Active Radiowave Plasma Experiments

Multi-nation and Spaceborne Projects at UML

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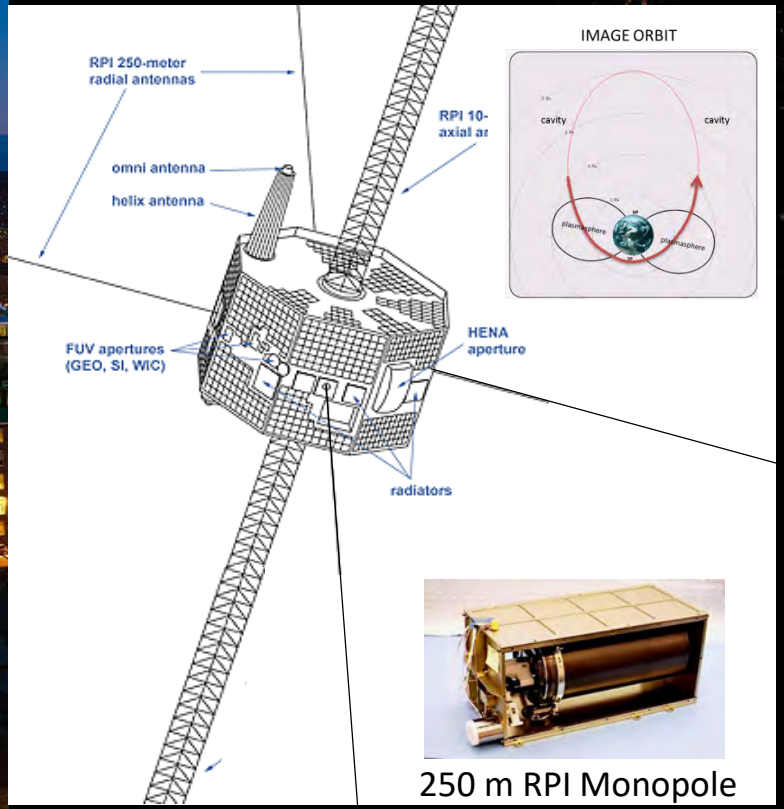
Northeast Radio Observatory Corporation (NEROC) Symposium Series
MIT Haystak Observatory ● November 1, 2019

Prelude

- Scott Tilley, VE7TIL
- Amateur radio astronomer with an S-band receiver at home, on a quest to search for [mostly] spy satellites
- Stunned NASA by discovering telemetry signal from IMAGE, a mission that went radio-silent in 2005 after a damaging SEU to TLM module
- Triggered an avalanche of spilled coffee…

…including our offices at UMass!

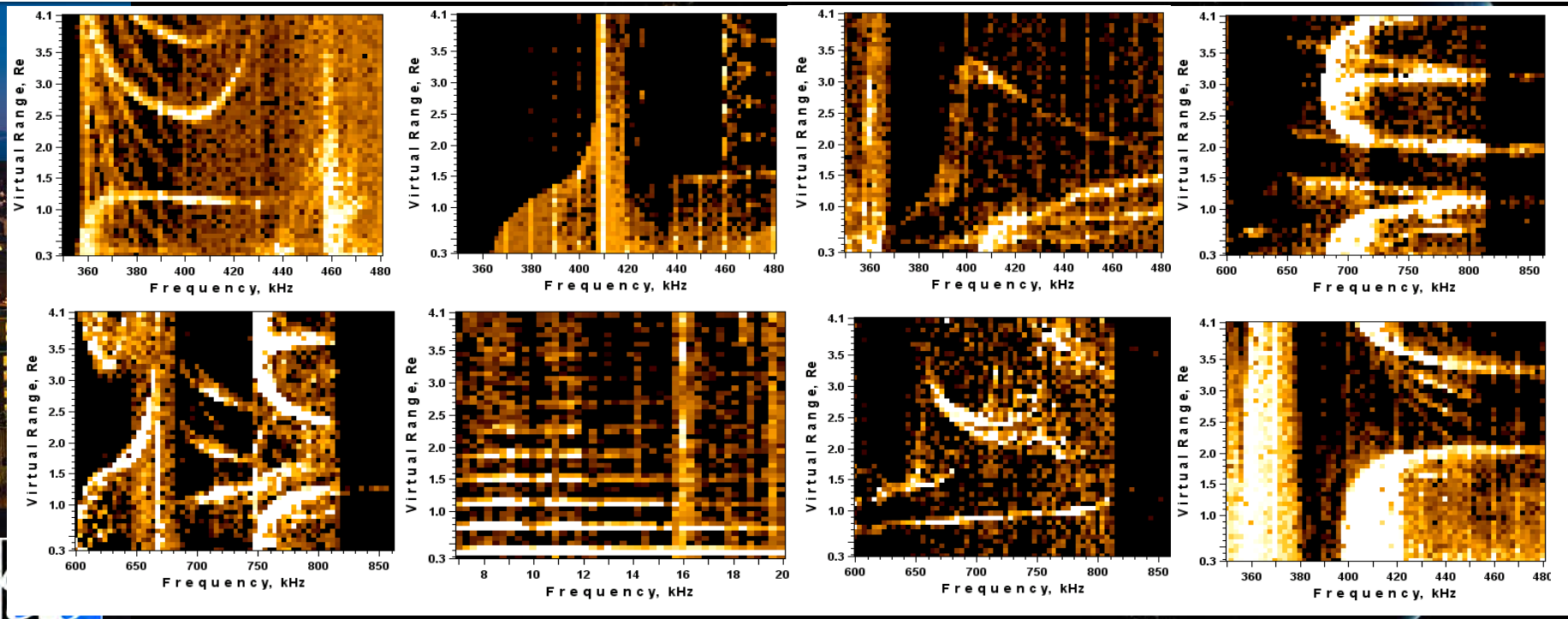
UML-Designed Radio Plasma Imager



250 m RPI Monopole

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

RPI Sounding Mode (Plasmagram)

