# Update on the Personal Space Weather Station Project & HamSCI Activities for 2021

**Nathaniel A. Frissell, W2NAF**

**The University of Scranton**

*Contest University 2021 Propagation Summit*
*January 23, 2021*



nathaniel.frissell@scranton.edu

# HamSCI Ham radio **S**cience **C**itizen **I**nvestigation


hamsci.org/dayton2017

*Founder/Lead HamSCI Organizer:*
**Dr. Nathaniel A. Frissell, W2NAF**
*The University of Scranton*

**A collective that allows university researchers to collaborate with the amateur radio community in scientific investigations.**

**Objectives:**

1. **Advance** scientific research and understanding through amateur radio activities.
2. **Encourage** the development of new technologies to support this research.
3. **Provide** educational opportunities for the amateur radio community and the general public.

# HamSCI Activities

- **Google Group (Over 350 Members)**
- **Weekly Telecons**
- **Participation in**
  - Professional Science Meetings
  - Amateur Radio Conventions
- **Annual HamSCI Workshop**
- **Close collaboration with TAPR (tapr.org)**

Join at *https://hamsci.org/get-involved*

# Current Projects

1. Personal Space Weather Station
   1. Development and Engineering
   2. Science
2. Research using existing amateur radio observation networks.


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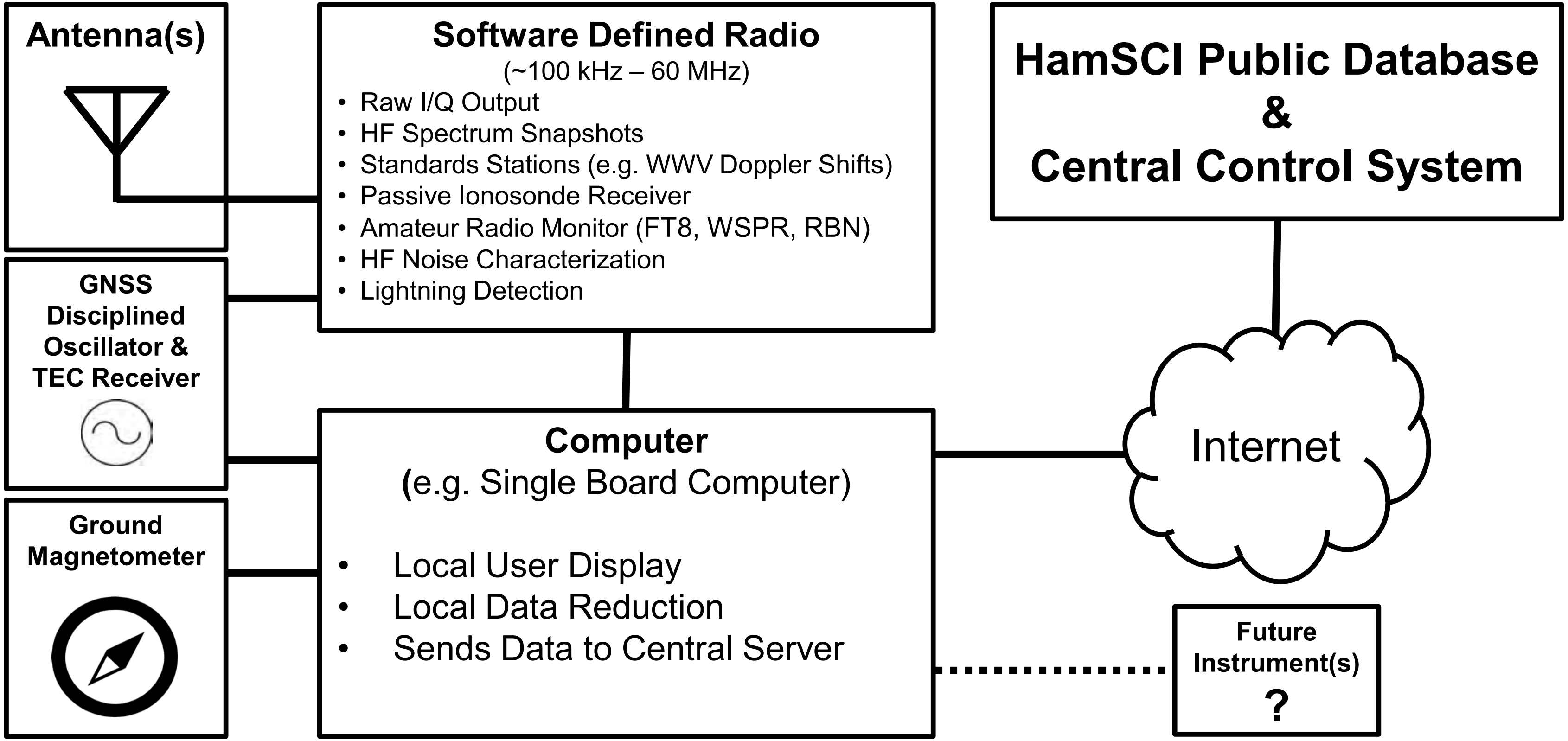
# HamSCI Personal Space Weather Station



# PSWS Teams

**University of Scranton**
- **Nathaniel Frissell W2NAF (PI)**
- Dev Joshi (Post-Doc)

**Responsibilities**
- Lead Institution
- HamSCI Lead
- Radio Science Lead

**TAPR & Zephyr Engineering**
- **Scotty Cowling WA2DFI (Chief Architect)**
- Tom McDermott (RF Board)
- John Ackerman N8UR (Clock Module)
- David Witten KD0EAG (Magnetometer)
- David Larsen KV0S (Website)

**Responsibilities**
- TangerineSDR (High Performance)
- Data Engine
- Ground Magnetometer

**University of Alabama**
- **Bill Engelke AB4EJ (Chief Architect)**
- Travis Atkison (PI)

**Responsibilities**
- Central Database
- Central Control Software
- Local Control Software

**Case Western Reserve University**
**Case Amateur Radio Club W8EDU**
- **David Kazdan AD8Y (Lead)**
- Kristina Collins KD8OXT
- John Gibbons N8OBJ
- Soumyajit Mandal (PI)
- Matt McConnell KC8AWM
- Skylar Dannhoff KD9JPX
- Aidan Montare KB3UMD

**Responsibilities**
- Low Cost PSWS System

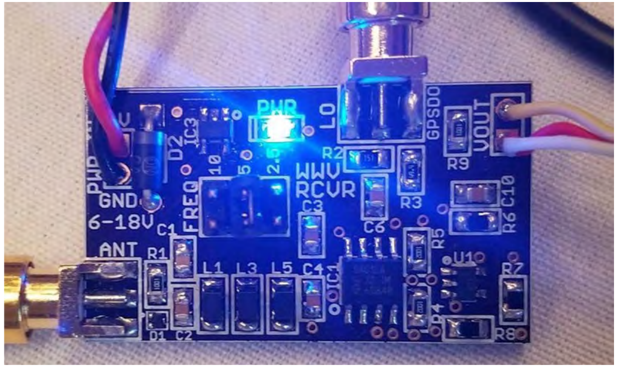
**MIT Haystack Observatory**
- **Phil Erickson W1PJE**

**Responsibilities**
- Science Collaborator

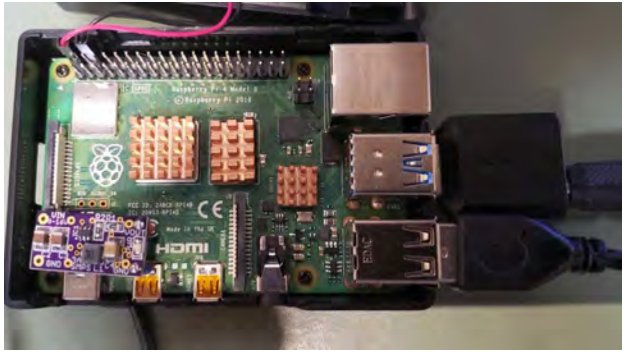
**New Jersey Institute of Technology**
- **Hyomin Kim KD2MCR (PI)**
- Gareth Perry KD2SAK
- Andy Gerrard KD2MCQ

**Responsibilities**
- Ground Mag Oversight & Testing
- Science Collaborators

# “Grape” Low Cost PSWS




“Grape Receiver” Generation 1 by J. Gibbons N8OBJ




Raspberry Pi 4 with Switching Mode Power Supply for Grape Receiver and GNSS Disciplined Oscillator

NIST Standards Station WWV in Fort Collins, CO is the primary signal source for Grape PSWS receivers.
[https://www.nist.gov/image-23112]

# Scientific SDR (TangerineSDR)

**Developed as "TangerineSDR" by TAPR**

## Data Engine Specifications

- Altera/Intel 10M50DAF672C6G FPGA 50K LEs
- 512MByte (256Mx16) DDR3L SDRAM
- 4Mbit (512K x 8) QSPI serial flash memory
- 512Kbit (64K x 8) serial EEPROM
- µSDXC memory card up to 2TByte

## Data Engine Features

- 11-15V wide input, low noise SMPS
- 3-port GbESwitch (Dual GbEdata interfaces)
- Cryptographic processor with key storage
- Temperature sensors (FPGA, ambient)
- Power-on reset monitor, fan header

## RF Module

- AD9648 125 dual 14 bit 122.88Msps ADC
- 0dB/10dB/20dB/30dB remotely switchable attenuator
- LTC6420 20 20dB LNA
- Fixed 55MHz Low Pass Filter
- Optional user defined plug in filter
- On-board 50Ω calibration noise source
- On-board low noise power supplies
- Dual SMA antenna connectors

## GNSS/Timing Module

- Precision timestamping (10 to 100 ns accuracy)
- Frequency reference (Parts in $10^{13}$ over 24 hr)

*More Information at tangerinesdr.com*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# Why a New SDR?

