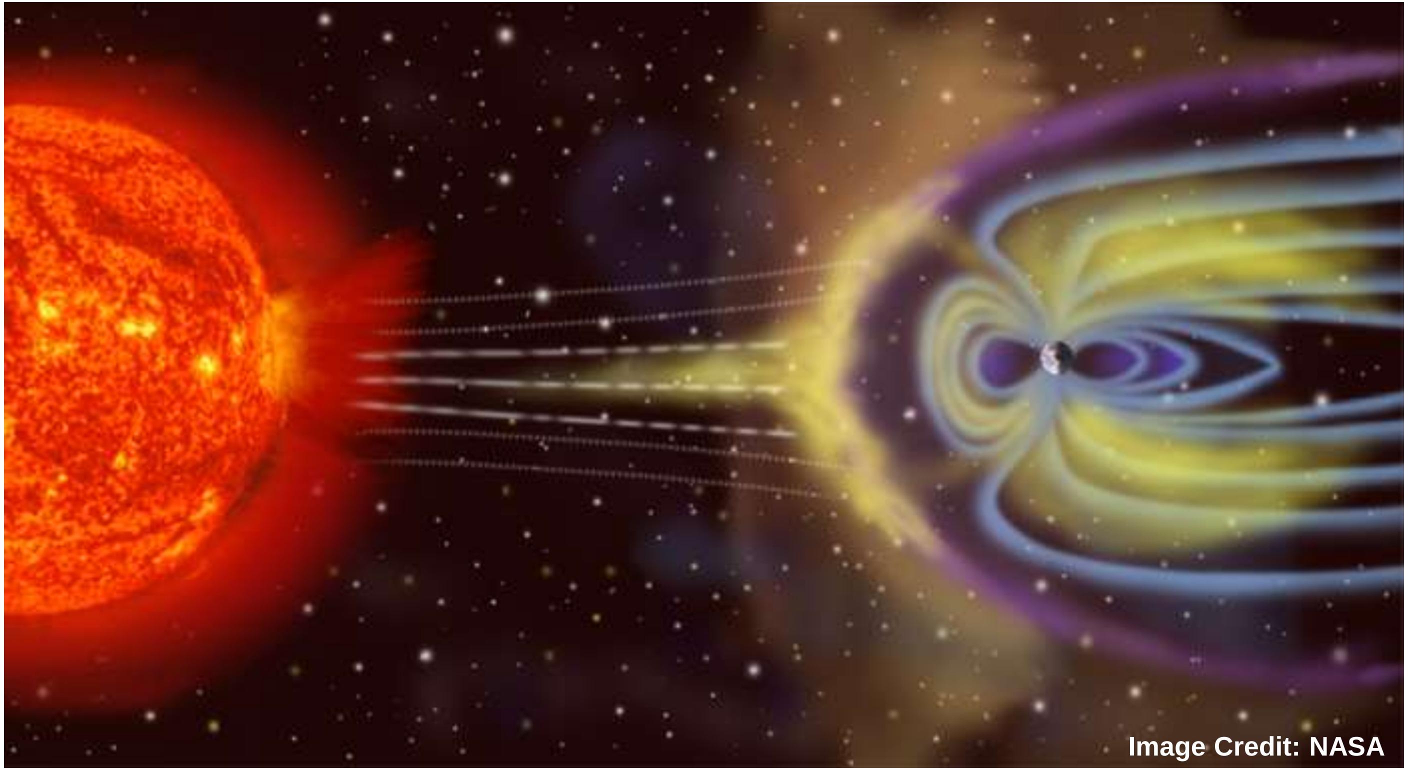
HamSCI:
The Ionosphere from Your Backyard

Nathaniel A. Frissell, W2NAF
The University of Scranton

Gwinnett Amateur Radio Society
November 9, 2021

Amateur Radio & Space Weather



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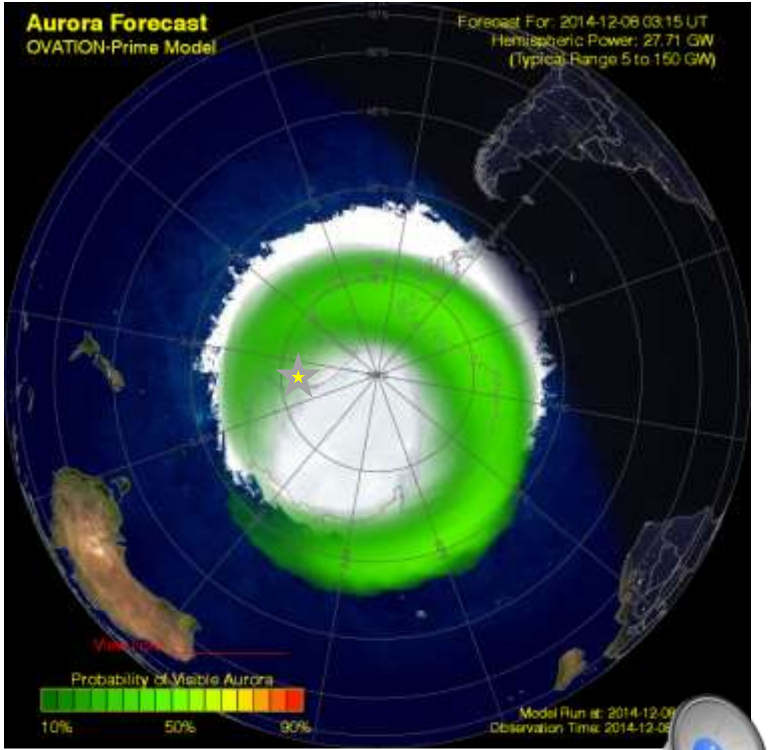
Space Weather and Ham Radio



20141227 0746 UT Aurora @ KC4USV 14010 kHz

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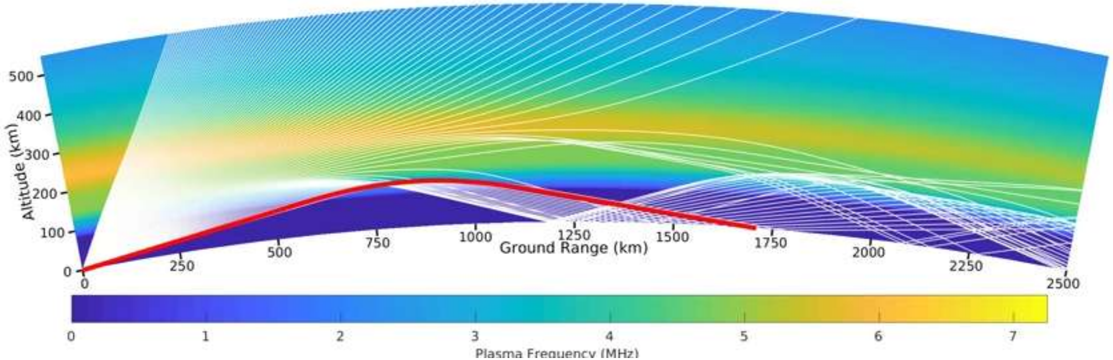
Amateur Radio Frequencies and Modes

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
Amateur Radio and the Eclipse: Frissell et al. (2018), https://doi.org/10.1029/2018GL077324

- **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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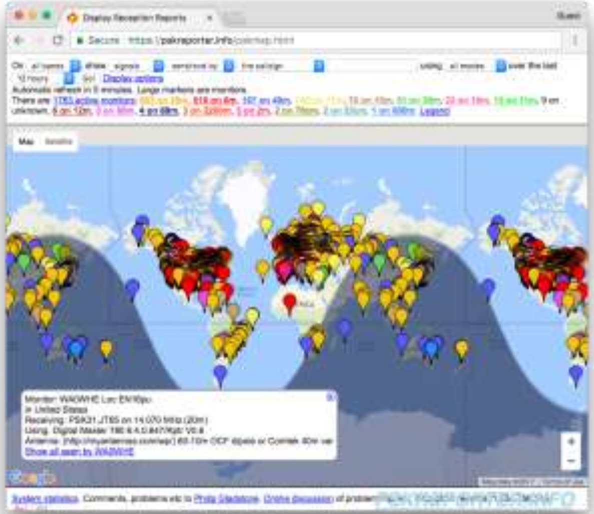
Amateur Radio Observation Networks

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!

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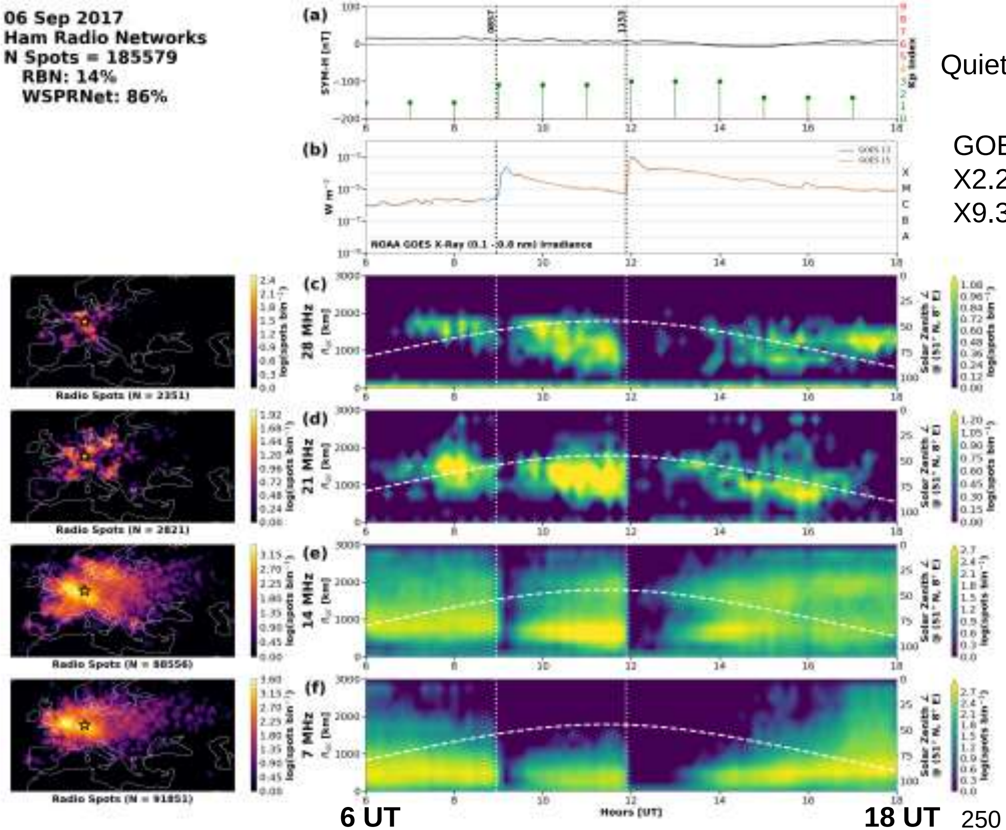
EU Response to Solar Flares

- Europe in daylight.
- Both flares cause deep blackouts.