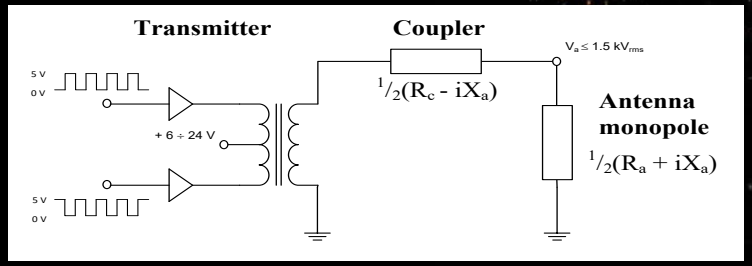


Contain signatures of active sensing remote plasma regions

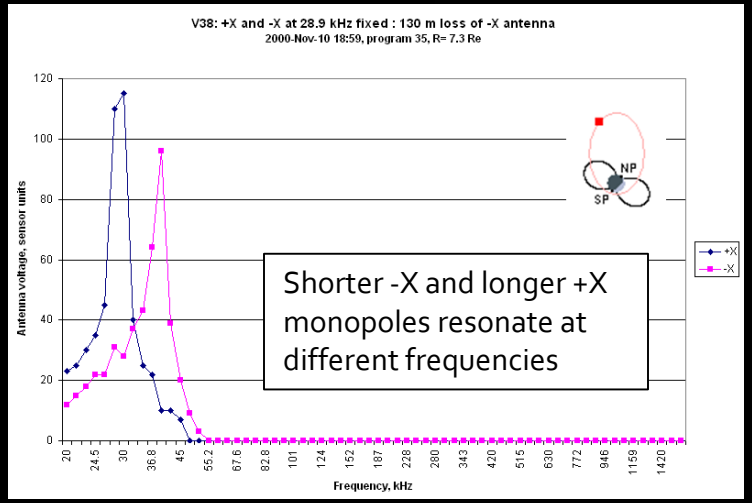
Recorded at opportune times and locations on orbit

10 kHz requires a 15 km half-wave dipole antenna in free space

Tuned VLF Transmissions in RPI



x2



- Establish resonance in transmitter-antenna system for max voltage (~kV) at the antenna foot
- Tuner inductance is adjusted to match antenna capacitance
  - Fine-tuning by adjustments to the tuner capacitance rather than inductance

VLF Transmission in Space Plasmas

RPI V71 study of X-axis power supply current

Plasmasphere fly-through on September 21-22, 2005

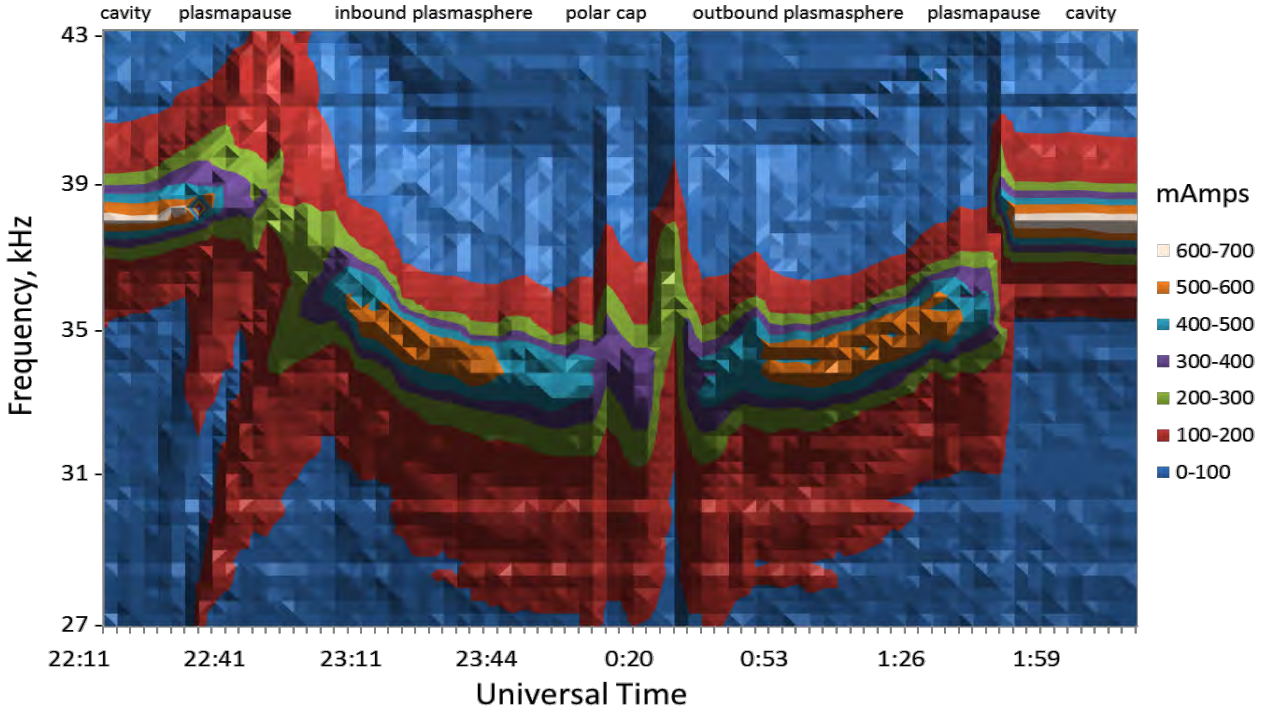
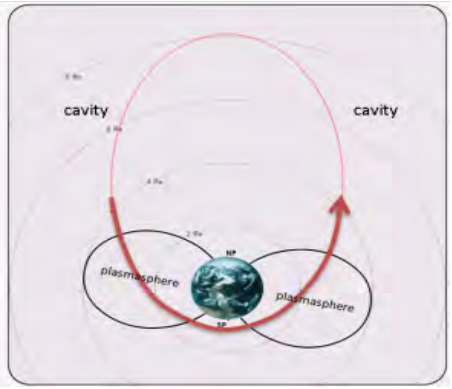
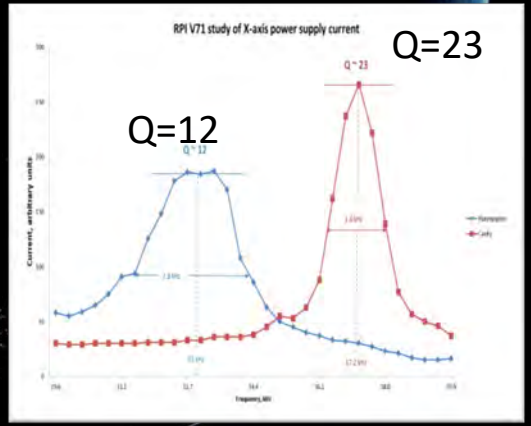