- Current commercial HF SDRs do not have:
  - Dual, phase-locked, receive channels
  - GPS precision timestamping
  - GPSDO Frequency Stability
  - Wide-band HF Signal Processing
  - Low cost

  - Integrated system for wide-scale scientific data collection


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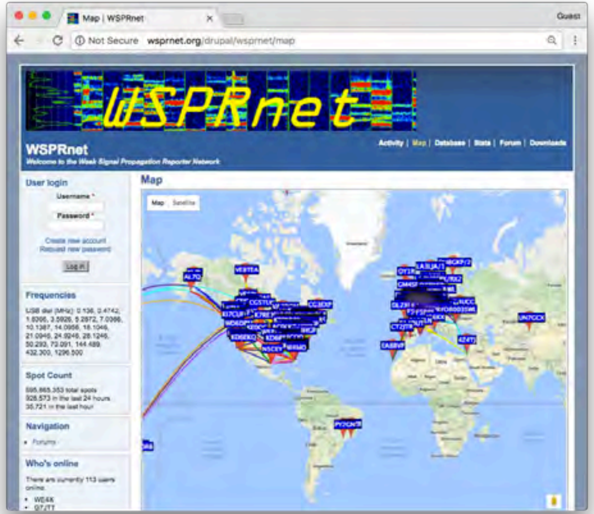
# What are the science goals we are after?

- Broadly, we are trying to design a general device that will be useful for many different science targets:
  - Solar Flare Impacts
  - Geomagnetic/Ionospheric Storms
  - Internal Ionospheric Electrodynamics
  - Short time scale/small spatial scale ionospheric variability
  - **Connections with Lower Atmosphere**

# How does this help amateur radio?

- The PSWS needs to have a direct benefit to amateur radio.
- FT8 / WSPRNet monitor already implemented.
- Working on best practices for having PSWS co-exist with amateur transmitting equipment
- Looking for novel approaches to use the science data to help amateur radio.
- What applications can you think of?

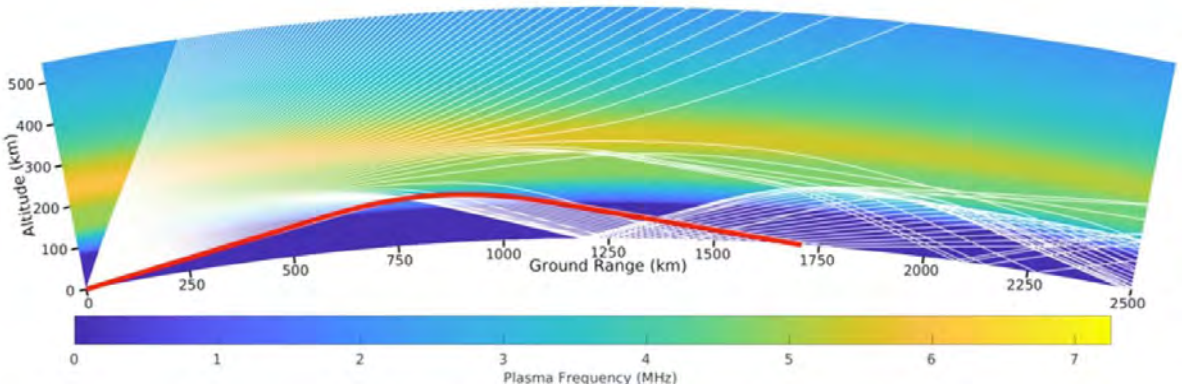



**WSPRNet**
*wsprnet.org*

# Amateur Radio Frequencies and Modes

**Eclipsed SAMI3 - PHaRLAP Raytrace**

1600 UT 21 Aug 2017 • 14.03 MHz • TX: AA2MF (Florida) • RX: WE9V (Wisconsin)




PHaRLAP: Cervera & Harris, 2014, https://doi.org/10.1002/2013JA019247
SAMI3: Huba & Drob, 2017, https://doi.org/10.1002/2017GL073549

- **Amateurs routinely use HF-VHF transionospheric links.**
- **Often ~100 W into dipole, vertical, or small beam antennas.**
- **Common HF Modes**
  - Data: FT8, PSK31, WSPR, RTTY
  - Morse Code / Continuous Wave (CW)
  - Voice: Single Sideband (SSB)

| | Frequency | Wavelength |
|---|---|---|
| LF | 135 kHz | 2,200 m |
| MF | 473 kHz | 630 m |
| | 1.8 MHz | 160 m |
| HF | 3.5 MHz | 80 m |
| | 7 MHz | 40 m |
| | 10 MHz | 30 m |
| | 14 MHz | 20 m |
| | 18 MHz | 17 m |
| | 21 MHz | 15 m |
| | 24 MHz | 12 m |
| | 28 MHz | 10 m |
| VHF+ | 50 MHz | 6 m |
| | And more… | |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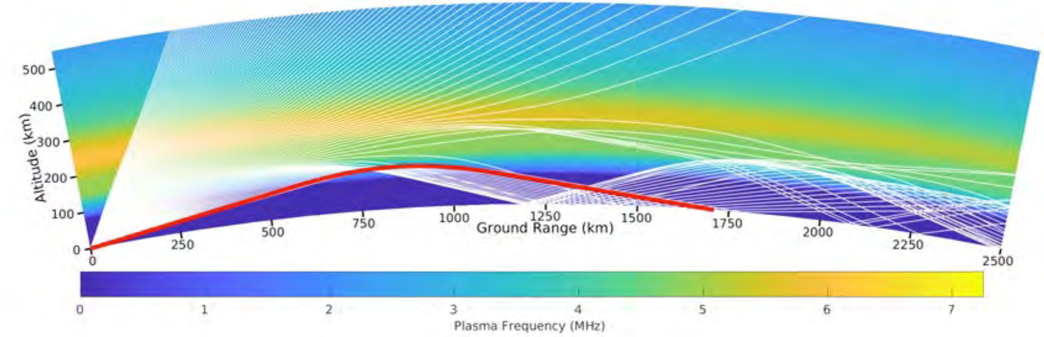
# SAMI3-PHaRLAP Raytrace

