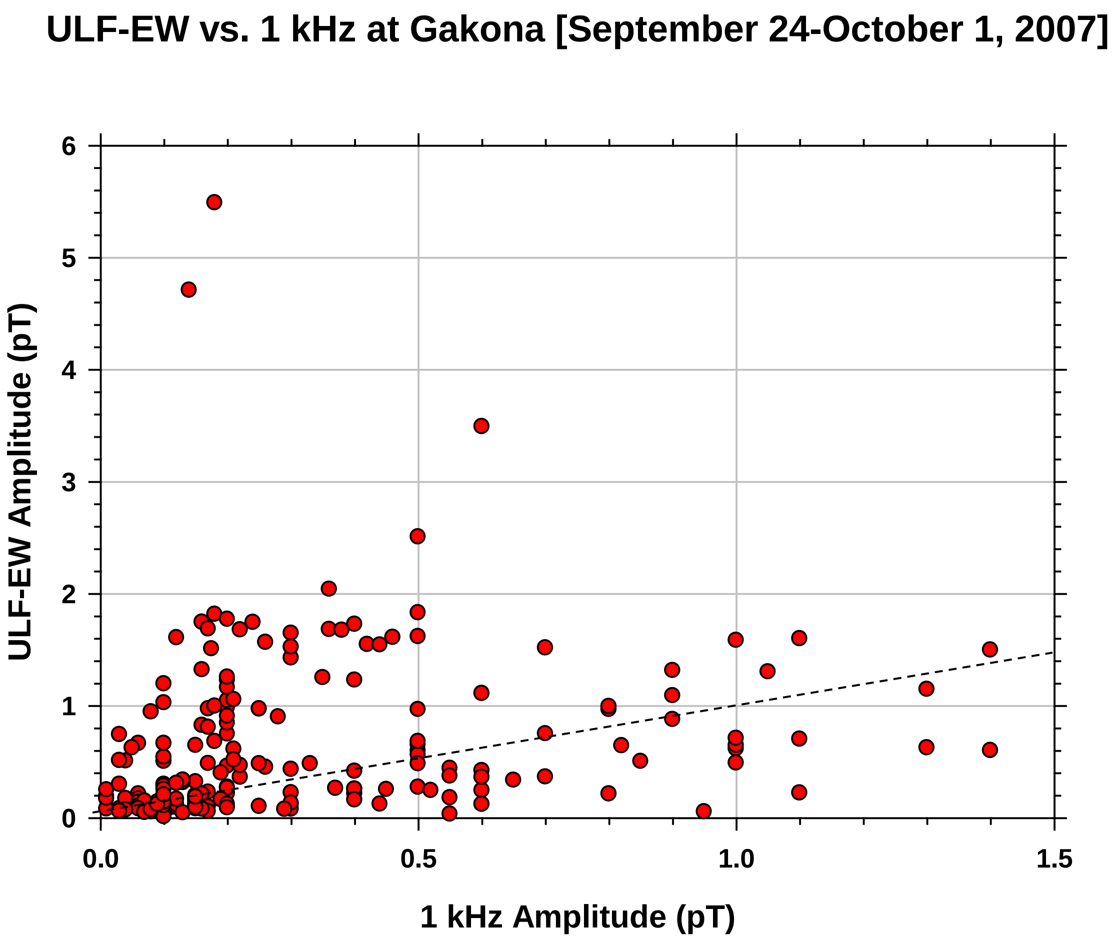
Response time .5-1 sec

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

(Gakona) ULF VS 1 kHz Amp.
All Times [04/28/2008 21:00:00 - 05/04/2008 09:20:00]