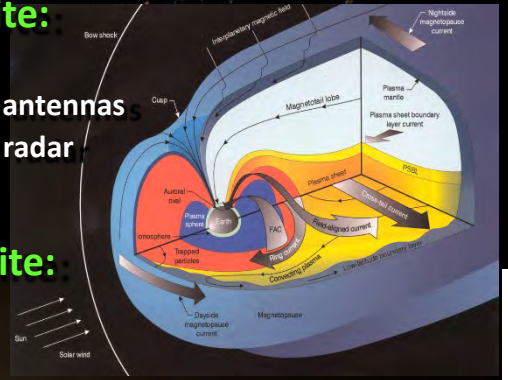
IMAGE ORBIT



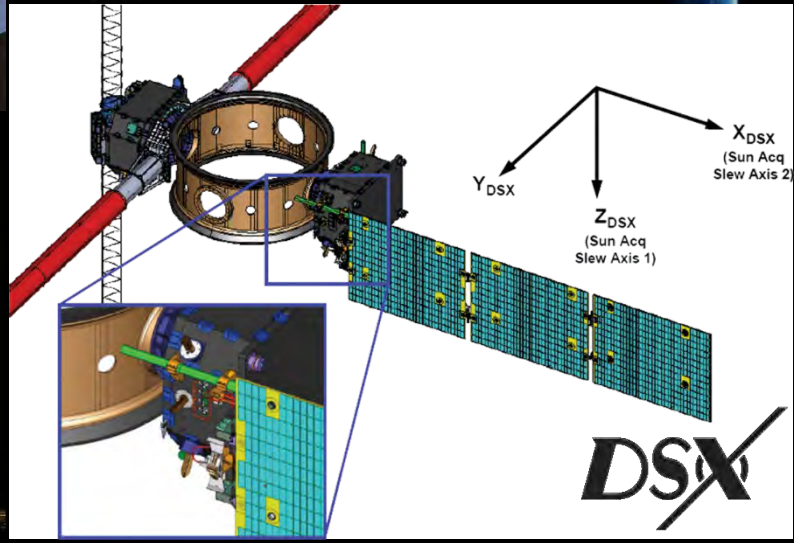


UML RF sounders in Space

- **NASA IMAGE satellite:**
  - Apogee: 8 Re
  - Two 500 m long wire antennas
  - Low frequency space radar
  - Operated for 6 years
- **Air Force DSX satellite:**
  - Apogee 5 Re
  - 80 m long antenna
  - High transmission power
  - Launched on June 25, 2019 on SpaceX Falcon Heavy

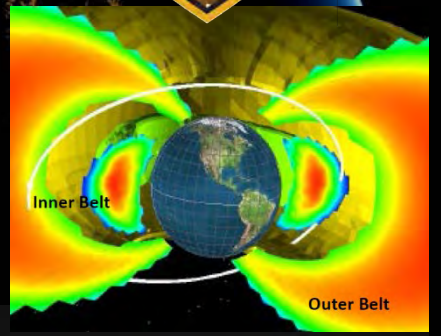


Dr. James Green
Director
NASA Planetary Science
April 4, 2019 at UML SSL



DSX WPx Science

- **UML-designed High Power VLF Transmitter**
  - The Wave Particle Interaction Experiment (WPIx) will investigate the influence of very-low frequency (VLF) radio waves on dynamics of particles trapped within the Earth radiation belts
  - The VLF antenna onboard DSX offers a rare opportunity to study the behavior of such an antenna *in-situ* and characterize its far-field radiation pattern and WPI efficiency
  - Purely scientific USAF mission to study MEO region and aide in the design of future flight experiments that may transverse this region

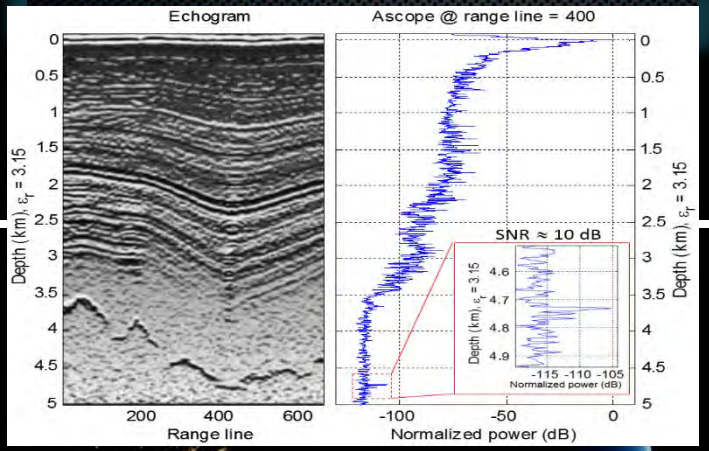


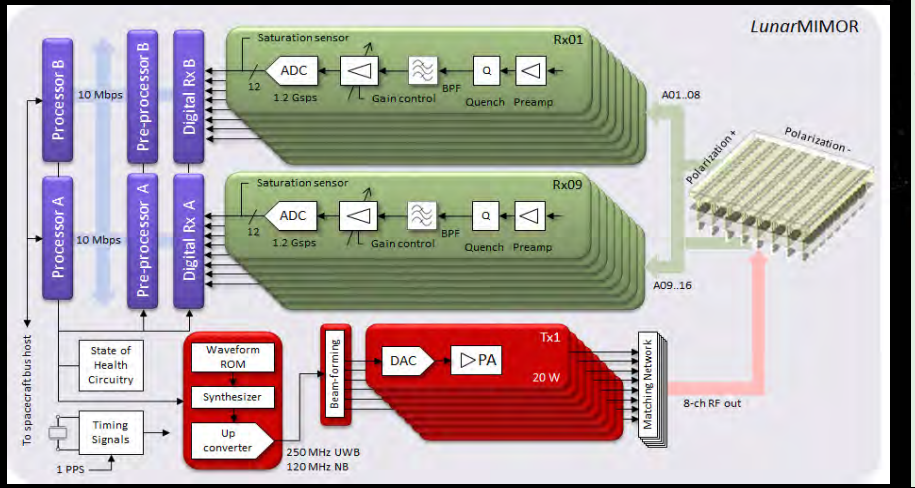
TNT Transmitter on DSX

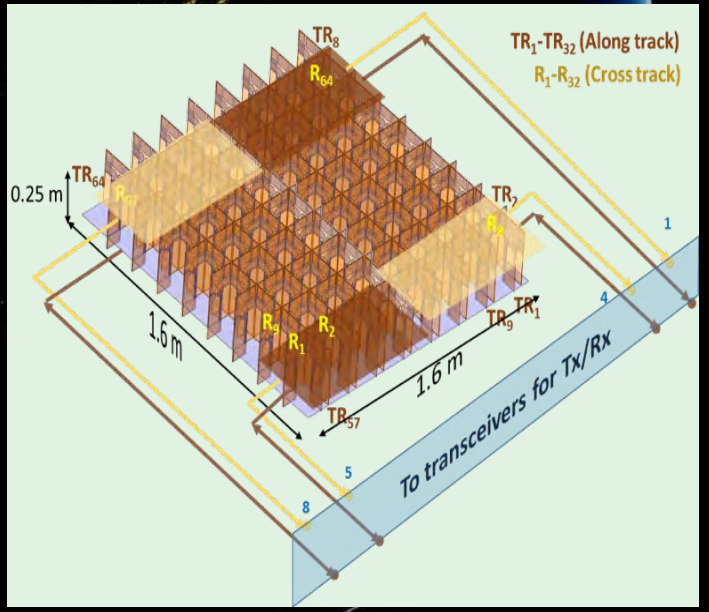
- High fidelity design for nominal 5 kVp
  - Q of 90 (lab) and 67 (low density plasma)
- Adaptive tuning:
  - Resonance discovery mode
  - Auto-correction of tuner parameters to match underlying plasma conditions
- Two presentations at upcoming AGU