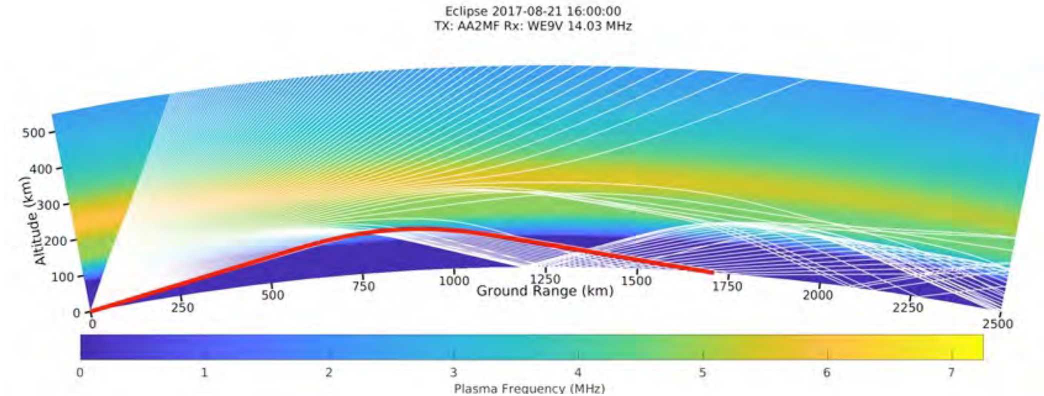
**SAMI3/PHaRLAP Simulation**

**21 August 2017**
**1600 – 2200 UT**
**14.03 MHz**
**TX: AA2MF (Florida)**
**RX: WE9V (Wisconsin)**

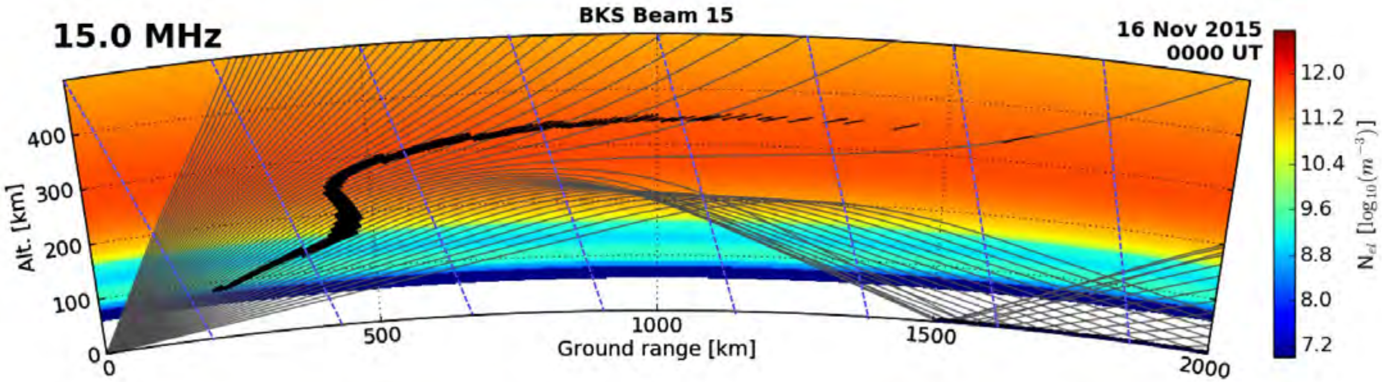
**Non-Eclipsed**

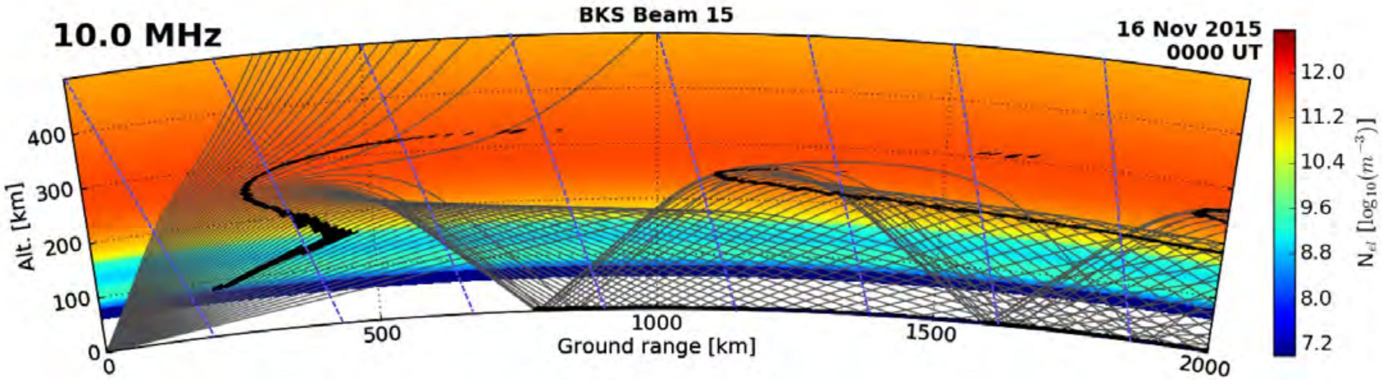



**Eclipsed**



# Refraction as a Function of Frequency



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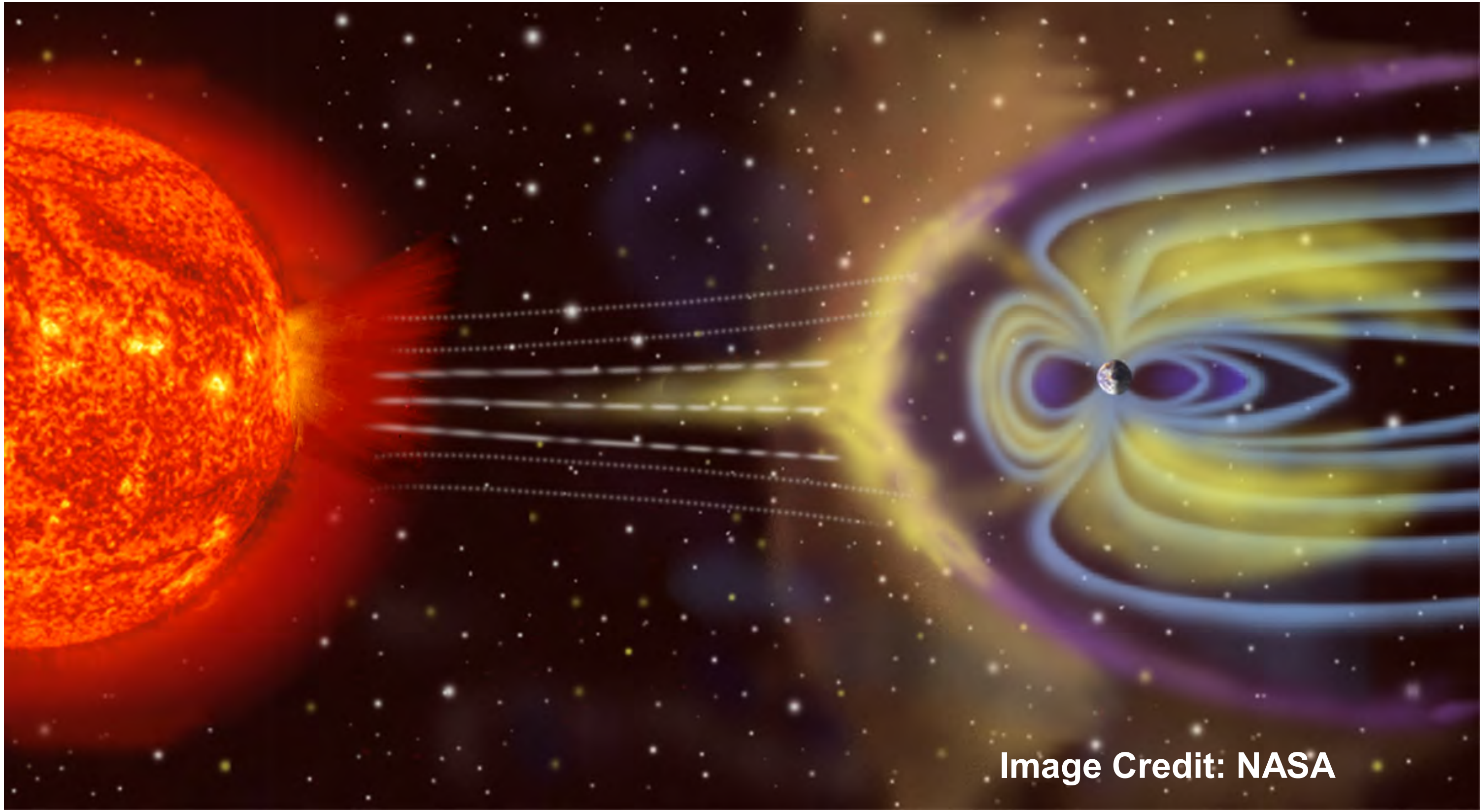
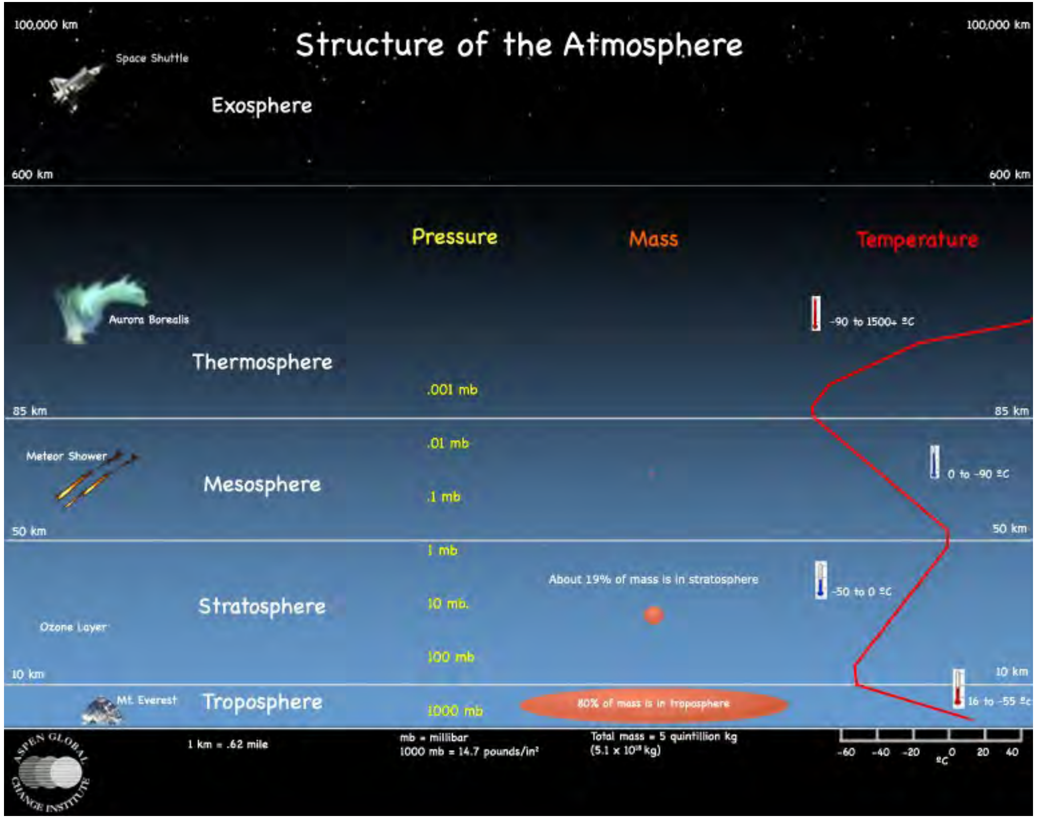
# Space Weather From Above



