Introduction to Ionospheric Sounding for Hams

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In Cooperation with:
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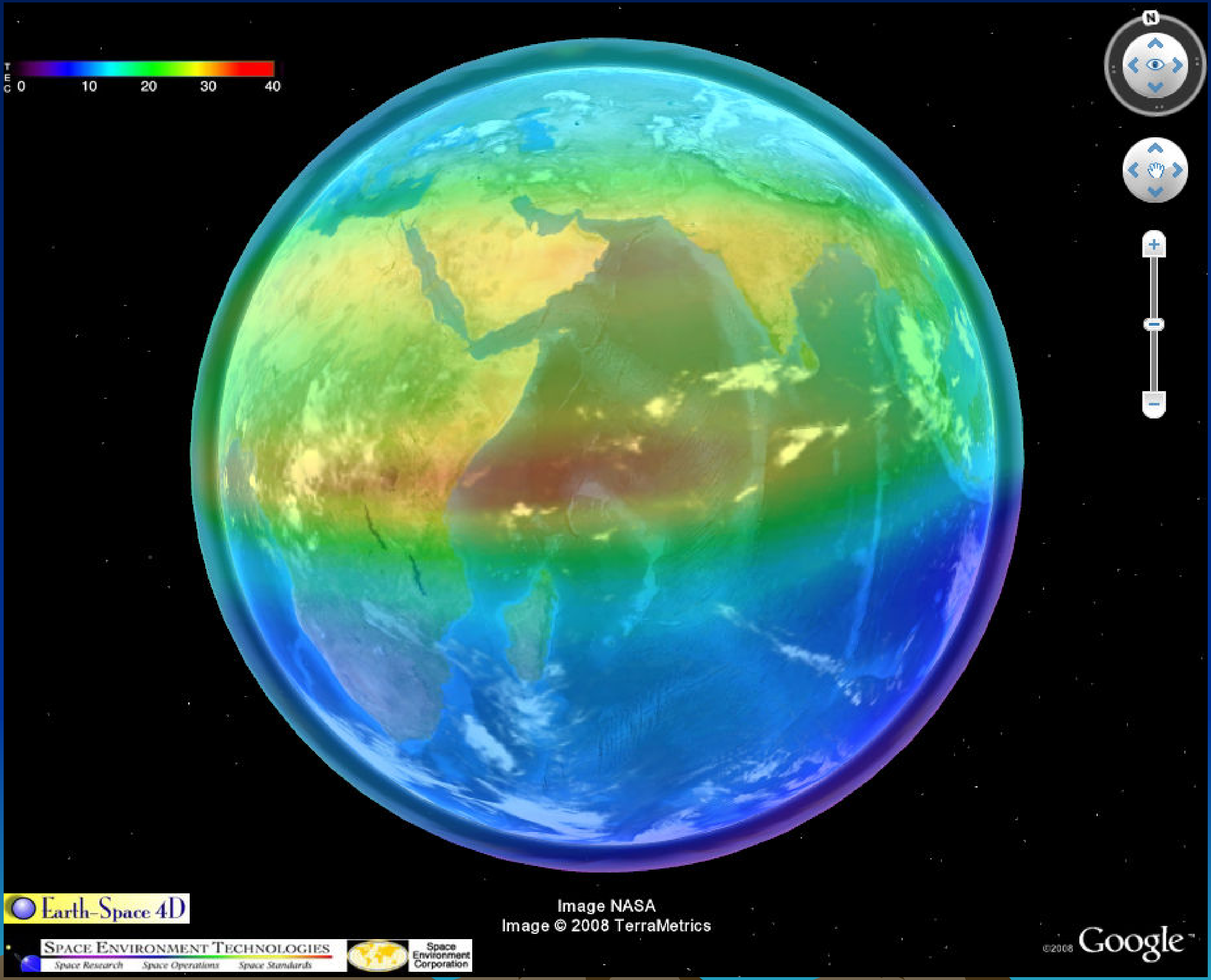
National Centers for Environmental Information
Solar and Terrestrial Physics Division

Outline

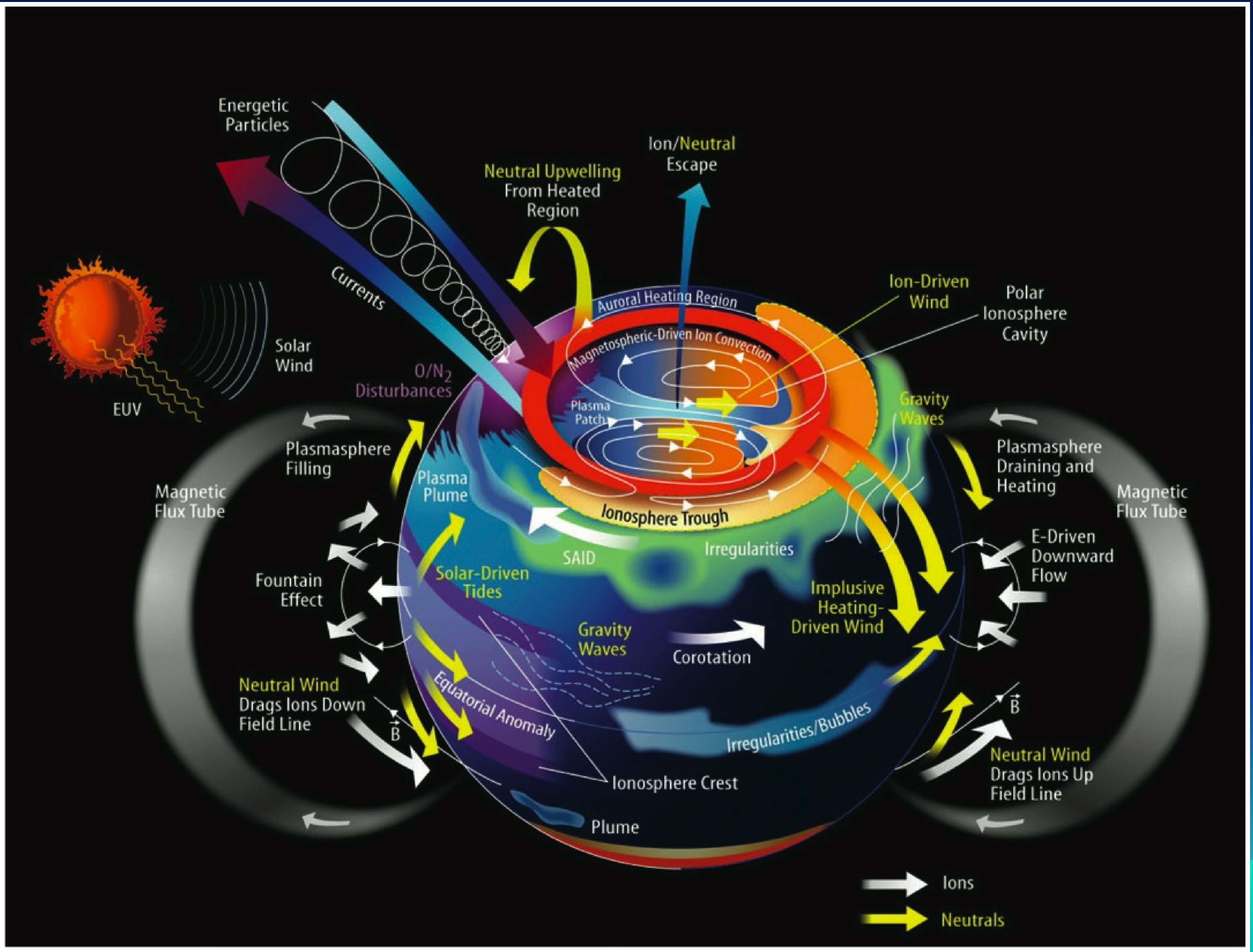
- Earth's Ionosphere
- Propagation in Plasma
- Ionosondes
- Ionograms
- Applications
- Data

