VLF to HF Ground and Spaceborne Instrumentation

for Active Radiowave Plasma Experiments

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Northeast Radio Observatory Corporation (NEROC) Symposium Series

Acknowledgements

Lowell Team (UML, LDI)

Other teams:

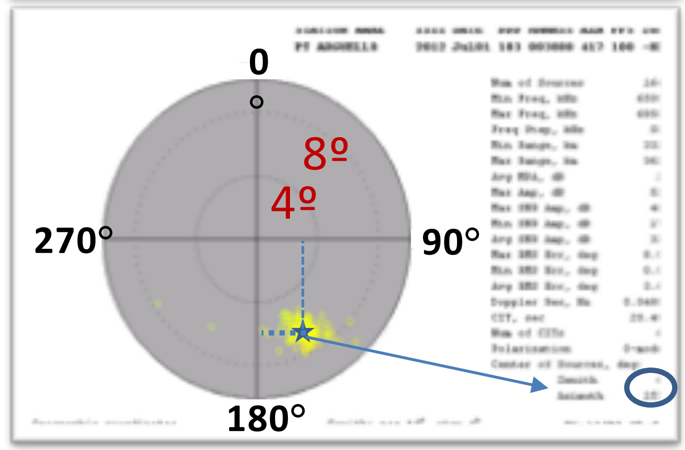
- SwRI
- NASA Goddard SFC
- AFRL
- Able Engineering / ATK
- Net-TIDE Europe
- HAARP
- Kansas University
- Stanford University
- Rice University

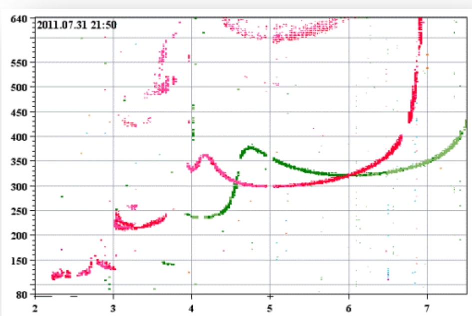
Outline

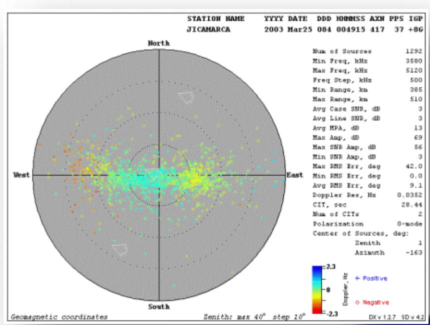
- HF ionosondes: the workhorse and the ground truth of ionospheric diagnostics with [near] real-time capability
  - Is there life after 85?
- VLF transmission in space
  - Radio Plasma Imager on NASA IMAGE
  - VLF Transmitter on USAF DSX
- Where do we go from here?
  - HF Topside Sounder / CubeSat challenge
  - Dual-band Subsurface Radar (GPR/IPR)

HF Ionosonde

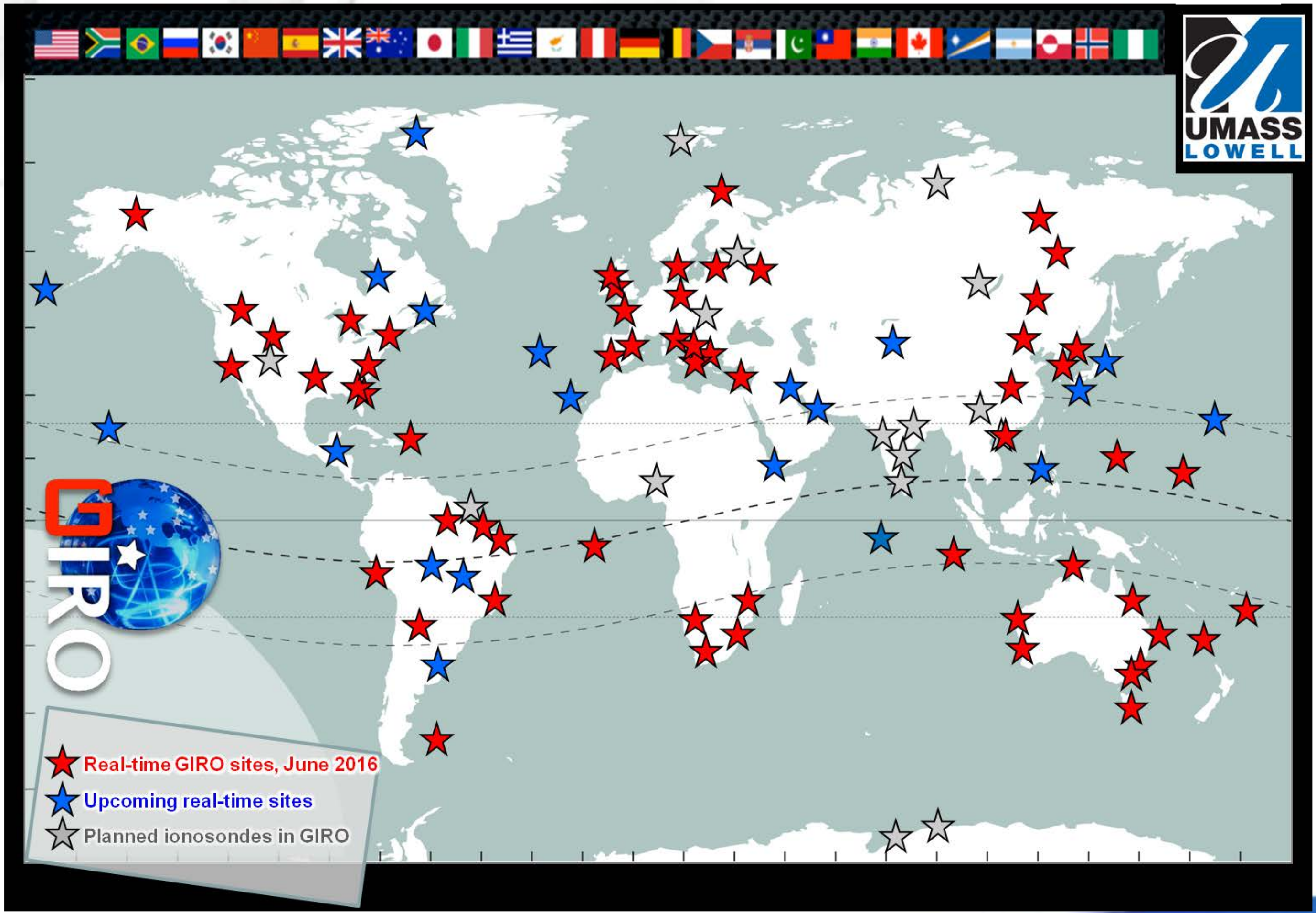
- First ionogram: Jan 11, 1931
- 1936: five ionosondes in the world
- 1957: 150 ionosondes in the world
- 1969: First Lowell Digisonde built
- 2016: <unknown> ionosondes in the world, but
  - 231 ionosonde locations registered in SPIDR (1942..current)
  - 164 Lowell digisondes

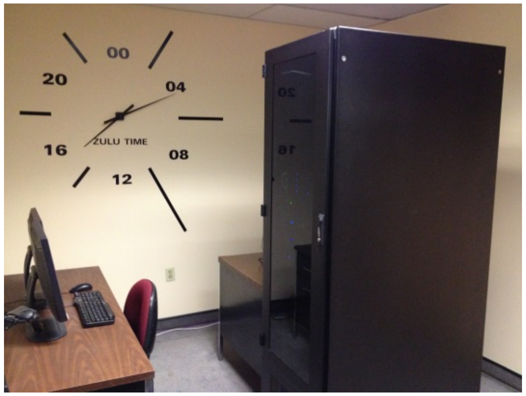






Global Ionosphere Radio Observatory (GIRO)





GIRO Wall and Tower in Lowell

Quiet Revolution in Sensor Networks

[NSF, March 2005]

- Access to data without time or distance barriers
- Remote control by operator
- Data interpretation without human attention
- Self-tested, "glass-room" operations
- Superior data management
- Automated, intelligent adjustment of sensor operation modes
- Data science (knowledge discovery)

DIGISONDE:

mid 1980s

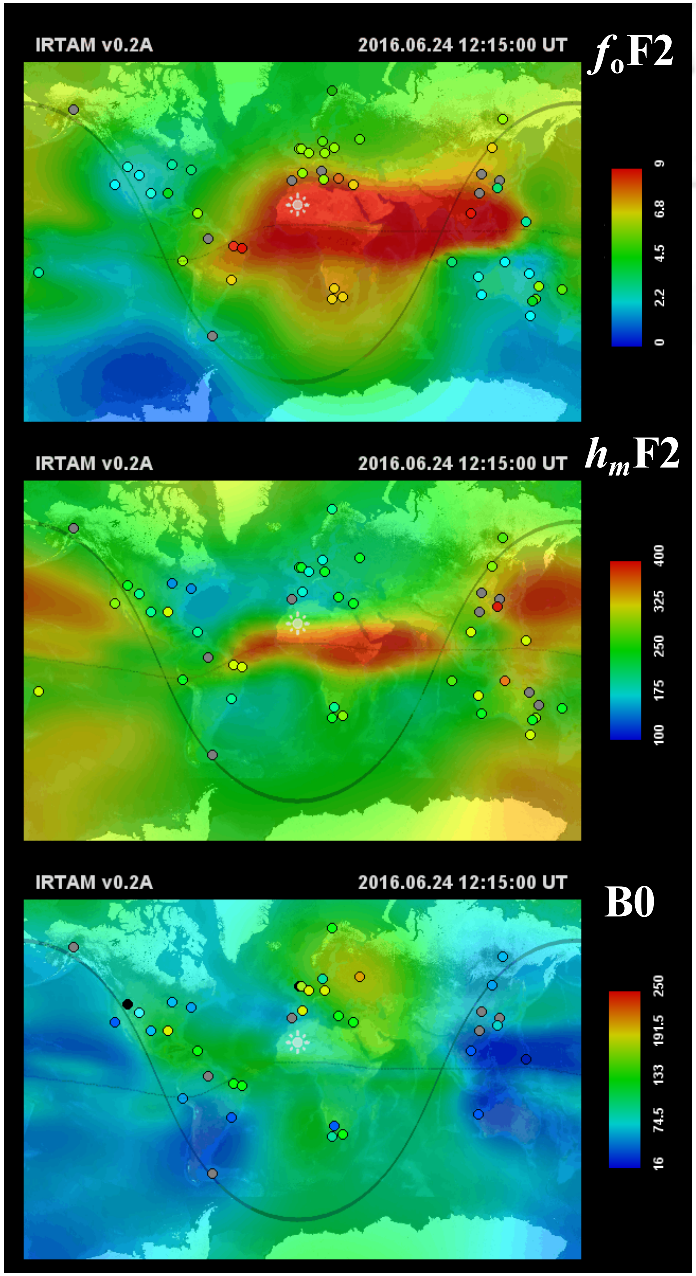
ARTIST (1982)