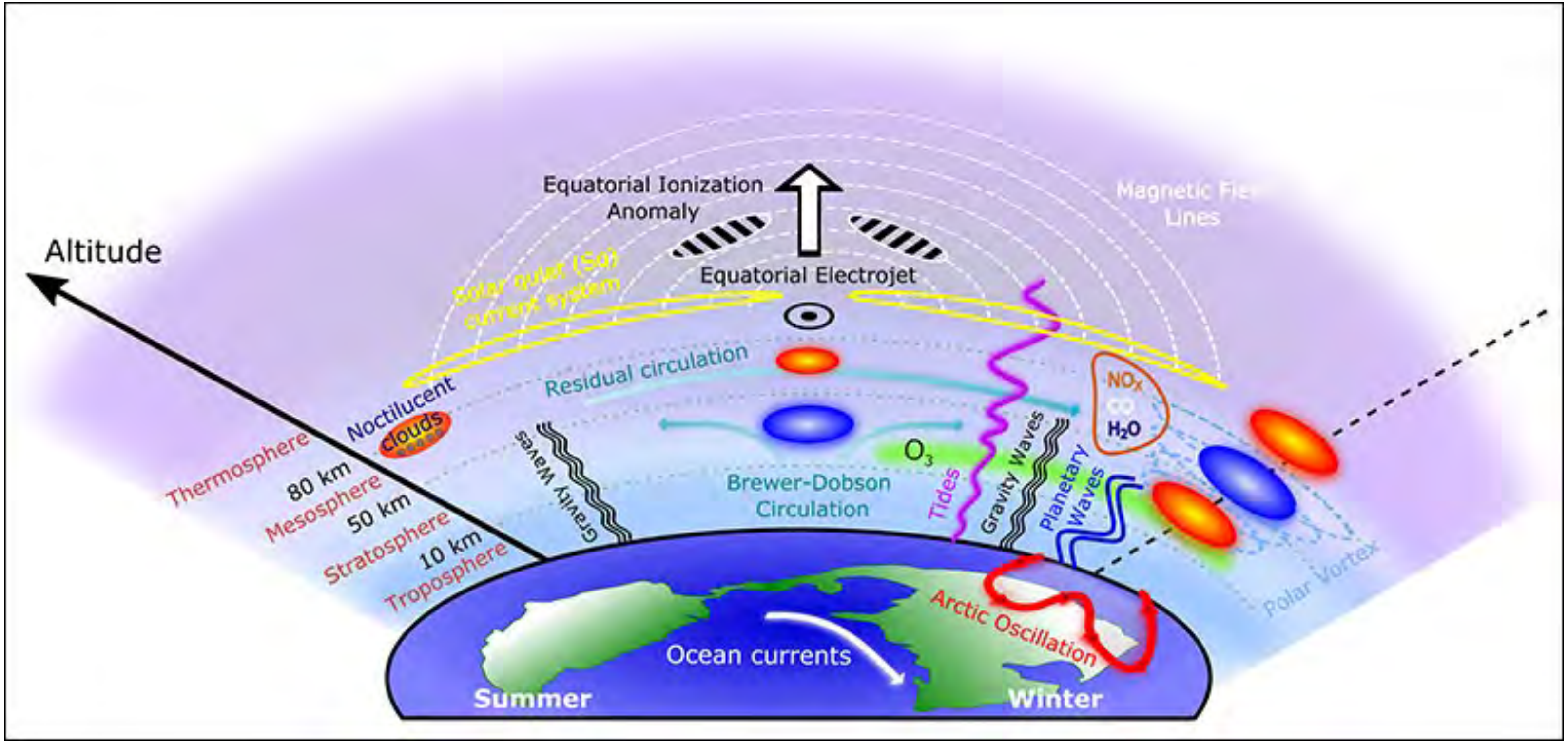
# Atmospheric Structure




Ionosphere
- F: 150 – 500 km
- E: 90 – 150 km
- D: 60 – 90 km

https://www.agci.org/earth-systems/atmosphere

# Whole Atmosphere Coupling




From *Pedatella et al., (2018) (https://doi.org/10.1029/2018EO092441)*

# What affects the ionosphere?

- **Forcing from Above**
  - Solar Origin
  - Magnetospheric Origin
- **Forcing from Below**
  - Tropospheric Origin
  - Stratospheric Origin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# Traveling Ionospheric Disturbances

- **TIDs are Quasi-periodic Variations of F Region Electron Density**
  - **Medium Scale (MSTID)**
    - $T \approx 15 - 60$ min
    - $v_H \approx 100 - 250$ m/s
    - $\lambda_H \approx$ Several Hundred km (< 1000 km)
    - Often Meteorological Sources
  - **Large Scale (LSTID)**
    - $\lambda_h > 1000$ km
    - $30 < T$ [min] $< 180$
    - Often Auroral Electrojet Enhancement, Particle Precipitation
- **Often associated with Atmospheric Gravity Waves**

[*Francis*, 1975; *Hunsucker* 1982; Ogawa et al., 1967; *Ding* et al., 2012; *Frissell et al.*, 2014; 2016]

- **Typically thought to be caused by**
  - **Auroral/Space Weather Activity**
  - **Lower/Middle Atmospheric Disturbances**


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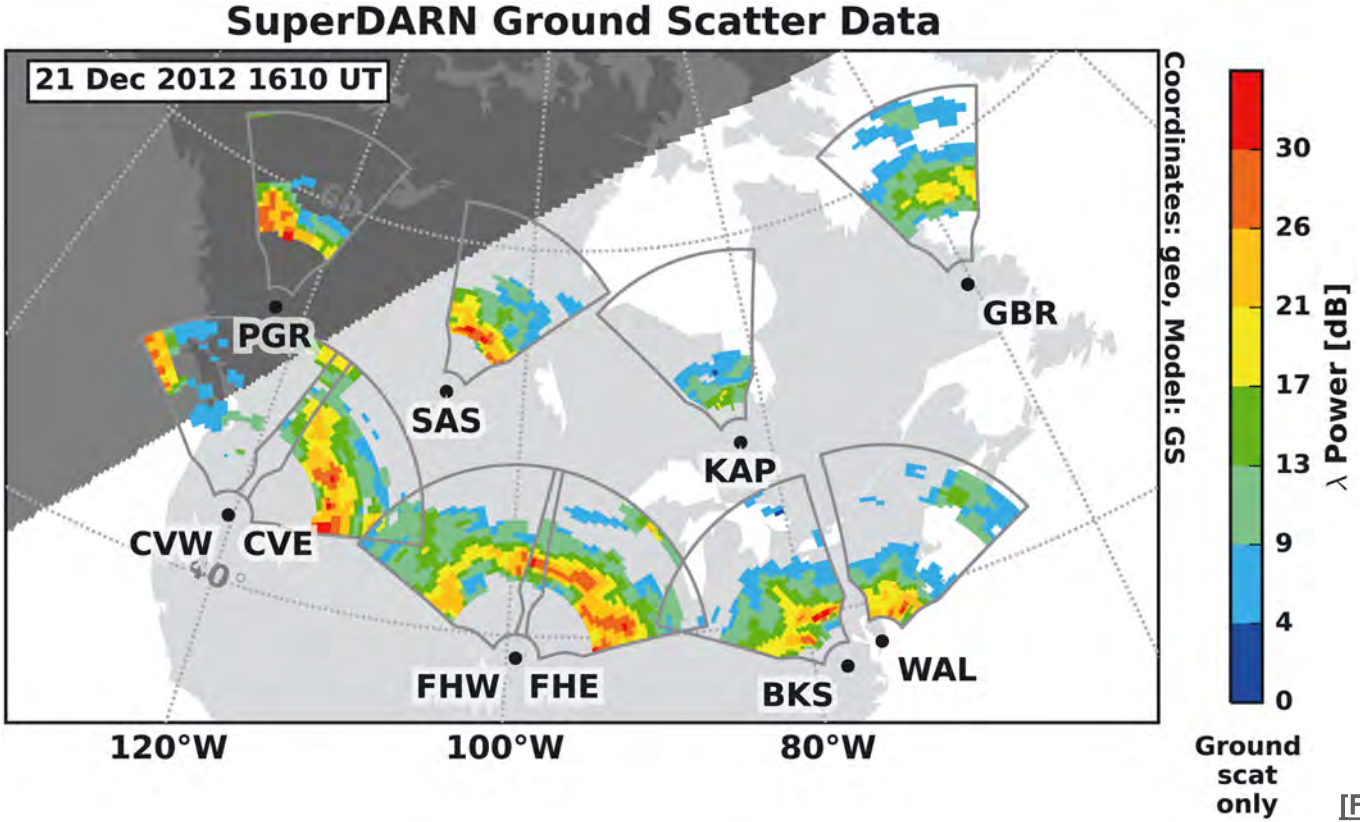
# SuperDARN Radars