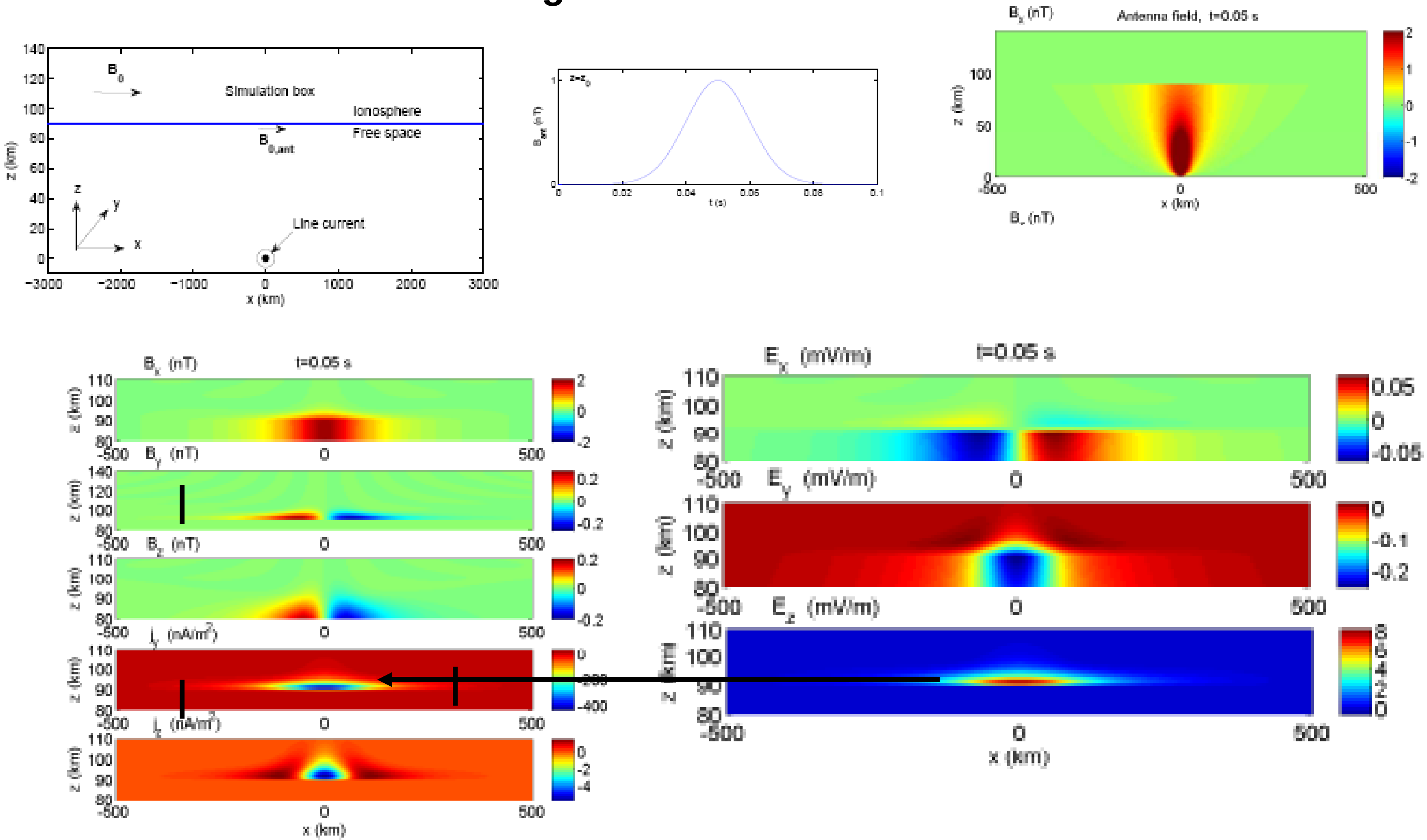


September 2007 Campaign



Two distinct groups: (1) ULF amp. ≈ kHz amp. along dashed line – electrojet mod.; (2) ULF amp. >> kHz amp. at ULF 2 pT or less

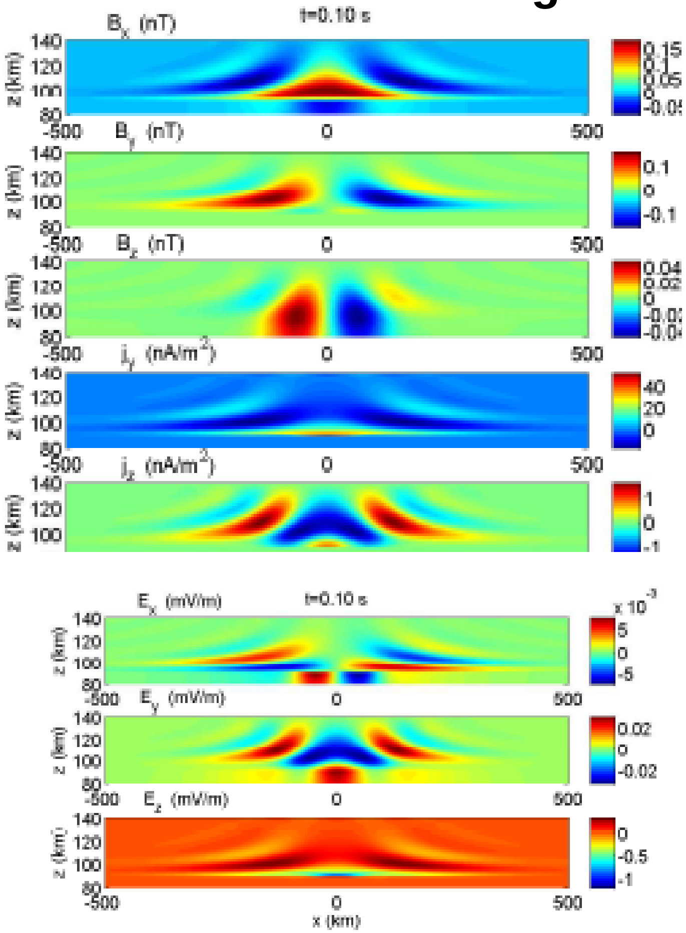
PACE E-Region Simulation – B. Eliason &DP