Future work: Space-borne Ground Penetrating Radar

- For planetary applications: Moon, Mars, Icy moons of Jupiter (Europa) and Saturn (Titan)
- Ultra-wideband (UWB), MIMO technologies
- Tightly-Coupled Dipole Arrays





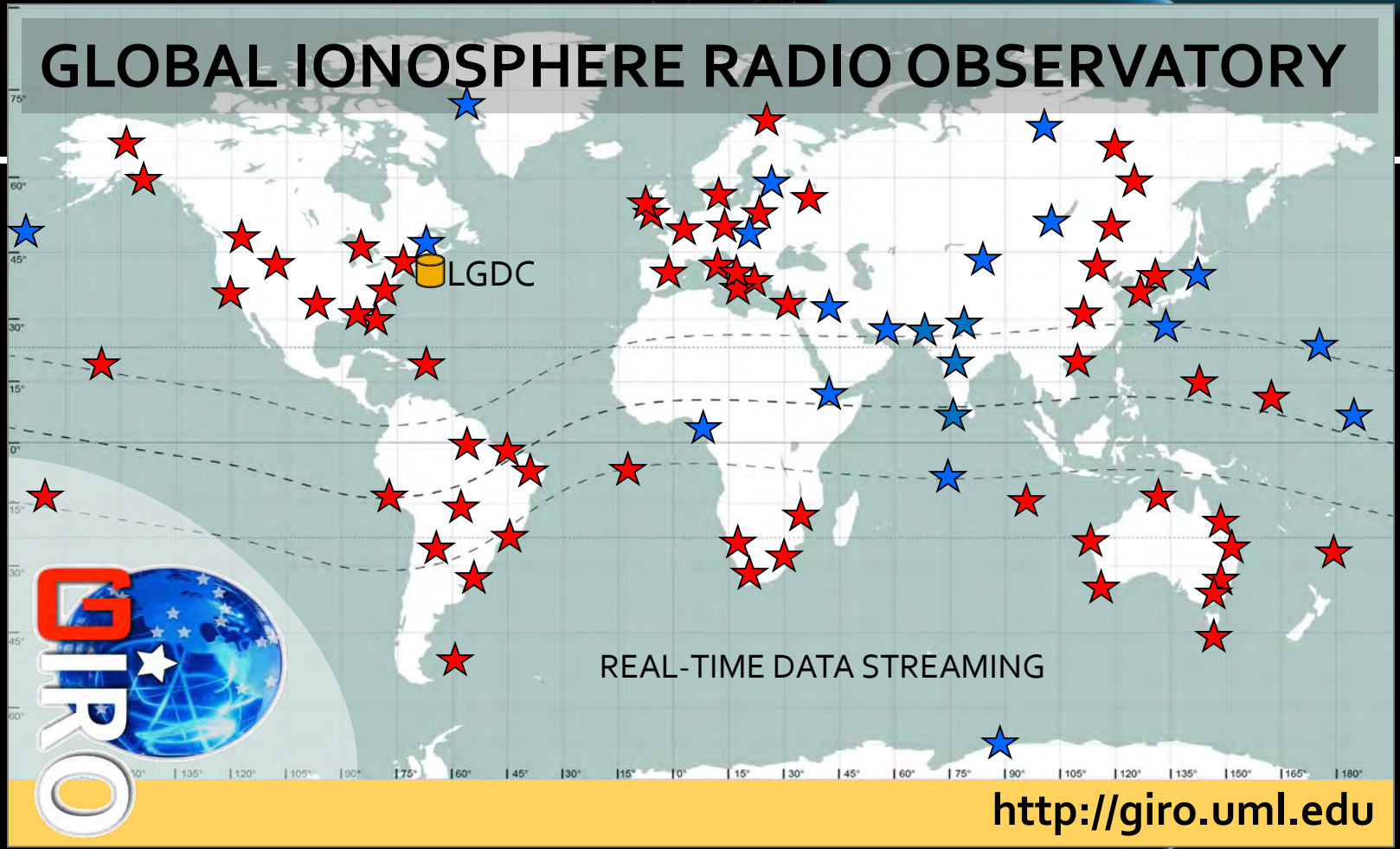


Collaboration of IGS and GIRO

IGS is International GNSS Service

GIRO is Global Ionosphere Radio Observatory

GLOBAL IONOSPHERE RADIO OBSERVATORY



Data latency < 5 min

Observatory • November 1, 2019

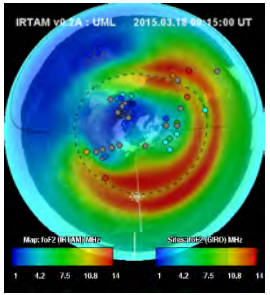
UML Realistic Ionosphere

RION

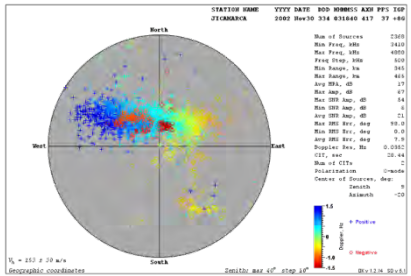
RION is member of United Nations Space Weather Initiative

