Space as an Open Nonlinear Plasma Laboratory

Dennis Papadopoulos

University of Maryland

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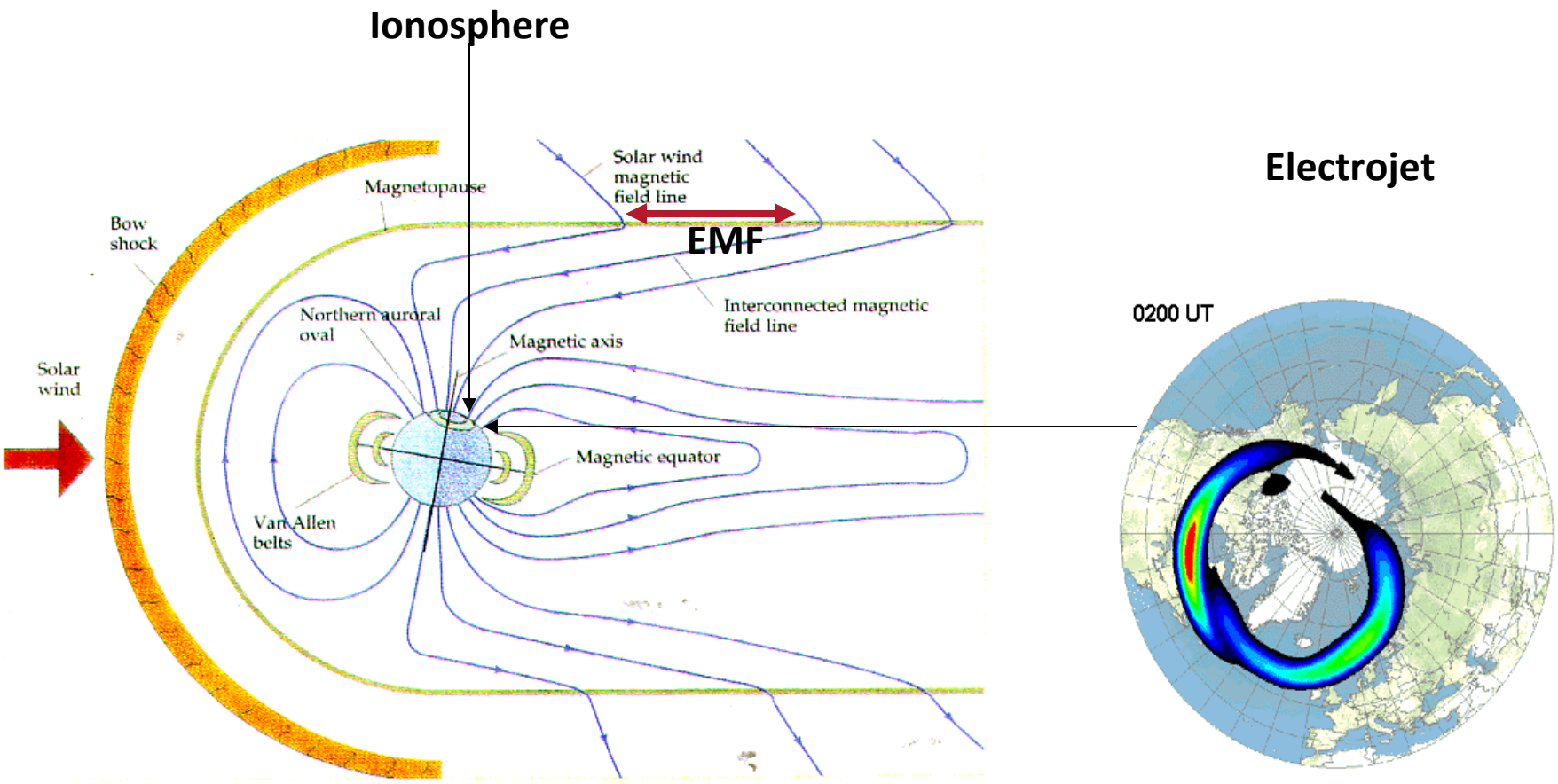
Session BM 10
53rd Annual Meeting of the APS
Plasma Physics Division
Salt Lake City, Utah
November 14, 2011

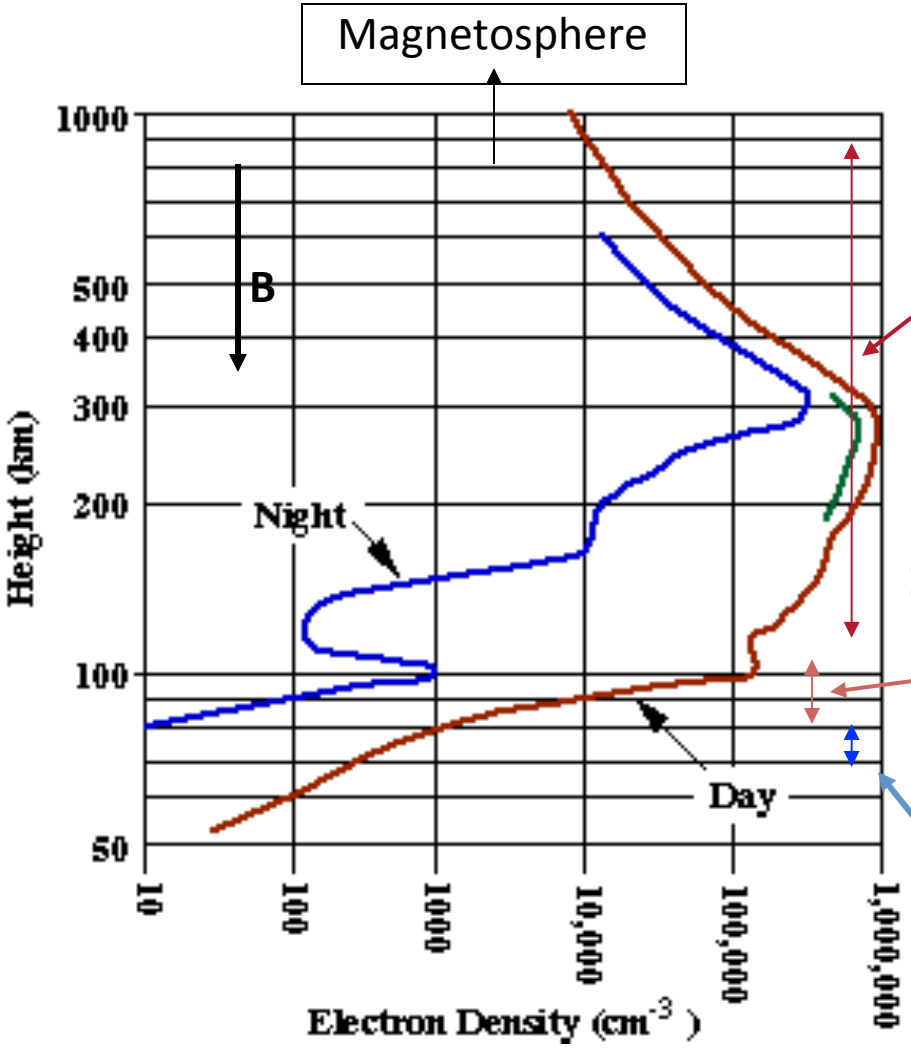
Space Plasma Environment



Active Experiments in Space

- **Use space plasma as an open laboratory to conduct cause-and-effect studies of plasma and space processes.**
- **Inject energy at particular locations and forms in space and diagnose their effects from space and ground**
  - **Space Based Injections**
    - **Electron, Ion and Neutral beams (ARAKS, ZARNITSA, Excede, Precede,…)**
    - **Neutral Gas (CRRES, AMPTE, Shuttle Exhaust..)**
    - **Electro-dynamic Tethers (TSS1 and TSS1R)**
    - **Waves (Aktivny, WISP)**
  - **Ground Based Injections**
    - **HF Radio-waves – Ionospheric Heaters**

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. Notice min. of V_A at F-peak.

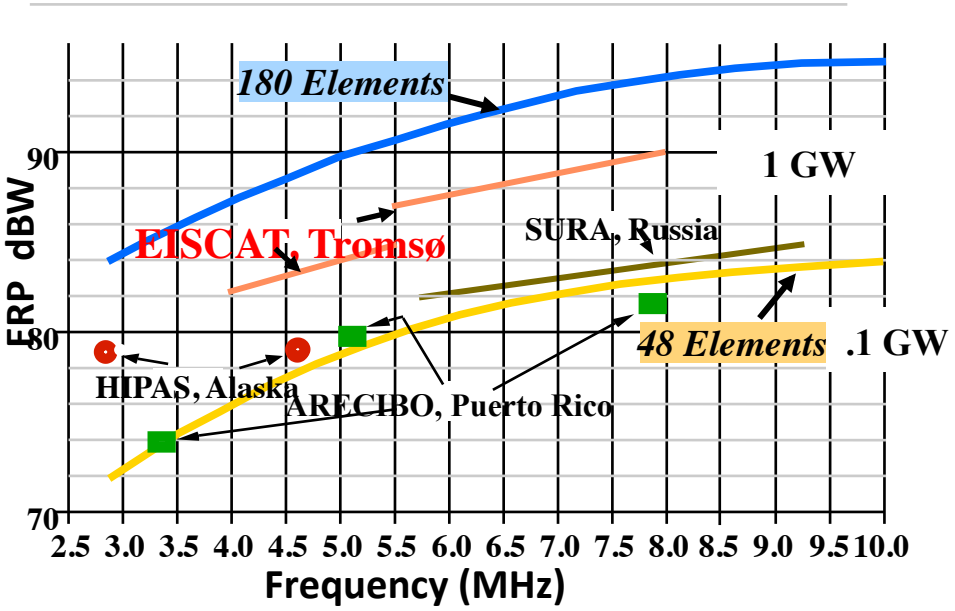
E(70<h<120 km): $\omega_e, \Omega_e > \nu$, $\Omega_i < \nu$ EMHD plasma – Helicon waves – no Alfven or Ion Cyclotron waves

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

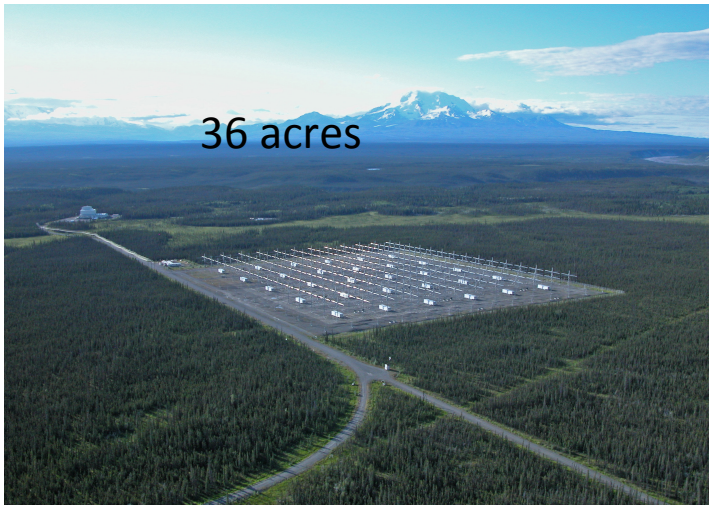
Active Regions (Plasmas with Free Energy): E-Electrojets

Ionospheric Heaters

- **Ionospheric heater - Powerful HF transmitter (2.8-10 MHz) that induces controlled temporary modification to the electron temperature at desired altitude in the lower ionosphere (70-300 km)**
- **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**



High-frequency Active Auroral Research Program (HAARP)



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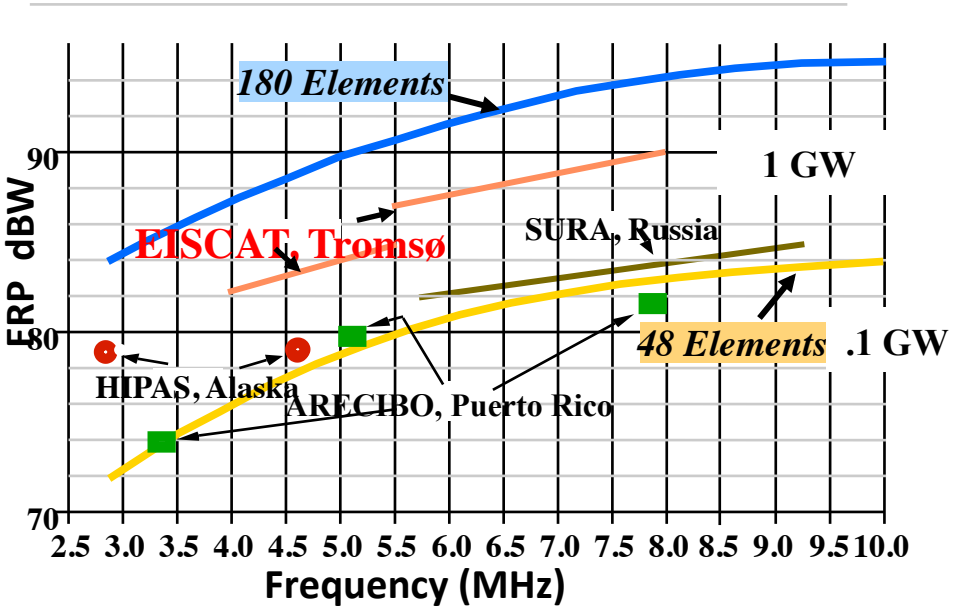
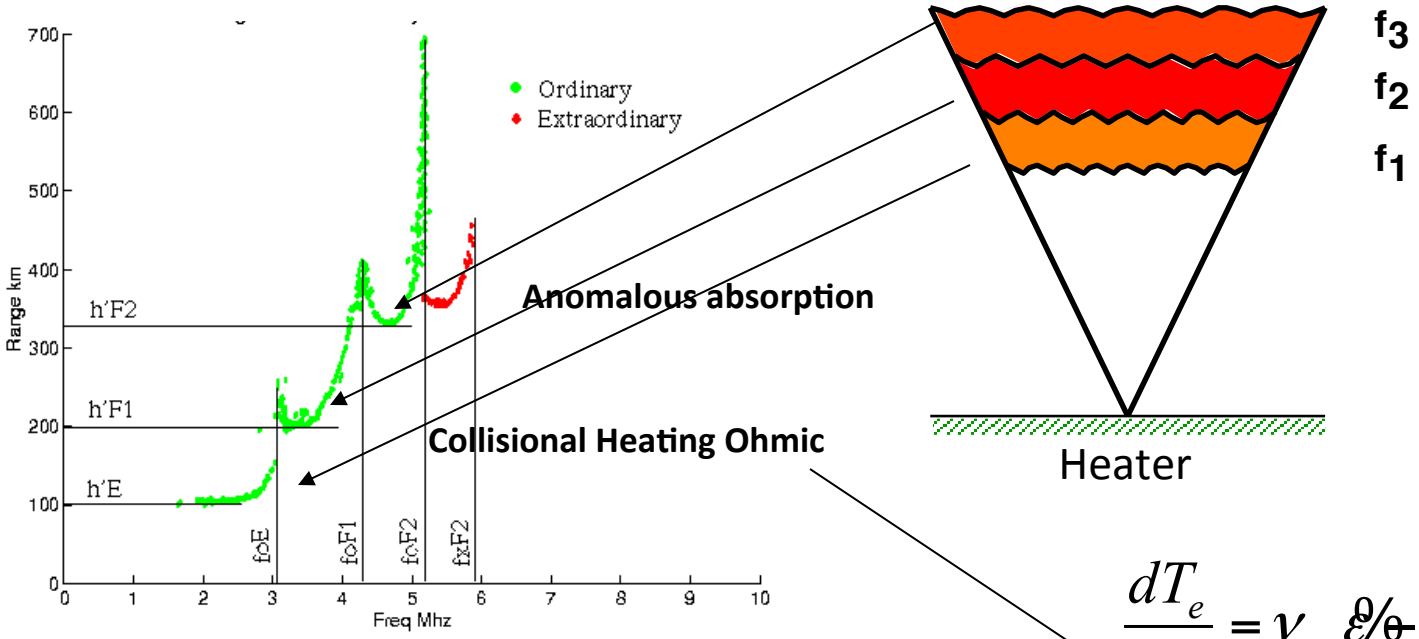


High-frequency Active Auroral Research Program (HAARP)

How to control location and profile of electron heating



Ionosonde - Radar

$$\omega_{pr} = \omega_e(h) = 5.6x10^4\sqrt{n(h)} \quad \text{O-mode}$$

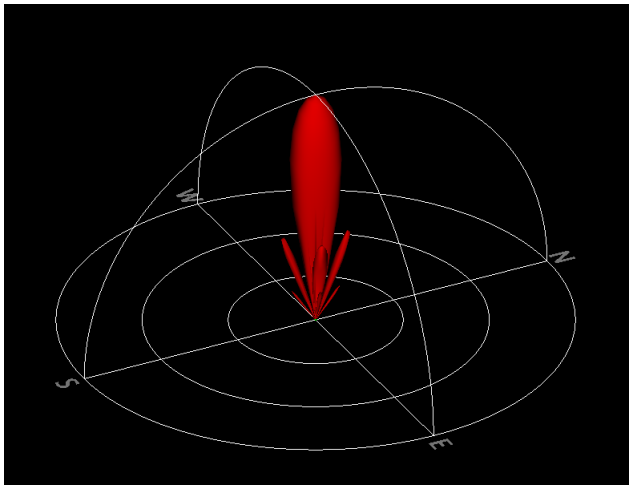
$$\omega_{pr} = \omega_e(h) + \Omega_e/2 \qquad \text{X-mode}$$

$$\frac{dT_e}{dt} = \nu_{en}\mathcal{E} - losses$$

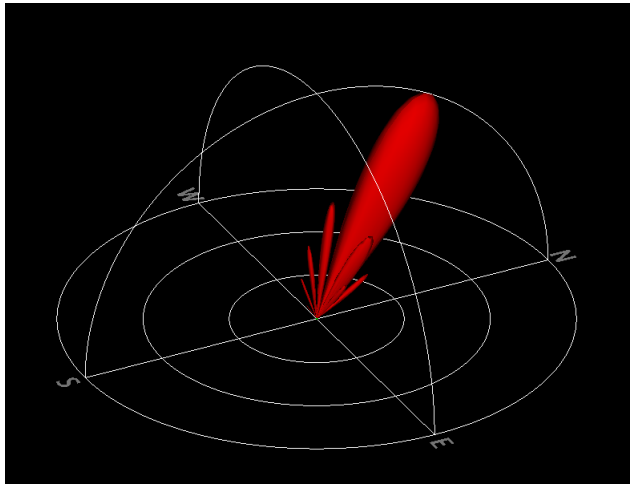
$$\mathcal{E} = \frac{1}{2}m\left(\frac{eE}{m\omega_{eff}}\right)^2$$

$$\omega_{eff}^2 \approx (\omega \pm \Omega_e)^2 + \nu_{en}^2$$

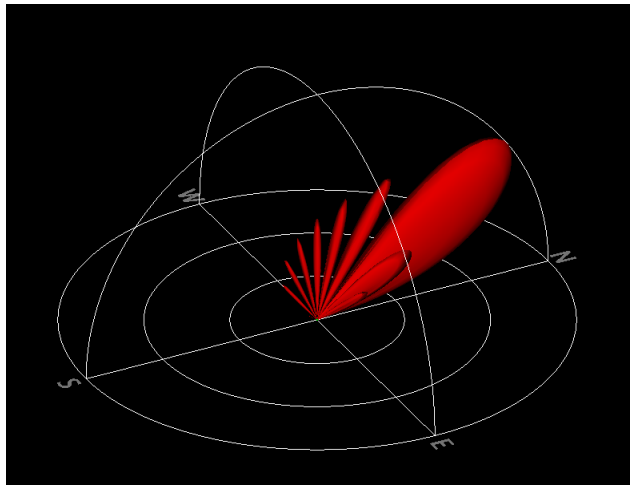
4.5 MHz, Azimuth=0



Zenith =0

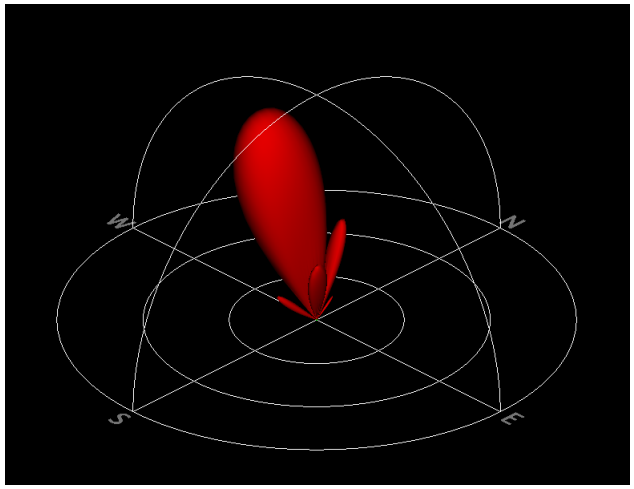


Zenith=45

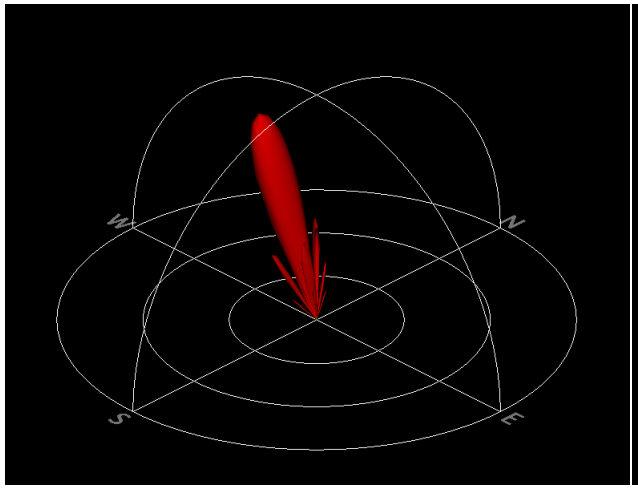


Zenith=60

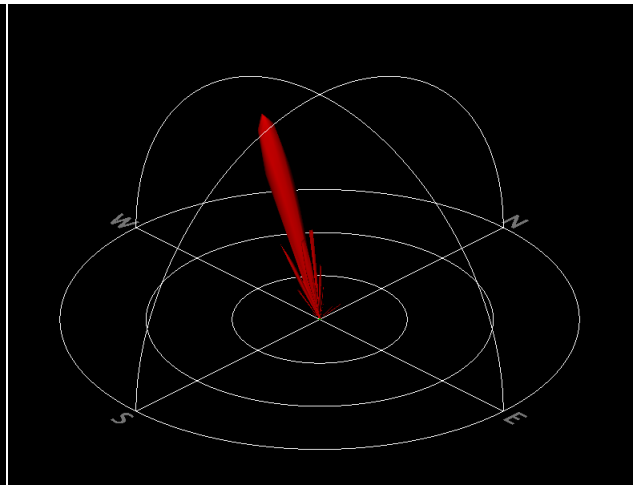
Magnetic Zenith



2.70 MHz



5.95 MHz



9.2 MHz

RESEARCH TOPICS

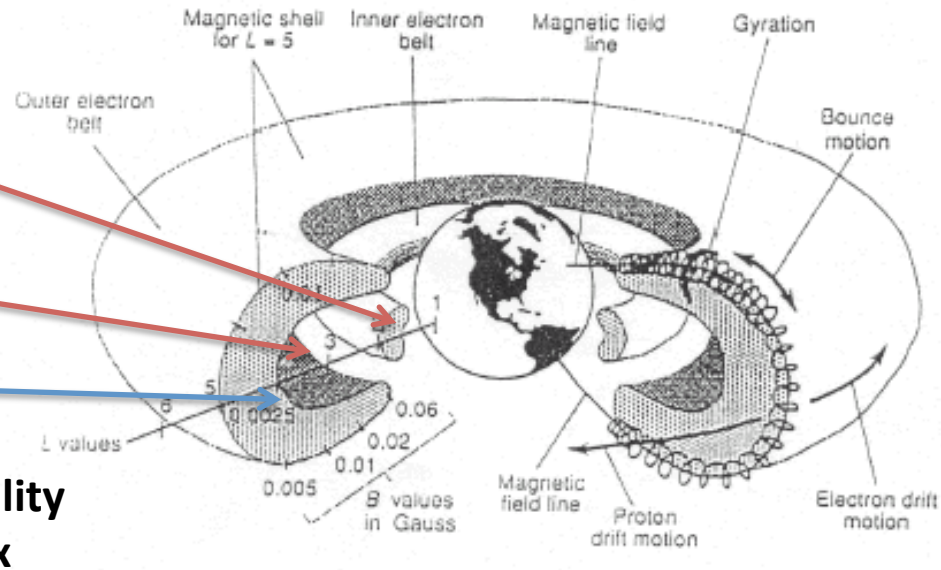
- **Injection of VLF (Whistler Range) and ELF/ULF [Alfven and Electro-Magnetic Ion Cyclotron (EMIC) Waves] in the Radiation Belts**
  - **High Latitude (Auroral zone)**
  - **Middle Latitude**
  - **The dip-Equator**
- **Electron Acceleration – Artificial Plasma Layers (APL) and Optical Emissions**

ELF/ VLF Injection in the Radiation Belts (RB) Why ?