BIT (1995)

DIDBase (2002)
Drift-DB (2005)

ADRES (2004)

Ongoing…



REAL TIME IRI Assimilative Mapping
IRTAM

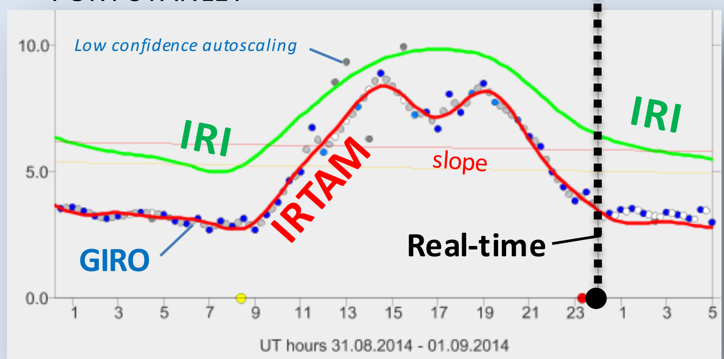
15 minute cadence

Real-Time IRI

3D global bottomside ionosphere in real-time

GIRO

PORT STANLEY ⟵ backcast | forecast ⟶



Diurnal fit to GIRO data

***4D** data assimilation:*
24-hour fit of differences between IRI and GIRO
+ diurnal trend analysis

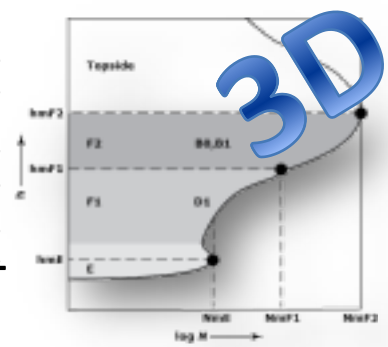
Port Stanley data courtesy of Sarah James, RAL UK

x 52 GIRO stations

Global Spatial fit

Jones-Gallet Gk basis (76)
= total map coefficients: **1064**
[24-hour global weather of *C*]

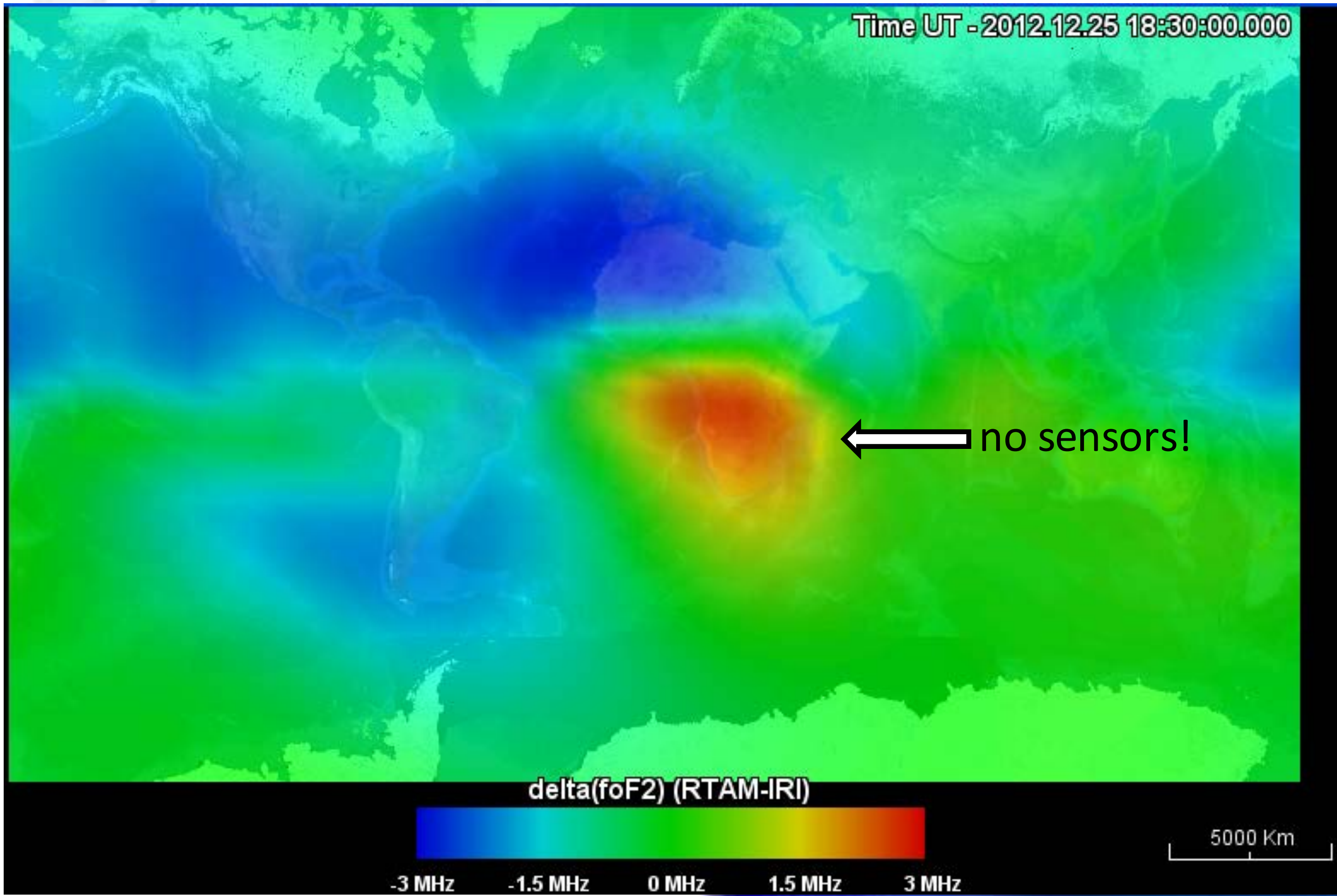
IRI profile formalism



NmF2, hmF2, B0, B1 anchors

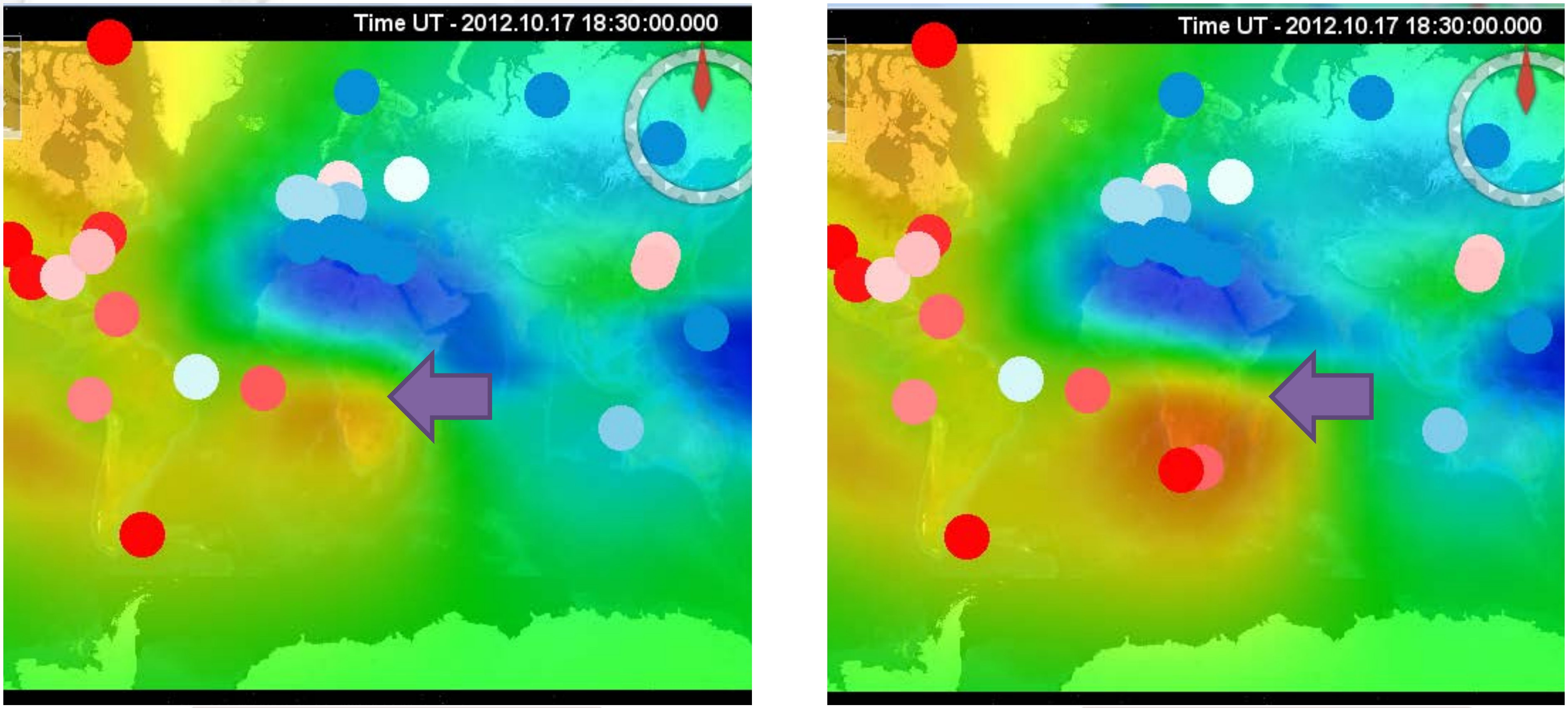
“Red Spot over Africa”