Research Opportunity

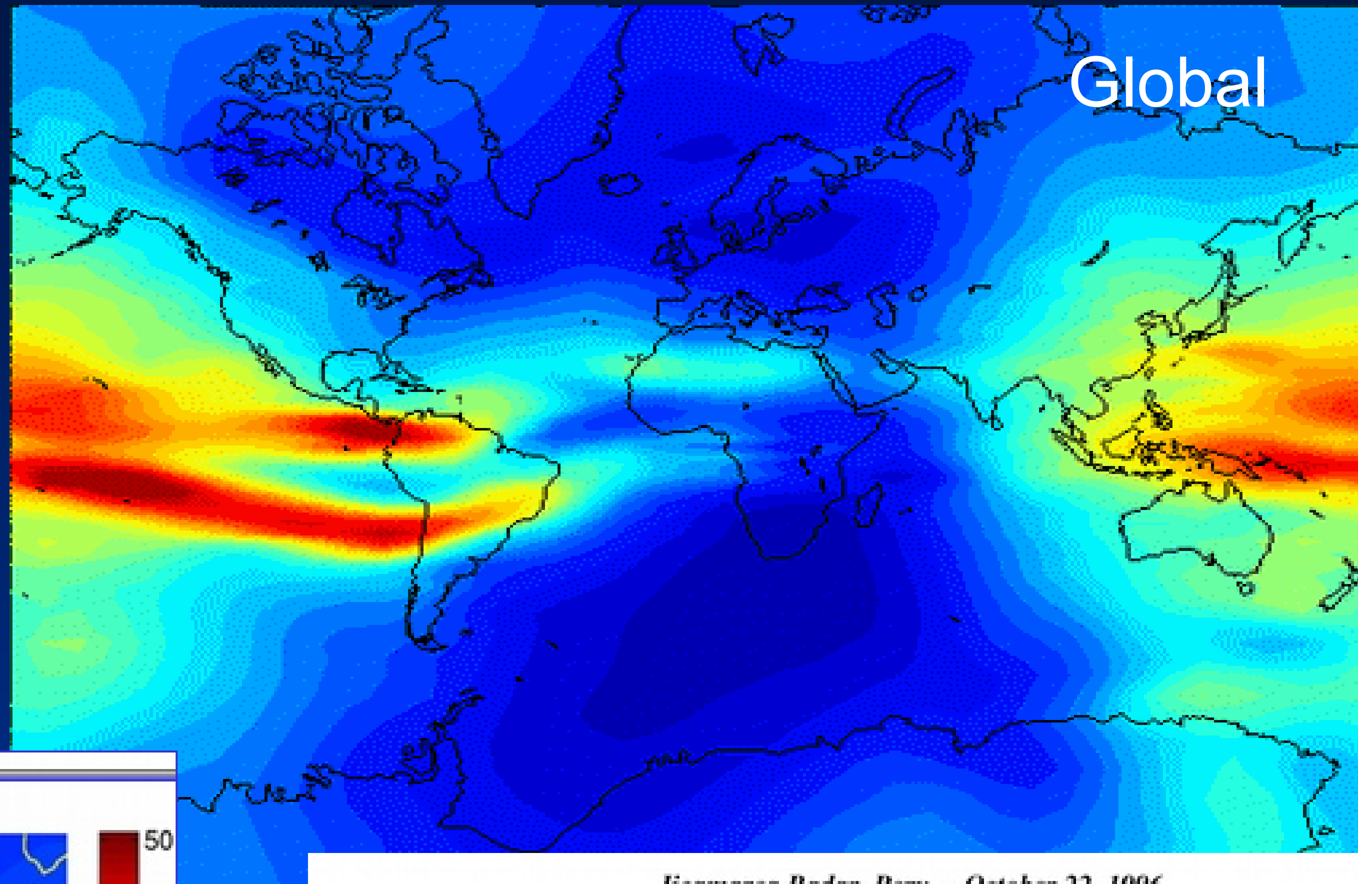
Introduction to the Ionosphere



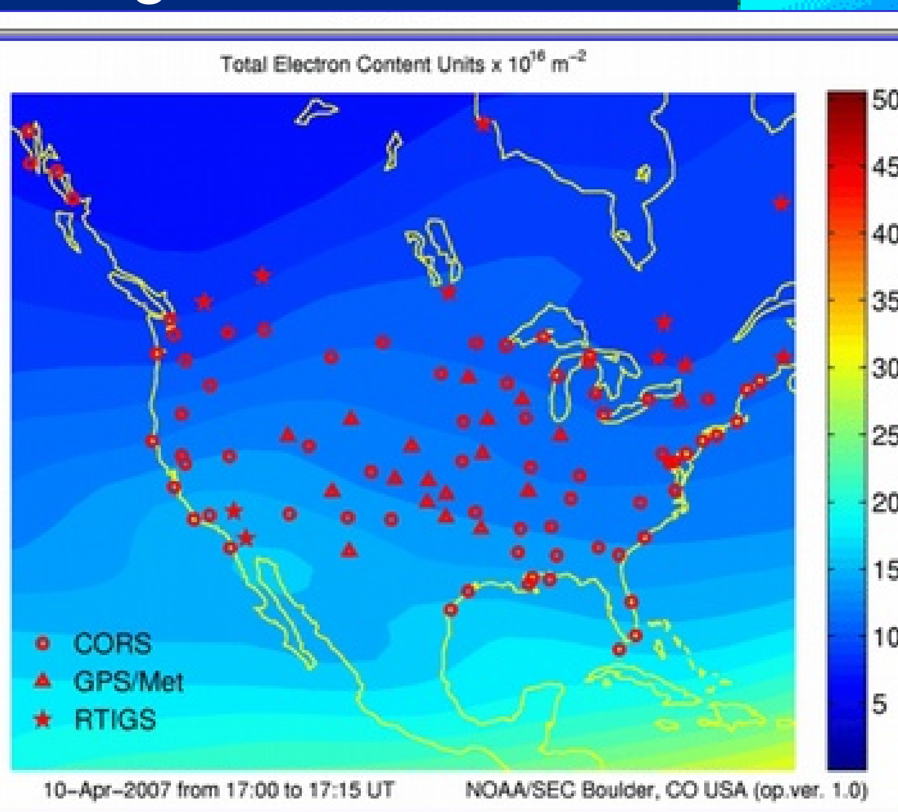
Ionospheric Processes

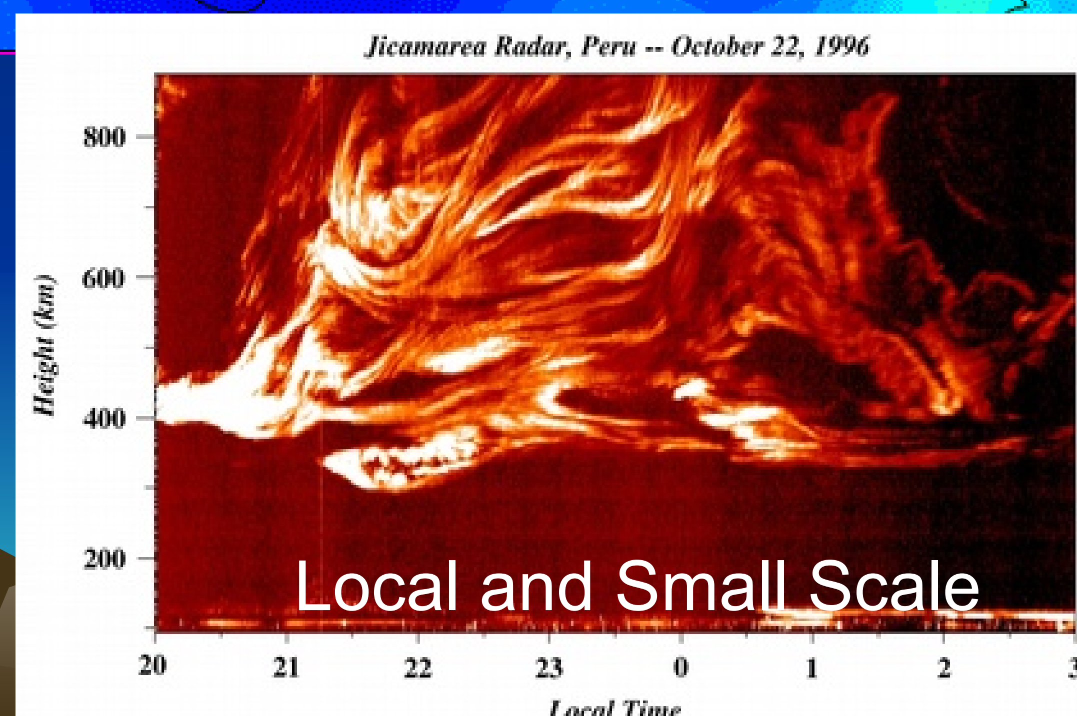


Ionosphere Structure



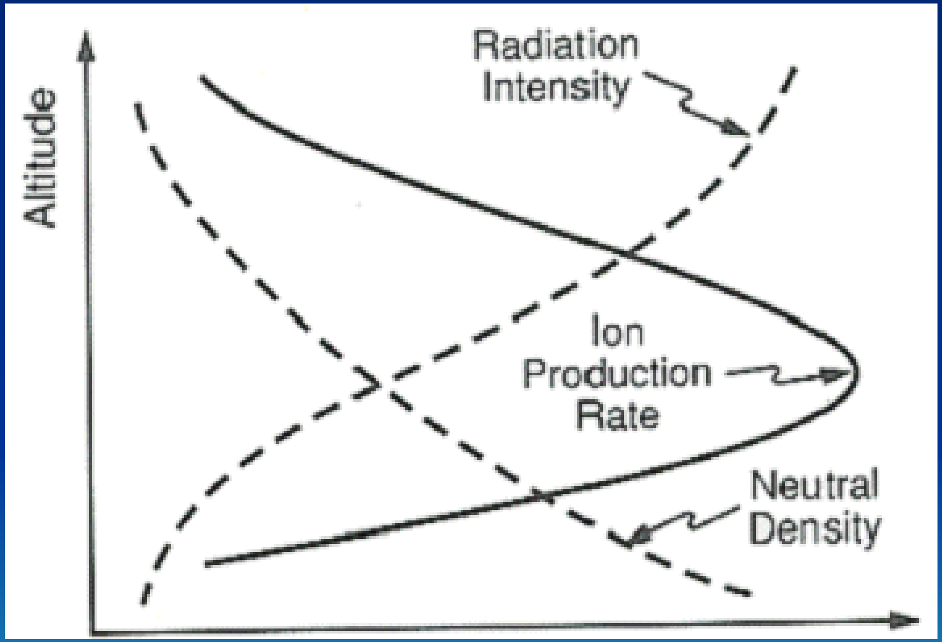
Regional





Earth's Ionosphere

- Occupies the same space as the thermosphere
- 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
- Forcing from below