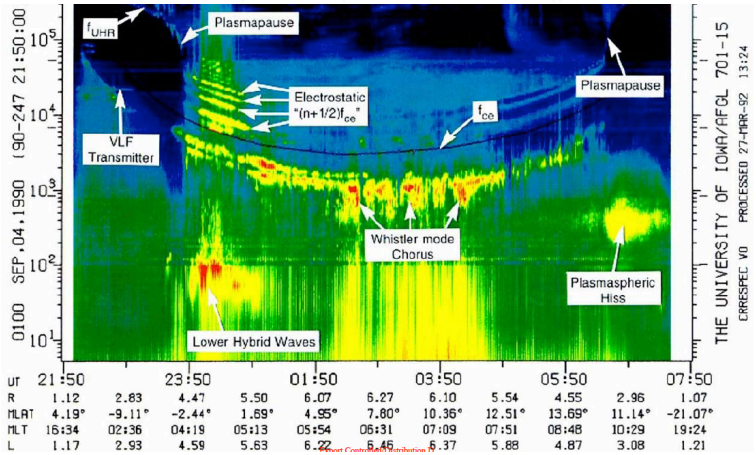
Inner RB 1.5<L<2

Slot 2<L<3

Outer RB L>3



Spacecraft lifetime and functionality function of RB stored particle flux



Physics Issues

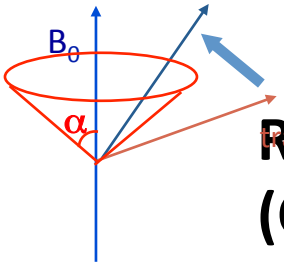
Injection

Transport

Energization

Loss

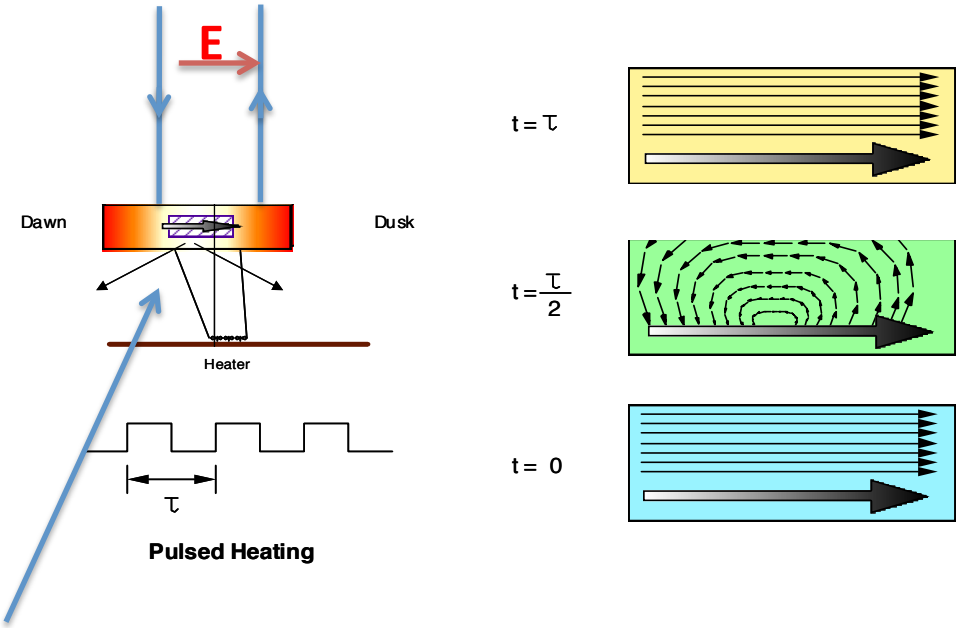
Wave-Particle Interactions (WPI)



Remediation – Extreme storms (Carrington 1859) and nuclear events

Wave-Particle Interactions Studies under Controlled Wave Injection

Ionospheric heaters as ELF/VLF wave injectors
The Polar Electojet (PEJ) antenna



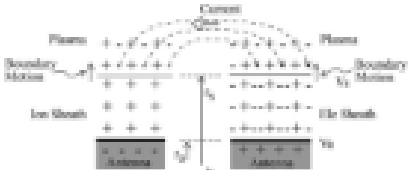
1.Modulated HF heating at the desired low frequency

2. Modulates ejet current

3. Creates a virtual antenna located a altitude 70-90 km

4. Injects ELF/VLF waves into the magnetosphere and into the earth ionosphere waveguide

The Plasma Physics of the PEJ



Injects whistlers and SAW

FAC

$J_P / J_H = \nu_{en} / \Omega_e$

$\nu_{en} \approx T_e^{\alpha}$

E

J

Hall

$\nu << \Omega_e$

$\nu = \Omega_e$

E

J

Pedersen

$\nu >> \Omega_e$

Bottom of the ionosphere

$\varepsilon\omega = \sigma$

Far field

Bo

E

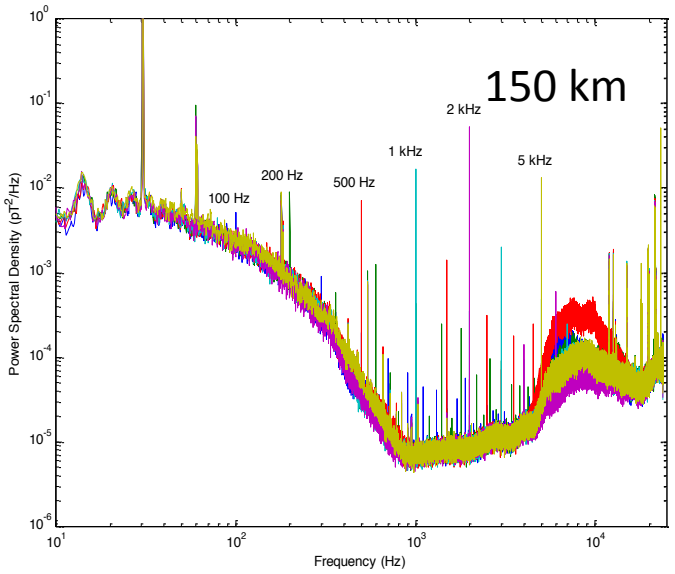
TEM mode

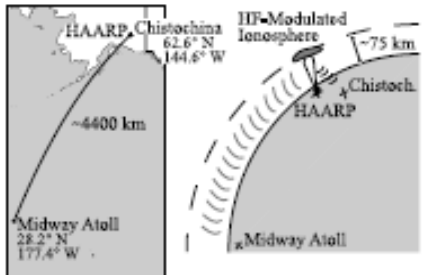
H

heater

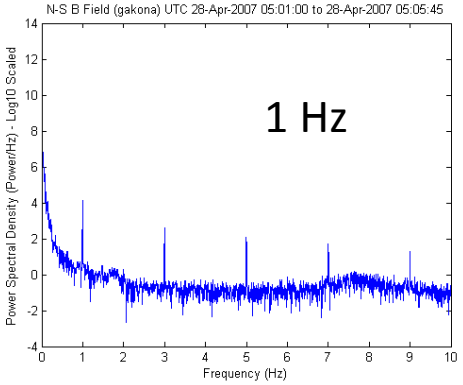
T

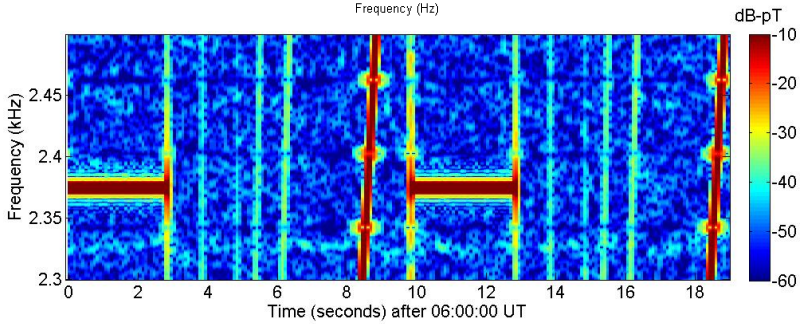
ELF/VLF ground detection and propagation

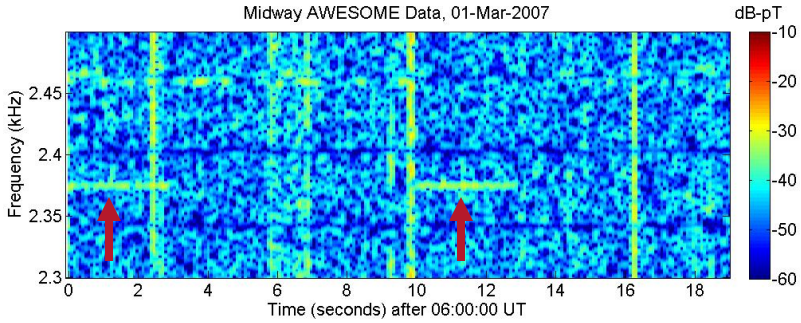




Moore et al.
GRL 2008



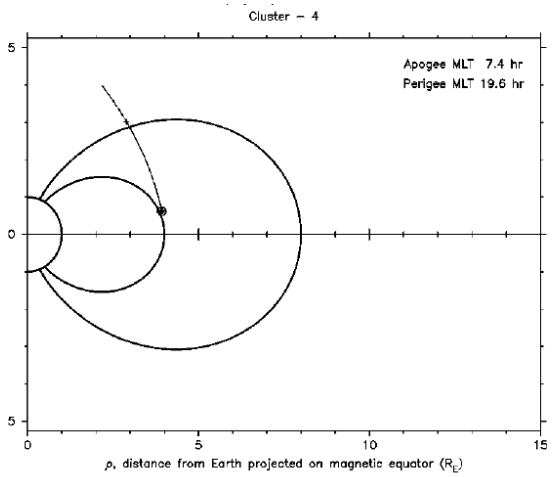


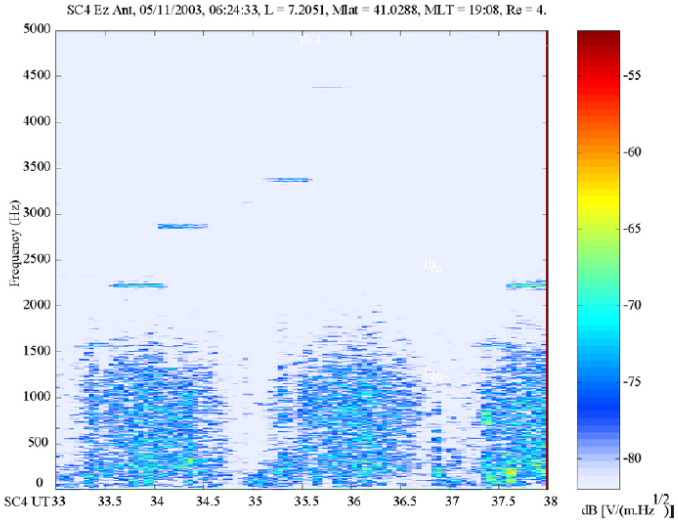


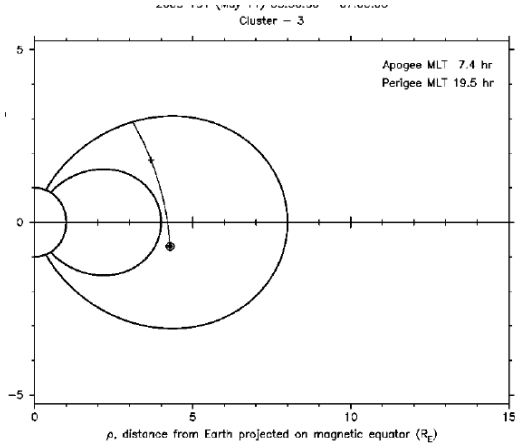
5400 km away

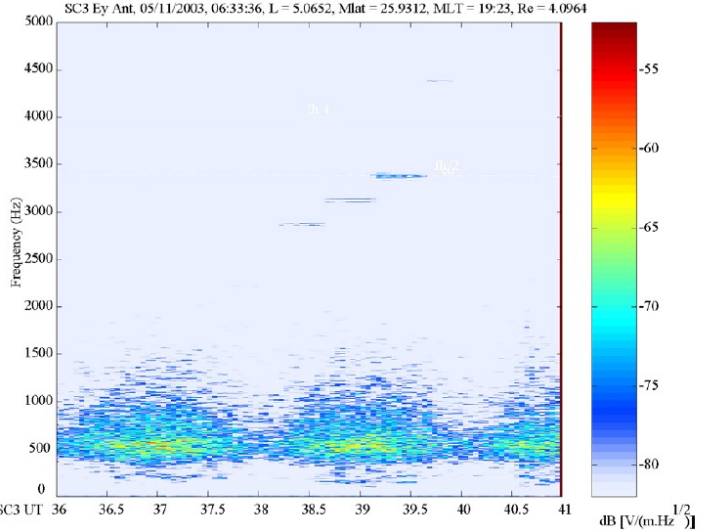
Midway

HAARP/CLUSTER INJECTION





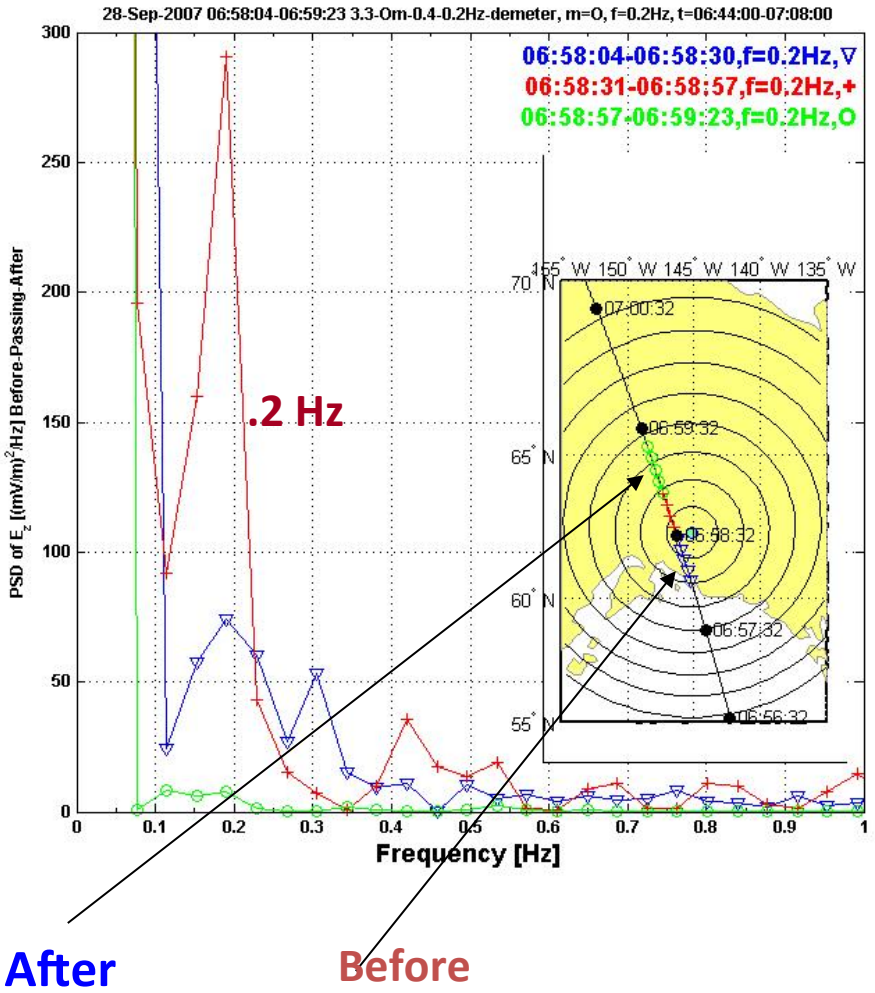


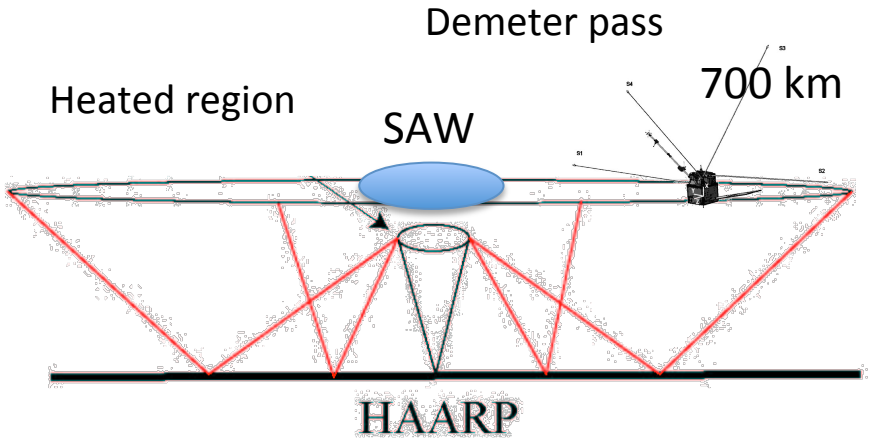


COURTESY STANFORD UNIVERSITY

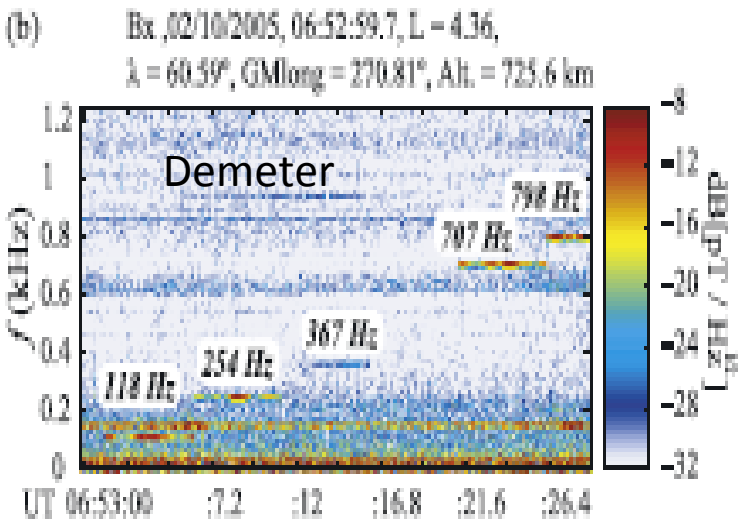
DEMETER Detections – 700 km

SHEAR ALFVEN WAVES (SAW)





WHISTLER WAVES



Ionospheric Current Drive (ICD)

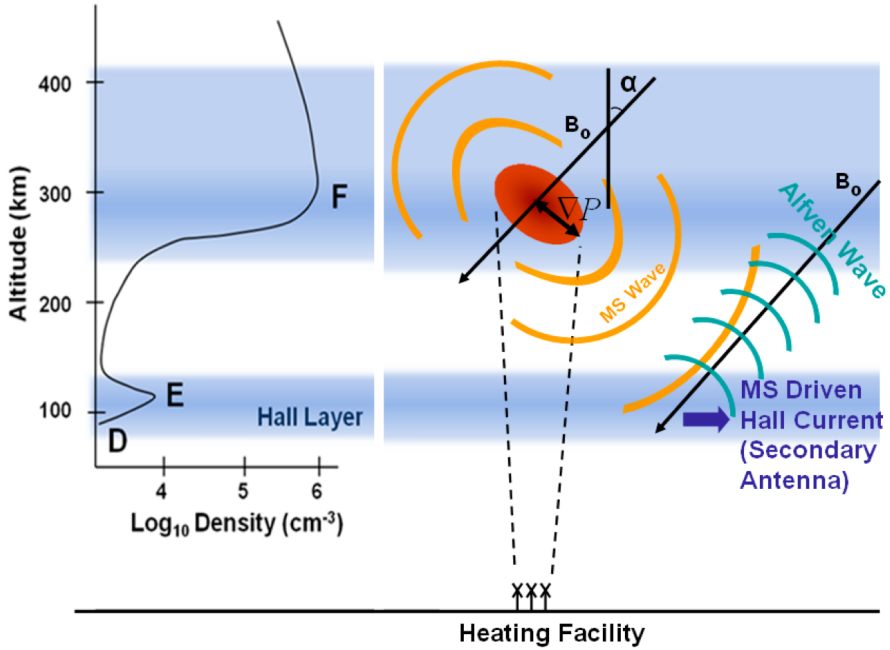
PEJ Limitation is the requirement of a strong electrojet current. Cannot be implemented by mid-latitude heaters. Can only inject waves in outer belt. Long periods without availability.