found on foF2 deviation map



Control site analysis with RSA Data

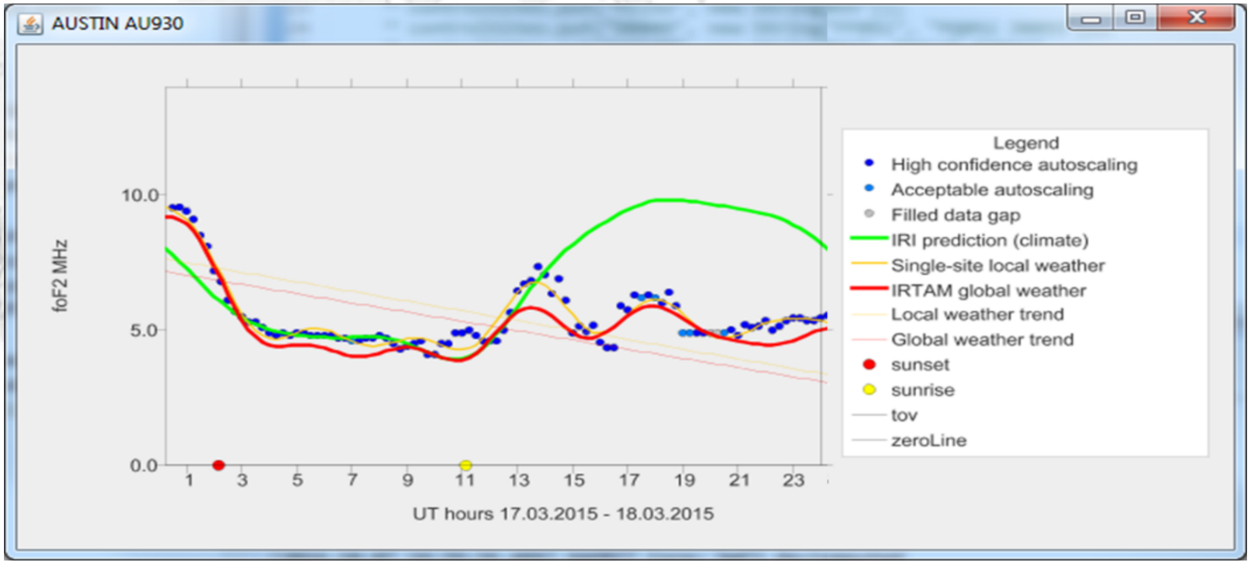
Spatial prediction?



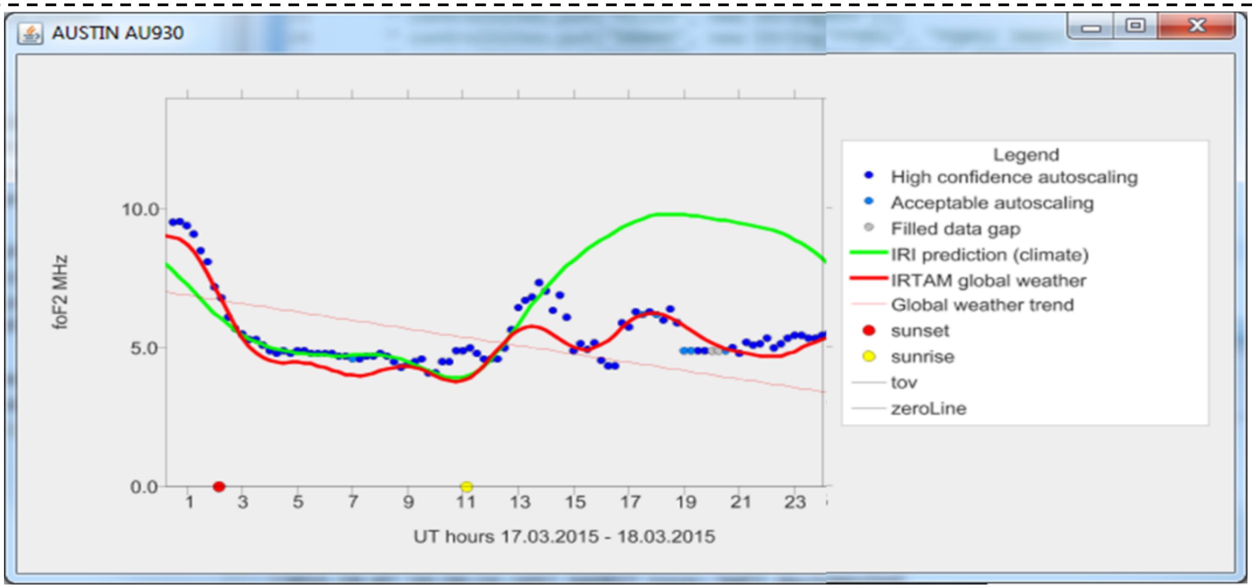
RSA data excluded

RSA data included

Control site comparison
of IRTAM assimilation



AUSTIN SITE INCLUDED



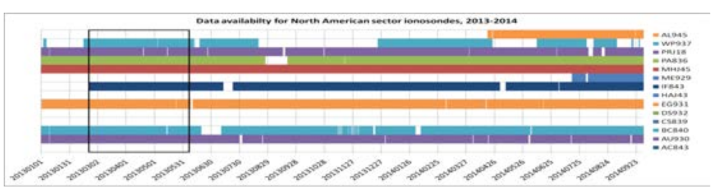
AUSTIN SITE EXCLUDED

But neighboring stations help:

Eglin AFB, FL (1073 km)
Boulder, CO (1270 km)
Melrose, FL (1512 km)
Vandenberg AFB (2186 km)

Real-Time IRI Improvement of Climatology

Average improvement ~ x2 (15 million comparisons) in terms of <Obs-Model> error reduction



Test Period: 2013.02.19 to 2013.06.11

foF2 Improvement factor

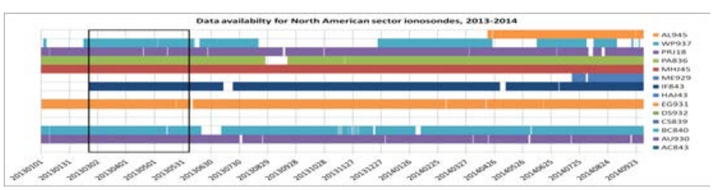
Comparisons with control site included vs excluded

Cntl Site	Included vs excluded	Lost Q
BC840	2.20 vs 1.75	20 %
IF843	1.92 vs 1.39	28 %
WP937	2.14 vs 1.46	32 %
AU930	2.10 vs 1.34	36 %
EG931	2.00 vs 1.28	36 %