Quiet Kp/Sym-H

GOES Flares
X2.2: 0857 UT
X9.3: 1153 UT

28 MHz

21 MHz

14 MHz

7 MHz

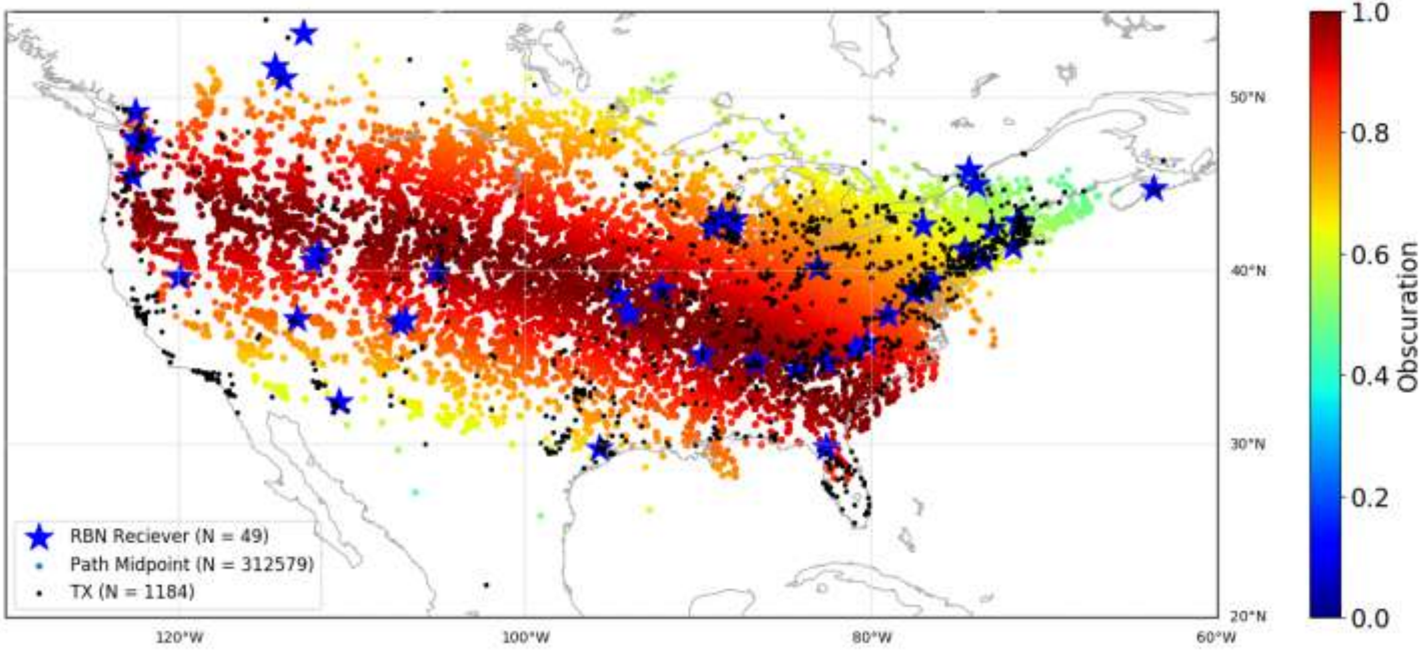
6 UT

18 UT

250 km × 10 min bins

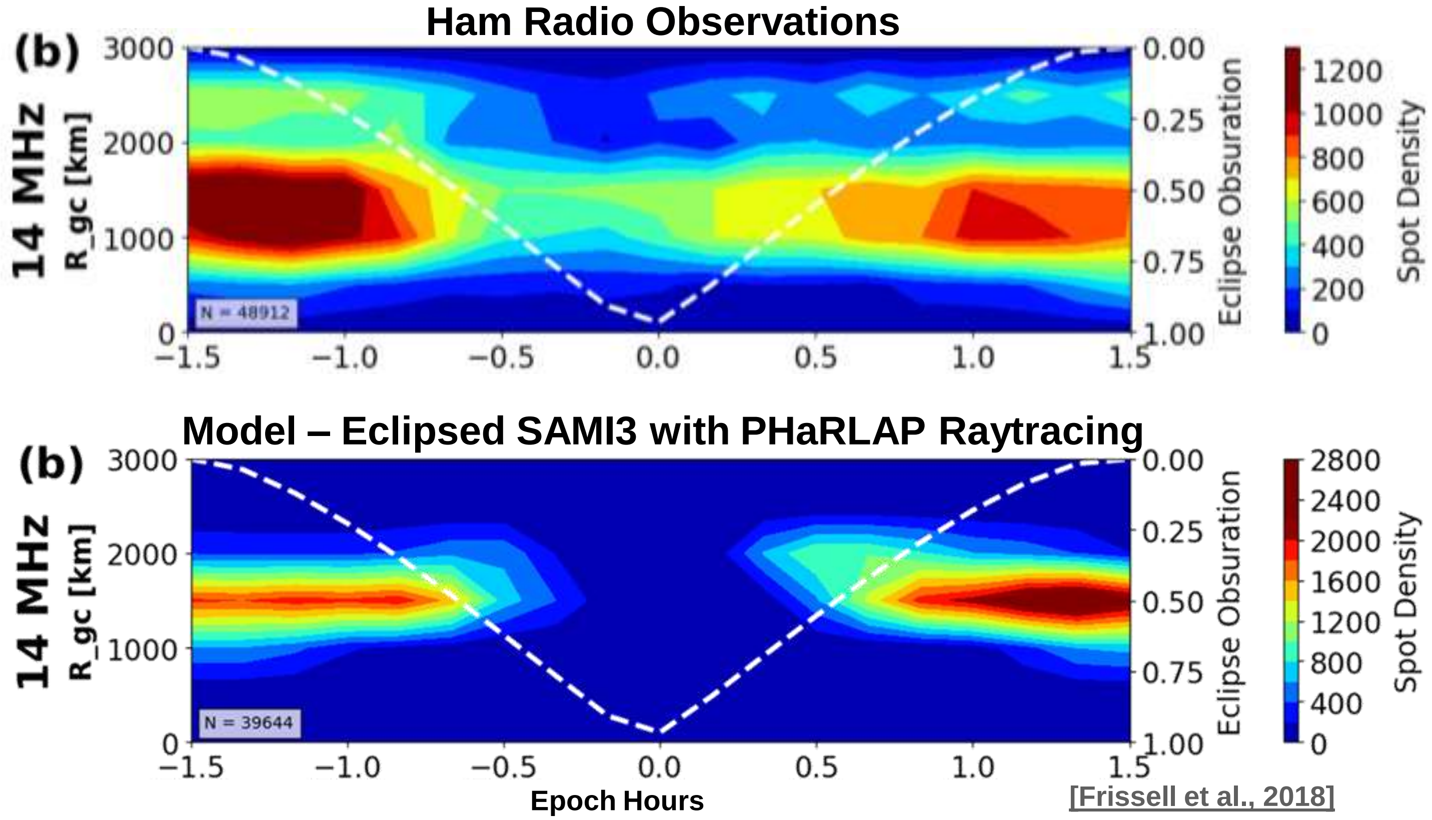
[Frissell et al., 2019]

Solar Eclipse QSO Party RBN Observations



[Frissell et al., 2018]

Linking Radio Observations to Physics with Modeling



[Frissell et al., 2018]

HamSCI Ham radio Science Citizen Investigation

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.

What are the science goals we are after?

Broadly, we are interested in any scientific question of interest to the amateur radio community or to the field of space physics. Examples include:

- Solar Flare Impacts
- Geomagnetic/Ionospheric Storms
- Internal Ionospheric Electrodynamics
- Short time scale/small spatial scale ionospheric variability
- Connections with Lower Atmosphere

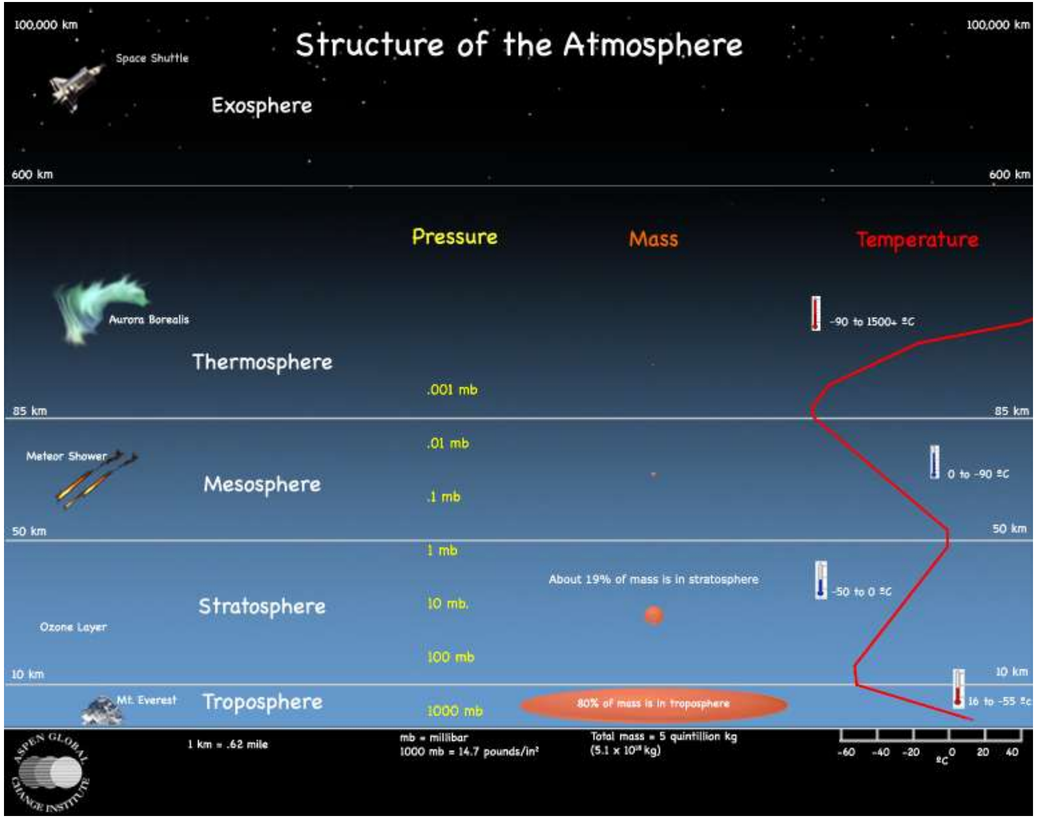
NASA SDO Observation of X9.3 Solar Flare on Sept 6, 2017. Flares such as this one can cause HF radio blackouts.

nathaniel.frissell@scranton.edu

Ionosphere Frontier Topics

- **Coupling from above vs. below**
  - Space weather drives the ionosphere from above
  - Terrestrial weather drives from below
- **Weather vs. Climate**
  - We have some reasonable understanding of ionospheric climate
  - Many, many open questions about ionospheric weather
- **How to make progress?**

Atmospheric Structure



Ionosphere

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

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

Traveling Ionospheric Disturbances

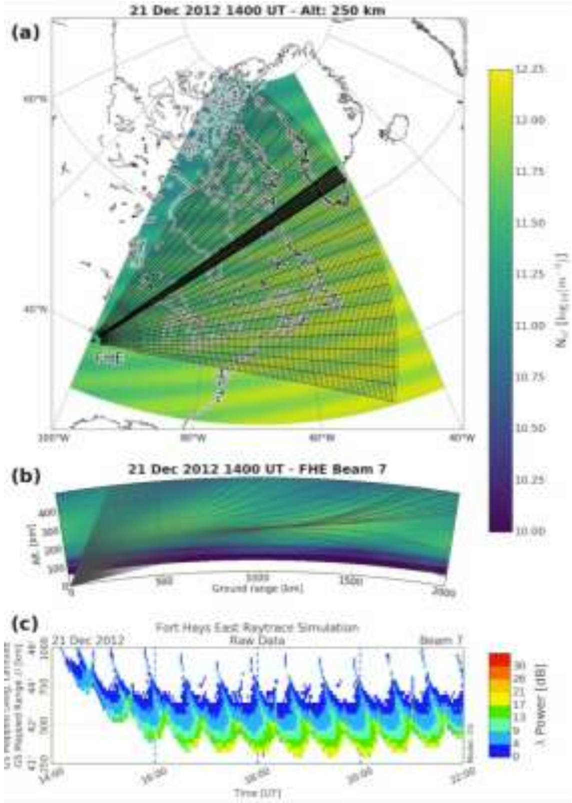
- **TIDs are Quasi-periodic Variations of F Region Electron Density**
  - **Medium Scale (MSTID)**
    - $T \approx 15 - 60$ min
    - $v_H \approx 100 - 250$ m/s
    - $\lambda_H \approx$ Several Hundred km (< 1000 km)
    - Often Meteorological Sources
  - **Large Scale (LSTID)**
    - $\lambda_h > 1000$ 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**

nathaniel.frissell@scranton.edu

14 MHz MSTID Simulation

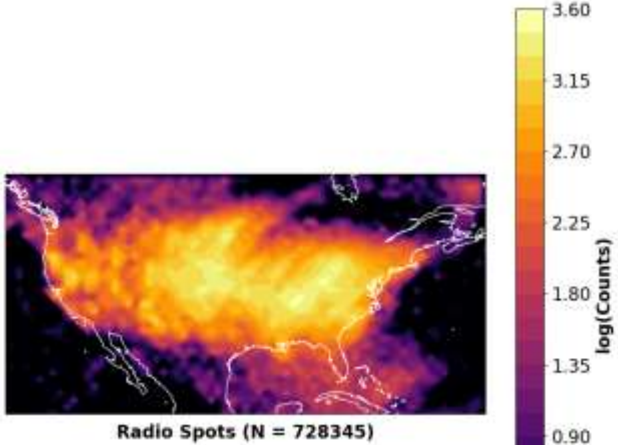


[Frissell et al., 2016]

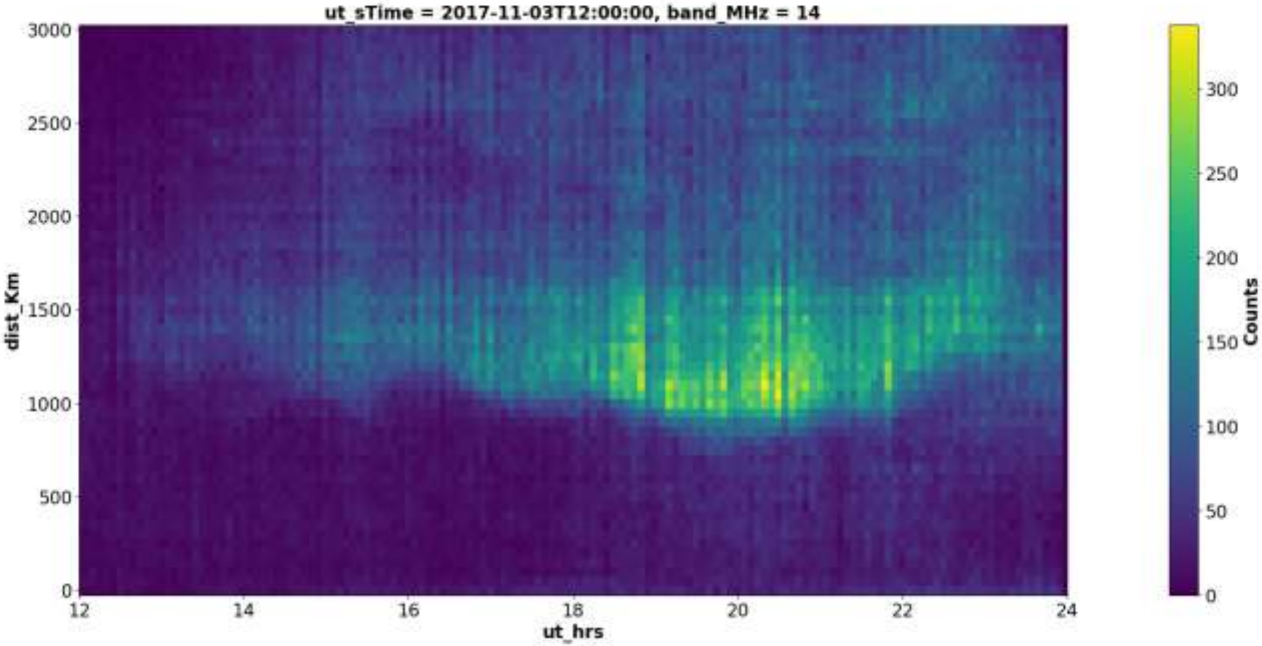
nathaniel.frissell@scranton.edu

November 3, 2017

20171103.1200-20171104.0000_timeseries.png



(1°x1° bins)



(5 min x 50 km bins)

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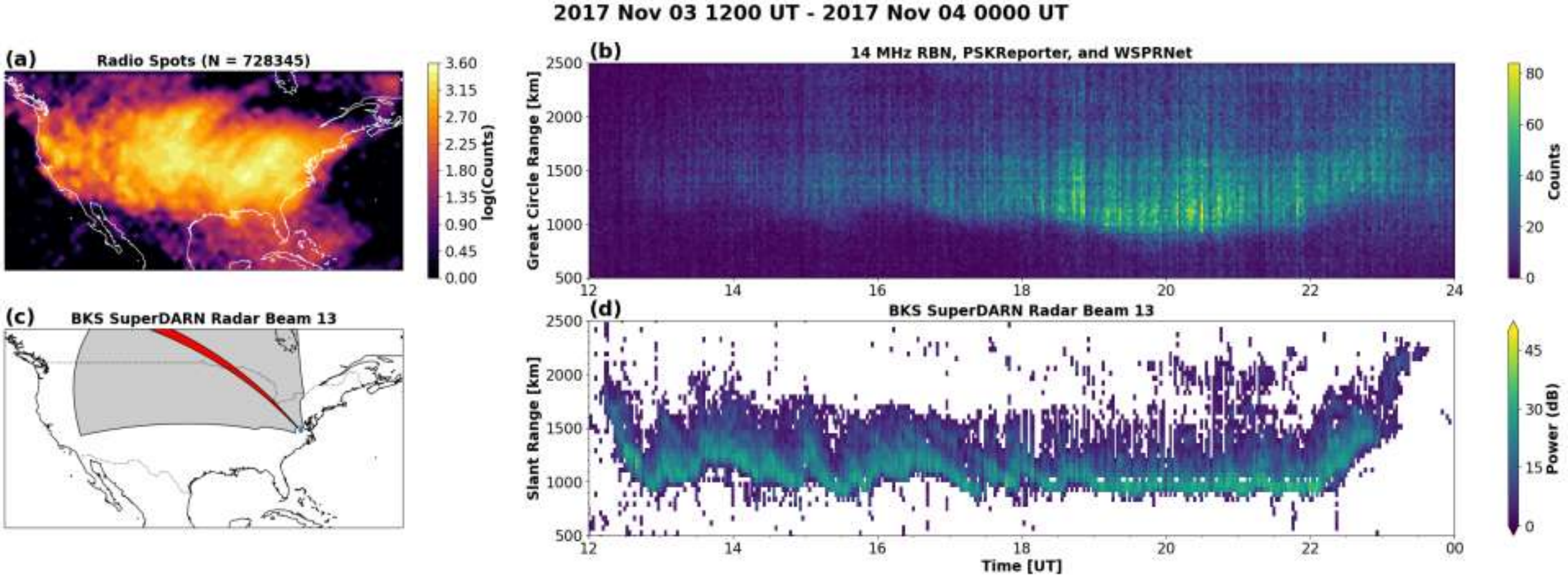
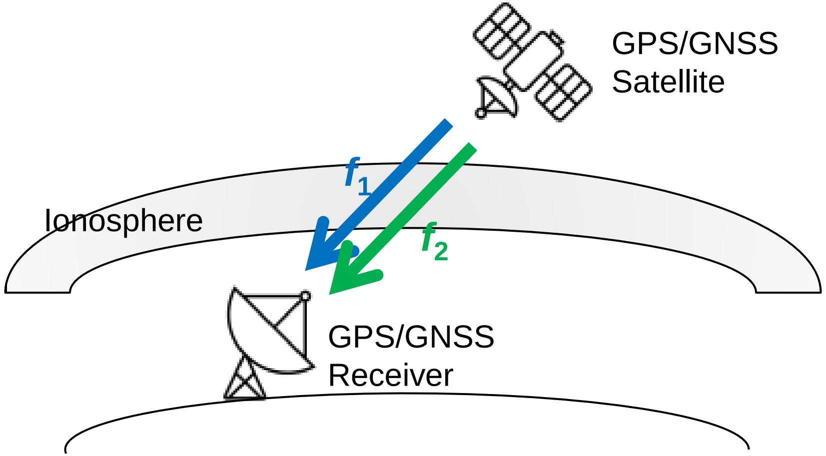
November 3, 2017