http://www.iswi-secretariat.org/

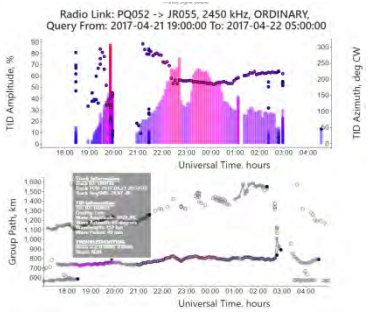
GIRO



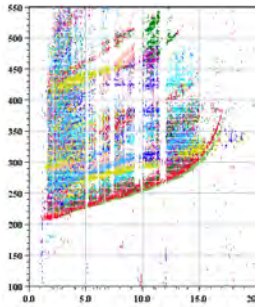
IRTAM 3D



SkyLITE



TID Explorer



IDI

Measurements

Global Model

Plasma Drifts

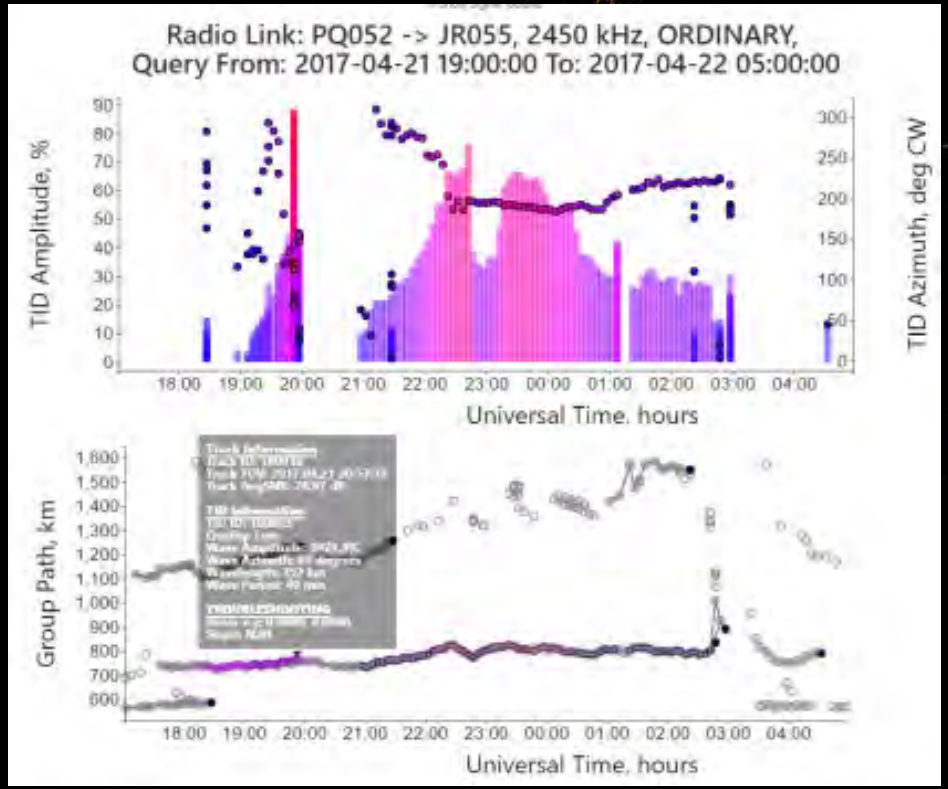
TID Warnings

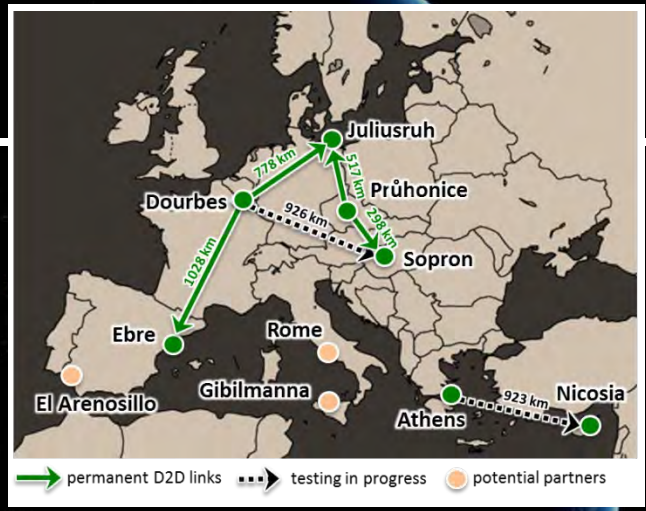
Disturbance Indicator


TechTIDE
TID
BOREALIS GLOBAL
F2
F1
F
E
E
D
350 km
250 km
110 km
80 km
TechTIDE
Capability Review
Presented by Ivan Galkin, Borealis Global Designs
Credits to TechTIDE Consortium & Experts
Bodo Reinisch, Anna Belehaki, Claudia Borries, David Altadill, Jaume Sanz, Dalia Buresova
Tobias Verhulst, Jens Mielich, Zama Katamzi, Haris Haralambous

TID Explorer on the Web

Individual TID detections and D2D data



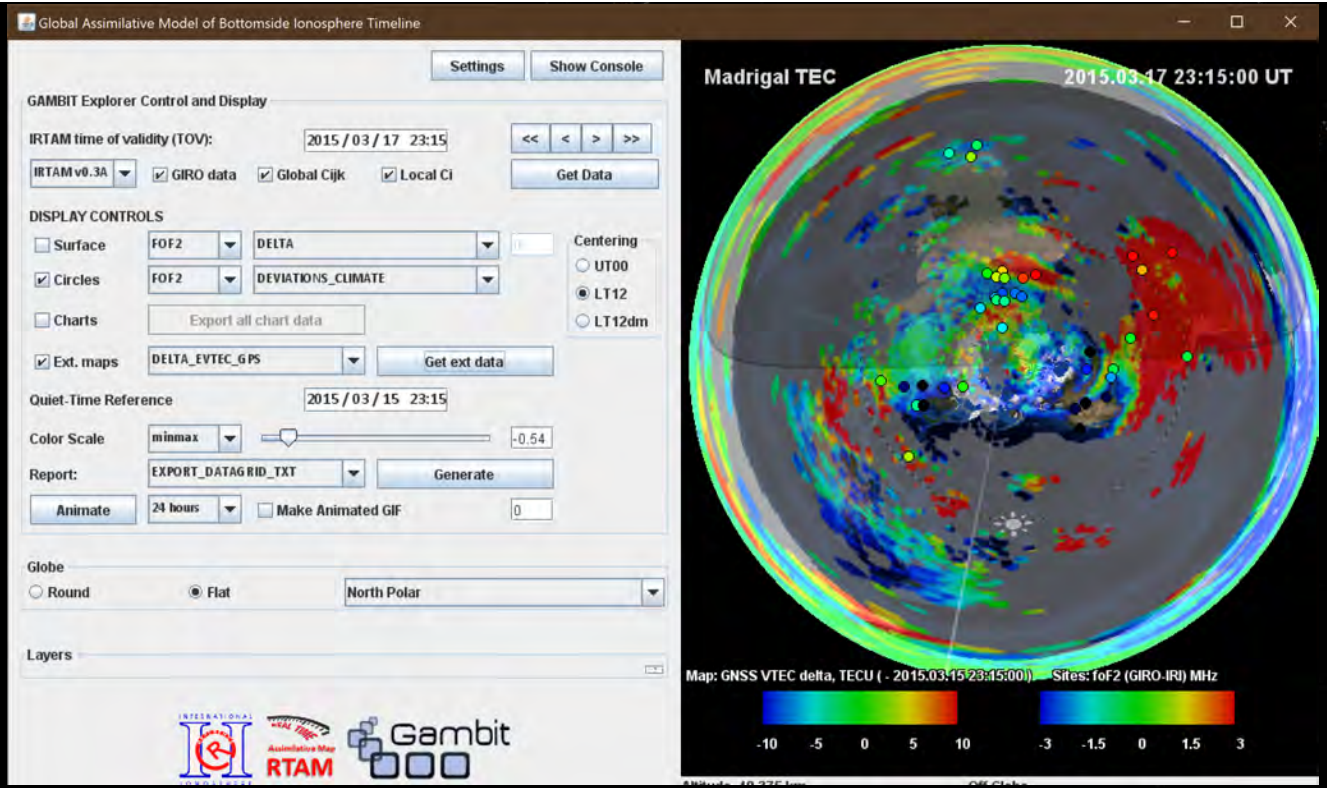


- + New TID warning system to start operations in South Africa, 4 station network

Free for academic use: GAMBIT Explorer 0.9.7
Download from http://giro.uml.edu/GAMBIT/
VTEC data courtesy MIT Haystack Madrigal, Anthea Coster
Soon: VTEC maps in real-time vs 30-day average (credits to IGS)