Technique required whose physics does not depend on the presence of ejet→ ICD

-> F-region heating

Step 1: $$\Delta J = \frac{B \times \nabla \delta p}{B^2} \exp(i\omega t)$$ Diamagnetic current -> MS wave

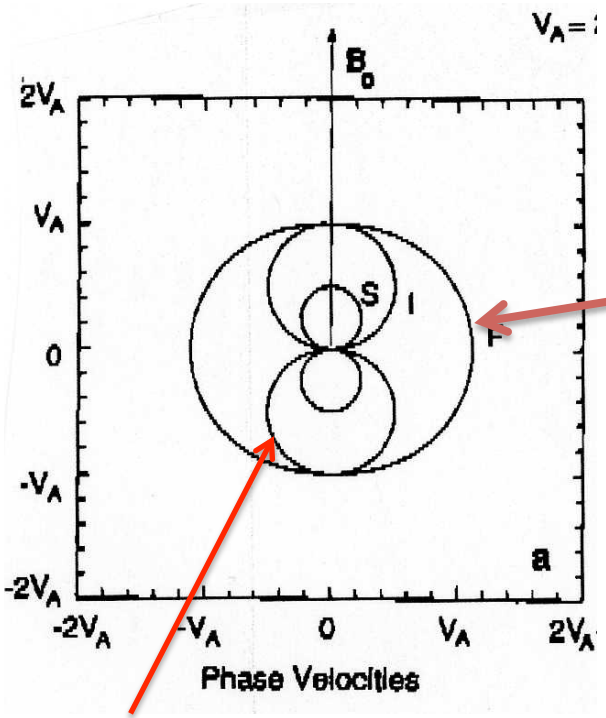
Step 2: E field of MS wave drives Hall current in E-region resulting in secondary antenna resembling PEJ



F- region cooling response does not allow frequencies higher than 60-70 Hz

Injects SAW upwards and ELF in the Earth-Ionosphere Waveguide

Insert: MHD WAVES (MS, SAW, EMIC)



MAGNETO-SONIC MS

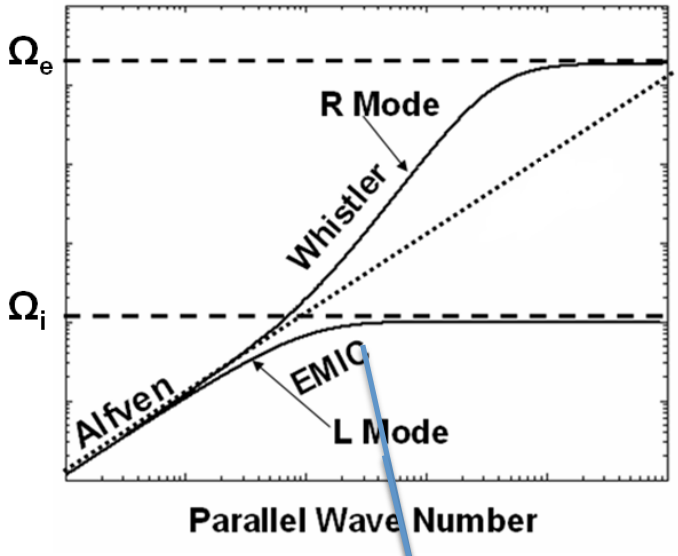
$$\omega / k = V_A$$

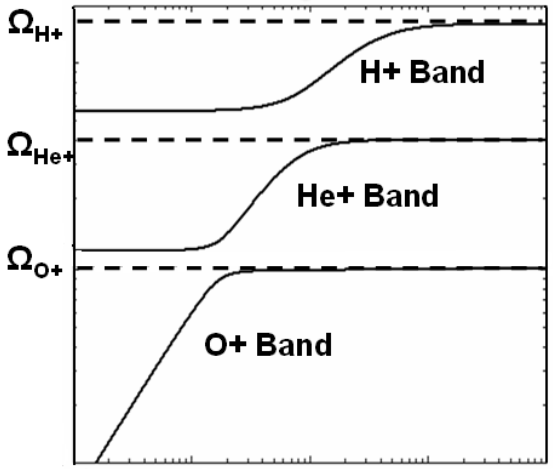
$$\omega / k_z = V_A \cos\theta$$

SHEAR ALFVEN WAVE(SAW)

$$\omega / k_z = V_A$$

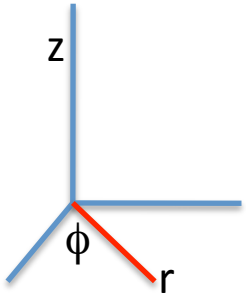
$$\vec{V}_g = V_A \hat{b}$$

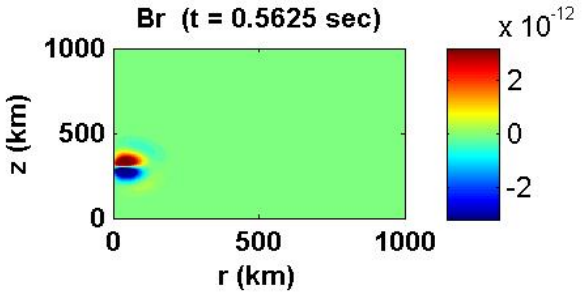


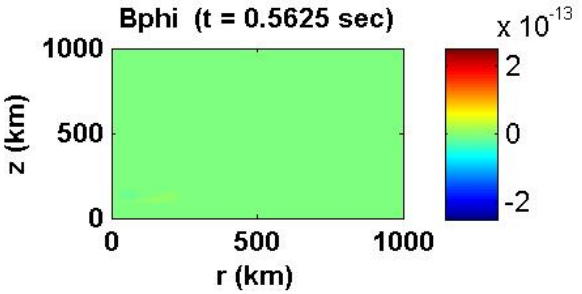


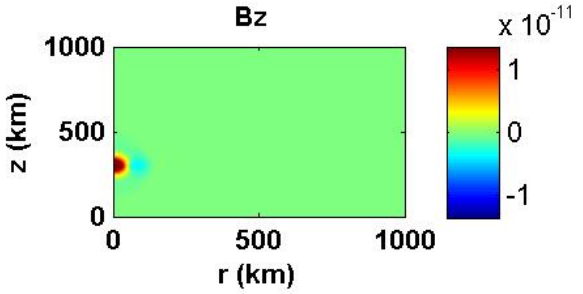
Cylindrical Coordinates

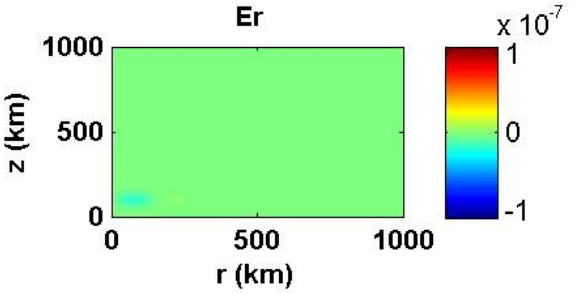
Papadopoulos et al. GRL 2011a; paper selected as GRL highlight

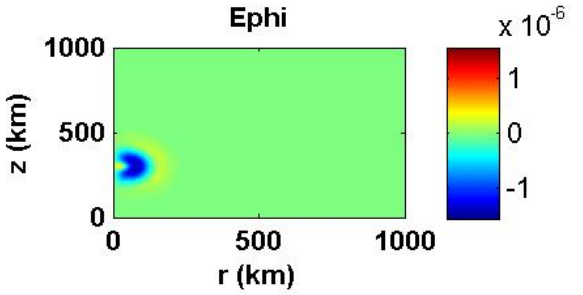


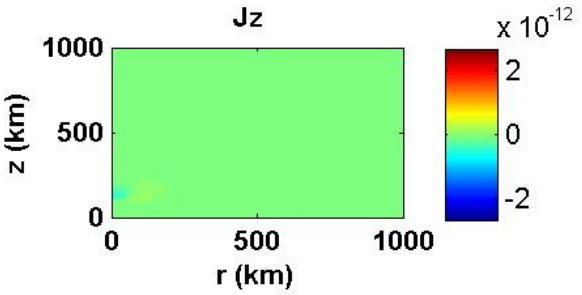




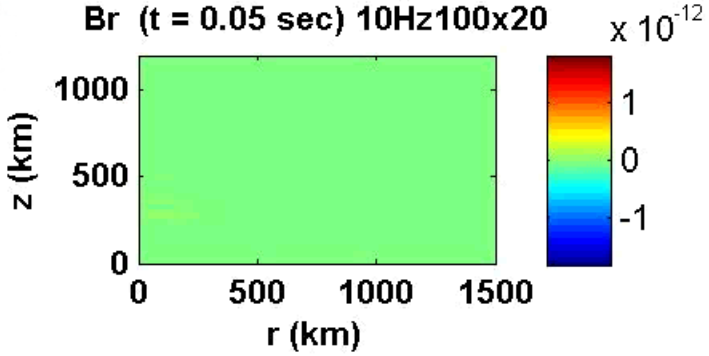


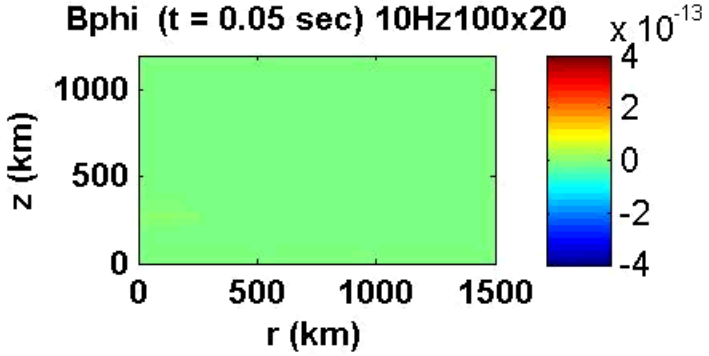


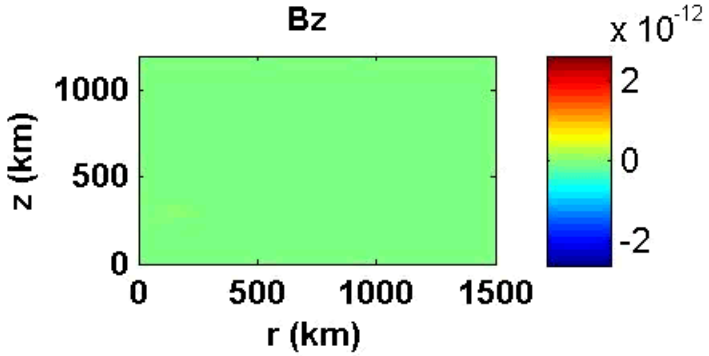


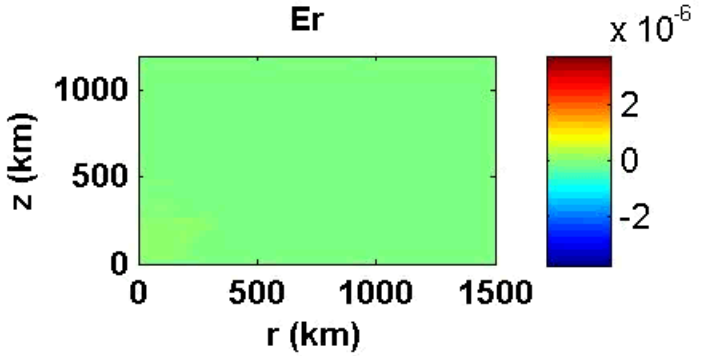


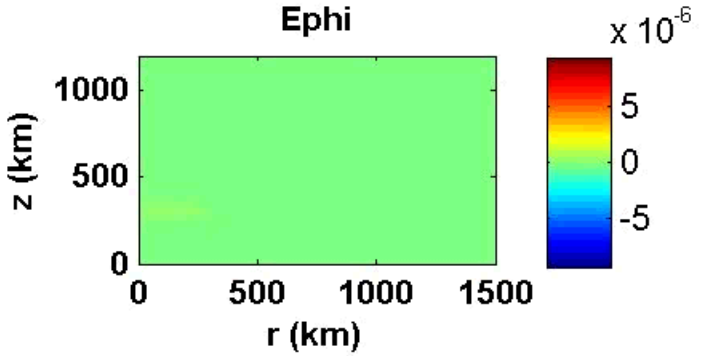
MS **SAW**

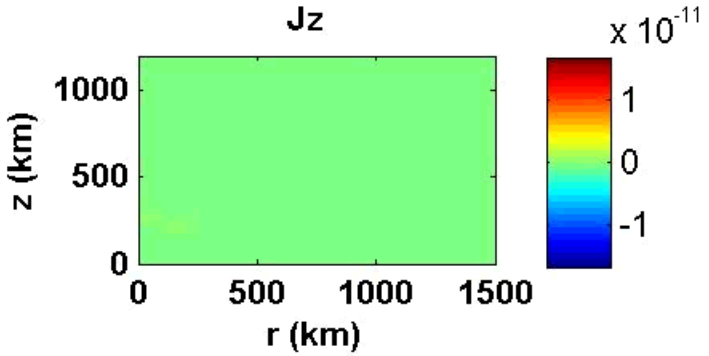

Br (t = 0.05 sec) 10Hz100x20
x 10^-12
1
0
-1
1000
500
0
z (km)
0
500
1000
1500
r (km)


Bphi (t = 0.05 sec) 10Hz100x20
x 10^-13
4
2
0
-2
-4
1000
500
0
z (km)
0
500
1000
1500
r (km)

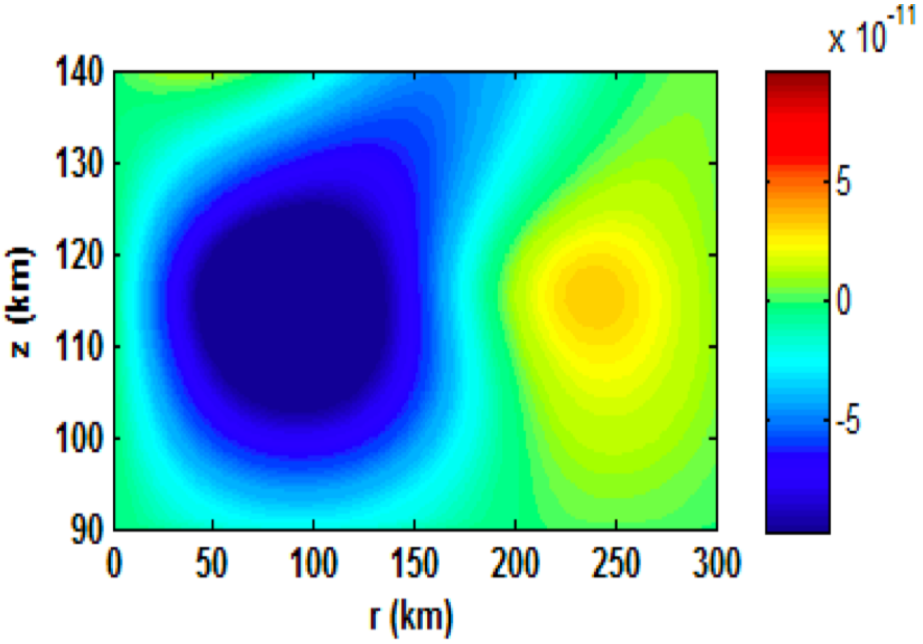

Bz
x 10^-12
2
0
-2
1000
500
0
z (km)
0
500
1000
1500
r (km)


Er
x 10^-6
2
0
-2
1000
500
0
z (km)
0
500
1000
1500
r (km)

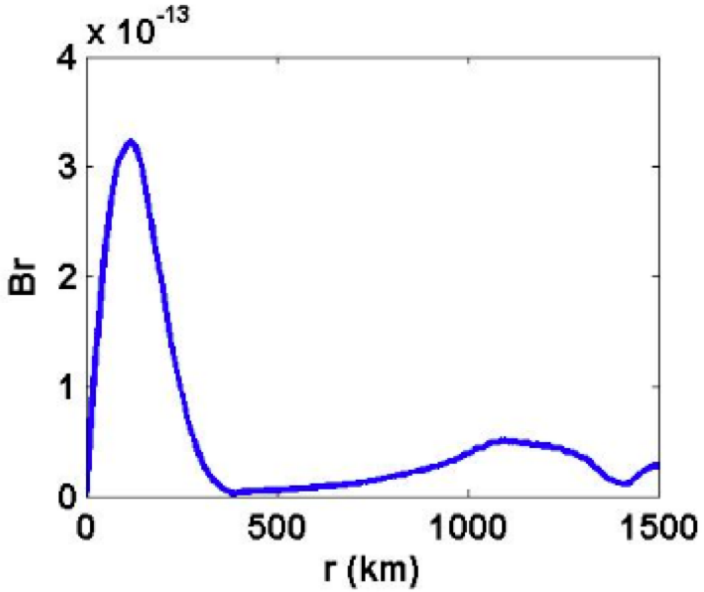

Ephi
x 10^-6
5
0
-5
1000
500
0
z (km)
0
500
1000
1500
r (km)


Jz
x 10^-11
1
0
-1
1000
500
0
z (km)
0
500
1000
1500
r (km)

Secondary Antenna Current and Ground Field

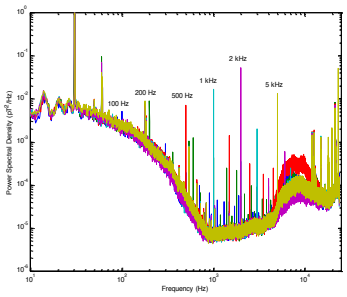


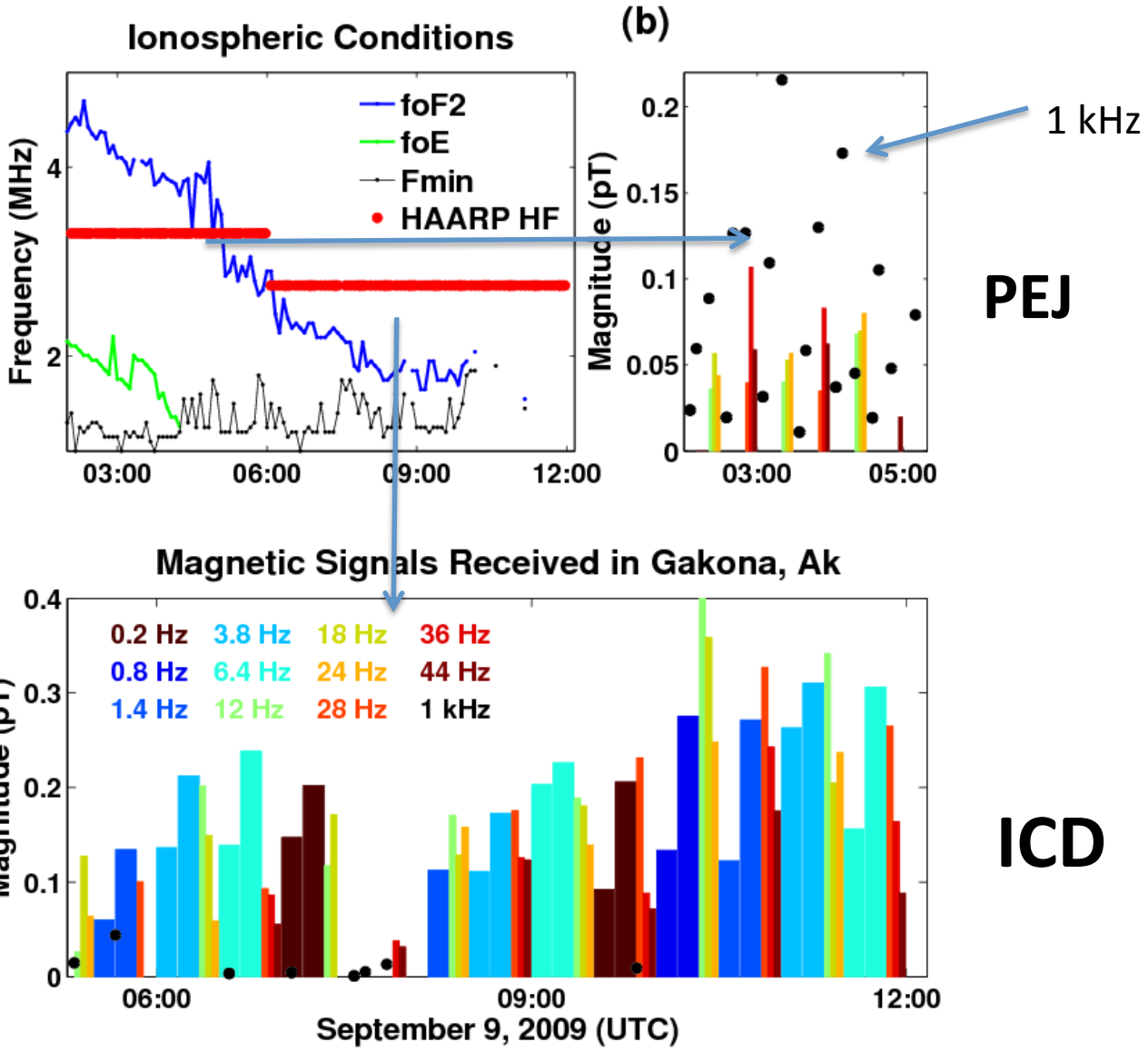
J_ϕ



B_r

PoP Exps: PEJ to ICD Transition



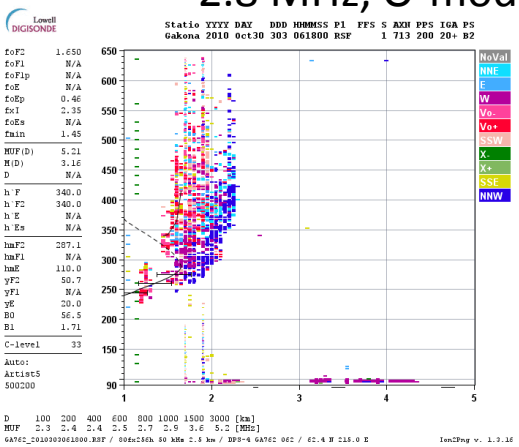


Scaling with power and frequency

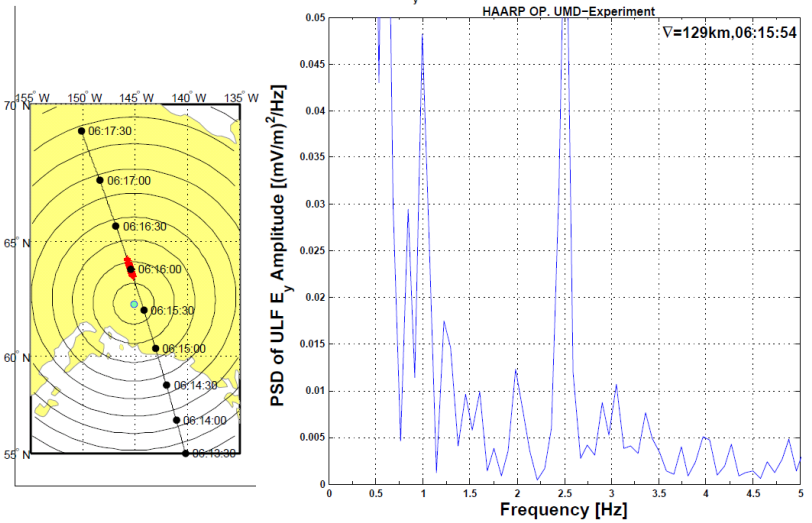
Proof of Concept ICD SAW Injection Experiment