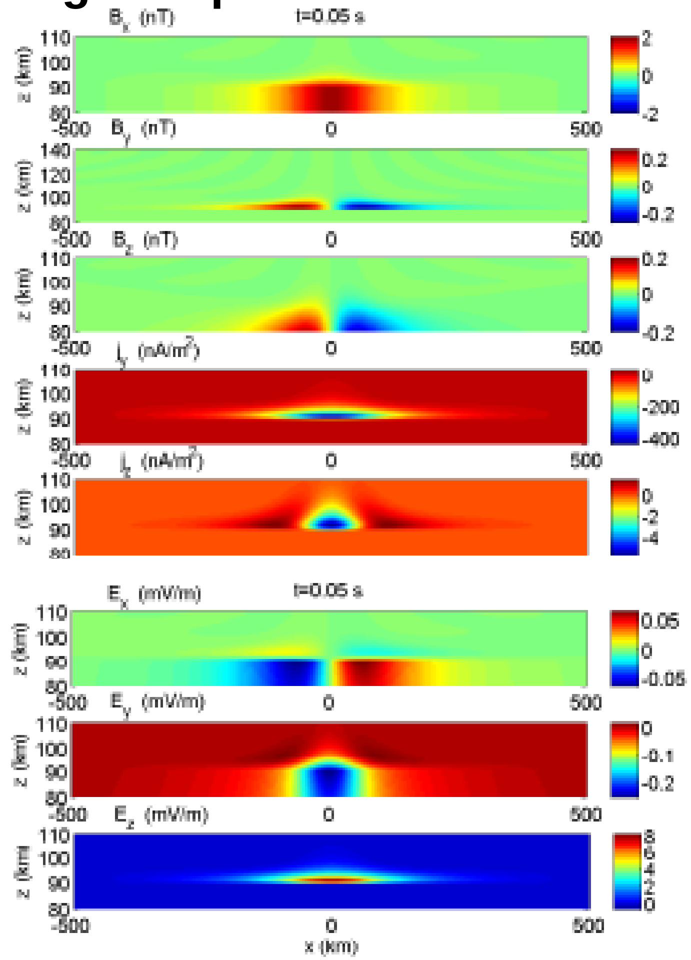


Estimates: Assume Δy≈100 km -> I_V**≈60 A,** I_VL**≈6x10**^{5} **A-m,** I_H**≈400 A,** I_HL**≈4x10**^{7} **A-m**

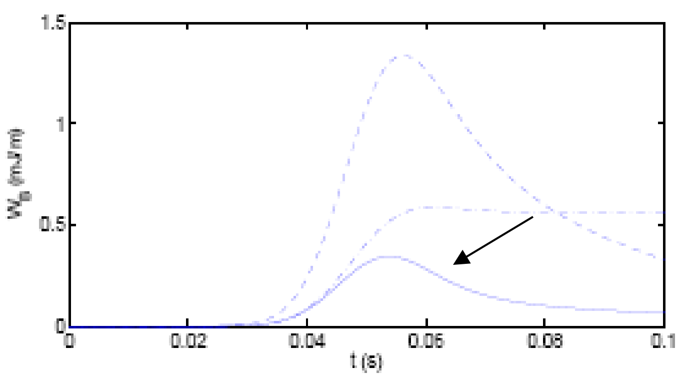
Current closure through field aligned currents carried by helicons

Loading Unloading Comparison





- **Lower intensity and flipping of currents and E-fields**
- **Prominent oblique helicon structure**

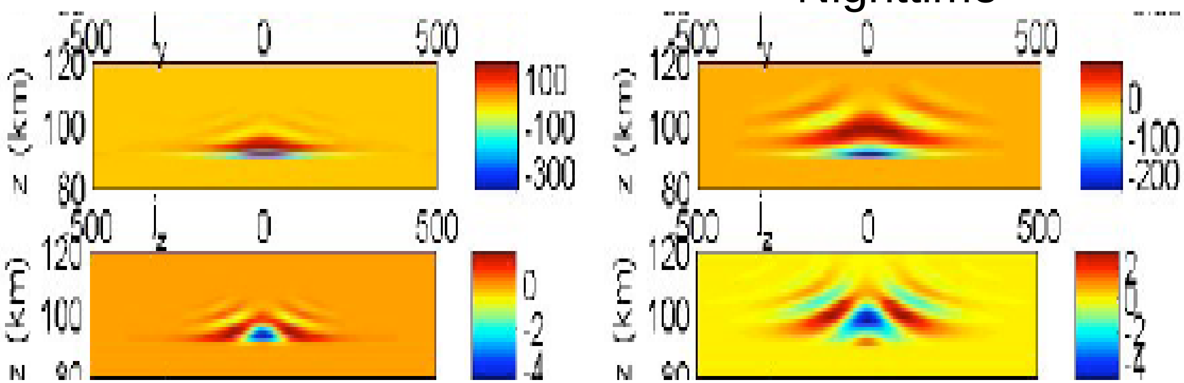


$W_B \approx .5$ mJ/m . If $\Delta y \approx 100$ km $W_{total} \approx 50$ J

$P \approx 50/.05 \approx 100$ W

Daytime

Nighttime



Vertical E