GAMBIT EXPLORER

ACCESS TO IRTAM DATA



Global ΔVTEC map
GIRO ΔfoF2

Nighttime Super-fountain
No Dayside Depression
Negative Southern hemi
St. Patrick storm
March 17-18, 2015

VTEC data courtesy Madrigal MIT Haystack Observatory, [Coster *et al.*, 2008]

Ideas for IGS + GIRO cooperation

- Global maps of slab thickness
- Weather versus climate comparisons
  - Available in GAMBIT: average VTEC maps
    - released by IGS/Olsztyn at 15 min cadence
- Assimilation of VTEC in IRTAM
  - Finer detail of global 3D ionosphere
    - Real-time capability is actively explored (UNB)

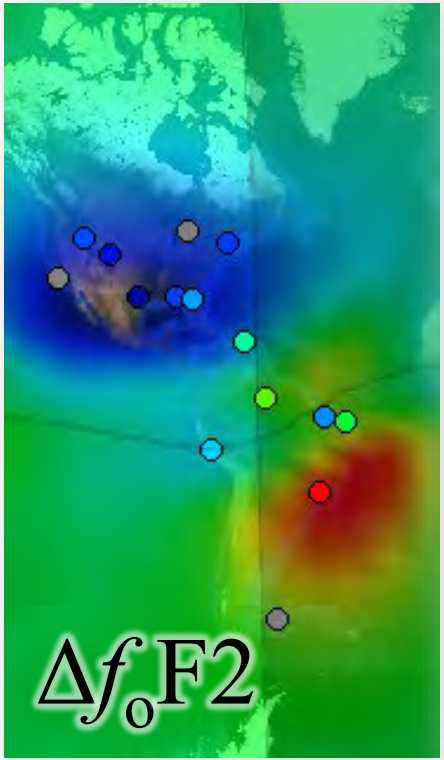
Outlook

- Near future: ground-penetrating radars for space exploration
- In progress: Realistic Ionosphere eXplorer (RIX) on the Web
  - http://giro.uml.edu
  - Rapid visualization of global 3D ionosphere timeline through some of the most interesting times of ionospheric dynamics