IRTAM foF2 = typical x2 improvement

Green sites: loss of quality < 40%

Not all GIRO sites are equal



Test Period: 2013.02.19 to 2013.06.11

foF2 improvement factor

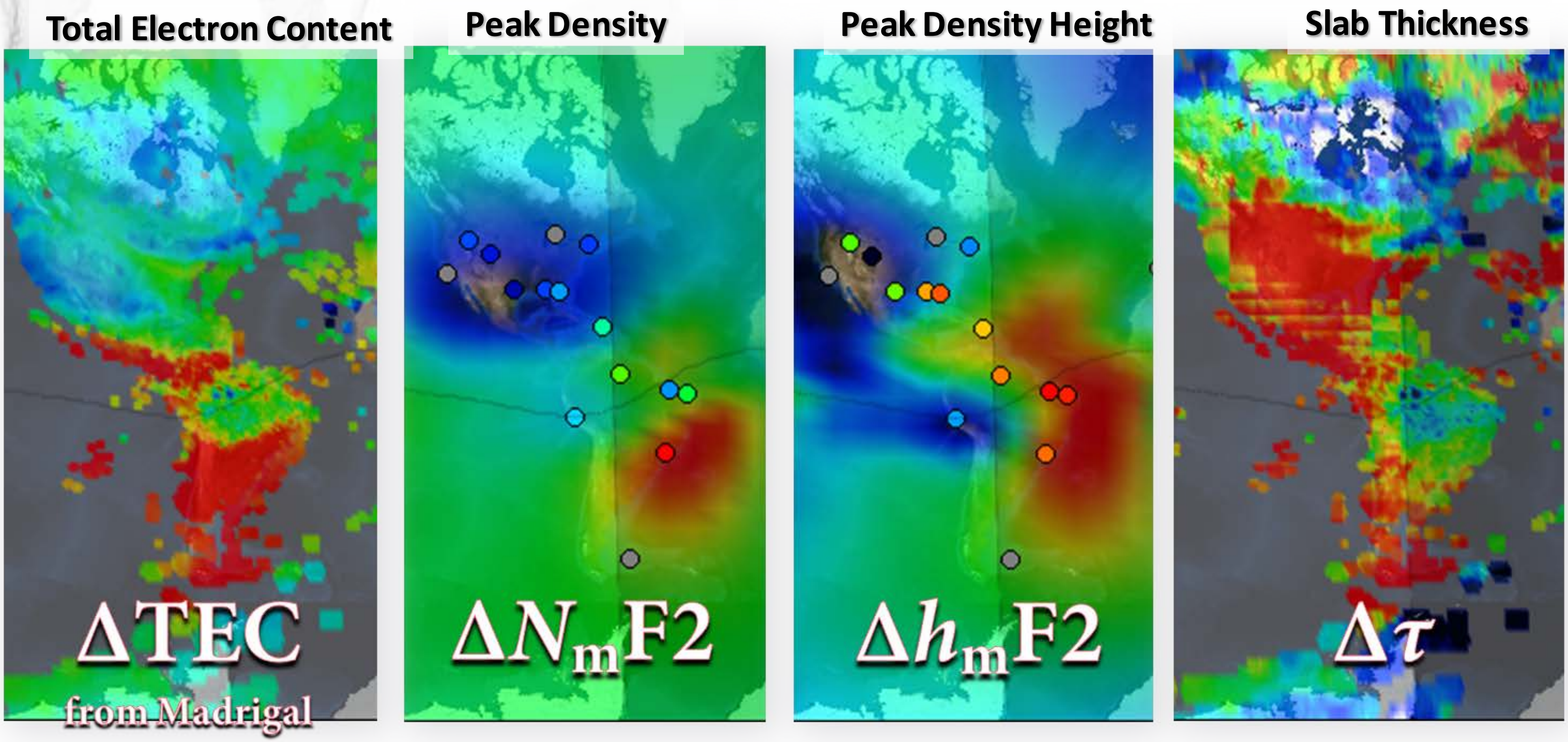
Comparisons with control site included vs excluded

Cntl Site	Included vs excluded	Lost Q
MHJ45	2.11 vs 1.24	41 %
PA836	2.61 vs 1.29	51 %
PRJ18	2.86 vs 1.05	63 %

No improvement to IRI climatology when PRJ18 is omitted

Red sites: loss of quality > 40%

In Combination with Madrigal TEC:

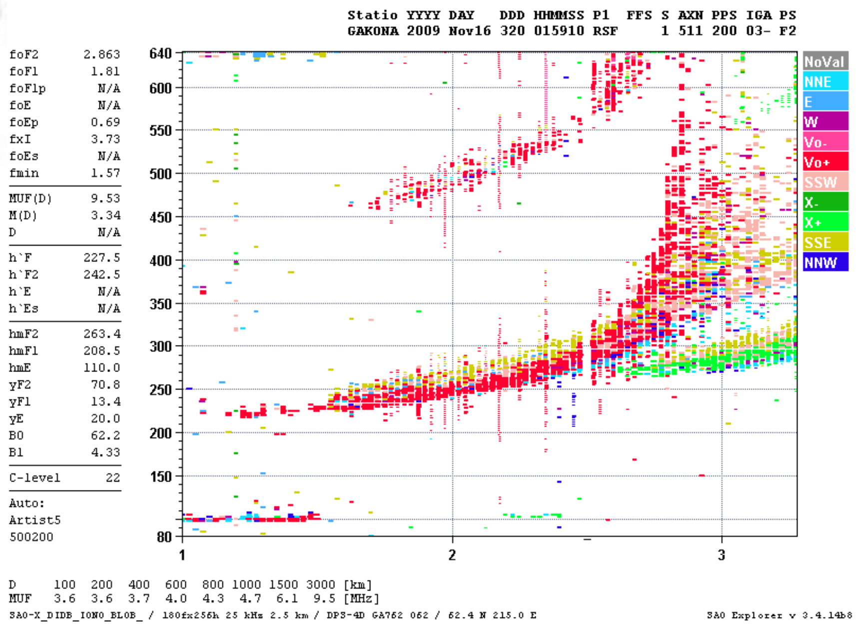


Deviation from expected quiet-time behavior

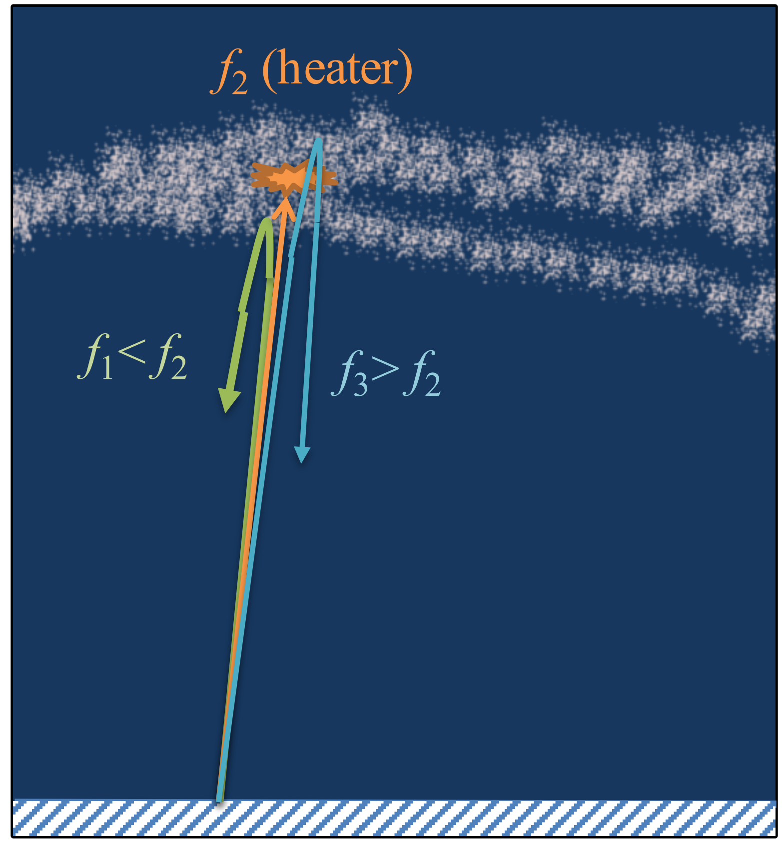
Red: larger than model   Blue: smaller than model

SINGLE-SITE HF IONOSONDE SCIENCE

HAARP Heating Experiments



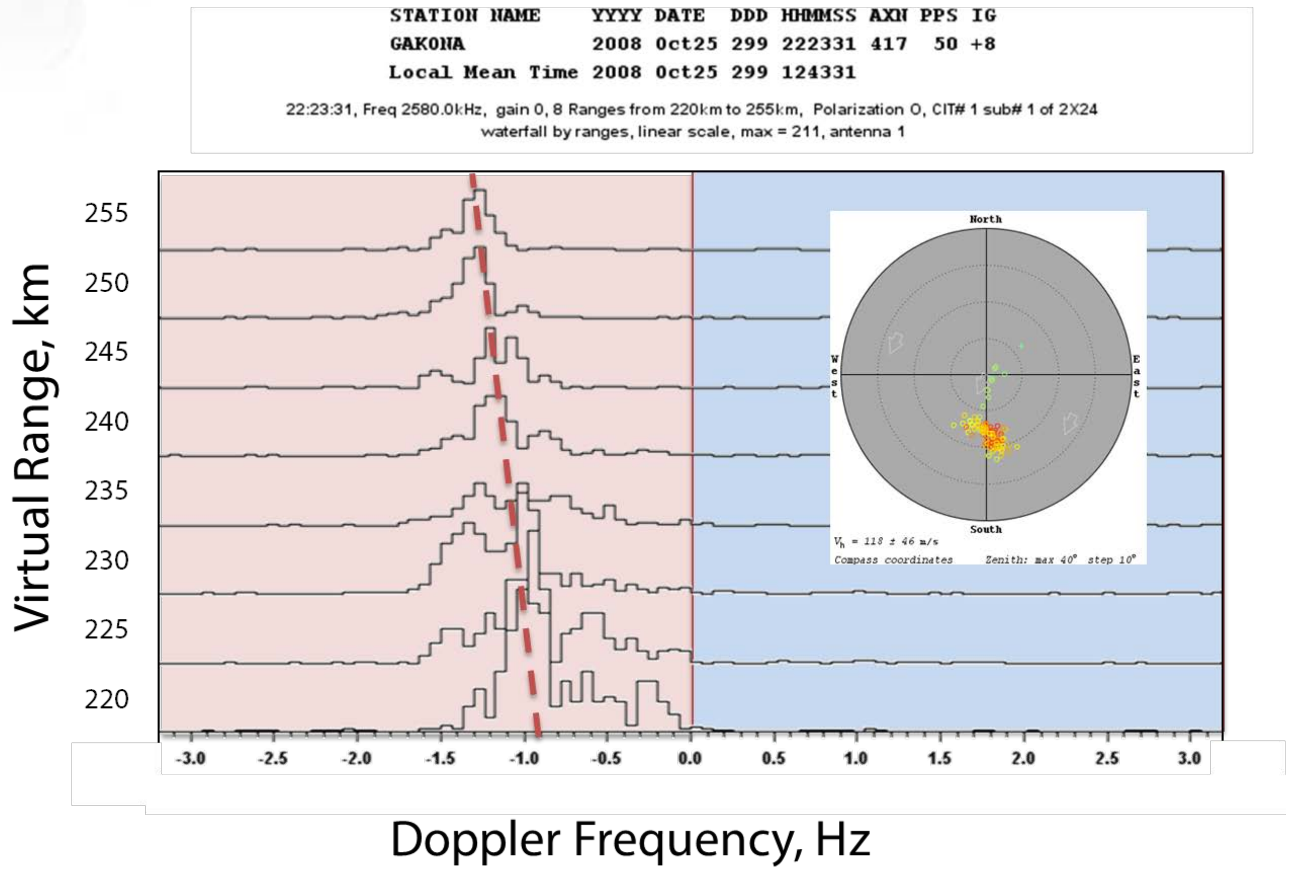
Ionograms show the bottomside of expanding plasma ball appearing as an artificial ionization layer