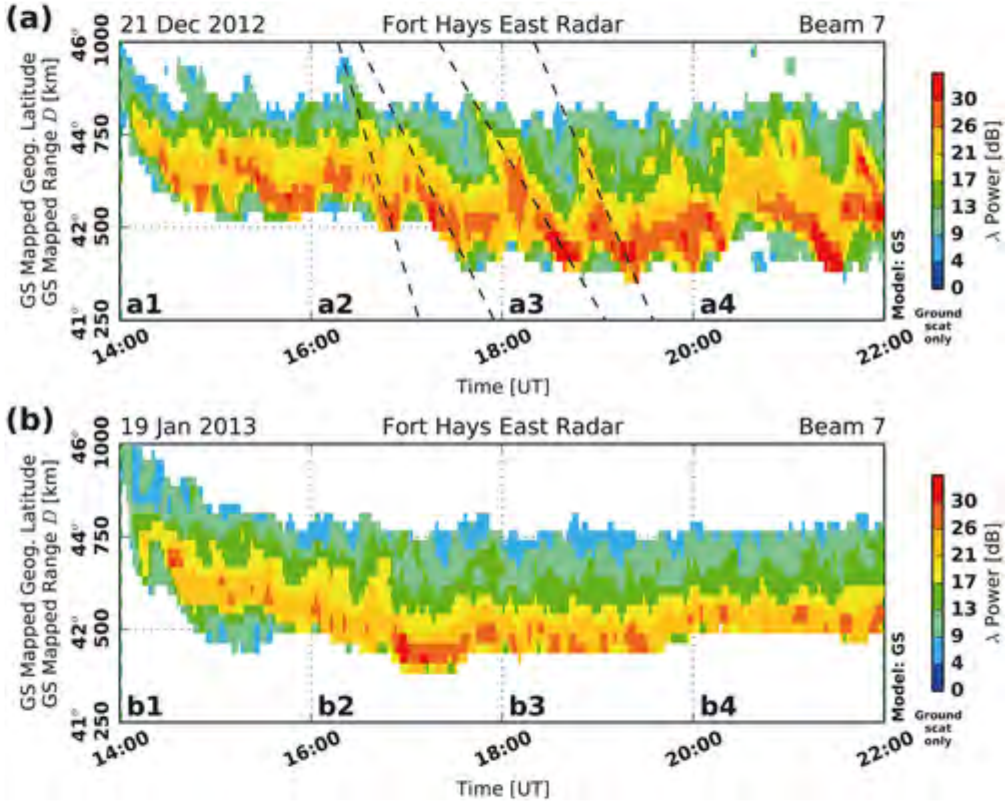



[Frissell et al., 2016]

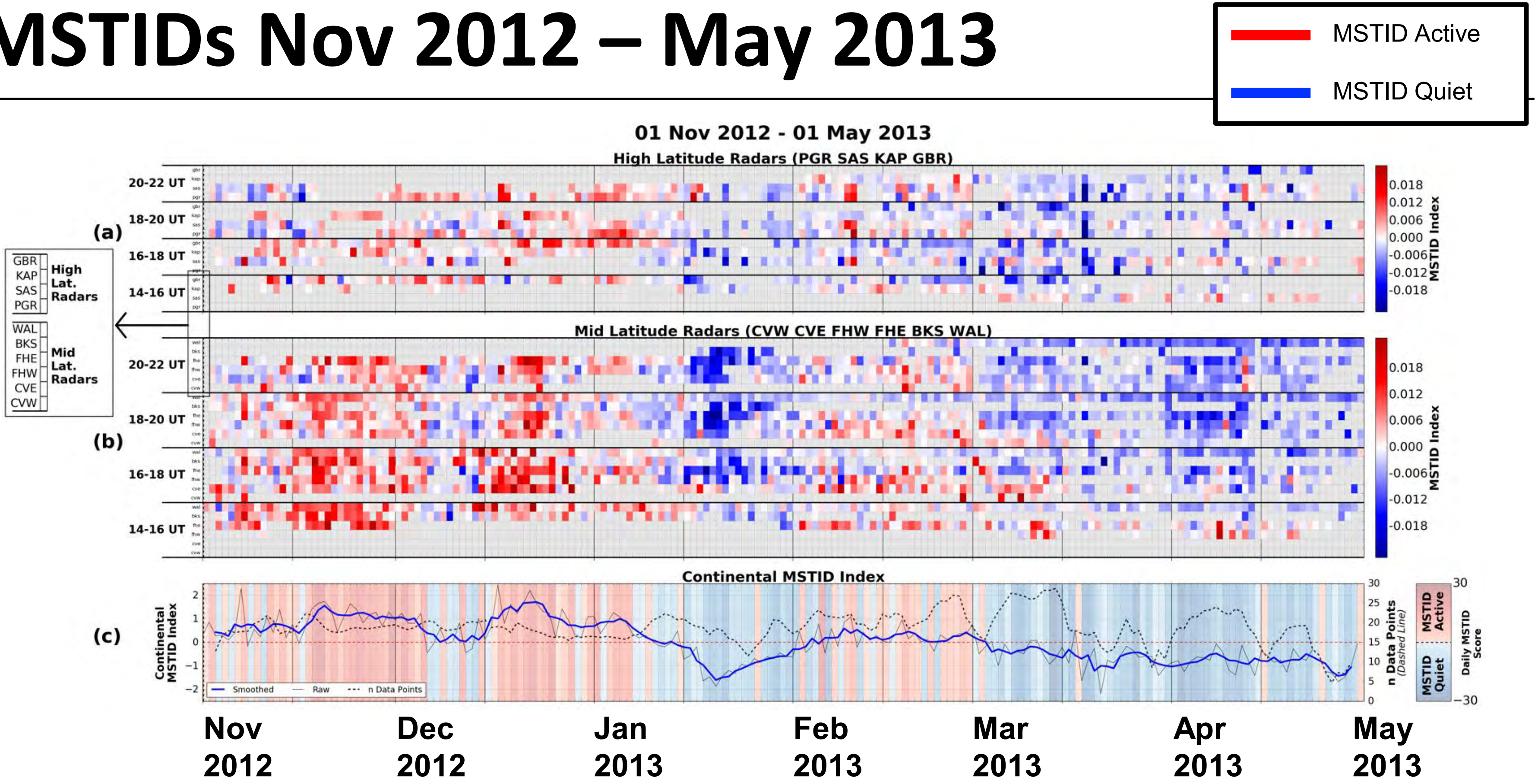
# 14 MHz MSTID Simulation

[Frissell et al., 2016]