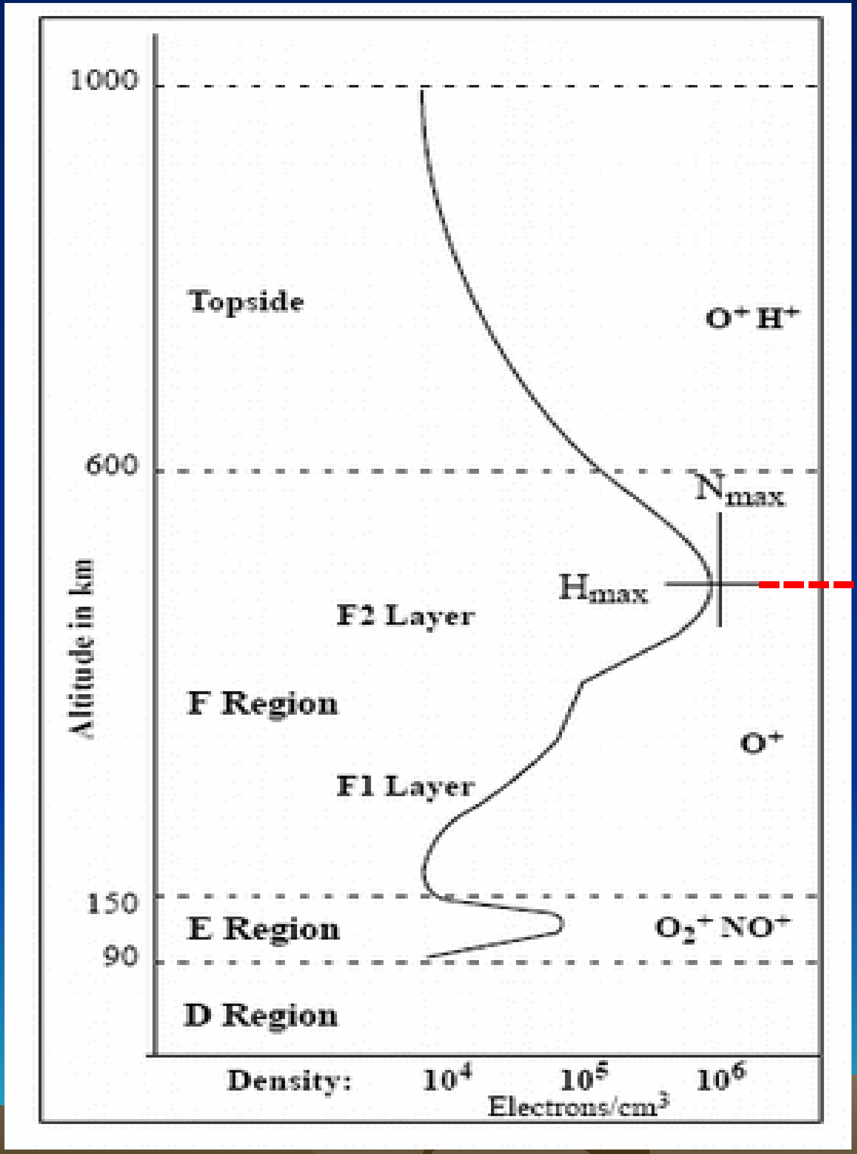


Ionosphere Vertical Electron Density Profile

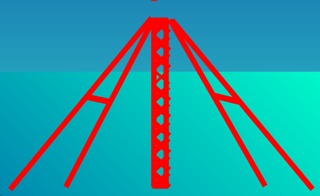
The F2 region varies by 3-5X diurnally, highest just after noon, lowest before dawn.

The F1 region and E region dissipate at night.

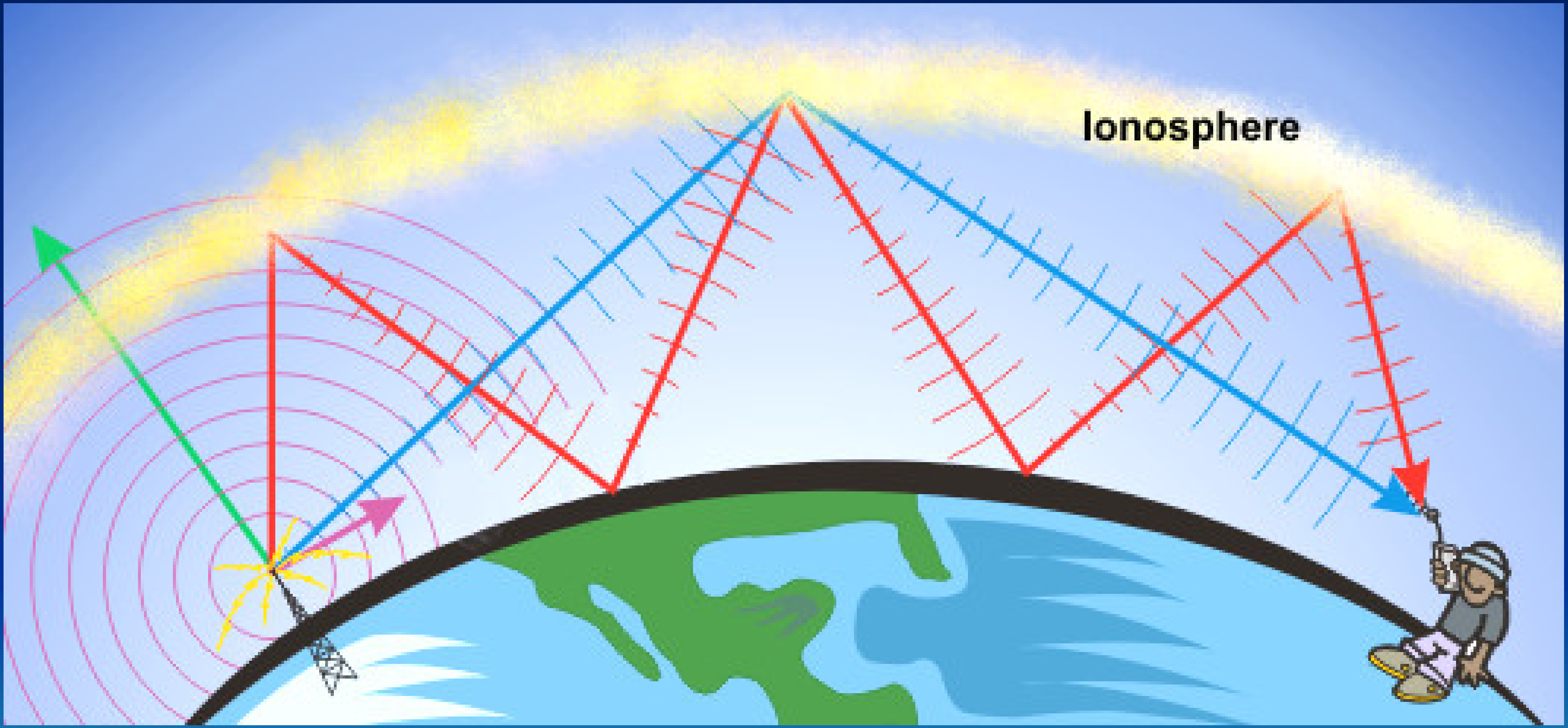
The D region is present only during daytime and in times of high activity.