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}

What is Total Electron Content (TEC)?

$$I_s = \frac{1}{40.3}\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}\left[(L_1 - L_2) - (\lambda_1 n_1 - \lambda_2 n_2) + b_r + b_s\right]$$

- **Slant TEC** (I_s)
- **Frequency Terms** ($\frac{1}{40.3}\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}$)
- **Recorded carrier phases of the signal (converted to distance units)** ($L_1 - L_2$)
- **Integer cycle ambiguities** ($\lambda_1 n_1 - \lambda_2 n_2$)
- **Instrument (satellite and receiver) bias terms** ($b_r + b_s$)

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

[Tsugawa et al., 2007, doi:10.1029/2007GL031663]

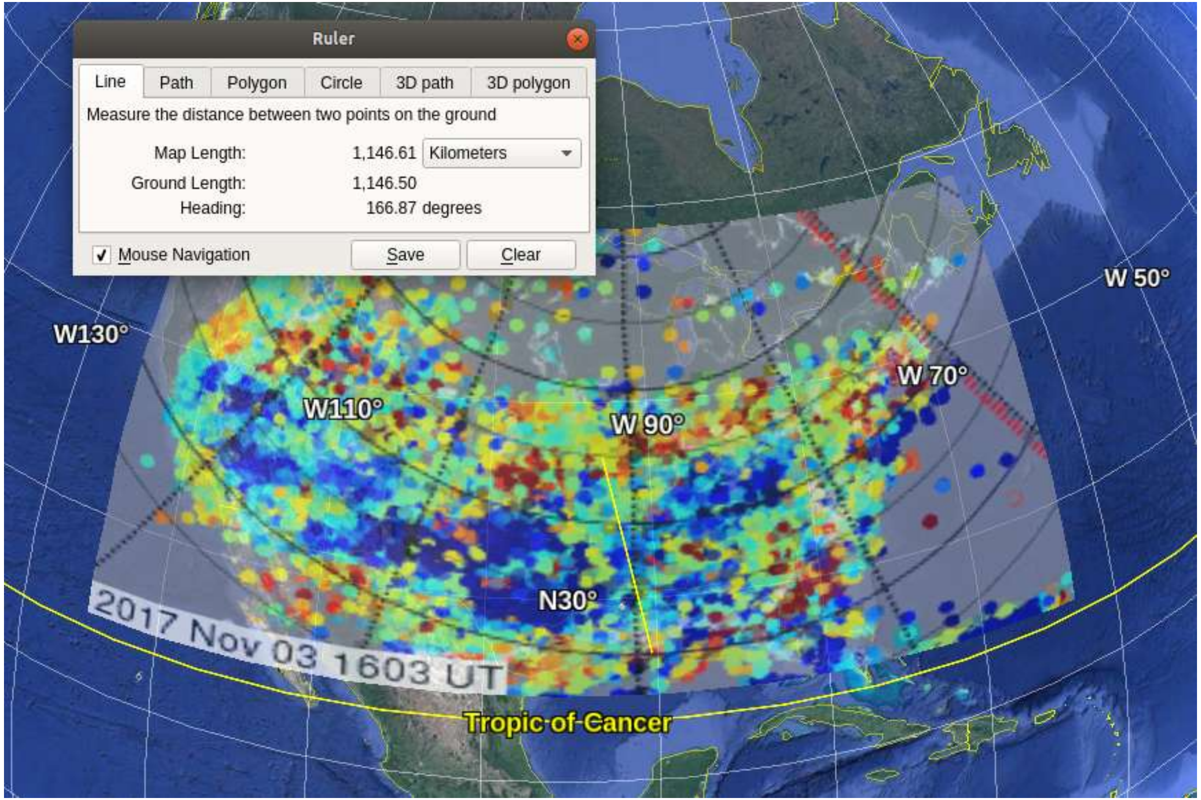
Estimated GNSS TEC LSTID Parameters

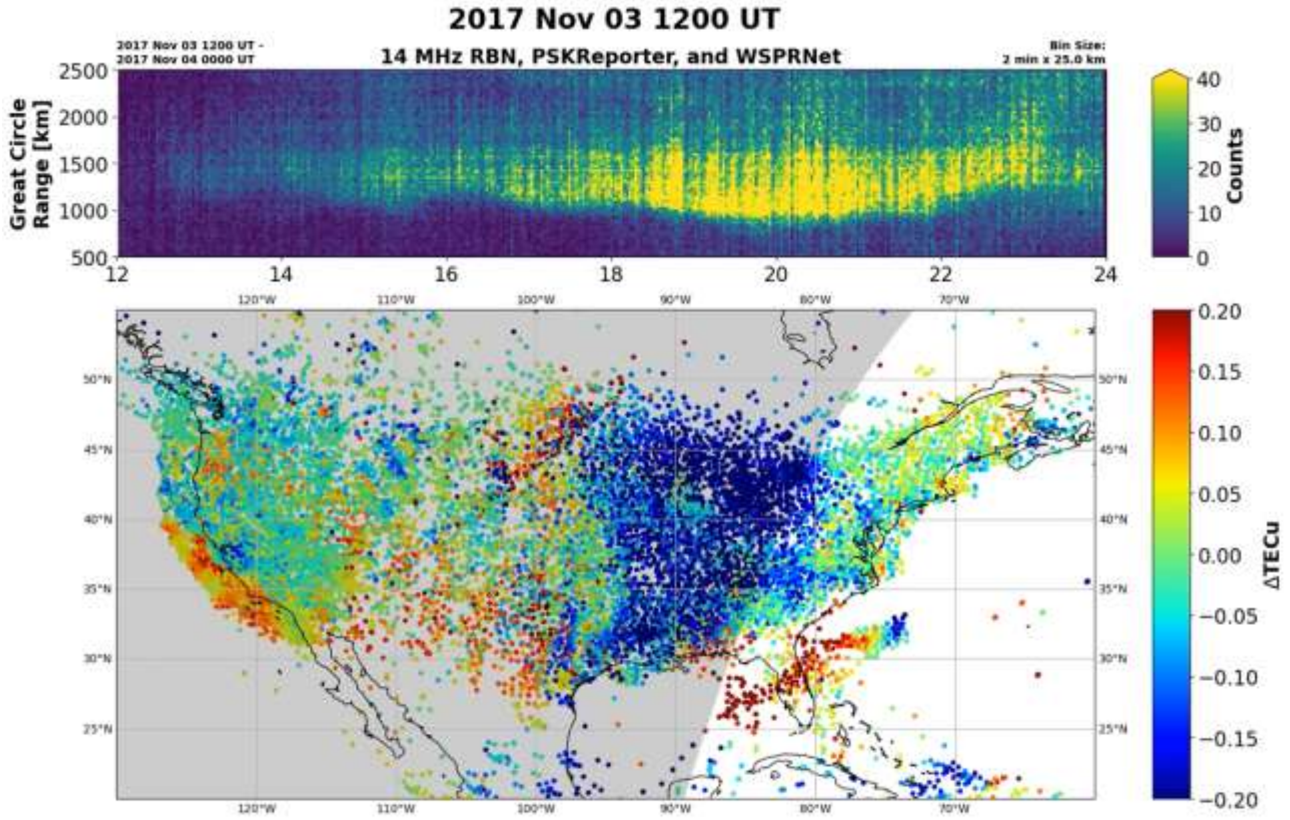
$\lambda_h \approx$ 1,100 km

$v_p \approx$ 950 km/hr

$T \approx$ 70 min

$\Phi_{Azm} \approx 135°$



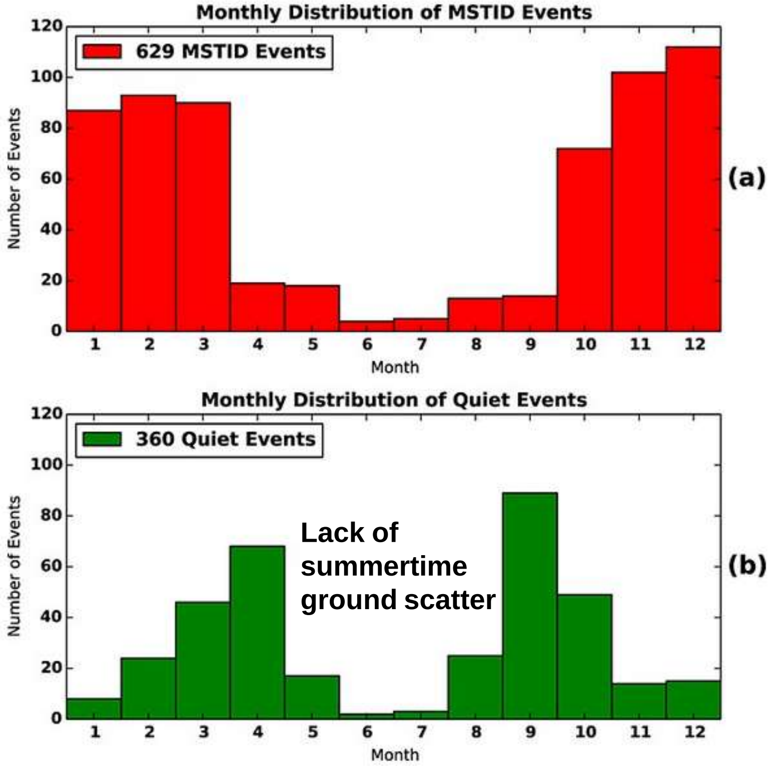


- Radio range is shortest when TEC is red (higher TEC)
- Higher electron densities → More HF refraction, communication range decreases

nathaniel.frissell@scranton.edu

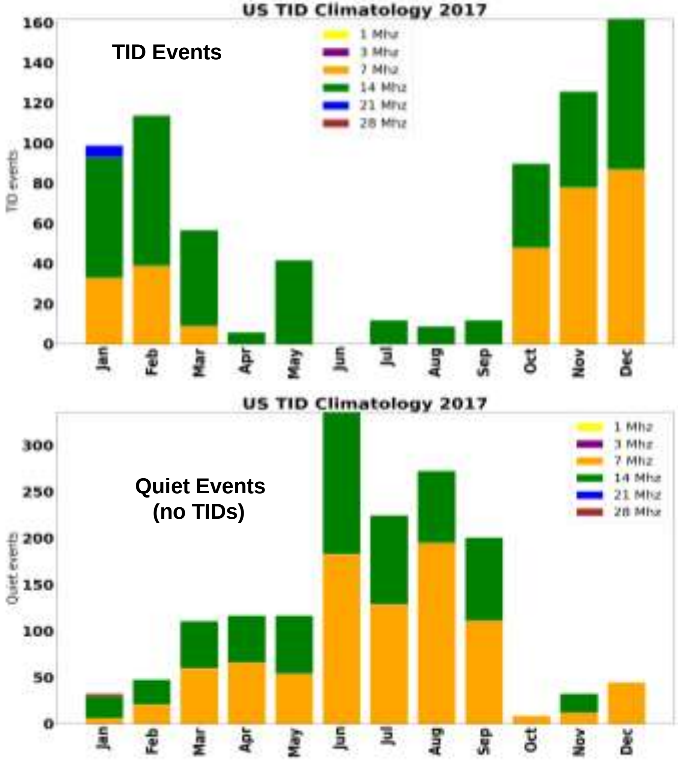
SuperDARN Climatology Comparison

SuperDARN



(*Frissell et al.*, 2014, https://doi.org/10.1002/2014JA019870)

Amateur Ham Radio



(*Diego Sanchez et al., 2021*)

nathaniel.frissell@scranton.edu

TID Studies: NASA SWO2R & NSF CAREER

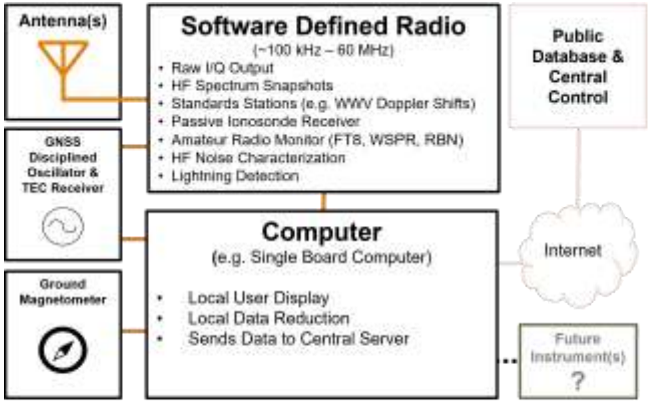
NASA SWO2R *(2 years, 2021-2023)* ***Enabling Space Weather Research with Global Scale Amateur Radio Datasets*** ***PI: N. Frissell W2NAF, Co-Is: T. Atkison, W. Engelke AB4EJ, and P. Erickson W1PJE***	NSF CAREER (5 years, 2021-2026) ***CAREER: Amateur Radio as a Tool for Studying Traveling Ionospheric Disturbances and Atmosphere-Ionosphere Coupling*** ***PI: N. Frissell W2NAF***
• Development of automated TID detection and parameter extraction algorithms. • Develop empirical TID models that use geophysical indices as independent variables and model the probability of TID occurrence signatures in terrestrial HF communications. • Validate models for the 7 and 14 MHz bands in the continental US and mainland Europe. • Deposit RBN/PSKReporter/WSPRNet data into public NASA data repositories.	• Identify the amount of TIDs observed by HF communications systems that are and are not associated with geomagnetic activity. • Determine the ability of data from amateur radio to fill TID observational gaps and be scientifically useful. • Establish TID longitudinal dependence on the 2D stratospheric polar vortex configuration. • Test the multistep vertical coupling paradigm of AGWs/TIDs theorized in the latest physics-based models.
NASA Partner · The University of Scranton, A Jesuit University · A · MIT Haystack Observatory	NSF · The University of Scranton, A Jesuit University

What is a Personal Space Weather Station?