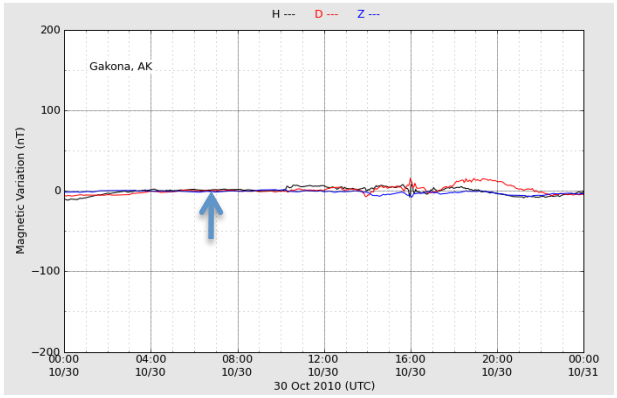
Chang-Lebinsky-Milikh-Papadopoulos

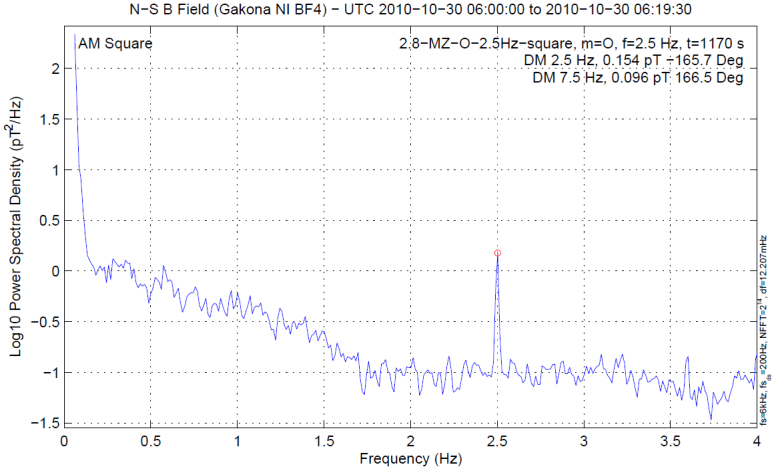
2.8 MHz, O-mode

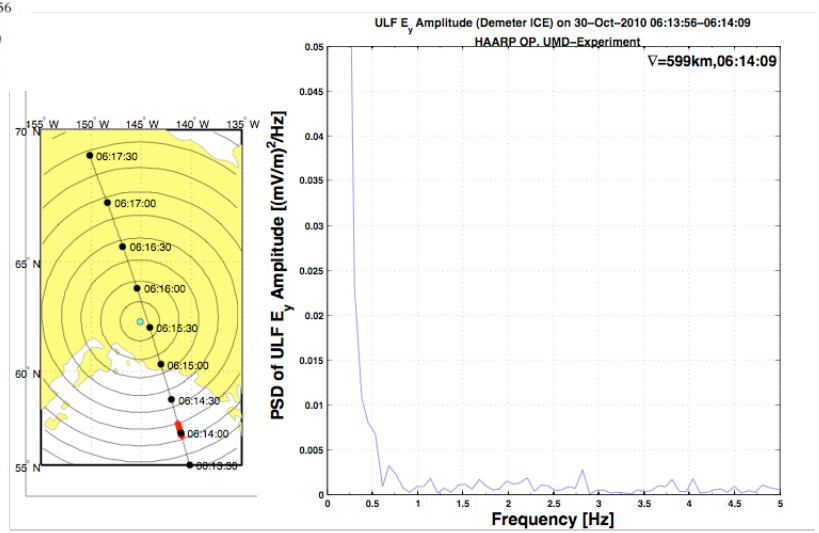


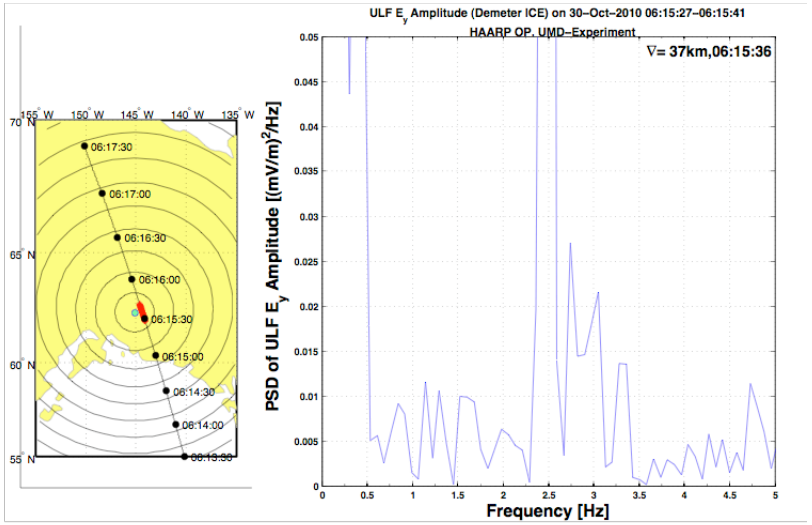
BRIOCHE

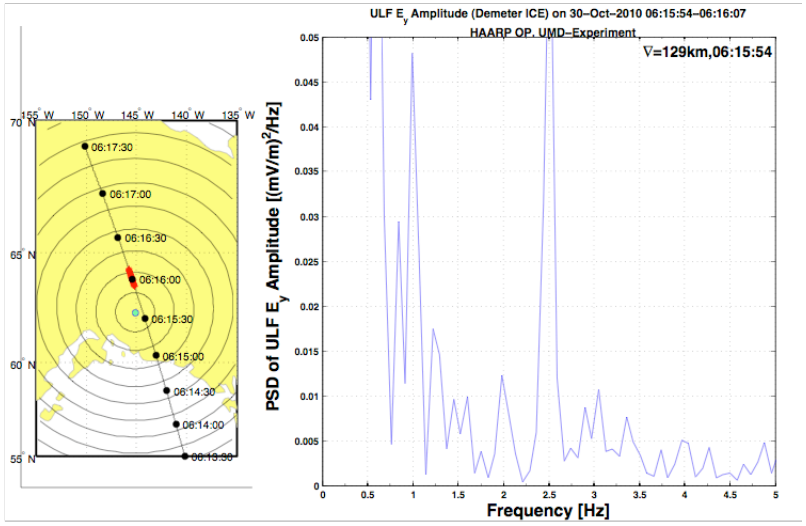


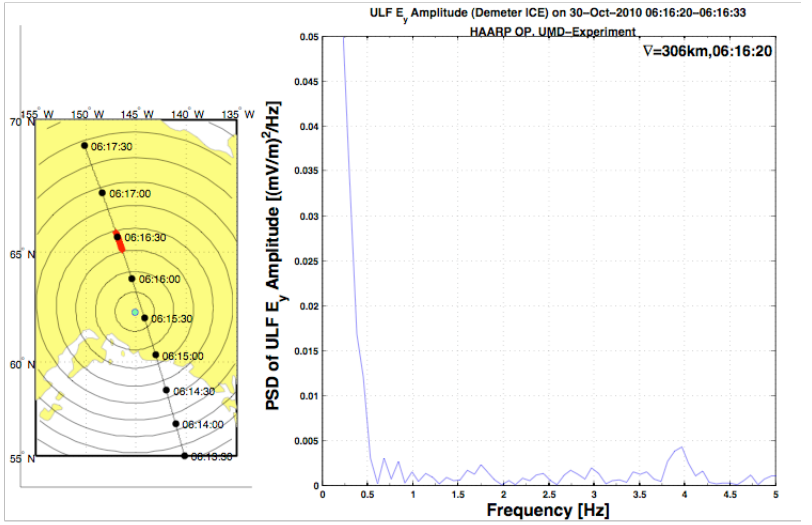





ULF E$_y$ Amplitude (Demeter ICE) on 30–Oct–2010 06:13:56–06:14:09
HAARP OP. UMD–Experiment
∇=599km,06:14:09
PSD of ULF E$_y$ Amplitude [(mV/m)^2/Hz]
Frequency [Hz]

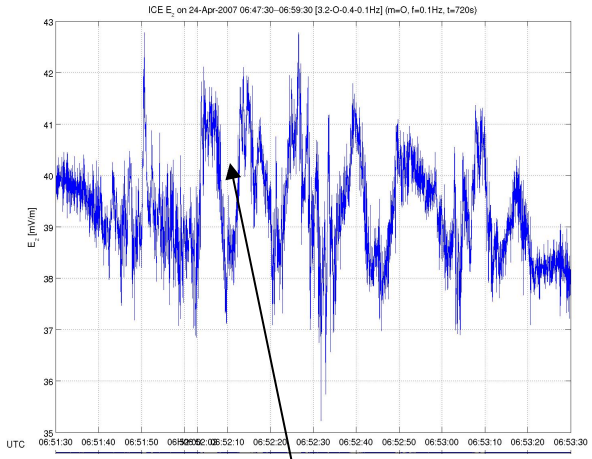

ULF E$_y$ Amplitude (Demeter ICE) on 30–Oct–2010 06:15:27–06:15:41
HAARP OP. UMD–Experiment
∇= 37km,06:15:36
PSD of ULF E$_y$ Amplitude [(mV/m)^2/Hz]
Frequency [Hz]


ULF E$_y$ Amplitude (Demeter ICE) on 30–Oct–2010 06:15:54–06:16:07
HAARP OP. UMD–Experiment
∇=129km,06:15:54
PSD of ULF E$_y$ Amplitude [(mV/m)^2/Hz]
Frequency [Hz]

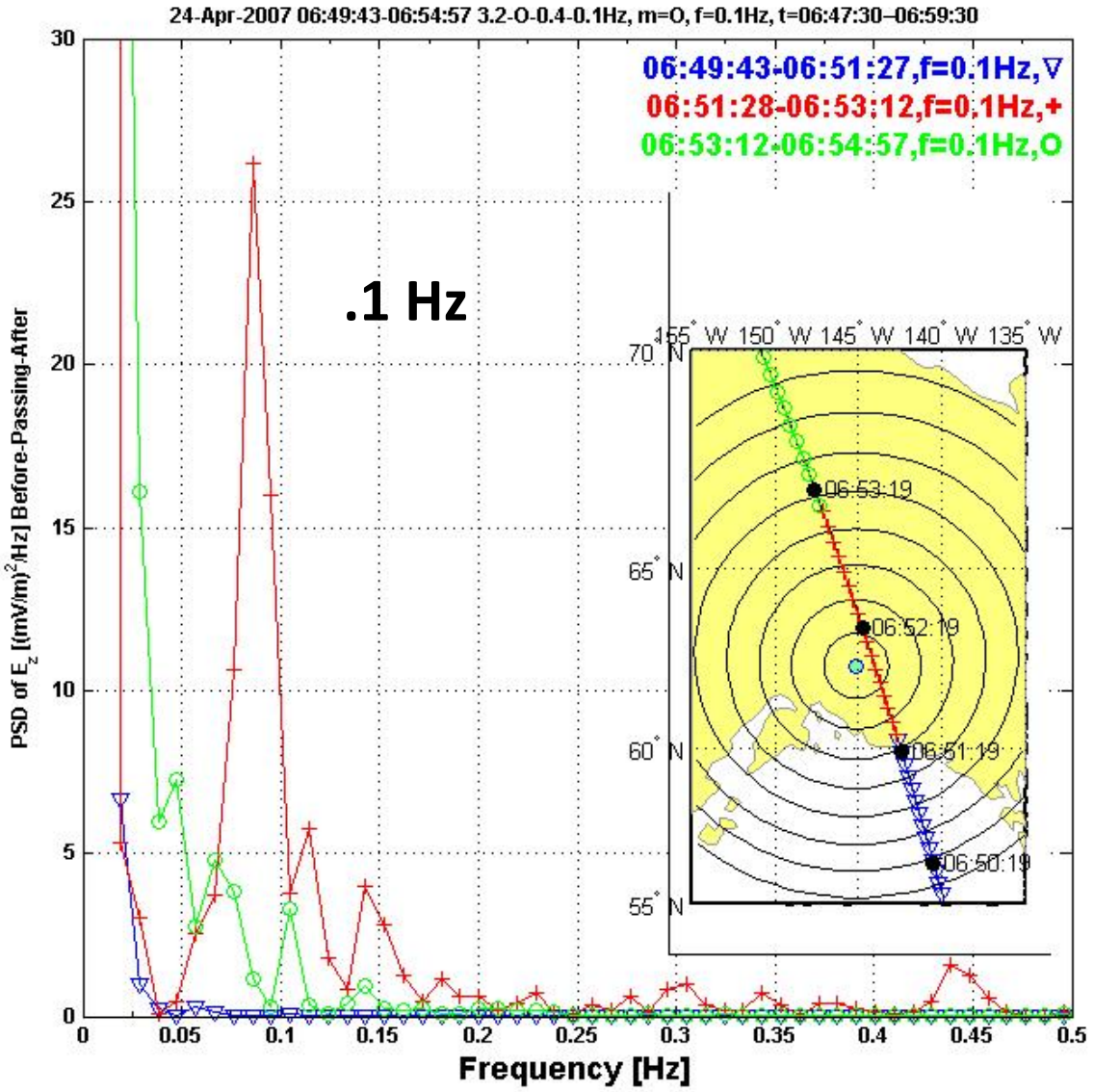

ULF E$_y$ Amplitude (Demeter ICE) on 30–Oct–2010 06:16:20–06:16:33
HAARP OP. UMD–Experiment
∇=306km,06:16:20
PSD of ULF E$_y$ Amplitude [(mV/m)^2/Hz]
Frequency [Hz]

Msonic Wave Injection

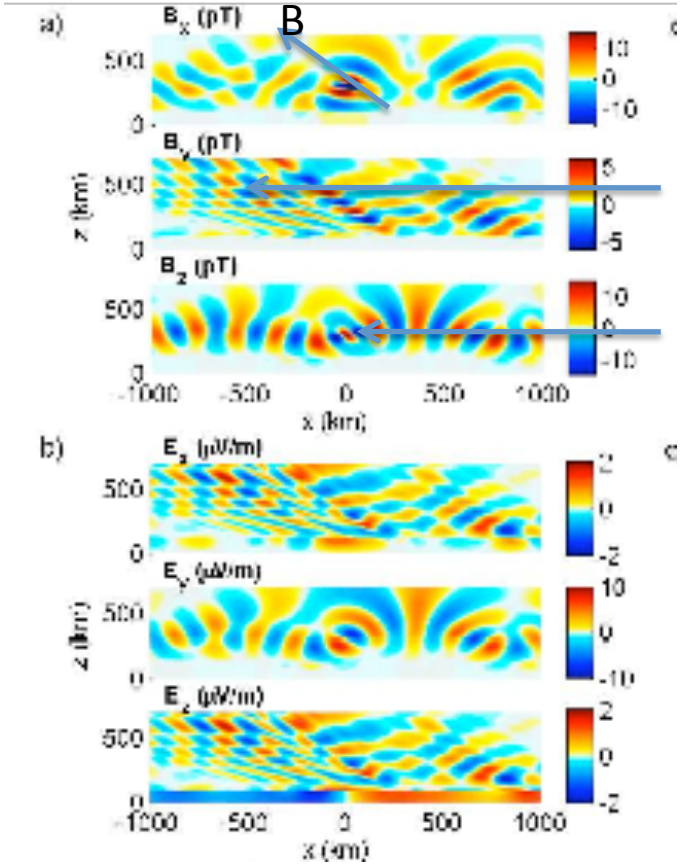
DEMETER



10 sec oscillations

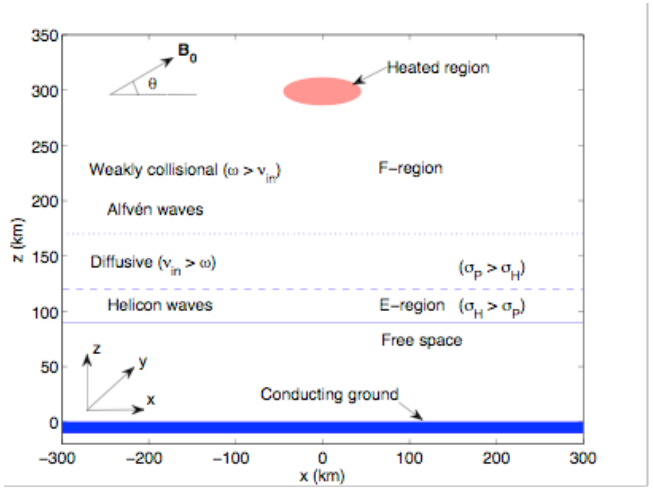


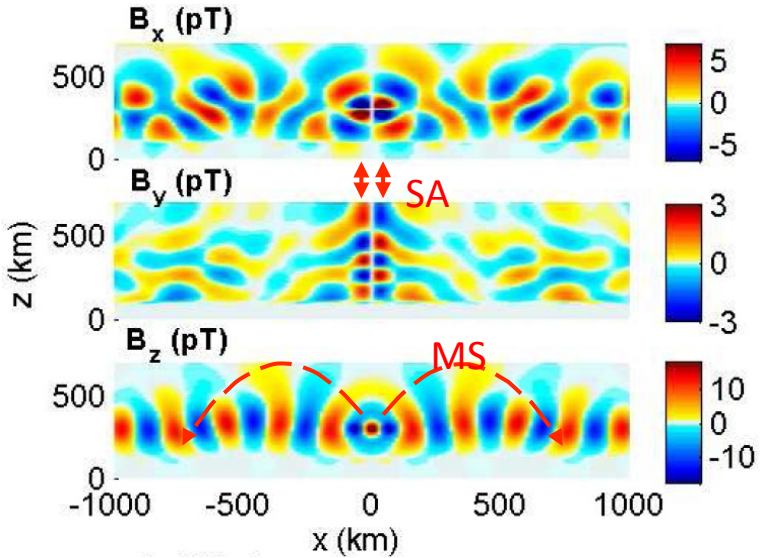
ELF Injection in the inner RB using the Arecibo Heater



SAW injection

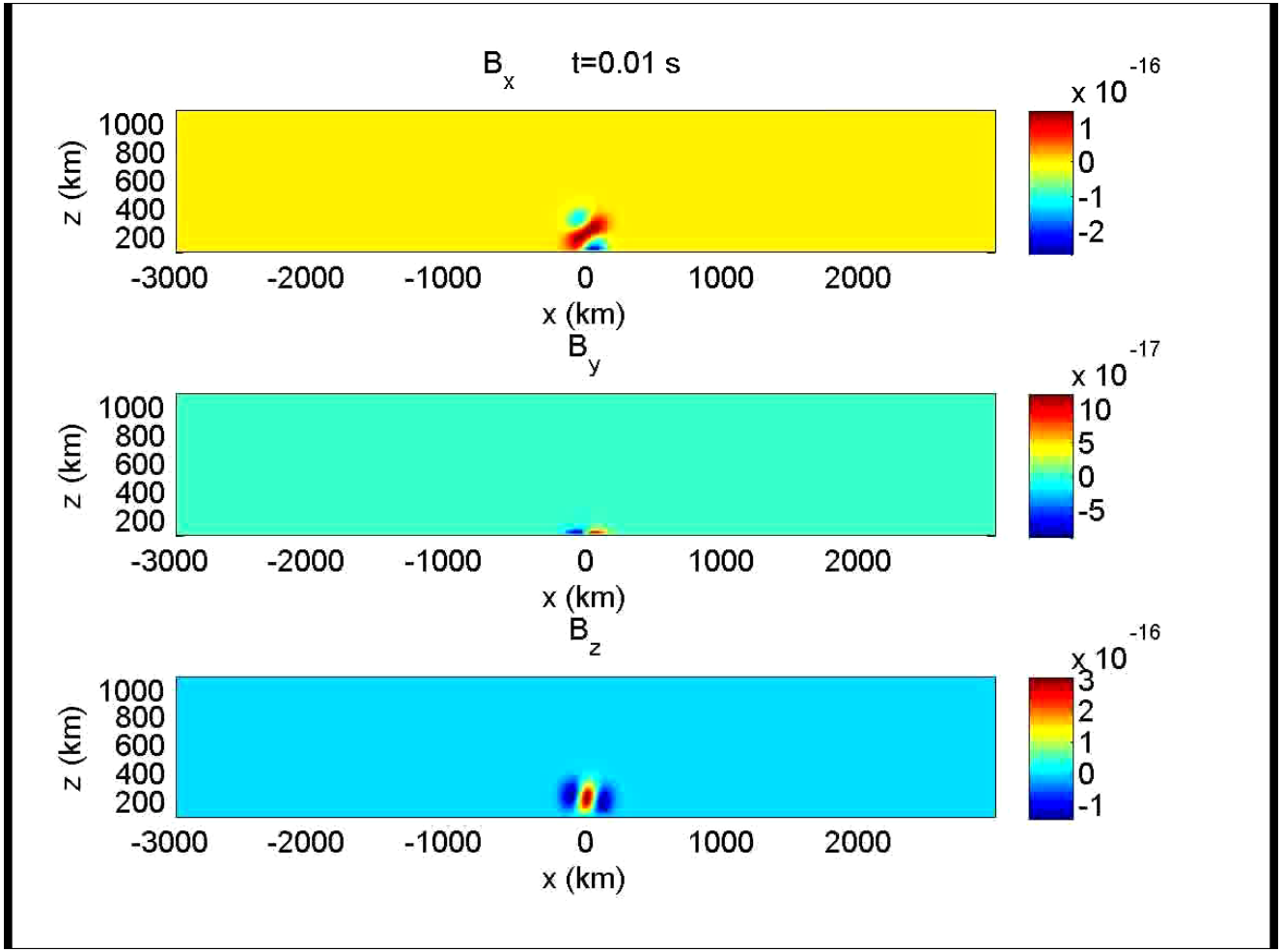
HF heating





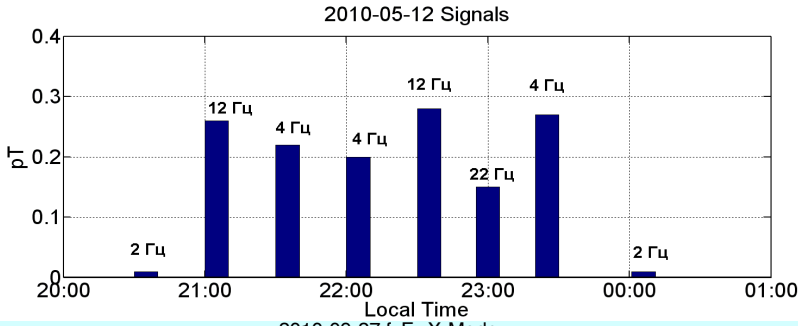
ICD - Implications

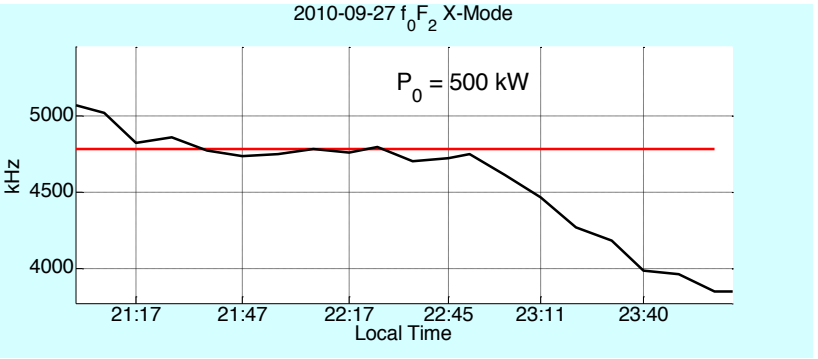
Mid-latitude Heaters – Arecibo , SURA : Wave Particle Interaction Studies in the inner Belt

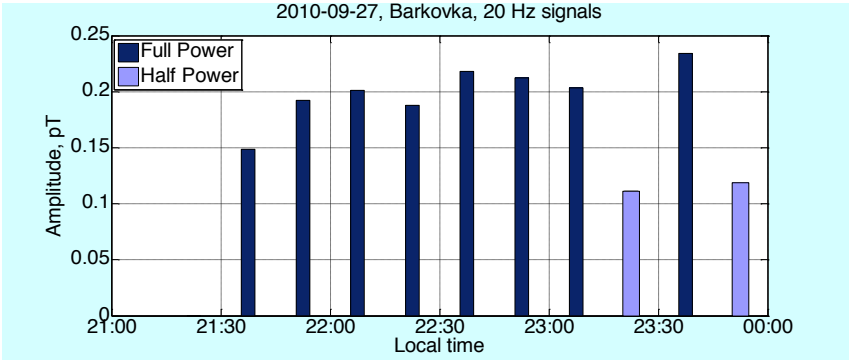


Mid-Latitude ICD – Arecibo, SURA

SURA – ICD Confirmation – D. Kotik 2011







Old Result
Ganguly-Gordon-Papadopoulos PRL 1985

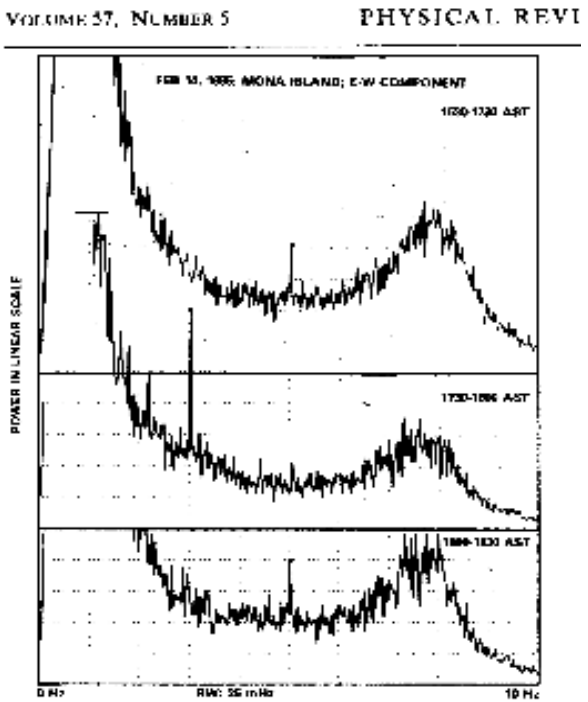


FIG. 1. Spectra of the received signal in the 0–10-Hz band (14 February 1985). Receiver was located at Moni Island. Data cover the period 16:30–18:30 AST. The HF transmitters were operated at 5.1 MHz and with a difference frequency Δf of 5 Hz during 16:30–17:30 AST, which was changed to 3 Hz during 17:30–18:00 AST and changed back to 5.0 Hz during 18:00–18:30 AST. The magnitude of the 5.0-Hz signal is about 160 $\mu\gamma$ $Hz^{-1/2}$ and that of the 3.0-Hz signal is about 340 $\mu\gamma$ $Hz^{-1/2}$.