Ionosondes Measure Up To H_{max}



Ionosphere Radio Propagation



http://www.srh.noaa.gov/jetstream/atmos/ionosphere_max.htm

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

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

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

Propagation slows dramatically when $f_p \to f\,;\, \mu \to 0$

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

After *Davies, 1965*

Propagation with a Magnetic Field

A magneto-plasma is birefringent

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

A magneto-plasma is anisotroptic

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:

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

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

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

Reflection occurs when

$f_p = f$ (Ordinary wave)

$X = 1 - Y$

$X = 1 + Y$ (eXtraordinary waves)

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

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

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

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*

Ionosonde History

- The first radar, invented in 1926
- Used to measure the height of the ionosphere
- Bi-static “chirp” and <u>mono-static “pulse”</u> varieties
- Longest ionosphere climate record
- ~ 100 Vertical Incidence ionosondes worldwide
- New technologies have evolved the ionosonde:
    - High power solid-state electronics
    - Data display and recording
    - Antennas
    - Computers & Digital Signal Processing
    - Software Defined Receivers

Ionosondes


HuaLien
(NCU)


Ascension Island (AFRL)


Bear Lake (USU)


Addis Ababa
(AAU)

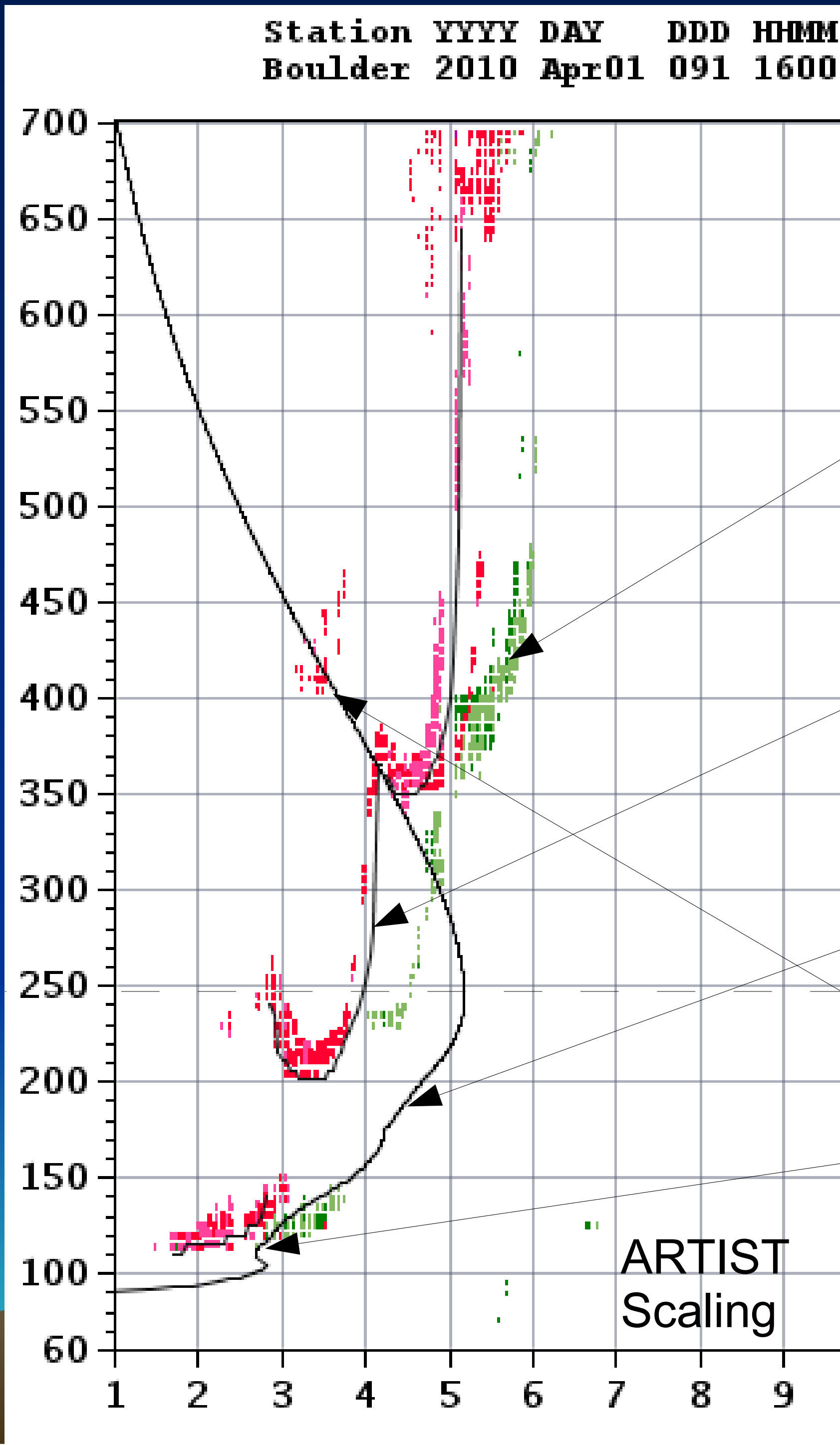

Sondrestrom (AFRL)


Nuie Island (IPS)


Stanley, Falklands (RAL)

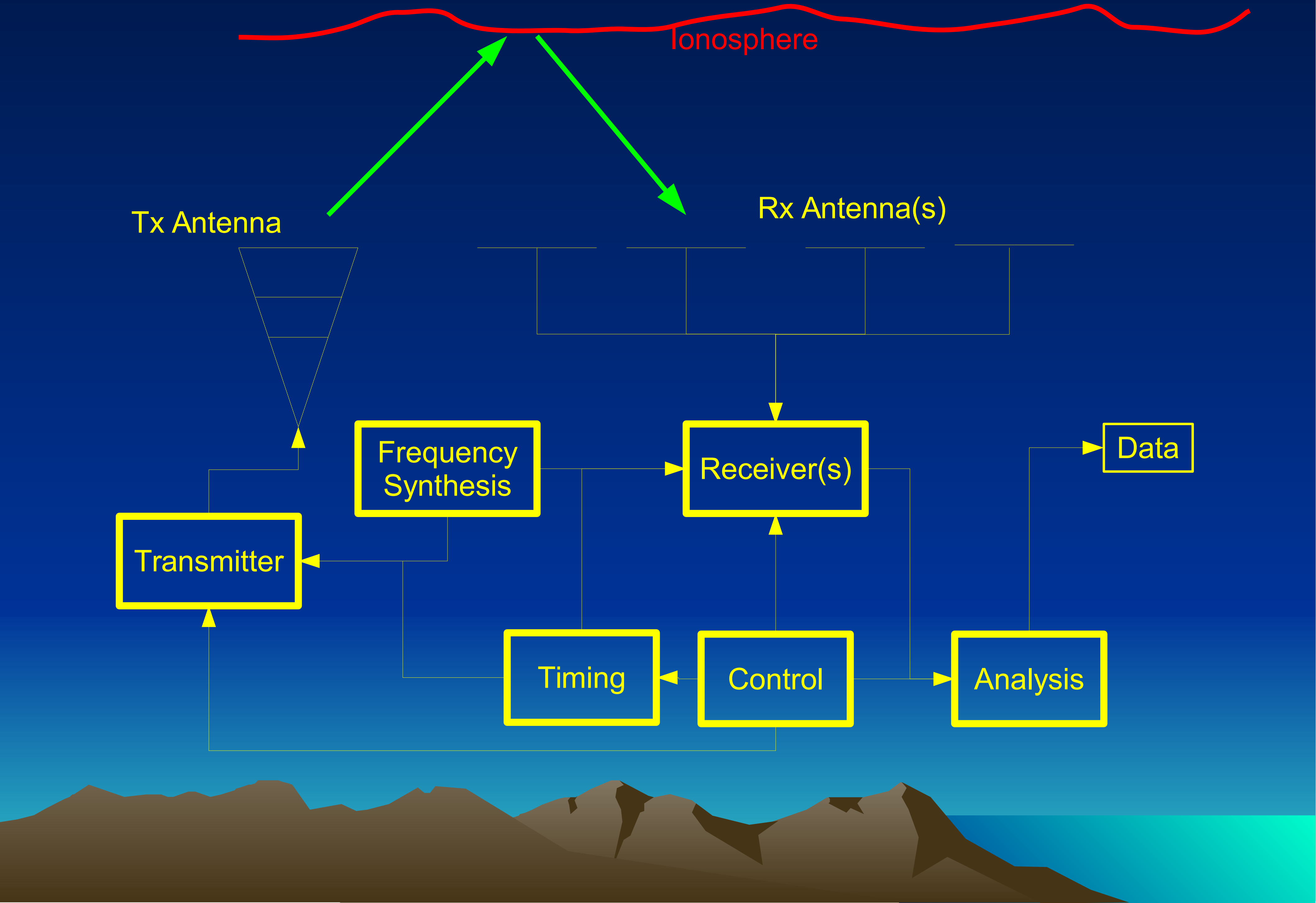

PIR-9 (May 1987 - March 2008)
DPS-4 (1st April 2008 - today)
Pakistan (SUPARCO)

What is an Ionosonde and what does it do?