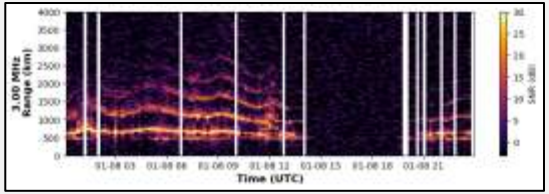
- The **HamSCI Personal Space Weather Station (PSWS)** is a multi-instrument, ground-based device designed to observe space weather effects both as a single-point measurement and as part of a larger, distributed network.
- It is **“Personal”** because it is being designed such that an individual should be able to purchase one and operate it in their own backyard.
- **For amateur radio operators, the PSWS should provide information about current radio propagation conditions both locally and as part of a global network.**
- In addition, the PSWS design takes into account the needs of professional researchers who want to study specific aspects of the ionosphere and space weather.

nathaniel.frissell@scranton.edu

Personal Space Weather Station

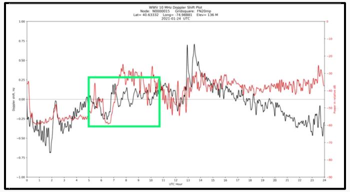


TangerineSDR



WA2DFI, N5EG, N8UR, KV0S, AB4EJ, N1HAC, AA8K, N4XWE, W2NAF, KC3PVE, W1PJE, Juha Vierinen, et al.

Grape PSWS

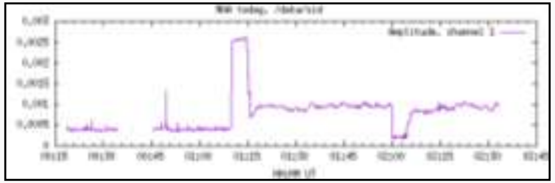


KD8OXT, AD8Y, N8OBJ, KB3UMD, WA5FRF, KD2UHN, NQ6Z, AB4EJ, W2NAF, K4BSE, KD8CGH, W7LUX, KE8QEP, et al.

Magnetometer Module

KD0EAG, K2KGJ, KD2MCR, KE8QEP, WA2DFI, KV0S, W2NAF, et al.

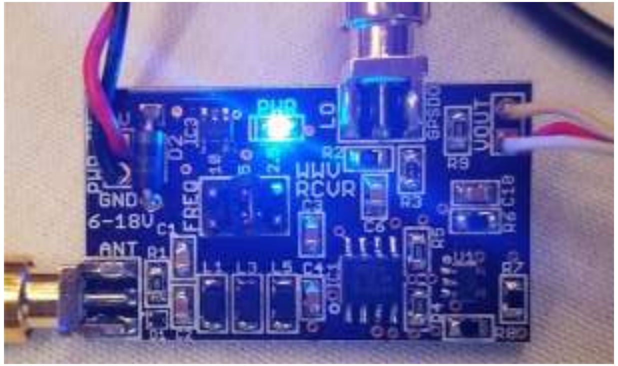
VLF RX



KC3EEY, WA2DFI, N5EG, N1HAC, et al.

"Grape" Low-Cost PSWS

- **Developed as the "Grape" Receiver by Case Western Reserve University and Case Amateur Radio Club W8EDU.**
- **Primary objective** is to measure Doppler Shift of HF standards stations such as WWV and CHU.
- **Cost of Grape v1 is ~$300 (not including antenna).**
- **Several stations** are currently deployed.
- Grape v1 build documentation is available at hamsci.org/grape1.
- Doppler shift data is collected via spectrographs and frequency estimation algorithms**.**
- Grape V2 is currently under development.
- Grape V2 will be capable of monitoring 4 HF channels simultaneously.



"Grape Receiver" Generation 1 by J. Gibbons N8OBJ

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

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

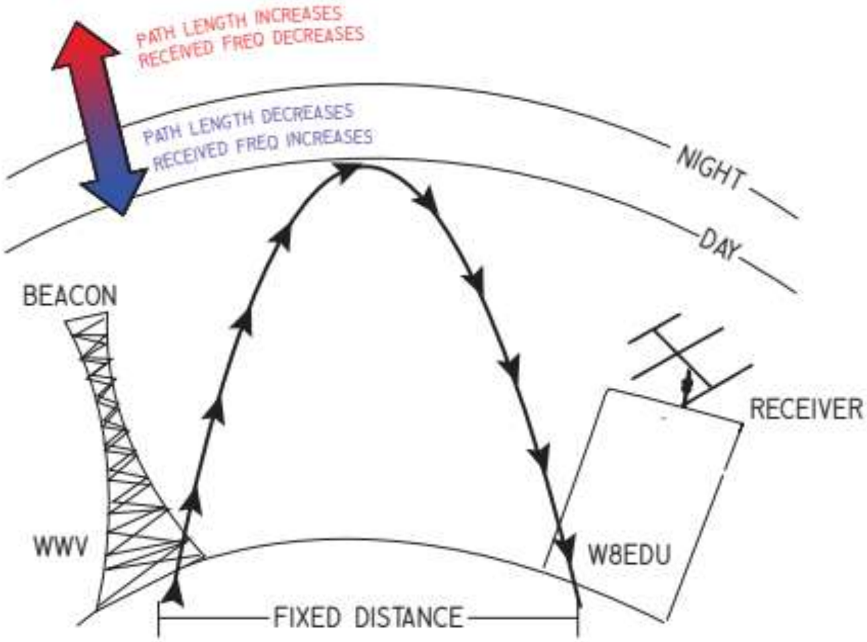
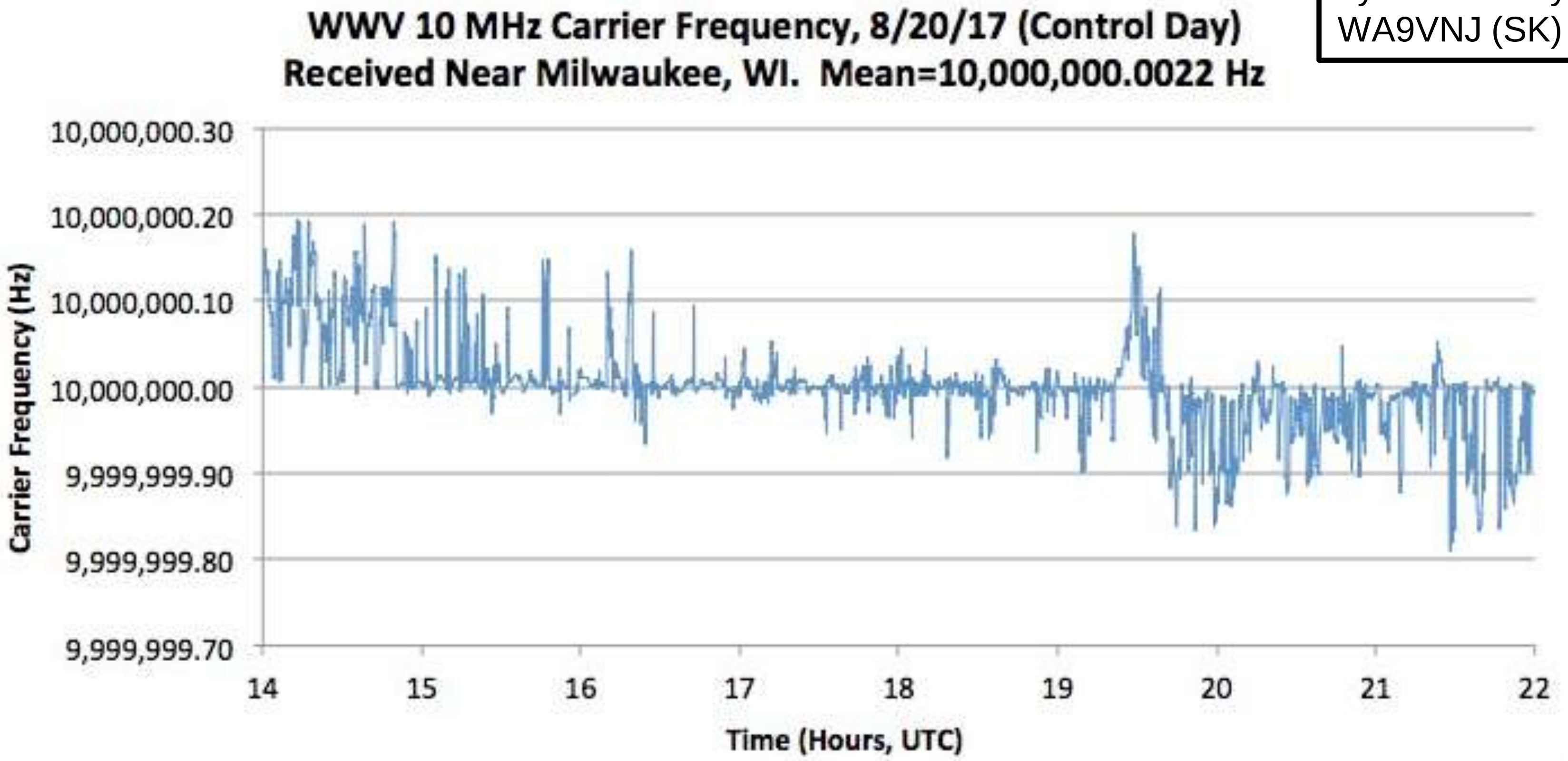


Figure by Kristina Collins, KD8OXT

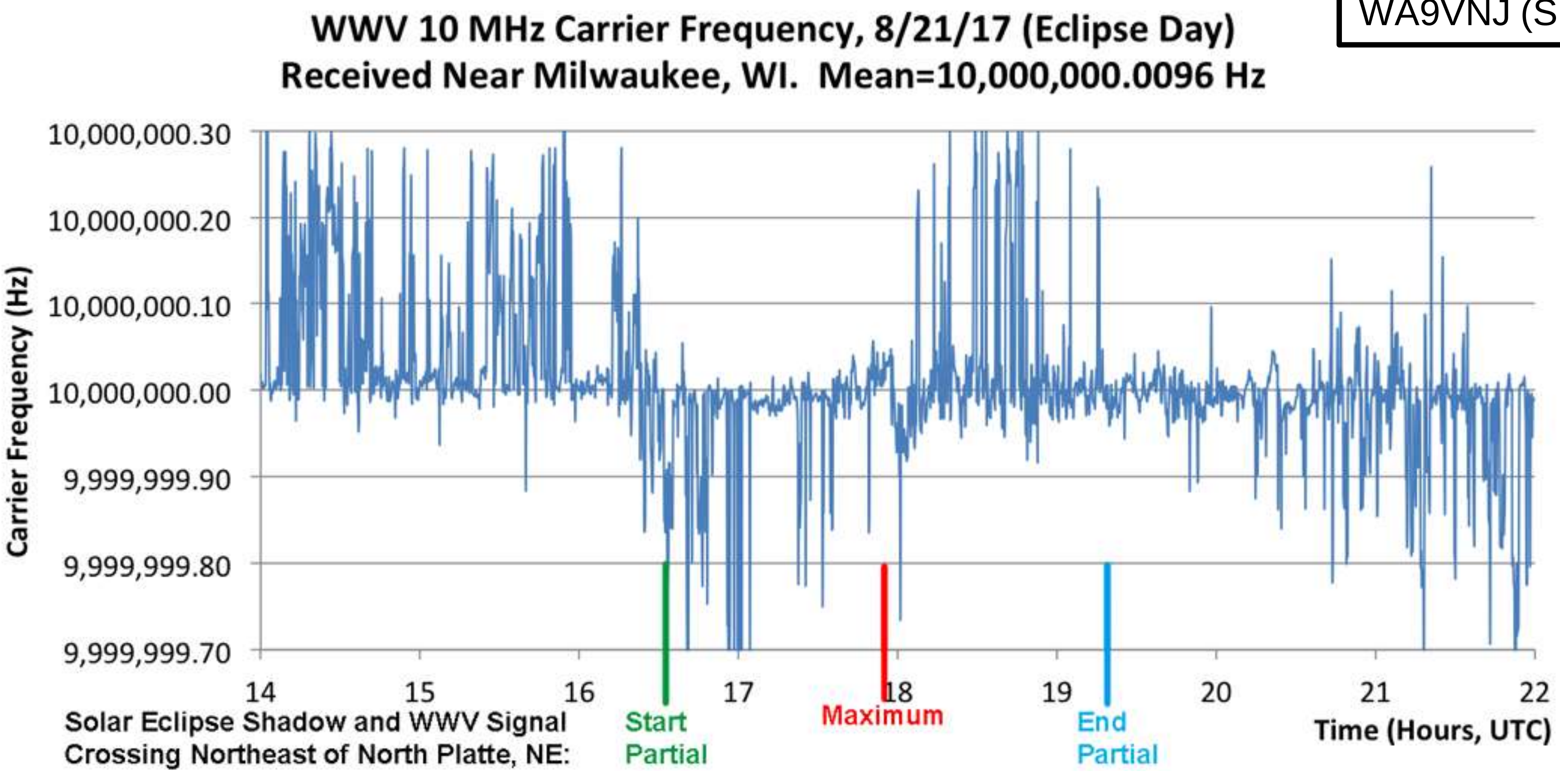
Example Doppler Measurements

Measurements by Steven Reyer WA9VNJ (SK)

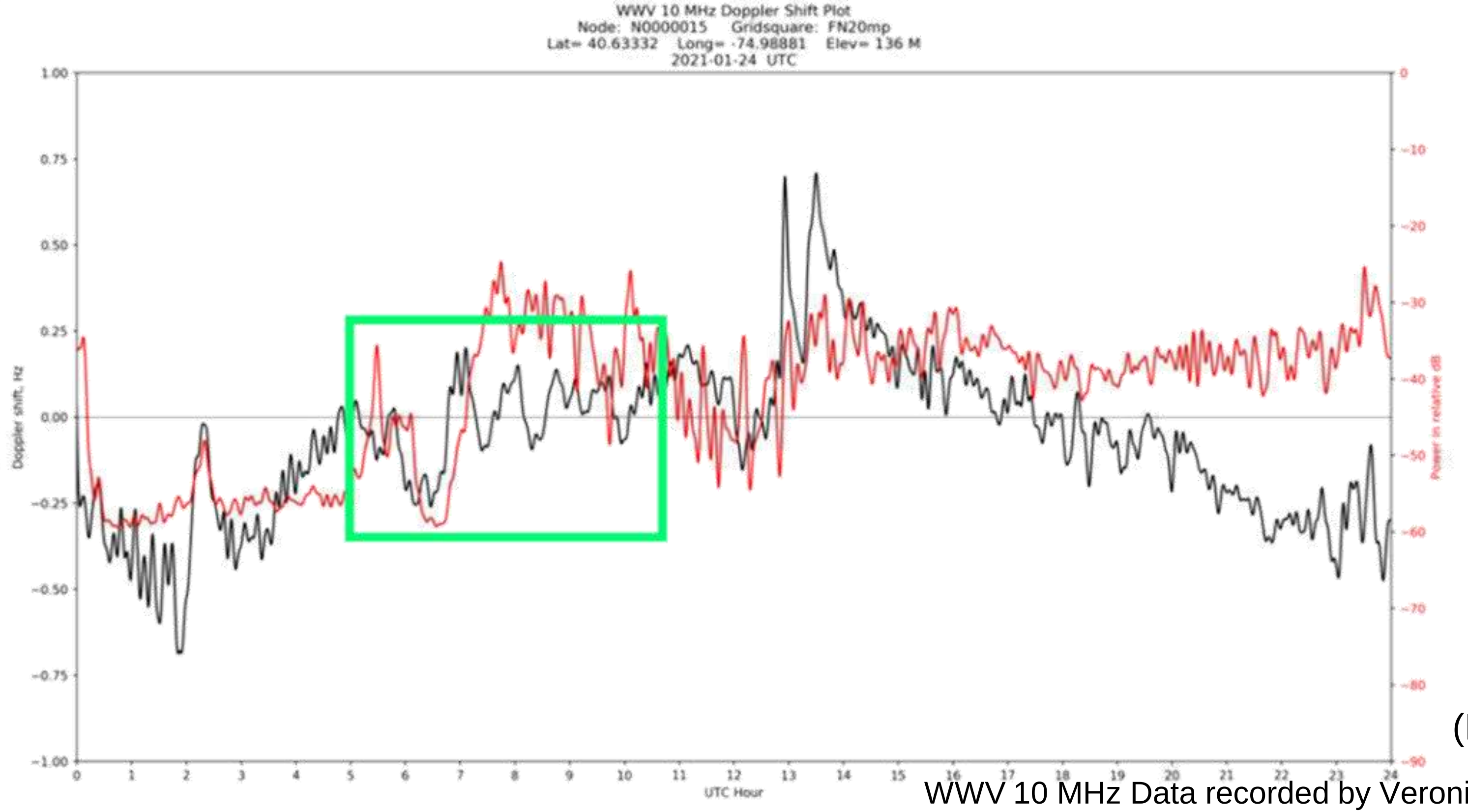


Example Doppler Measurements

Measurements by Steven Reyer WA9VNJ (SK)