Wave-particle interactions study under controlled wave injection

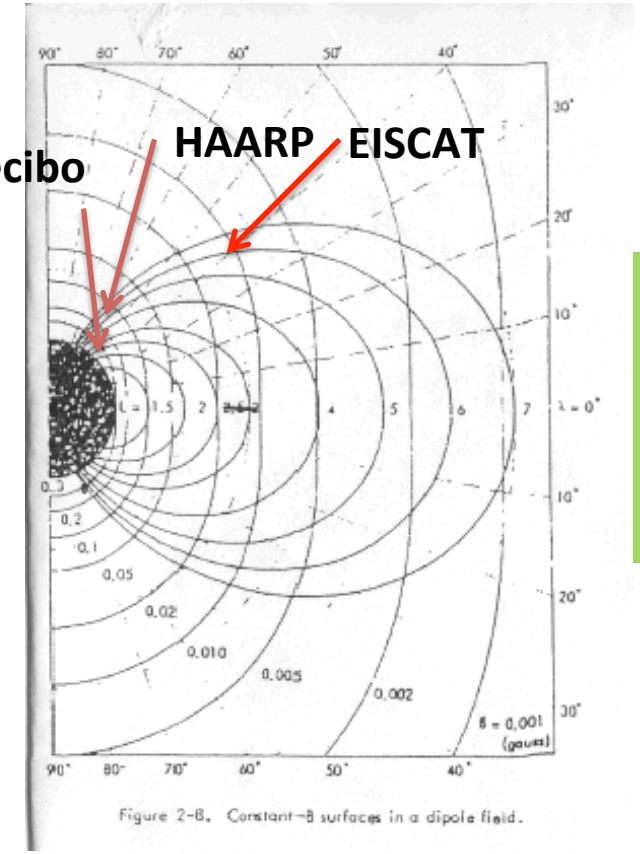


Figure 2-8. Constant-B surfaces in a dipole field.

- Inner RB (1.5<L<2)
- Slot (2<L<3)
- Outer (L>3)

• Use Ionospheric heaters (HF) to inject ULF/ELF/VLF waves in the L-shell that spans the heater.

Ionospheric Heaters
HAARP (L≈4.9)
Arecibo (L≈1.4)
EISCAT (L≈5.9)
SURA (L≈2.6)

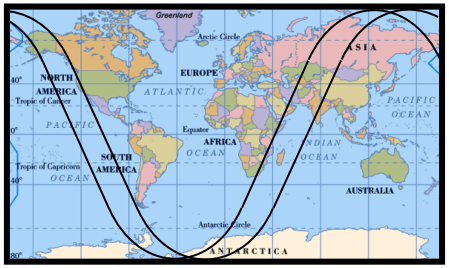
Diagnosed by
RBSP ,Resonance, DSX, ePOP, Orbitals, Barrel

Techniques to transform HF to ULF/ELF/VLF frequencies

1.Polar Electrojet Antenna (PEJ)
a. Requires an electrojet current in the D/E region (70-90 km)- Restricted to high latitudes
b. Can inject frequencies up to 20 kHz [Whistlers and Shear Alfven Waves (SAW)]

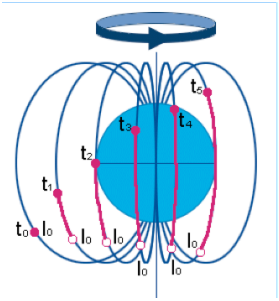
2. Ionospheric Current Drive (ICD)
a. Does not require electrojet
b. Restricted to frequencies below 70 Hz [SAW, EMIC, Magneto-Sonic (MS)]

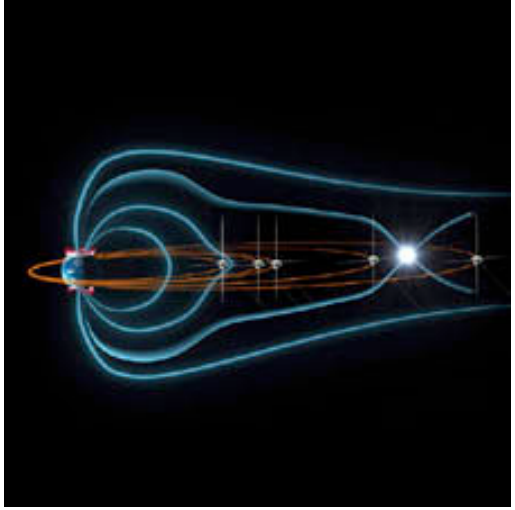
ePOP – NRL
Launch -2012
Inclination 80

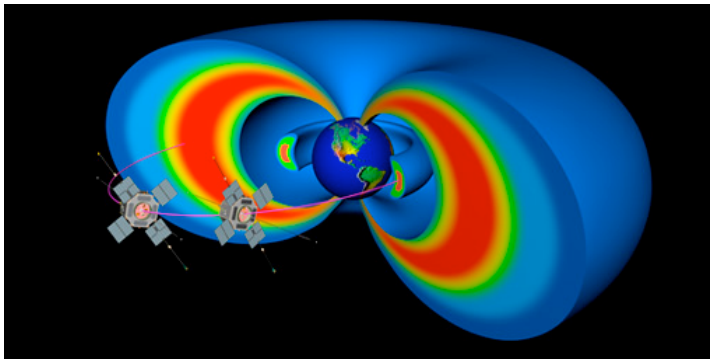


RESONANCE (Russia)

Launch ~2013-14, 4-spacecraft
Orbit:1800x30,000km, ~63° incl.



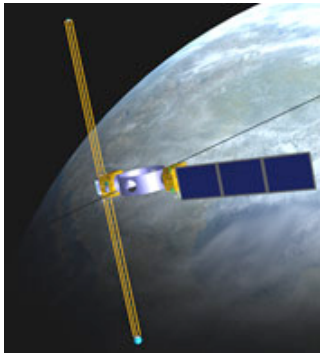




THEMIS (NASA)

Launch Feb 17, 2007
5 identical probes (3)

- Launch May 18, 2012
- 2 probes, <1500 kg for both
- ~10° inclination, 9 hr orbits
- ~500 km x 30,600 km



DSX (AFRL)

Launch ~2012
MEO, wave/particle

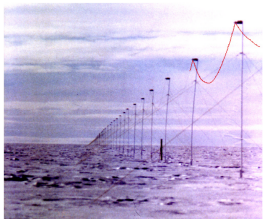
ORBITALS (CSA)

Launch 2012-2013
Orbit(?) ~L=2 to L=6

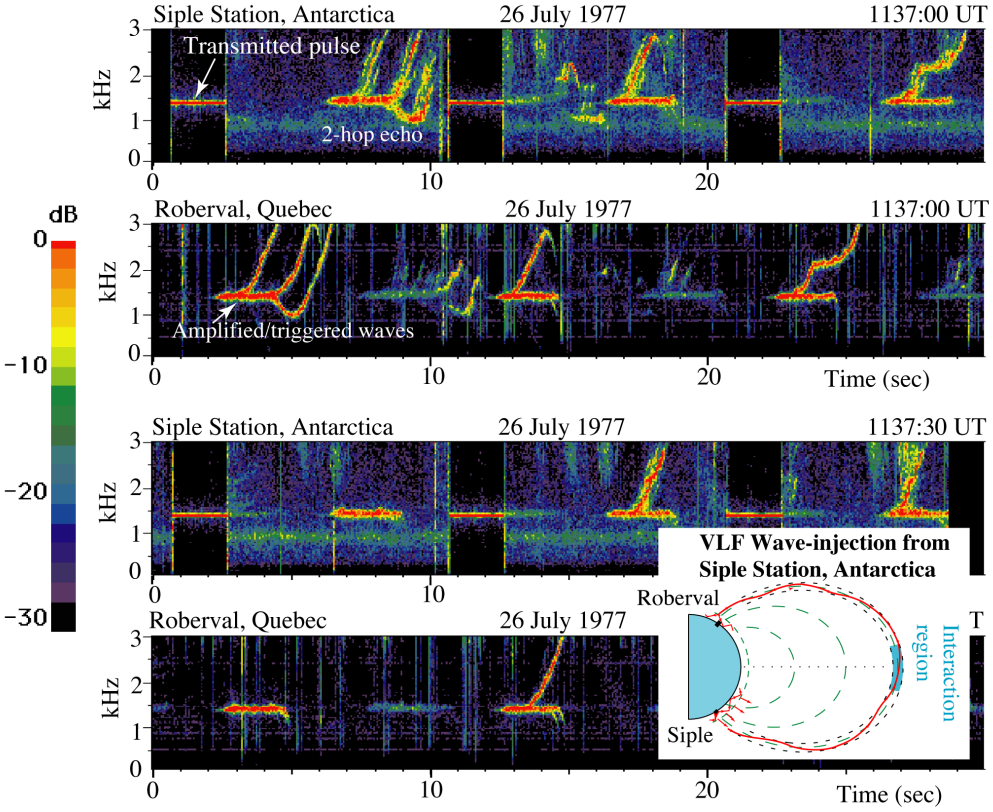
HAARP Active Experiments

Controlled VLF Wave Injection Artificially Stimulated Emissions (ASE)

Siple Station Antartica – (Stanford – NSF) Helliwell (1973-1987):

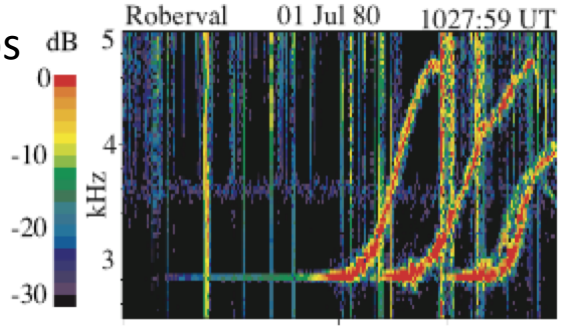


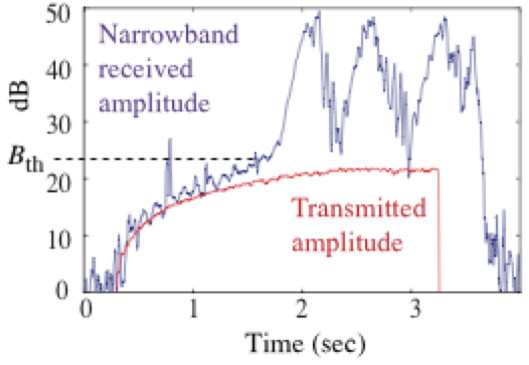
L=4.2, 1.5 MW, 42 km length antenna on 2 km thick ice sheet,
Inject 3-6 kHz (Very narrow frequency range)
Very difficult and inefficient to inject ELF/VLF with ground



2 hops

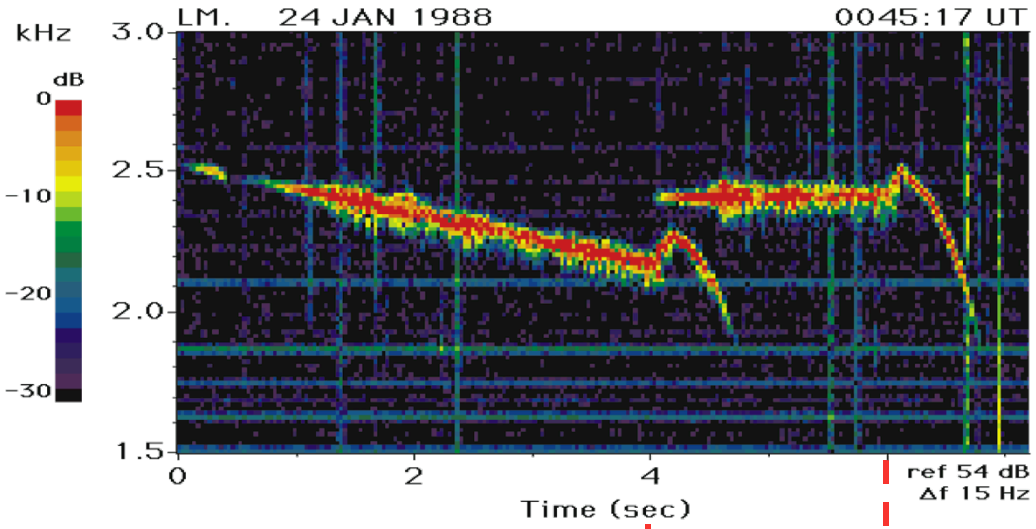
1 hop



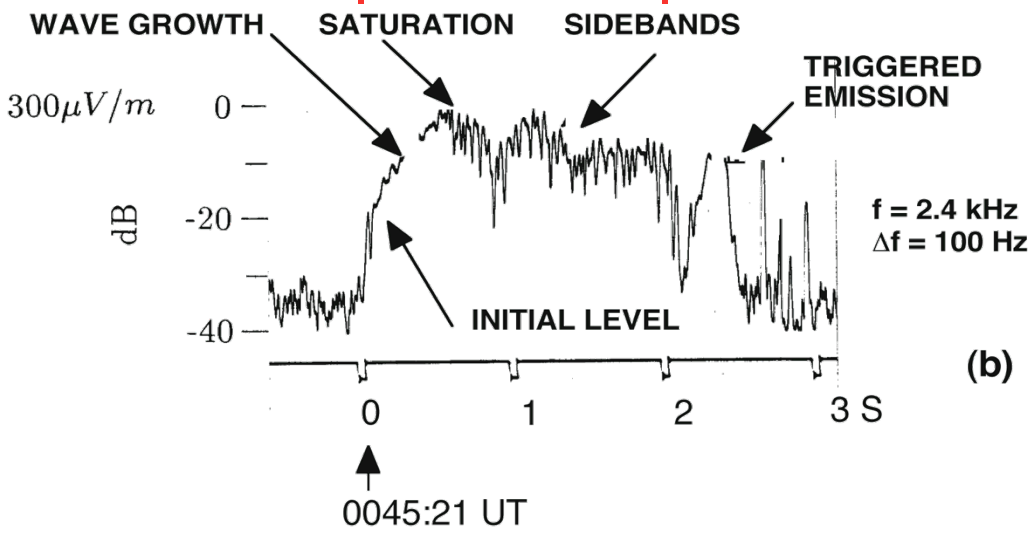


Triggered Emissions

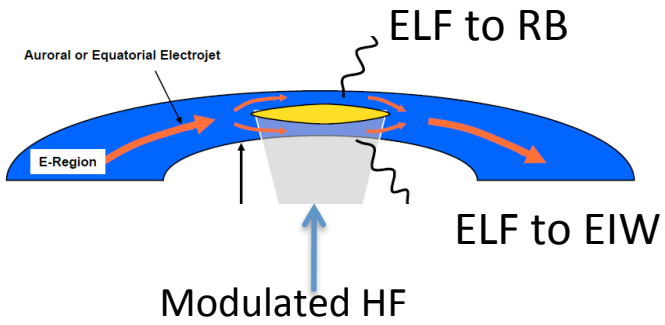
Growth & Saturation



Amplitude in ~100 Hz band

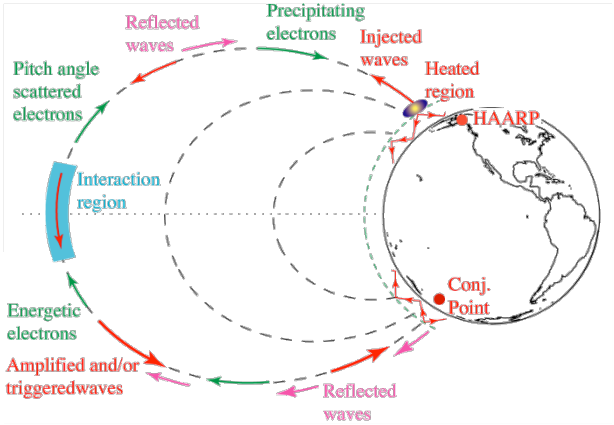


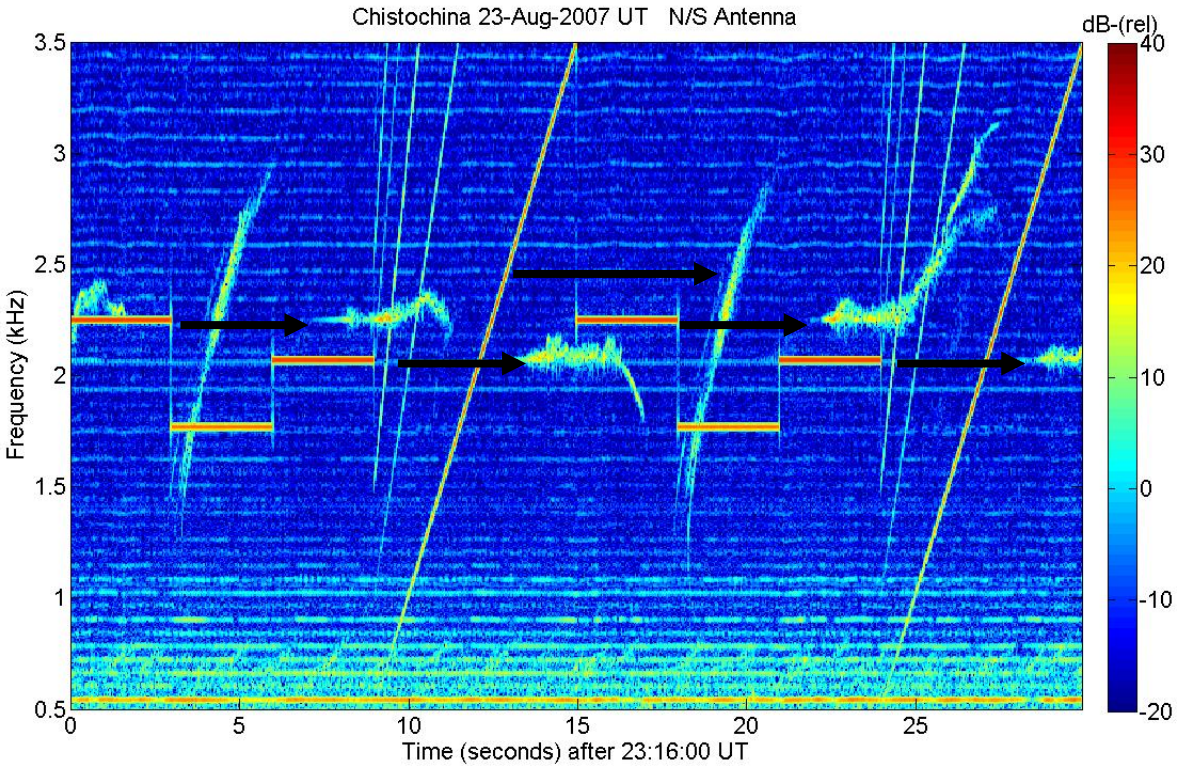
ASE Using the PEJ

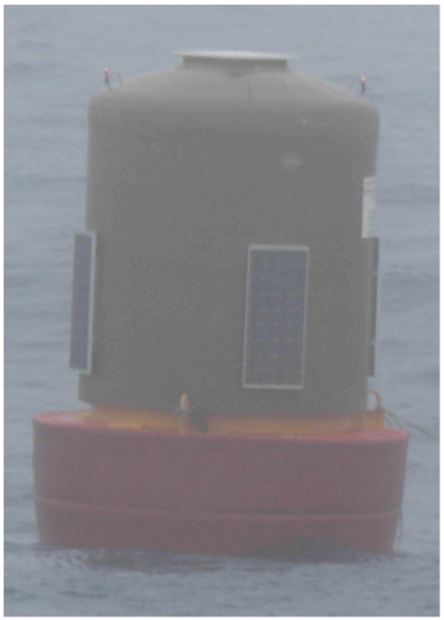


Stanford University - Inan

ASE Studies

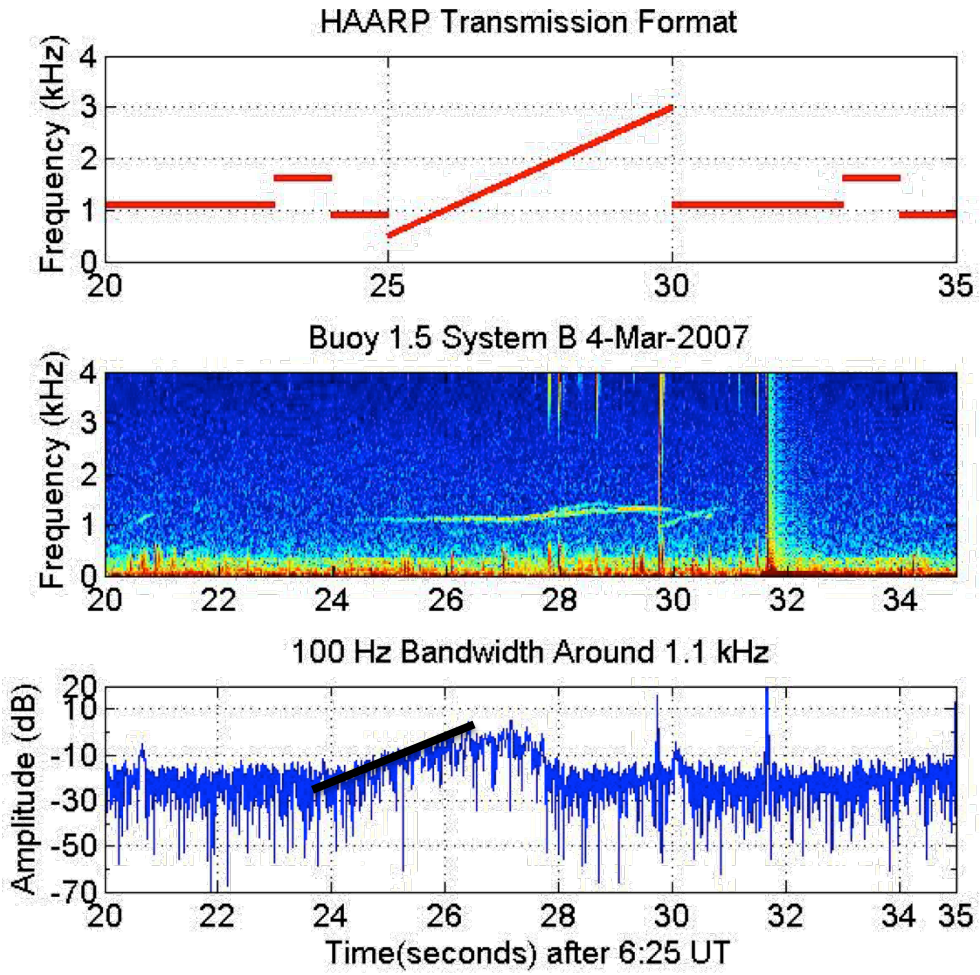






Pulses above 2 kHz have 1-hop echoes with triggered emissions
Pulse near 1.7 kHz does not; ramps have echoes with no emissions