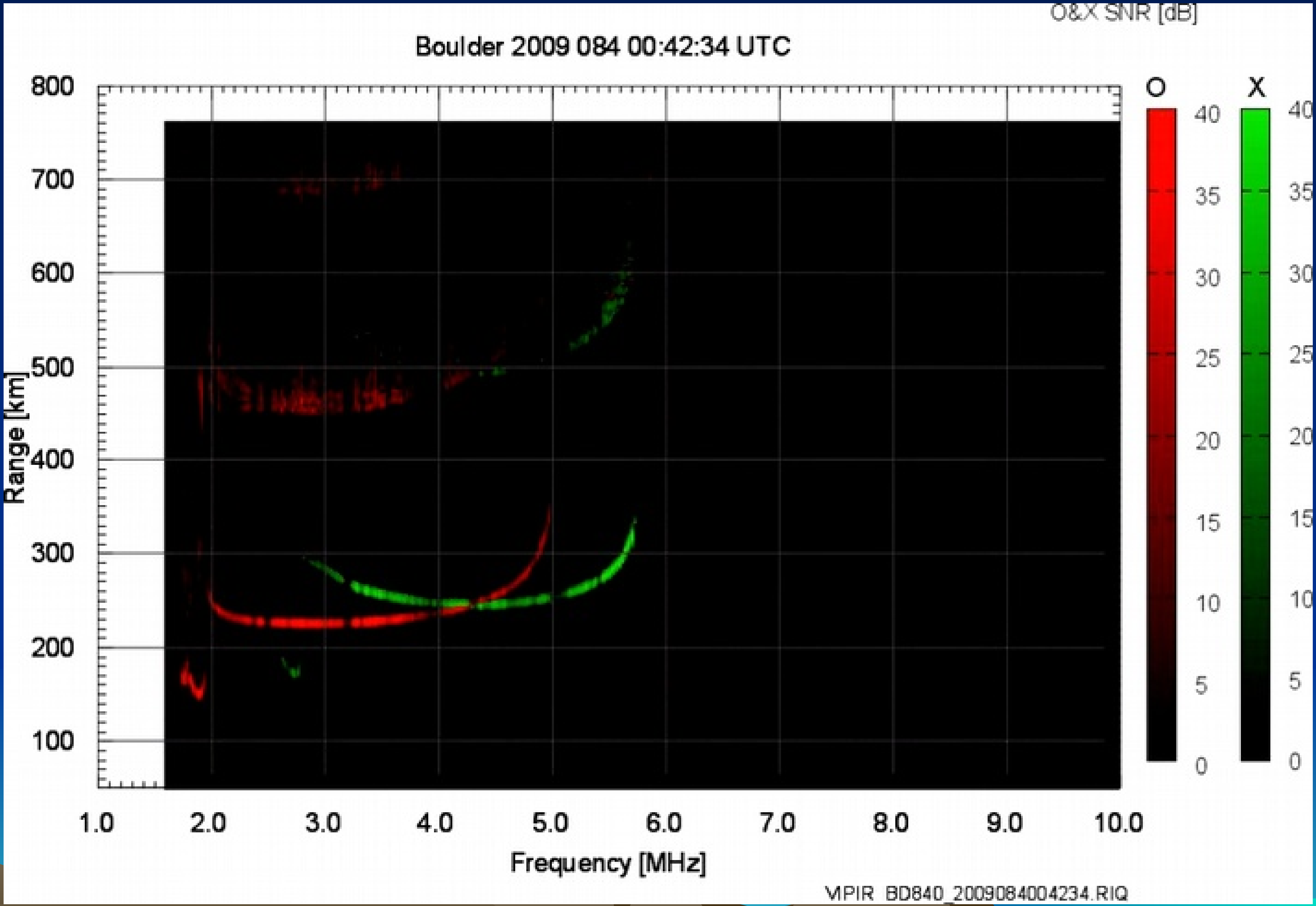


- MF-HF Radar (1-20 MHz)
- A acre or ten of antennas
- Measures ionosphere reflection height at a precise density (sounding frequency)
- Feature recognition software needed in an often complex image
- Inversion process required to obtain bottom-side electron density profile
- Valleys and Topside are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