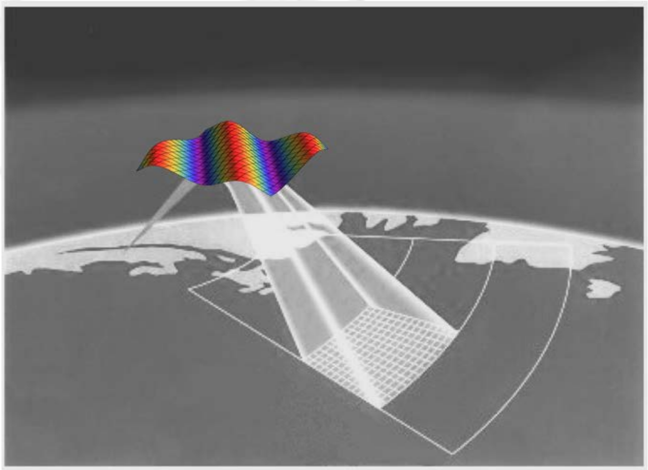
credits to Todd Pedersen and HAARP/AFRL team

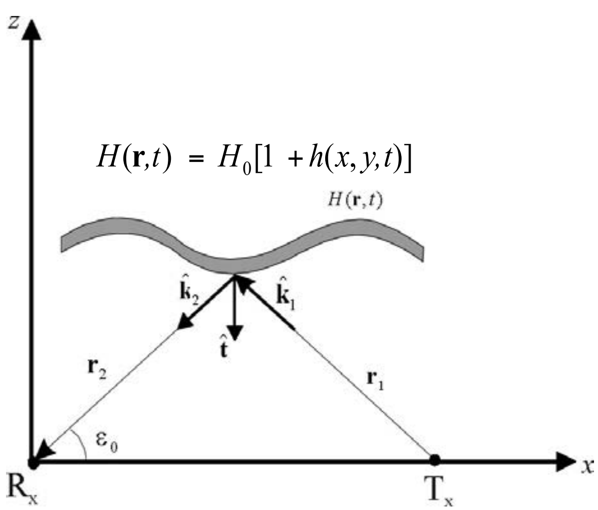
Digisonde Skymap and Waterfall Display

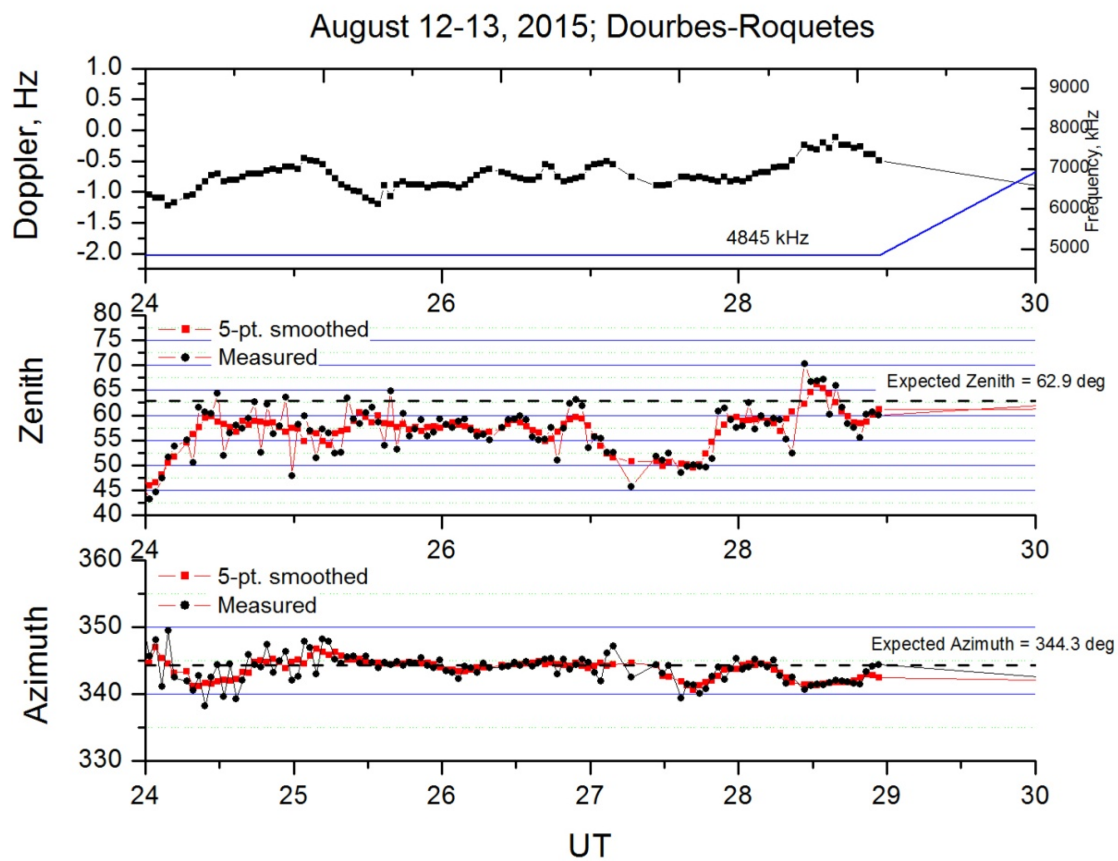
Topside of the expanding plasma structure ~50 km wide, accelerating upward along the magnetic field line at 80-100 m/s



