High Frequency Radars and Ionospheric Sounding with VIPIR

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In Cooperation with:
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National Geophysical Data Center
Solar and Terrestrial Physics Division

Agenda

1. Ionosonde Principles

- Earth's Ionosphere
- Propagation in Plasma
- Ionospheric Sounding
- Ionosonde Applications

2. Ionosonde hardware

- Historical Ionosondes
- Modern Ionosondes
- VIPIR
- Research Topics

3. VIPIR Operations

- Measurement Concepts
- Data Formats
- VIPIR Operations
- VIPIR Data

4. VIPIR Calibration & Misc

- Calibration Tests
- Free Software
- Hardware Tour
- Resources & Credits

Earth's Ionosphere

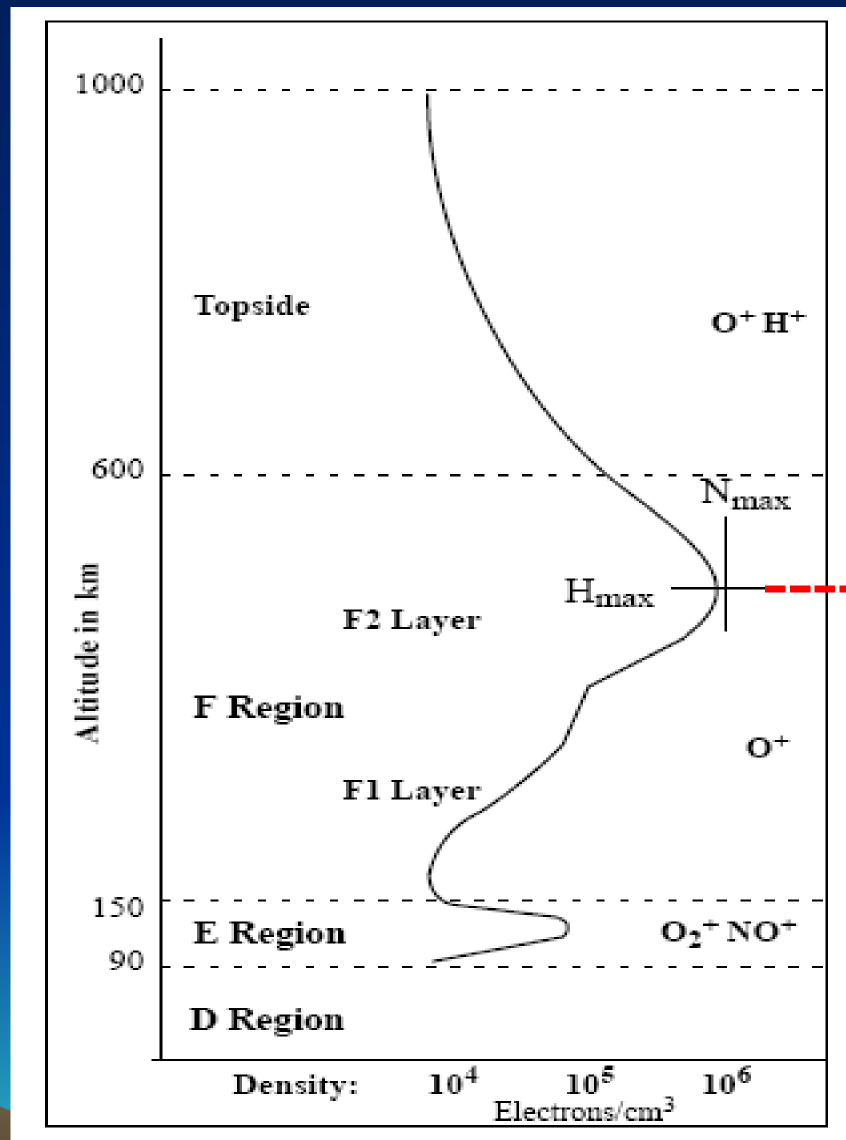
- Plasma of ionized atmospheric gases
  - NO, O2, O, H, He
- Produced by solar EUV (mostly)
- ~50 to ~1000 km altitude
- Strong temporal variations
  - Daily
  - Seasonal
  - Solar Cycle
- Strong interaction with Earth's magnetic field
  - Solar produced magnetic disturbances
  - High, Middle and Low Latitudes

Ionosphere Vertical Electron Density Profile

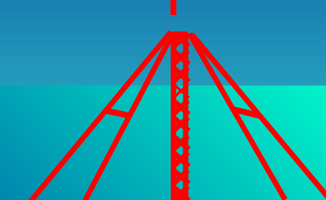
The F2 region varies by 3-5X diurnally, highest just after noon, lowest before dawn.

The F1 region and E region dissipate at night.

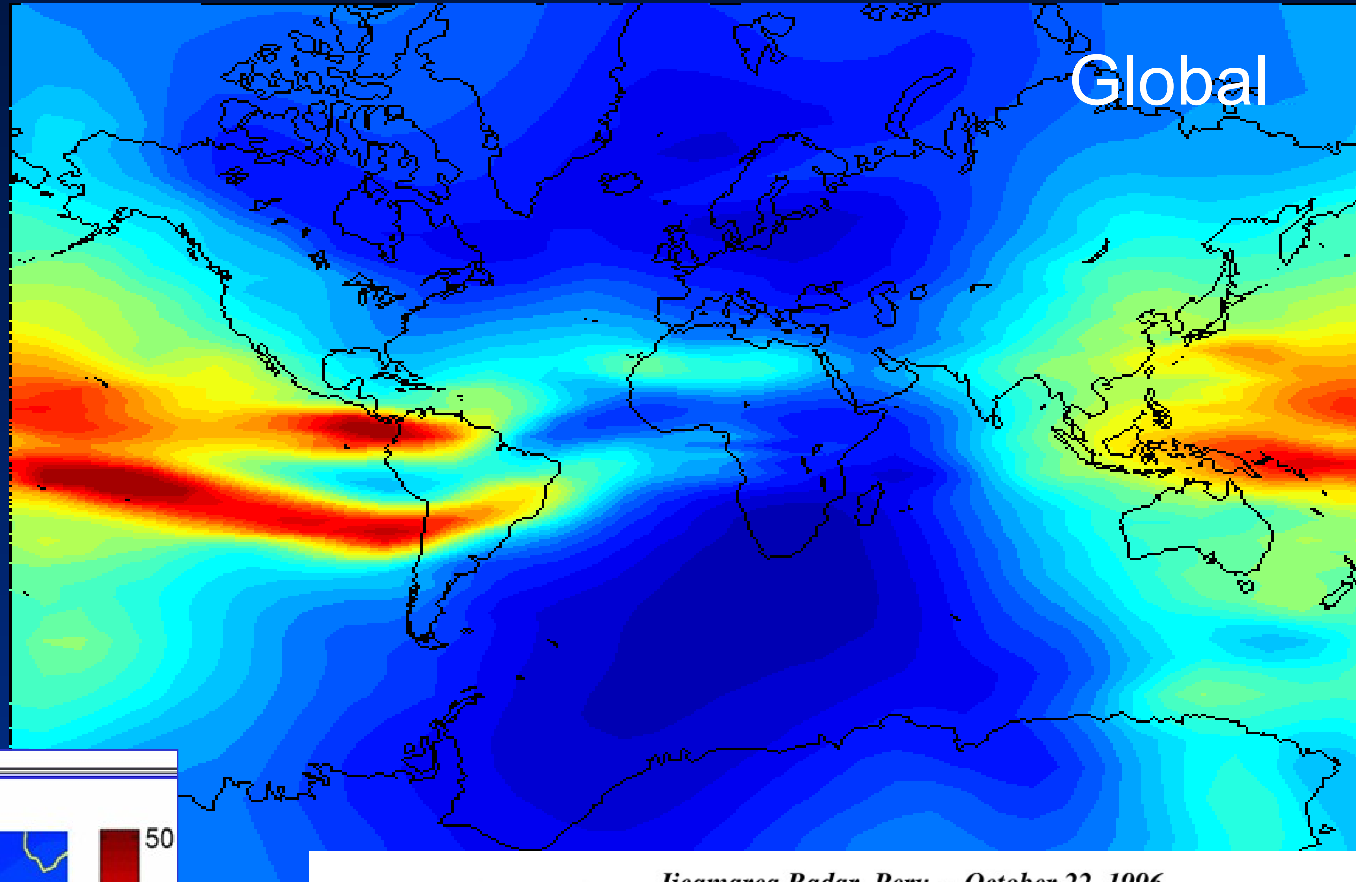
The D region is present only during daytime and in times of high activity.



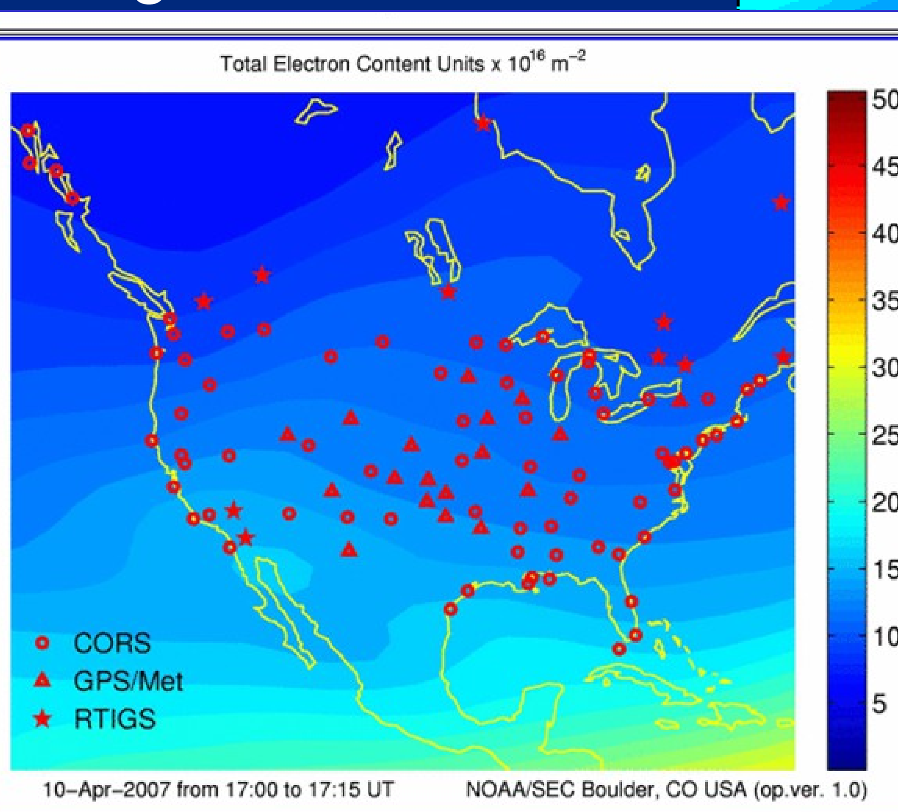
Ionosondes Measure Up To H_{max}

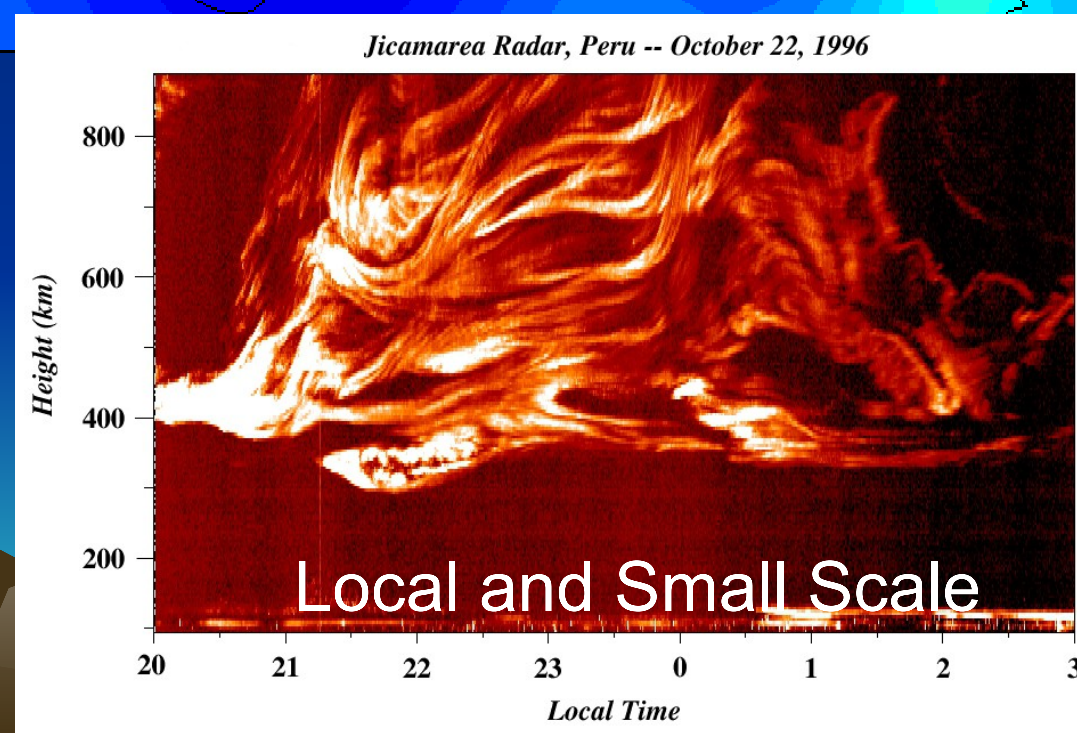


Ionosphere Structure



Regional





Radio Waves in Plasmas

Plane Wave Electric Field $E(z) = \Re\left(E_o e^{i(\omega t - kz)}\right)$

Index of Refraction $n = \frac{ck}{\omega} = (\mu - i\chi)$

- Cool plasma
- No Collisions
- No Magnetic Field

$$\mu^2 = 1 - X = 1 - \frac{f_N^2}{f^2} = 1 - \frac{\kappa N}{f^2} \qquad \kappa = \frac{e^2}{4\pi^2 \epsilon_o m} \cong 80.5$$

Propagation near the speed of light when $f_N \ll f ; \mu \approx 1$

Propagation slows dramatically when $f_N \to f ; \mu \to 0$

Specular (total) reflection occurs when $f_N = f ; \mu = 0$

After *Davies, 1965*

Propagation with a Magnetic Field

A magneto-plasma is <u>birefringent</u>

The index of refraction depends on the polarization of the radio wave

A magneto-plasma is <u>anisotroptic</u>

The index of refraction depends on the direction of propagation

Index of refraction:

$$\mu^2 = 1 - \frac{2X(1-X)}{2(1-X) - Y_T^2 \pm \sqrt{Y_T^4 + 4(1-X)^2 Y_L^2}}$$

With respect to the direction of propagation:

$Y_L =$ Longitudinal component of $\bar{\boldsymbol{Y}}$

$Y_T =$ Transverse component of $\bar{\boldsymbol{Y}}$

The + and – refer to the Ordinary and Extraordinary polarized radio waves

Reflection occurs when

$f_N = f$ (Ordinary wave)

$X = 1 - Y$ (eXtraordinary waves)

$X = 1 + Y$

$$\bar{\boldsymbol{Y}} = \bar{\boldsymbol{B}} \frac{e}{m\omega}$$

$$Y = \frac{f_H}{f}$$

$$f_H = |\bar{\boldsymbol{B}}| \frac{e}{2\pi m}$$

O&X are circularly polarized over most the Earth

Linearly polarized at the magnetic equator

After *Davies, 1965*

Appleton Equation

A magneto-plasma is <u>absorptive</u>

The radio wave amplitude decreases as energy is lost due to collisions

The full Appleton equation with collisions $Z = \frac{f_\nu}{f}$

$$n^2 = 1 - \frac{X}{1 - iZ - \frac{Y_T^2}{2(1-X-iZ)} \pm \sqrt{\frac{Y_T^4}{4(1-X-iZ)} + Y_L^2}}$$

With propagation below 30 MHz in the Earth's Ionosphere,
all of these factors can substantially influence the radio wave

This influence provides both Great Opportunity and Great Difficulty with Remote Sensing and Radio Science with Ionosondes

After *Davies, 1965*

Phase and Group Velocity

Phase velocity is defined as: $v = \frac{c}{\mu} \quad \therefore \quad v = c \rightarrow \infty$ as $\mu = 1 \rightarrow 0$

Which means the radio wavelength increases in a plasma

Group velocity is: $u = \left(\frac{d\omega}{dk}\right)_{k_0}$ $\quad u = c \rightarrow 0$ as $\mu = 1 \rightarrow 0$

Which means the propagation speed decreases in a plasma

Group Refractive Index is: $\mu' = \frac{c}{u} = c\frac{dk}{d\omega} = \mu + f\frac{d\mu}{df}$

With no magnetic field: $\mu' = \frac{1}{\mu} \quad \therefore \quad \mu' = 1 \rightarrow \infty$ as $\mu = 1 \rightarrow 0$

After *Davies, 1965*

Virtual Height and Density Profiles

- Ionosondes measure the time of flight of a packet of radio frequency energy
- Virtual Height or Group Path
- Integral of the Group Refractive Index

Virtual height
$$h'(f) = \int_0^{h_R} \mu'(f)\,dh$$

For a parabolic electron density profile:
$$N(h) = \frac{f_p^2}{80.5}\left[1 - \left(\frac{h-h_o}{y_m}\right)^2\right]$$

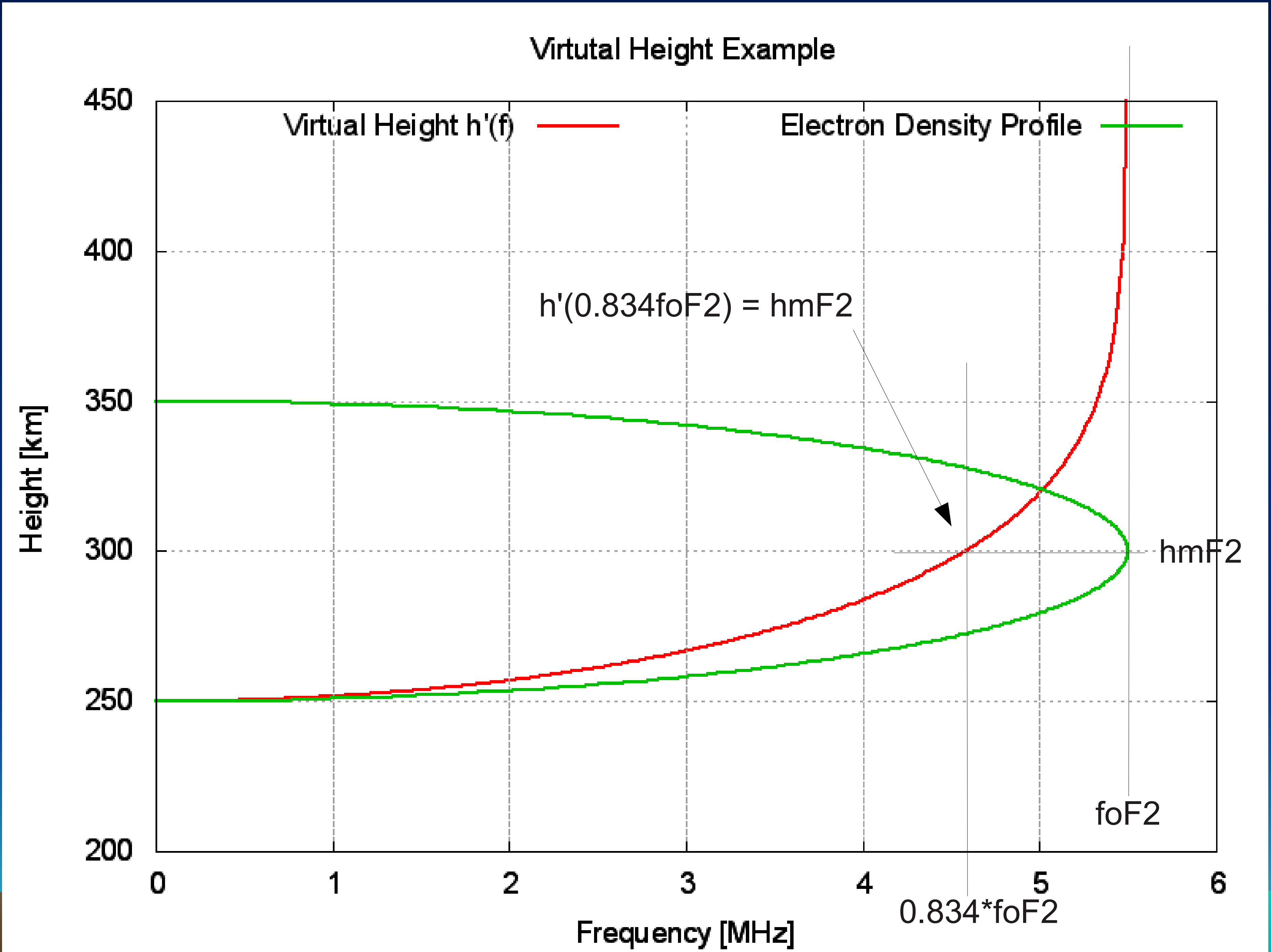
Virtual Height (reflection):
$$h'(f) = h_o - y_m + \frac{y_m}{2}\frac{f}{f_p}\ln\frac{f_p+f}{f_p-f}$$

Virtual Height (through the layer)
$$h'(f) = h_o - y_m + y_m\frac{f}{f_p}\ln\frac{f+f_p}{f-f_p}$$

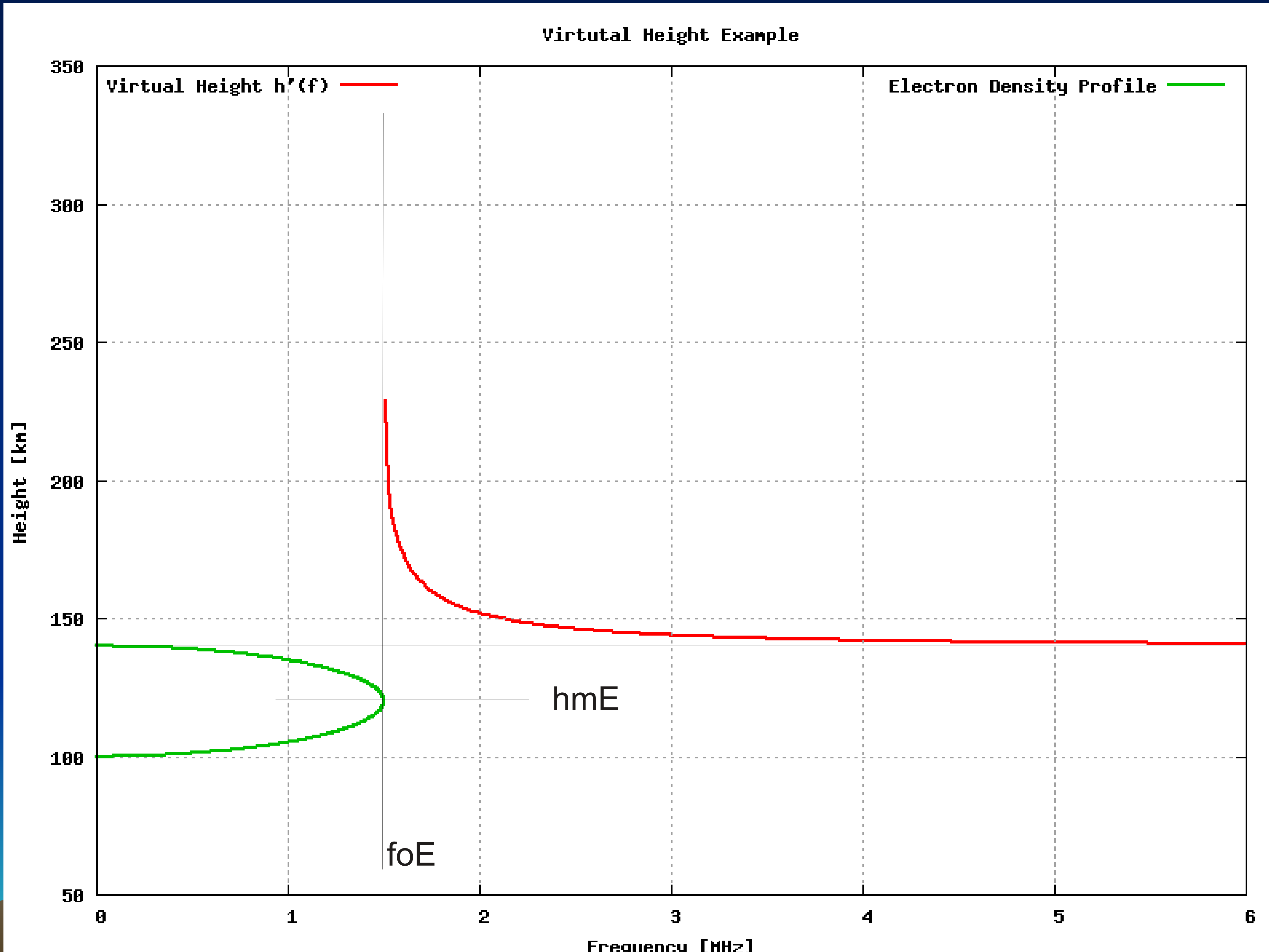
After *Davies, 1965*

(no magnetic field)

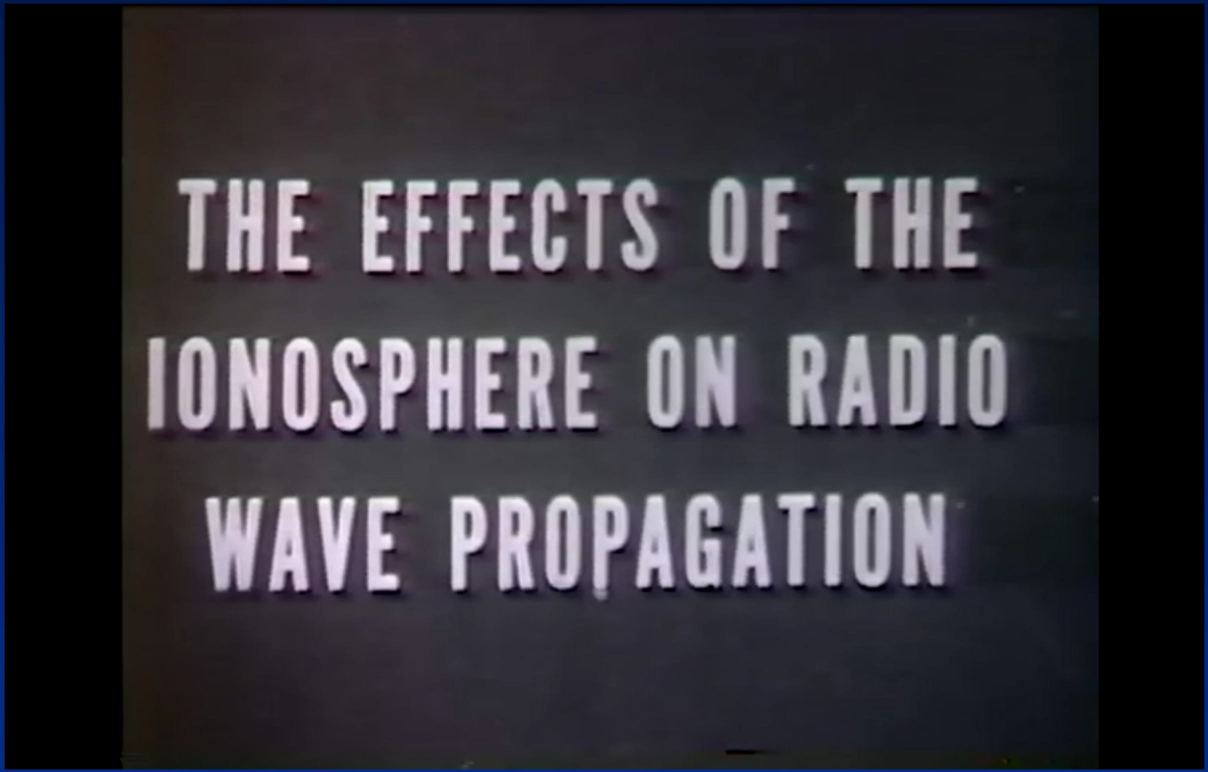
Parabolic EDP and Virtual Height



Propagation through a Layer

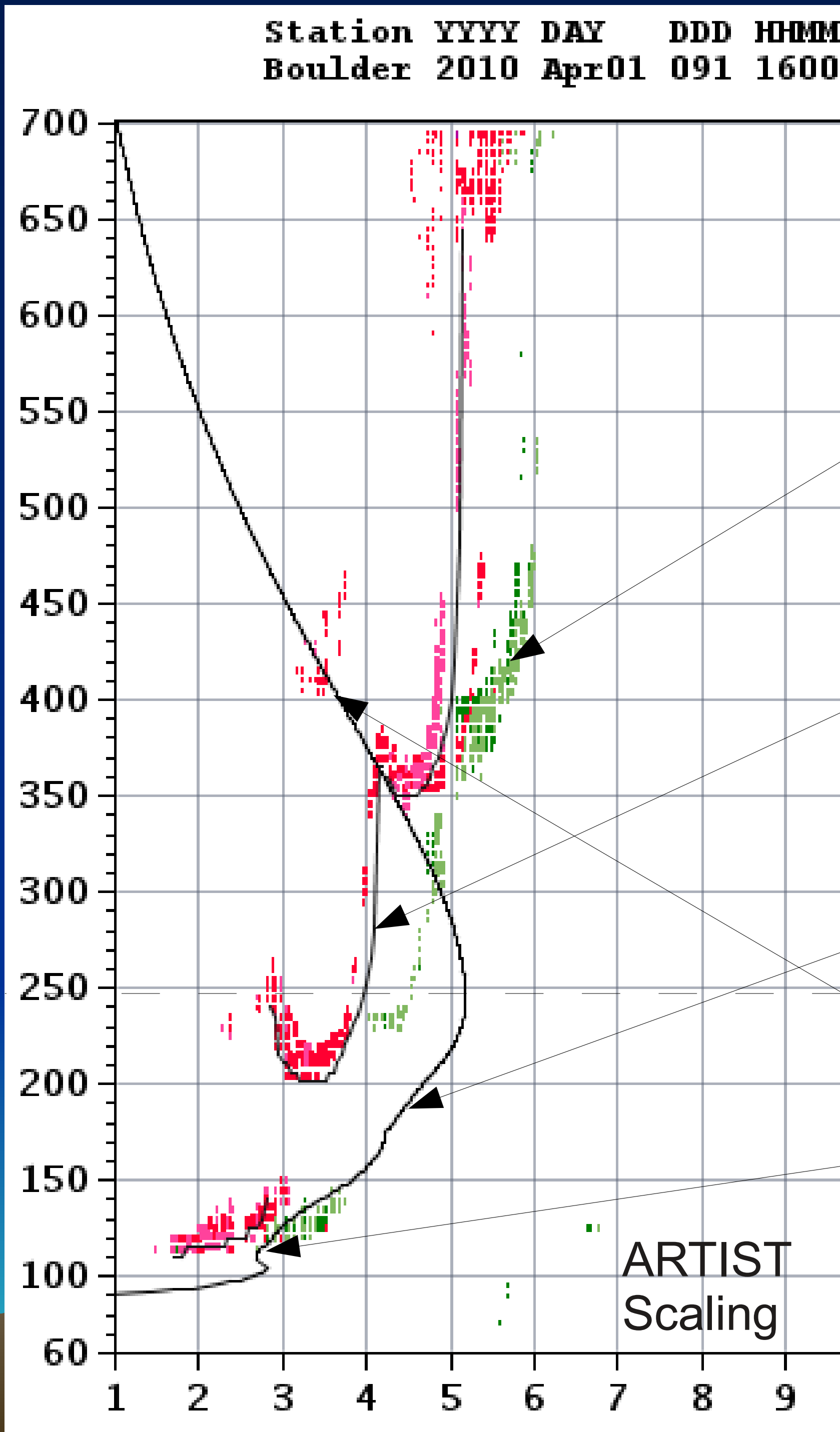


Movie



- U.S. Army Training film from 1960
- Very basic introduction to radio waves
- Surprisingly good explanation of the ionosphere and its effects on radio wave propagation
- 45 minutes

What is an Ionosonde and what does it do?

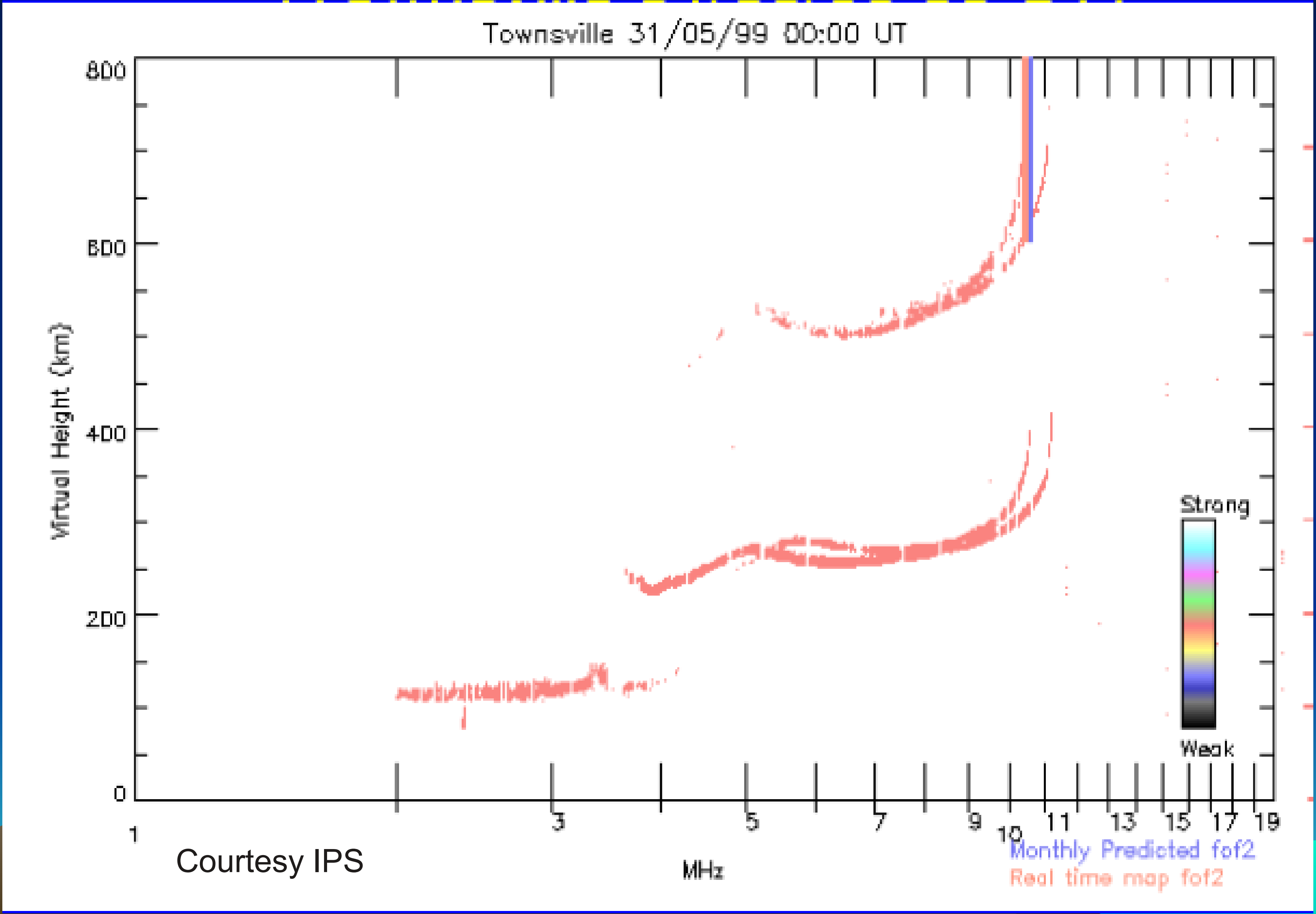


- MF-HF Radar (1-20 MHz)
- A acre or ten of antennas
- Measures ionosphere reflection height at a precise density (sounding frequency)
- Feature recognition software needed in an often complex image
- Inversion process required to obtain bottom-side electron density profile
- Valleys and Topside are modeled or extrapolated

Ionosondes: Reversed Independent Variables

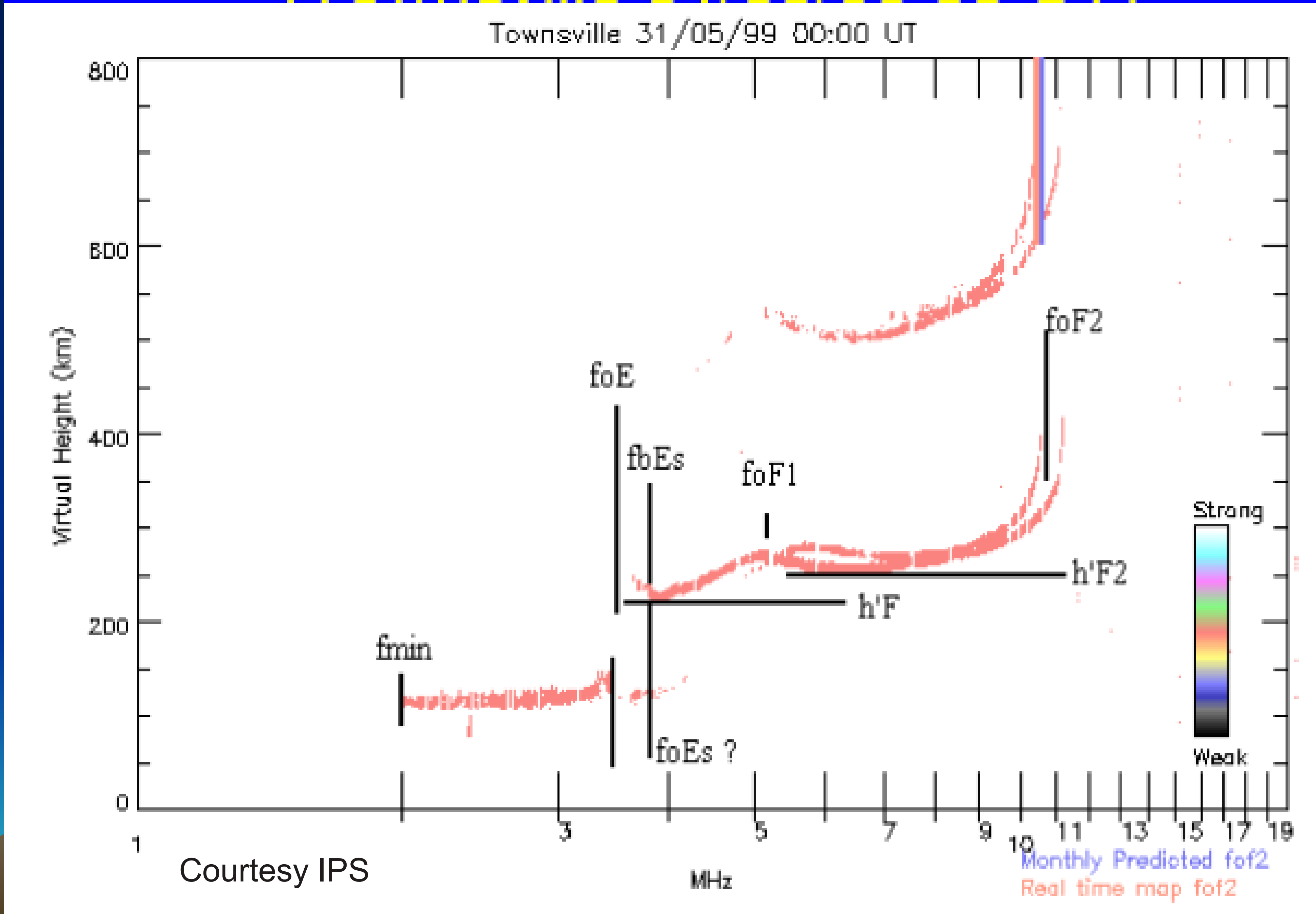
- With most ionosphere sensors, the observation location is selected by the instrument
  - Radar look direction
  - Satellite orbit
- The plasma density is measured
  - Radar Reflectivity
  - Local Plasma probe
  - TEC along a known path
- With an ionosonde, the plasma density is set by the frequency of observation.
- The measurement is the location (range, direction) of the ionosphere which has that density.