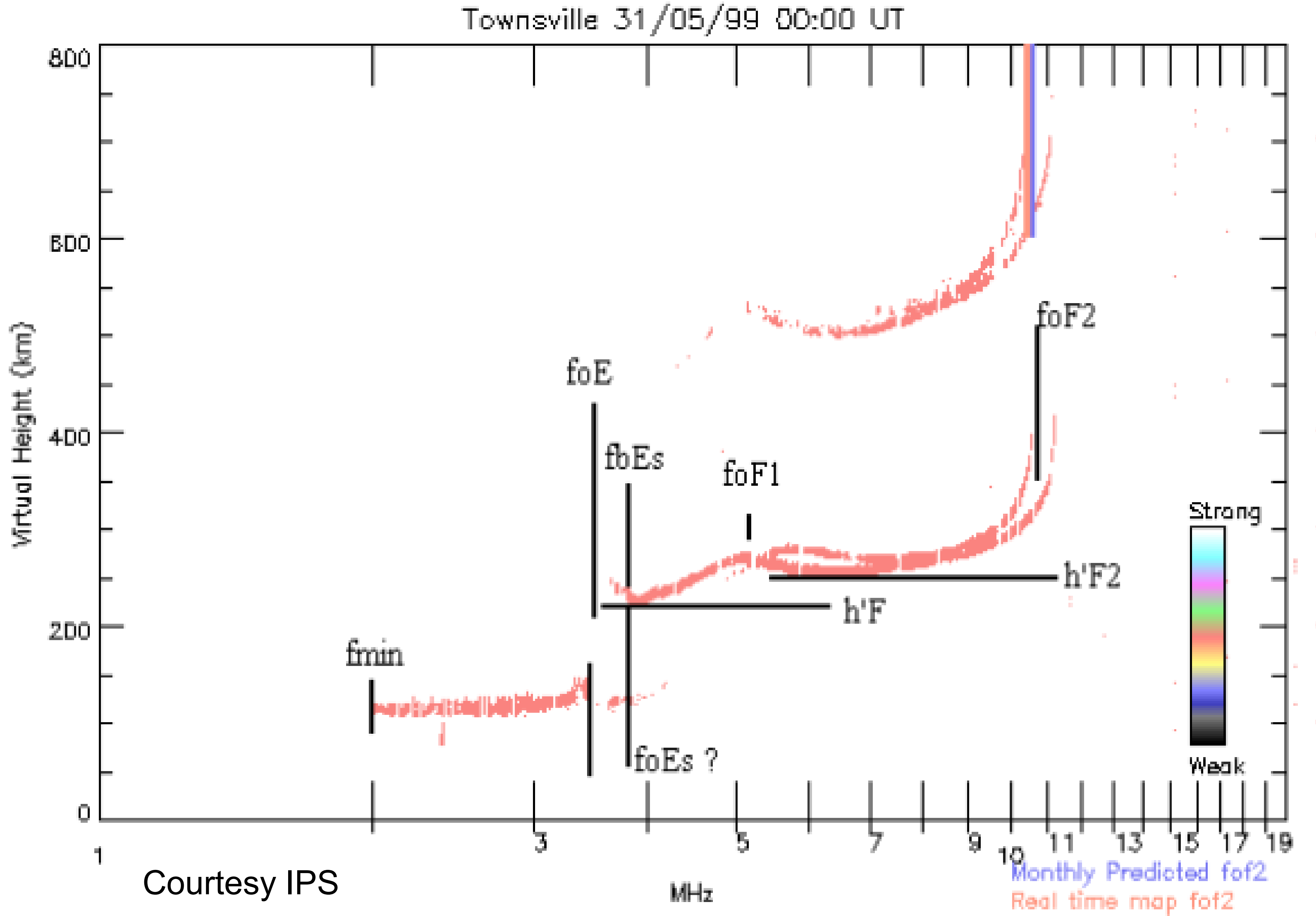
Ionosonde Components



Boulder Ionogram Movie



Ionogram Scaling

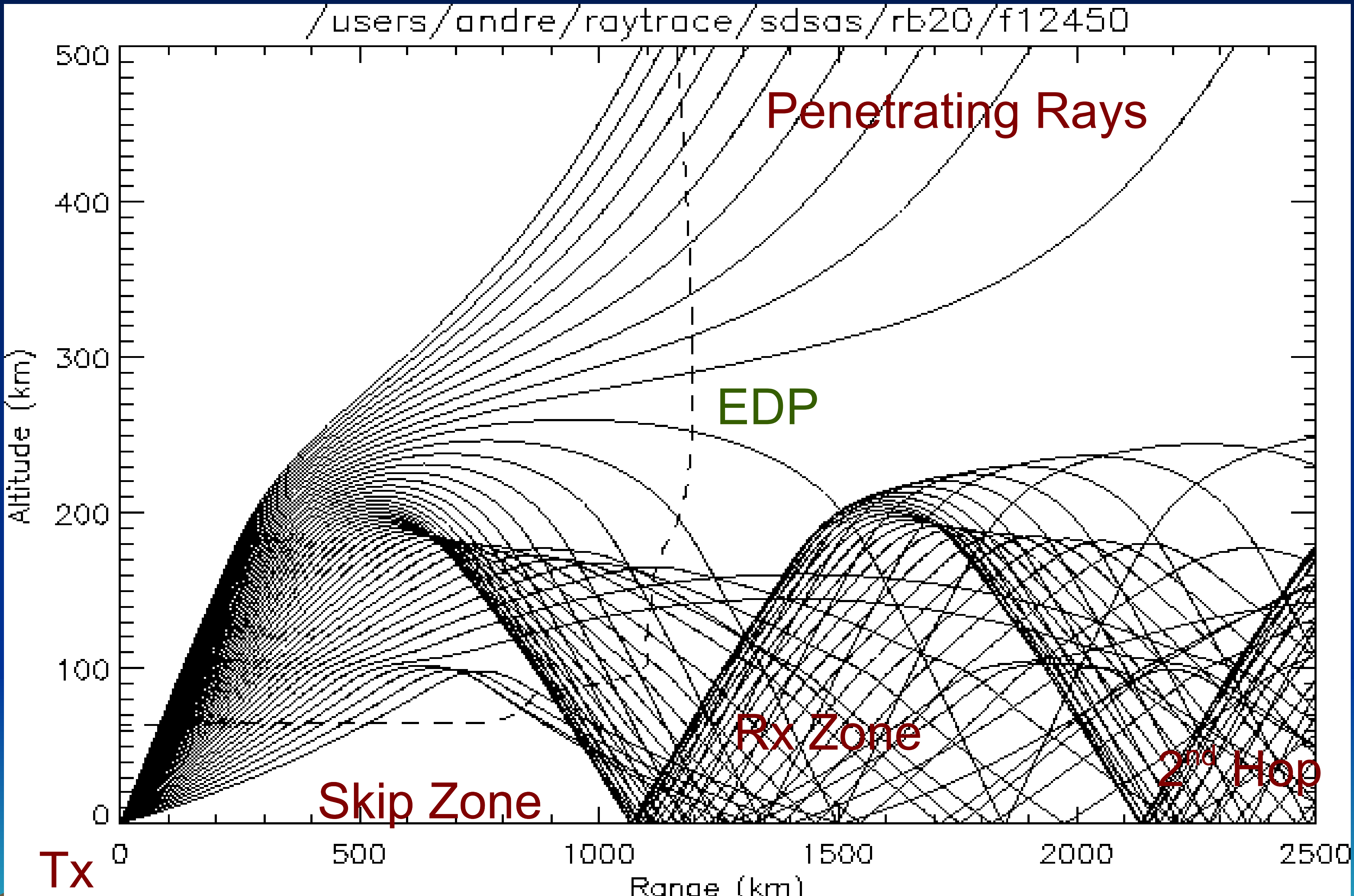


Courtesy IPS

Communication Engineering with Ionosondes

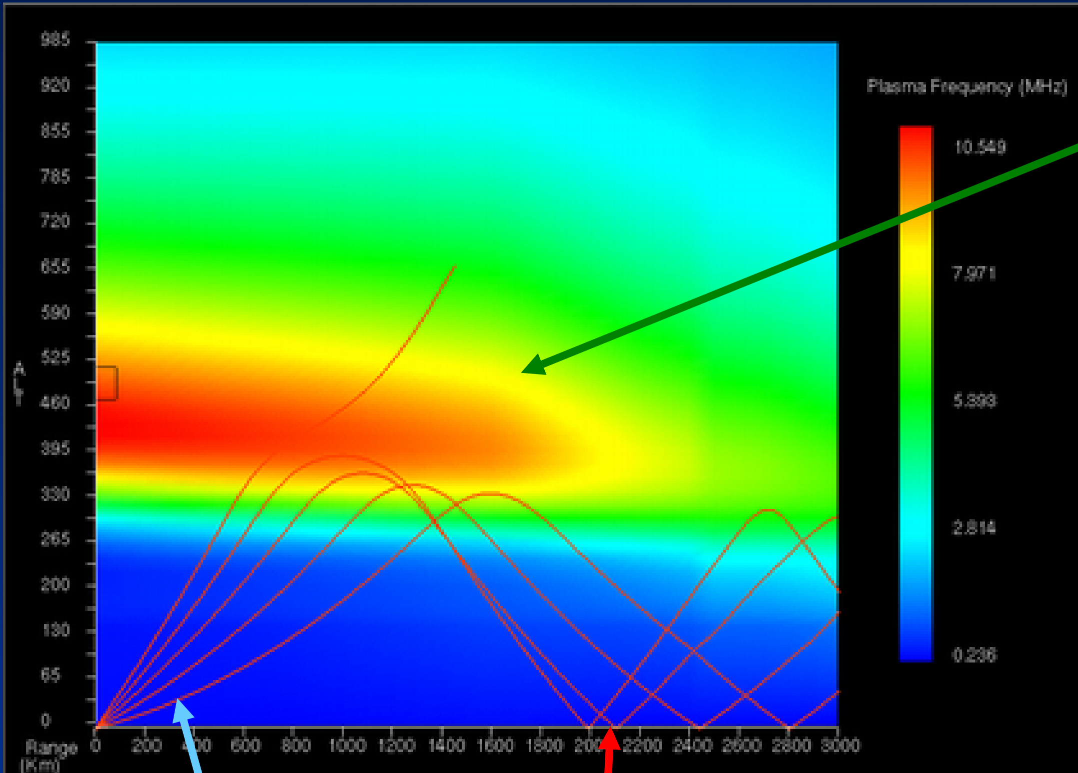
- Analyze the nature of radio propagation to:
  - Design Communication Systems
    - Antennas
    - Transmitters
    - Receivers
    - Modulation schemes
  - Operate Communications Systems
    - Operations procedures
    - Frequency management
    - Schedule