TID Detection and Evaluation

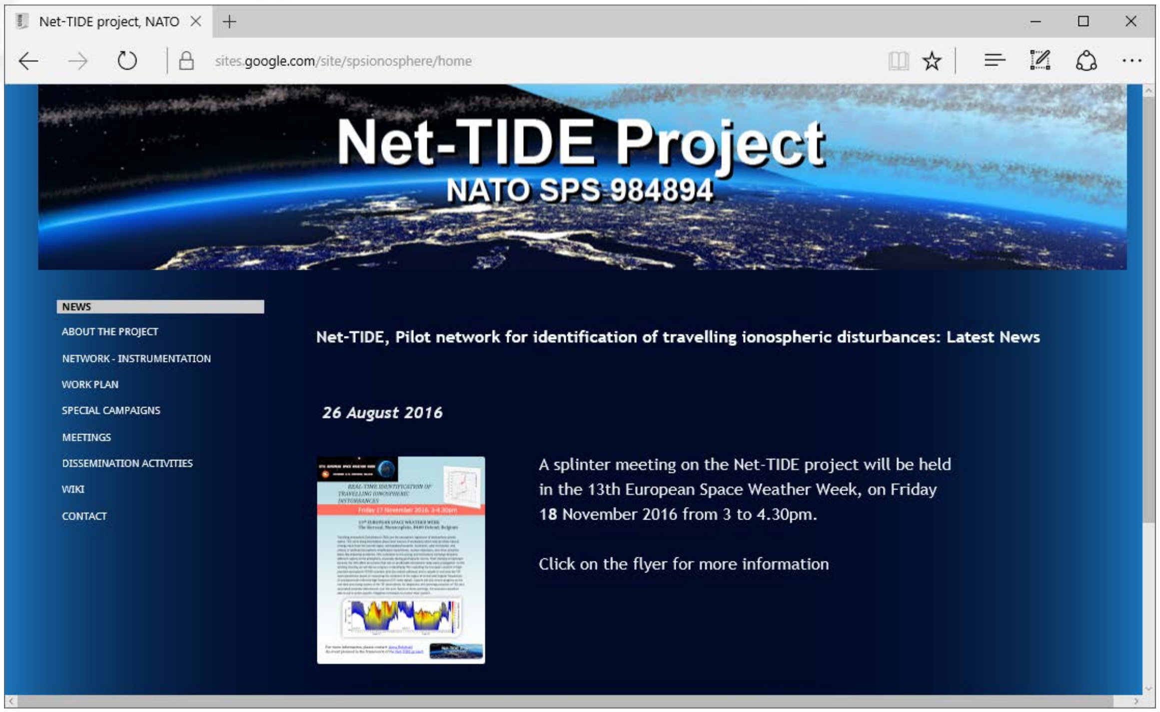


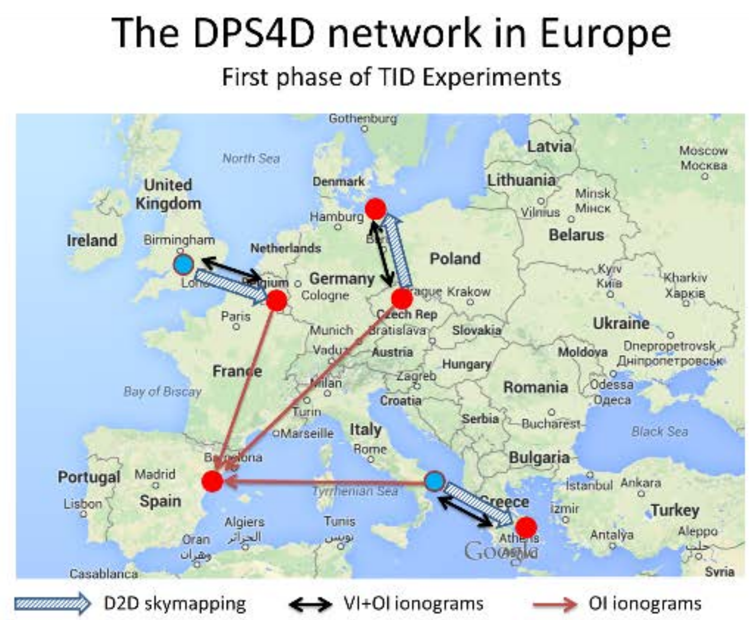




Net-TIDE Europe

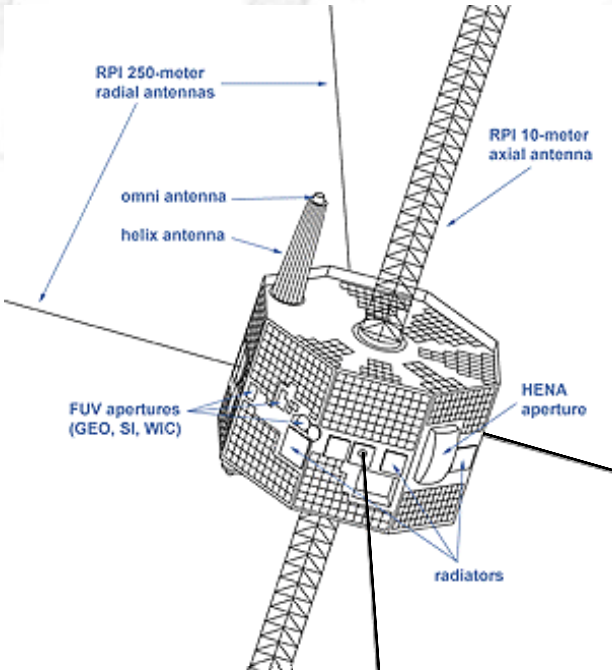
https://sites.google.com/site/spsionosphere/

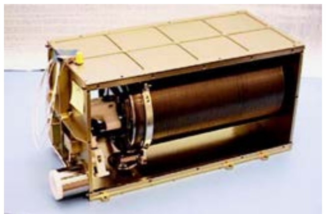




VLF TRANSMISSION IN SPACE

Radio Plasma Imager on IMAGE

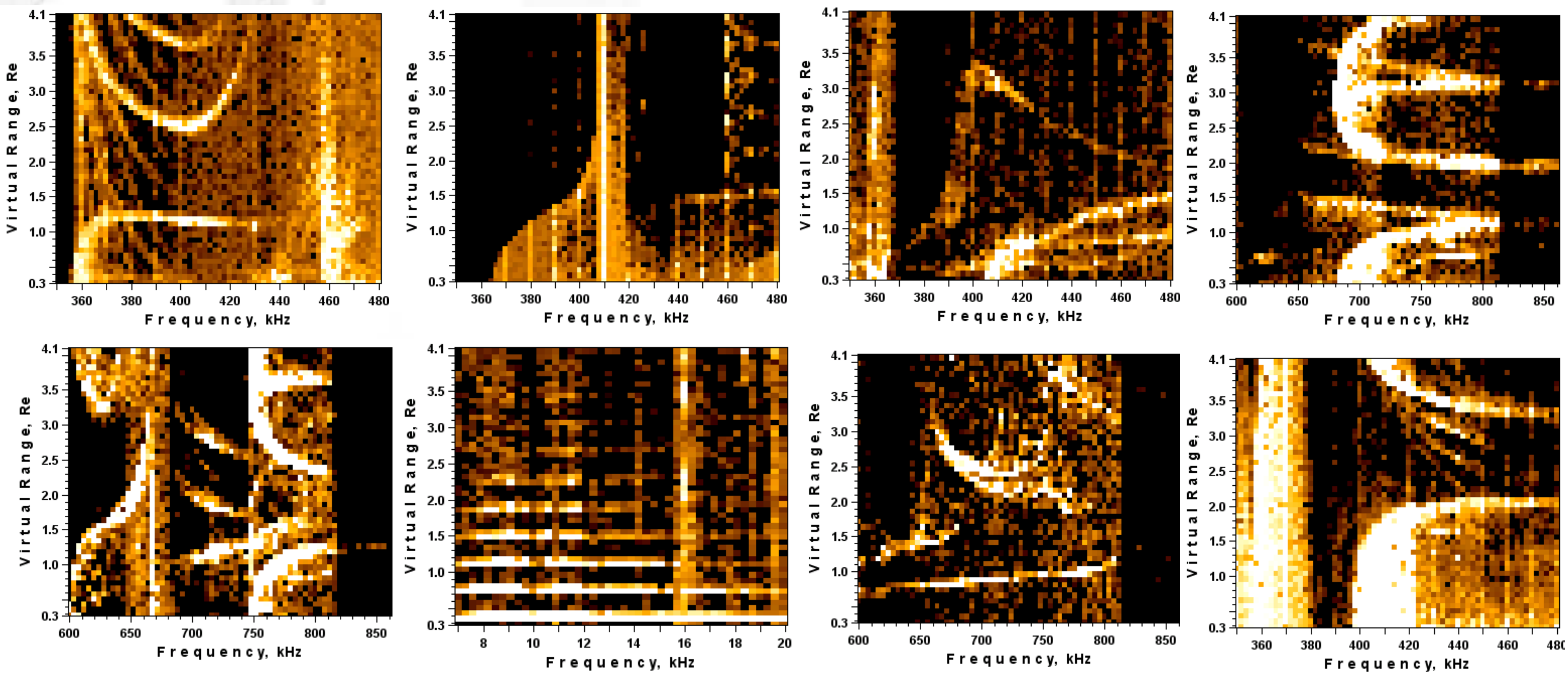




250 m RPI Monopole

- **Low-power VLF to MF magnetospheric sounder**
- **Active mode:**
  - Remote electron density profiles from traces of echoes
  - Local plasma sensing from resonance signatures
- **Passive mode (spectrograms)**

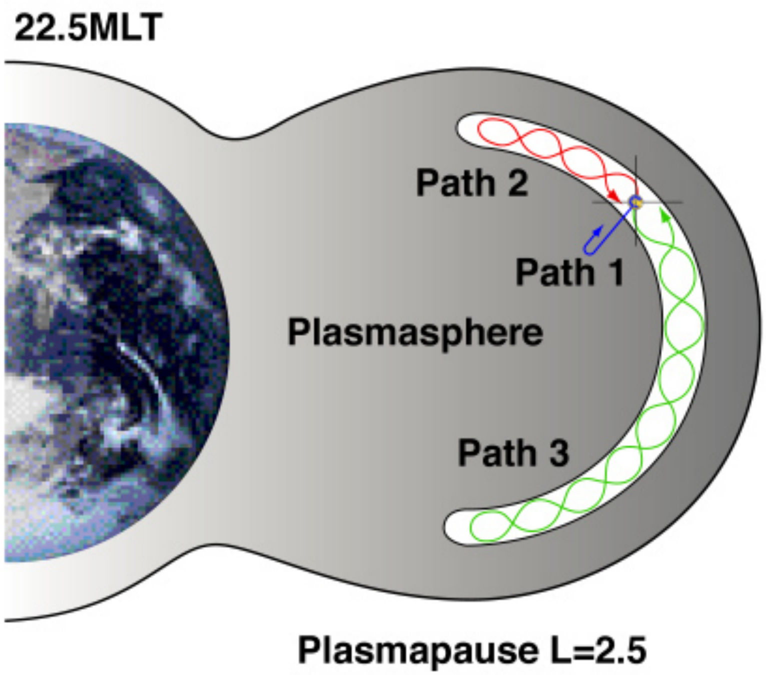
RPI Sounding Mode (Plasmagram)