Classic Ionogram



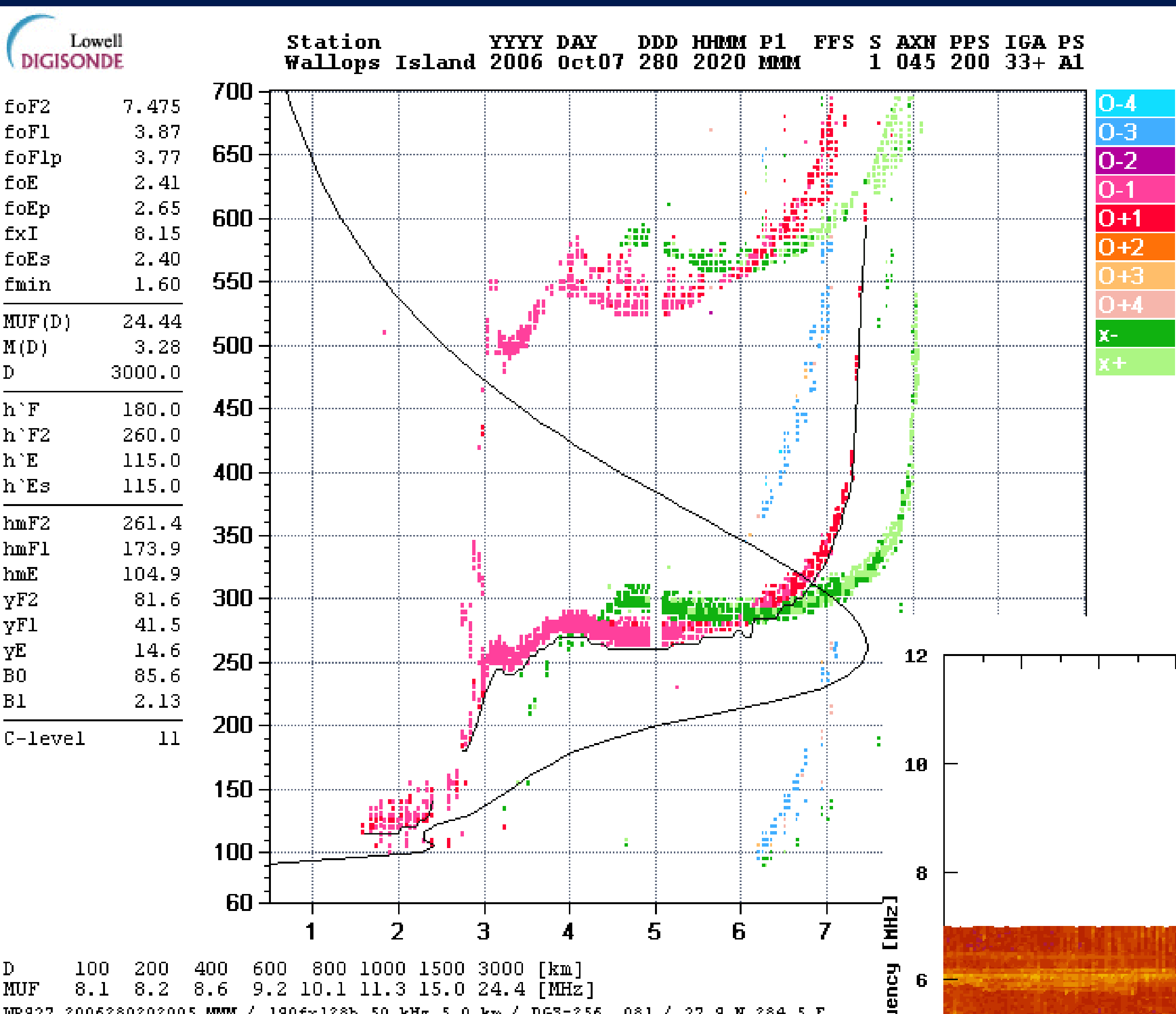
Courtesy IPS

Classic Ionogram Scaling

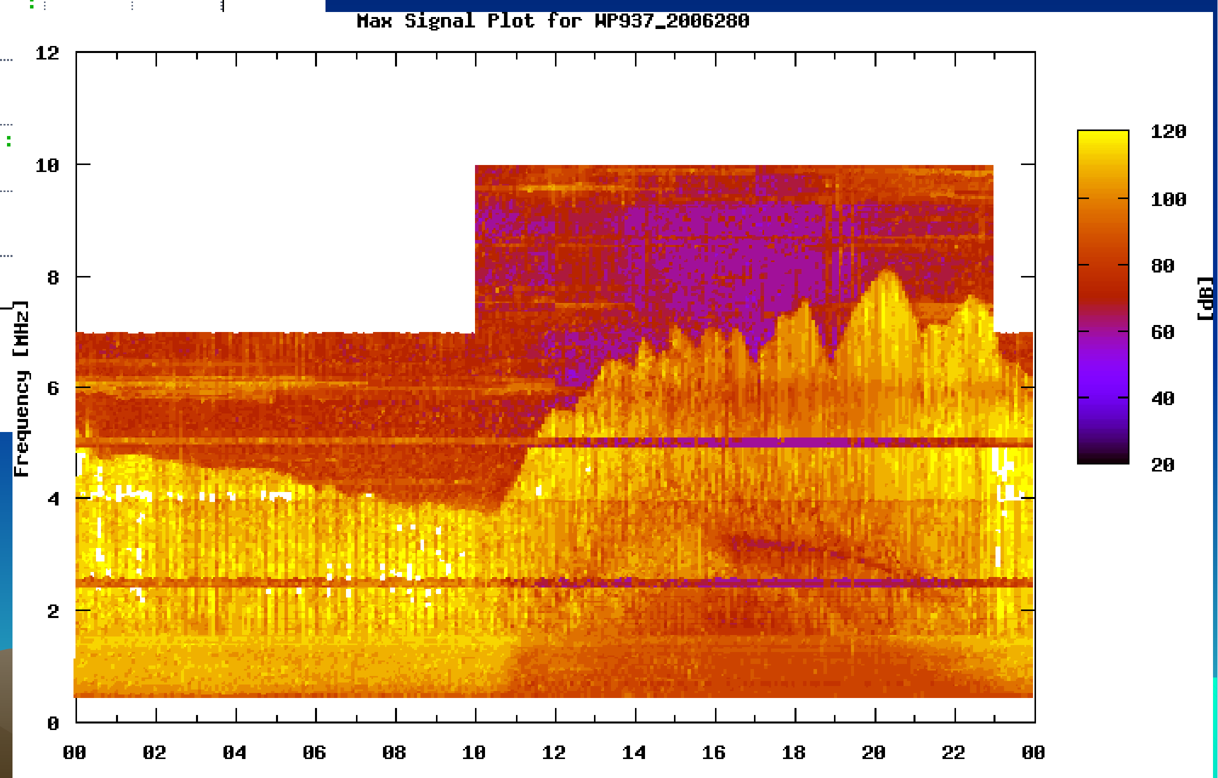


Courtesy IPS

Digisonde 256 Data



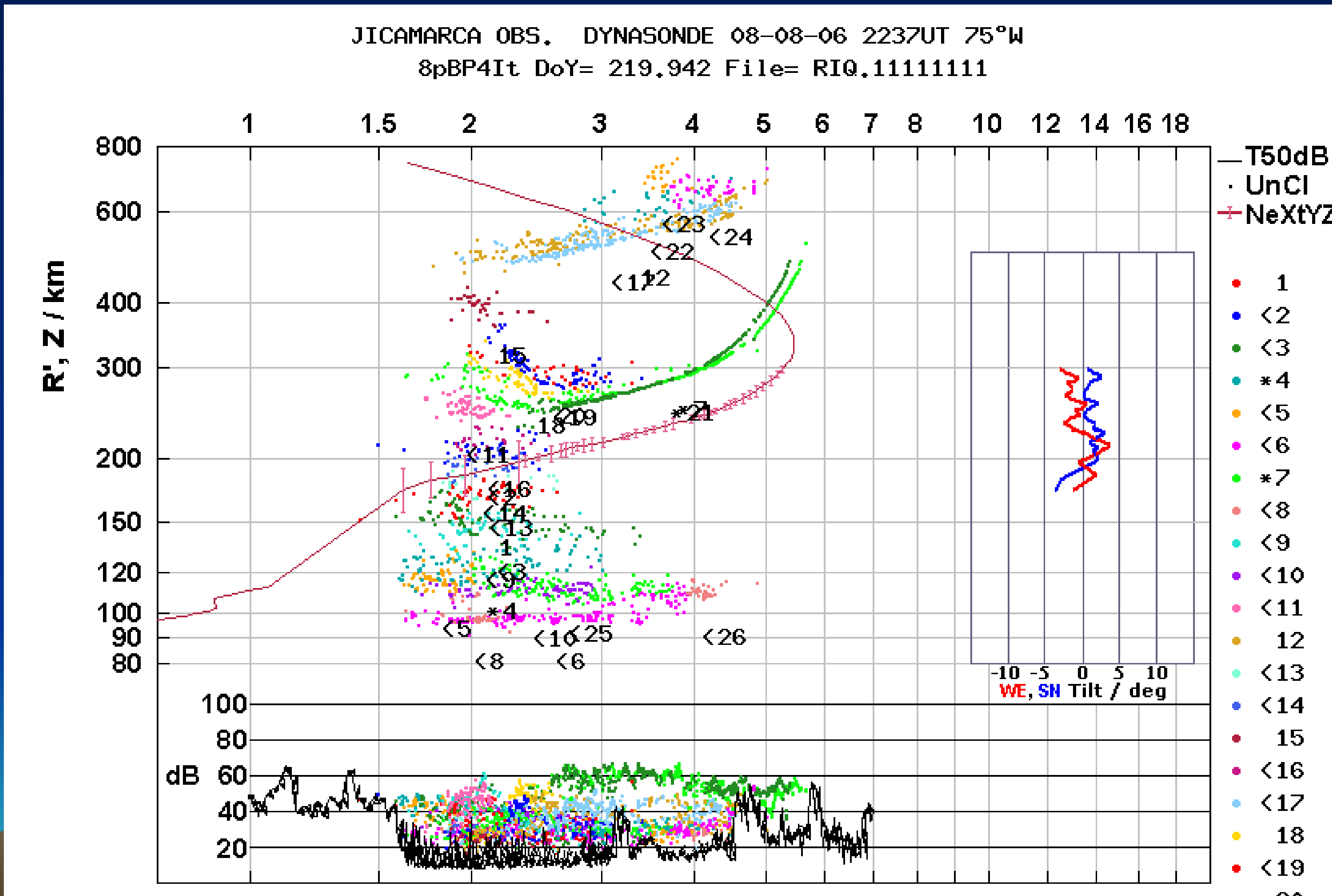
Ionogram data with polarization, Doppler and autoscaling



Daily plot of maximum received signal

Dynasonde21

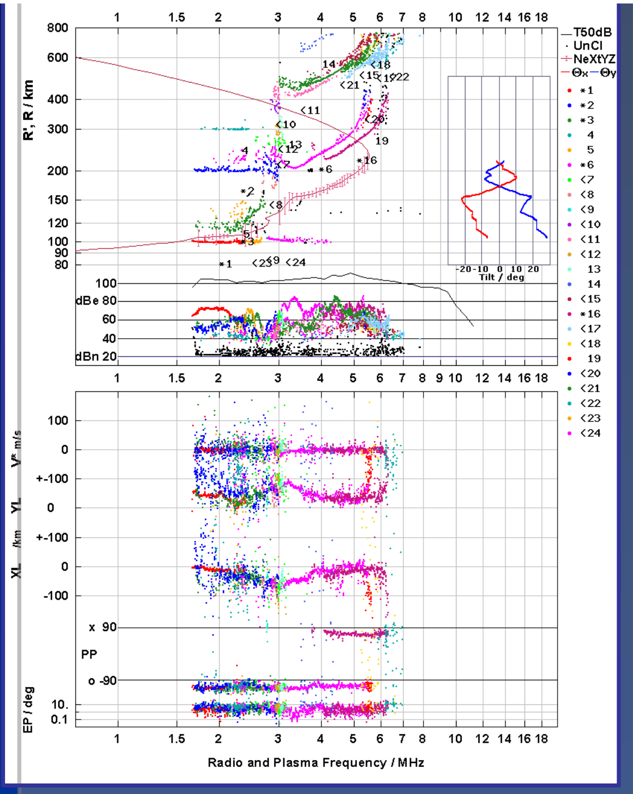
Jicamarca, Peru : VIPIR ionogram : Dynasonde21 Analysis



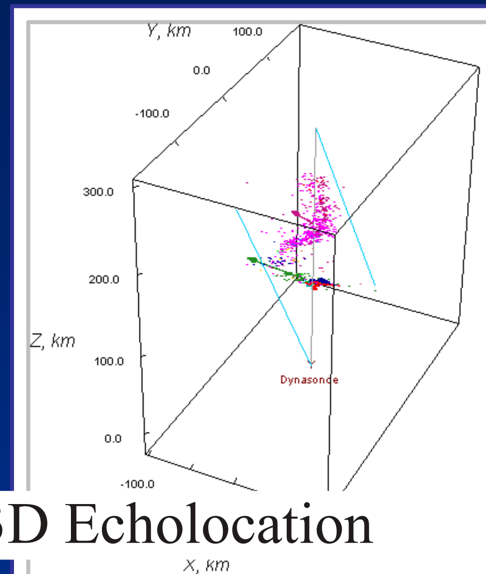
Courtesy JRO and DSL

Dynasonde21

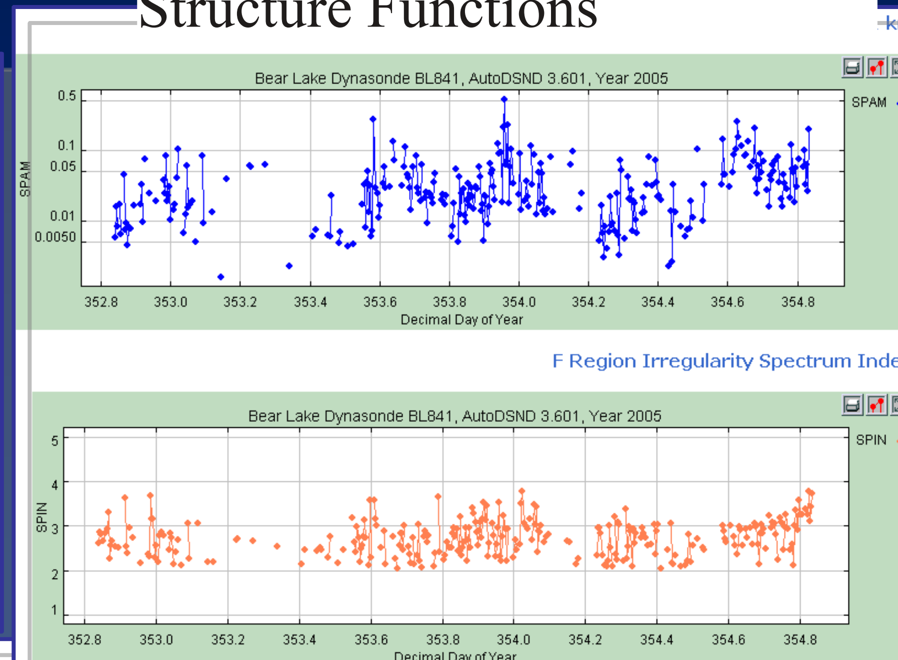
Dynasonde Ionogram Analysis



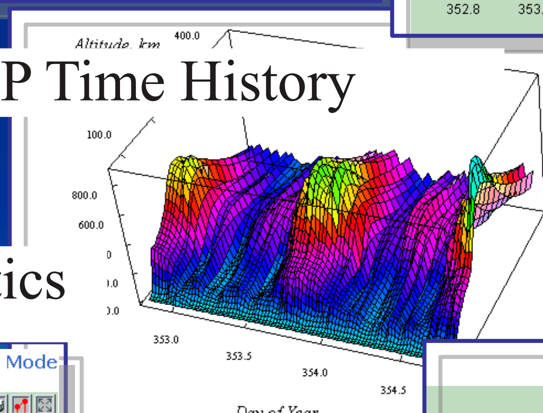
3D Echolocation



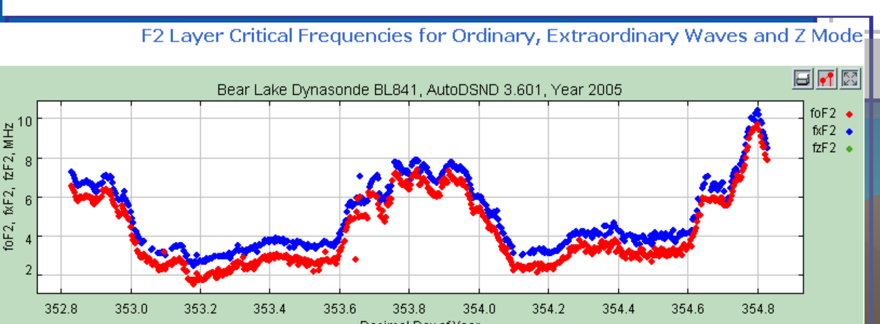
Structure Functions



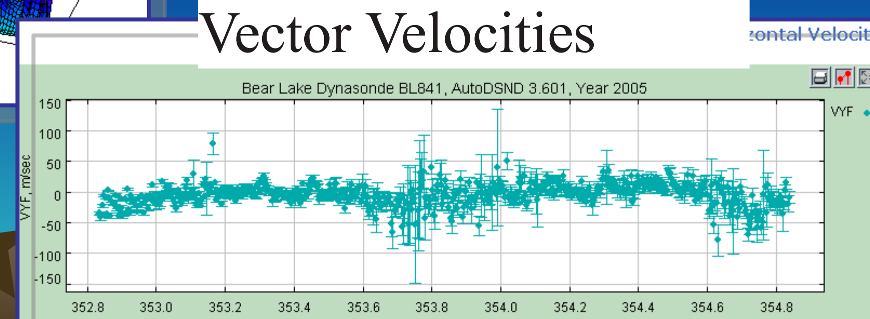
EDP Time History



Classical URSI scaled characteristics



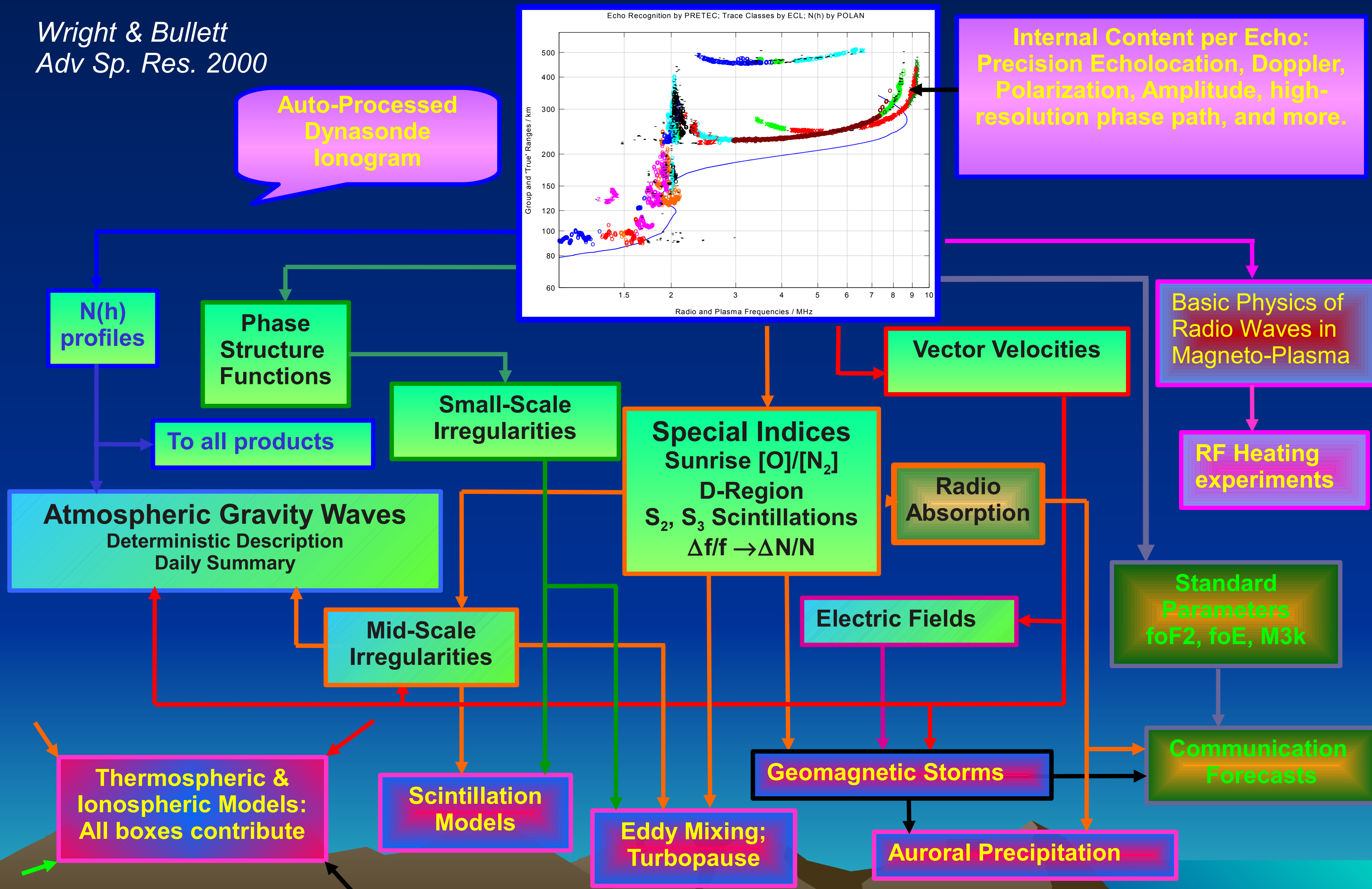
Vector Velocities



Dynasonde21 ©
Dynasonde Solutions Ltd
(Courtesy Wright & Zabotin)

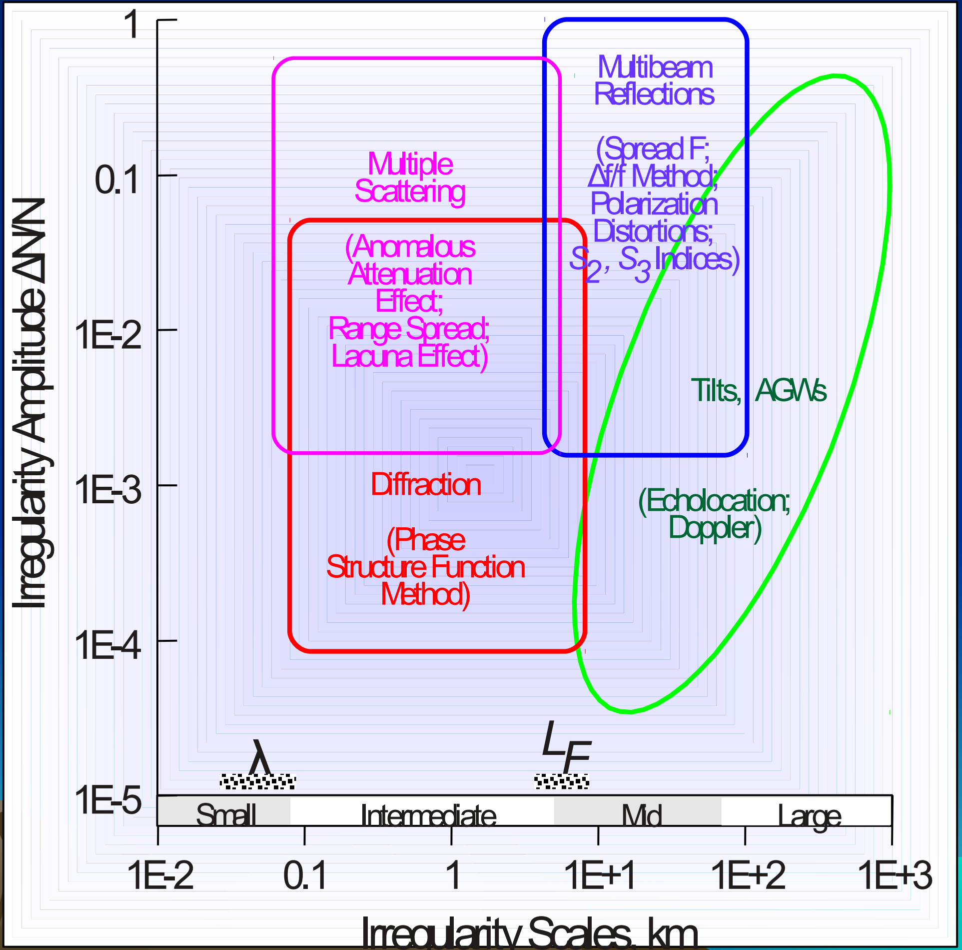
Applications of the Modern Ionosonde

Wright & Bullett
Adv Sp. Res. 2000



Plasma Physics with Ionosondes

- Careful examination of changes in transmitted radio wave properties:
  - Amplitude, Range, Frequency, Doppler, Direction, Phase
- Determine the plasma properties
  - Densities
  - Waves
  - Turbulence
  - Structure
  - Composition
  - Physical Processes
    - Natural
    - Artificial



Courtesy Wright & Zabotin

Modern Data Analysis

Data Analysis Techniques
for use on
Modern Ionosondes

"Making sense of an ocean of raw data"

Analysis Background

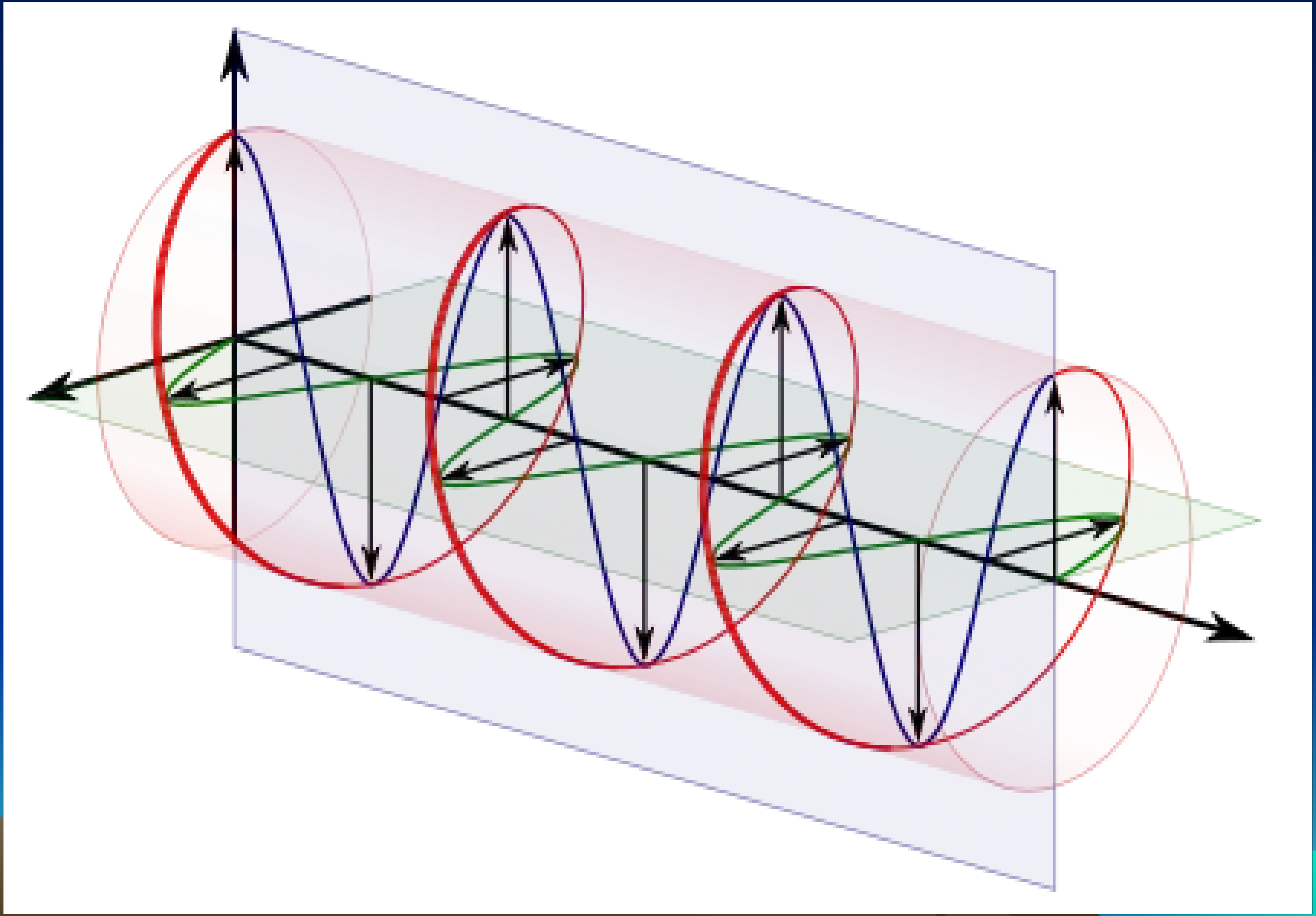
- High SNR values allow for several options
    - Build a small and/or cheap radar
    - Integrate / pulse compress to get your SNR back
    - Digisonde, CADI, AIS, etc
- Build a good radar and exploit the opportunities
    - Stable single-pulse statistics
    - Precision techniques
    - Rapid measurements
    - Scientific Discovery
    - Dynasonde, FAR, VIPIR

Polarization

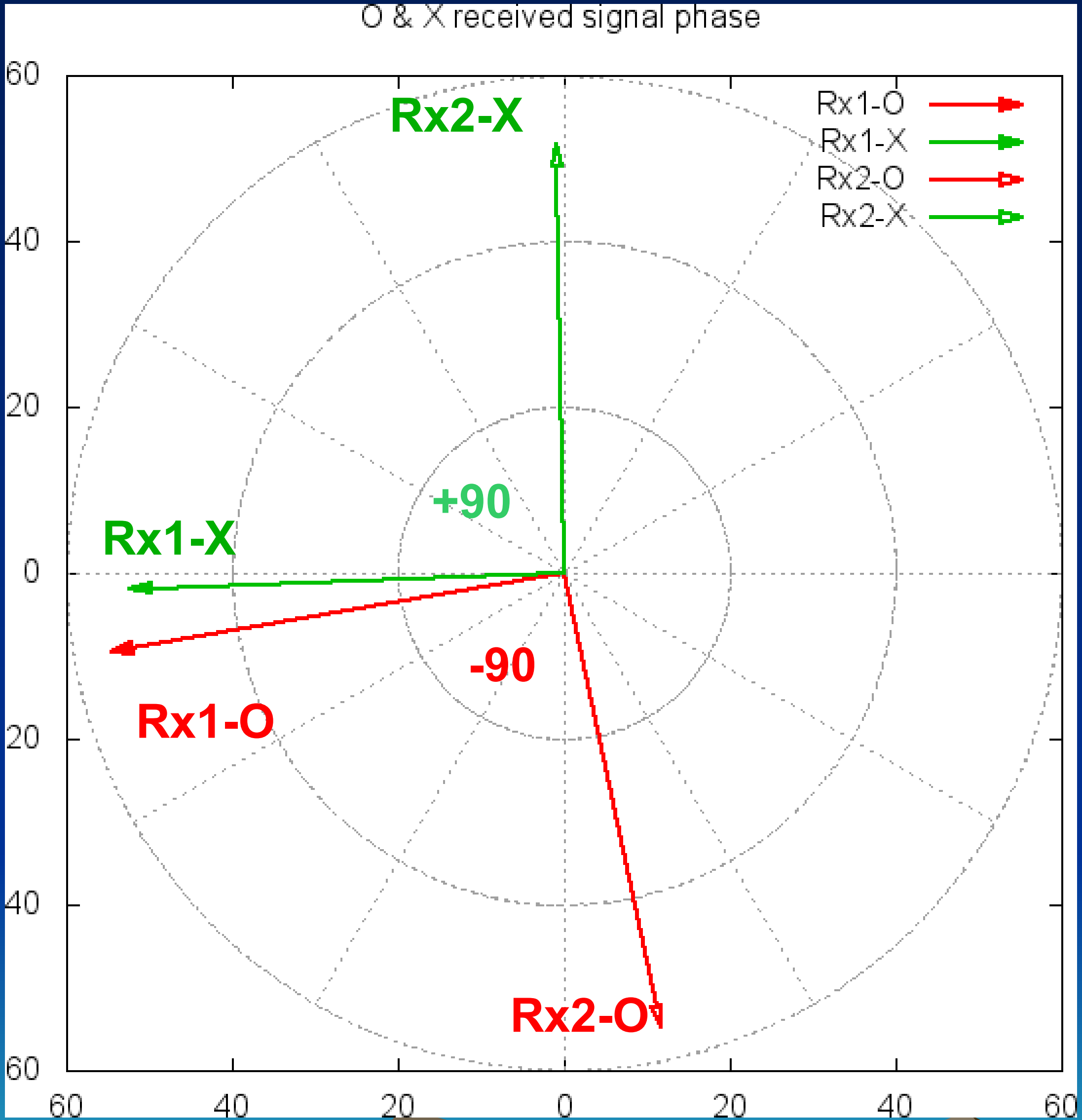
- Ordinary and eXtraordinary polarizations are circular and of opposite rotation
  - Except very near the magnetic equator, it is linear
- Two orthogonal, linearly polarized antennas can form a circularly polarized antenna
  - Digisondes do this in hardware at the antenna
  - VIPIR and Dynasonde do this in the analysis software

San Juan, Puerto Rico

Circular Polarization



Circular Polarization Example

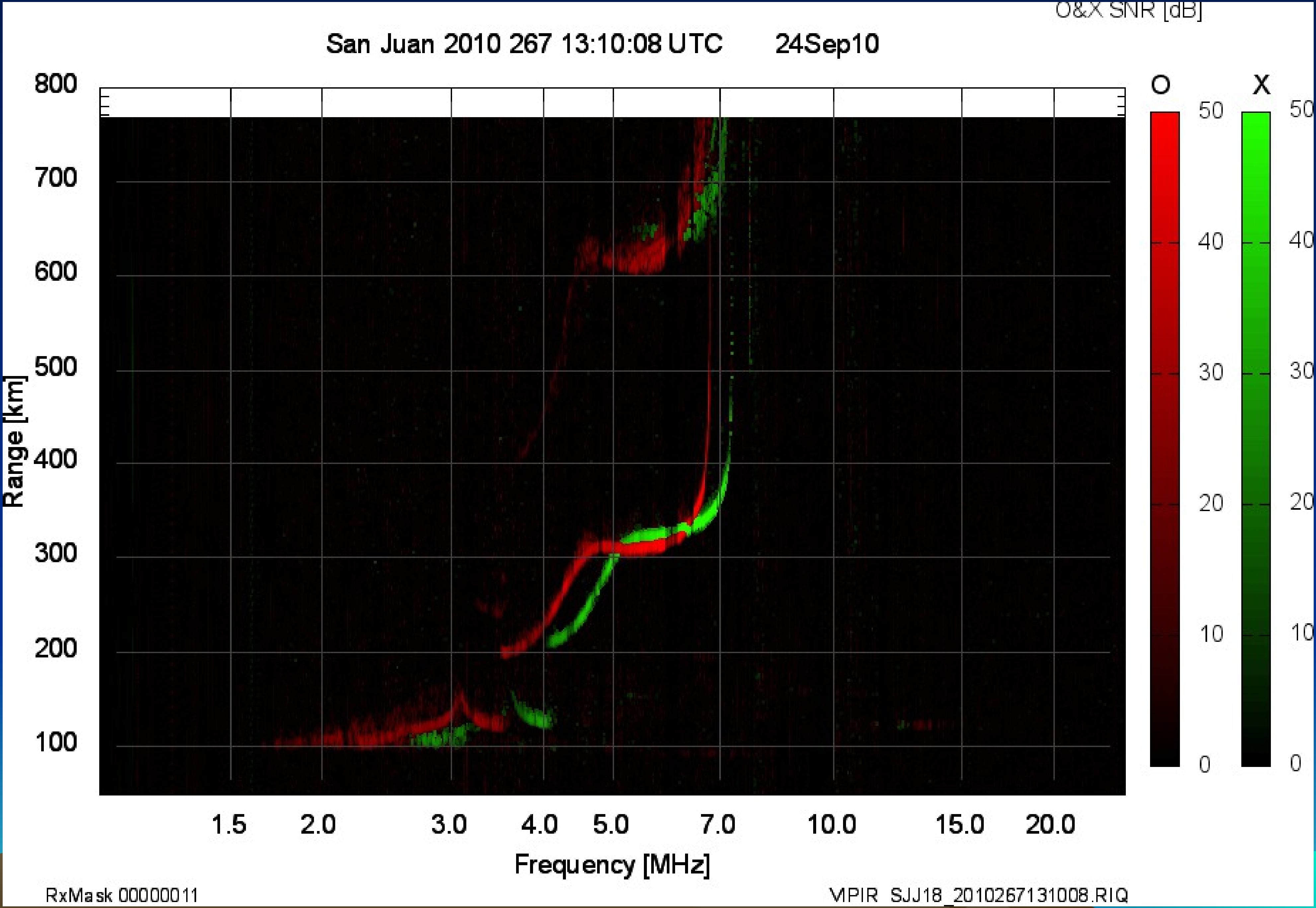


SJJ18_20100308180508.RIQ

- Two orthogonal antennas
- Separate receivers
- O and X mode signals
- Magnitude [dB]
- Phase [deg]
- -90 for O-mode
- +90 for X-mode
- Phase shift even receiver data +90 and – 90 and sum with odd receiver data

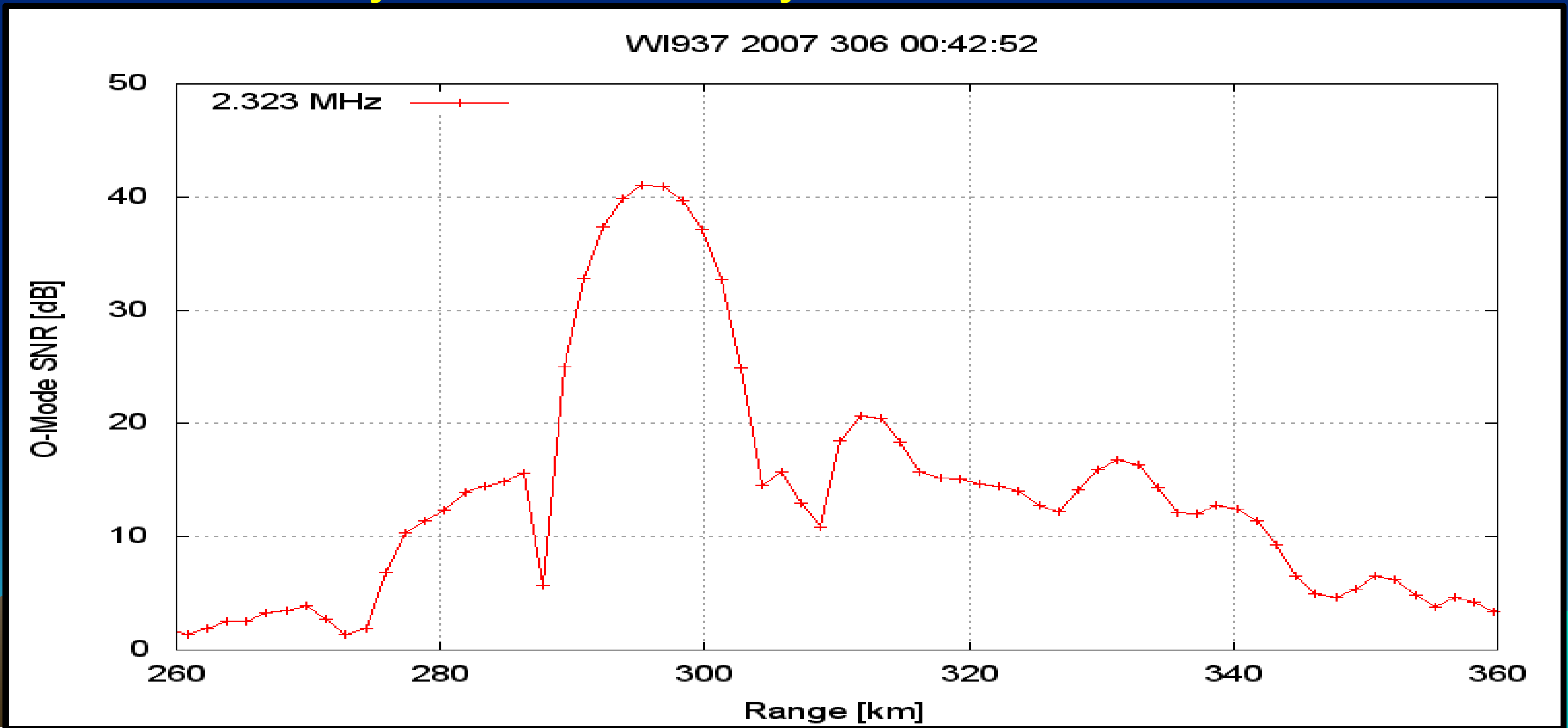
Equatorial O/X Polarizations are orthogonal linear!