# Example SuperDARN MSTID

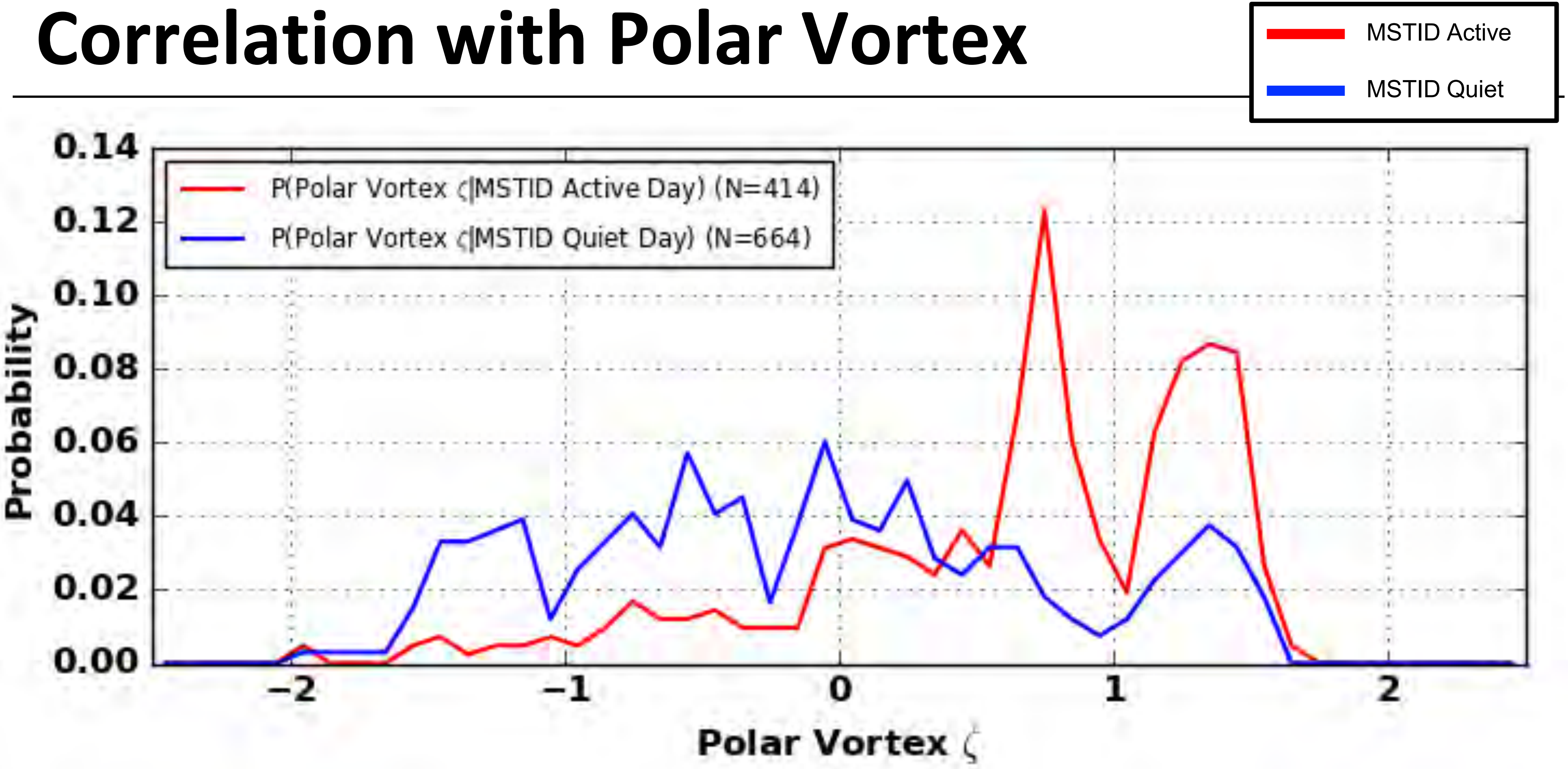


# MSTIDs Nov 2012 – May 2013



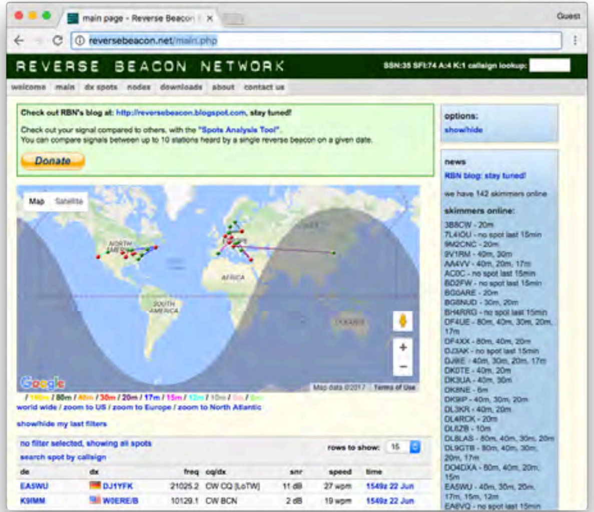

[Frissell et al., 2016]

# Correlation with Polar Vortex

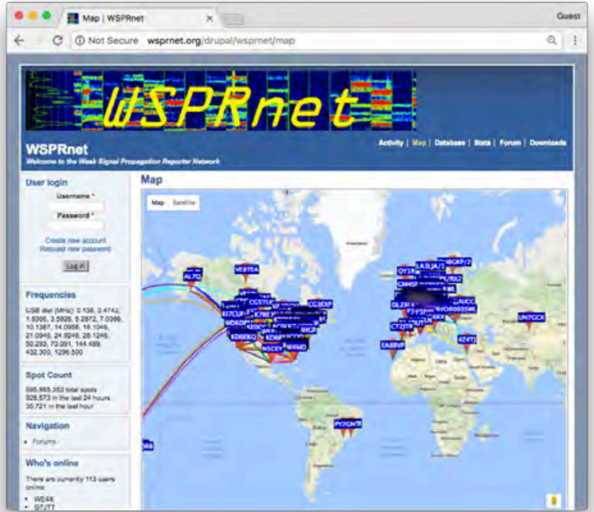



[Frissell et al., 2016]

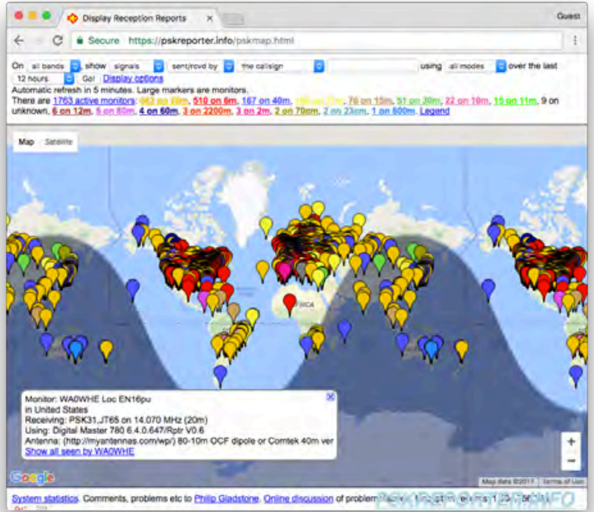
# Amateur Radio Observation Networks




**Reverse Beacon Network (RBN)**
*reversebeacon.net*




**WSPRNet**
*wsprnet.org*



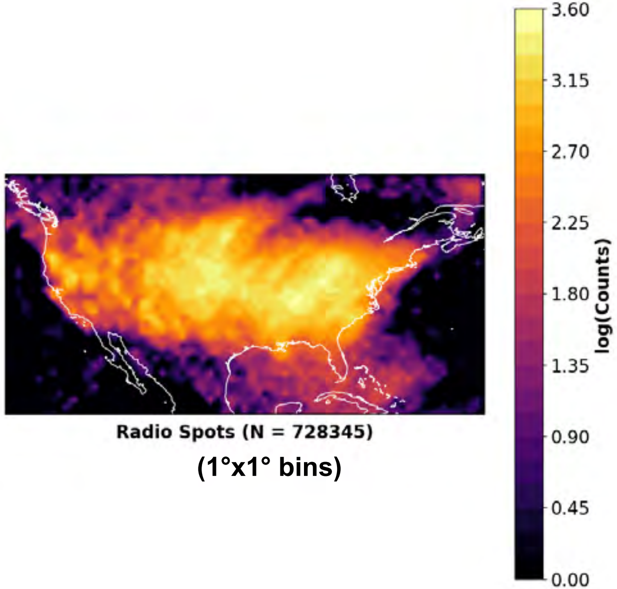

**PSKReporter**
*pskreporter.info*

- Quasi-Global
- Organic/Community Run
- Unique & Quasi-random geospatial sampling

- Data back to 2008 (A whole solar cycle!)
- Available in real-time!