15 dB/s Amplification & Triggered Emissions



Only the pulse at 1100 Hz is amplified

COHERENT GROWTH 20-30 dB

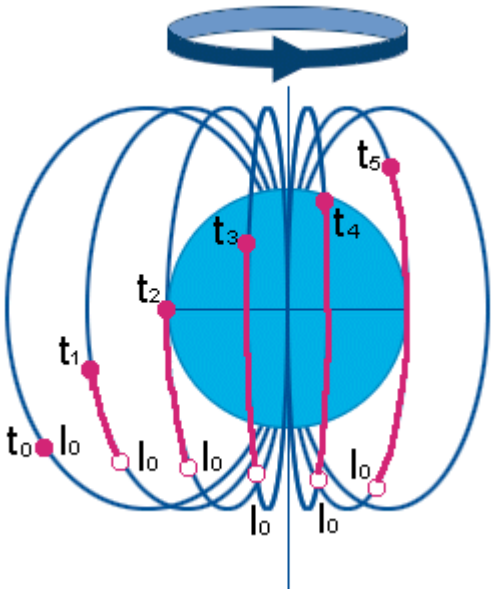
- **THRESHOLD**
- **SIGNAL SATURATION**
- **TRIGGERED EMISSIONS – risers, fallers, hooks**
- **ENTRAINMENT**

Resolution of key cause and effect issues requires long time observations on flux tube

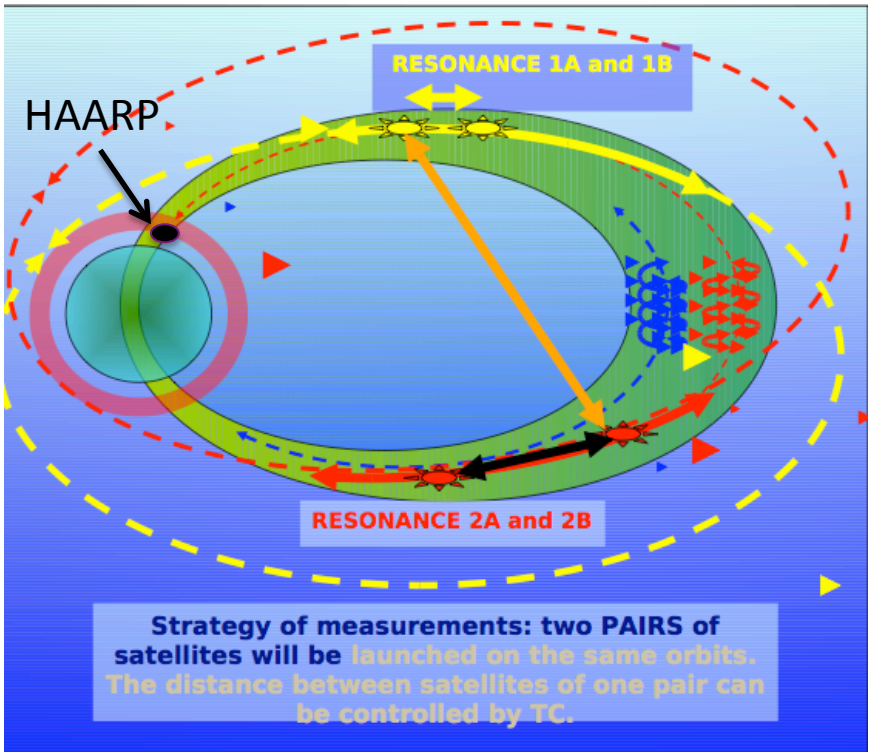
The Resonance Project -IKI

The HAARP/ Resonance Project –UMCP/ IKI

Magneto-synchronous Orbits



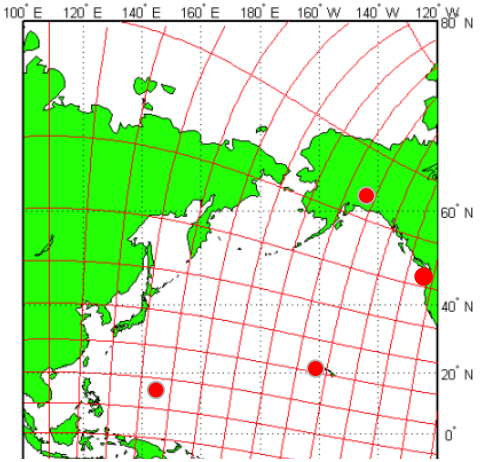
Perigee: 500 km
Apogee: 28000 km
Inclination:
+ 63.4 and -63.4
Period: 8 hours

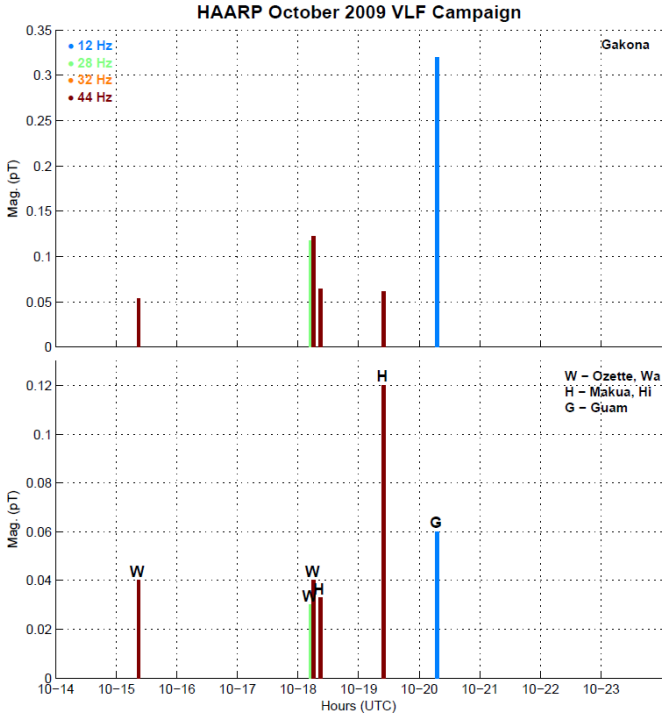


Orbits of two spacecraft pairs glide for 1-2 hours along the same selected flux tube – Co-rotate with Earth

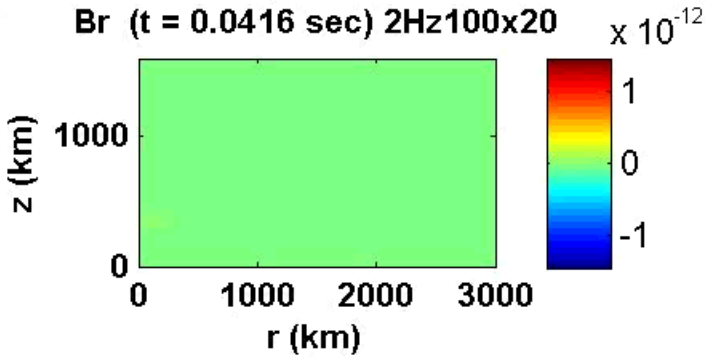
Provides dynamic feedback to the heater operation

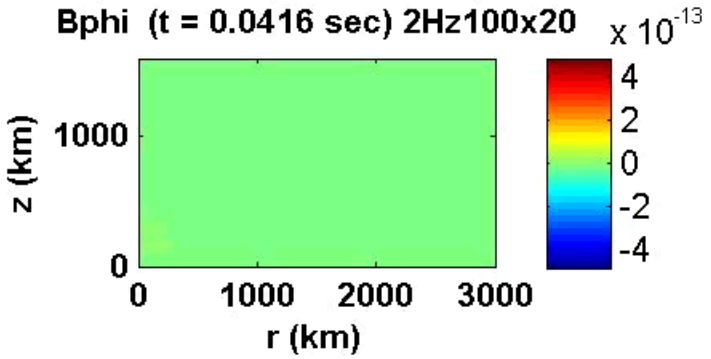
ELF detection at Distant Sites

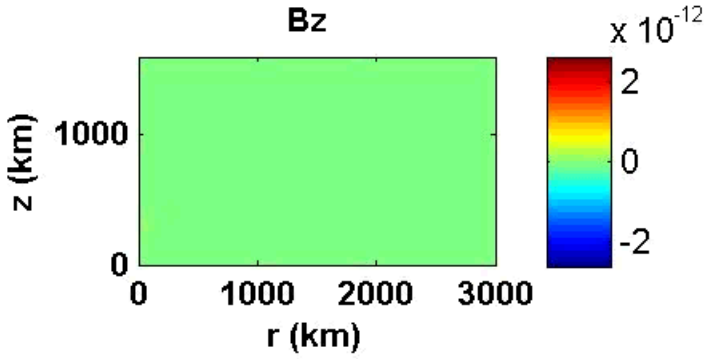


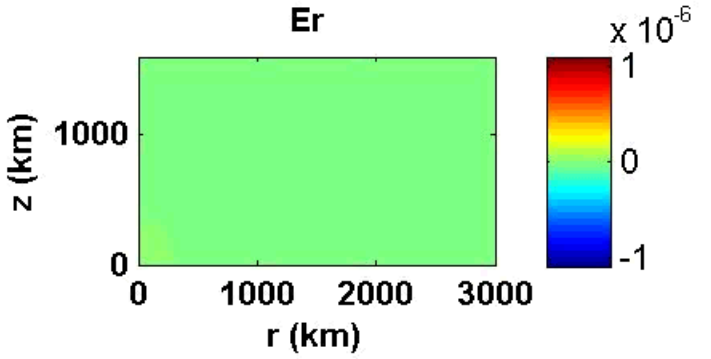


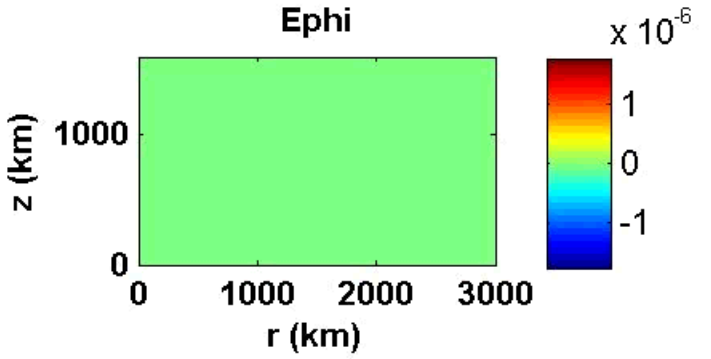
- Distance to Gakona
  - Lake Ozette, WA (W)
    - 1300 mi
  - Hawaii (H)
    - 2900 mi
  - Guam (G)
    - 4800 mi
- Detection under quiet Gakona cond.
- No detection during electrojet days Oct. 22-23

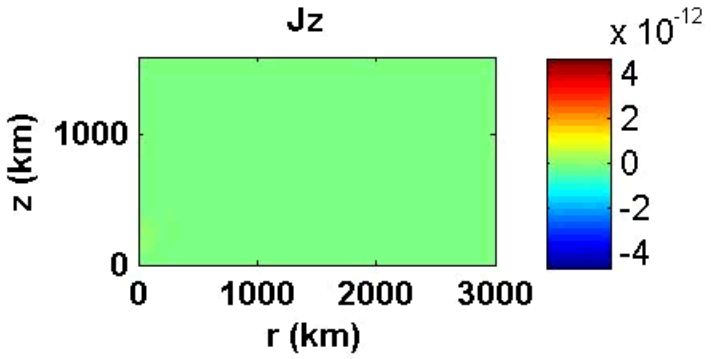

Br (t = 0.0416 sec) 2Hz100x20
x 10^-12
1
0
-1
z (km)
1000
0
0
1000
2000
3000
r (km)


Bphi (t = 0.0416 sec) 2Hz100x20
x 10^-13
4
2
0
-2
-4
z (km)
1000
0
0
1000
2000
3000
r (km)

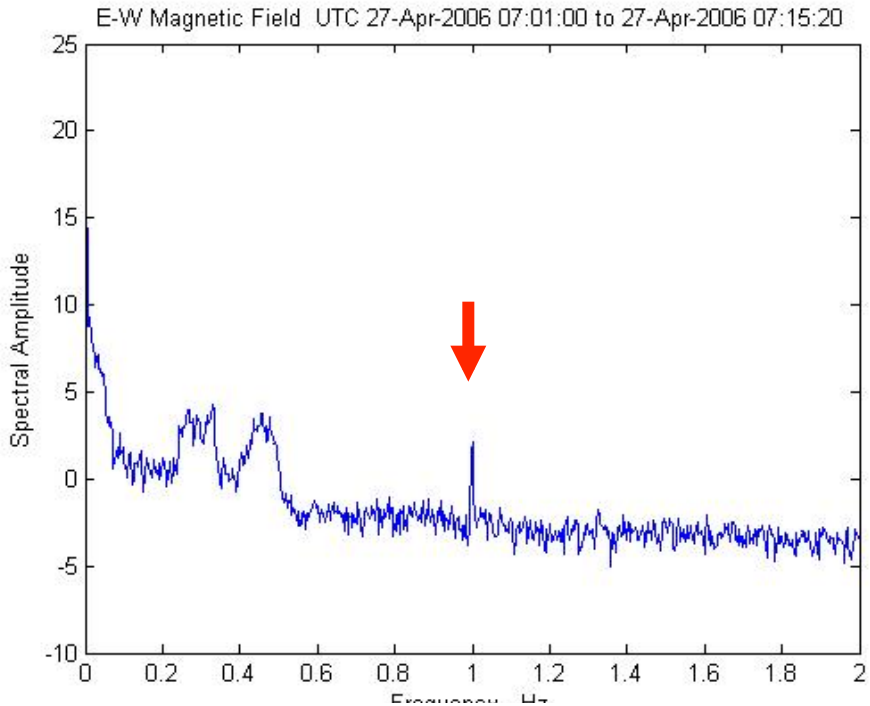

Bz
x 10^-12
2
0
-2
z (km)
1000
0
0
1000
2000
3000
r (km)

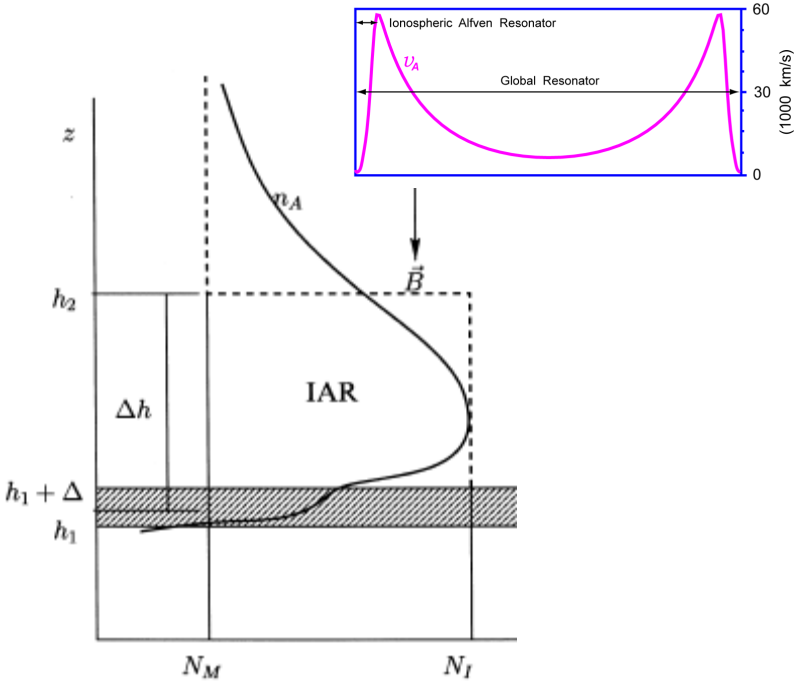

Er
x 10^-6
1
0
-1
z (km)
1000
0
0
1000
2000
3000
r (km)

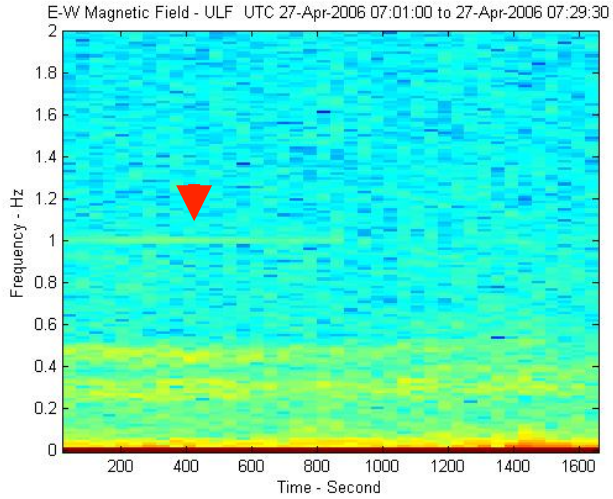

Ephi
x 10^-6
1
0
-1
z (km)
1000
0
0
1000
2000
3000
r (km)


Jz
x 10^-12
4
2
0
-2
-4
z (km)
1000
0
0
1000
2000
3000
r (km)

Ionospheric Alfven Resonator (IAR) Excitation



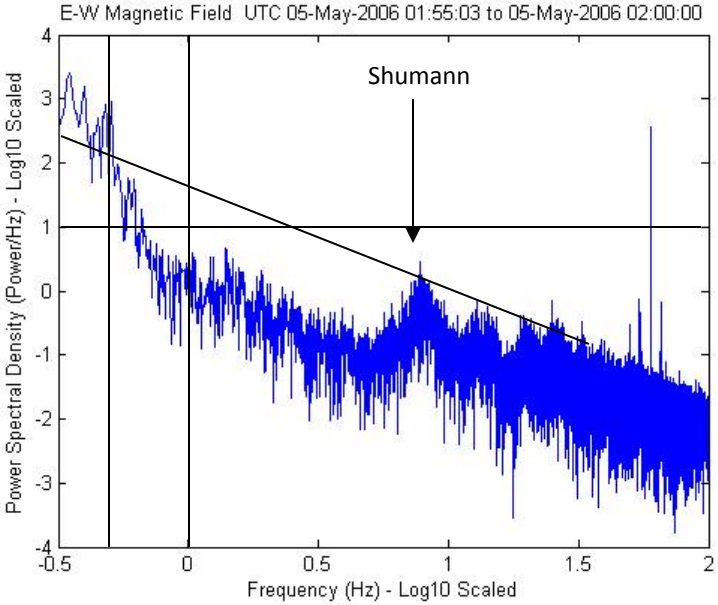




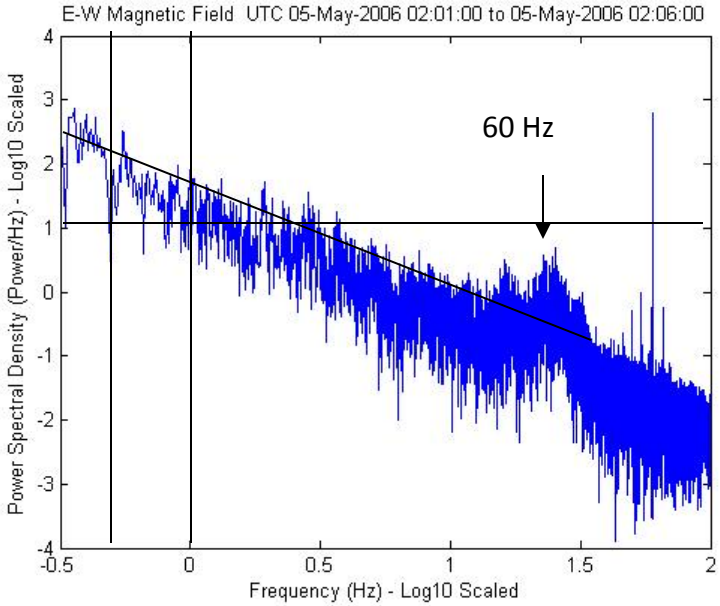
Excitation of the IAR due naturally excited waves at .25 Hz and .5 Hz and by HAARP generated SA at 1.0 Hz.

BAE SYSTEMS

SAW Triggered Emissions ?