Polarization Example



Precision vs Resolution

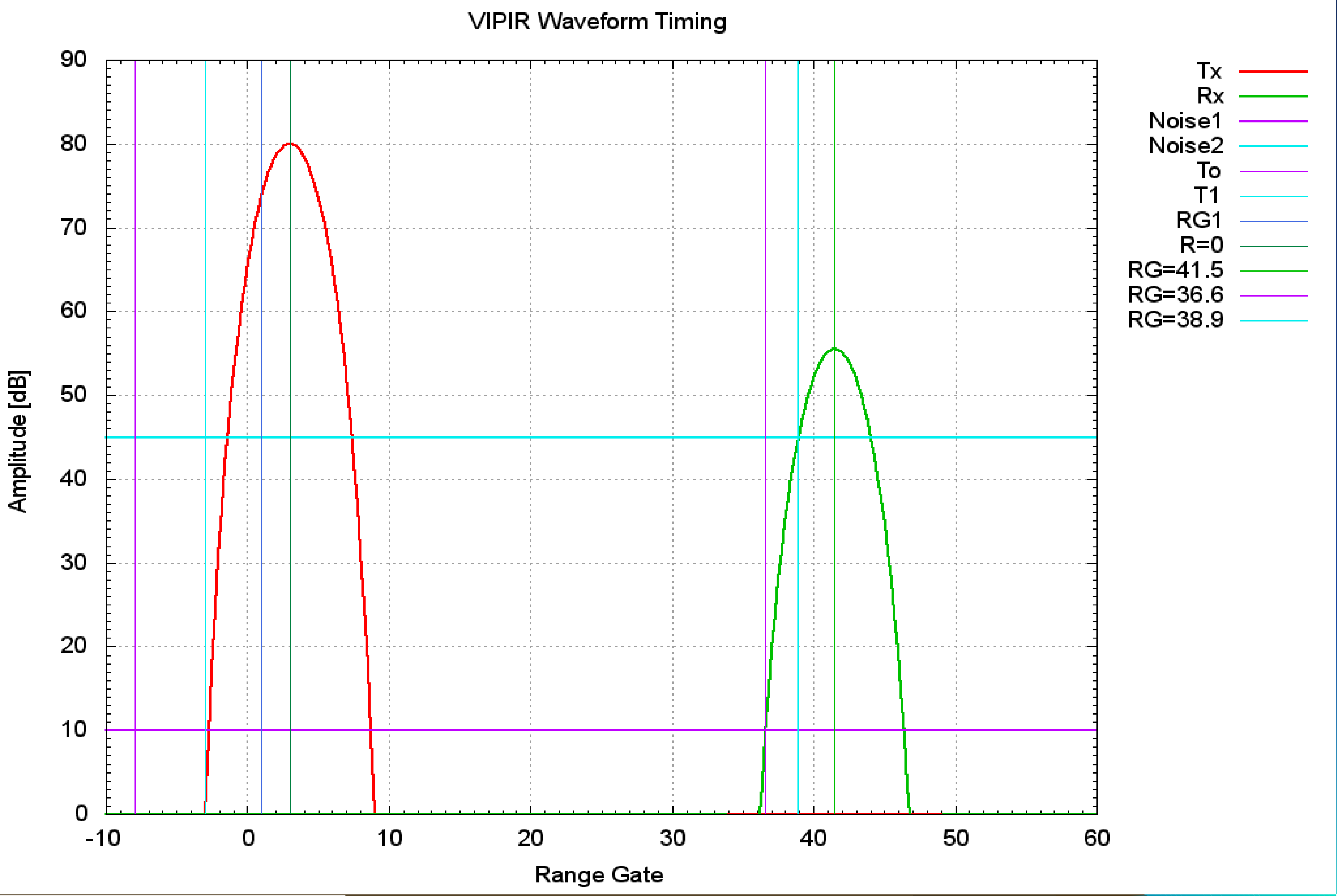
- Resolution is the ability to separate 2 objects
    - Closely spaced in some dimension (i.e. Range)
    - Determined by waveform (bandwidth)
- Precision is the ability to measure a resolved object
    - Mostly determined by SNR



Radar Timing

- T_0 is the start of a Pulse Repetition Interval
- Waveform is started some time after T_0
- Waveform has finite duration
- Receiver sampling is started some (other) time after T_0
- The PRECISE range of the received waveform is defined as the peak of the receiver impulse response
- The ACCURATE values of the range gates are determined by multi-hop Sporadic-E
- Therefore:
    - A calibration factor RANGE0 is provided as the "correct" range of the 0^{th} (non-existent) range gate
    - Some range gates can have negative range if they start before the peak of the transmitted waveform

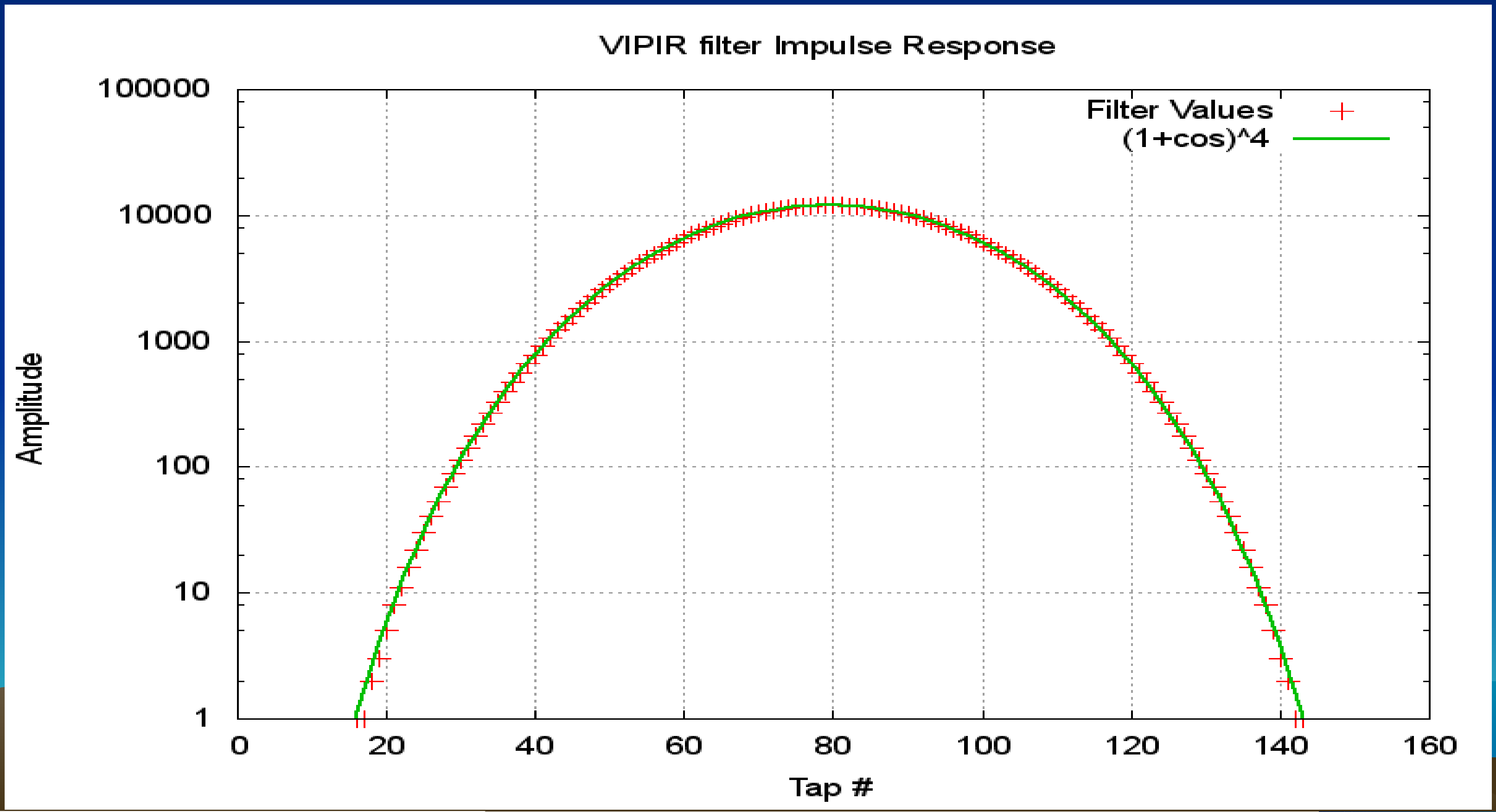
Waveform Timing



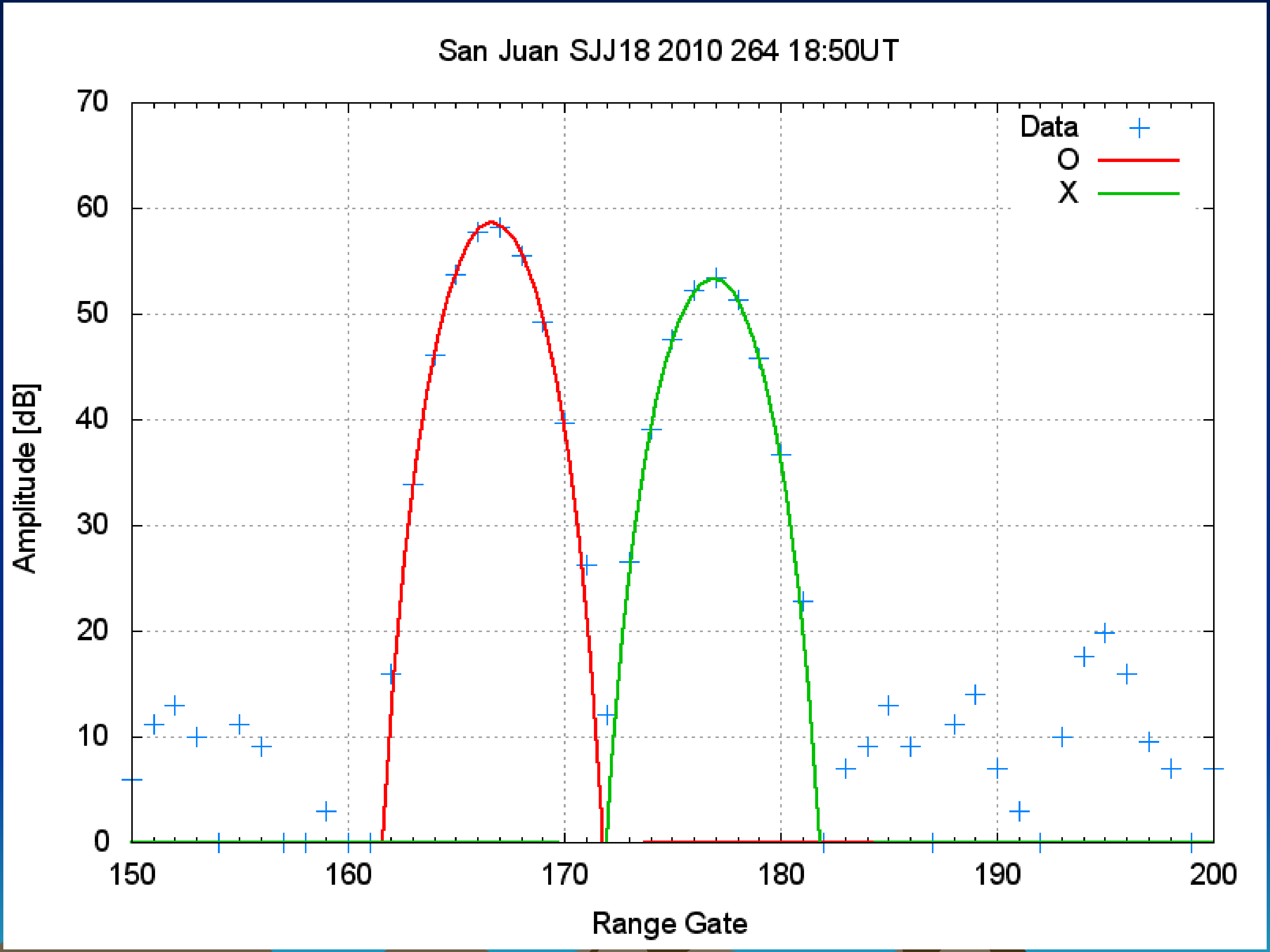
Precision Range

- Use the high SNR and precise receiver response
- Properly sampled receiver output
- Fit a raised cosine function to the amplitude data
    - Ao, Ro, W

$$A(x) = Ao\left[\frac{1}{2}\left(1+\cos\pi\frac{x-Ro}{W}\right)\right]^4$$



Impulse Response Fitting



Ao=58.6 ; Ro=166.7
Ax=53.3 ; Rx=176.9

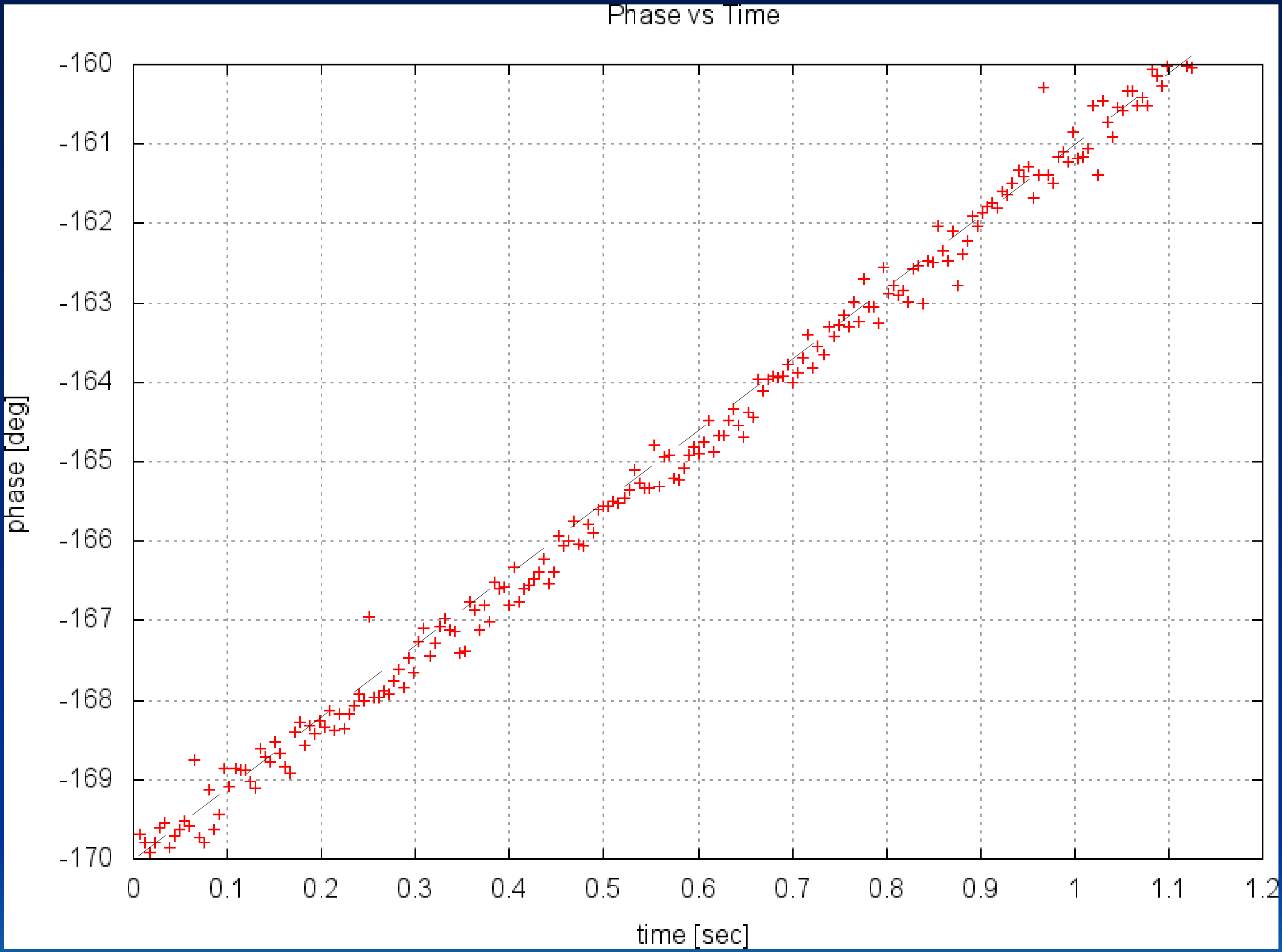
Precision is about 0.1 range gate (150m)
Depending on SNR and echo separation

Doppler Shift

- Doppler shift is a change in radio phase with time due to the change in phase path
- Details are beyond the scope of this presentation
- For ionosondes, this means a change in the ionosphere plasma
  - Motion
  - Photochemistry
  - Irregularities
  - Waves

Research Opportunity

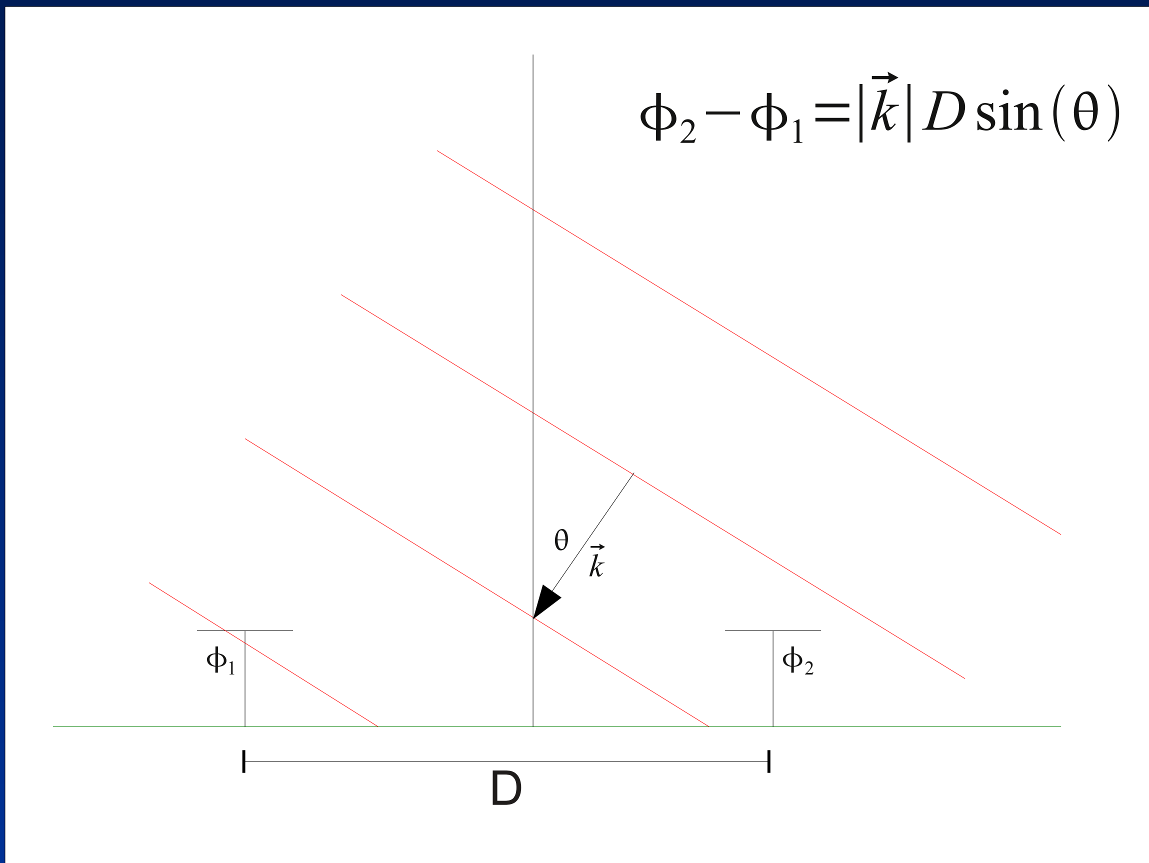
Doppler Example



- Doppler is the first moment of the phase vs time.
- Higher order moments due to ionosphere structure

Research Opportunity

Interferometry

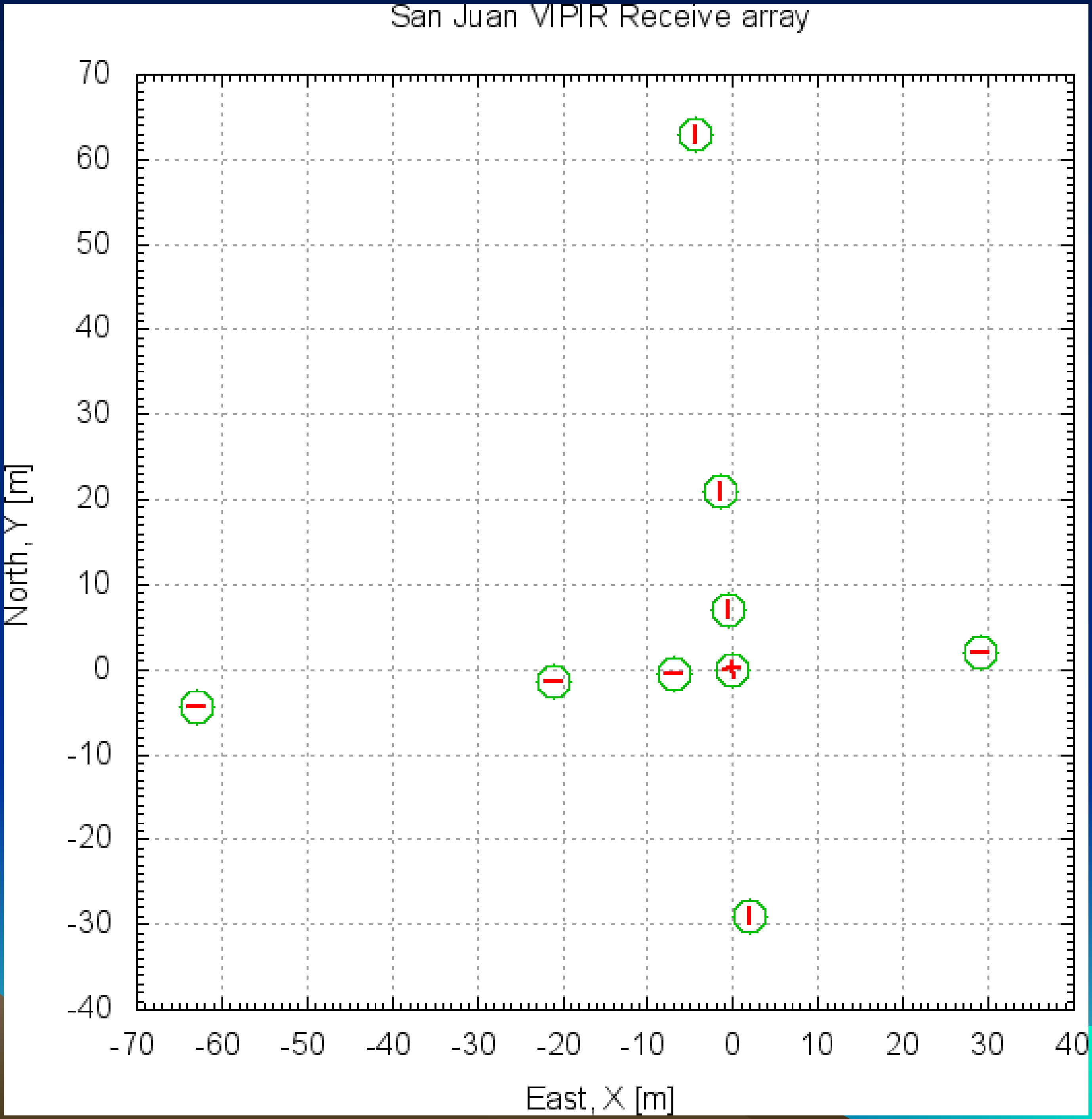


- The phase difference between spaced antennas related to the angle of arrival of a plane radio wave
- Issues:
  - 2π ambiguity
  - Non-plane wave
  - Mutual Coupling
- Multiple antennas and spacings aid to resolve this problem
- Room for Improvement

Research Opportunity

Receive Array: San Juan

Antennas at locations:
-9 -3 -1 0 +4
Gives separations of
1 2 3 4 5 6 7 8 9 13
Units of 7m

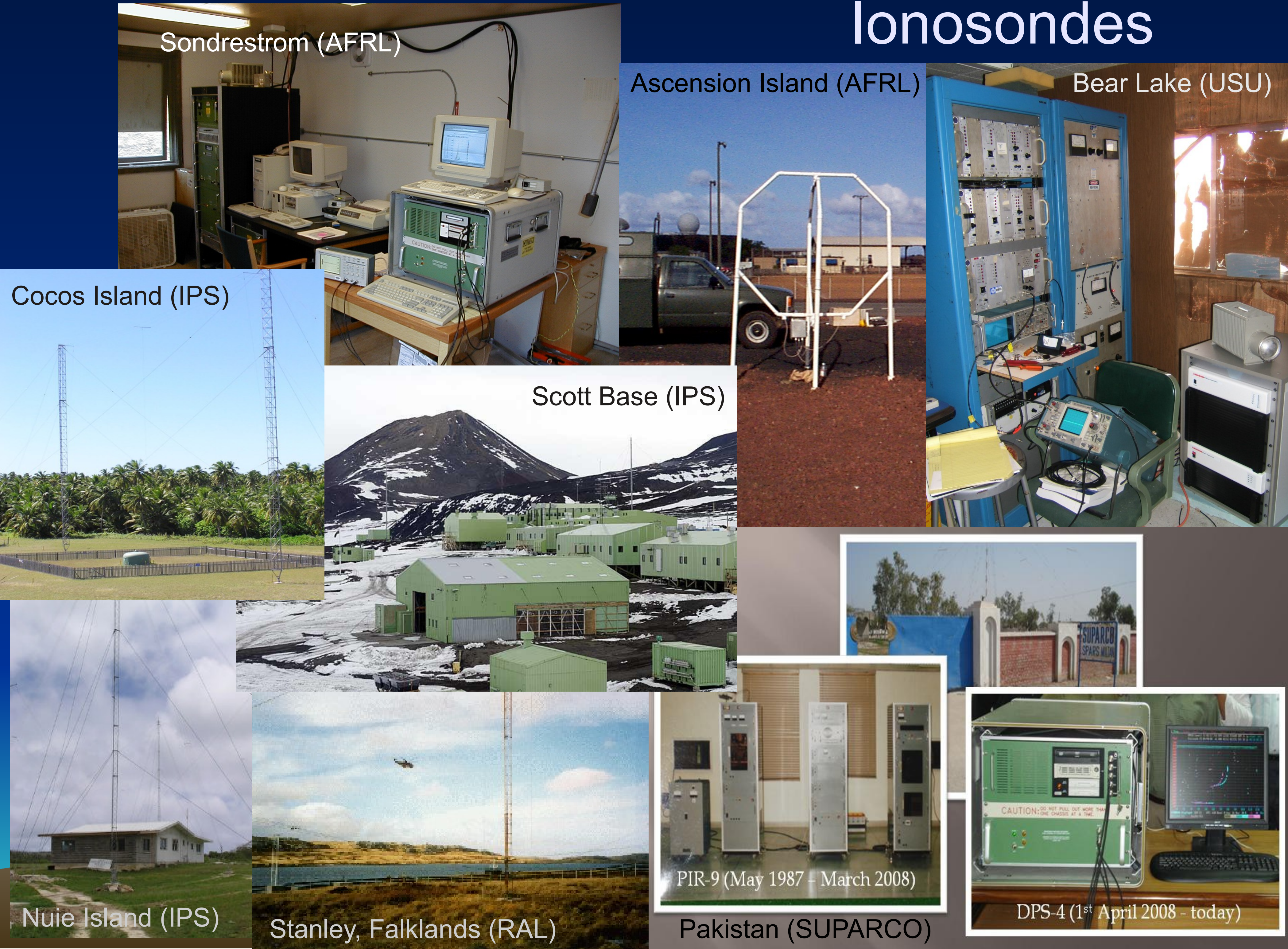


Can use any 8 antennas simultaneously

End of Section 1

Questions?

Ionosondes

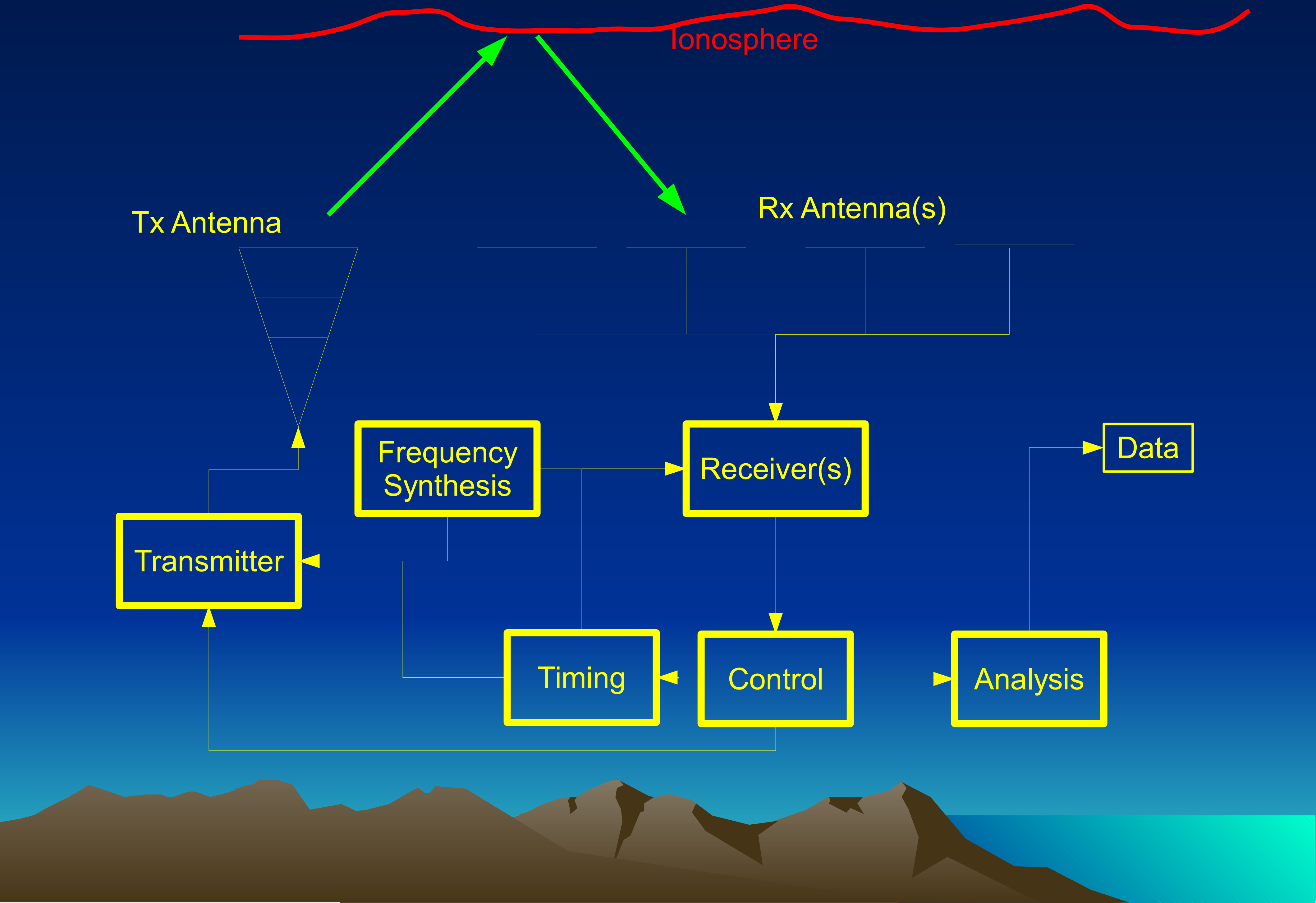


Sondrestrom (AFRL)
Ascension Island (AFRL)
Bear Lake (USU)
Cocos Island (IPS)
Scott Base (IPS)
SUPARCO
PIR-9 (May 1987 – March 2008)
CAUTION:
DPS-4 (1st April 2008 - today)
Nuie Island (IPS)
Stanley, Falklands (RAL)
Pakistan (SUPARCO)

Ionosonde History

- The first radar, invented in 1926
- Used to measure the height of the ionosphere
- Bi-static "chirp" and mono-static "pulse" varieties
- Longest ionosphere climate record
- ~ 100 Vertical Incidence ionosondes worldwide
- New technologies have evolved the ionosonde:
    - High power electronics
    - Data display and recording
    - Antennas
    - Computers
    - Digital Signal Processing