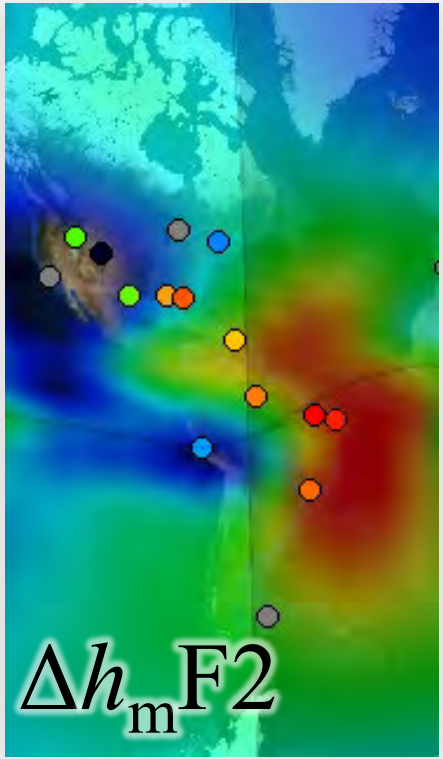
BACKUP SLIDES

IRTAM paired with GNSS TEC

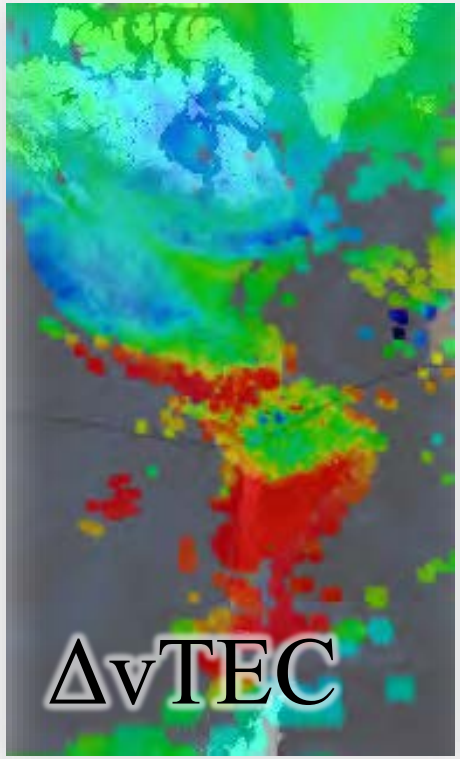
Δ Peak Density



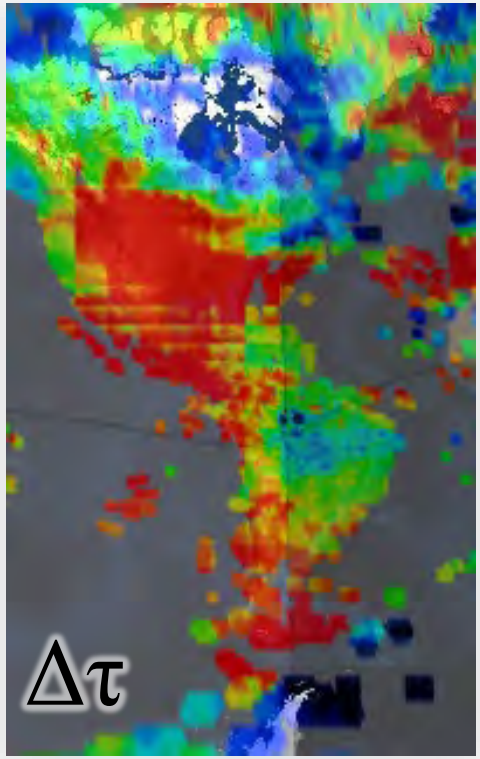
Δ Peak Density Height



Δ vTEC

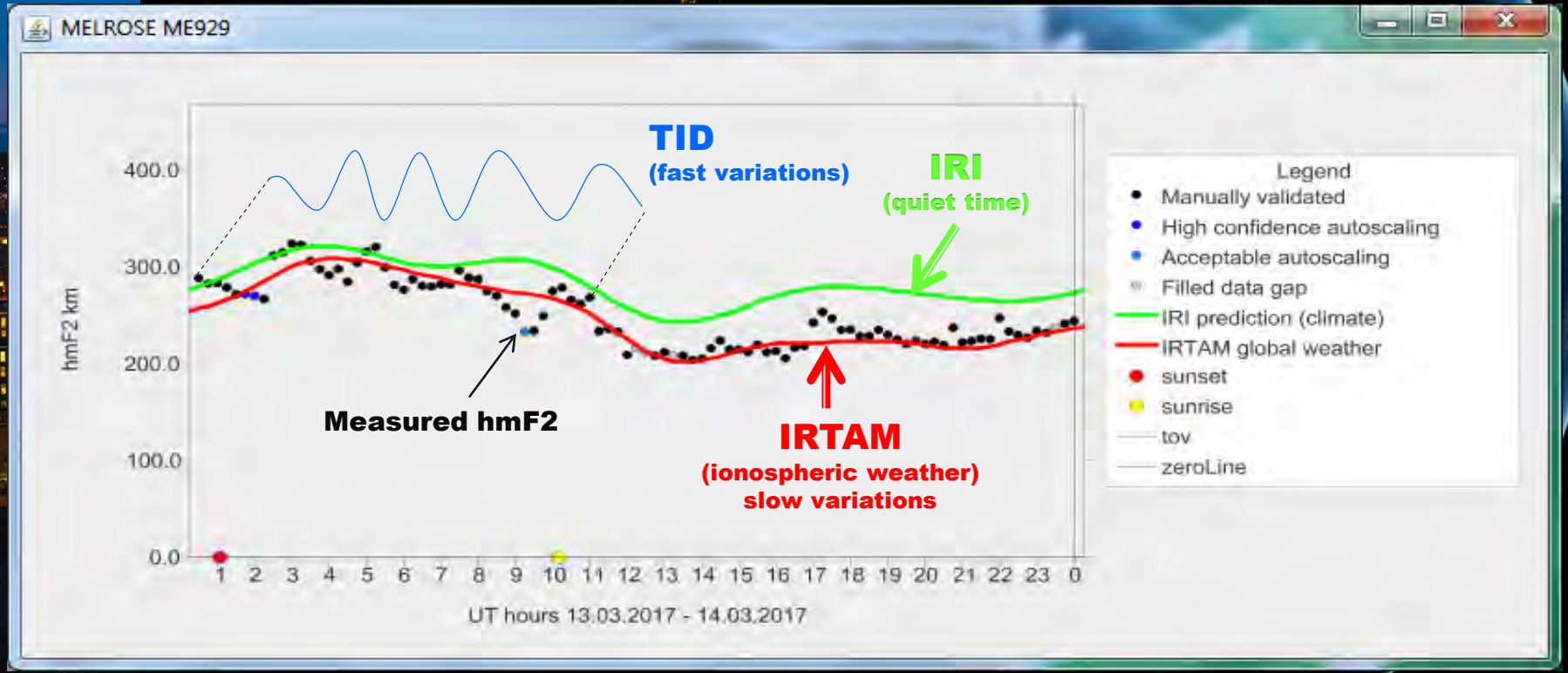


Δ Slab Thickness



VTEC data courtesy Anthea Coster, MIT Madrigal

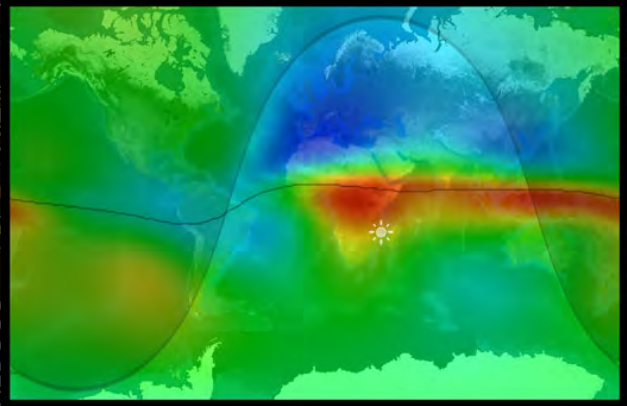
Realistic Ionosphere: IRTAM+TIDx



Digisonde data courtesy of Robert Moore, Florida University

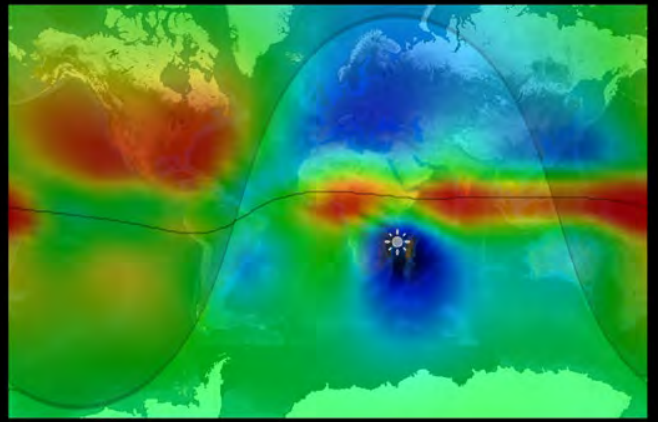
IRI Real-Time Extension

Global hmF2 "Climatology" IRI

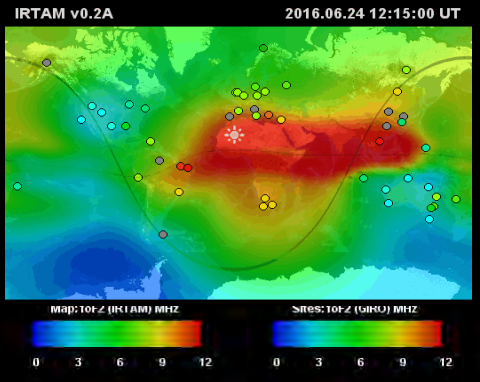


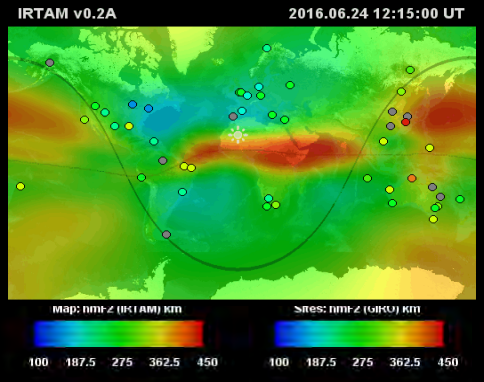
Ionosonde Network Real-Time hmF2

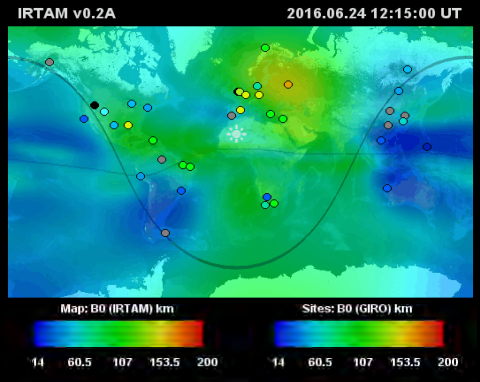
Global hmF2 Weather

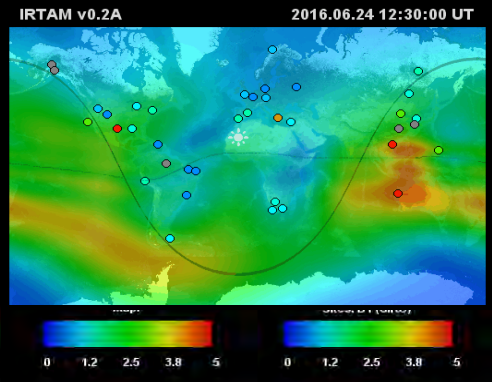


IRTAM 24-hour Animations