Basic HF Raytrace



Ray Tracing is the calculation of the propagation path of a radio wave

HF Propagation Prediction

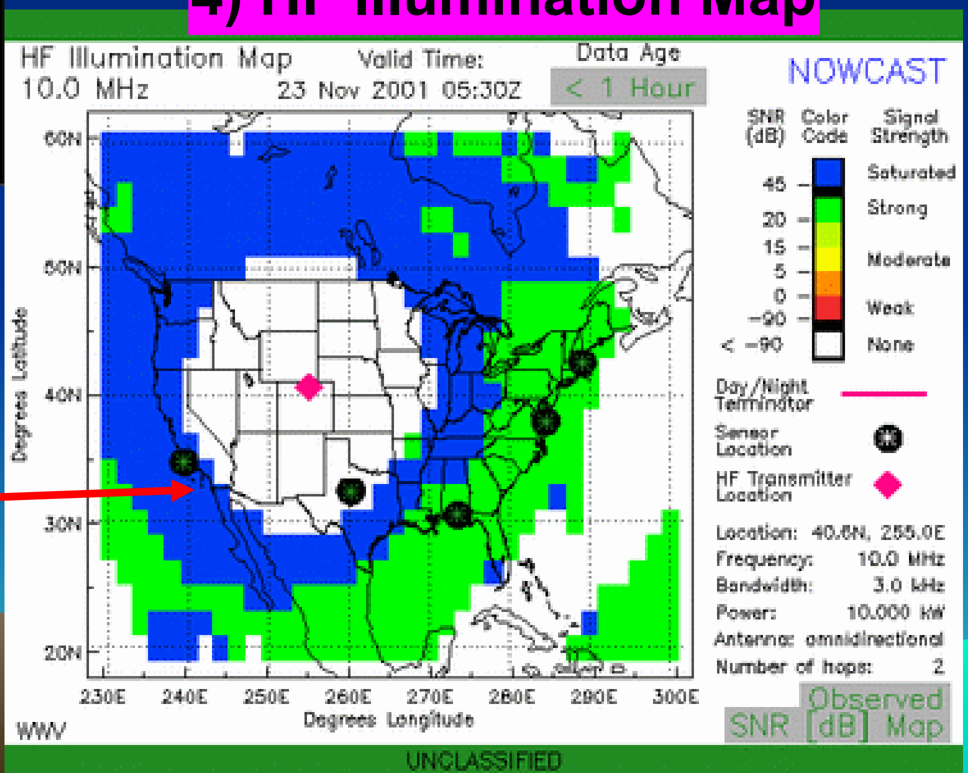


1) Ionosphere model, determined (in part) from ionosonde data

2) Predict HF propagation from known transmitter

3) HF raytrace energy integrated in each pixel

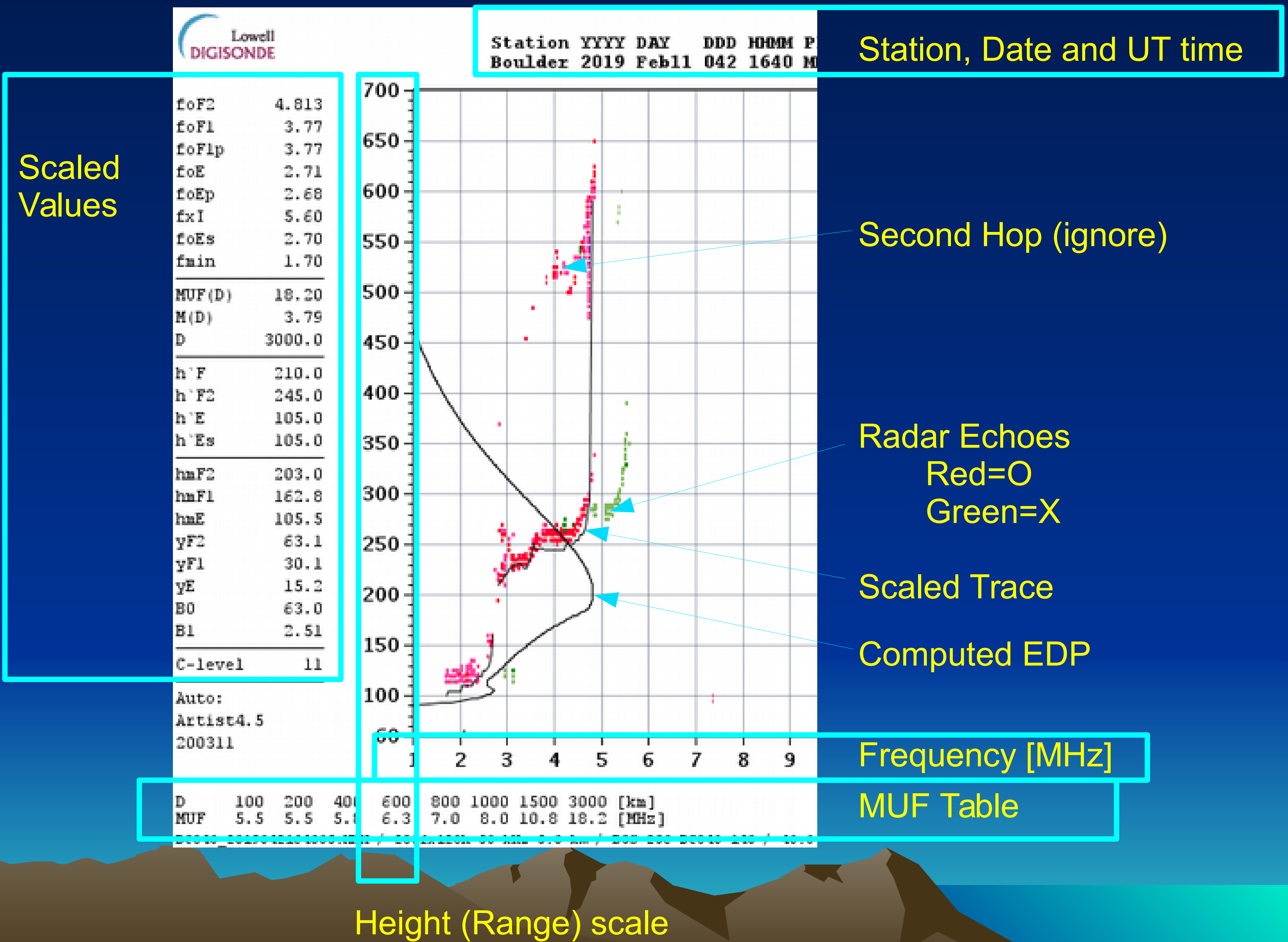
4) HF Illumination Map



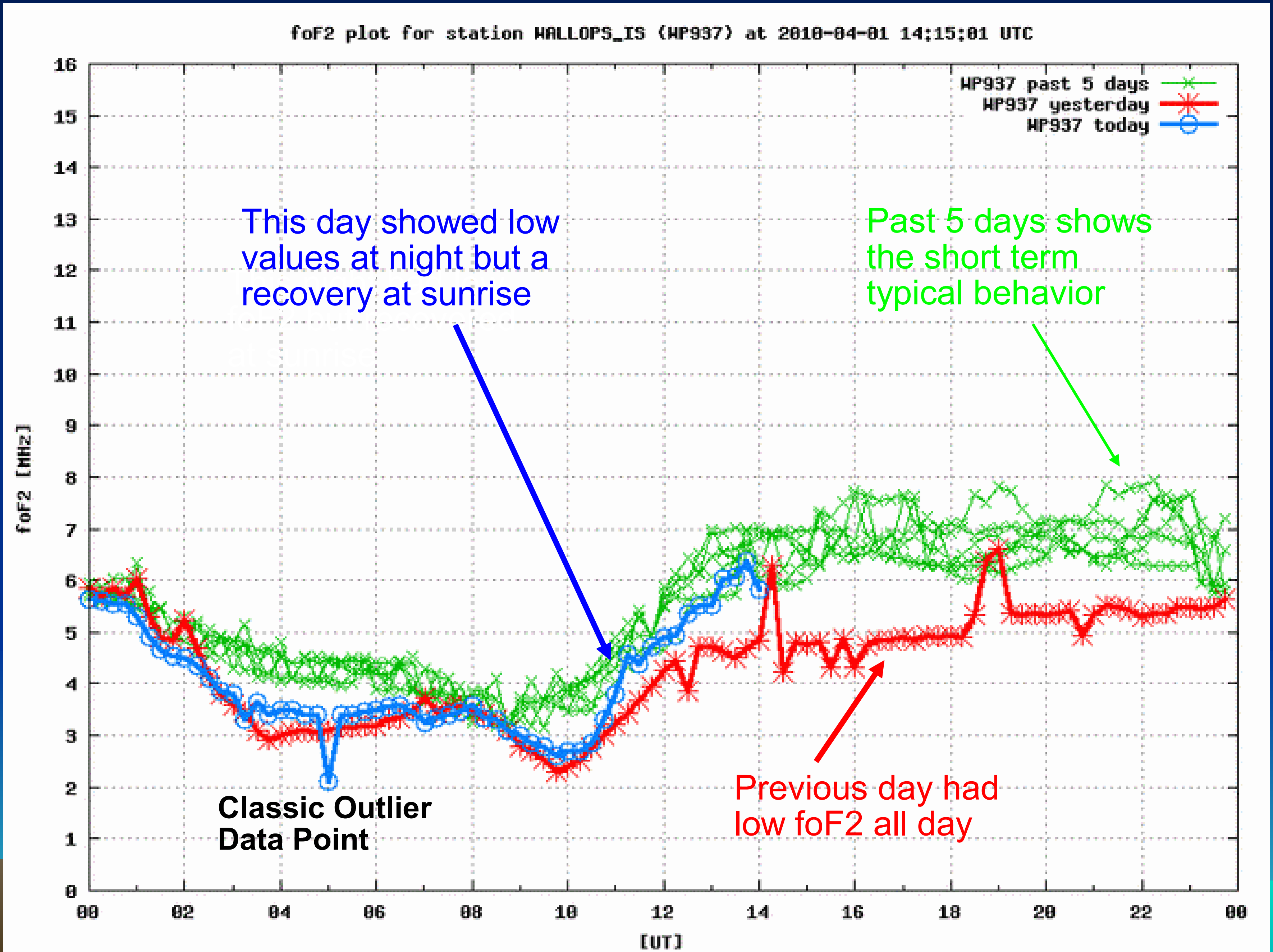
How Can You Do This Yourself?

Use the Source, Luke!