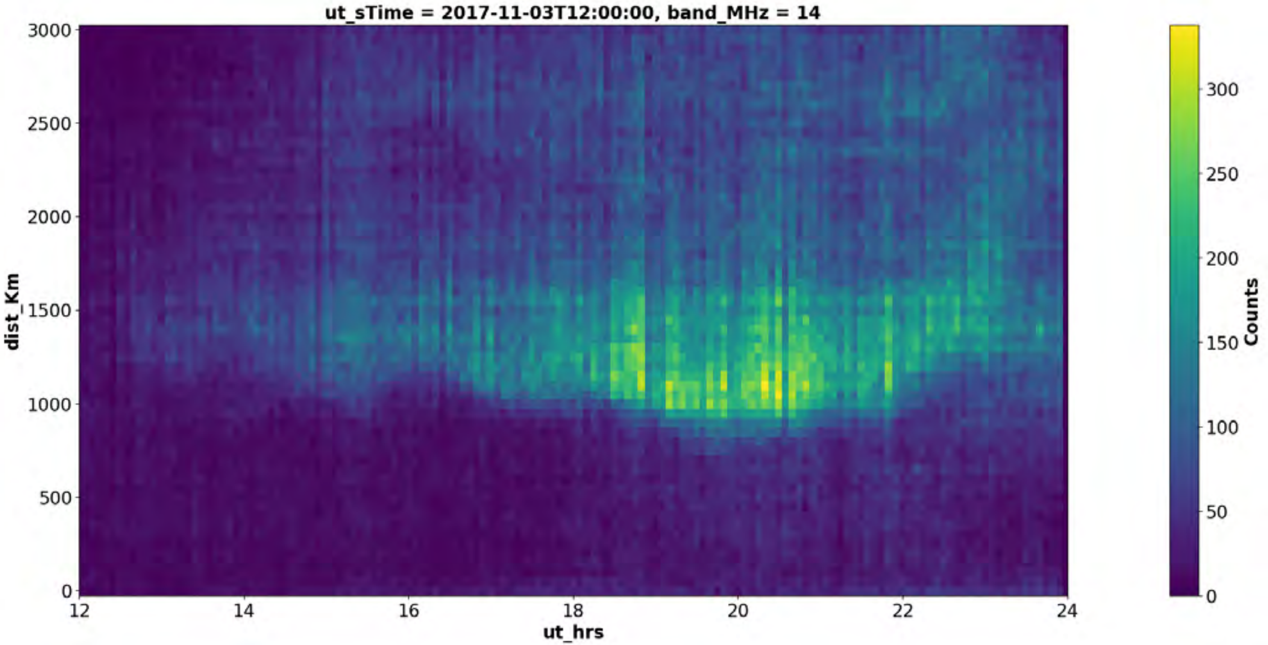
# November 4, 2017

20171103.1200-20171104.0000_timeseries.png




Radio Spots (N = 728345)

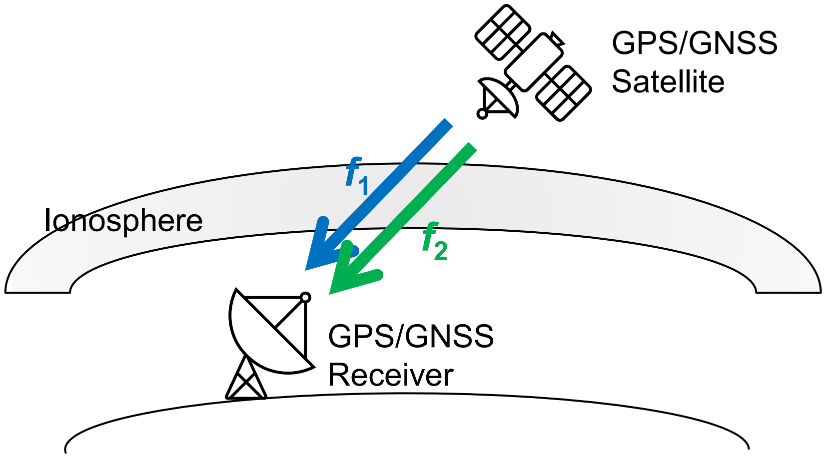
(1°x1° bins)




(5 min x 50 km bins)

# What is Total Electron Content (TEC)?

- TEC is a measure of the total number of electrons between a GPS/GNSS satellite transmitter and GPS/GNSS receiver.
- It is derived from the difference in phase delay of two different frequencies passing through the ionospheric plasma.




$f_1$ = 1575.42 MHz (GPS L1)
$f_2$ = 1227.60 MHz (GPS L2)
1 TECU = $10^{16}$ Electrons $m^{-2}$

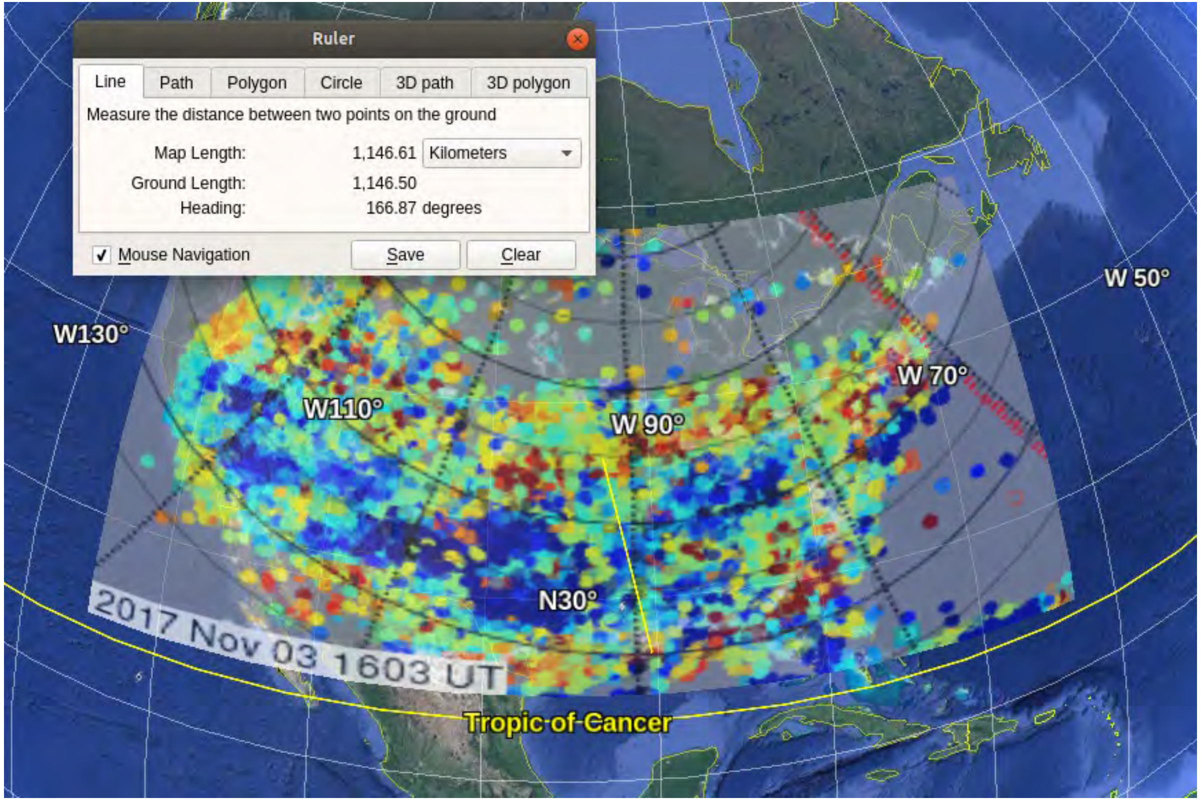
# Estimated GNSS TEC LSTID Parameters

$\lambda_h \approx$ 1,100 km

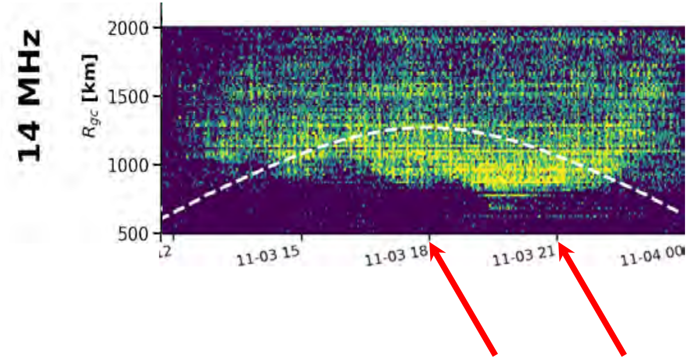
$v_p \approx$ 950 km/hr

$T \approx$ 70 min

$\Phi_{Azm} \approx 135°$



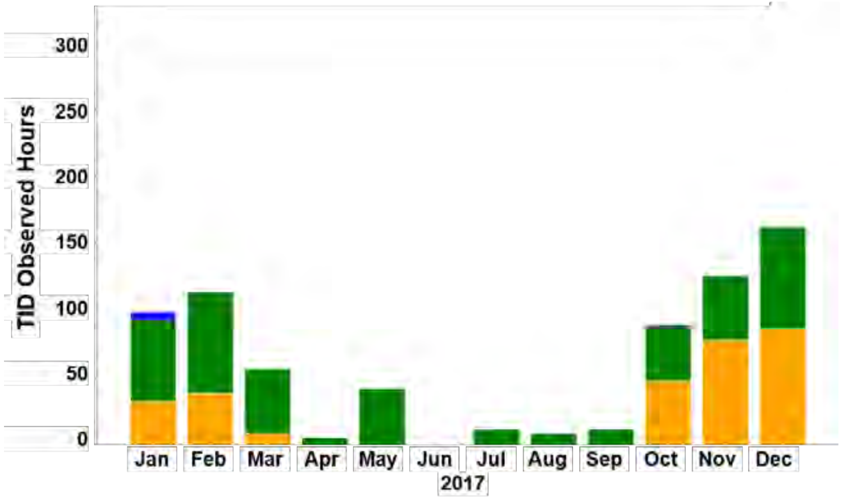
# GNSS TEC Comparison 18:00 - 21:00




- Radio range is shortest when TEC is red (higher TEC)