Grape Data Example



(Romanek et al., 2021)

WWV 10 MHz Data recorded by Veronica Romanek, Hampton, NJ

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

nathaniel.frissell@scranton.edu

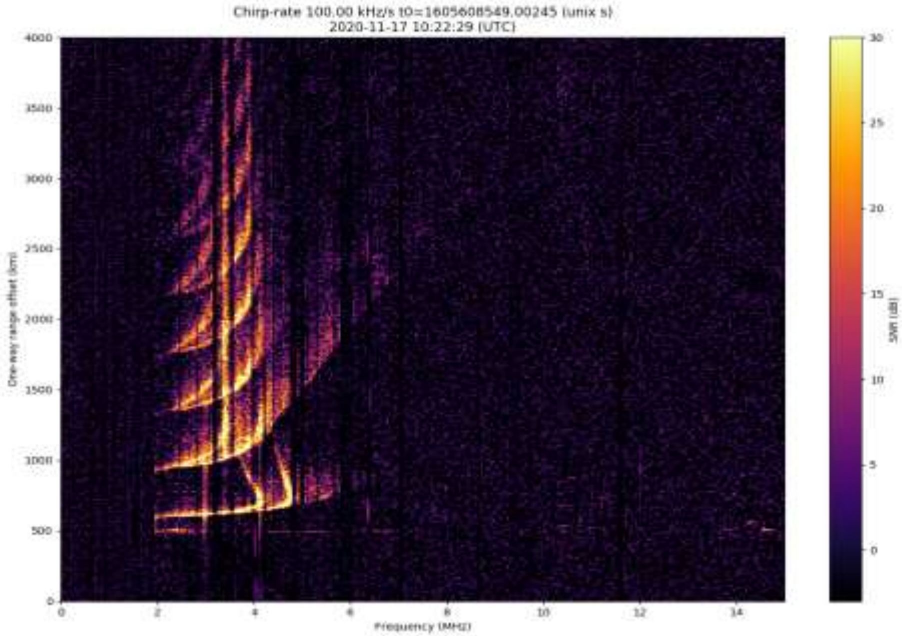
Why a New SDR?

- 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

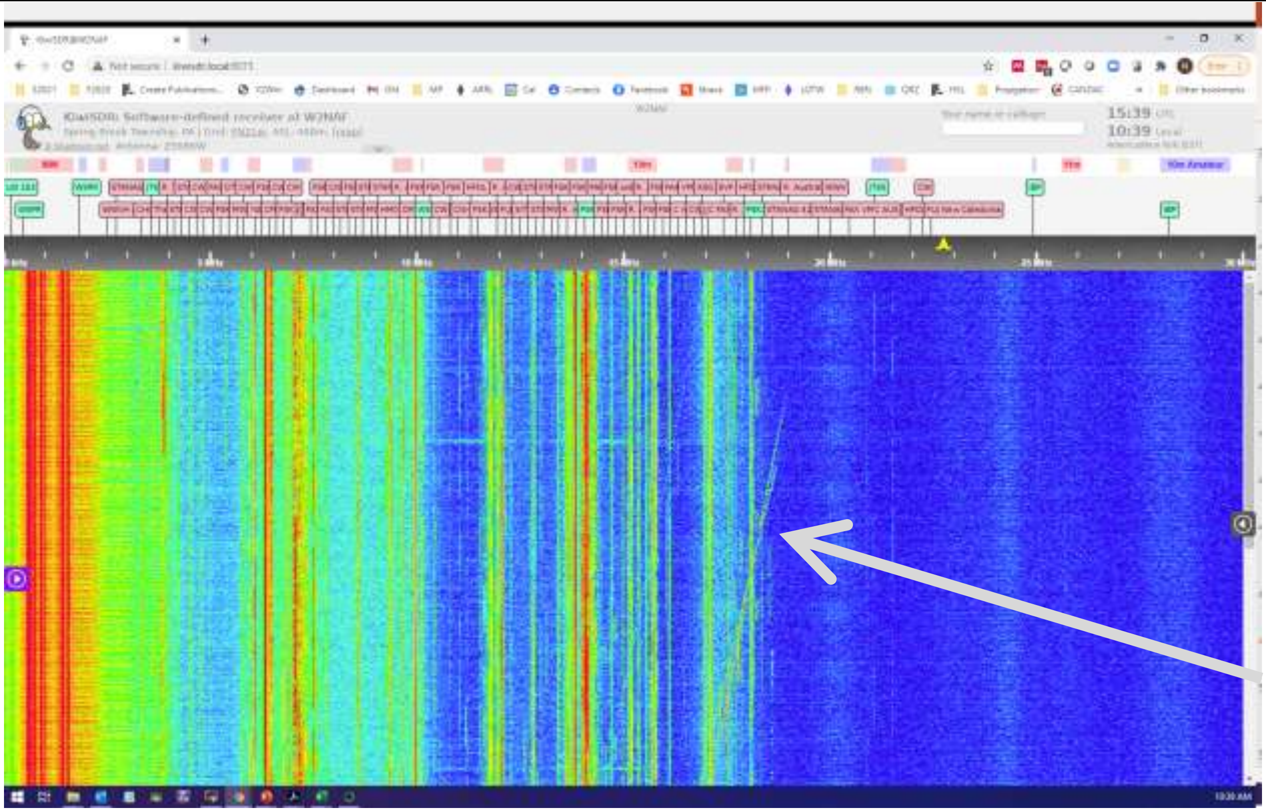
Chirp Ionosonde Studies

- Science mode to take advantage of the TangerineSDR
- Make oblique ionograms using FM Chirp Ionosondes of opportunity
- Made possible by open source software and help from **Dr. Juha Vierinen**
- Science effort led by HamSCI/Scranton Post-Doc **Dr. Dev Joshi, KC3PVE**



An ionogram processed with **Chirpsounder2** software showing the single-hop and the multi-hop propagation of high-frequency (HF) radio waves transmitted from Relocatable Over-the-Horizon Radar site in Virginia to Spring Brook, Pennsylvania – the receiver station on Nov. 17, 2020.

KiwiSDR Capture of Chirp Ionosonde



Chirp
Ionosonde

nathaniel.frissell@scranton.edu

Prototype Receive Station

The Universal Software Radio Peripheral (USRP) N200 kit. **Image Source:** https://ettus.com/all-products/un200-kit

The ZS6BKW Multiband HF Antenna employed in receiving the HF signals at the receiver station. **Image Source :** https://www.awarc.org/the-zs6bkw-multiband-hf-antenna/

- Implemented on Intel Core i9 with 128GB RAM Ettus USRP N200
- Receiver located in Spring Brook, PA (~10 miles from Scranton)
- Antenna: ZS6BKW @ 30 ft Altitude (Dipole-Like)
- A goal of TangerineSDR PSWS is to reduce the hardware requirements of this application substantially.

nathaniel.frissell@scranton.edu

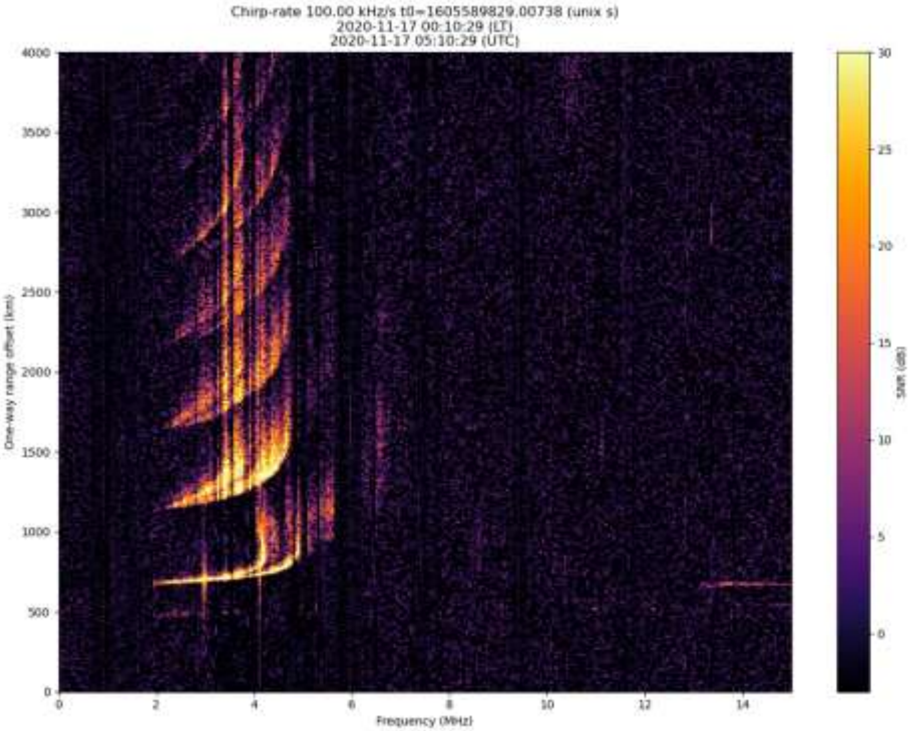
GNU Chirpsounder2 by Juha Vierinen

- **The** software **Chirpsounder2 (**https://github.com/jvierine/chirpsounder2**)** can be used to detect chirp sounders and over-the-horizon radar transmissions over the air, and to calculate ionograms from them. The software relies on Digital RF recordings of HF.
- This is a new implementation of the GNU Chirp Sounder. This new version allows to automatically find chirps without knowledge of what the timing and chirp-rate is.
- The process starts with a data capture with **THOR** (comes with DigitalRF), a USRP N2x0, a GPSDO, and a broadband HF antenna.

The following parts of the **chirpsounder2** software are then implemented to plot the ionograms from the collected data:

•**detect_chirps.py** # To find chirps using a chirp-rate matched filterbank
•**find_timings.py** # To cluster detections and determine what chirp timings and chirp rates exist
•**calc_ionograms.py** # To calculate ionograms based on parameters
•**plot_ionograms.py** # To plot calculated ionograms

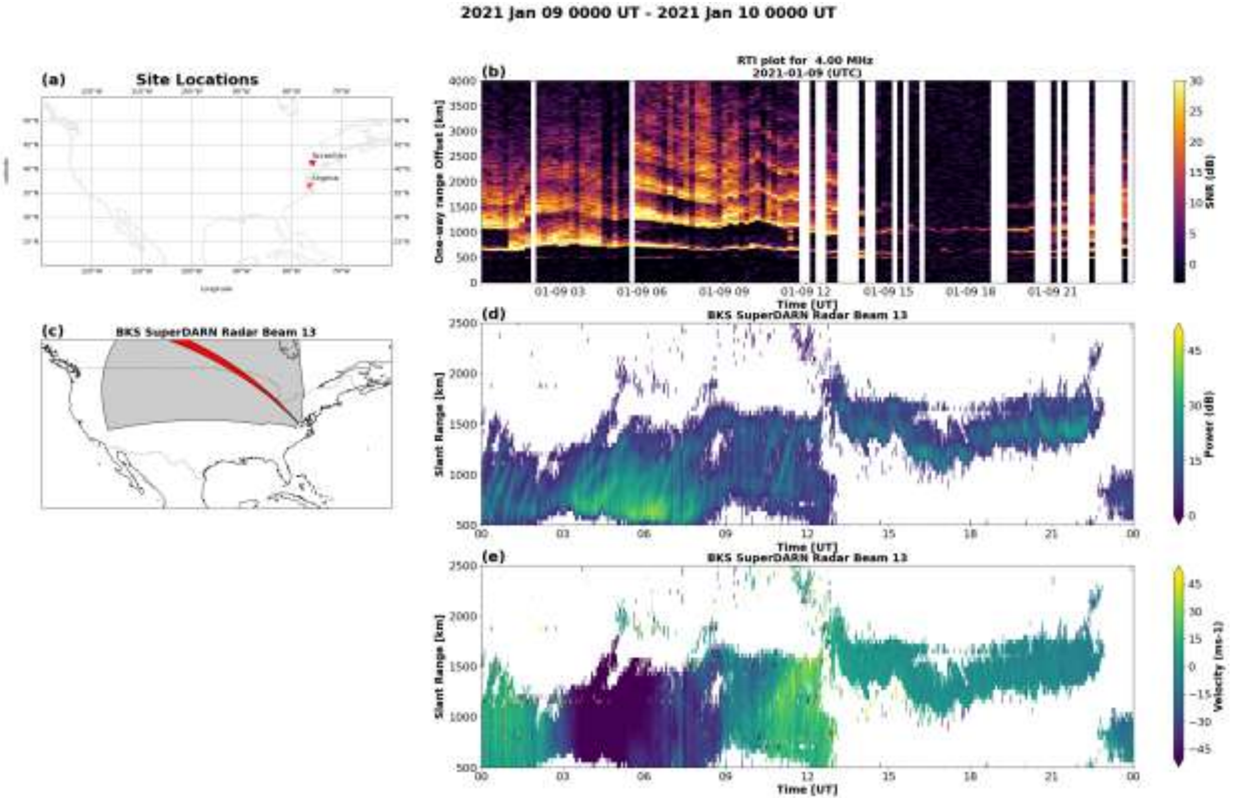
Chirp Ionosonde Studies



17 Nov 2020

[*Joshi et al.*, 2020, https://github.com/jvierine/chirpsounder2]

Chirpsounder Example



(Joshi et al., 2021, https://hamsci.org/publications/observations-mid-latitude-irregularities-using-oblique-ionosonde-sounding-mode-hamsci)

Ground Magnetometer

Developed by TAPR and NJIT

Purpose

- To establish a densely-spaced magnetic field sensor network to observe Earth's magnetic field variations in three vector components.