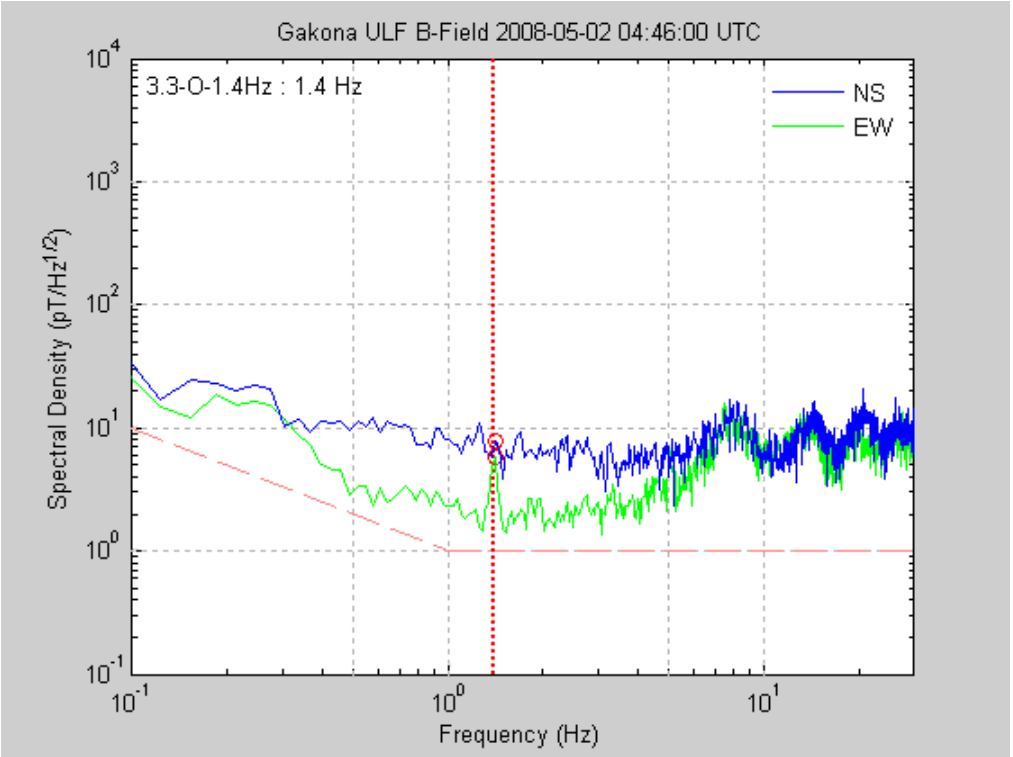
Spectrum before HAARP ULF Start Experiment – Ambient Noise



Spectrum after HAARP ULF Start Noise Increase by more than 10-20 dB between .7-10 Hz

ULF at Gakona – Power Spectral Density (PSD)

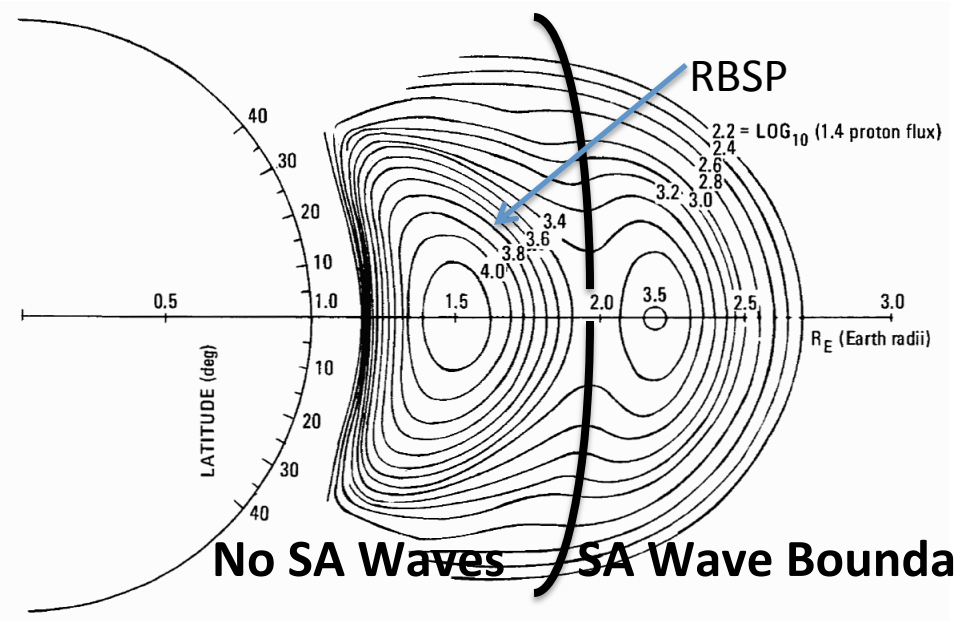
- Frequency spectrum in a moving time window
- Clear Schumann resonances at 8, 14, .. Hz
- Signals emerge as freq. peaks in sync with HAARP ULF operation
- Greatly varying background below 1 Hz

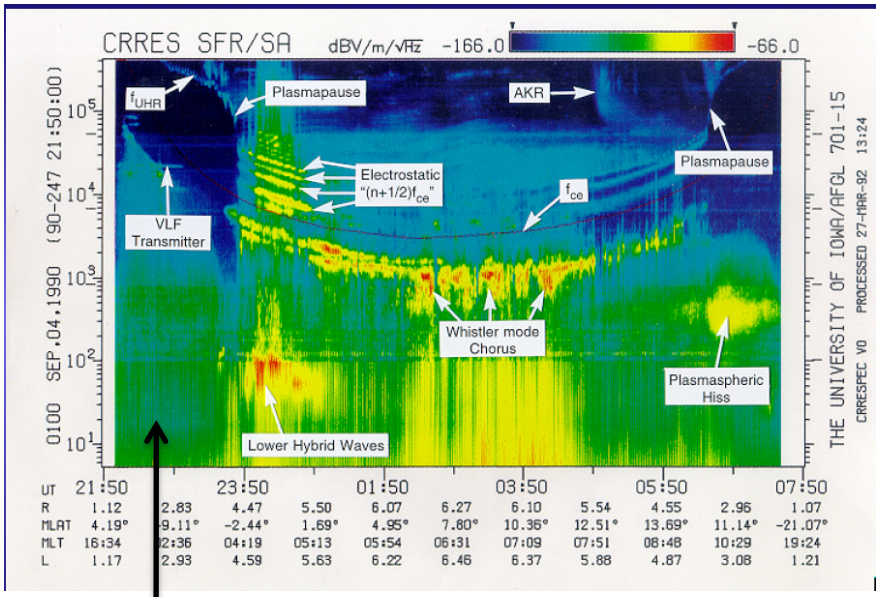


Triggered Pc1 broadband

The Inner Radiation Belt
Arecibo Active Experiments

Inner Proton Belt – Accessible from Arecibo



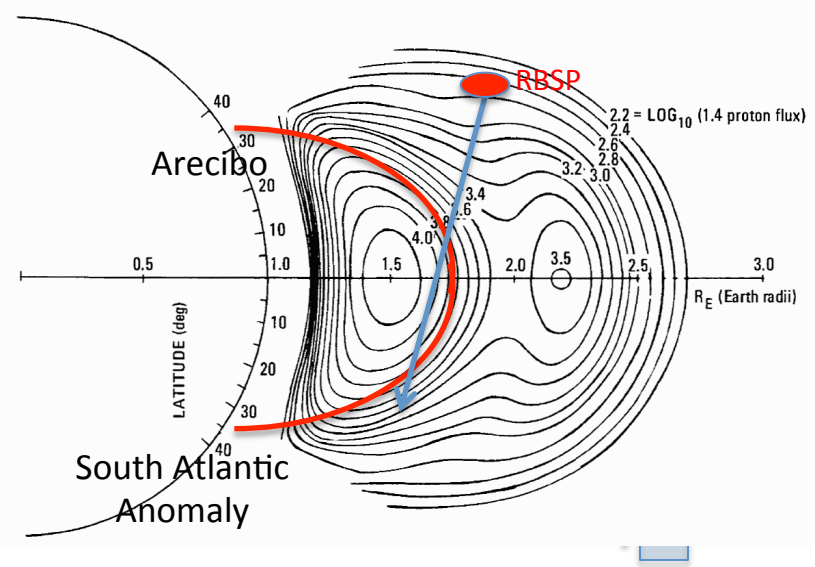


Typical inner belt proton lifetimes:

- **10 MeV – decades**
- **50 MeV – century**

No wave activity at SAW and EMIC branches

Active Probing of Inner RB Using the Arecibo Heater



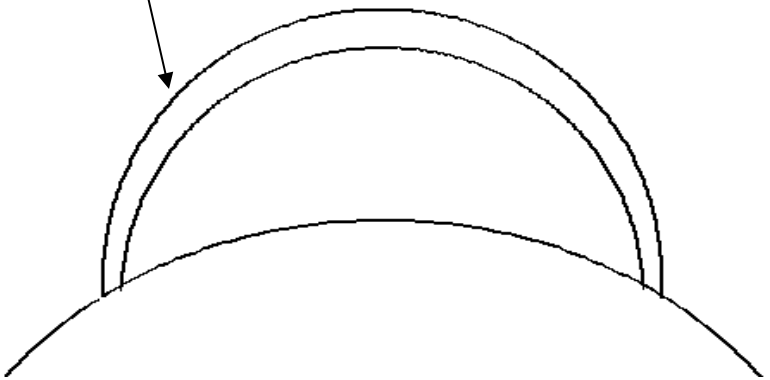
Focus on SAW for protons and EMIC for electrons

WPI critical aspect of RB physics. RBSP will study interactions in the natural environment. A wave injection facility at Arecibo at frequencies that resonate with energetic protons and electrons with RBSP monitoring will provide cause and effect understanding of the induced transport processes.

Frequency Selection for Protons

Example for L=1.5

SAW Injection

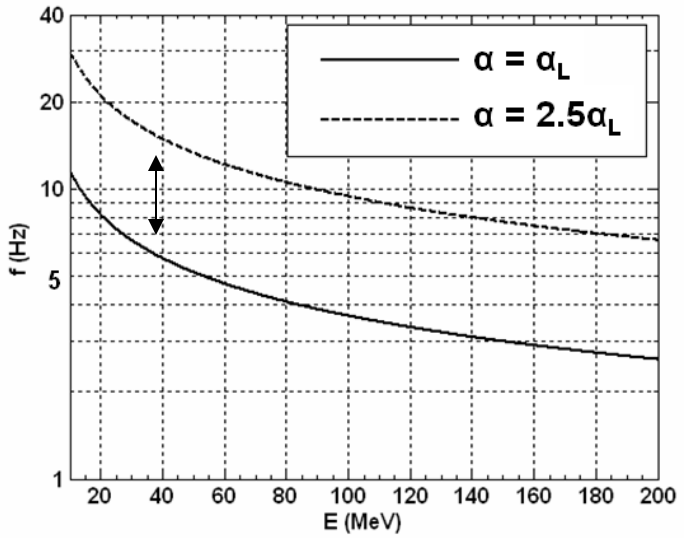


Frequency Selection for Resonance of Protons with SAW

$$\omega \approx k_z V_p$$

$$\omega = k_z V_A$$

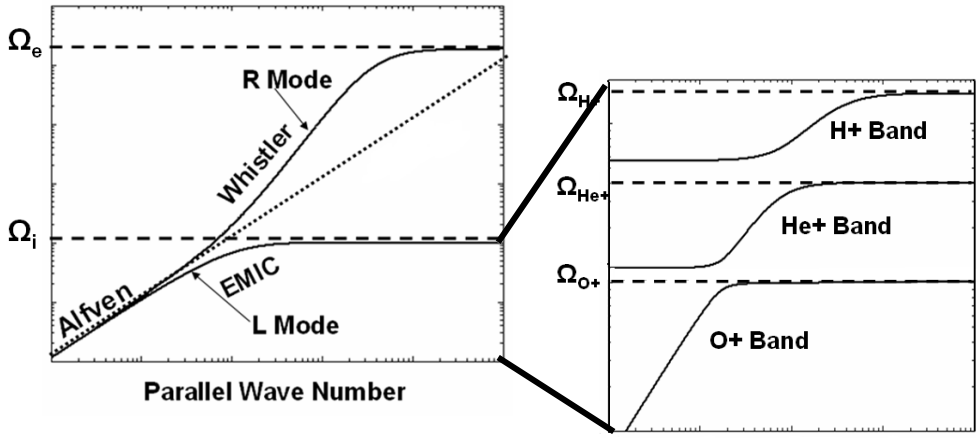
$$\omega(E,\alpha) \approx \frac{\Omega}{\cos\alpha}\sqrt{\frac{MV_A^2}{2E}}$$



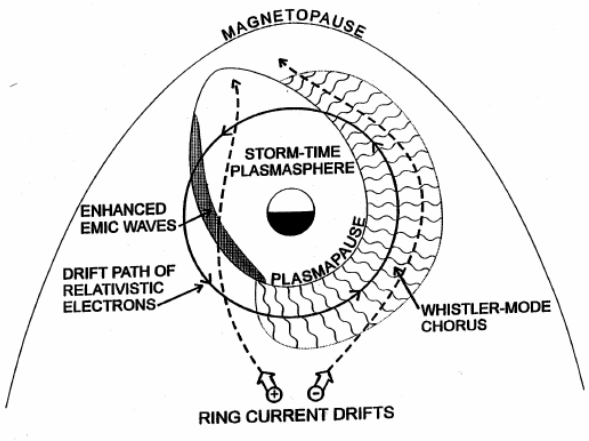
Frequency requirement for equatorial resonance with SAW at L=1.5

Frequency range 5-30 Hz

ENERGETIC ELECTRON WP INTERACTIONS DUE TO EMIC WAVES



Outer Belts



Summers et al., 1998, 2000, 2003

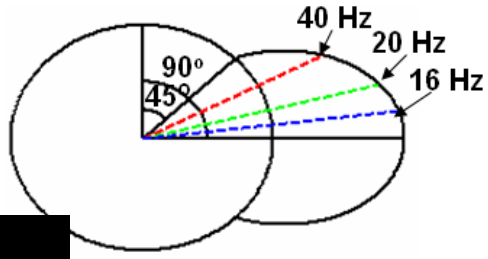
$$-k_z v_z = |\Omega_e| / \gamma$$

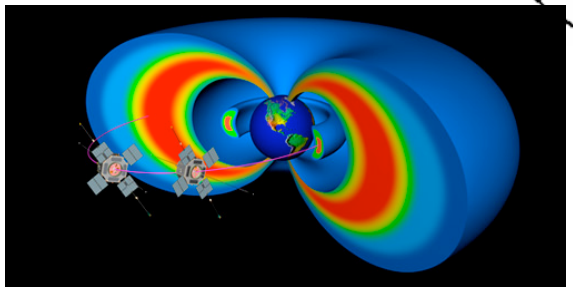
$$\frac{k^2 c^2}{\omega^2} = 1 - \frac{\omega_{pe}^2}{\omega(\omega + |\Omega_e|)} - \sum_{j=1}^{3} \frac{\omega \omega_{pj}^2}{(\omega - \Omega_j)}$$

$$\frac{k^2 c^2}{\omega^2} \to \infty \quad \text{for } \omega \to \Omega_j$$

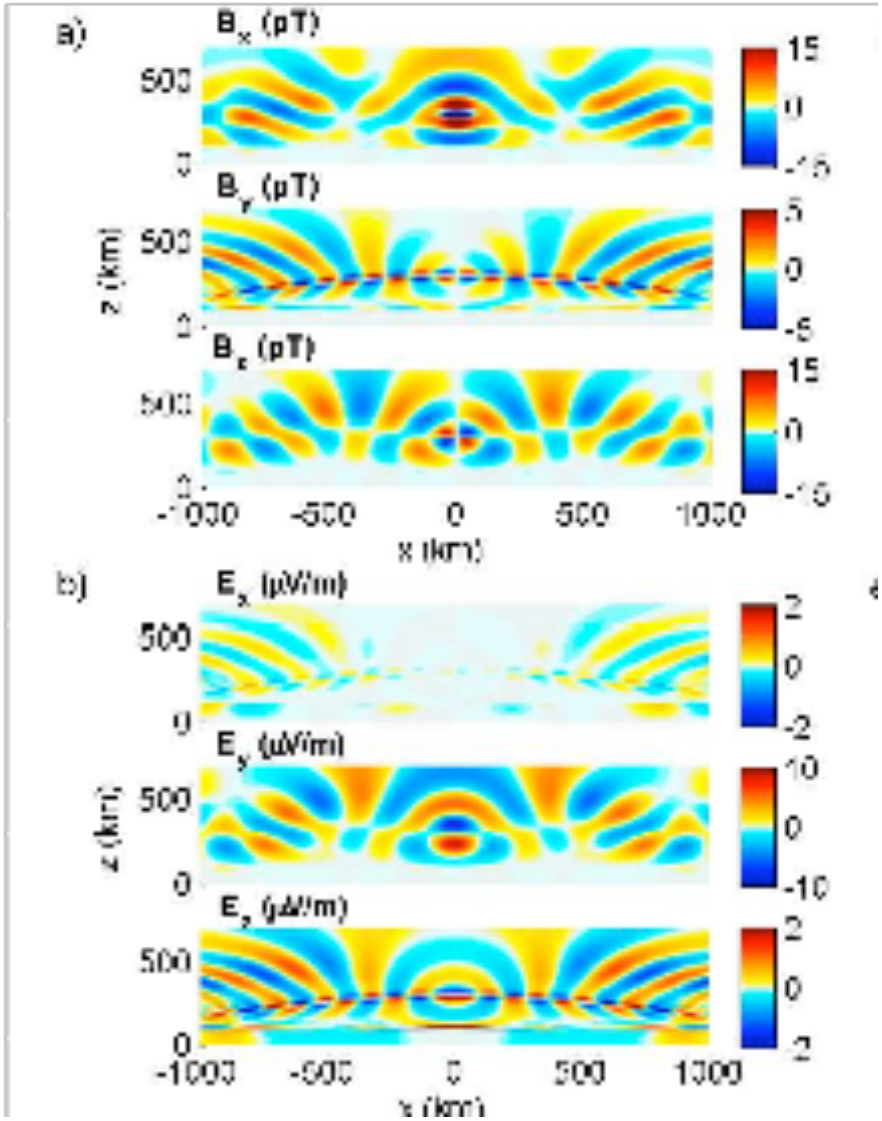
As a result $1/k_z \to |\Omega_e| / \gamma v_z$ before reaching resonance $(1/k_z \to 0)$

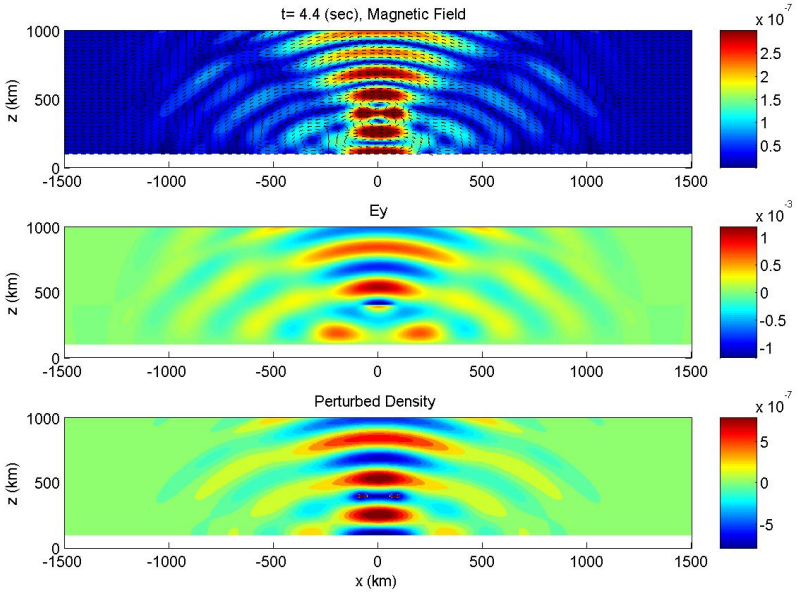
HELIUM BRANCH





Heater in the Dip-Equator - Jicamarca

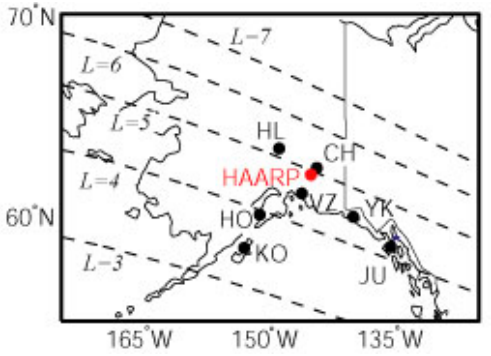


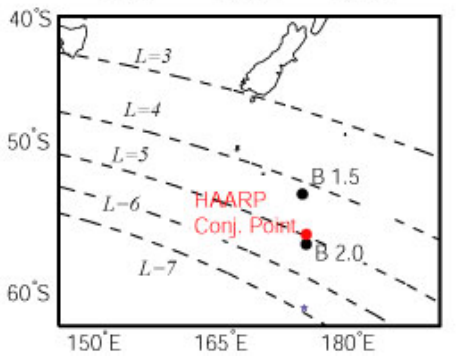


Supplement

Physics Studies with HAARP

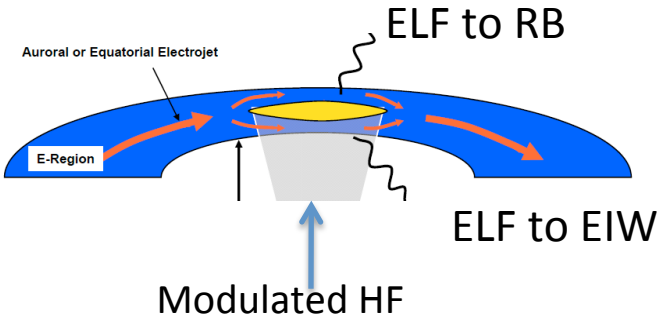
- Wave-particle interactions in the Radiation Belts – Whistler range
  - Artificially Stimulated Emissions (ASE)
- ULF - MHD Study
  - SA ,EMIC and MS wave injection in space. Interactions with trapped electron and ions
  - Excitation of the Ionospheric Alfven Resonator (IAR)
  - SA wave (Pc1) triggering

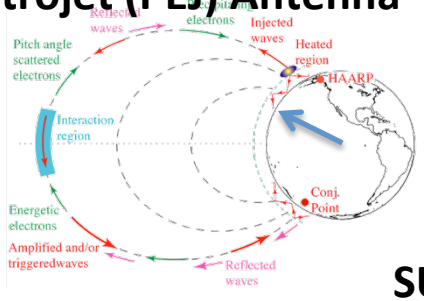




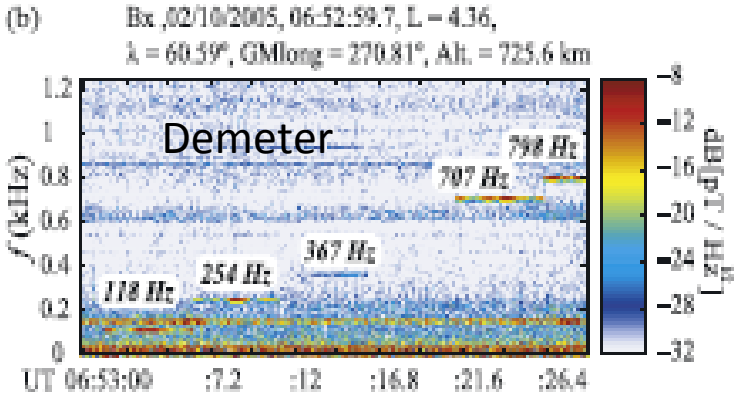
The PEJ Antenna

Status: Need the presence of an electrojet – Polar Electrojet (PEJ) Antenna

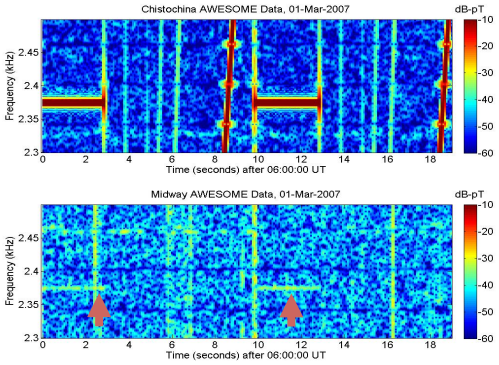




SU - UMD

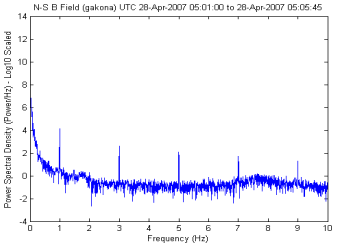


- **PEJ Very Successful in Injecting ELF in the EIW and the RB if there are strong Electrojet Currents.**
- **Highly dependent on ionospheric conditions with long periods of no ELF generation**
- **PEJ not available at mid-latitude locations**
- **Efficient at the 2-4 kHz range but very inefficient at low ELF/ULF frequencies**
- **Relies in D/E region heating**