Ionosonde Components



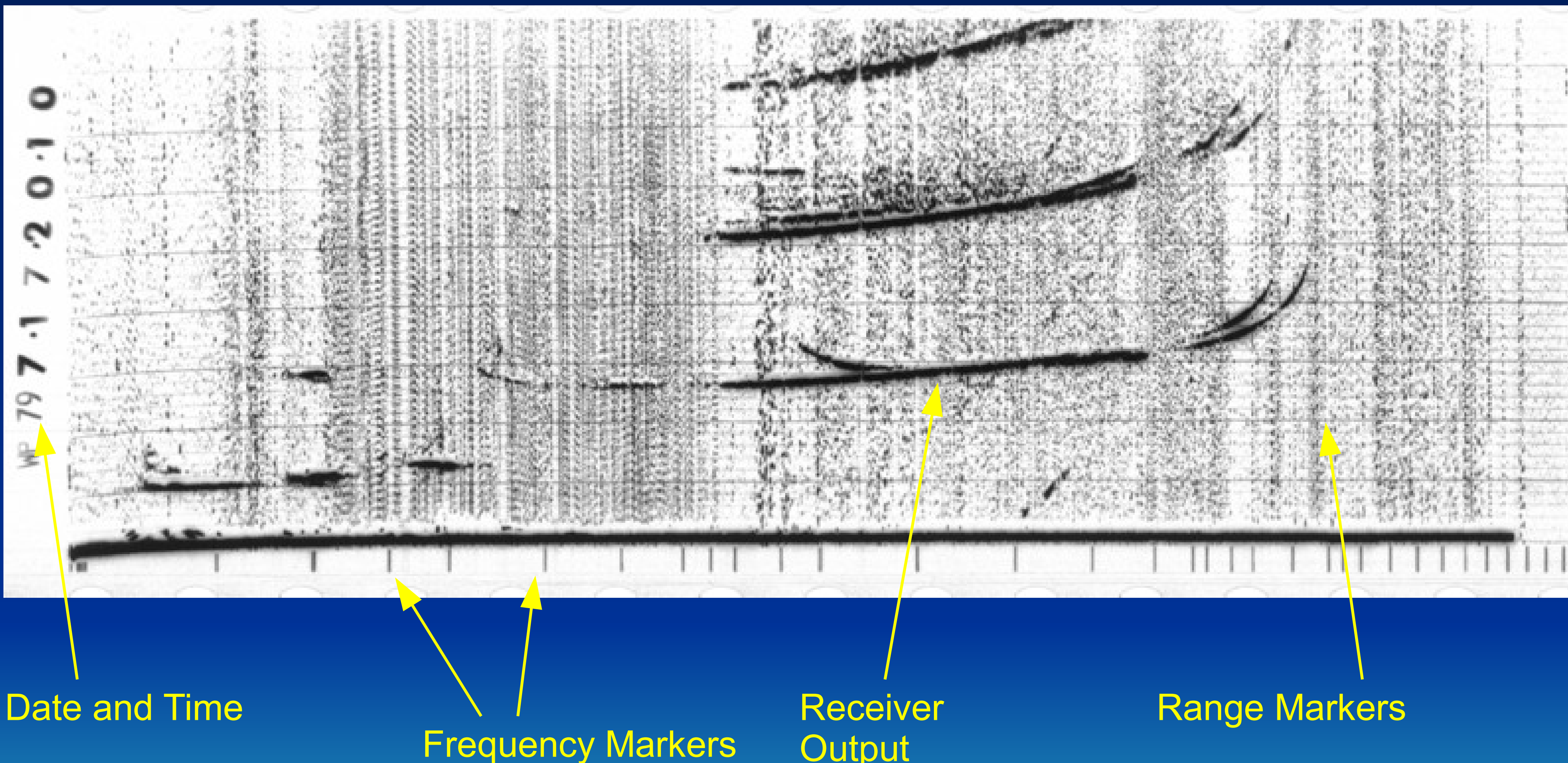
Historical Ionosondes

C3 – Circa 1955

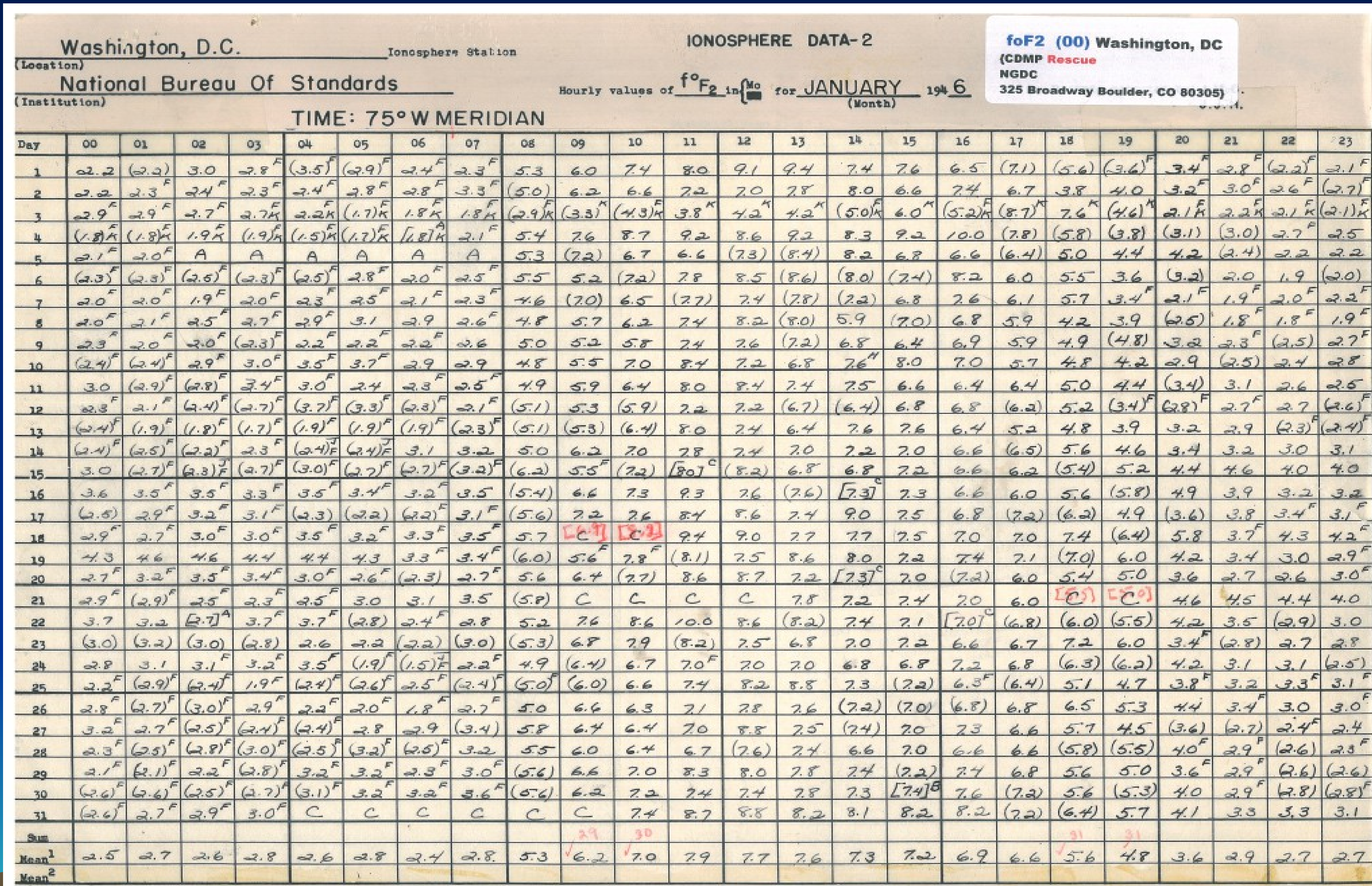
IPS42 – Circa 1975

Courtesy Manila Ionosphere Observatory

Analog Ionogram on Film



Manual Scaling Sheets



Washington, D.C. Ionosphere Station
(Location)
National Bureau Of Standards
(Institution)

IONOSPHERE DATA-2

Hourly values of f^oF_2 in Mc for JANUARY (Month) 1946

TIME: 75° W MERIDIAN

foF2 (00) Washington, DC
(CDMP Rescue
NGDC
325 Broadway Boulder, CO 80305)

Day	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	2.2	(2.2)	3.0	2.8F	(3.5)F	(2.9)F	2.4F	2.3F	5.3	6.0	7.4	8.0	9.1	9.4	7.4	7.6	6.5	(7.1)	(5.6)	(3.6)F	3.4F	2.8F	(2.2)F	2.1F
2	2.2	2.3F	2.4F	2.3F	2.4F	2.8F	2.8F	3.3F	(5.0)	6.2	6.6	7.2	7.0	7.8	8.0	6.6	7.4	6.7	3.8	4.0	3.2F	3.0F	2.6F	(2.7)F
3	2.9F	2.9F	2.7F	2.7FK	2.2FK	(1.7)FK	1.8FK	1.8FK	(2.9)FK	(3.3)K	(4.3)FK	3.8K	4.2K	4.2K	(5.0)FK	6.0K	(5.2)FK	(8.7)K	7.6K	(4.6)K	2.1FK	2.2FK	2.1FK	(2.1)FK
4	(1.8)FK	(1.8)FK	1.9FK	(1.9)FK	(1.5)FK	(1.7)FK	[1.8]AK	2.1F	5.4	7.6	8.7	9.2	8.6	9.2	8.3	9.2	10.0	(7.8)	(5.8)	(3.8)	(3.1)	(3.0)	2.7F	2.5
5	2.1F	2.0F	A	A	A	A	A	A	5.3	(7.2)	6.7	6.6	(7.3)	(8.4)	8.2	6.8	6.6	(6.4)	5.0	4.4	4.2	(2.4)	2.2	2.2
6	(2.3)F	(2.3)F	(2.6)F	(2.3)F	(2.5)F	2.8F	2.0F	2.5F	5.5	5.2	(7.2)	7.8	8.5	(8.6)	(8.0)	(7.4)	8.2	6.0	5.5	3.6	(3.2)	2.0	1.9	(2.0)
7	2.0F	2.0F	1.9F	2.0F	2.3F	2.5F	2.1F	2.3F	4.6	(7.0)	6.5	(7.7)	7.4	(7.8)	(7.2)	6.8	7.6	6.1	5.7	3.4F	2.1F	1.9F	2.0F	2.2F
8	2.0F	2.1F	2.5F	2.7F	2.9F	3.1	2.9	2.6F	4.8	5.7	6.2	7.4	8.2	(8.0)	5.9	(7.0)	6.8	5.9	4.2	3.9	(2.5)	1.8F	1.8F	1.9F
9	2.3F	2.0F	2.0F	(2.3)F	2.2F	2.2F	2.2F	2.6	5.0	5.2	5.8	7.4	7.6	(7.2)	6.8	6.4	6.9	5.9	4.9	(4.8)	3.2	2.3F	(2.5)	2.7F
10	(2.4)F	(2.4)F	2.9F	3.0F	3.5F	3.7F	2.9	2.9	4.8	5.5	7.0	8.4	7.2	6.8	7.6H	8.0	7.0	5.7	4.8	4.2	2.9	(2.5)	2.4	2.8
11	3.0	(2.9)F	(2.8)F	3.4F	3.0F	2.4	2.3F	2.5F	4.9	5.9	6.4	8.0	8.4	7.4	7.5	6.6	6.4	6.4	5.0	4.4	(3.4)	3.1	2.6	2.5
12	2.3F	2.1F	(2.4)F	(2.7)F	(3.7)F	(3.3)F	(2.3)F	2.1F	(5.1)	5.3	(5.9)	7.2	7.2	(6.7)	(6.4)	6.8	6.8	(6.2)	5.2	(3.4)F	(2.8)F	2.7F	2.7	(2.6)F
13	(2.4)F	(1.9)F	(1.8)F	(1.7)F	(1.9)F	(1.9)F	(1.9)F	(2.3)F	(5.1)	(5.3)	(6.4)	8.0	7.4	6.4	7.6	7.6	6.4	5.2	4.8	3.9	3.2	2.9	(2.3)F	(2.4)F
14	(2.4)F	(2.5)F	(2.2)F	2.3F	(2.4)JF	(2.4)JF	3.1	3.2	5.0	6.2	7.0	7.8	7.4	7.0	7.2	7.0	6.6	(6.5)	5.6	4.6	3.4	3.2	3.0	3.1
15	3.0	(2.7)F	(2.3)JF	(2.7)F	(3.0)F	(2.7)F	(2.7)F	(3.2)F	(6.2)	5.5F	(7.2)	[8.0]C	(8.2)	6.8	6.8	7.2	6.6	6.2	(5.4)	5.2	4.4	4.6	4.0	4.0
16	3.6	3.5F	3.5F	3.3F	3.5F	3.4F	3.2F	3.5	(5.4)	6.6	7.3	9.3	7.6	(7.6)	[7.3]C	7.3	6.6	6.0	5.6	(5.8)	4.9	3.9	3.2	3.2
17	(2.6)	2.9F	3.2F	3.1F	(2.3)	(2.2)	(2.2)F	3.1F	(5.6)	7.2	7.6	8.4	8.6	7.4	9.0	7.5	6.8	(7.2)	(6.2)	4.9	(3.6)	3.8	3.4F	3.1F
18	2.9F	2.7F	3.0F	3.0F	3.5F	3.2F	3.3F	3.5F	5.7	[6.7] C	[8.3] C	9.4	9.0	7.7	7.7	7.5	7.0	7.0	7.4	(6.4)	5.8	3.7F	4.3	4.2F
19	4.3	4.6	4.6	4.4	4.4	4.3	3.3F	3.4F	(6.0)	5.6F	7.8F	(8.1)	7.5	8.6	8.0	7.2	7.4	7.1	(7.0)	6.0	4.2	3.4	3.0	2.9F
20	2.7F	3.2F	3.5F	3.4F	3.0F	2.6F	(2.3)	2.7F	5.6	6.4	(7.7)	8.6	8.7	7.2	[7.3]C	7.0	(7.2)	6.0	5.4	5.0	3.6	2.7	2.6	3.0F
21	2.9F	(2.9)F	2.5F	2.3F	2.5F	3.0	3.1	3.5	(5.8)	C	C	C	C	7.8	7.2	7.4	7.0	6.0	[6.5] C	[5.0] C	4.6	4.5	4.4	4.0
22	3.7	3.2	[2.7]A	3.7F	3.7F	(2.8)	2.4F	2.8	5.2	7.6	8.6	10.0	8.6	(8.2)	7.4	7.1	[7.0]C	(6.8)	(6.0)	(5.5)	4.2	3.5	(2.9)	3.0
23	(3.0)	(3.2)	(3.0)	(2.8)	2.6	2.2	(2.2)	(3.0)	(5.3)	6.8	7.9	(8.2)	7.5	6.8	7.0	7.2	6.6	6.7	7.2	6.0	3.4F	(2.8)	2.7	2.8
24	2.8	3.1	3.1F	3.2F	3.5F	(1.9)F	(1.5)JF	2.2F	4.9	(6.4)	6.7	7.0F	7.0	7.0	6.8	6.8	7.2	6.8	(6.3)	(6.2)	4.2	3.1	3.1	(2.5)
25	2.2F	(2.9)F	(2.4)F	1.9F	(2.4)F	(2.6)F	2.5F	(2.4)F	(5.0)F	(6.0)	6.6	7.4	8.2	8.8	7.3	(7.2)	6.3F	(6.4)	5.1	4.7	3.8F	3.2	3.3F	3.1F
26	2.8F	(2.7)F	(3.0)F	2.9F	2.2F	2.0F	1.8F	2.7F	5.0	6.6	6.3	7.1	7.8	7.6	(7.2)	(7.0)	(6.8)	6.8	6.5	5.3	4.4	3.4F	3.0	3.0F
27	3.2F	2.7F	(2.5)F	(2.4)F	(2.4)F	2.8	2.9	(3.4)	5.8	6.4	6.4	7.0	8.8	7.5	(7.4)	7.0	7.3	6.6	5.7	4.5	(3.6)	(2.7)	2.4F	2.4
28	2.3F	(2.5)F	(2.8)F	(3.0)F	(2.5)F	(3.2)F	(2.5)F	3.2	5.5	6.0	6.4	6.7	(7.6)	7.4	6.6	7.0	6.6	6.6	(5.8)	(5.5)	4.0F	2.9F	(2.6)	2.3F
29	2.1F	(2.1)F	2.2F	(2.8)F	3.2F	3.2F	2.3F	3.0F	(5.6)	6.6	7.0	8.3	8.0	7.8	7.4	(7.2)	7.4	6.8	5.6	5.0	3.6F	2.9F	(2.6)	(2.6)
30	(2.6)F	(2.6)F	(2.5)F	(2.7)F	(3.1)F	3.2F	3.2F	3.6F	(5.6)	6.2	7.2	7.4	7.4	7.8	7.3	[7.4]B	7.6	(7.2)	5.6	(5.3)	4.0	2.9F	(2.8)	(2.8)F
31	(2.6)F	2.7F	2.9F	3.0F	C	C	C	C	C	C	7.4	8.7	8.8	8.2	8.1	8.2	8.2	(7.2)	(6.4)	5.7	4.1	3.3	3.3	3.1
Sum										29	30								31	31				
Mean[1]	2.5	2.7	2.6	2.8	2.6	2.8	2.4	2.8	5.3	6.2	7.0	7.9	7.7	7.6	7.3	7.2	6.9	6.6	5.6	4.8	3.6	2.9	2.7	2.7
Mean[2]																								

A month (Jan 1946) of foF2 data from Washington DC

Recent Ionosondes

Dynasonde – Circa 1990

Digisonde – Circa 1990

NOAA Dynasonde Data

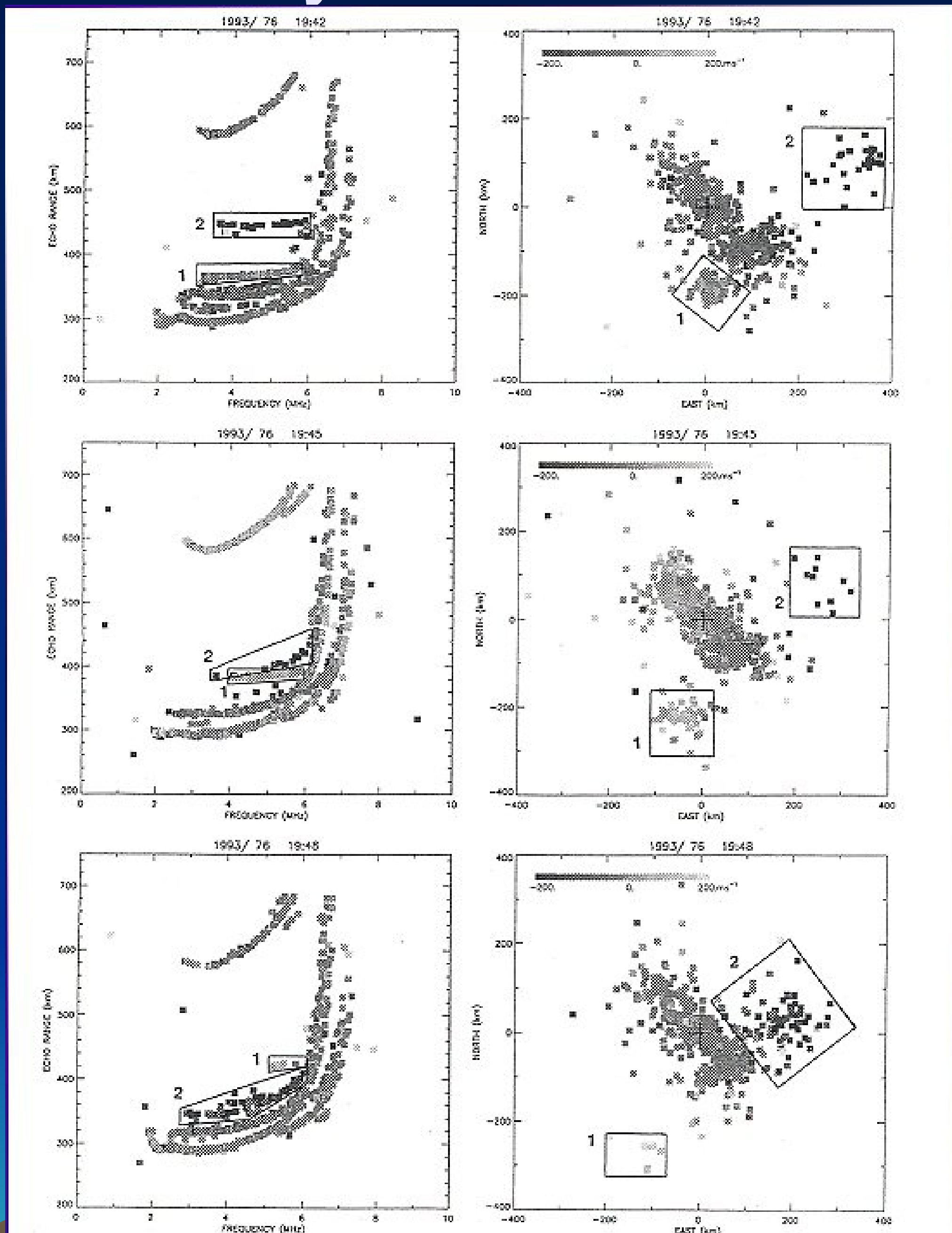
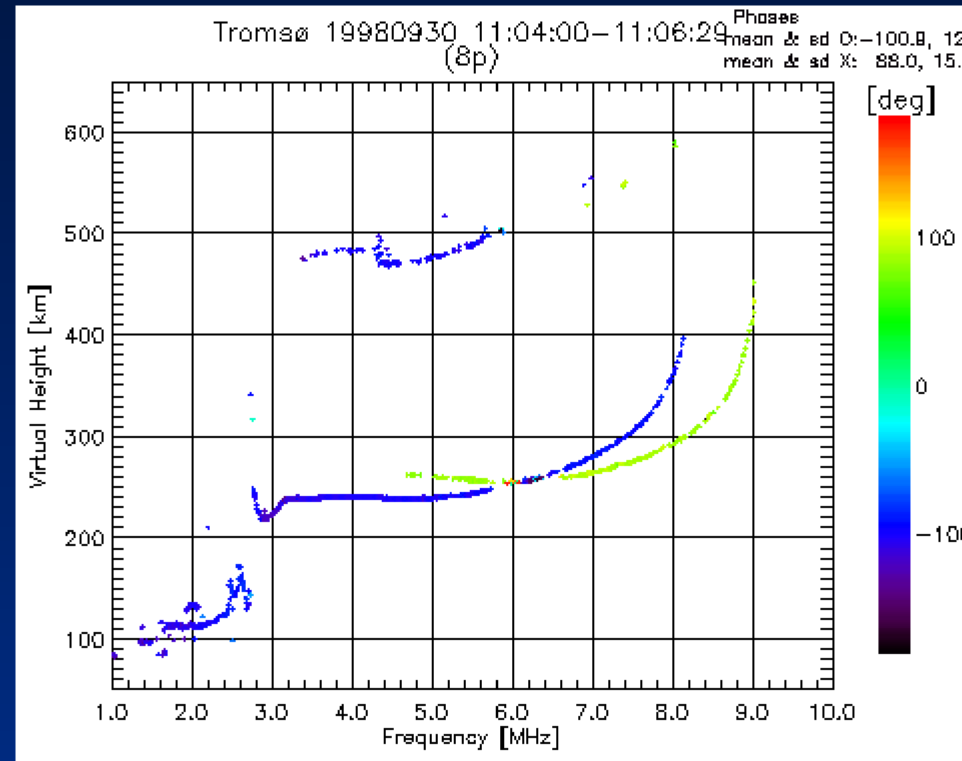
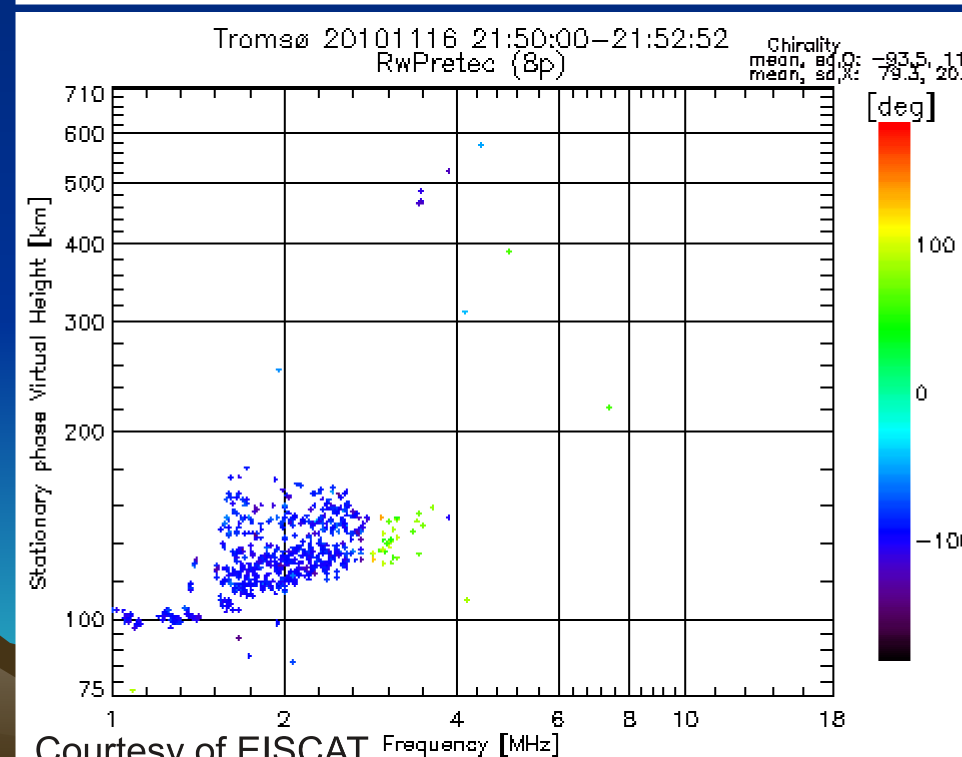


Fig 1: Ionograms (left) and sky-map echo-location plots (right) for a sequence of three soundings from Halley on 17 March (day 76) 1993. Two ionogram traces and their corresponding echo-location positions have been highlighted (1 & 2). Grey-scale shading indicates line-of-sight Doppler velocity.