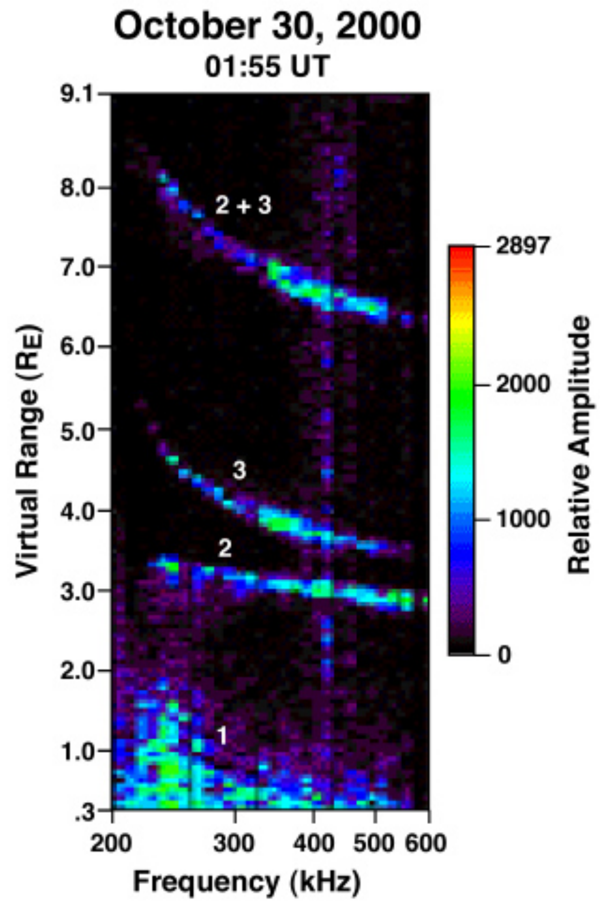


Contain signatures of active sensing remote plasma regions

Recorded at opportune times and locations on orbit

Guided/Field-aligned/Ducted propagation





VLF Transmission in Space Plasmas

Dynamics of RPI Antenna Voltage Resonance

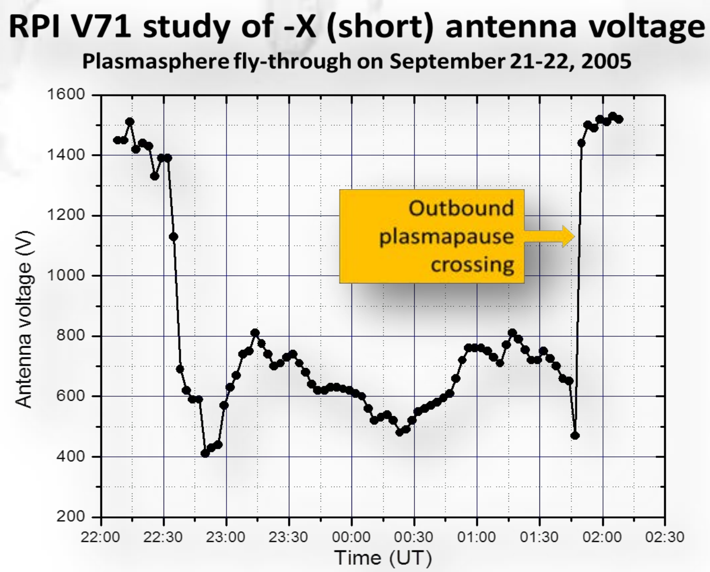
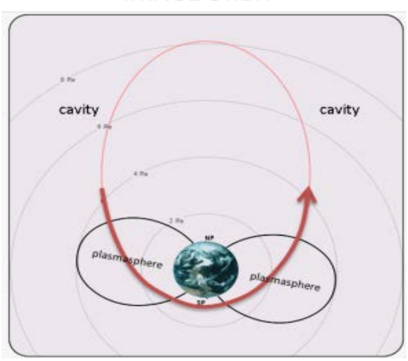
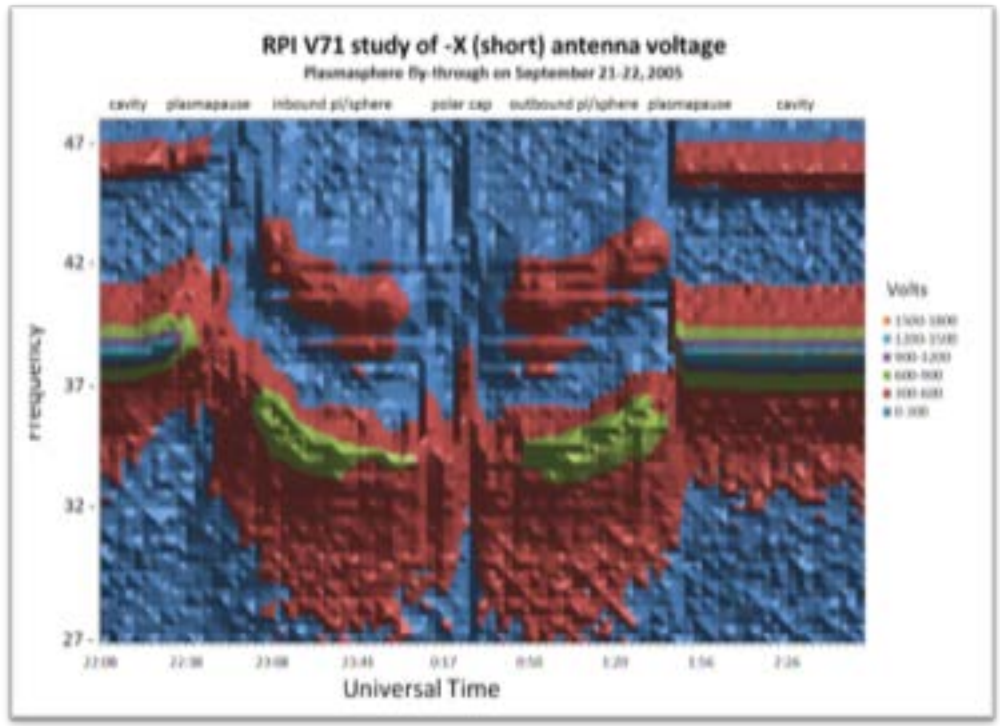


IMAGE ORBIT





Circuit resonance frequency varies as RPI moves into denser plasma

VLF Transmission in Space Plasmas

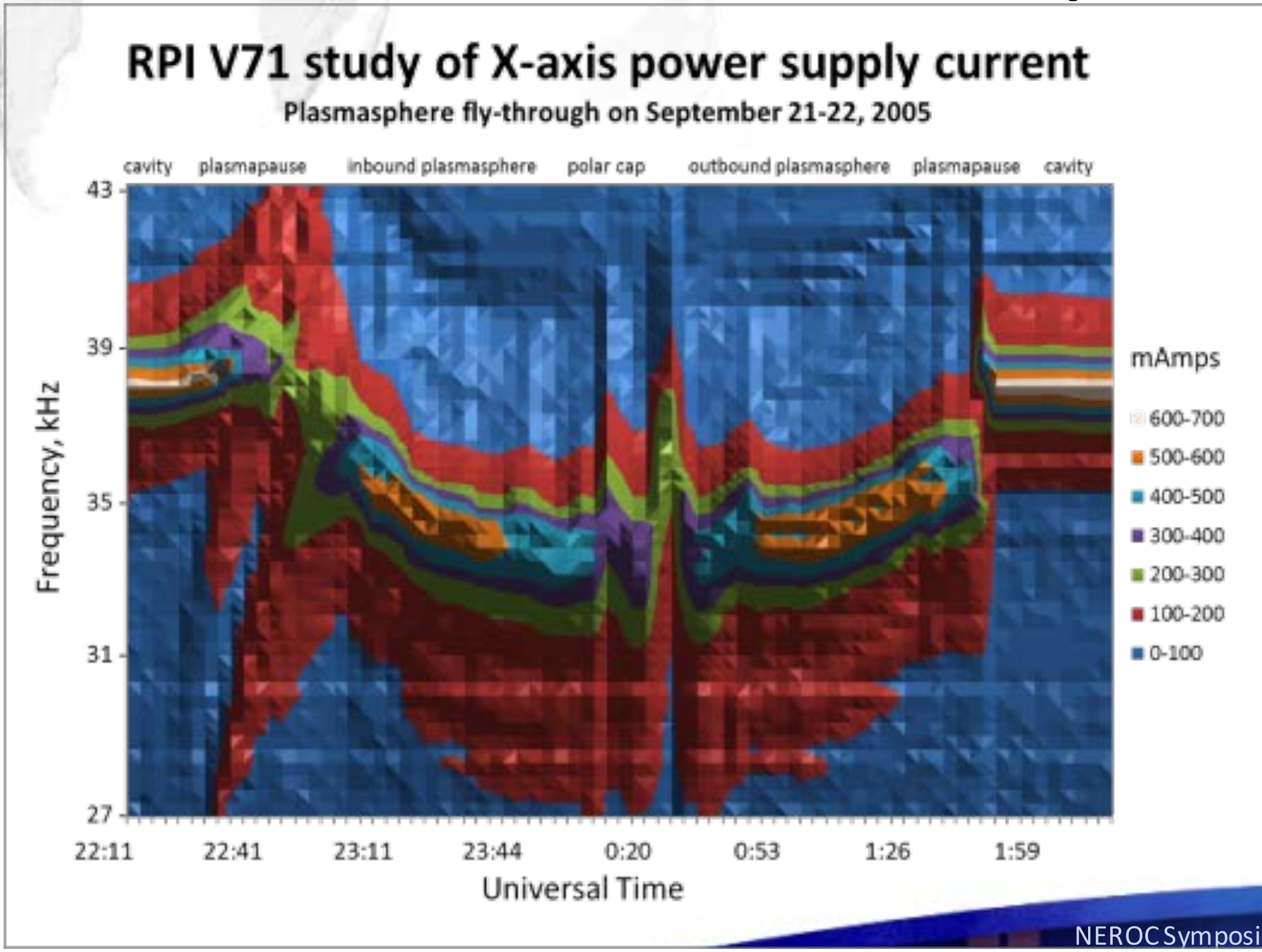
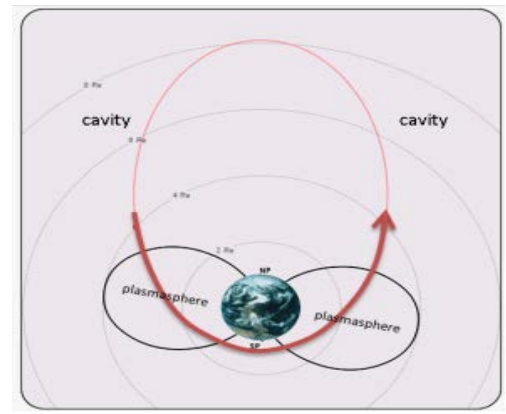
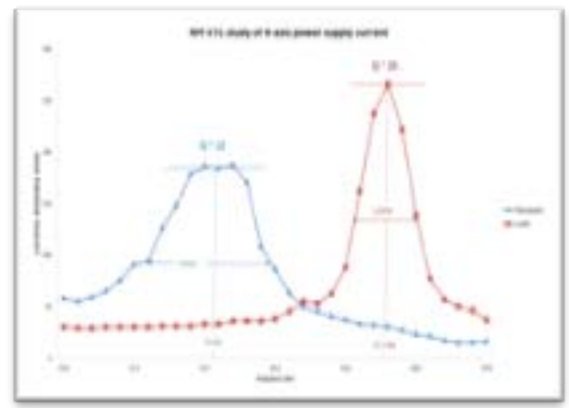