Target performance level

- ~10 nT field resolution
- 1-sec sample rate (note: Earth's magnetic field ranges from 25,000 to 65,000 nT)

Sensors

- PNI RM3100 magnetometer module
  - 3 axis magneto-inductive measurement module
  - Low cost (≤ $20) allows widespread deployment
  - Very small (25.4 x 25.4 x 8 mm)
- MCP9808 temperature sensor

Prototypes have been made

Software driver development

- Current low-level software is rudimentary
- Both low-level and user facing software must be created to support further characterization and optimization of the sensors.

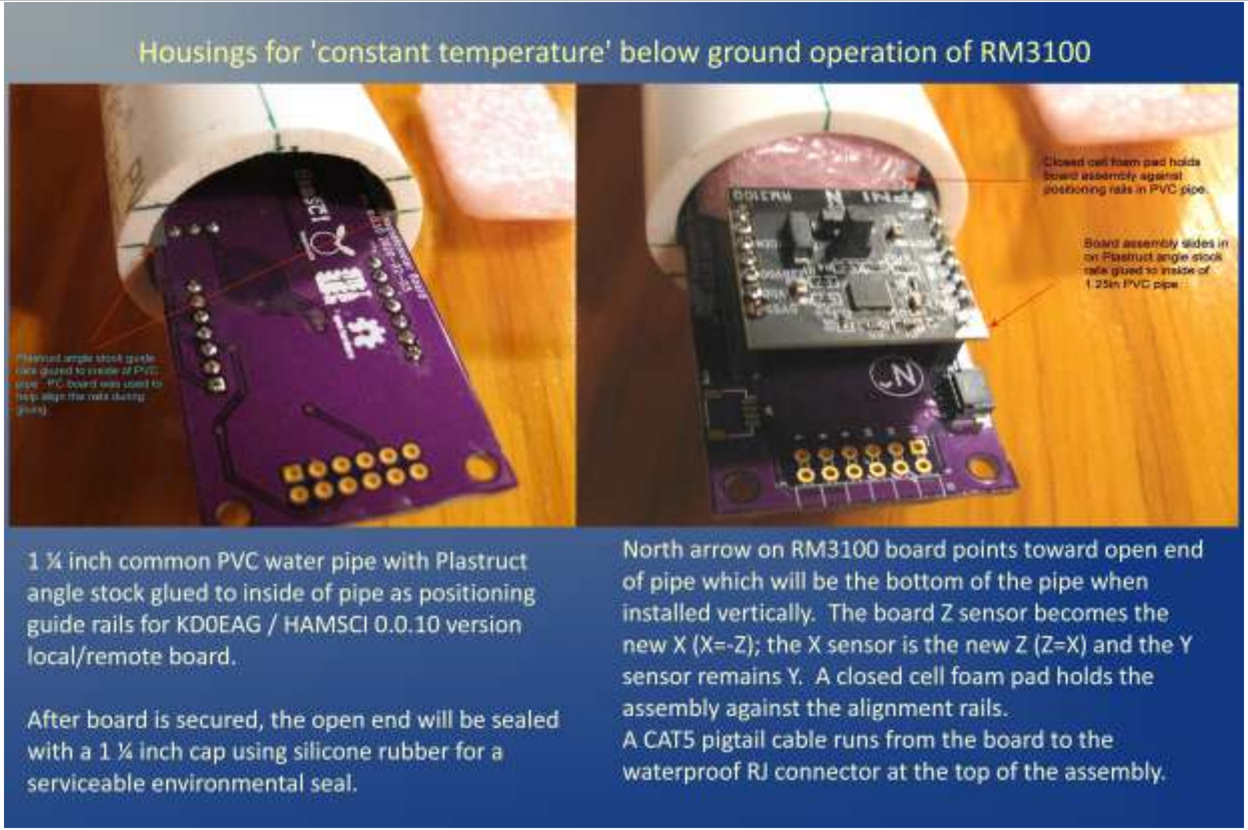
Planned Testing

- Testing at established quiet sites.
- Comparison with calibrated sensors of established quality.

Magnetometer prototype designed by David Witten KD0EAG at the 2020 HamCation conference in Orlando, FL

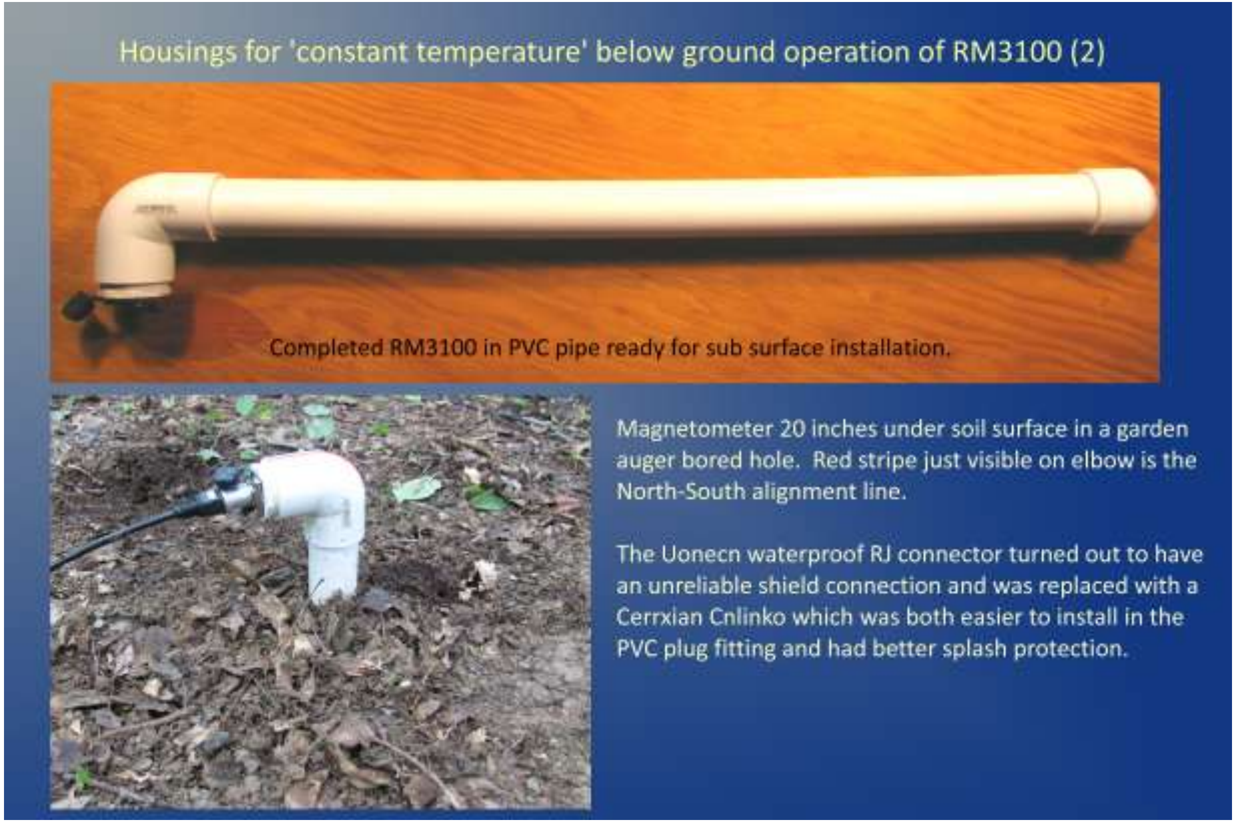
nathaniel.frissell@scranton.edu

K2KGJ Ground Magnetometer Installation



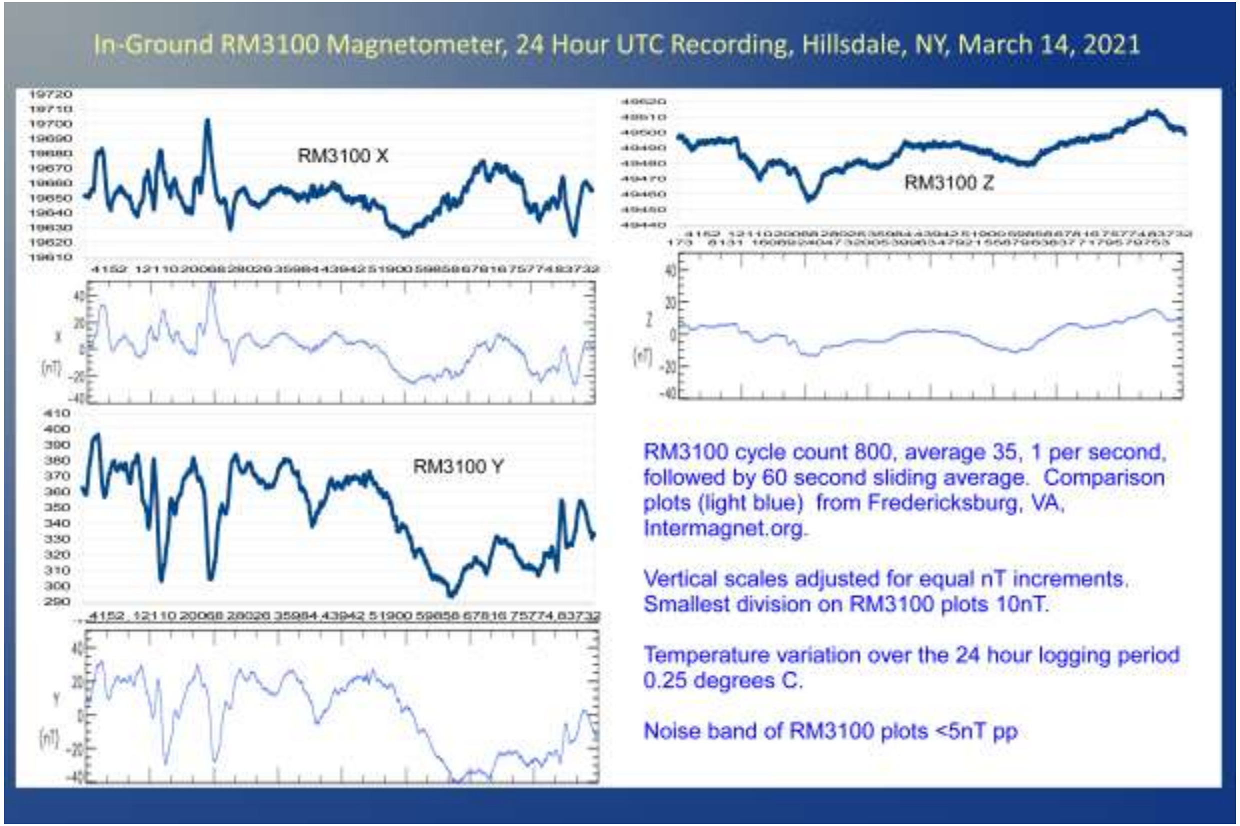
(Madey et al., 2021)

K2KGJ Ground Magnetometer Installation



(Madey et al., 2021)

Ground Magnetometer Example



Hillsdale, NY data and data comparison by Jules Madey K2KGJ

(Madey et al., 2021)

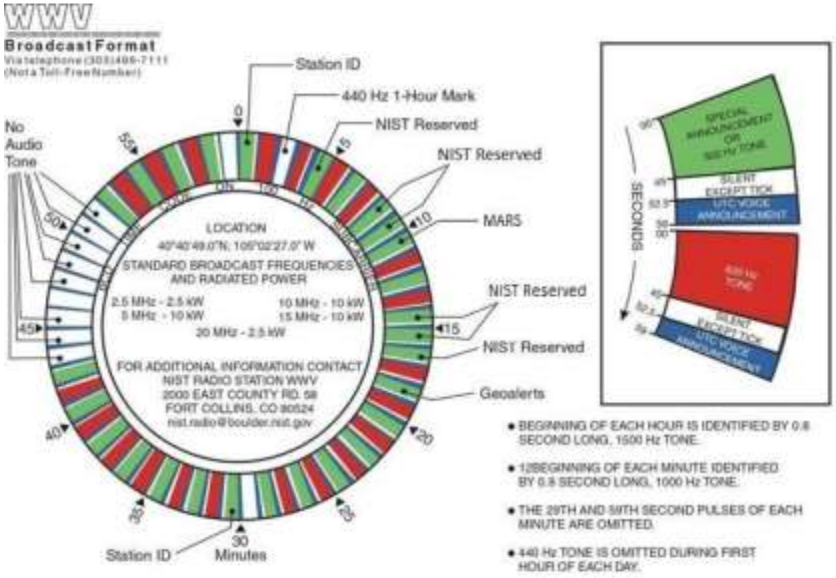
HamSCI Activities

- **Google Group (Over 450 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*

WWV Modulation Project

- What information besides time-of-flight and frequency measurements can we get from WWV?
- Listen for the signal on WWV and WWVH starting November 15th!
  - WWV: Minute 8
  - WWVH: Minute 48
- More information: www.hamsci.org/wwv



nathaniel.frissell@scranton.edu

Summary

- HamSCI is a collective that aims to bring together the amateur radio and professional space science research communities for mutual benefit.
- In an effort to improve the scientific usability of amateur radio observations, HamSCI is developing a Personal Space Weather Station designed with science requirements in mind from the very beginning. These modular systems will include:
    - HF Radio Receivers for studying the ionosphere using signals of opportunity
    - Ground Magnetometer with ~10 nT resolution
    - GNSS Receivers for precision timestamping and frequency stability
    - Target price between $300 - $1000, depending on capabilities.

Acknowledgments

The authors gratefully acknowledge the support of NSF Grants AGS-2002278, AGS-1932997, and AGS-1932972. We are especially grateful to the amateur radio community who voluntarily produced and provided the HF radio observations used in this presentation, especially the operators of the Reverse Beacon Network (RBN, reversebeacon.net), the Weak Signal Propagation Reporting Network (WSPRNet, wsprnet.org), PSKReporter (http://pskreporter.info), qrz.com, and hamcall.net. The Kp index was accessed through the OMNI database at the NASA Space Physics Data Facility (https://omniweb.gsfc.nasa.gov/). The SYM-H index was obtained from the Kyoto World Data Center for Geomagnetism (http://wdc.kugi.kyoto-u.ac.jp/). GOES data are provided by NOAA NCEI (https://satdat.ngdc.noaa.gov/). GPS-based total electron content observations and the Madrigal distributed data system are provided to the community as part of the Millstone Hill Geospace Facility by MIT Haystack Observatory under NSF grant AGS-1762141 to the Massachusetts Institute of Technology. We acknowledge the use of the Free Open Source Software projects used in this analysis: Ubuntu Linux, python, matplotlib, NumPy, SciPy, pandas, xarray, iPython, and others.