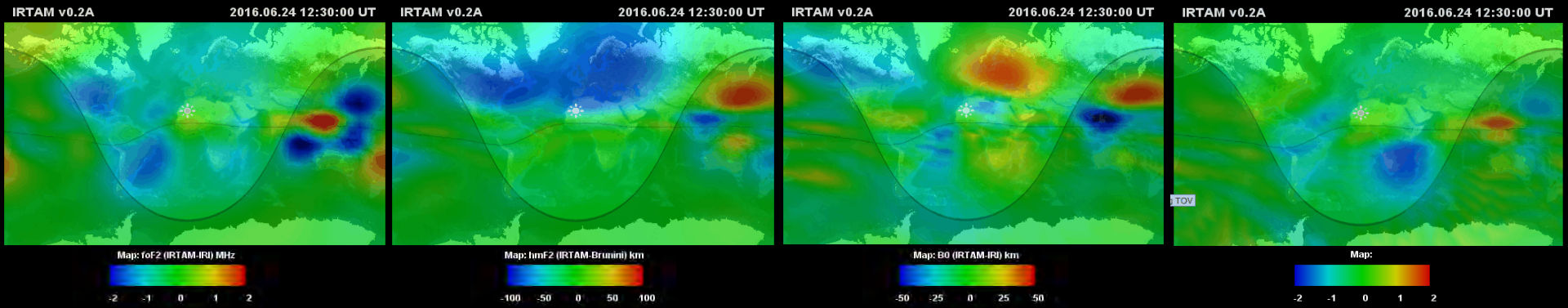


f_oF2 h_mF2 *B0* *B1*

Used as input drivers to IRI density profile for 3D specification

IRTAM Deviation Maps

HOW IONOSPHERE IS DIFFERENT FROM ITS QUIET-TIME STATE



Δf_0F2 Δh_mF2 $\Delta B0$ $\Delta B1$

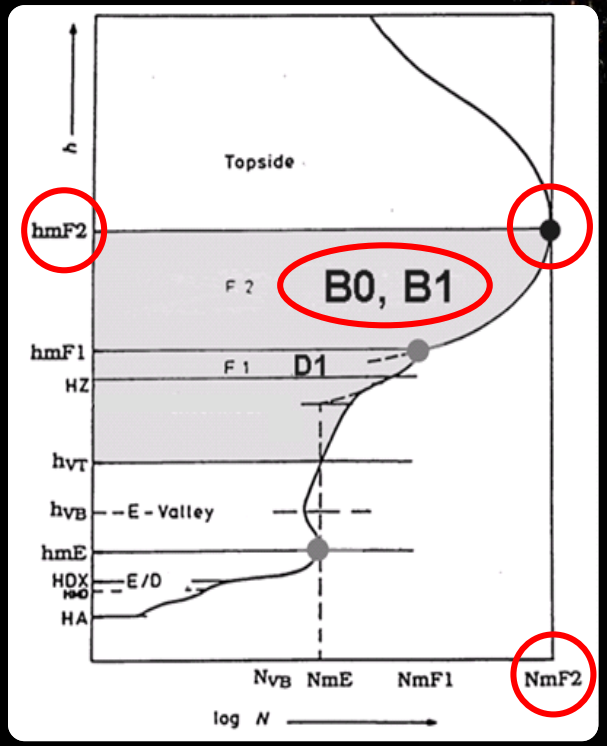
November 1, 2019

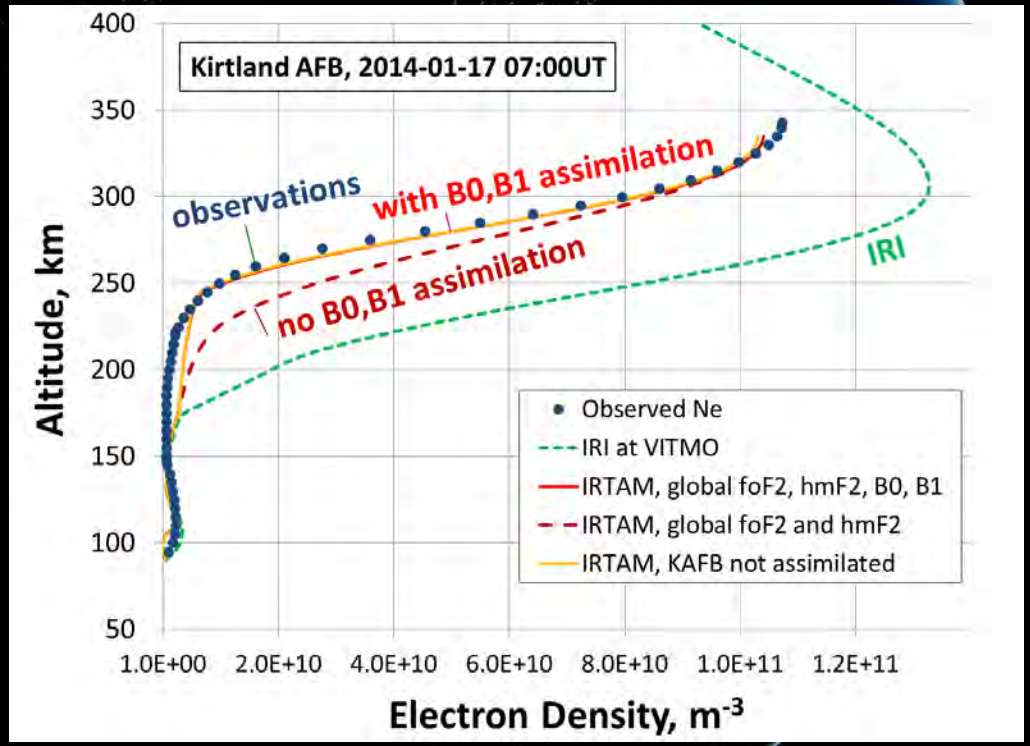
4th Annual NEROC Syn

UMASS LOWELL

NECTAR

IRTAM 3D


h
Topside
hmF2
F 2
B0, B1
hmF1
F 1
D1
HZ
hVT
hVB
E - Valley
hmE
HDX
E/D
HA
NVB
NmE
NmF1
NmF2
log N


Kirtland AFB, 2014-01-17 07:00UT
observations
with B0,B1 assimilation
no B0,B1 assimilation
IRI
Observed Ne
IRI at VITMO
IRTAM, global foF2, hmF2, B0, B1
IRTAM, global foF2 and hmF2
IRTAM, KAFB not assimilated
Altitude, km
400
350
300
250
200
150
100
50
1.0E+00
2.0E+10
4.0E+10
6.0E+10
8.0E+10
1.0E+11
1.2E+11
Electron Density, m-3