Courtesy of British Antarctic Survey

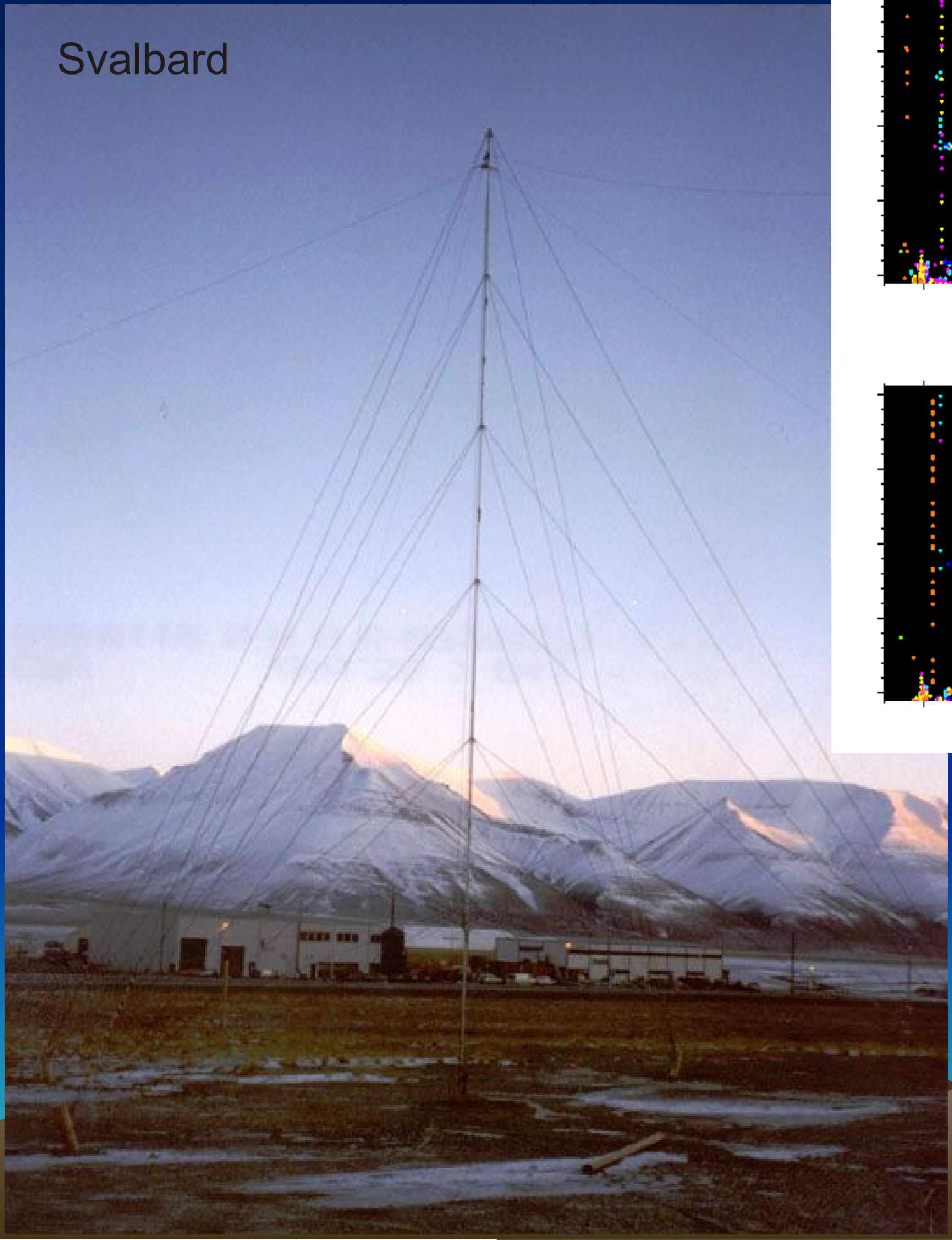




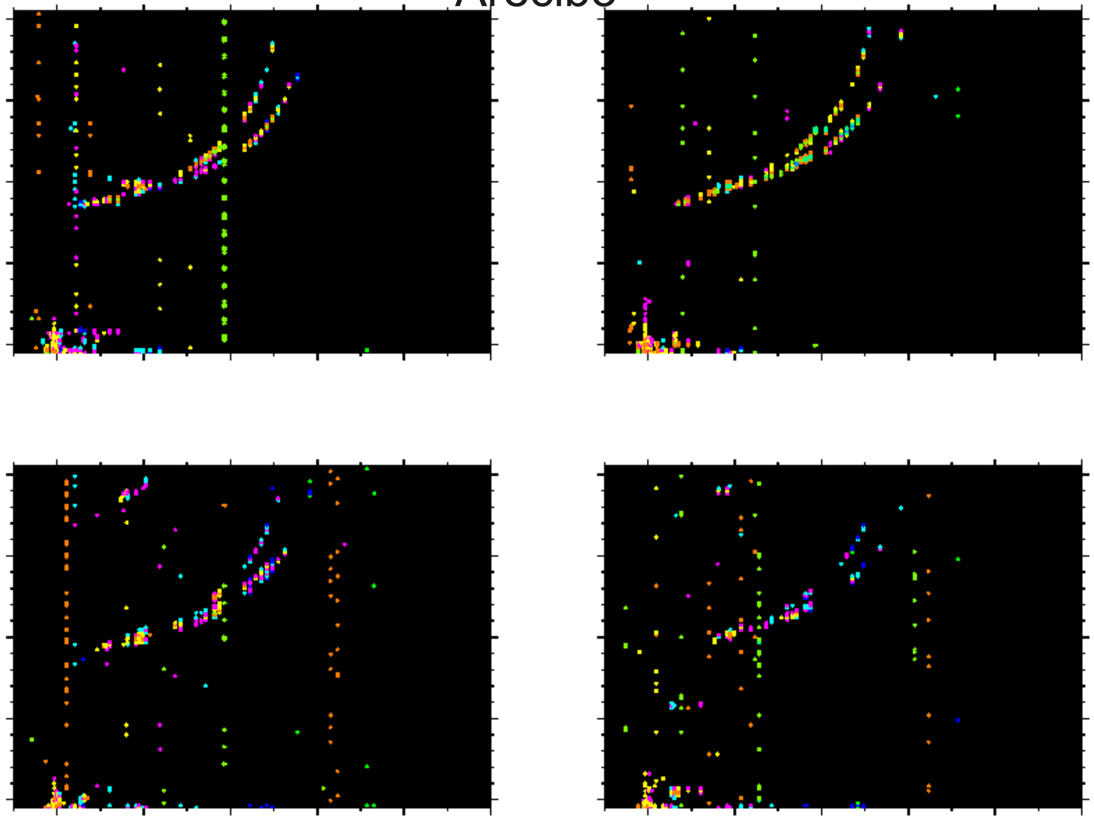
Courtesy of EISCAT

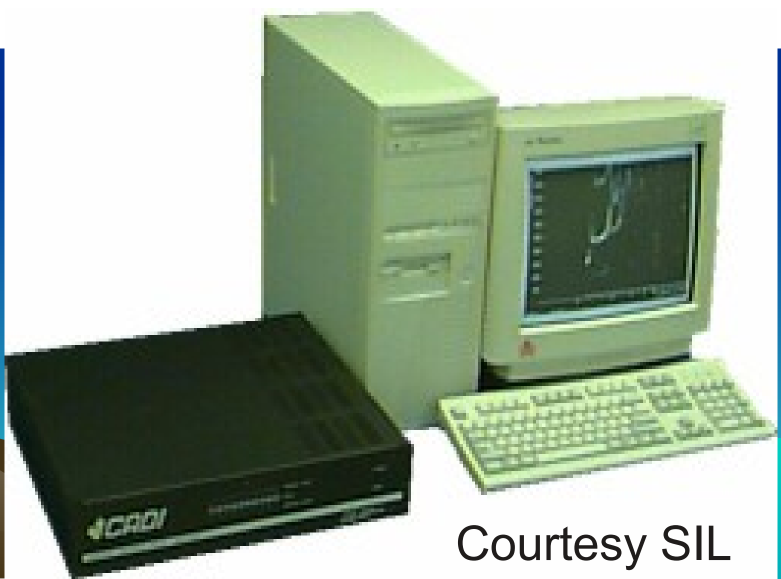
CADI

Canadian Advanced Digital Ionosonde



Arecibo



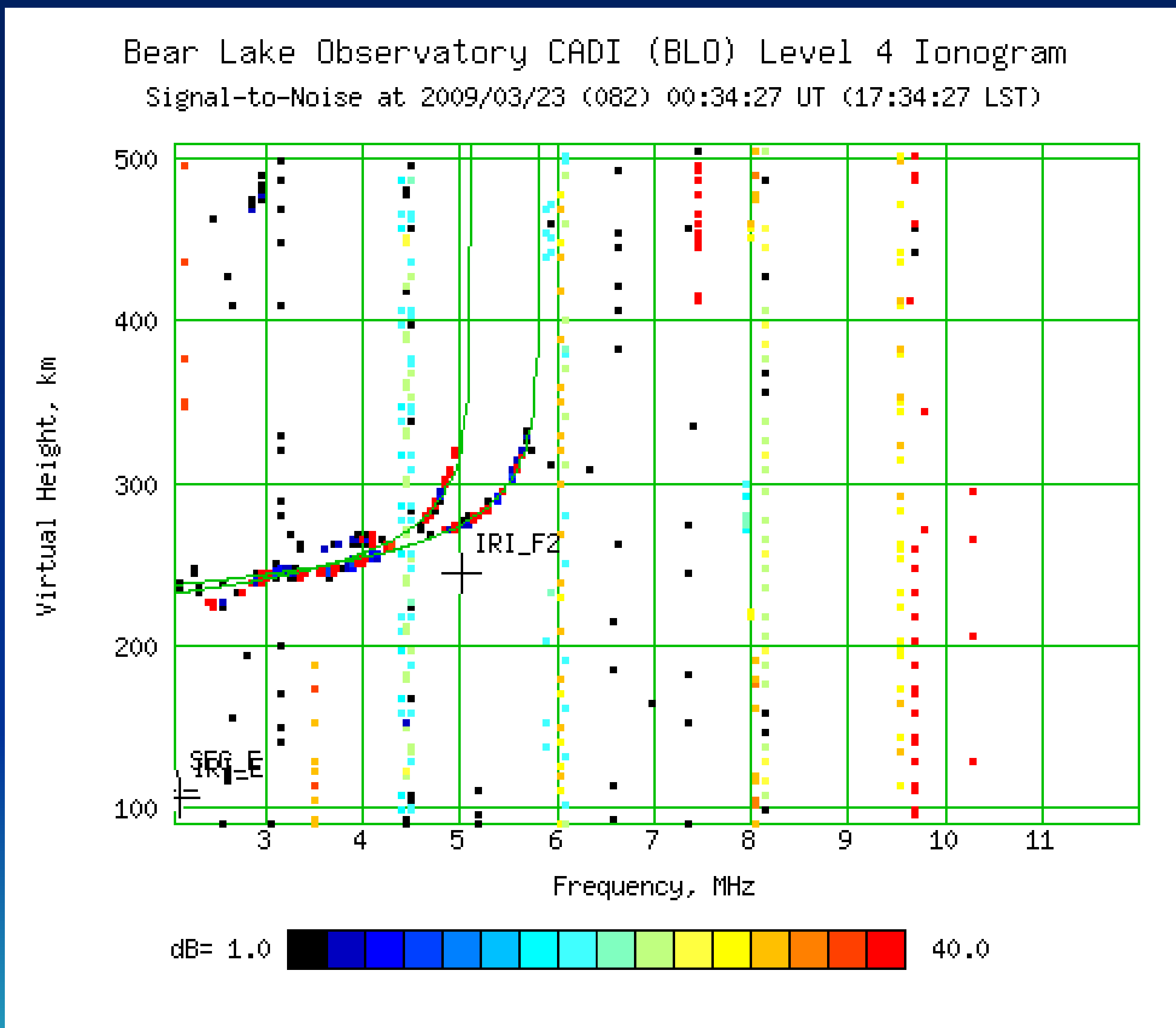


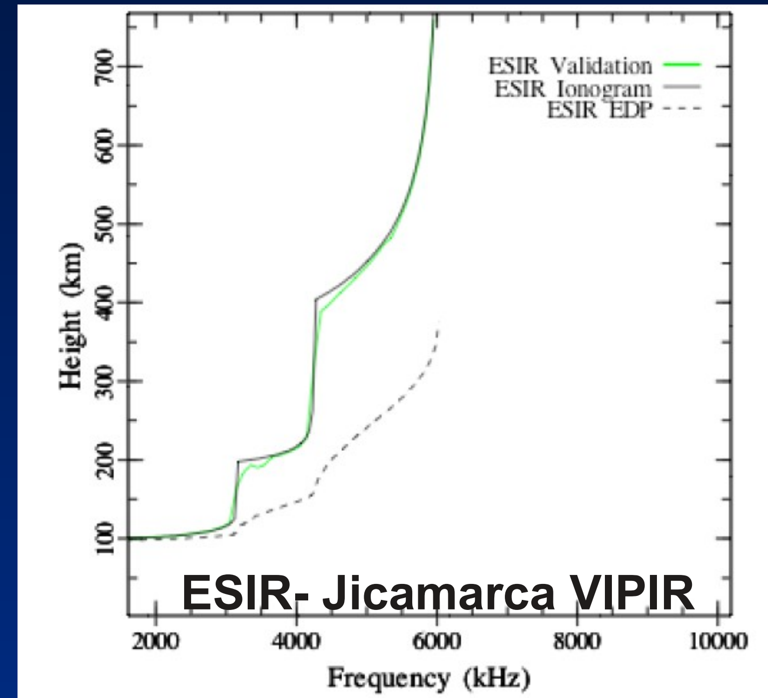
Courtesy SIL

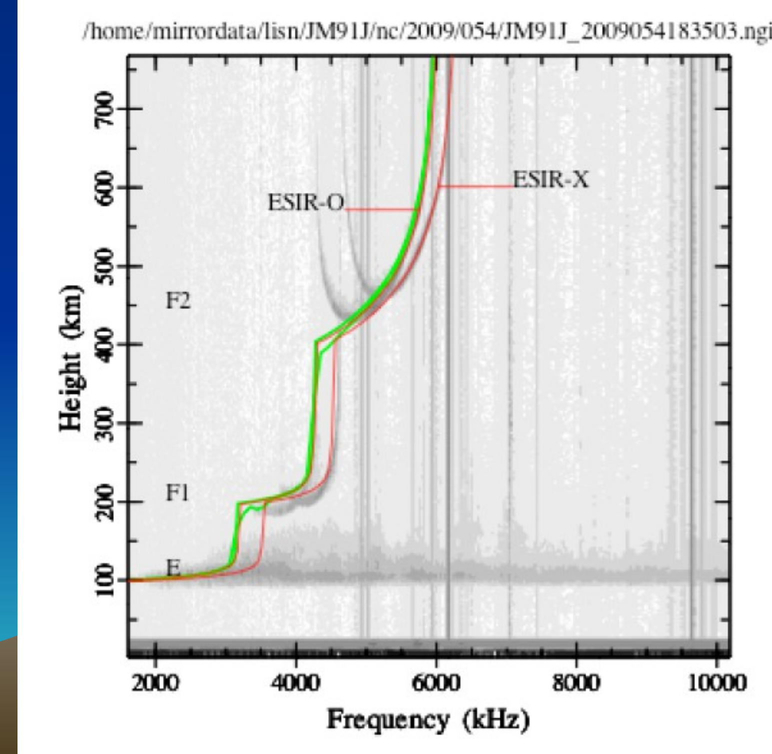
Expert System for Ionogram Reduction

ESIR

ESIR-CADI



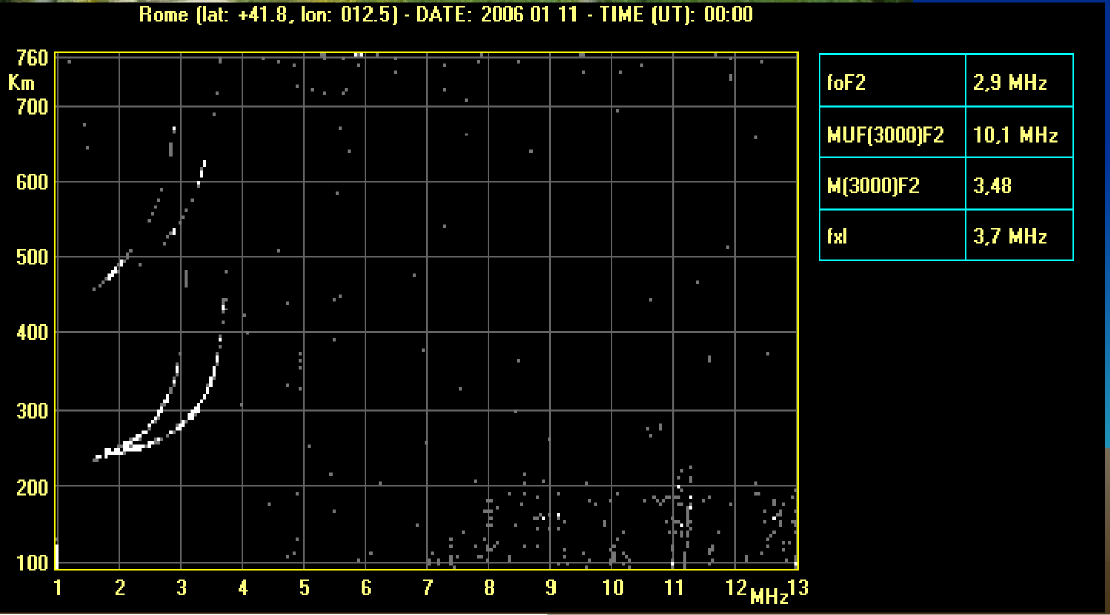




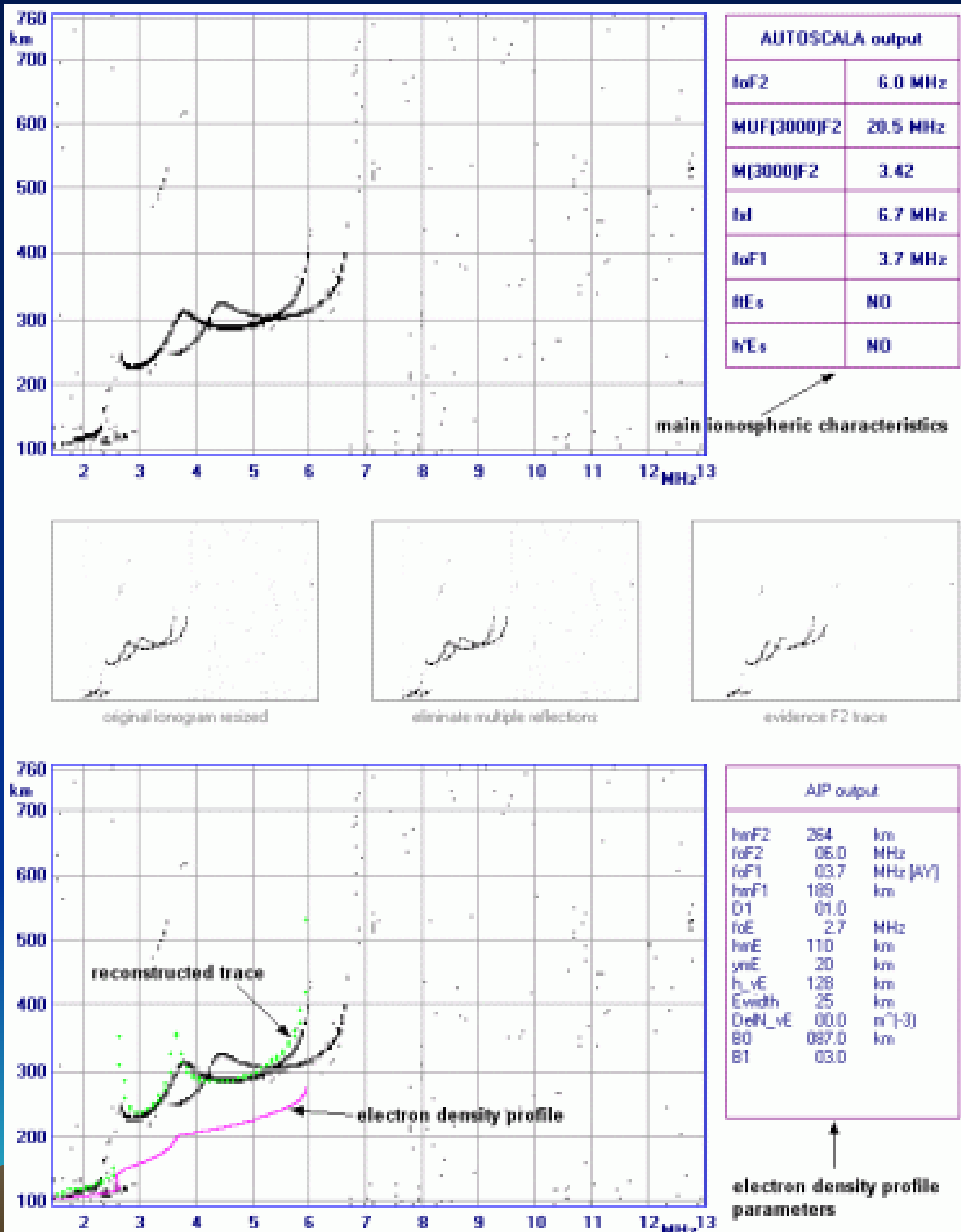
Courtesy Space Environment Corporation and Boston College

INGV-AIS

Italian Advanced Ionospheric Sounder

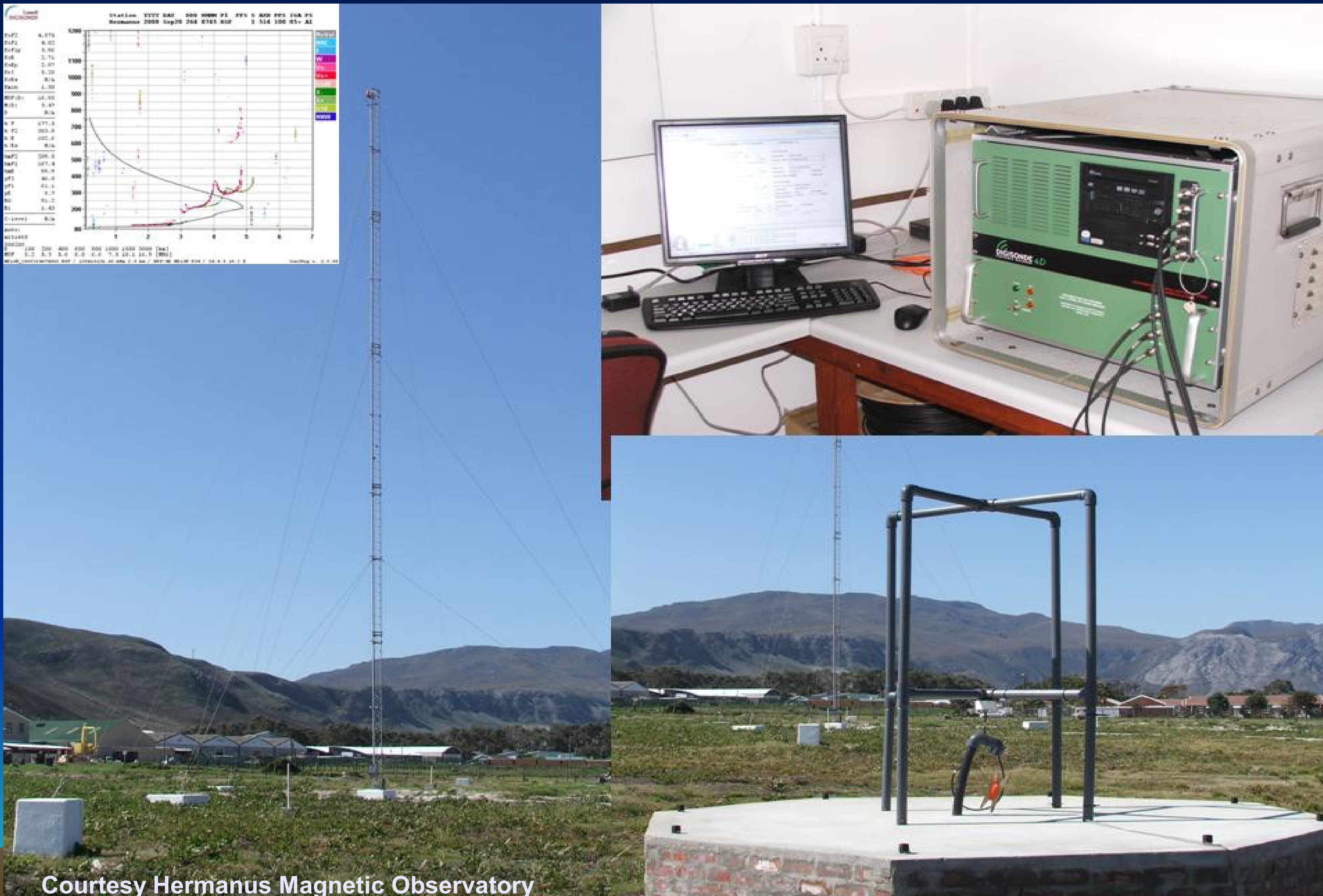


Autoscala

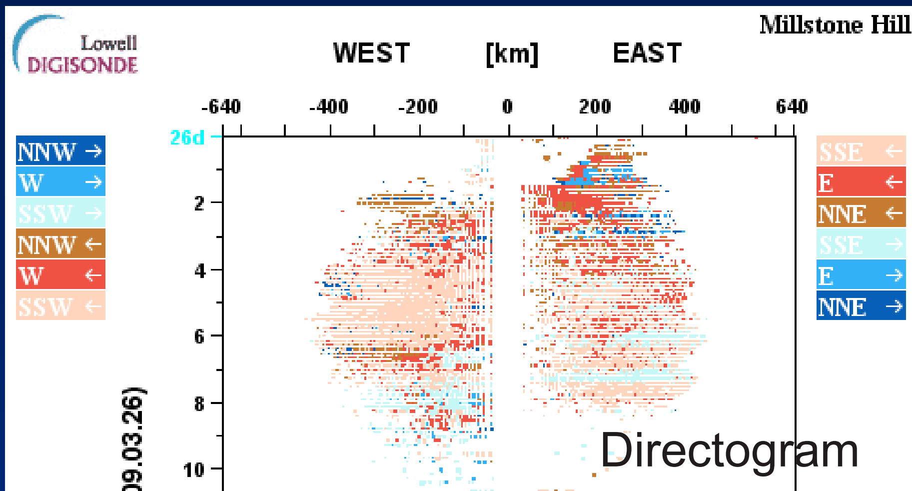


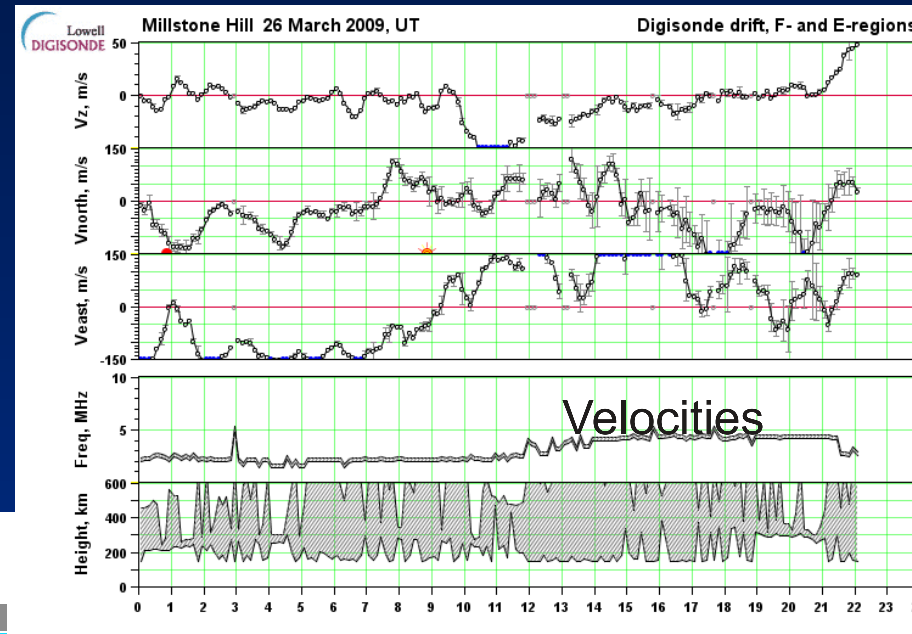
- Italian automatic ionogram scaling software
- Basic URSI scaled characteristics
- Electron Density Profile
- Works on VIPIR, AIS,PARUS
- CADI?

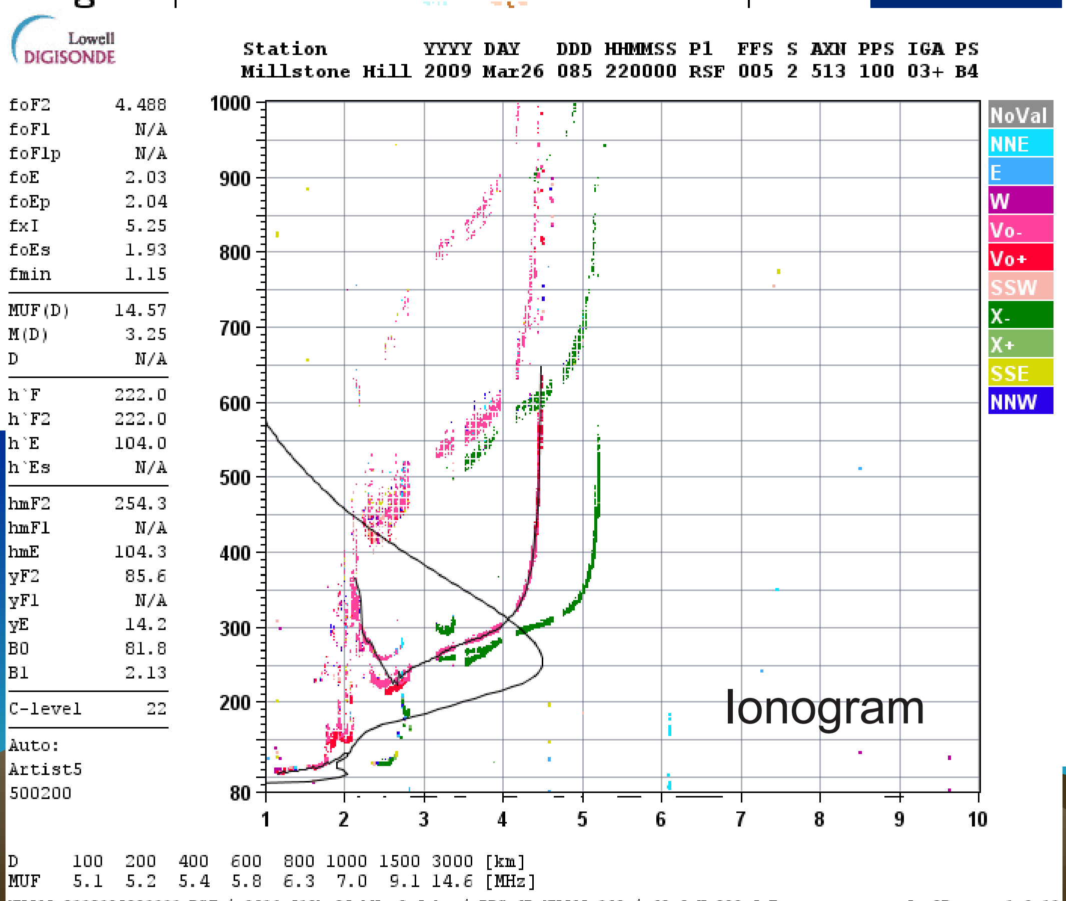
DPS-4D

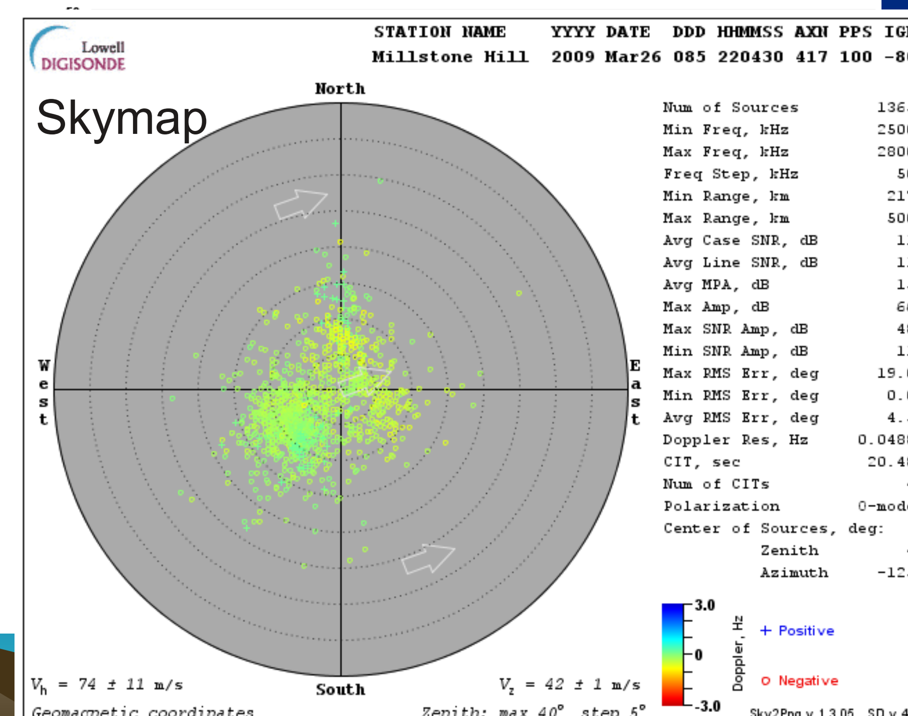


ARTIST


Lowell DIGISONDE
Millstone Hill
WEST [km] EAST
-640 -400 -200 0 200 400 640
26d
NNW →
W →
SSW →
NNW ←
W ←
SSW ←
SSE ←
E ←
NNE ←
SSE →
E →
NNE →
09.03.26)
Directogram


Lowell DIGISONDE
Millstone Hill 26 March 2009, UT
Digisonde drift, F- and E-regions
Vz, m/s
Vnorth, m/s
Veast, m/s
Freq, MHz
Height, km
Velocities

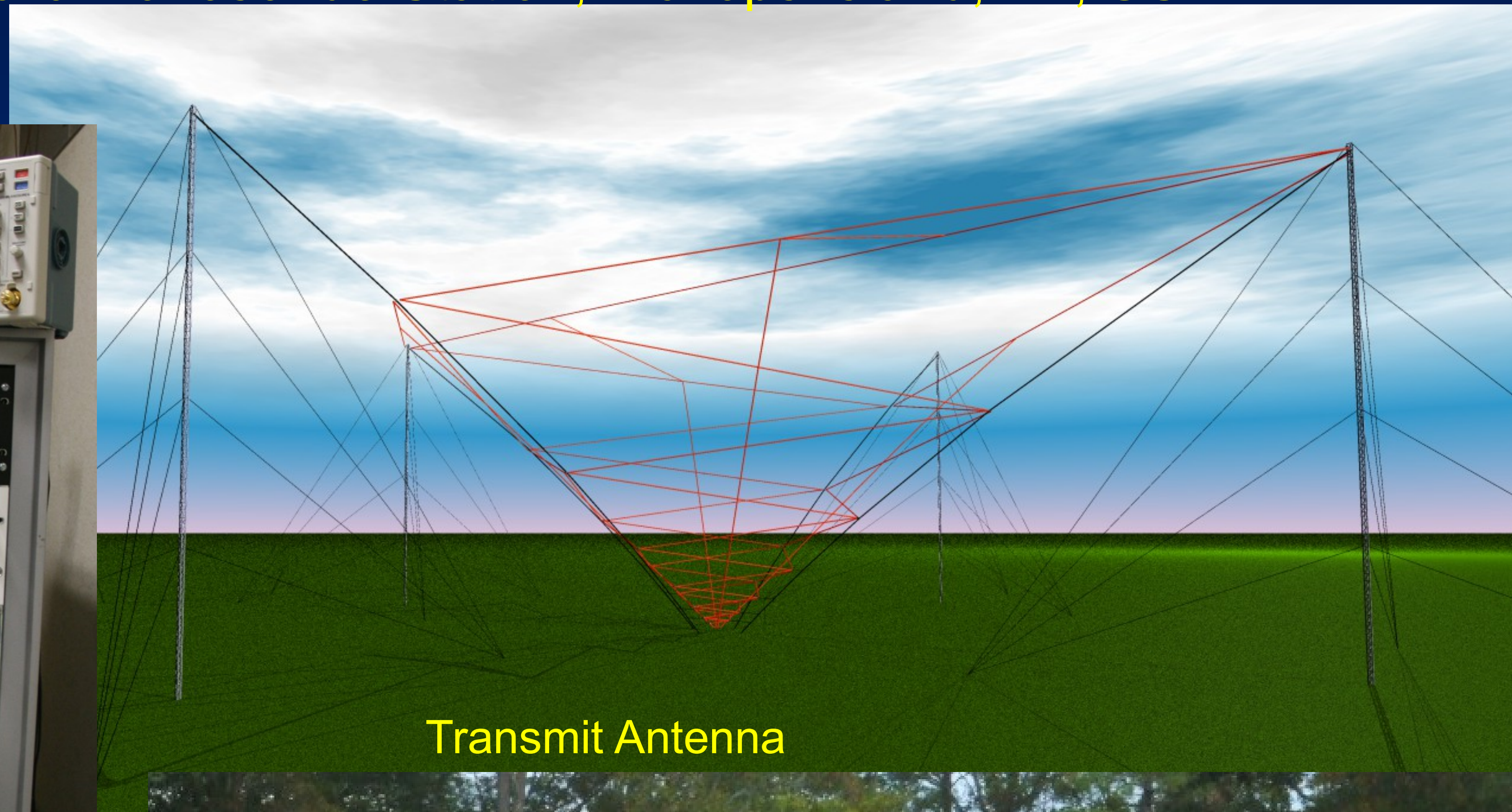

Lowell DIGISONDE
Station YYYY DAY DDD HHMMSS P1 FFS S AXN PPS IGA PS
Millstone Hill 2009 Mar26 085 220000 RSF 005 2 513 100 03+ B4
foF2 4.488
foF1 N/A
foF1p N/A
foE 2.03
foEp 2.04
fxI 5.25
foEs 1.93
fmin 1.15
MUF(D) 14.57
M(D) 3.25
D N/A
h`F 222.0
h`F2 222.0
h`E 104.0
h`Es N/A
hmF2 254.3
hmF1 N/A
hmE 104.3
yF2 85.6
yF1 N/A
yE 14.2
B0 81.8
B1 2.13
C-level 22
Auto:
Artist5
500200
NoVal
NNE
E
W
Vo-
Vo+
SSW
X-
X+
SSE
NNW
Ionogram
D 100 200 400 600 800 1000 1500 3000 [km]
MUF 5.1 5.2 5.4 5.8 6.3 7.0 9.1 14.6 [MHz]
MHJ45_2009085220000.RSF / 360fx512h 25 kHz 2.5 km / DPS-4D MHJ45 042 / 42.6 N 288.5 E
Ion2Png v. 1.3.10


Lowell DIGISONDE
STATION NAME YYYY DATE DDD HHMMSS AXN PPS IGP
Millstone Hill 2009 Mar26 085 220430 417 100 -8G
Skymap
North
South
West
East
Num of Sources 1365
Min Freq, kHz 2500
Max Freq, kHz 2800
Freq Step, kHz 50
Min Range, km 217
Max Range, km 500
Avg Case SNR, dB 11
Avg Line SNR, dB 11
Avg MPA, dB 15
Max Amp, dB 66
Max SNR Amp, dB 48
Min SNR Amp, dB 11
Max RMS Err, deg 19.0
Min RMS Err, deg 0.0
Avg RMS Err, deg 4.5
Doppler Res, Hz 0.0488
CIT, sec 20.48
Num of CITs 4
Polarization O-mode
Center of Sources, deg:
Zenith 4
Azimuth -125
+ Positive
o Negative
Doppler, Hz
Vh = 74 ± 11 m/s
Vz = 42 ± 1 m/s
Geomagnetic coordinates
Zenith: max 40° step 5°
Sky2Png v 1.3.05 SD v 4.2

Vertical Incidence Pulsed Ionospheric Radar

World Class Research Ionosonde Station, Wallops Island, VA, USA

VIPIR


Transmit Antenna


Receive Array

VIPIR Radar Features

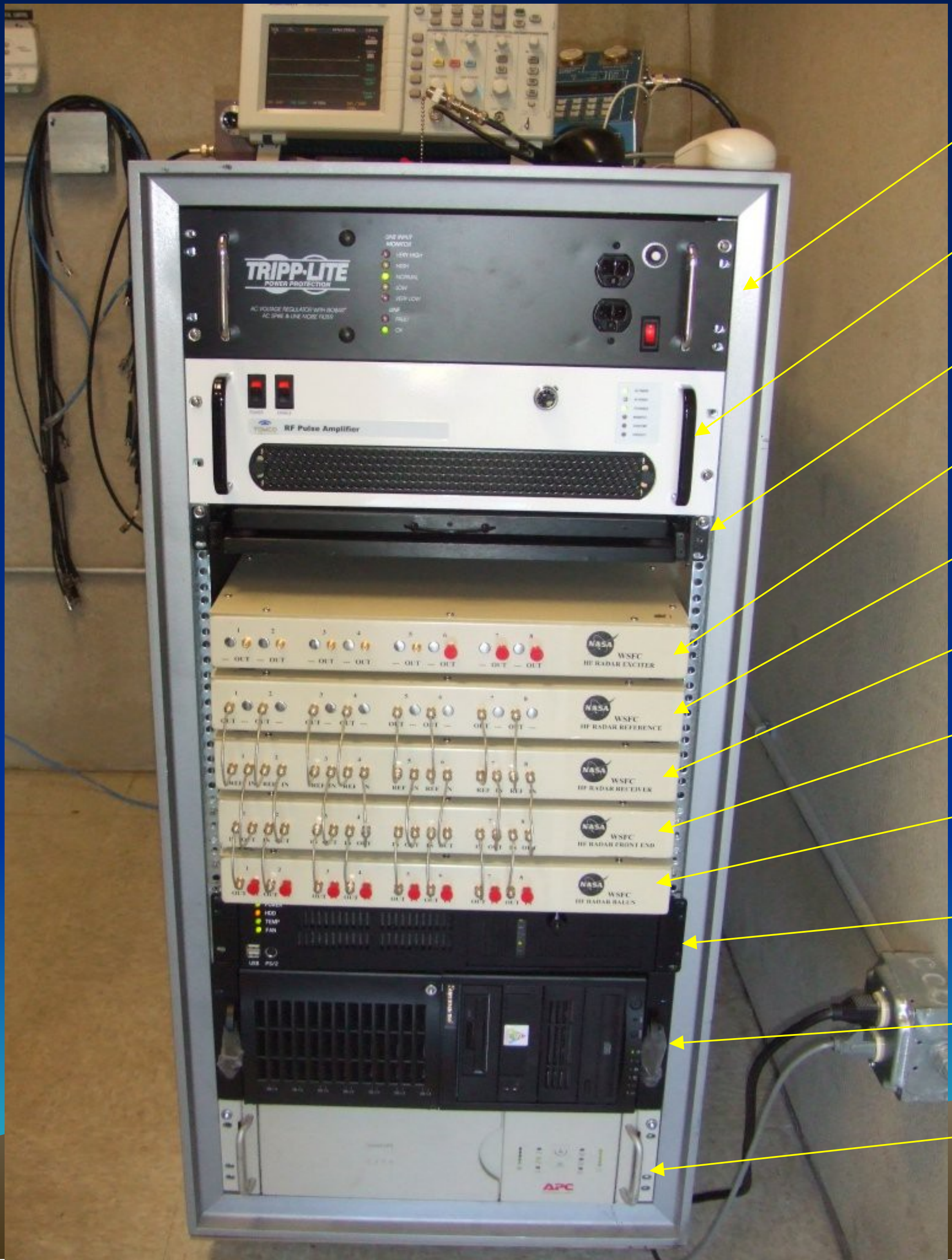
- Very high interference immunity: IP3 > 40 dBm
- High Dynamic Range: 115(I) +30(V) dB
- Direct RF sampling 14 bits at 80 MHz
- Fully digital conversion, receiver and exciter
- Waveform Agility: 2 µs to 2 ms pulse/chip width
- USB-2 Data and Command/Control Interfaces
- 8 coherent receive channels; Frequency: 0.3 – 25 MHz
- 4 kW class AB pulse amplifier: 3rd harmonic < -30 dBc
- Precise GPS timing for bi-static operation
- Radar software Open Source C code; runs under Linux

Designed for extreme performance and flexibility

Upgrades for the VIPIR Mark II

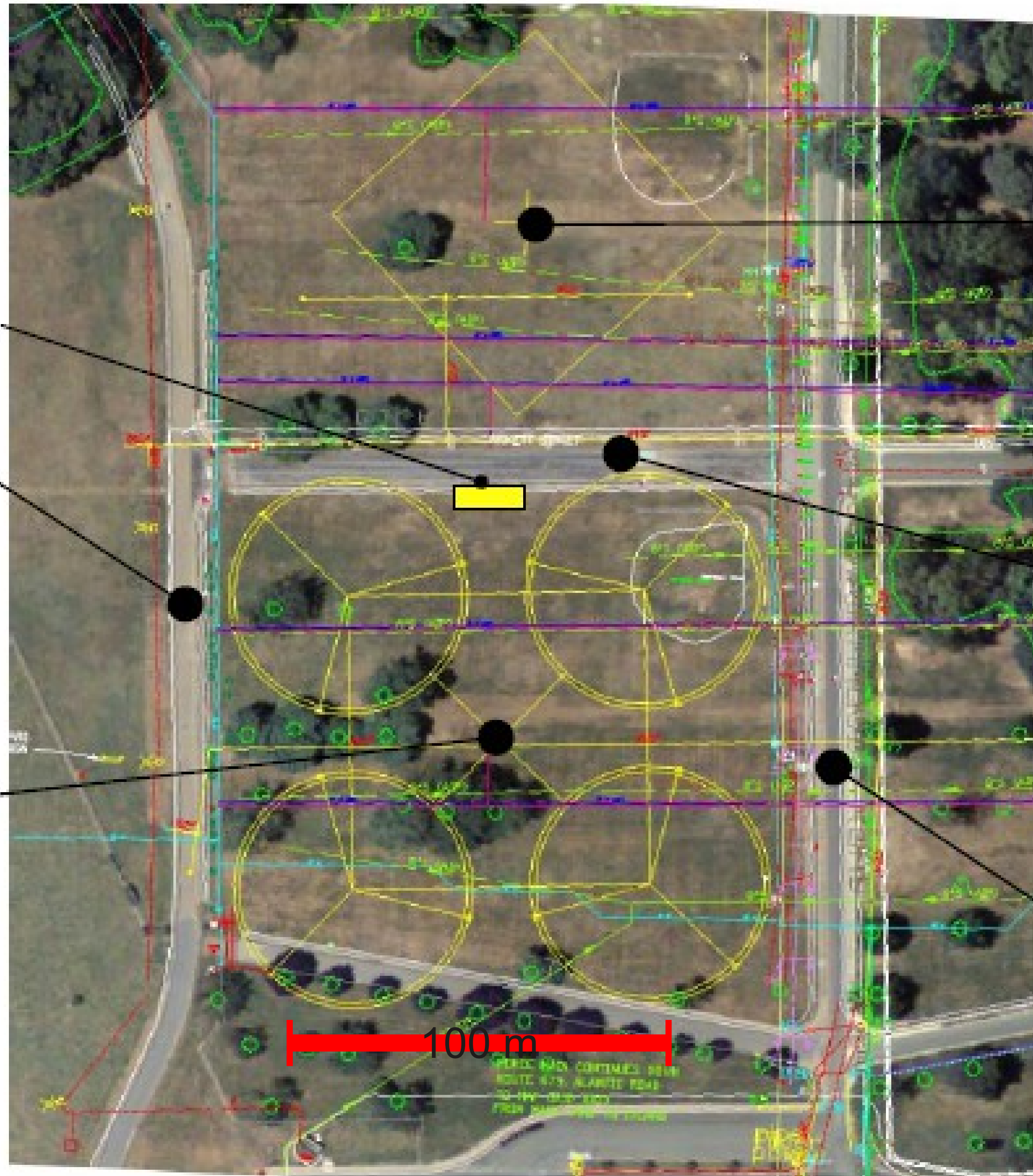
- FPGA based digital receiver
- 16 bit, 120 MHz ADC
- USB3 data transfer
- Improved analog front end
- Improved receive antenna pre-amplifiers
- Contemporary computers and data storage
- Options:
  - High power low pass transmit harmonic filter
  - Rubidium oscillator for oblique phase measurements
  - Loop Receiving Antennas

Wallops Island VIPIR hardware



- Power Conditioner
- 4kW RF Amplifier
- KVM
- Exciter
- Reference
- Receiver
- Front End
- Balun
- Control Computer
- Analysis Computer
- UPS

Wallops Island Overview



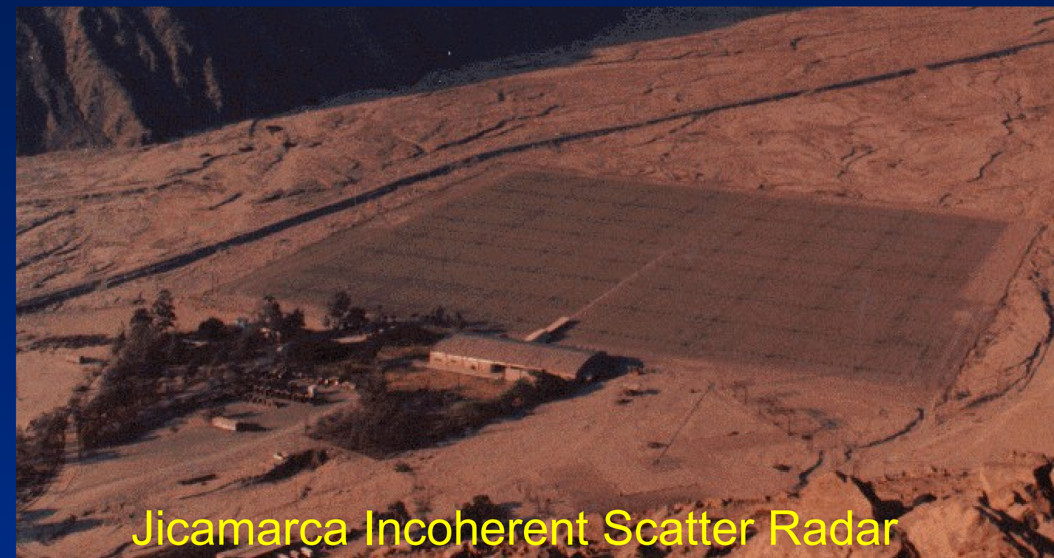
150mx250m

37,500 sq. m

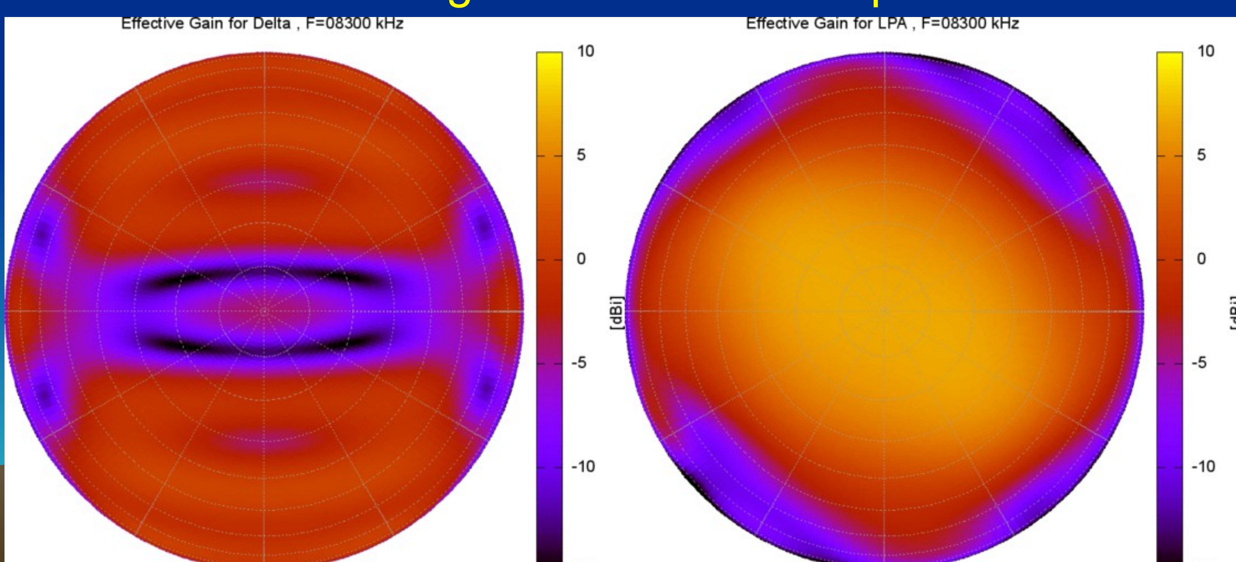
9 acres

What makes a World Class Ionosonde?