Thank You!

nathaniel.frissell@scranton.edu

Acronym Glossary

AE	Auroral Electrojet Index
BKS	Blackstone, VA SuperDARN Radar
GNSS	Global Navigation Satellite System
HF	High Frequency (3-30 MHz)
LSTID	Large Scale Traveling Ionospheric Disturbance
MSTID	Medium Scale Traveling Ionospheric Disturbance
RBN	Reverse Beacon Network
SAMI3	SAMI3 is Another Model Ionosphere
SuperDARN	Super Dual Auroral Radar Network
Sym-H	Symmetric-H Index (For measuring geomagnetic storms)
TEC	Total Electron Content
TID	Traveling Ionospheric Disturbance
WSPRNet	Weak Signal Propagation Reporting Network

nathaniel.frissell@scranton.edu

Abstract

The Ham Radio Science Citizen Investigation (HamSCI) is a platform to foster collaborations between the amateur (ham) radio and professional space science and space weather communities. Its mission is to (1) advance scientific research and understanding through amateur radio activities, (2) encourage the development of new technologies to support this research, and (3) provide educational opportunities for the amateur radio community and the general public. Similar to amateur astronomy, amateur radio allows individuals new to the avocation a path for learning, and those with years of experience a place to apply their advanced skills. This is accomplished through collaborative projects, coordinated experiments, workshops, telecons, and e-mail groups. In this presentation, we describe current HamSCI activities, available datasets, recent results, and future plans. This includes the HamSCI Personal Space Weather Station (PSWS) project, analysis of near-global communications monitoring networks such as the Reverse Beacon Network (RBN) and Weak Signal Propagation Reporting Network (WSPRNet), and analysis of observed Doppler shifts for high frequency signals of opportunity.

nathaniel.frissell@scranton.edu

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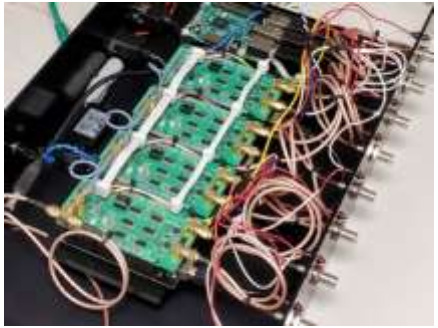
nathaniel.frissell@scranton.edu

Backup Slides

Amateur Radio, Space Weather, & Propagation


W3USR University of Scranton


N8UR multi-TICC: Precision Time Interval Counter


AB4EJ Home Station


Field Day / Emergency Prep


KD2JAO & WB2JSV at K2MFF


K3LR Contest Super Station

DXing from Adak Island


K2BSA Scout Jamboree

What is Amateur (Ham) Radio?

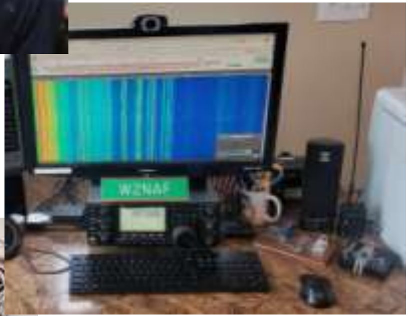
- **Hobby for Radio Enthusiasts**
  - Communicators
  - Builders
  - Experimenters
- **Wide-reaching Demographic**
  - All ages & walks of life
  - Over 760,000 US amateurs; ~3 million Worldwide

(http://www.arrl.org/arrl-fact-sheet)

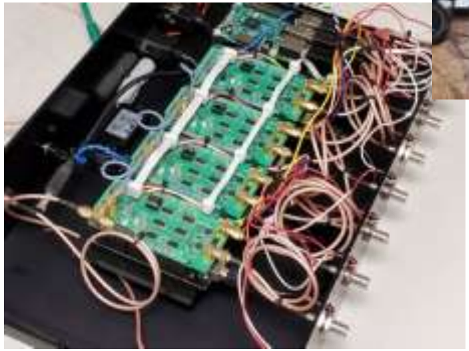
- **Licensed by the Federal Government**
  - Basic RF electrical engineering knowledge
  - Licensing provides a path to learning and ensures a basic interest and knowledge level from each participant
  - Each amateur radio station has a government-issued "call sign"
- **Ideal Community for Citizen Science**

Note: A license is not required to operate a PSWS because it is receive

University of Scranton Students at W3USR



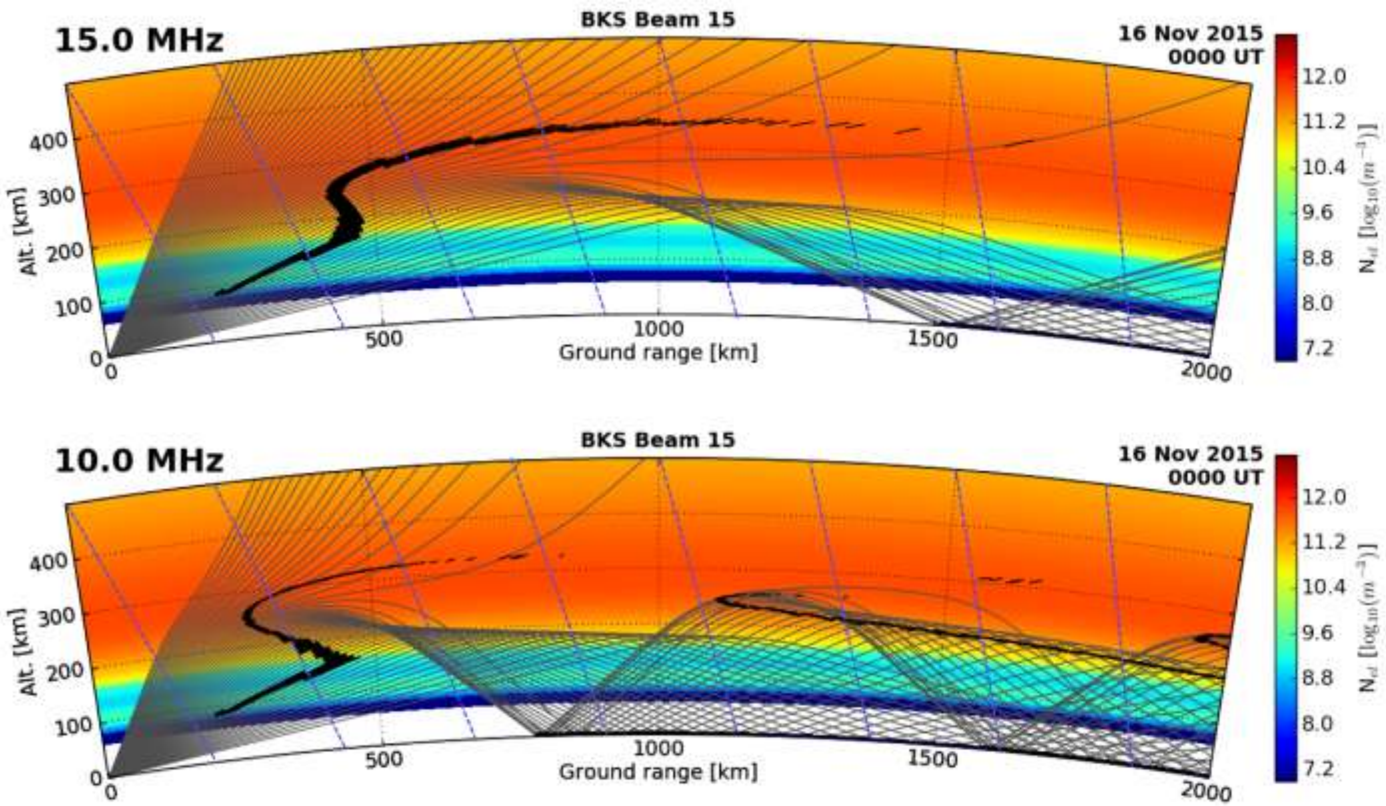
W2NAF Home Station



N8UR multi-TICC: Precision Time Interval Counter

Adak Island SuperDARN/DXPedition

Refraction as a Function of Frequency



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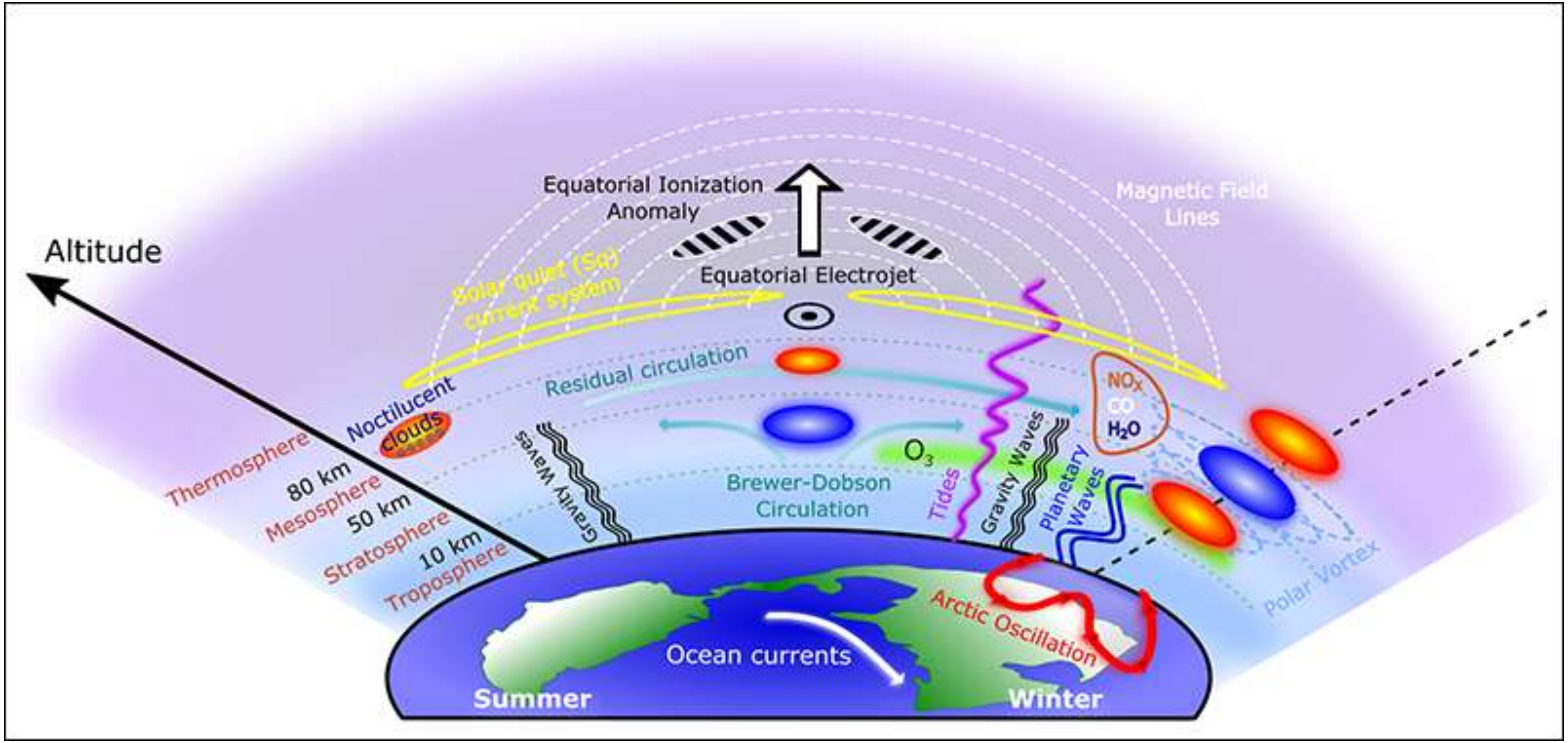
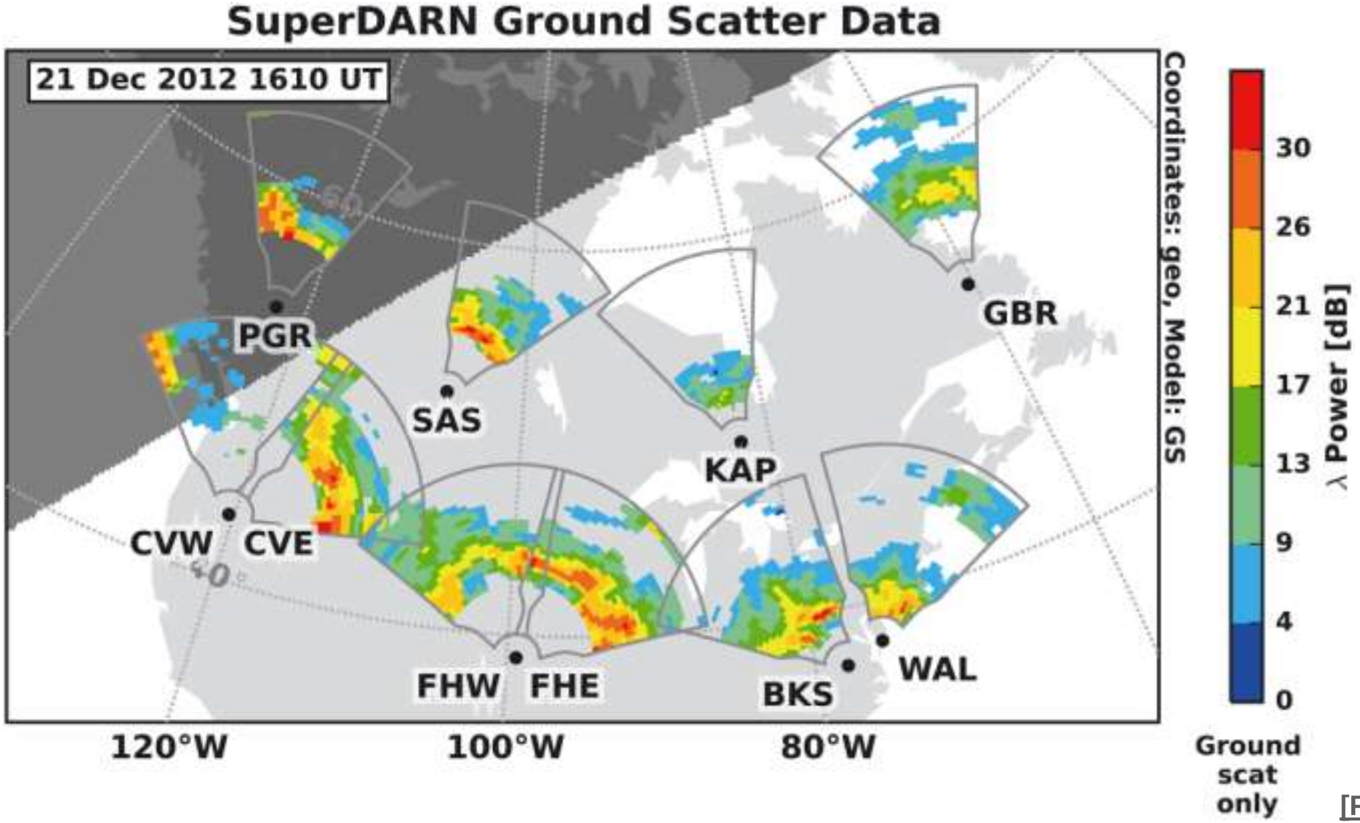
Whole Atmosphere Coupling