IMAGE ORBIT



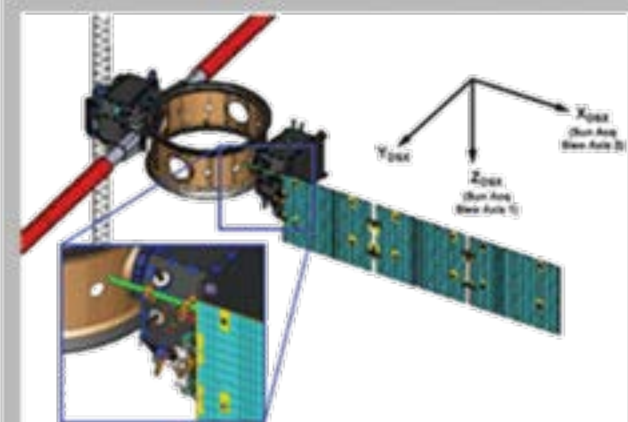


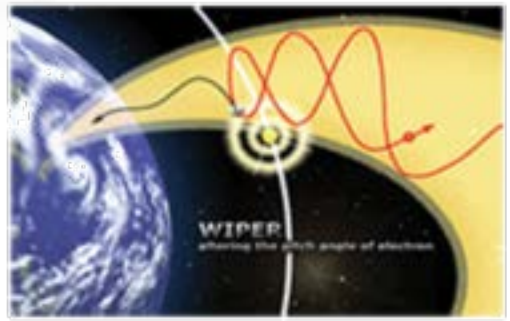
Adaptive Tuning of VLF Transmitter

DSX

Abstract—The Air Force Research Laboratory (AFRL) Space Vehicles Directorate has developed the Demonstration and Sciences Experiment (DSX) to research the technologies needed to deploy space assets in the harsh MEO radiation environment. The DSX comprises three basic research experiments:

1) Wave Particle Interaction Experiment
2) Space Weather Experiment
3) Space Environmental Effects Experiment

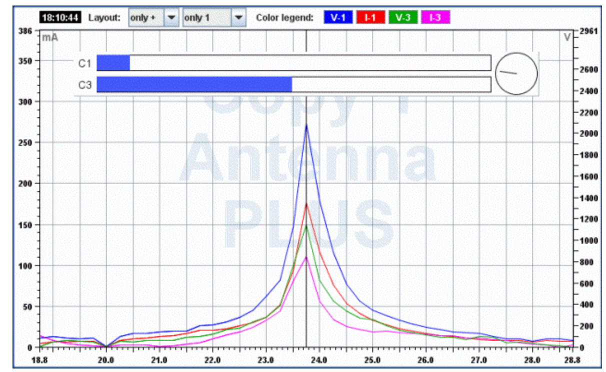


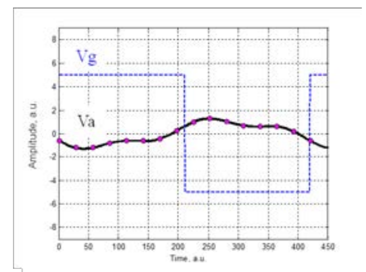


WPIx

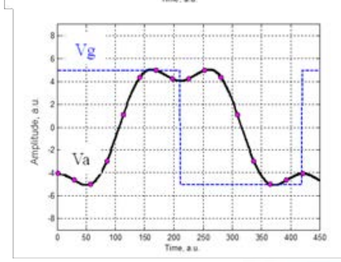
The Wave Particle Interaction Experiment will explore the transmission, propagation, and amplification of very low frequency (VLF) waves in the magnetosphere. The experiment will be performed using a mission architecture that includes space transmitters and receivers on DSX, ground transmitters such as High frequency Active Auroral Research Program (HAARP) and VLF broadcast stations.

http://ulcar.uml.edu/tntdsx.html





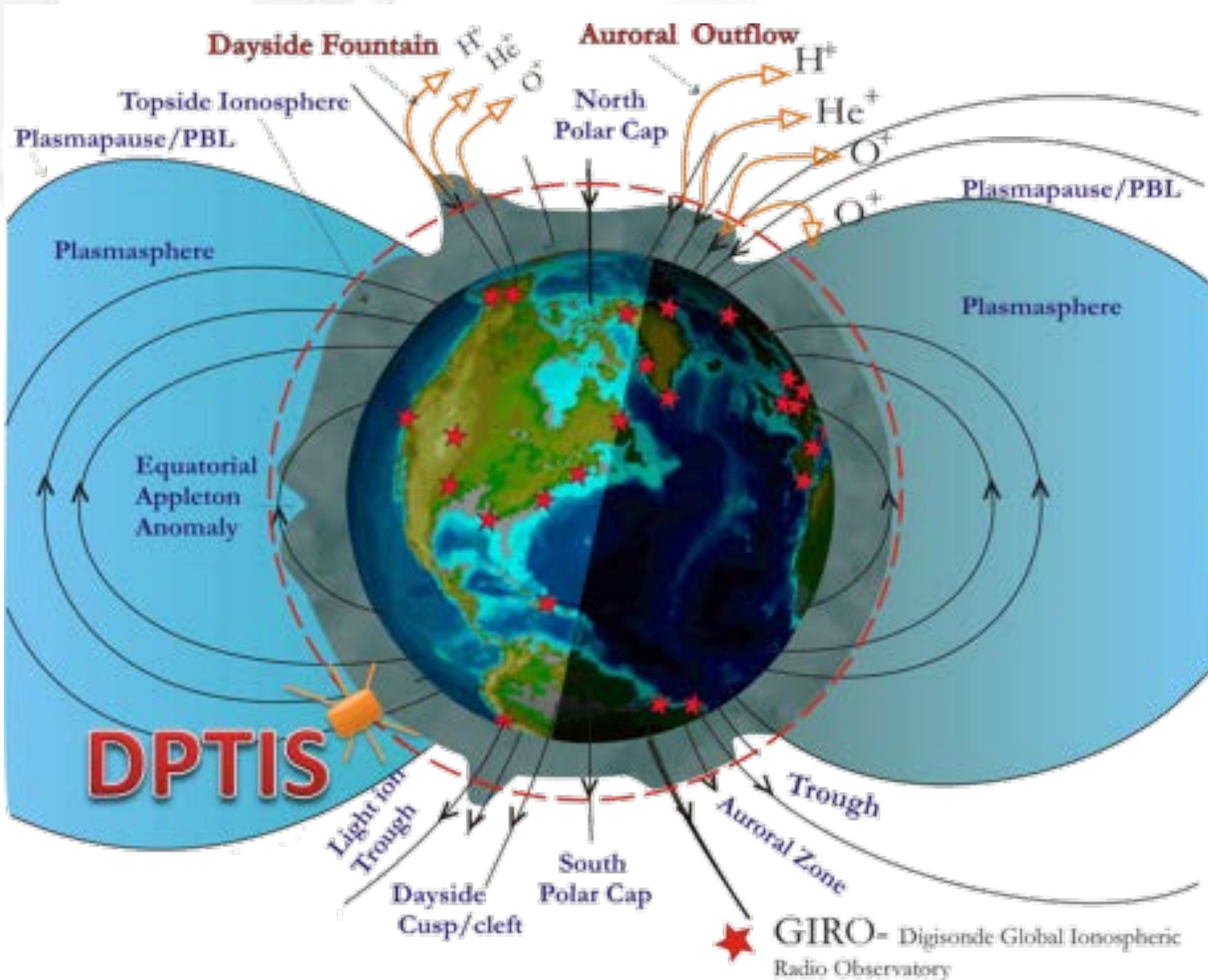
Out of tune

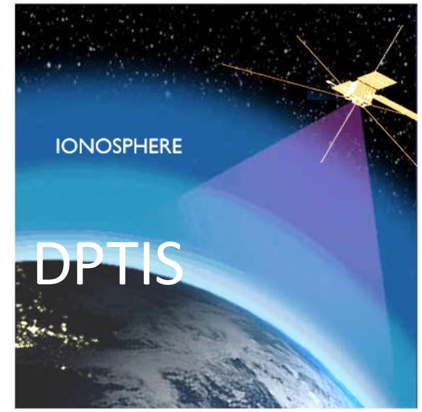


Tuned

Topside Ionospheric Sounder

800 – 1,000 km altitude

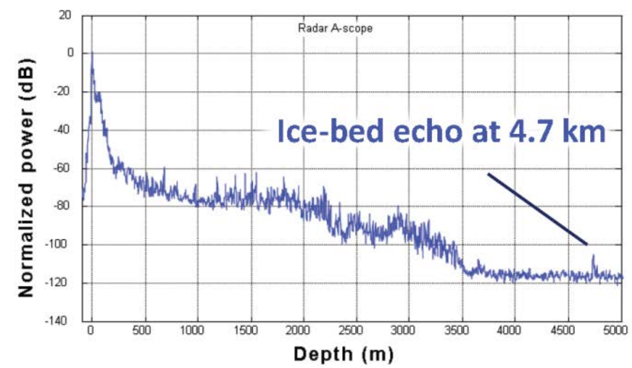




- 4-7 s ionograms
- Doppler skymaps for irregularities
- 0.5 s relaxation sounding sweep
- 3-axis antenna with Tx beamforming and Rx direction and polarization
- 3D Double probe E-field sensor

GPR

- Concept Instrument
  - VHF 50 MHz Ice Penetrating Radar
    - Kansas U. Team
    - 120+ dB dynamic range
    - Chirp waveform



  - MF-HF IPR/Sounder
    - UMass Lowell Team
    - Narrowband signal with quiet frequency search