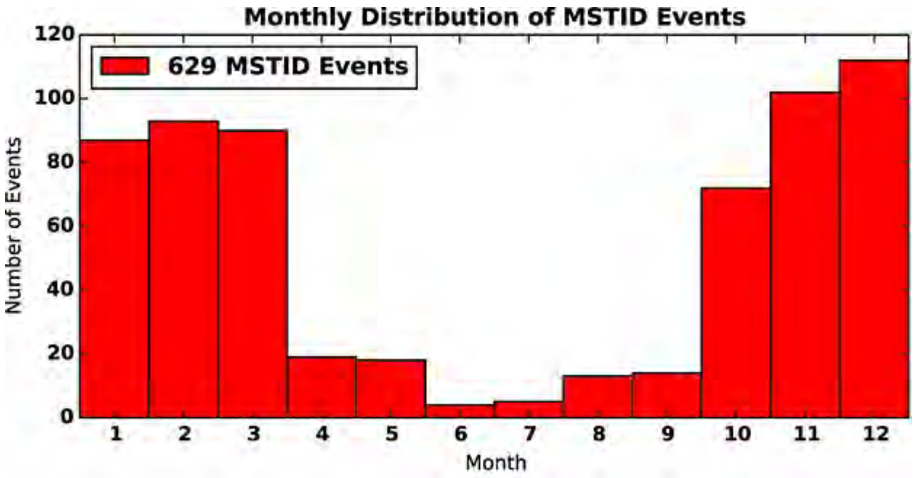
# Comparison with SuperDARN MSTID Statistics

**Amateur Radio TID Statistics**
**2017**




RBN/WSPR statistical study by
Diego Sanchez, KD2RLM [2020]

**Blackstone, VA SuperDARN MSTID Statistics**
**2010**




[*Frissell et al.*, 2014]

# Measuring TIDs (and More) with Doppler Shifts

- When the propagation path length changes as the refraction heigh moves up and down, the ionosphere imposes a Doppler shift on the signal.
- Typical observed values are fractions of a Hz to a few Hz.
- Causes include TIDs, Solar Flares, Eclipses, Dawn/Dusk Terminator

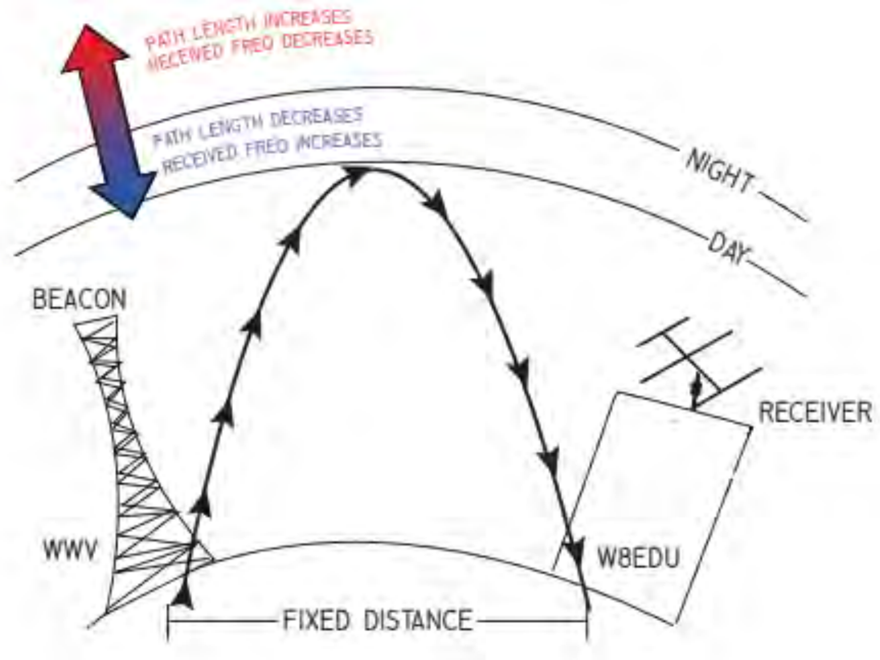



Figure by Kristina Collins, KD8OXT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# Measuring Doppler – Ham Rig?

- You can’t use just any old Ham rig to measure Doppler shift!

- A typical amateur receiver often has frequency stability and accuracy on the order of ±5-10 Hz.
  - Fine for normal communications.
  - **Not fine** for ionospheric Doppler measurements, which are often smaller than ±3 Hz.


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# GPS Disciplined Oscillators (GPSDO)

- Synchronizes to GPS Clocks
- GPS Clocks use Cesium References
- Long-term stability approaches $10^{-12}$
  - $\pm 0.00001$ Hz at 10 MHz

- Some, but not all amateur radios let you connect a GPSDO without modification.


Mini Precision GPS Reference Clock
http://www.leobodnar.com/
~$135 USD

# Icom IC-7610

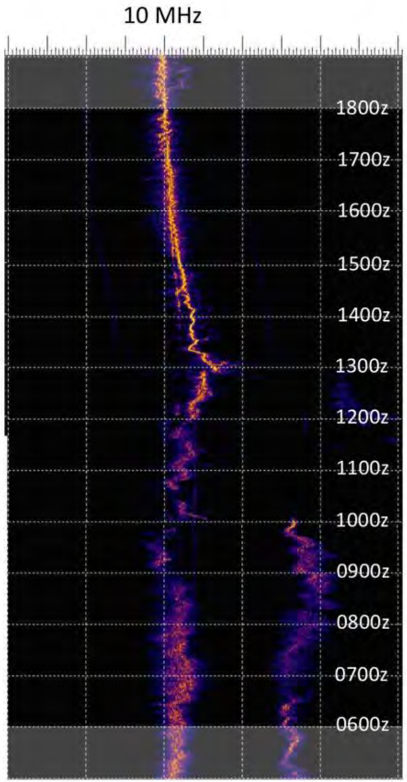

ICOM
POWER
TRANSMIT
TIMER
TUNER
PHONES
MAIN:AF-RF/SQL
TX/RX
ELEC-KEY
NB
NR
SUB:AF-RF/SQL
MIC
HF/50MHz TRANSCEIVER
IC-7610
7.070.000
14.025.000
SPECTRUM SCOPE
<MENU1>
EDGE
HOLD
CENT/FIX
MAIN/SUB
DUAL
EXPD/SET
MENU
M.SCOPE
MP-W
MP-R
AUTO TUNE
QUICK
EXIT
REC
PLAY
MULTI
SPLIT
DUAL-W
GENE
XFC
CHANGE
TWIN-PBT
FILTER
APF/TPF
KEY SPEED-PITCH
RIT
CLEAR
SPEECH

# Icom IC-7610


10 MHz Reference In

# Amateur Radio HF Doppler Measurements

1. GPSDO-lock receiver.
2. Put radio in USB mode.
3. Tune dial 1 kHz below carrier to be measured
   (e.g. 9999 kHz for 10 MHz WWV)
4. Feed audio into Spectrum Lab by DL4YHF to record WAV files and visualize spectrum.



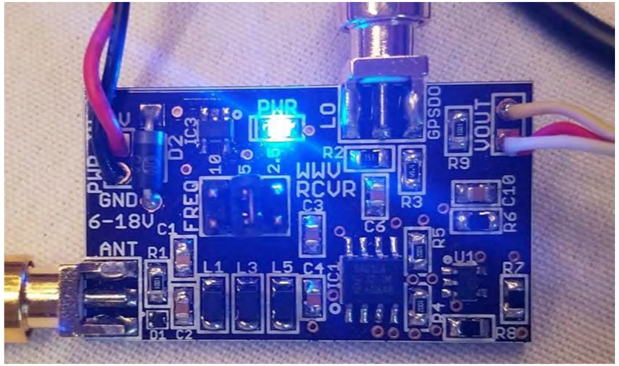

13 Oct 2019

Ft. Collins, CO
40.68°N, -105.04°E
to
San Antonio, TX
29.57°N, -98.89°W

Courtesy of
Steve Cerwin WA5FRF

# "Grape" Low Cost PSWS

- The Grape Generation 1 mixes the incoming HF signal directly with the Leo Bodnar GPSDO reference.
- This provides a relatively inexpensive way to make these precision measurements.




"Grape Receiver" Generation 1 by J. Gibbons N8OBJ

Raspberry Pi 4 with Switching Mode Power Supply for Grape Receiver and GNSS Disciplined Oscillator