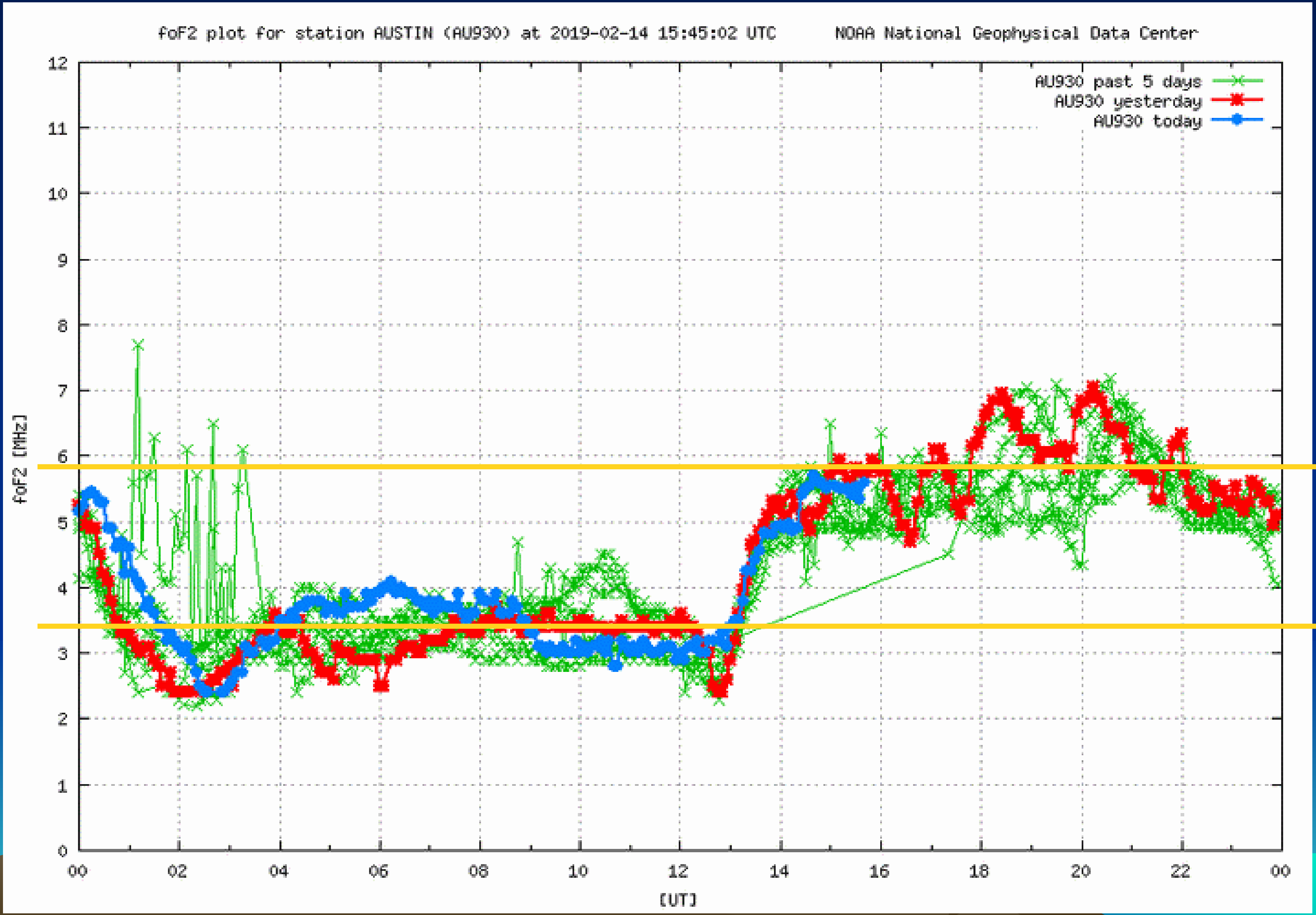
Interpreting Ionograms



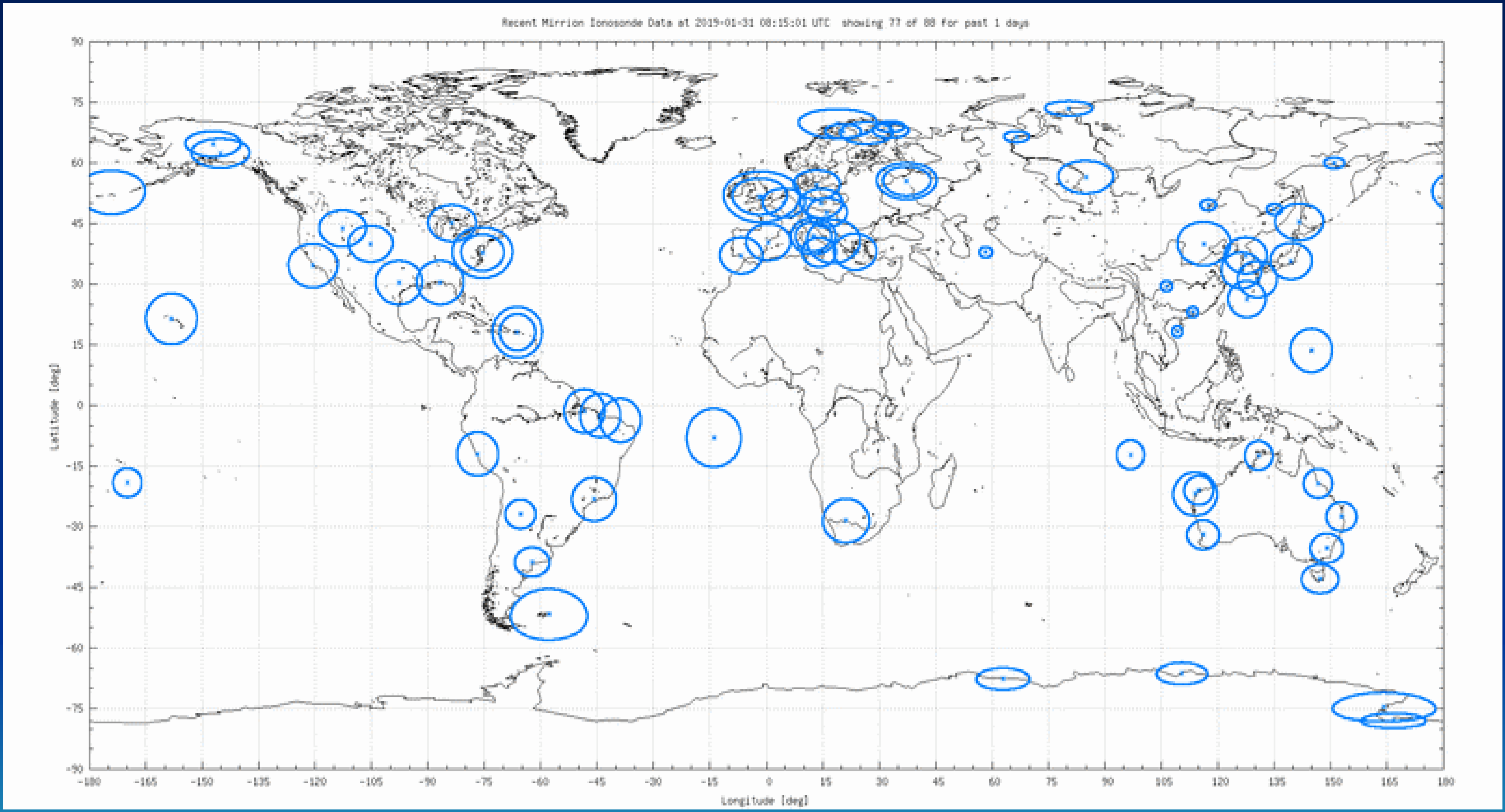
Real Time Data Plots : Magnetic Storm



Daily Space Weather



Real Time Ionosonde Data at NOAA

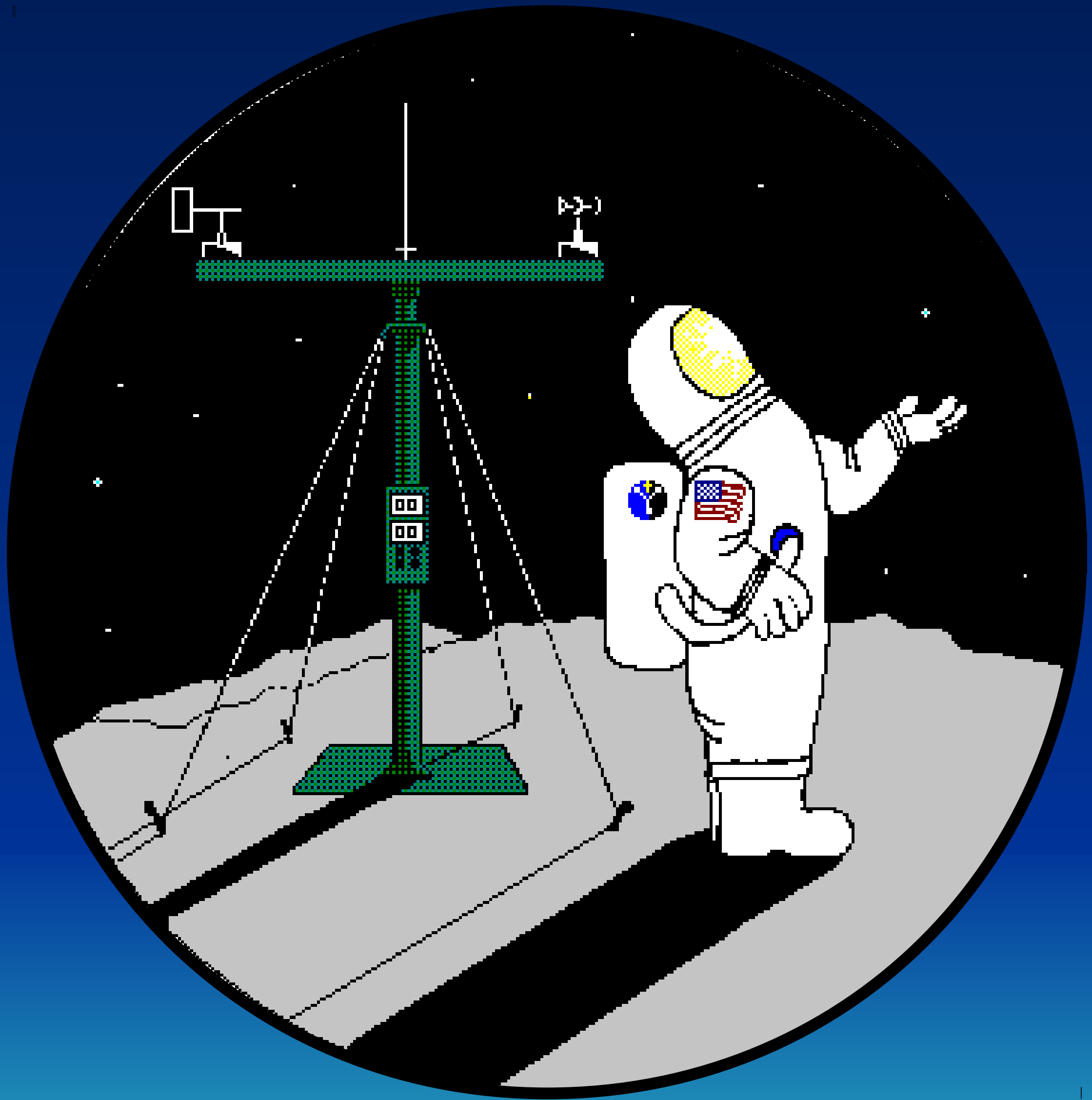


Shameless Plug

Get the Data From Here

- https://www.ngdc.noaa.gov/stp/IONO/rt-iono/
- Google: MIRRION
- This is a stupid-simple web page updated with cron scripts, not a fancy database application
- “Because he’s an ignorant monkey and doesn't know any better” – Heart of Gold
- “Share and Enjoy” – Cirius Cybernetics

Questions?



Space Weather?