- Large, Efficient Transmit antenna
- Large receive array
- Modern, powerful sounder
- Co-located Instruments
- Dedicated Scientists


Jicamarca Incoherent Scatter Radar

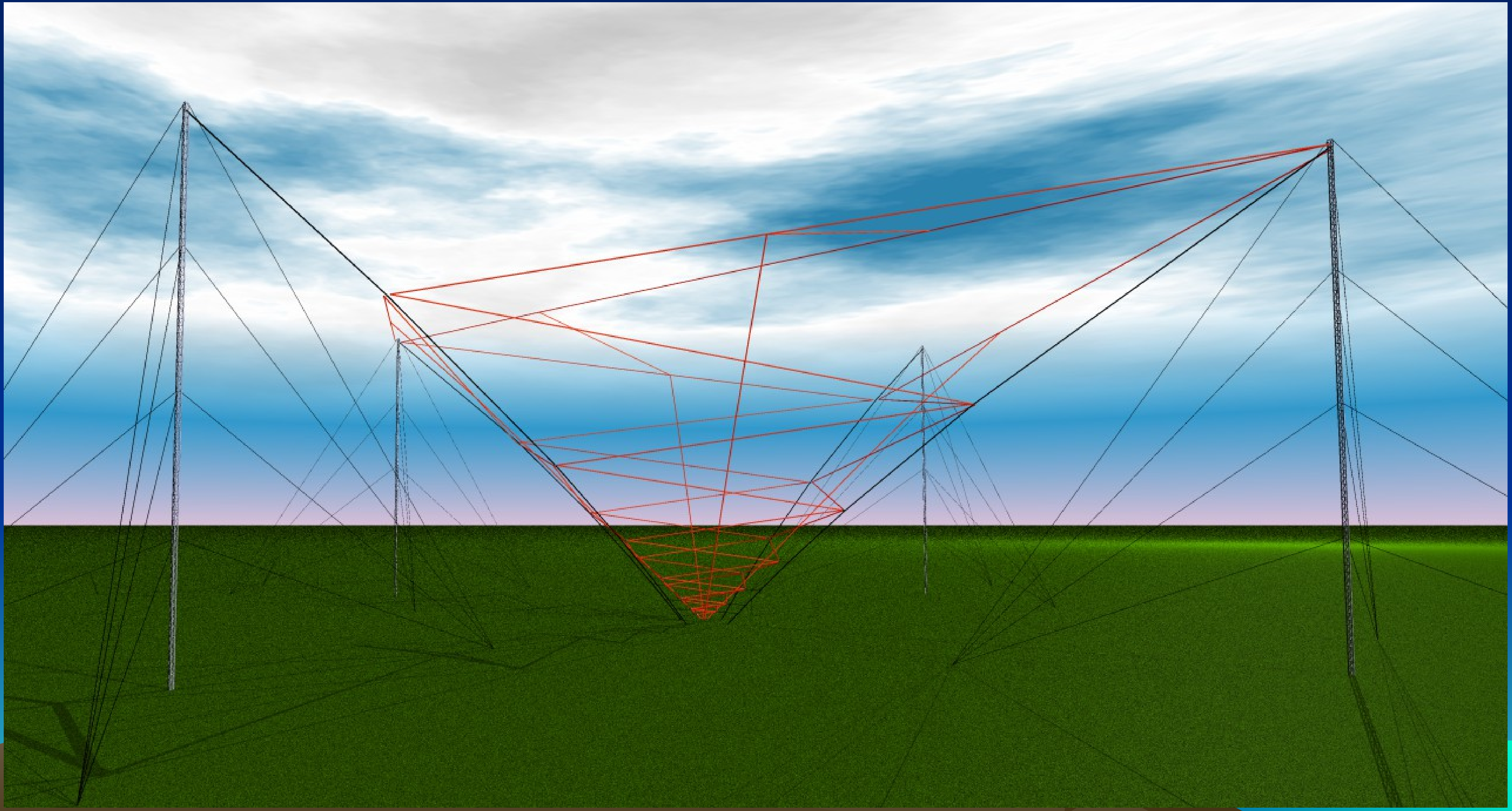
Delta vs Log Periodic Transmit patterns



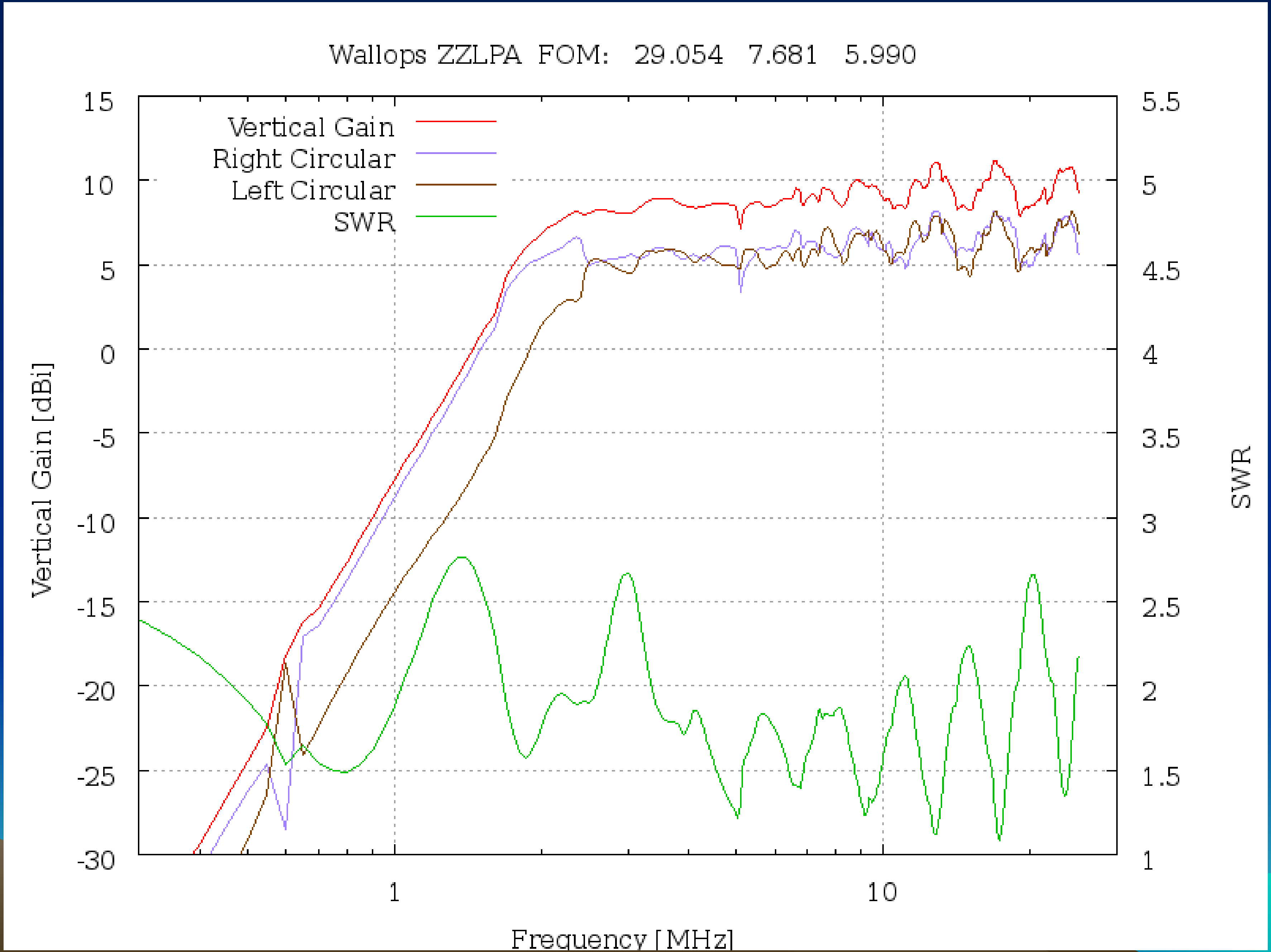

Sounding Rocket

Wallops Log Periodic Transmit Antenna

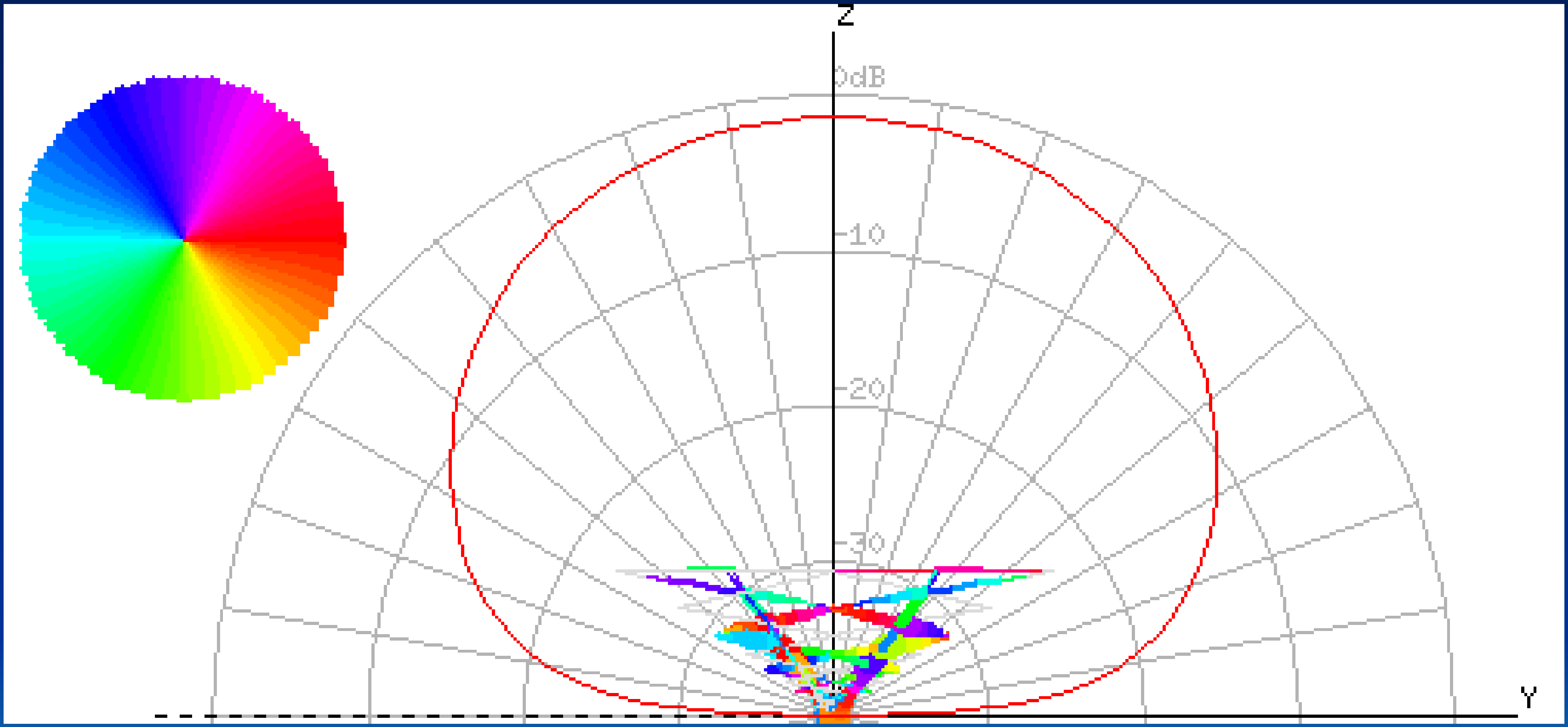
Height: 36m
Size: 75x75m



Transmit Antenna Performance

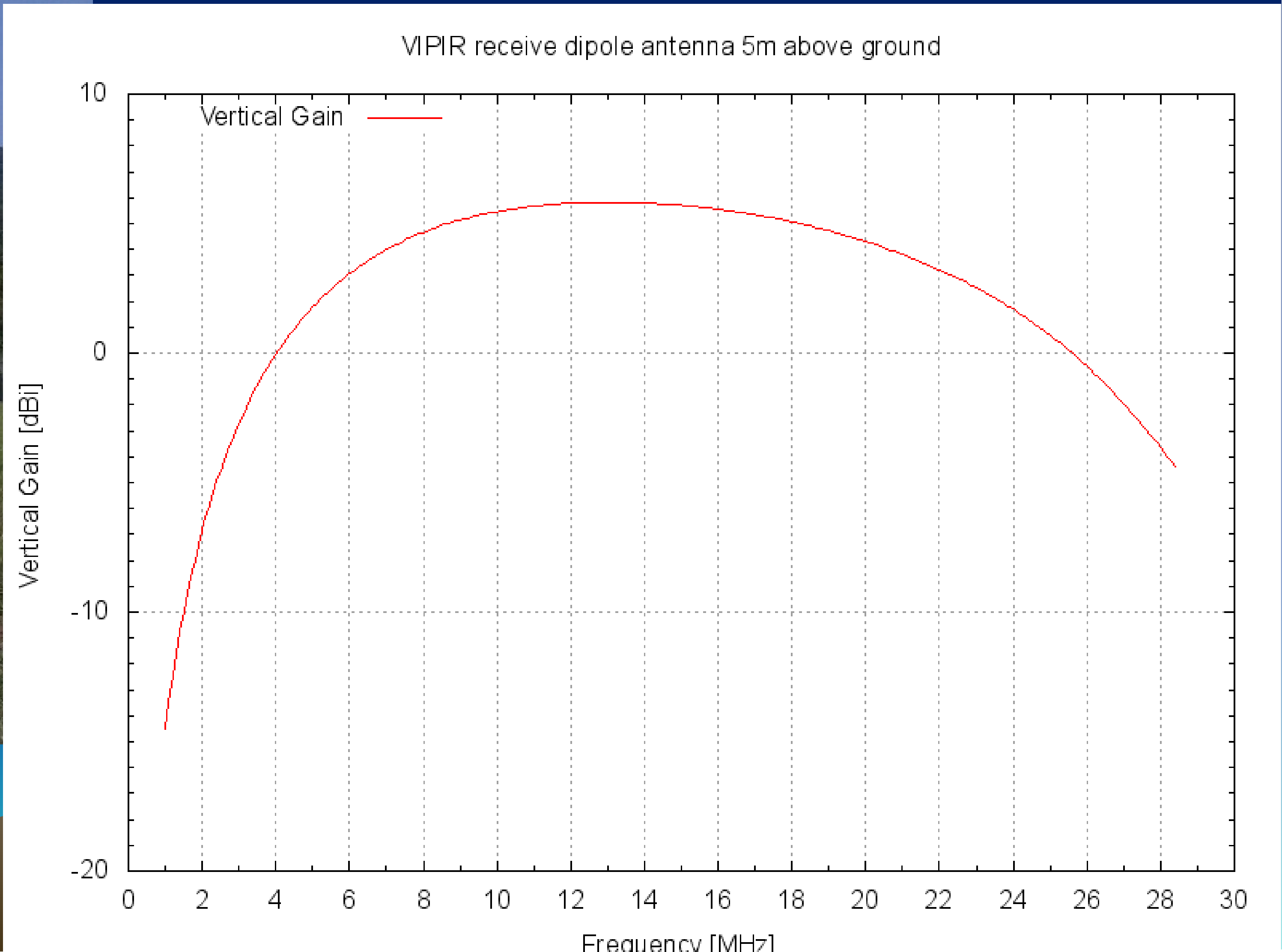


Typical Transmit Antenna Pattern

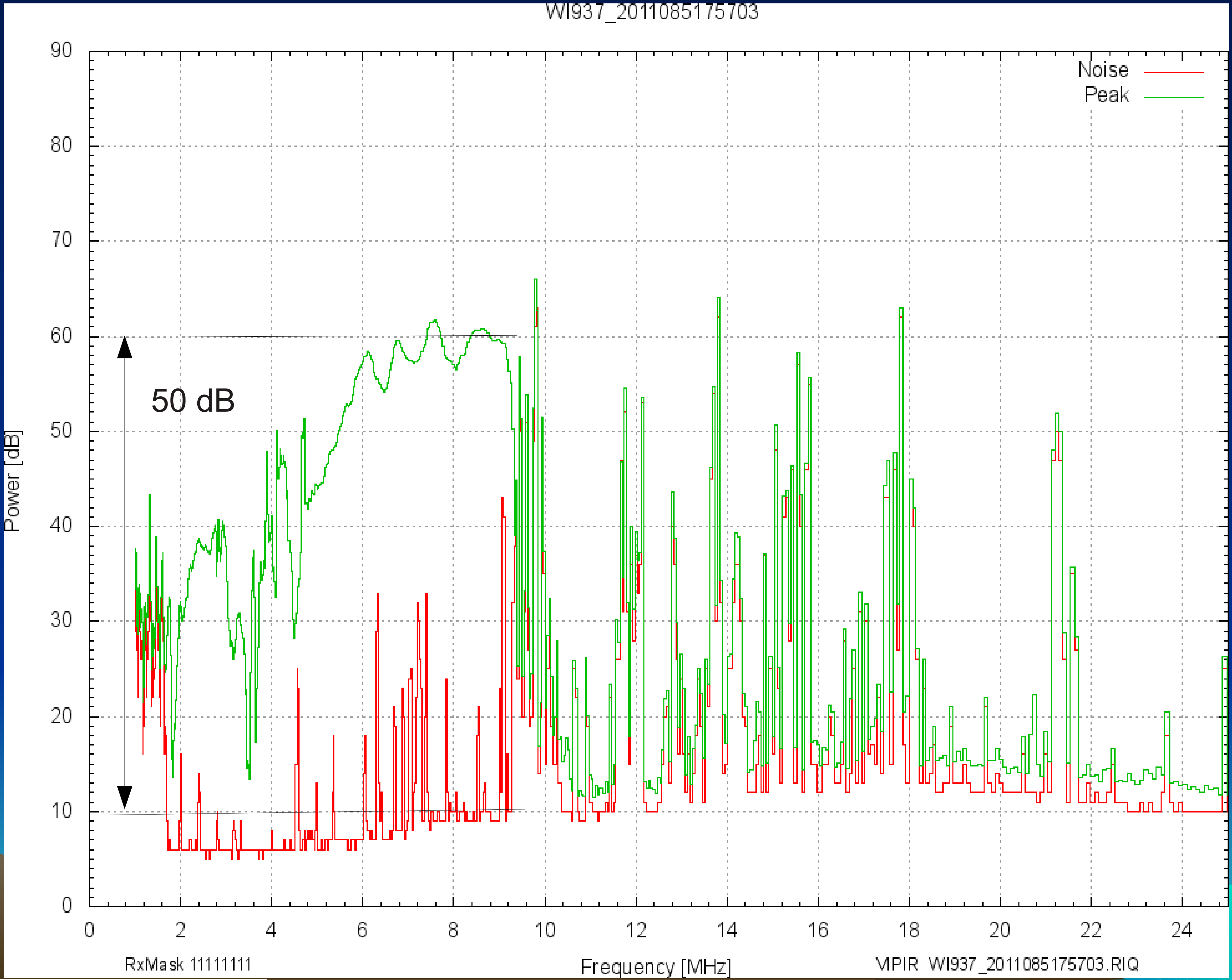


Receive Antennas

4m dipoles , 5m high



WI937 Signal and Noise Spectrum



Radar Engineering

Radar Equation

The basic radar equation for a “small” target: *(ignoring losses, etc)*

$$S = \frac{P_t G_t}{4\pi R^2} \frac{\sigma}{4\pi R^2} A_r$$

(Power_at_Target) x (Power_at Receiver) x (Effective Rx_Area)

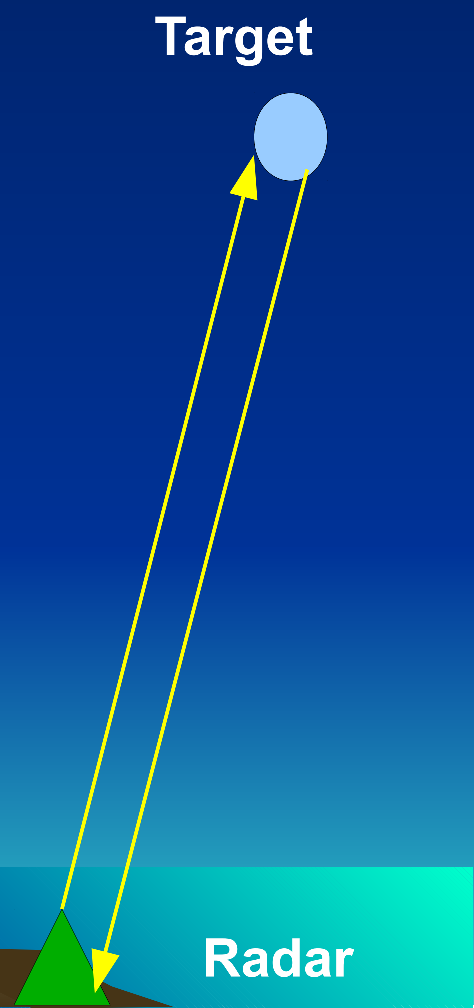
$$S = \frac{P_t G_t}{4\pi R^2} \frac{\sigma}{4\pi R^2} A_r \qquad A_r = \frac{\lambda^2}{4\pi} G_r$$

$$S = \frac{P_t G_t G_r \lambda^2}{(4\pi)^3 R^4} \sigma$$

1 m wavelength
1 sm target
400 km range

$$\frac{1}{4\pi^3} = -33\text{dB}$$

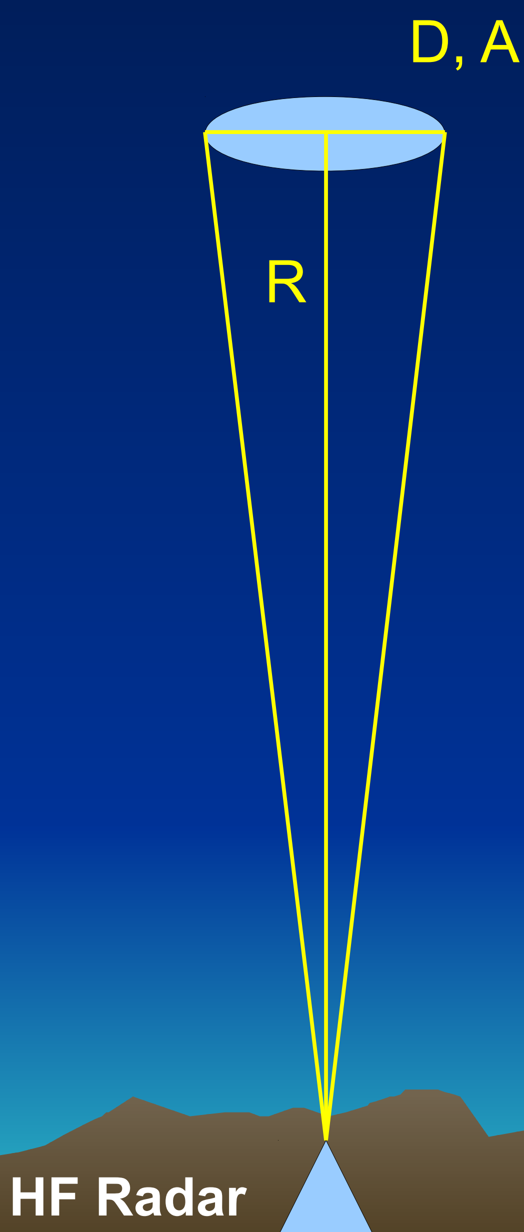
$$\frac{\lambda^2}{R^4} \sigma = -224\text{dB}$$



http://www.radartutorial.eu/01.basics/rb13.en.html

Fresnel Zone

The area over which radio reflections return "in phase" and contribute to the radar return



$$D = \sqrt{\lambda R}$$

$$A = \sigma = \frac{\pi}{4} \lambda R$$

$$S = \frac{P_t G_t G_r \lambda^3}{256 \pi^2 R^3}$$

$$\frac{1}{256 \pi^2} = -34\text{dB}$$

$$\frac{\lambda^3}{R^3} = -94\text{dB}$$

300 m wavelength
400 km range

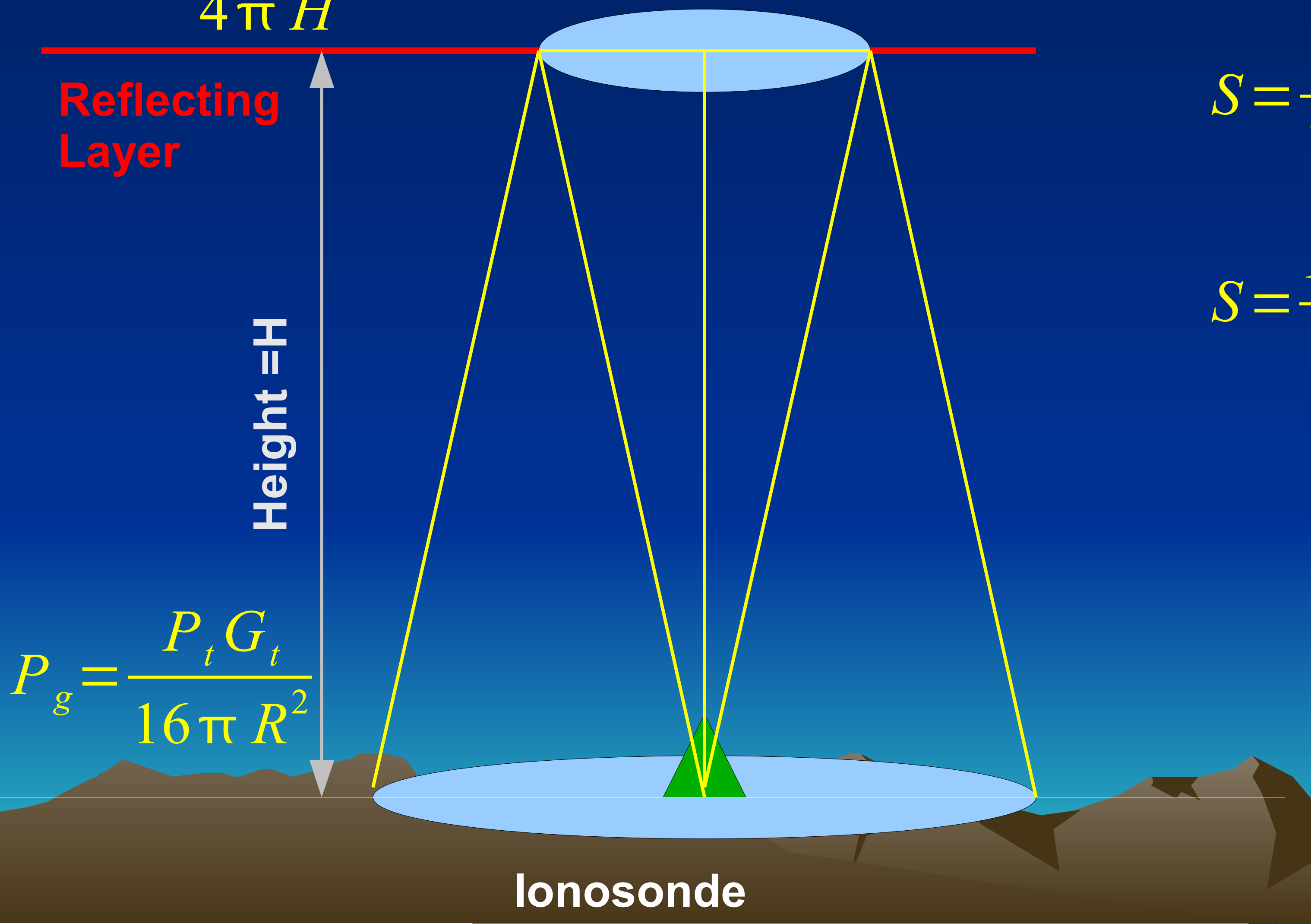
Examples

- R=100 km, λ=15m
  - D=1.2 km, A=60 dBsm
- R=400 km, λ=15m
  - D=2.5 km, A=66 dBsm
- R=100 km, λ=300m
  - D=5.5 km, A=75 dBsm
- R=400 km, λ=300m
  - D=11.0 km, A=80 dBsm

Specular Reflection

The ionosphere spectacularly reflects "all" of the incident energy
The power density at the ground is equivalent to that at Range = 2H

$$P_i = \frac{P_t G_t}{4\pi H^2}$$



$$P_g = \frac{P_t G_t}{16\pi R^2}$$

$$S = \frac{P_t G_t}{16\pi R^2} \frac{\lambda^2 G_r}{4\pi}$$

$$S = \frac{P_t G_t G_r}{64\pi^2} \left(\frac{\lambda}{R}\right)^2$$

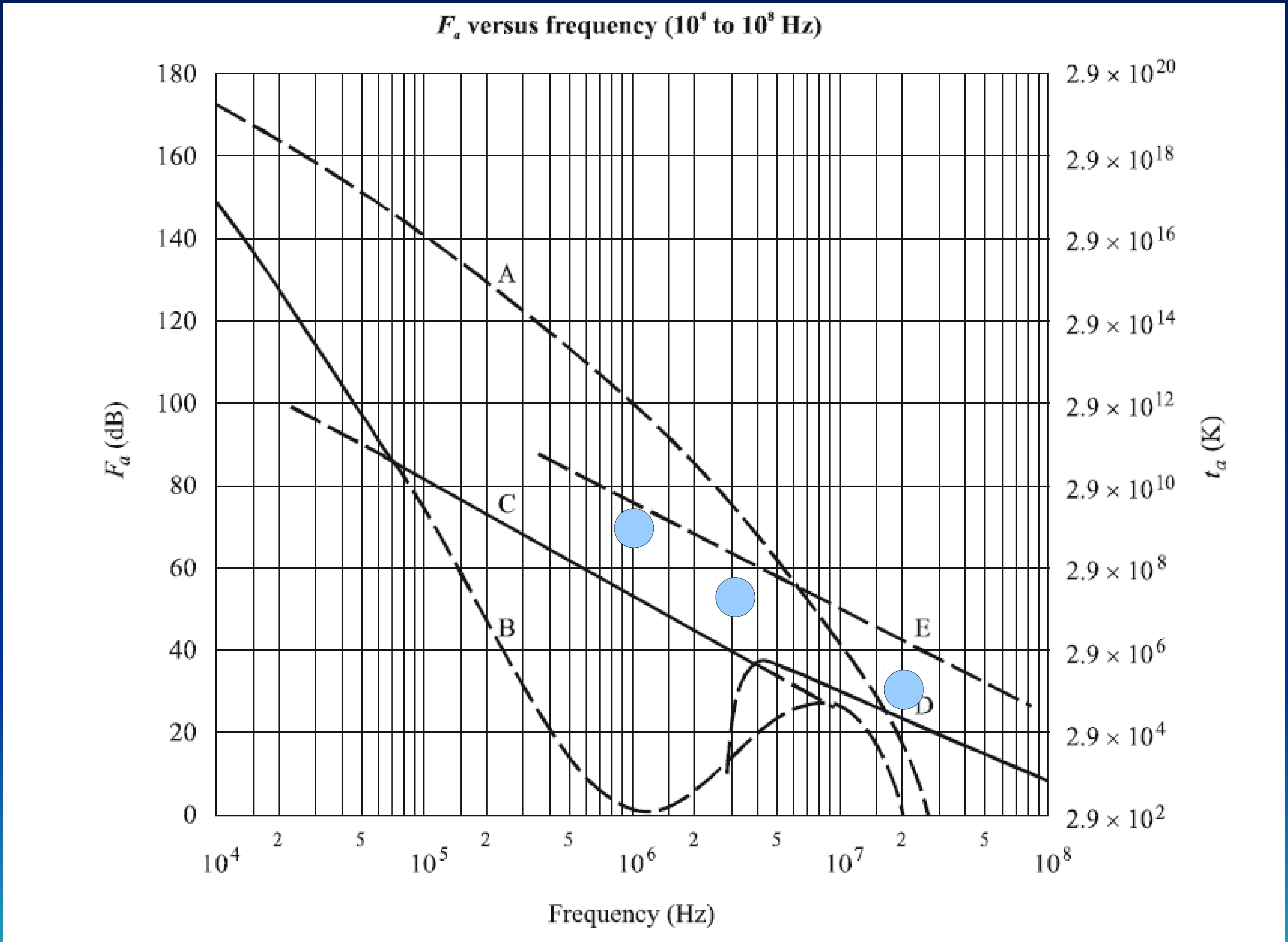
$$\frac{1}{64\pi^2} = -28\text{dB}$$

$$\frac{\lambda^2}{R^2} = -63\text{dB}$$

300 m wavelength
400 km range

Atmospheric Noise Factor at HF

- Noise below 30 MHz is dominated by atmosphere and man-made sources



A) Atmospheric 99.5%tile

B) Atmospheric 0.5%tile

C) Man-made (Quiet)

D) Galactic

E) Man-made (City)

$At\ \lambda = 300\text{m}$

$F_a \cong 70\text{dB}$

$At\ \lambda = 100\text{m}$

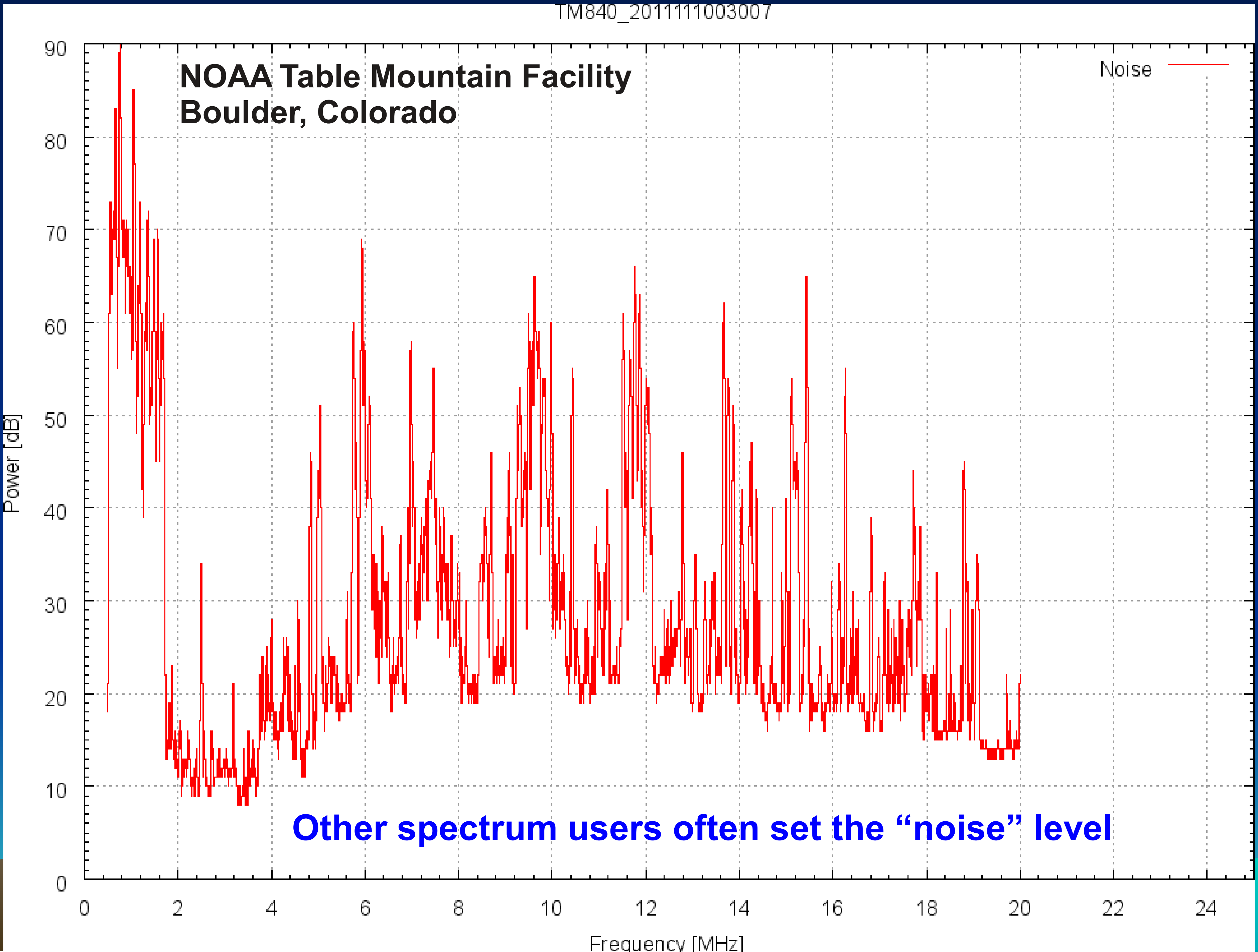
$F_a \cong 50\text{dB}$

$At\ \lambda = 15\text{m}$

$F_a \cong 30\text{dB}$

Source:ITU-R P.372-10 (2009)

Interference



Radar Equation for Ionosondes

Signal

$$S = \frac{P_t G_t}{16\pi R^2} \frac{1}{L_p} \frac{\lambda^2 G_r}{4\pi}$$

Ignoring propagation losses

$$S = \frac{P_t G_t G_r}{64\pi^2} \left(\frac{\lambda}{R}\right)^2$$

$$P_t \cong 1\,kW = +60\,dBm$$

$$G_t \cong G_r \cong 3\,dB$$

$$S \cong +38 + 10\log_{10}\left(\frac{\lambda}{R}\right)^2 \,[dBm]$$

Noise

$$N = k\,T_0\,B\,F_n\,F_a$$

$$B = 15\text{kHz}$$

$F_n \cong 6\,dB$ Active Preamp

$$At\,\lambda = 300\text{m}$$

$$F_a \cong 70\text{dB}$$

$$At\,\lambda = 100\text{m}$$

$$F_a \cong 50\text{dB}$$

$$At\,\lambda = 15\text{m}$$

$$F_a \cong 30\text{dB}$$

$$k\,T_0\,B\,F_n = -124\,dBm$$

SNR Examples (20 and 3 MHz)

- R=100 km, λ=15m (20 MHz)
    - S=-38dBm ; N= -96 dBm ; SNR=+58 dB
- R=400 km, λ=15m (20 MHz)
    - S=-50 dBm ; N=-96 dBm ; SNR=+45 dB

$\pm 10\, dB$

- R=100 km, λ=100m (3 MHz)
    - S=-22 dBm ; N= -76 dBm ; SNR=+54 dB
- R=400 km, λ=100m (3 MHz)
    - S=-34 dBm ; N= -76 dBm ; SNR=+41 dB

$\pm 20\, dB$

For sites with “reasonable” noise,
very high SNR can be obtained with “modest” antennas

SNR Example (1 MHz)

- Antenna gains are no longer constant
  - Transmit antenna is small and inefficient (-10 dBi)
  - Receive antenna is close to the ground (-15 dBi)
- R=100 km, λ=300m (1 MHz)
  - S=-37 dBm ; N=-56 dBm ; SNR= +19 dB
- R=400 km, λ=300m (1 MHz)
  - S=-49 dBm ; N=-56 dBm ; SNR= +6 dB

$\pm 30\, dB$

Even "large" antennas become electrically small at low frequencies
Inefficiencies and atmospheric noise take over.

This ignores propagation loss, which is significant!

Polarization

- Ordinary and eXtraordinary polarizations are circular and of opposite rotation
  - Except very near the magnetic equator, it is linear
- Two orthogonal, linearly polarized antennas can form a circularly polarized antenna
  - Digisondes do this in hardware at the antenna
  - VIPIR and Dynasonde do this in the analysis software

San Juan, Puerto Rico

End of Section 2

Questions?