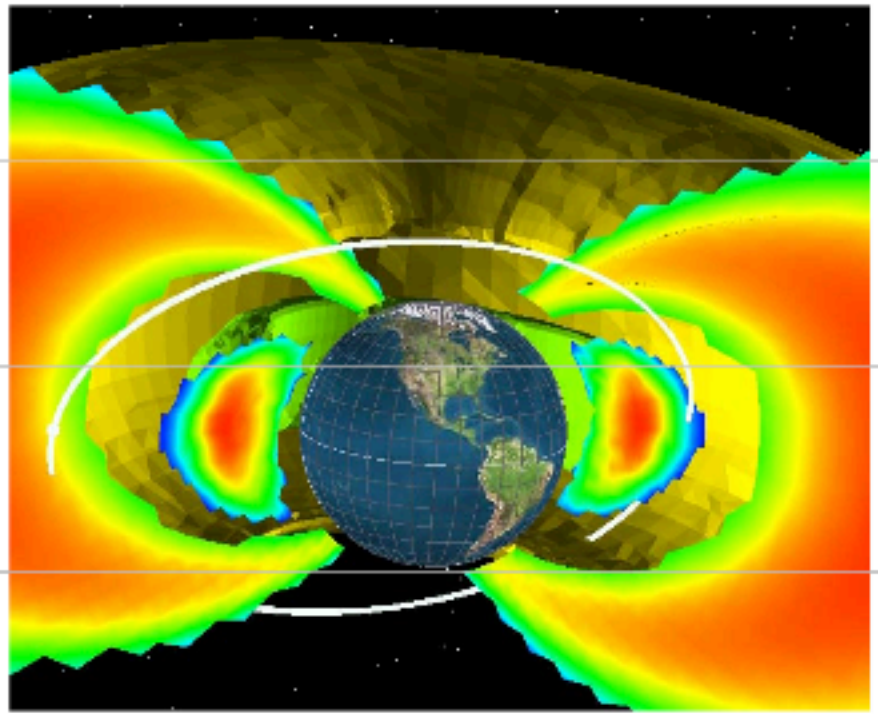
2.3 kHz Midway 4.5 Mm

1 Hz



HAARP

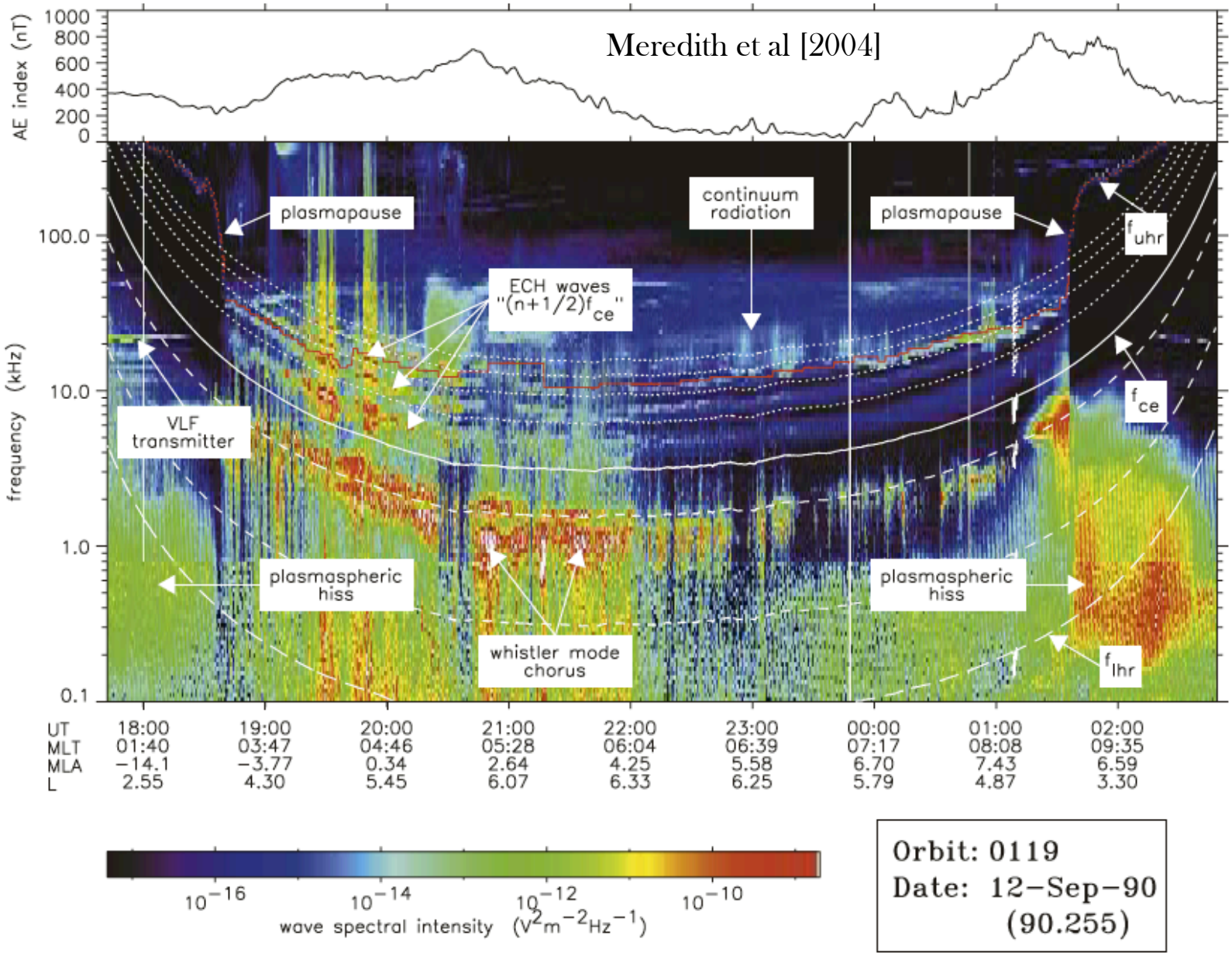
DSX



Apogee (altitude in km)	12,000
Perigee (altitude in km)	6,000
Inclination (degs)	120
Argument of perigee (degs)	357.9 (90)
Right ascension of the ascending node (degs)	TBD (90)
True anomaly (degs)	TBD (180)
Start time (UT)	12:00:00 01 Oct 2012
Period (hours)	5.277

(…) used for analysis in this report

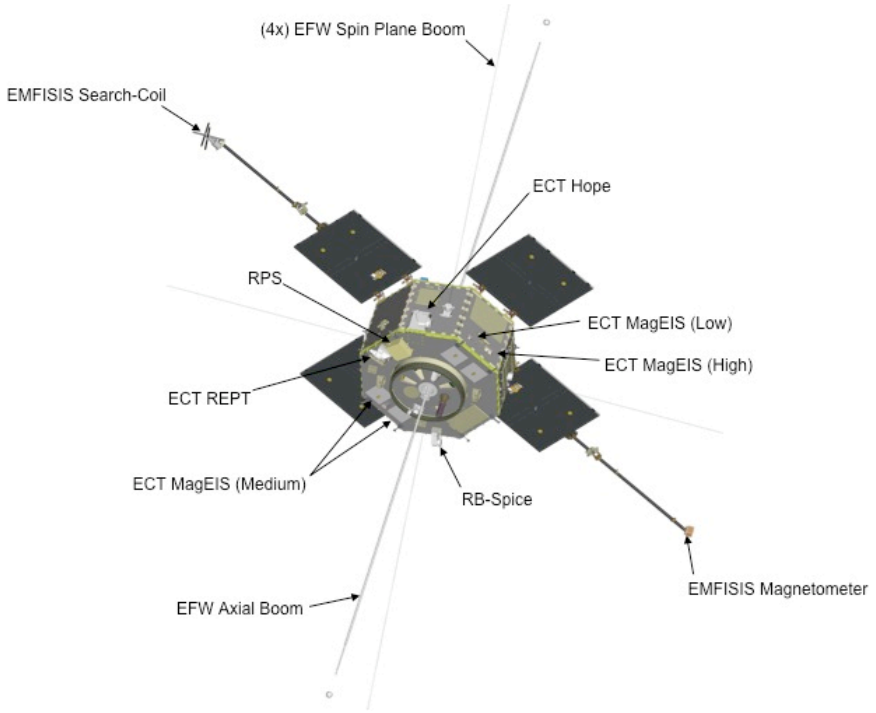
The wave environment in space

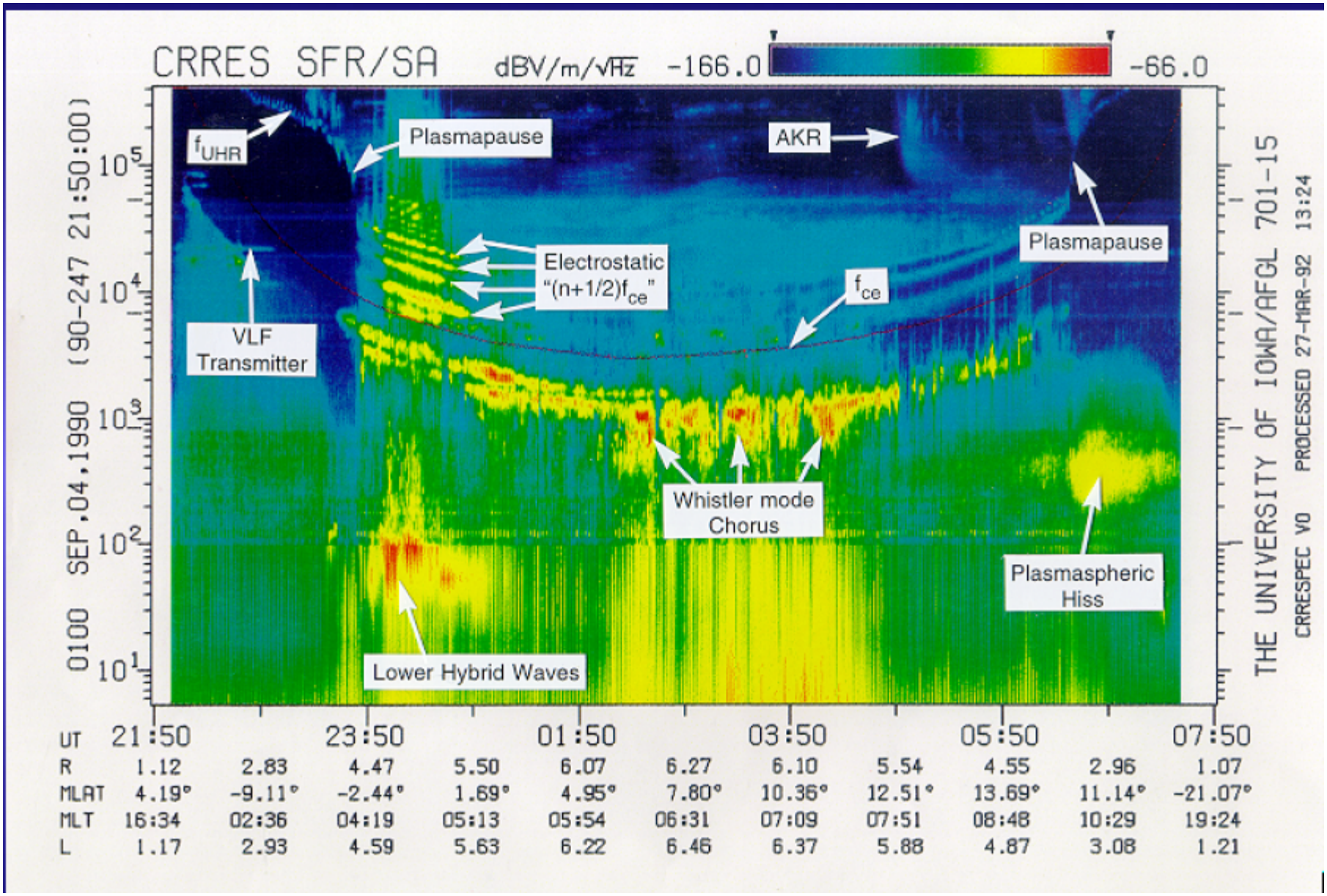


RBSP Instrumentation

Will measure: E & α spectra, ~1 eV to 10's MeV (e^-), 2 GeV (H^+), ion composition & spectra; Waves ~0-12 kHz, E & B, 3-channel, spectra & wave normals, polarization; E-field (1 channel) to 400 kHz;

1. **Energetic Particle, Composition, and Thermal Plasma Suite (ECT)**
   H. Spence, University of New Hampshire
2. **Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS)**
   C. Kletzing, University of Iowa
3. **Electric Field and Waves Suite (EFW)**
   J. Wygant, University of Minnesota
4. **Radiation Belt Storm Probes Ion Composition Experiment (RBSPICE)**
   L. Lanzerotti, NJ Institute of Technology
5. **Relativistic Proton Spectrometer (RPS)**
   D. Byers, National Reconnaissance Office




CRRES SFR/SA
dBV/m/√Hz
-166.0
-66.0
f_{UHR}
Plasmapause
AKR
Plasmapause
Electrostatic
"(n+1/2)f_{ce}"
f_{ce}
VLF
Transmitter
Whistler mode
Chorus
Plasmaspheric
Hiss
Lower Hybrid Waves
0100 SEP.04.1990 (90-247 21:50:00)
10^5
10^4
10^3
10^2
10^1
THE UNIVERSITY OF IOWA/AFGL 701-15
CRRESPEC V0 PROCESSED 27-MAR-92 13:24
UT 21:50 23:50 01:50 03:50 05:50 07:50
R 1.12 2.83 4.47 5.50 6.07 6.27 6.10 5.54 4.55 2.96 1.07
MLAT 4.19° -9.11° -2.44° 1.69° 4.95° 7.80° 10.36° 12.51° 13.69° 11.14° -21.07°
MLT 16:34 02:36 04:19 05:13 05:54 06:31 07:09 07:51 08:48 10:29 19:24
L 1.17 2.93 4.59 5.63 6.22 6.46 6.37 5.88 4.87 3.08 1.21

Physics Studies HAARP/Resonance

- Wave-particle interactions in the Radiation Belts – Whistler range
  - Artificially Stimulated Emissions (ASE)
- ULF - MHD Study
  - SA ,EMIC and MS wave injection in space. Interactions with trapped electron and ions
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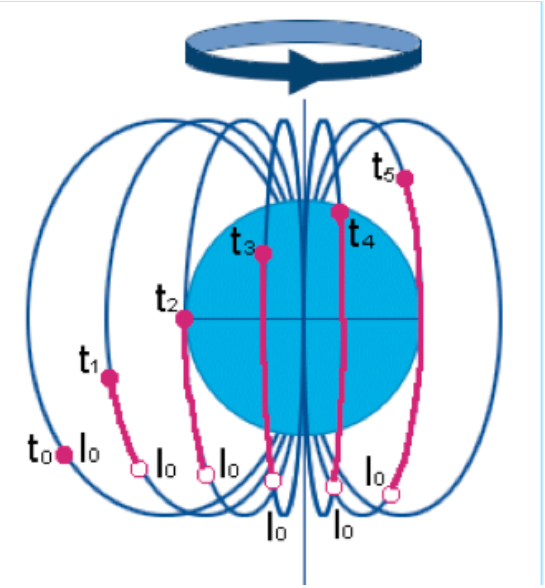
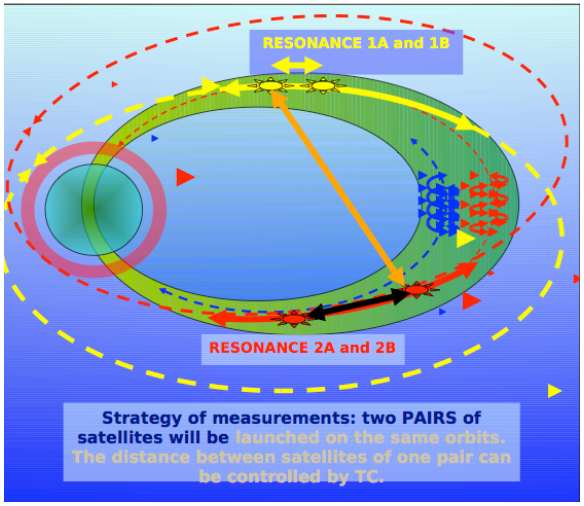
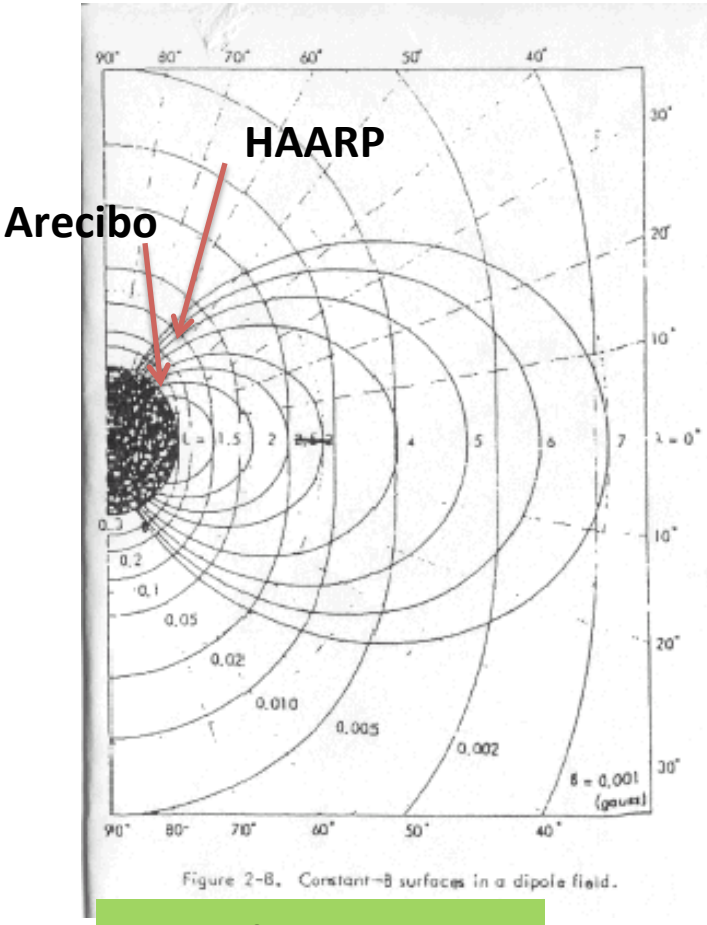




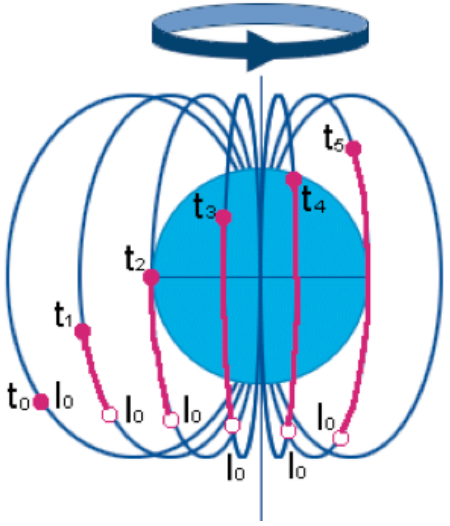
The Future

- **Use Ionospheric heaters (HF) to inject ULF/ELF/VLF waves in the L-shell that spans the heater and diagnose it with RBSP, Resonance, DSX, ePOP**

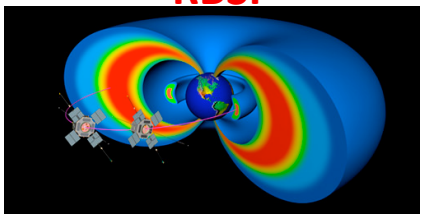


Ionospheric Heaters
HAARP (L≈4.9)
Arecibo (L≈1.4)
Tromso (L≈5.9)
SURA (L≈)

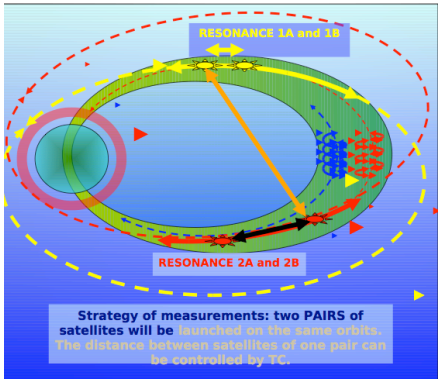
Magneto-synchronous



RBSP

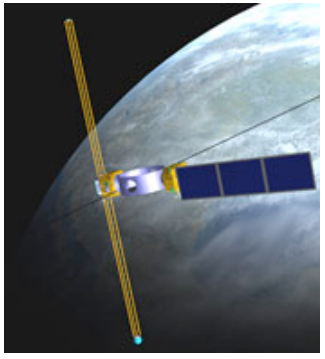


Launch May 18, 2012
2 probes, <1500 kg for both
10° inclination, 9 hr orbits
~500 km x 30,600 km

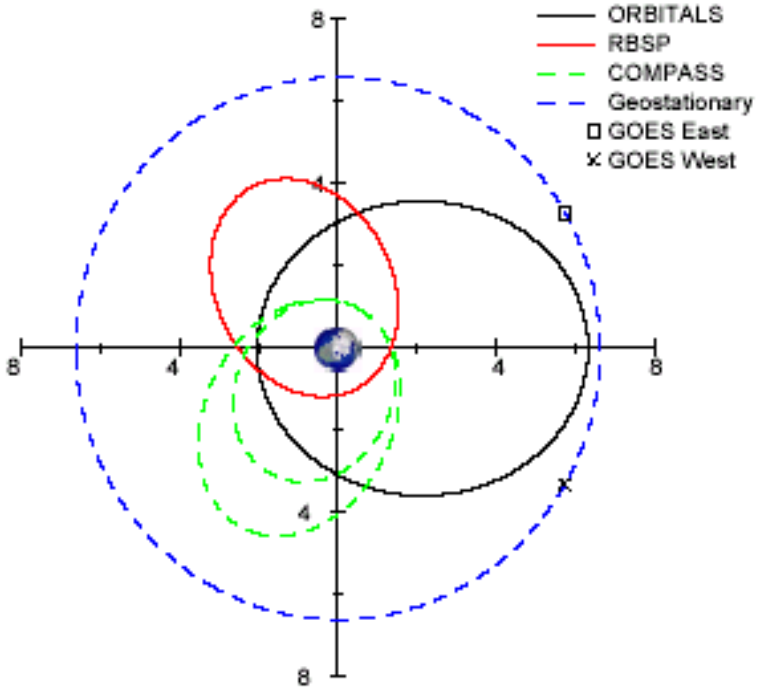


RESONANCE (Russia)
Launch ~2012-14, 4-spacecraft
Orbit:1800x30,000km, ~63° incl.

DSX (AFRL)
Launch ~2012
MEO, wave/ particle

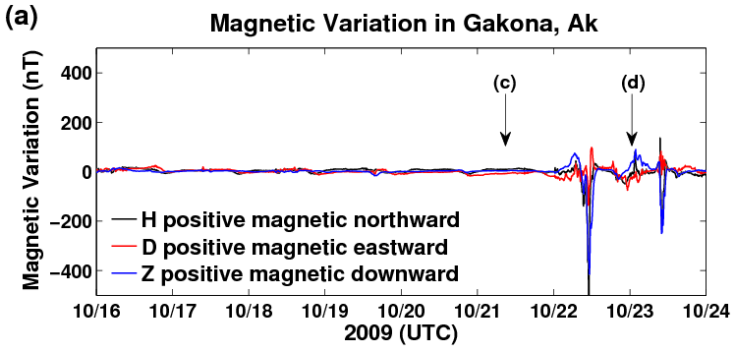


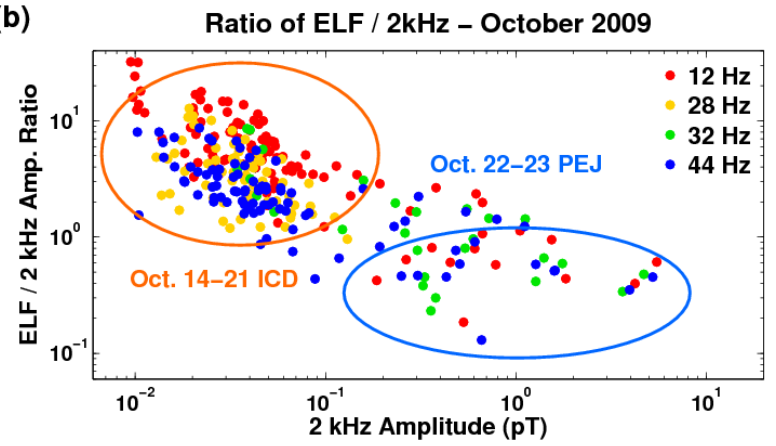

BARREL
Balloon
Array for
RBSP
Relativistic
Electron
Losses


ORBITALS
RBSP
COMPASS
Geostationary
GOES East
GOES West
8
4
4
8
8
4
4
8

ICD PoP Experiments

Papadopoulos et al GRL 2011b





- 10/14-10/21 Magnetometer below 10 nT
- 10/14-10/23 55 hours of VLF/ELF/ULF tests
- 6 hours of VLF ground measurements –PEJ operational
- 51 hours of low ELF/ULF (12-44 Hz) ground measurements