VIPIR Operations

SPGR

- The virtual height of the ionosphere can be measured using the phase differences between two closely spaced frequencies.
- The result is called Stationary Phase Group Range or Precision Group Height
- Assumes the actual height of reflection is constant
    - Can be relaxed by using multiple values of Δf
- Subject to 2π ambiguities
- Subject to Doppler shift
- Range precision becomes related to phase precision: → 100 m

$$h' = \frac{c}{4\pi} \frac{\Delta \phi}{\Delta f}$$

Pulse Sets

- A pulset is a sequence of pulses at a nominal frequency with a pattern of frequency offsets intended to accomplish a desired experimental objective
- "Atomic"
- Stationary Phase Group Range (SPGR)
    - Precision Group Height
- Spectral Analysis (i.e. FFT)
- Example: 8 pulse pulset for Dynasonde
    - +1, -3, +3, -1, -1, +3, -3 ,+1 {kHz}
- Controls the statistics of SPGR and Doppler

Ramps, Repeats and Ionograms

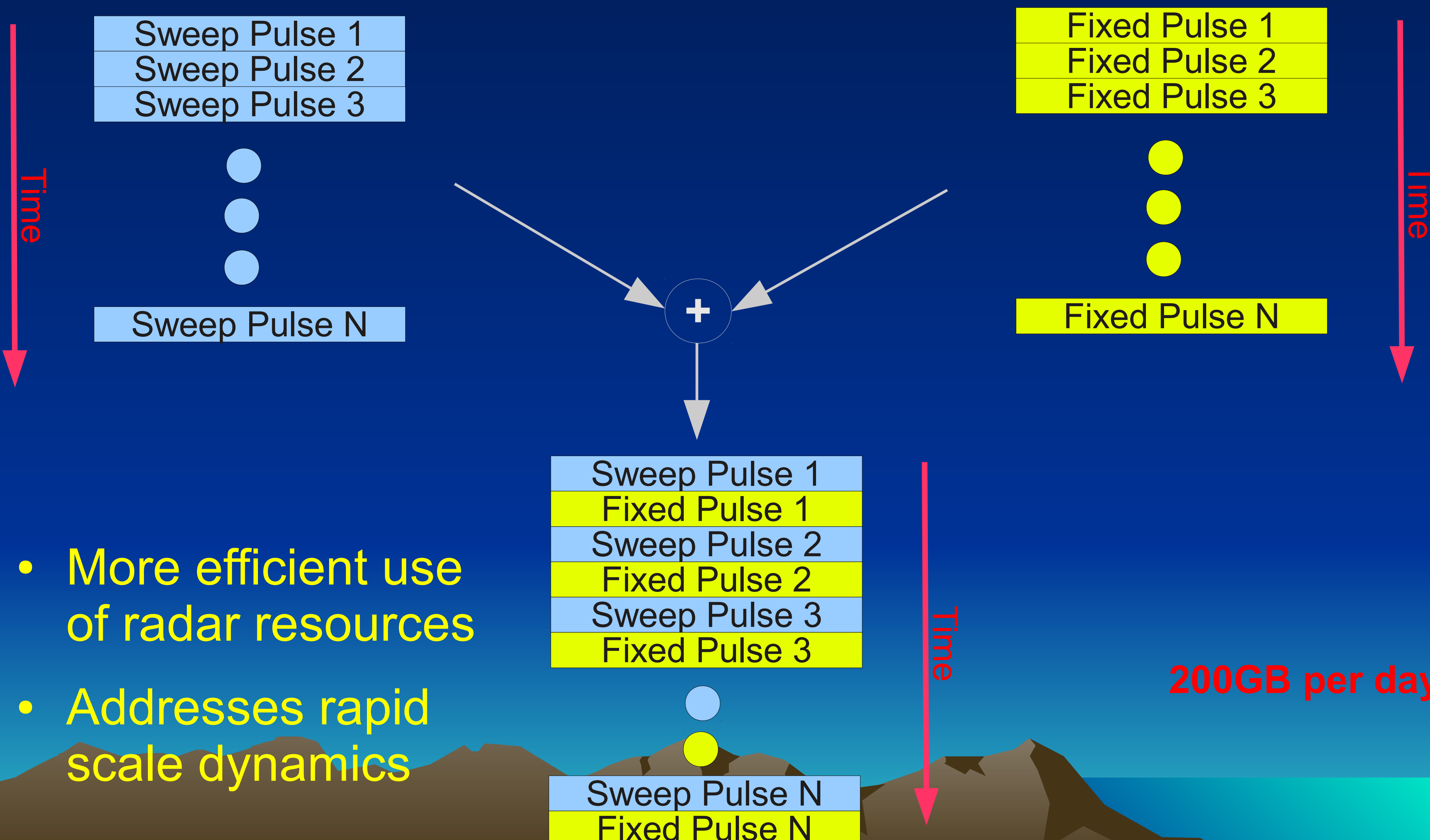
- A Ramp is a group of pulsets taken at a sequence of nominal frequencies
- Repeats are the number of times each Ramp is repeated before going on to the next ramp
- An Ionogram is a continuous set of Ramps and Repeats which cover the entire specified set of Nominal Frequencies
- This concept is used to control the statistics of the observation sequence within the coherency limitations of the ionosphere

Dynasonde Principles

- Phase differences among several (4-8) pulsed signals of a carefully designed pulse set, received through several (4-8) antenna/receiver channels, define, by a least squares solution, a radio “echo” with physical parameters:
    - **“Doppler” or phase-path velocity V*, m/s**
    - **“Stationary-Phase Group Range” R´, km**
    - **Eastward XL and northward YL echolocations, km**
    - **Polarization rotation or “chirality” PP, degrees**
    - **The pulse set mean phase φ_0, degrees**
    - **A least-squares residual EP, degrees**
    - **An echo peak amplitude A, decibels, from signal magnitude**
    - **Possible 2nd order parameters with 8 antennas and receivers**

Shuffle Mode

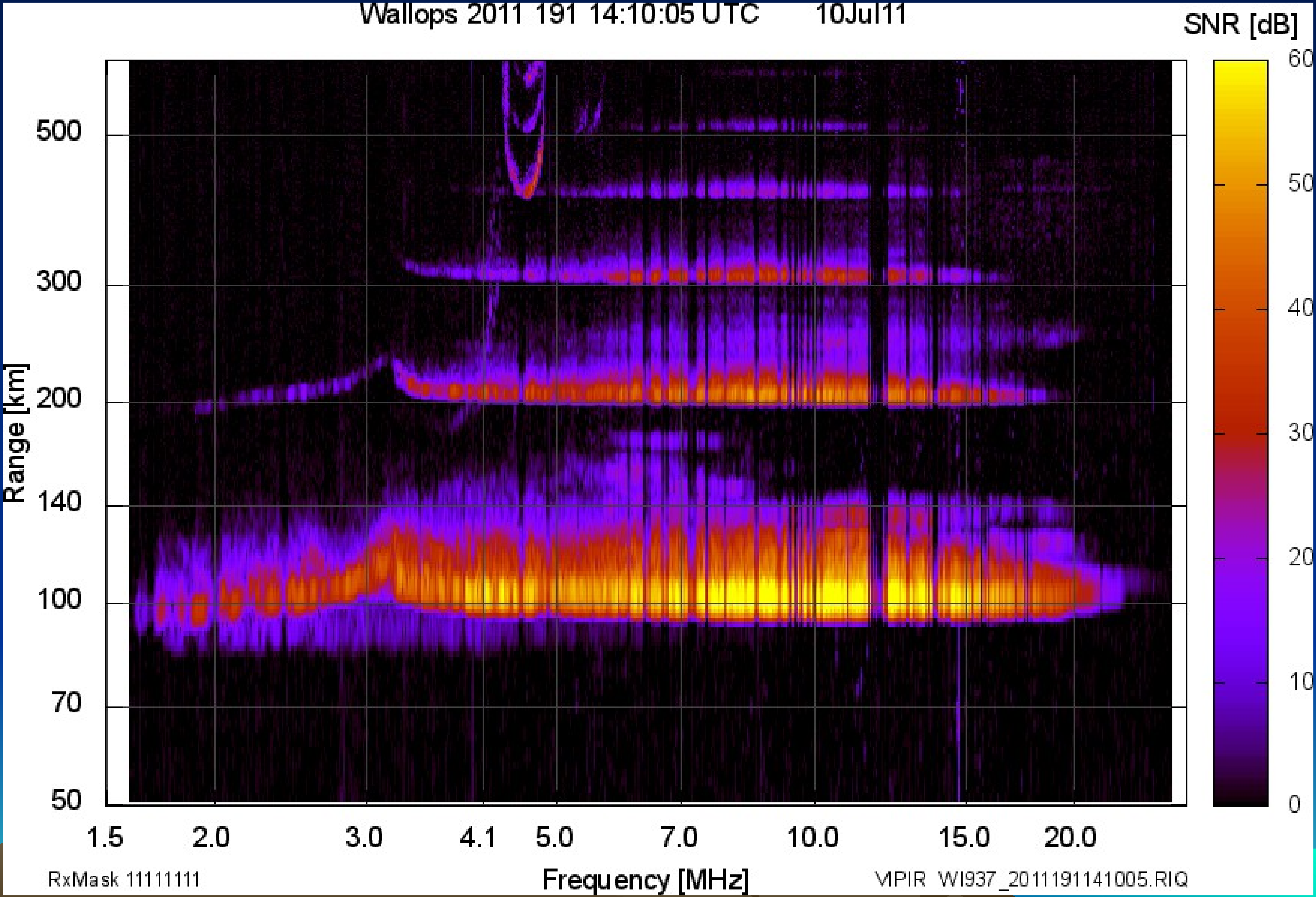
Interleave a sweep frequency ionogram with a fixed frequency HF radar observation on a pulse-by-pulse basis



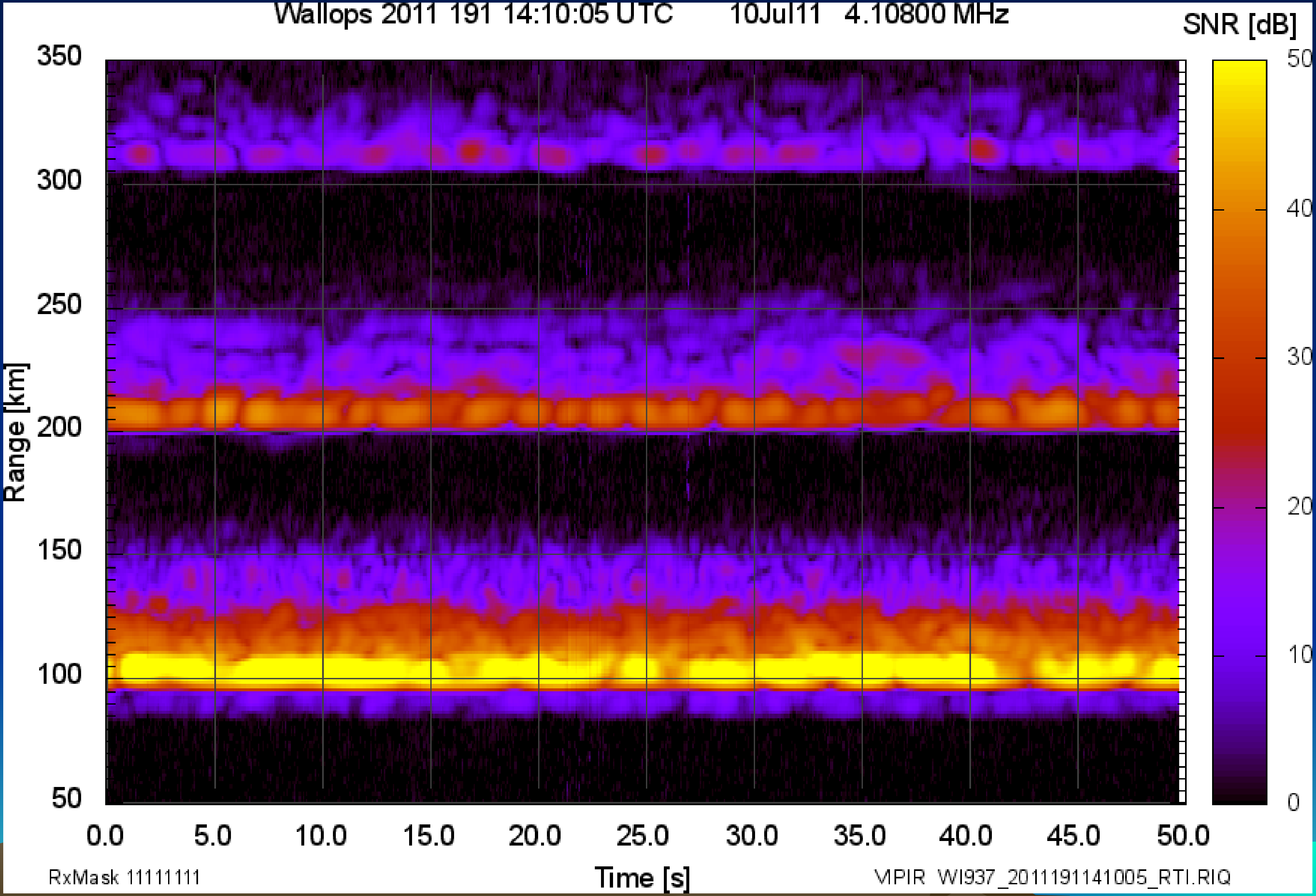
- More efficient use of radar resources
- Addresses rapid scale dynamics

200GB per day!

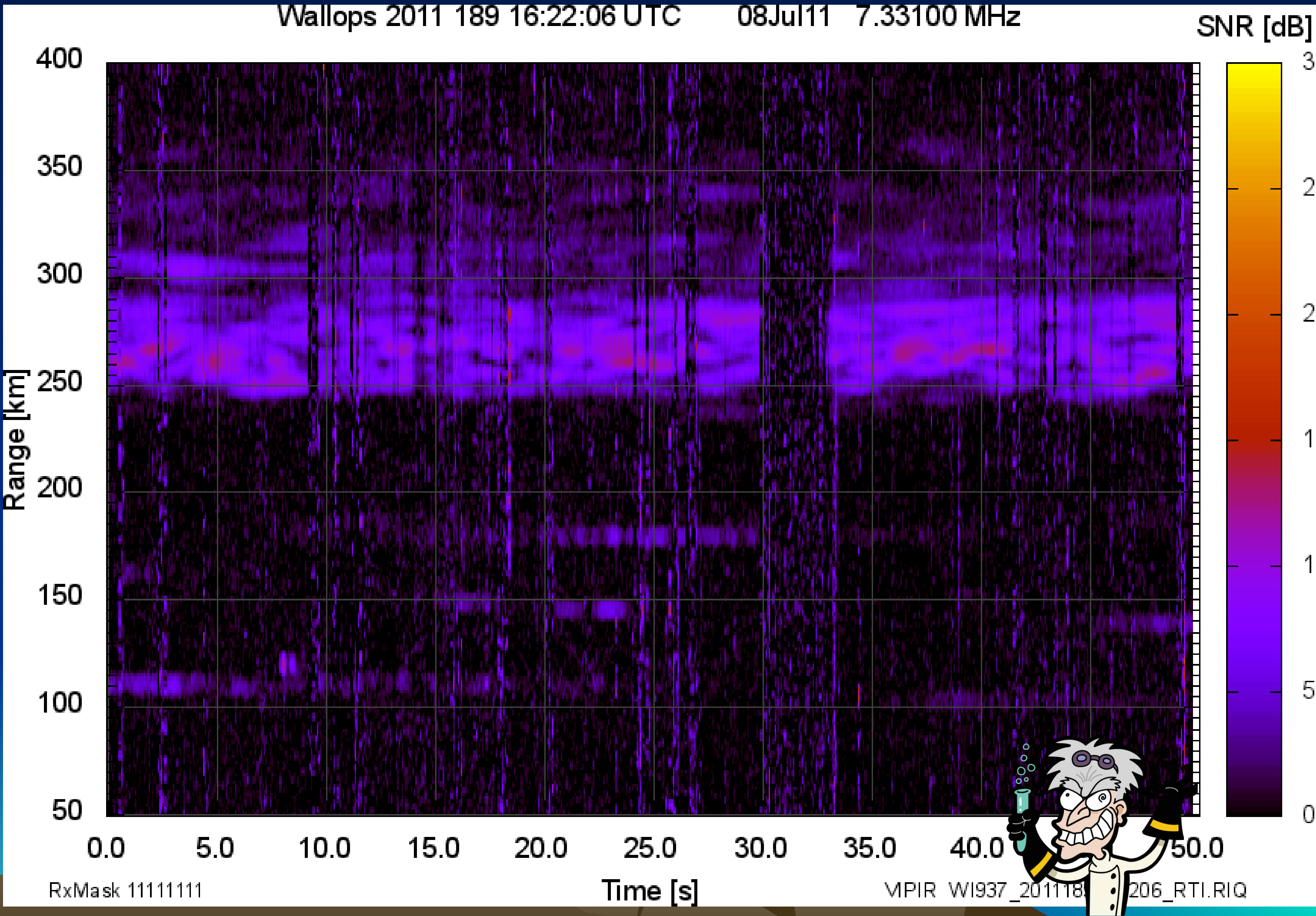
Shuffle Mode Ionogram



Shuffle Mode Fixed Frequency

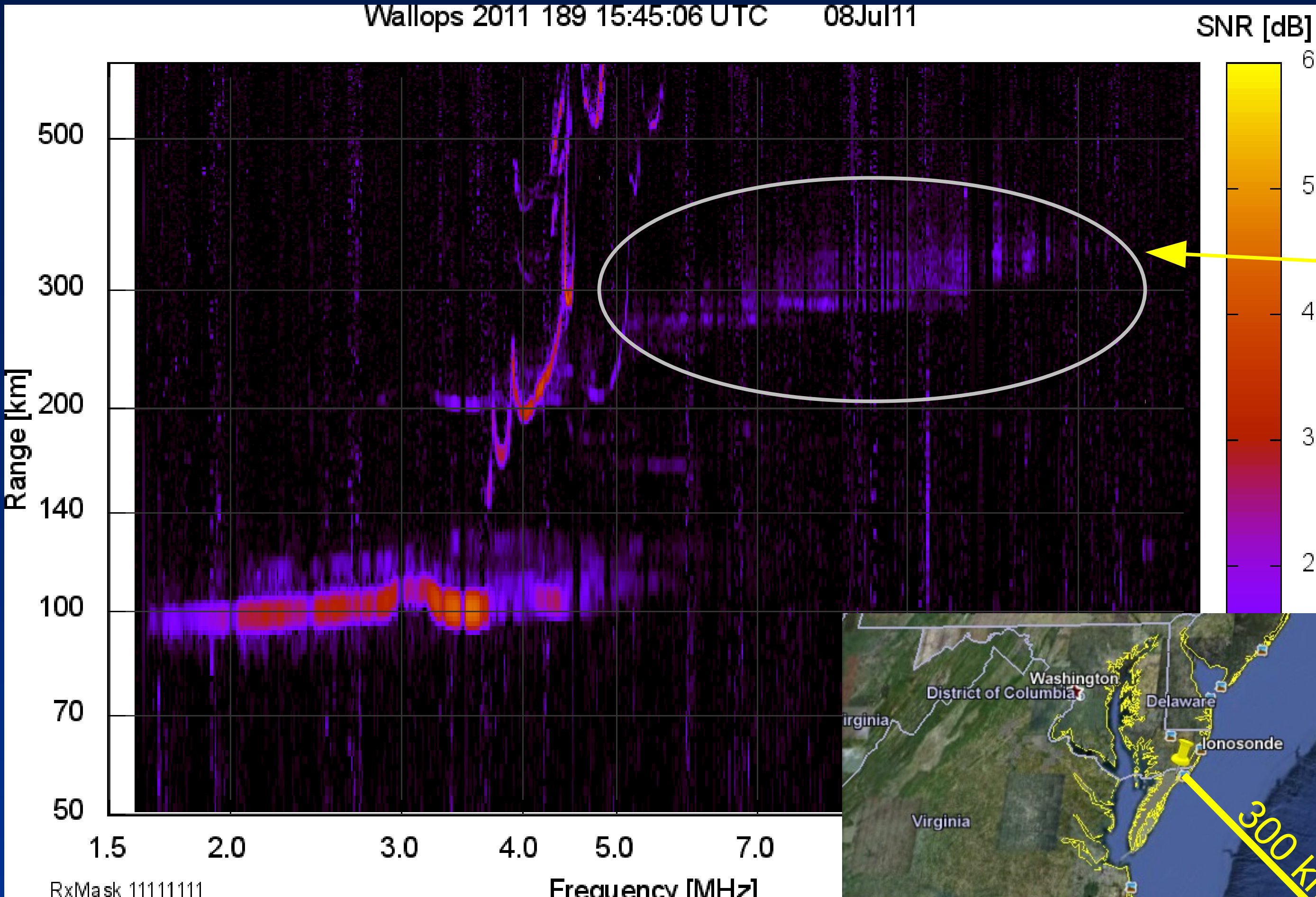


Detailed View



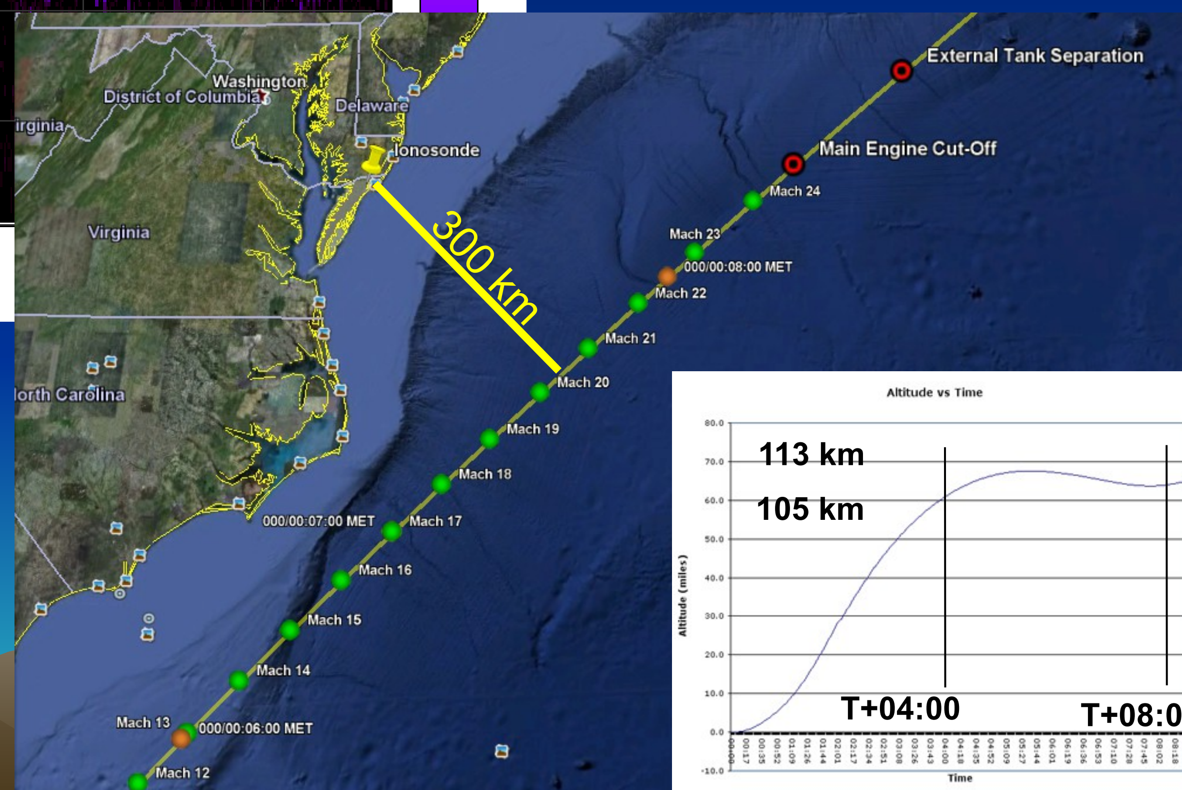
Research Opportunity

Space Shuttle Modified Ionosphere



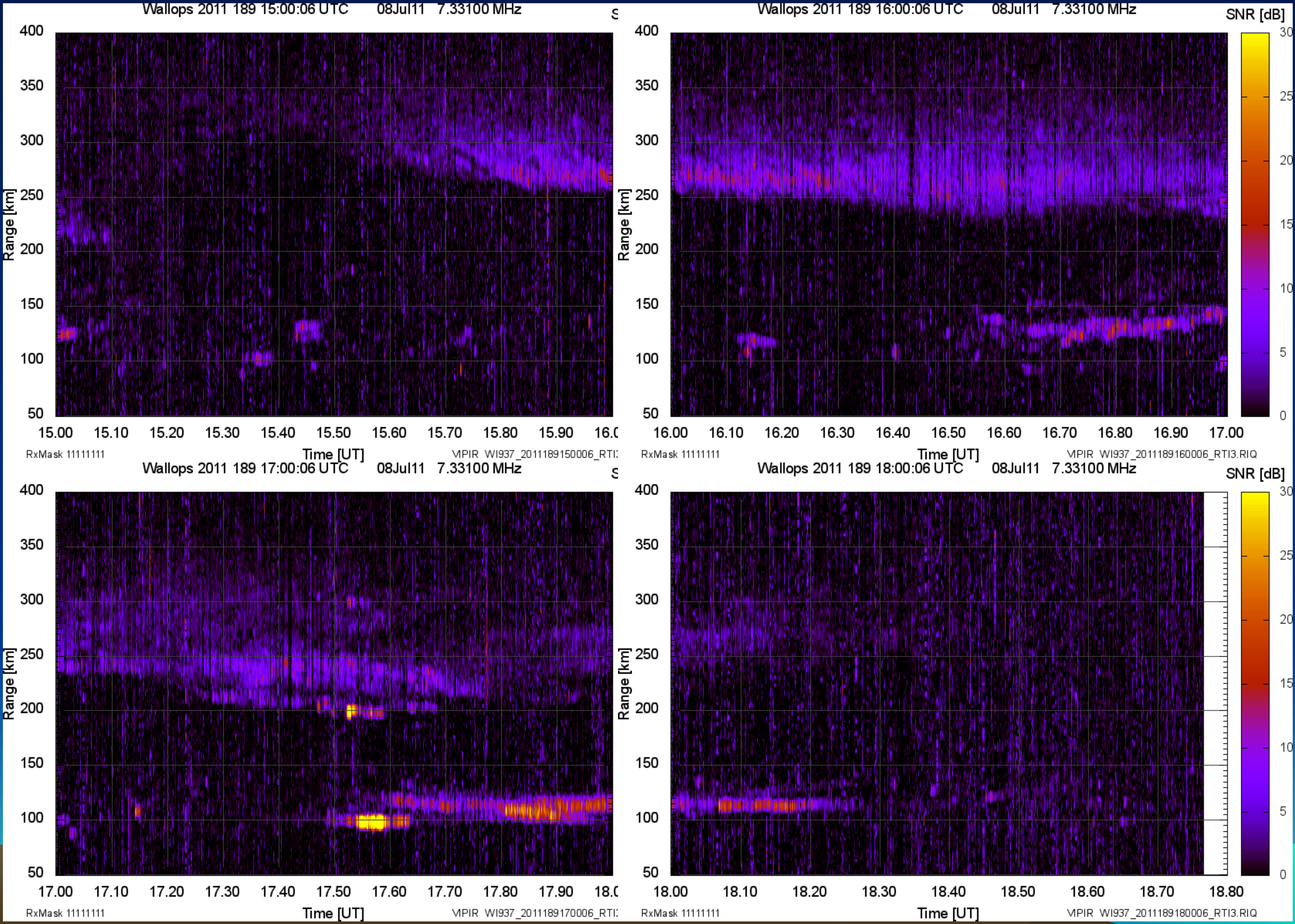
Modified Ionosphere Signature

STS-135 Trajectory



Research Opportunity

Shuttle Modified Ionosphere

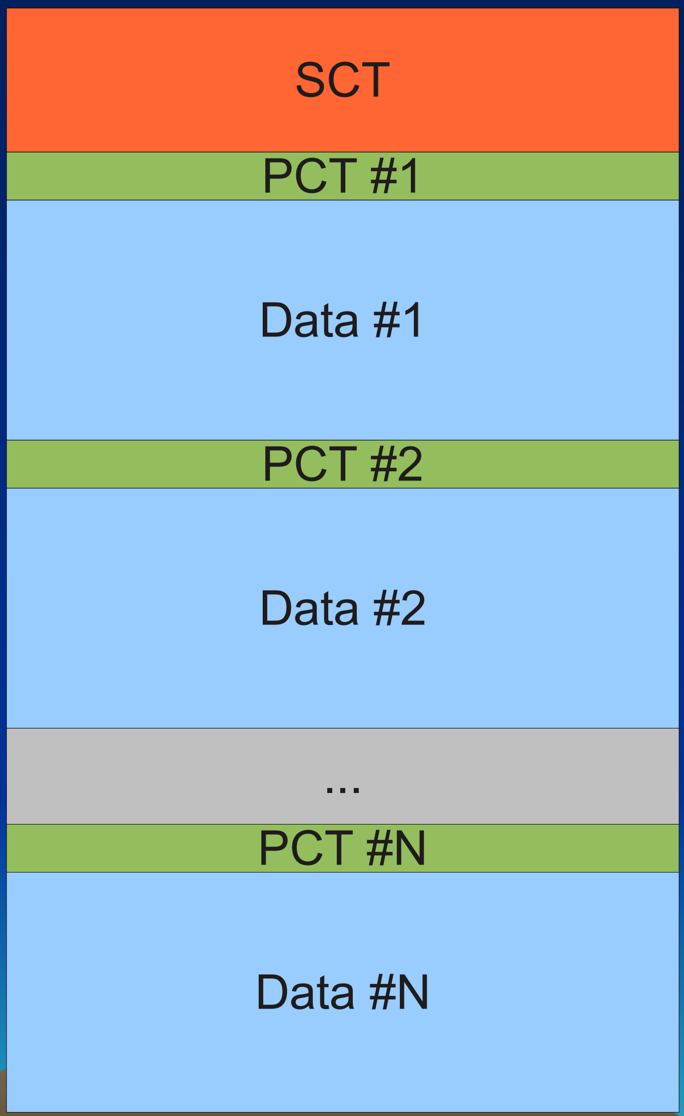


VIPIR Operation

- Operating the VIPIR radar involves editing text files and loading these files into the radar.
    - station.txt – Site specific information
    - freq_settings.txt – Frequency settings
    - timing.txt – Timing settings
    - frequency_table.txt – Arbitrary frequency table
    - ddc_setting.txt – Receiver filter settings
    - duc_settings.txt – Transmitter filter settings
- The continents of these files fill the SCT
- Mapping between these files and SCT values is straightforward

RIQ Data Format

- VIPIR data: Raw In-phase and Quadrature



- SCT: Sounding Configuration Table
  - Instrument settings (output)
  - Instrument control (input)
- PCT: Pulse Configuration Table
  - Pulse-to-pulse variable settings
- Data Block
  - 16 bit values
  - In-phase and Quadrature
  - 8 receivers
  - Requested number of range gates

Sounding Configuration Table

- Binary object used to control the radar and record the instrument settings
- C or FORTRAN structure

```
! Top level Sounding Configuration Table, Version 1.2
!
TYPE :: SCTtype
INTEGER(KIND=4) :: magic                 ! magic number 0x51495200
INTEGER(KIND=4) :: sounding_table_size   ! bytes in sounder configuration structure (this file)
INTEGER(KIND=4) :: pulse_table_size      ! bytes in pulse configuration structure
INTEGER(KIND=4) :: raw_data_size         ! bytes in raw data block (one PRI)
REAL(KIND=4)    :: struct_version        ! Format Version Number.  Currently 1.2
INTEGER(KIND=4) :: start_year            ! Start Time Elements of the ionogram (Universal Time)
INTEGER(KIND=4) :: start_daynumber       !
INTEGER(KIND=4) :: start_month           !
INTEGER(KIND=4) :: start_day             !
INTEGER(KIND=4) :: start_hour            !
INTEGER(KIND=4) :: start_minute          !
INTEGER(KIND=4) :: start_second          !
INTEGER(KIND=4) :: start_epoch           ! epoch time of the measurement start.
CHARACTER(128)  :: readme                ! Operator comment on this measurement
INTEGER(KIND=4) :: decimation_method     ! If processed, 0=no process (raw data)
REAL(KIND=4)    :: decimation_threshold ! If processed, the threshold value for the given method
CHARACTER(128)  :: user                  ! user-defined

TYPE(STATIONtype)   :: station       ! Station info substructure
TYPE(TIMINGtype)    :: timing        ! Radar timing substructure
TYPE(FREQUENCYtype) :: frequency     ! Frequency sweep substructure
TYPE(RECEIVERtype)  :: receiver      ! Receiver settings substructure
TYPE(EXCITERtype)   :: exciter       ! Exciter settings substructure
TYPE(MONITORtype)   :: monitor       ! Built In Test values substructure
```

SCT Station

```
TYPE :: STATIONtype
CHARACTER(64)    :: file_id      ! name of station settings file
CHARACTER( 8)    :: ursi_id      ! URSI standard station ID code
CHARACTER(32)    :: rx_name      ! Receiver Station Name
REAL(KIND=4)     :: rx_latitude  ! Position of the Receive array reference point [degrees North]
REAL(KIND=4)     :: rx_longitude !                                              [degrees East]
REAL(KIND=4)     :: rx_altitude  ! meters above mean sea level
INTEGER(KIND=4)  :: rx_count     ! Number of defined receive antennas
CHARACTER(32),DIMENSION(32)  :: rx_antenna_type ! Rx antenna type text descriptors
REAL(KIND=4),DIMENSION(3,32) :: rx_position     ! X,Y,Z = (East,North,Up) Positon [m] of each Rx
REAL(KIND=4),DIMENSION(3,32) :: rx_direction    ! X,Y,Z = (East,North,Up) Direction of each Rx
REAL(KIND=4),DIMENSION(32)   :: rx_height       ! Height above ground [m]
REAL(KIND=4),DIMENSION(32)   :: rx_cable_length ! physical length of receive cables [m]
REAL(KIND=4)     :: frontend_atten   ! Front End attenuator setting
CHARACTER(32)    :: tx_name          ! Transmitter Station Name
REAL(KIND=4)     :: tx_latitude      ! Position of the Transmit Antenna reference point [degrees North]
REAL(KIND=4)     :: tx_longitude     !                                                  [degrees East]
REAL(KIND=4)     :: tx_altitude      ! meters above mean sea level
CHARACTER(32)    :: tx_antenna_type ! Tx antenna type text descriptors
REAL(KIND=4),DIMENSION(3) :: tx_vector ! tx antenna direction vector [m]
REAL(KIND=4)     :: tx_height            ! antenna height above reference ground [m]
REAL(KIND=4)     :: tx_cable_length      ! physical length of transmit cables [m]
INTEGER(KIND=4)  :: drive_band_count     ! Number of antenna drive bands
REAL(KIND=4),DIMENSION(2,64) :: drive_band_bounds ! drive bands start/stop in kHz
REAL(KIND=4),DIMENSION(64)   :: drive_band_atten  ! antenna drive atteunuation in dB
INTEGER(KIND=4)  :: rf_control   ! -1 = none, 0 = drive/quiet, 1 = full, 2 = only quiet, 3 = only atten
CHARACTER(32)    :: ref_type     ! Type of reference oscillator
CHARACTER(32)    :: clock_type   ! Source of absoulte UT timing
CHARACTER(128)   :: user         ! Spare space for user-defined information
END TYPE STATIONtype
```

SCT Timing

```
! Timing of the measurement
TYPE :: TIMINGtype   ! Time values are in microseonds unless otherwise indicated
CHARACTER(64)    :: file_id           ! Name of the timing settings file
REAL(KIND=4)     :: pri               ! Pulse Repetition Interval (PRI) (microseconds)
INTEGER(KIND=4) :: pri_count          ! number of PRI's in the measurement
INTEGER(KIND=4) :: ionogram_count     ! repeat count for ionogram within same data file
REAL(KIND=4)     :: holdoff           ! time between GPS 1 pps and start
REAL(KIND=4)     :: range_gate_offset ! true range to gate 0
INTEGER(KIND=4) :: gate_count         ! Number of range gates, adjusted up for USB blocks
REAL(KIND=4)     :: gate_start        ! start gate placement [us], adjusted
REAL(KIND=4)     :: gate_end          ! end gate placement [us], adjusted
REAL(KIND=4)     :: gate_step         ! range delta [us]
REAL(KIND=4)     :: data_start        ! data range placement start [us]
REAL(KIND=4)     :: data_width        ! data pulse baud width [us]
INTEGER(KIND=4) :: data_baud_count    ! data pulse baud count
CHARACTER(64)    :: data_wave_file    ! data baud pattern file name
COMPLEX(KIND=4),DIMENSION(1024) :: data_baud ! data waveform baud pattern
INTEGER(KIND=4) :: data_pairs        ! number of IQ pairs in waveform memory
REAL(KIND=4)     :: cal_start        ! cal range placement start [us]
REAL(KIND=4)     :: cal_width        ! cal pulse baud width [us]
INTEGER(KIND=4) :: cal_baud_count    ! cal pulse baud count
CHARACTER(64)    :: cal_wave_file    ! alternative baud pattern file name
COMPLEX(KIND=4),DIMENSION(1024) :: cal_baud ! cal waveform baud pattern
INTEGER(KIND=4) :: cal_pairs         ! number of IQ pairs in waveform memory
CHARACTER(128)   :: user             ! Spare space for user-defined information
END TYPE TIMINGtype
!
```

SCT Frequency

```
TYPE :: FREQUENCYtype  ! Values are in kilohertz unless otherwise indicated
CHARACTER(64)  :: file_id       ! Frequency settings file
REAL(KIND=4)   :: base_start    ! Initial base frequency
REAL(KIND=4)   :: base_end      ! Final base frequency
INTEGER(KIND=4):: base_steps    ! Number of base frequencies
INTEGER(KIND=4):: tune_type     ! Tuning type flag:  1=log, 2=linear, 3=table, 4=ShuffleMode
REAL(KIND=4),DIMENSION(8192) :: base_table ! Nominal or Base frequency table
REAL(KIND=4)   :: linear_step    ! Linear frequency step [kHz]
REAL(KIND=4)   :: log_step       ! Log frequency step, [percent]
CHARACTER(64)  :: freq_table_id ! Manual tuning table filename
INTEGER(KIND=4):: tune_steps     ! all frequencies pre-ramp repeats
INTEGER(KIND=4):: pulse_count    ! pulset frequency vector length
INTEGER(KIND=4),DIMENSION(256) :: pulse_pattern ! pulset frequency vector
REAL(KIND=4)   :: pulse_offset   ! pulset offset [kHz]
INTEGER(KIND=4):: ramp_steps     ! pulsets per B-mode ramp (ramp length,base freqs per B-block)
INTEGER(KIND=4):: ramp_repeats   ! repeat count of B-mode ramps
REAL(KIND=4),DIMENSION(8192):: drive_table ! base frequencies attenuation/silent table
CHARACTER(128) :: user           ! Spare space for user-defined information
END TYPE FREQUENCYtype
```

SCT Receiver and Exciter

```
! Receiver Settings
TYPE :: RECEIVERtype
CHARACTER(64)    :: file_id        ! Frequency settings file
INTEGER(KIND=4) :: rx_chan        ! Number of receivers
INTEGER(KIND=4),DIMENSION(16) :: rx_map ! receiver-to-antenna mapping
INTEGER(KIND=4) :: word_format    ! 0=big endian fixed, 1=little endian, 2=floating_point
INTEGER(KIND=4) :: cic2_dec       ! DDC filter block
INTEGER(KIND=4) :: cic2_interp    ! DDC filter block
INTEGER(KIND=4) :: cic2_scale     ! DDC filter block
INTEGER(KIND=4) :: cic5_dec       ! DDC filter block
INTEGER(KIND=4) :: cic5_scale     ! DDC filter block
CHARACTER(32)    :: rcf_type       ! text descriptor of FIR filter block
INTEGER(KIND=4) :: rcf_dec        ! decimation factor for FIR filter block
INTEGER(KIND=4) :: rcf_taps       ! number of taps in FIR filter block
INTEGER(KIND=4), DIMENSION(160) :: coefficients    ! Receiver filter coefficients
REAL(KIND=4)     :: analog_delay   ! analog delay of receiver, us
CHARACTER(128)   :: user           ! Spare space for user-defined information
END TYPE RECEIVERtype
!
! Exciter Settings
TYPE :: EXCITERtype
CHARACTER(64)    :: file_id         ! Frequency settings file
INTEGER(KIND=4) :: cic_scale       ! DUC filter block
INTEGER(KIND=4) :: cic2_dec        ! DUC filter block
INTEGER(KIND=4) :: cic2_interp     ! DUC filter block
INTEGER(KIND=4) :: cic5_interp     ! DUC filter block
CHARACTER(32)    :: rcf_type        ! text descriptor of FIR filter block
INTEGER(KIND=4) :: rcf_taps        ! number of taps in FIR filter block
INTEGER(KIND=4) :: rcf_taps_phase ! number of taps in FIR filter block
INTEGER(KIND=4), DIMENSION(256) :: coefficients    ! Receiver filter coefficients
REAL(KIND=4)     :: analog_delay    ! analog delay of exciter/transmitter, us
CHARACTER(128)   :: user            ! Spare space for user-defined information
END TYPE EXCITERtype
```

SCT monitor and PCT

```
! System status and Built-In-Test info
TYPE :: MONITORtype
INTEGER(KIND=4),DIMENSION(8) :: balun_currents  ! As read prior to ionogram
INTEGER(KIND=4),DIMENSION(8) :: balun_status    ! As read prior to ionogram
INTEGER(KIND=4),DIMENSION(8) :: front_end_status! As read prior to ionogram
INTEGER(KIND=4),DIMENSION(8) :: receiver_status ! As read prior to ionogram
INTEGER(KIND=4),DIMENSION(2) :: exciter_status  ! As read prior to ionogram
CHARACTER(512) :: user                          ! Spare space for user-defined information
END TYPE MONITORtype

! Pulse Configuration Table   Version 1.2
TYPE :: PCTtype
INTEGER(KIND=4) :: record_id            ! Sequence number of this PCT
REAL(KIND=8)    :: pri_ut               ! UT of this pulse
REAL(KIND=8)    :: pri_time_offset      ! Time read from system clock, not precise.
INTEGER(KIND=4) :: base_id              ! Base Frequency counter
INTEGER(KIND=4) :: pulse_id             ! pulse set element for this PRI
INTEGER(KIND=4) :: ramp_id              ! ramp set element for this PRI
INTEGER(KIND=4) :: repeat_id            ! ramp repeat element for this PRI
INTEGER(KIND=4) :: loop_id              ! Outer loop element for this PRI
REAL(KIND=4)    :: frequency            ! Frequency of observation (kHz)
INTEGER(KIND=4) :: nco_tune_word        ! Tuning word sent to the receiver
REAL(KIND=4)    :: drive_attenuation    ! Low-level drive attenuation [dB]
INTEGER(KIND=4) :: pa_flags             ! Status flags from amplifier
REAL(KIND=4)    :: pa_forward_power     ! Forward power from amplifier
REAL(KIND=4)    :: pa_reflected_power   ! Reflected power from amplifier
REAL(KIND=4)    :: pa_vswr              ! Voltage Standing Wave Ratio from amplifier
REAL(KIND=4)    :: pa_temperature       ! Amplifier temperature
INTEGER(KIND=4) :: proc_range_count     ! Number of range gates kept this PRI
REAL(KIND=4)    :: proc_noise_level     ! Estimated noise level for this PRI
CHARACTER(64)   :: user                 ! Spare space for user-defined information
END TYPE PCTtype
```

Floating Point Output

- Digital Down-converter AD6624 has internal 24 bit RAM Coefficient Filter (RCF)
- USB2 interface limits raw data to 16 bits per I/Q sample
- Current software reports 16 bit signed integer
- Floating point mode is tested
  - 12 bit mantissa + 4 bit exponent
- Increases Theoretical dynamic range from 90dB to 138dB
  - Better noise observations
  - Improves strong interference tolerance

RCF Mapping

23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

24 bit RCF

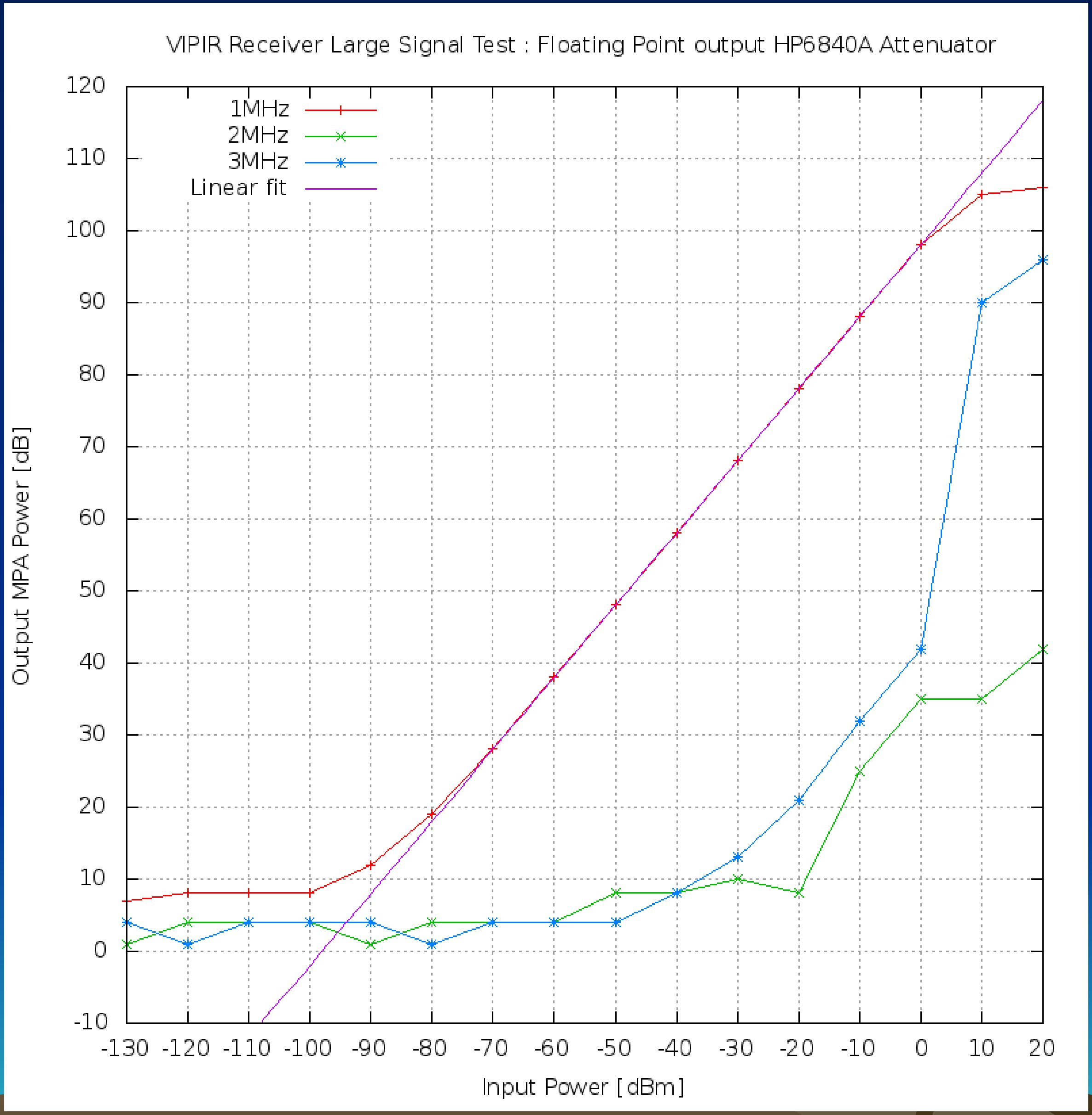
x	x	x	x	x	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	x	x	x

16 Bit Fixed

M11	M10	M9	M8	M7	M6	M5	M4	M3	M2	M1	M0	E3	E2	E1	E0

12+4 Floating Point

Large Signal Tests



Internal noise is +10 dB

Peak signals are +105 dB

Linear range +5 to +105 dB

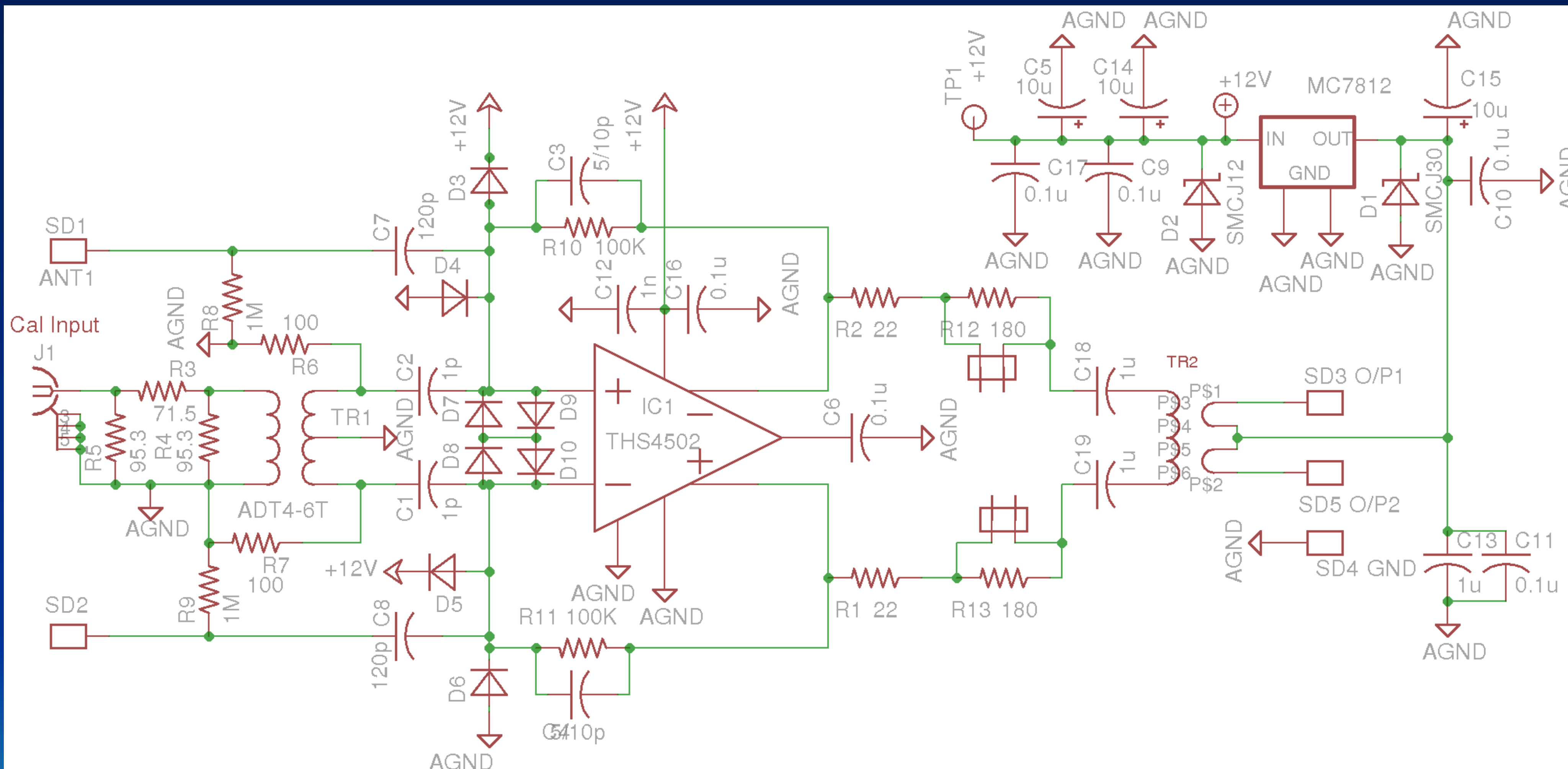
Minimum signal is -10 dB

Noise is not severely quantized

End of Section 3

Questions?

Preamp Calibration



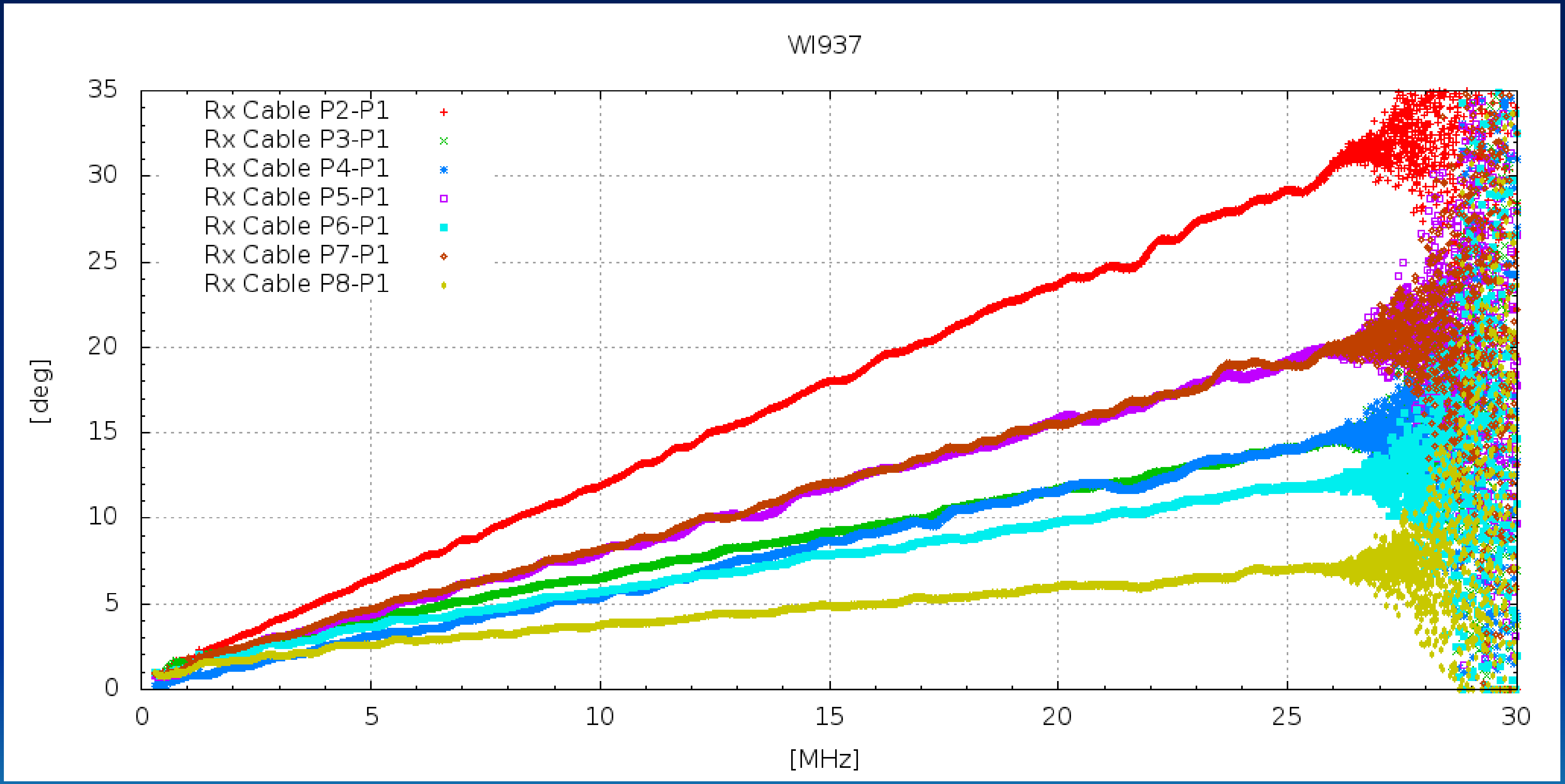
Phase Calibration

- Internal calibration signal is inserted into the far end of each receive cable or receiver preamplifier with a common cable
- First performed at San Juan with Dr. Zabotin
  - Discovered DC bias problem
  - Discovered and Repaired Receiver Impedance problem
- Receive cables trimmed to match phase response.
- Wallops: Phase error < 1º at 20 MHz
- To Do
  - Apply to Boulder
  - Re-visit San Juan

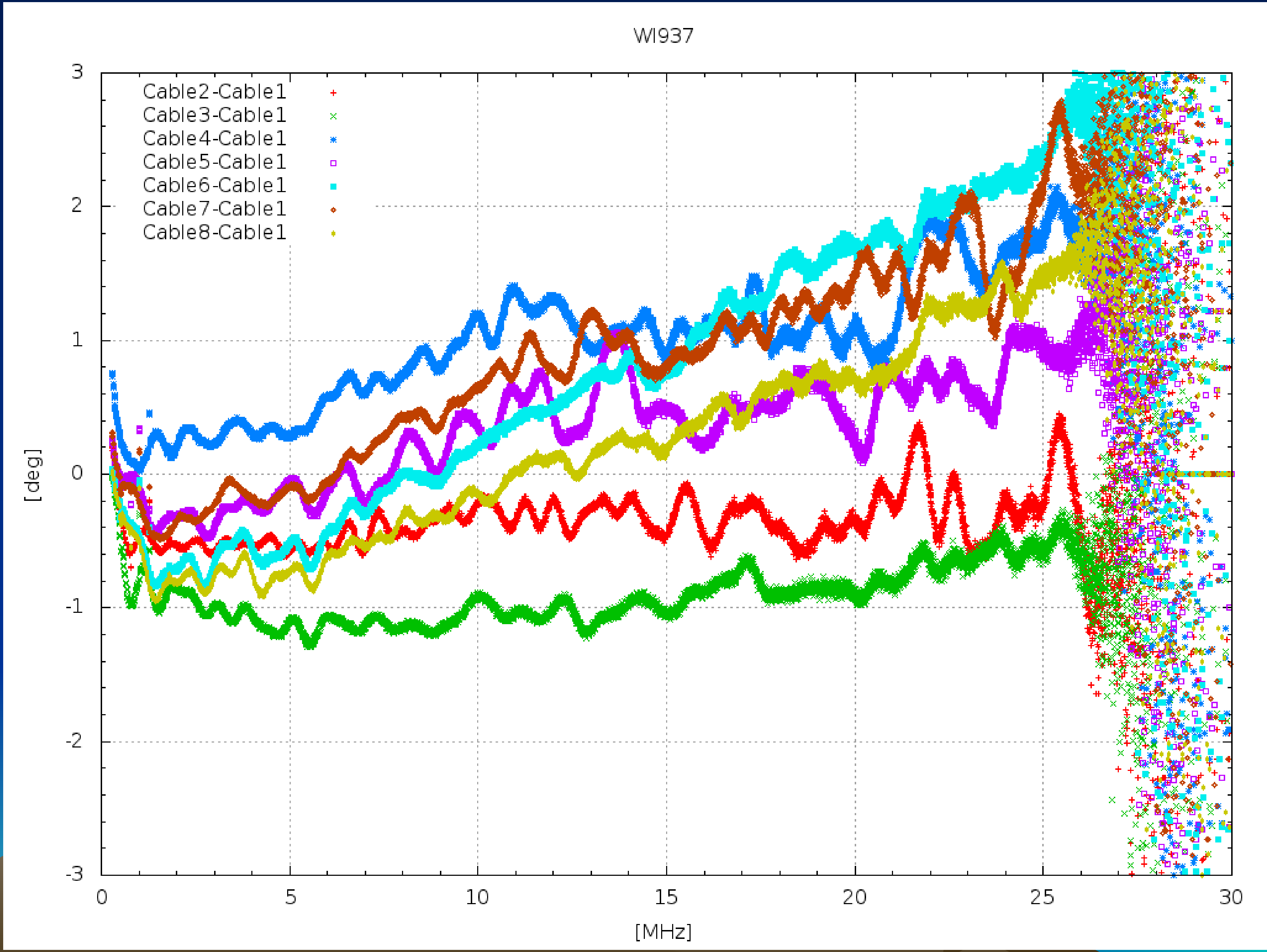
San Juan, Puerto Rico

San Juan upgrade and calibration
April 2013

Wallops Rx Cables: Before

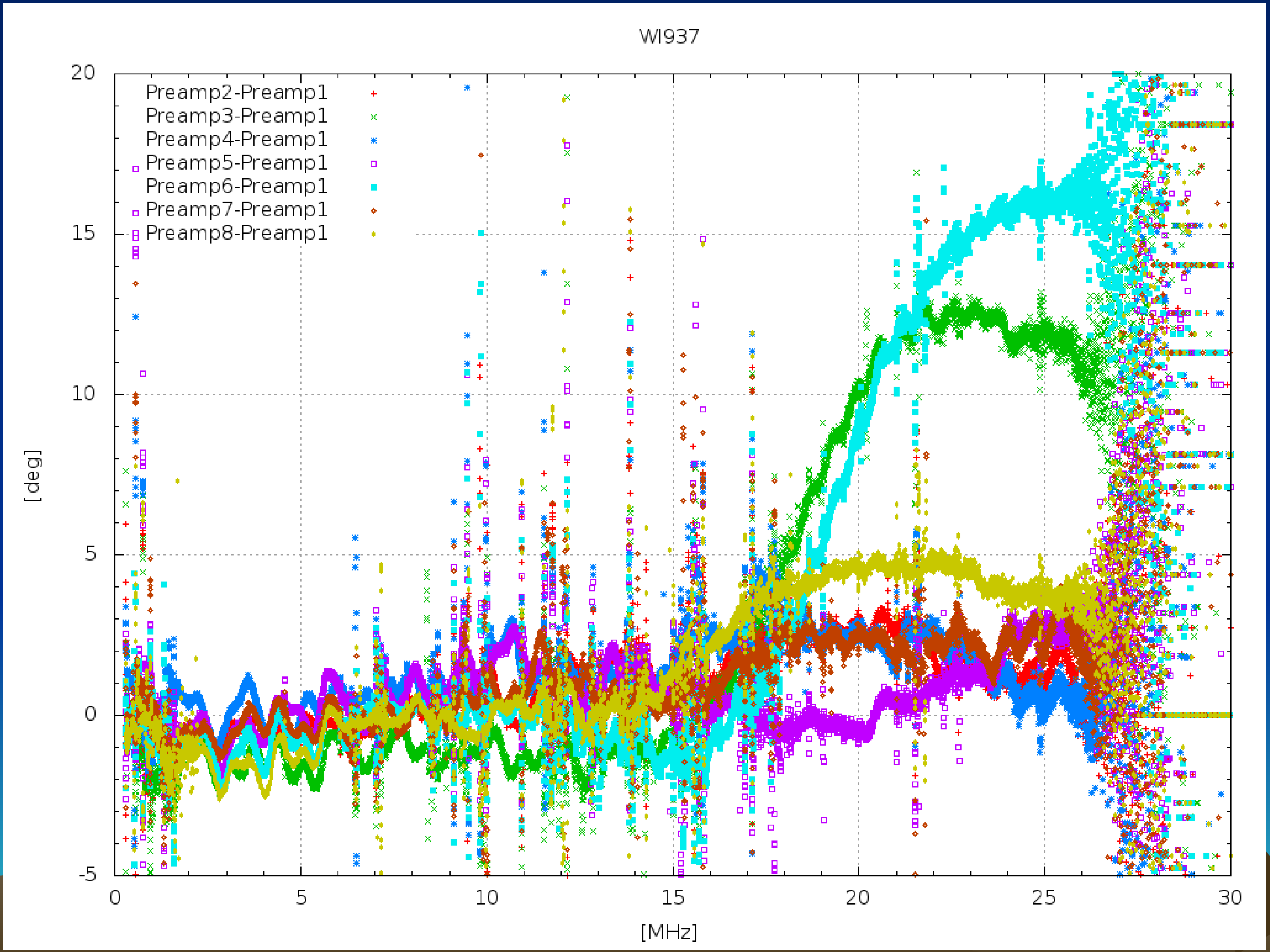


Wallops Rx Cables: After



Total Field Calibration

- Total calibration of all 8 receive antennas
- #3 and #6 are outliers above 18 MHz

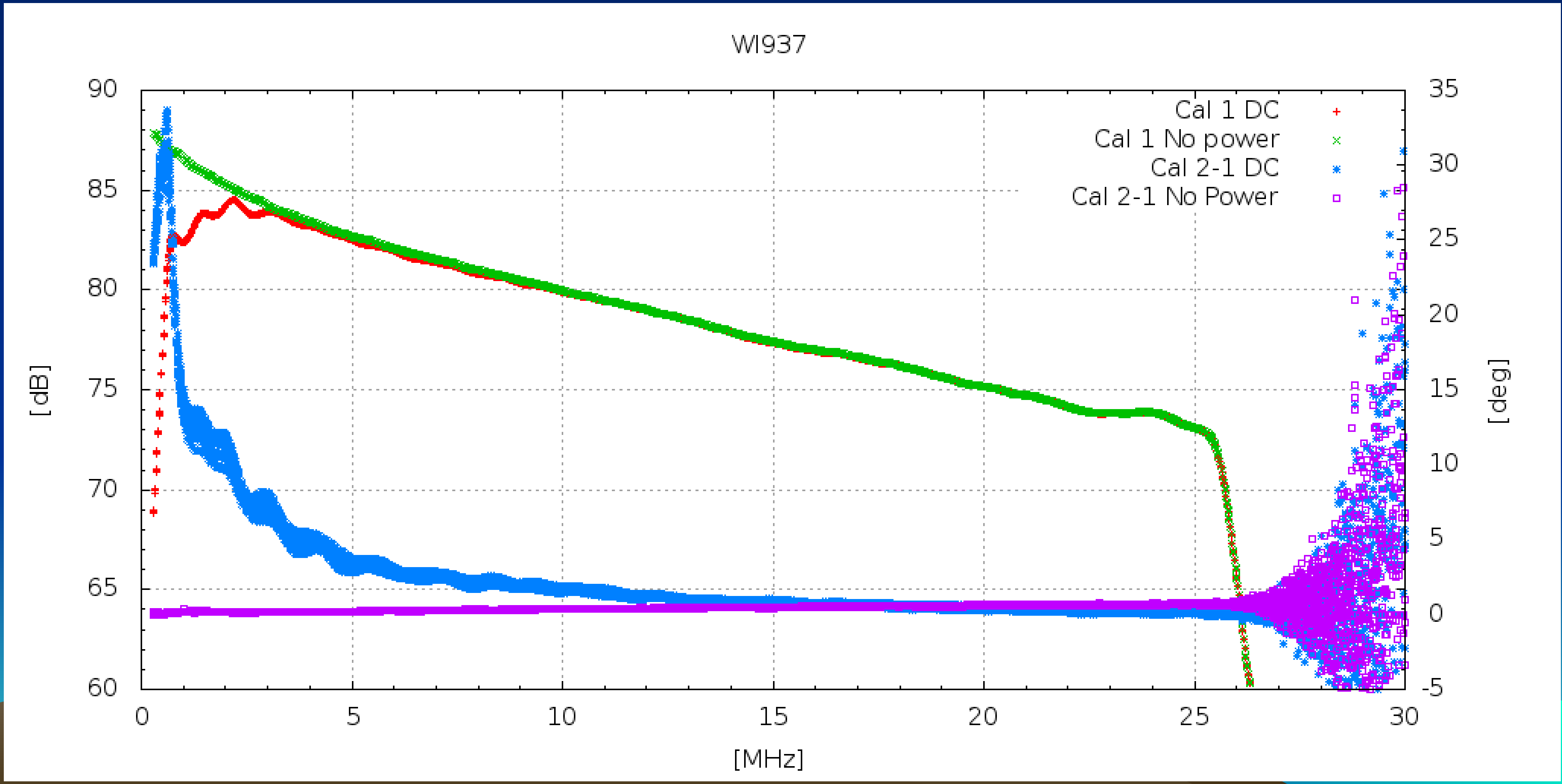


Wallops field calibration data show phase differences within +/- 2 degrees up to 17 MHz.

F region traces are not often observed above ~12 MHz.

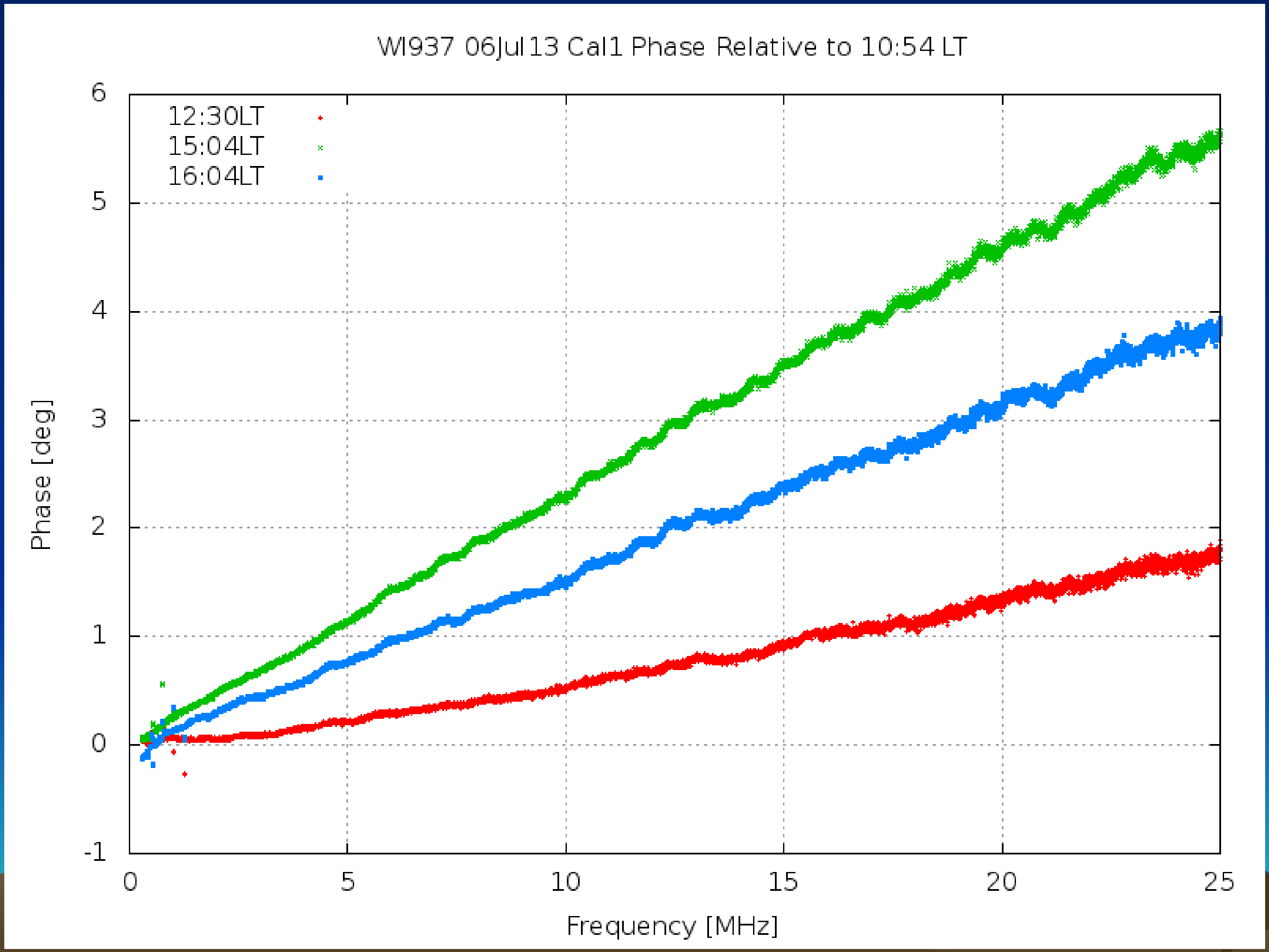
DC bias in Calibration Circuit

- Preamplifier DC return current through calibration circuit saturated the RF signal splitters.
- Installing DC blocks resolved the issue.



Temperature Sensitivity of Rx Cables

- Wallops calibrations showed strong variability
- Temperature is suspected



Wallops cal data for the same Rx twinax cable at three different times relative to a 4th measurement.

Lab measurements have confirmed this temperature response.

Electrical length change is -0.0026% per ºC

Calibration objectives are ~ 0.007%

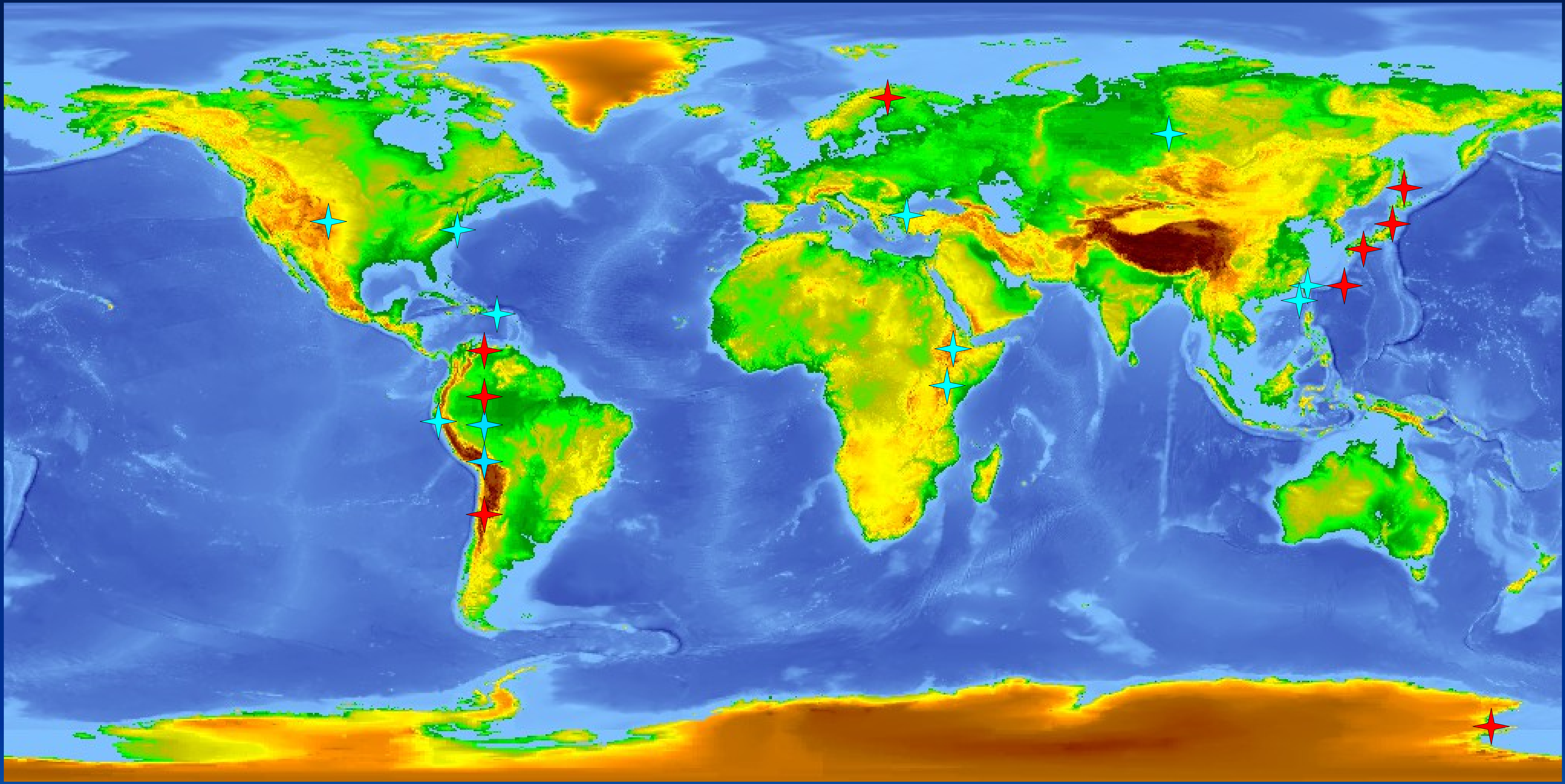
Some options are being considered

Free VIPIR Software

- riq-ionogram - Terry Bullett
    - FORTRAN-95 Linux Version 2.07 in development
    - Operational code for plots and NetCDF
- Plot-VIPR – Dick Grubb
    - Matlab program to make images
- Get_data_simple – Dick Grubb
    - Matlab read subroutine, for teaching
- riq_idl   – Justin Mabie
    - IDL raw data reader, for teaching

ftp://ftp.ngdc.noaa.gov/ionosonde/software/VIPIR/

VIPIR Facilities



Current (13)   Planned (9)

Updated June 2013

Science and Engineering Needs

- Improved dynamic range → 16 bit ADC
- Greater data bandwidth → USB3
- More Digital Filters
- Manual Ionogram Analysis Software
- Echo Detection and Parametrization
- Improved Ionogram Scaling
- Amplitude and Phase Calibrations
- Improved data collection → continuous
- Super-resolution direction finding & plasma imaging
- Interference removal

Internet Resources

- World Data Center A, Boulder: http://www.ngdc.noaa.gov/stp/IONO/ionohome.html
- Digisondes and ARTIST : http://ulcar.uml.edu/
- Autoscala: http://roma2.rm.ingv.it/en/facilities/software/18/autoscala
- ESIR : http://www.spacenv.com/
- Dynasonde21: Bill.Wrightster@gmail.com
- Low-latitude Ionospheric Sensing System: http://jro.igp.gob.pe/lisn/
- Vertical Incidence Pulsed Ionosphere Radar (VIPIR): Terry.Bullett@noaa.gov
- Canadian Advanced Digital Ionosonde (CADI): http://cadiweb.physics.uwo.ca/
- Ionospheric Prediction Services (IPS): http://www.ips.gov.au/
- Ionosonde Network Advisory Group (INAG) http://www.ips.gov.au/IPSHosted/INAG/
- SPIDR: http://spidr.ngdc.noaa.gov/spidr/index.jsp

Credits

- Jicamarca Radio Observatory
- Korean Polar Research Institute
- NICT, Japan
- National Central University, Taiwan
- NOAA National Geophysical Data Center
- NASA Wallops Island Flight Facility
- US Geological Survey
- US Air Force Research Laboratory
- INGV, Italy
- IPS, Australia
- Boston College
- Scion Associates
- All ionosonde data producers who freely share their data!