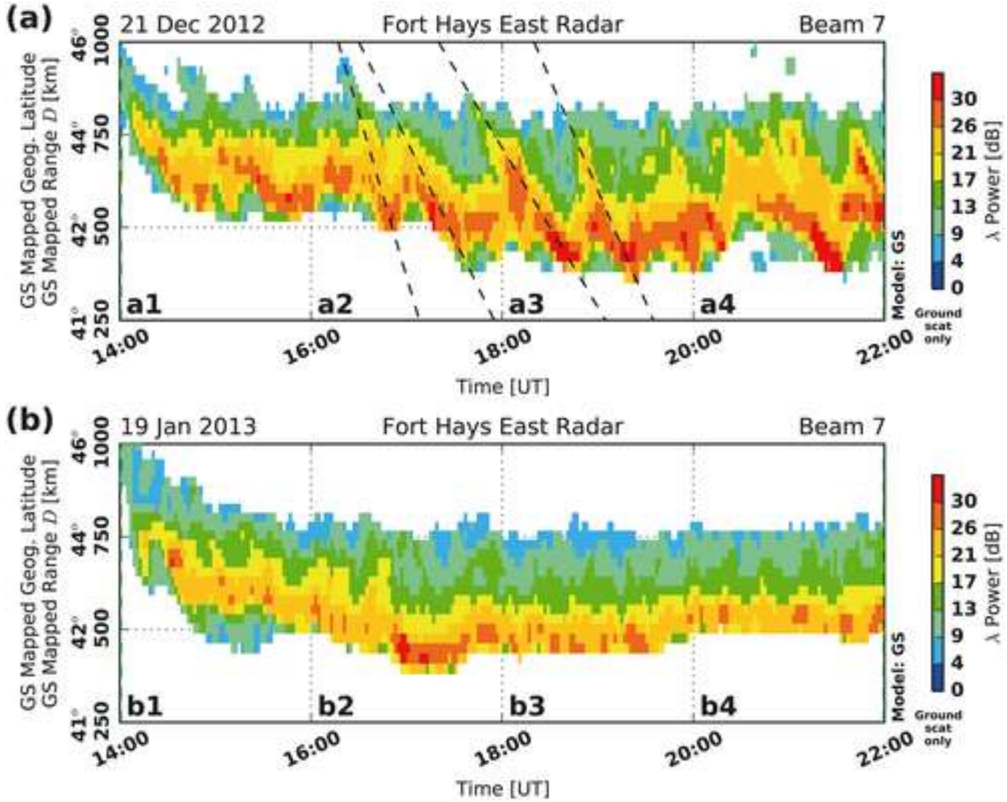
From *Pedatella et al., (2018)* (*https://doi.org/10.1029/2018EO092441*)

SuperDARN Radars



[Frissell et al., 2016]

Example SuperDARN MSTID

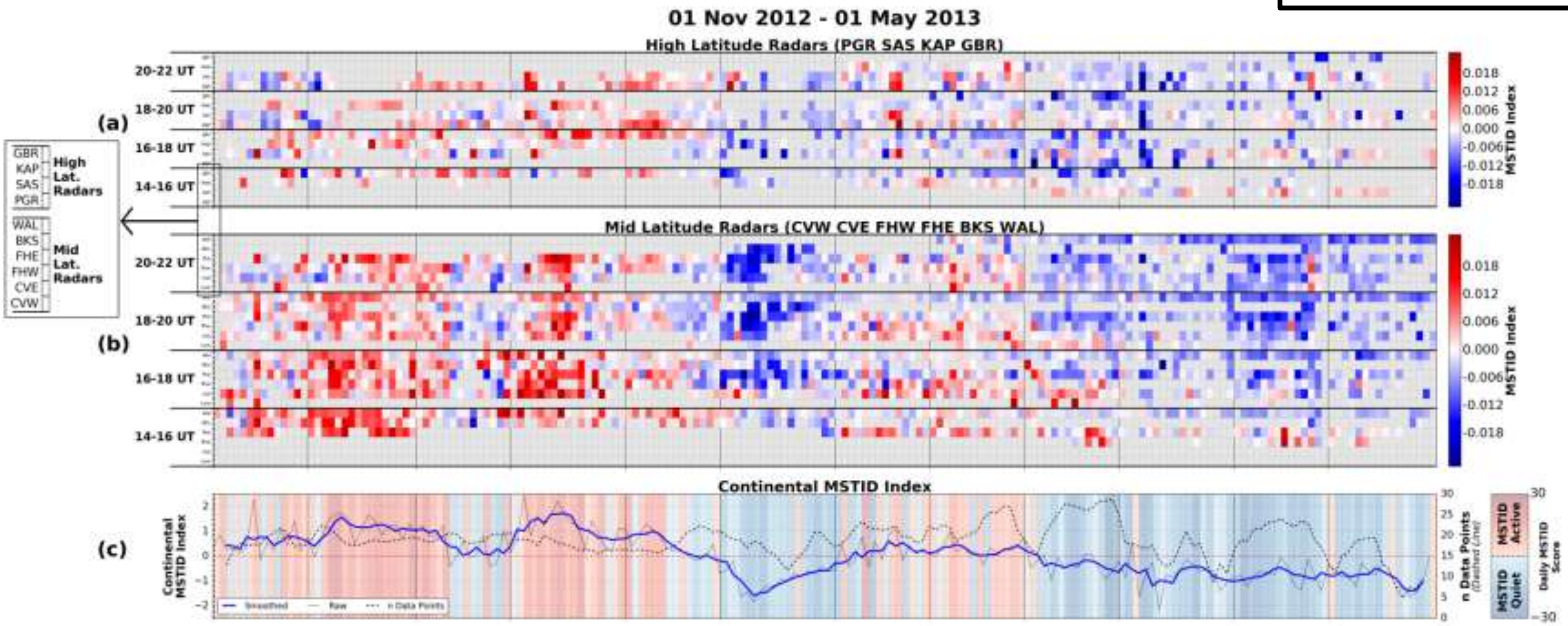


nathaniel.frissell@scranton.edu

MSTIDs Nov 2012 – May 2013

MSTID Active

MSTID Quiet



Nov 2012 **Dec 2012** **Jan 2013** **Feb 2013** **Mar 2013** **Apr 2013** **May 2013**

[Frissell et al., 2016]

HamSCI
http://hamsci.org

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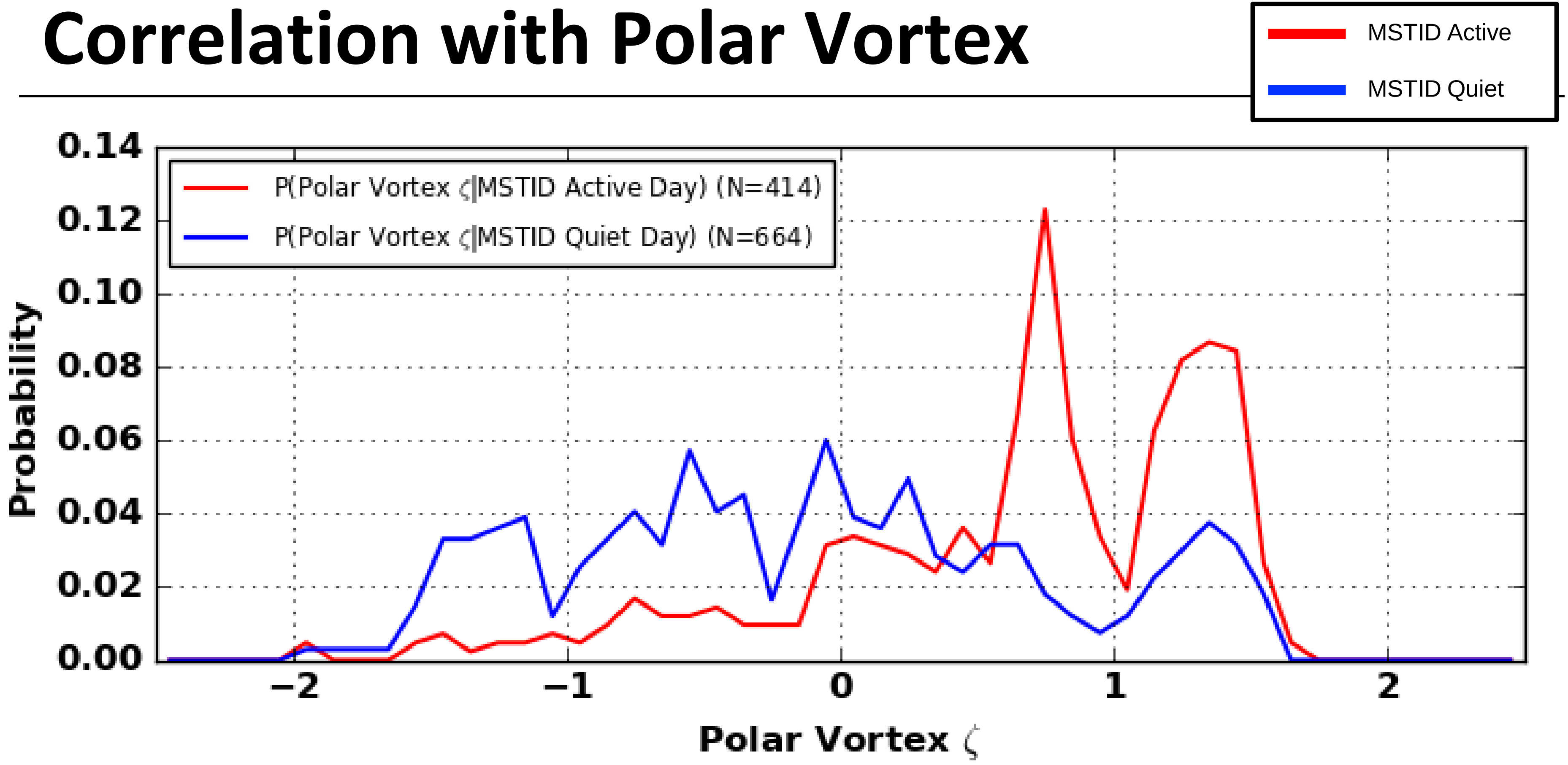
Correlation with Polar Vortex



[Frissell et al., 2016]

PSWS Current Engineering Status

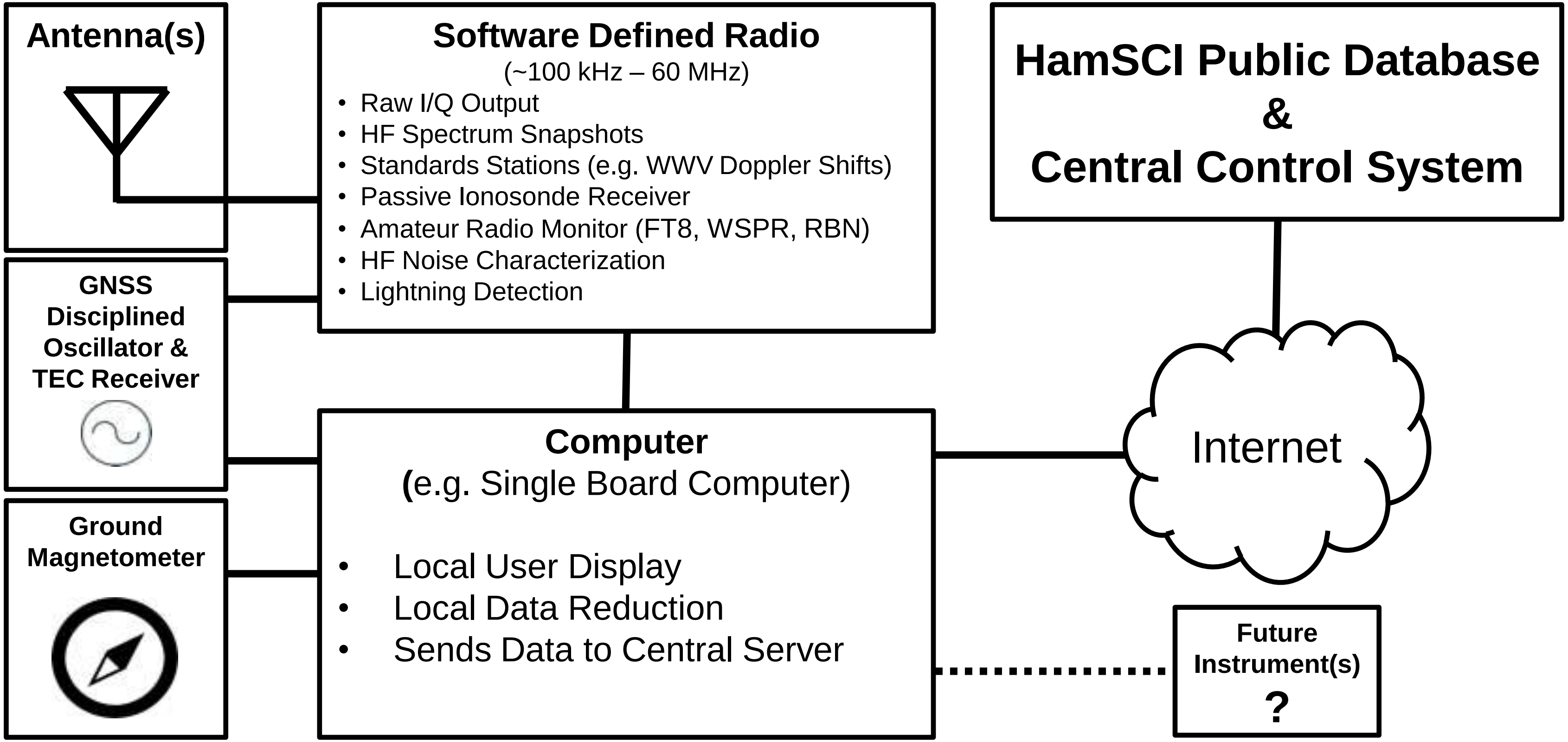
- **Tangerine Data Engine (MAX10)**
  - Schematic capture: 100% complete
  - BOM: 100% complete
  - Component placement: 100% complete
  - Almost all parts delivered
  - Next step: Waiting for FPGA and USB chip delivery
- **Tangerine RF Module (dual-channel 0.1-54MHz)**
  - Schematic capture: 100% complete
  - BOM: 100% complete
  - Component placement and routing: 100% complete
  - Update will be required for DE compatibility
- **Tangerine Clock Module (ZED-F9T SynthDO)**
  - Schematic capture: 100% complete
  - BOM: 100% complete
  - Component Placement: 100% complete
- **MagnetoPi Hat**
  - Schematic capture: 100% complete
  - BOM: 100% complete
  - PC Board placement and layout: 100% complete
  - Compatibility review with LC-PSWS: 100% complete
  - Prototype build of 50 units: 100% complete

- **Low Cost PSWS (Grape)**
  - Grape Generation 1 consists of
    - Leo Bodnar GPSDO frequency standard
    - low IF receiver
    - USB based A/D converter
    - RaspberryPi running a modified version of FLDIGI
  - Several Grape V1 stations operational, and build instructions available at hamsci.org/grape1.
  - Grape v2 Design in Progress, will be capable of receiving 4 HF channels simultaneously.

- **Control Software and Database**
  - Prototype of local control software exists
  - Runs on Odroid N2 Single Board Computer
  - Uses data from a TangerineSDR Simulator (FlexRadio with GPSDO + DAX IQ output)
  - Can monitor up to 16 band segments at a time
  - 4 types of data collection: Snapshotter, Ring Buffer, Firehose(L+R), and FT8/WSPR Propagation Monitoring
  - Proof of concept code working for all modes except WSPR and Firehose L (supercomputer interface)

nathaniel.frissell@scranton.edu

HamSCI Personal Space Weather Station



PSWS Teams

University of Scranton
- **Nathaniel Frissell W2NAF (PI)**
- Dev Joshi KC3PVE (Post-Doc)
- Veronica Romanek KC2UHN (Undergrad)
- Cuong Nguyen (Undergrad)

Responsibilities
- Lead Institution
- HamSCI Lead
- Radio Science Lead

TAPR & Zephyr Engineering
- **Scotty Cowling WA2DFI (Chief Architect)**
- Tom McDermott N5EG (RF Board)
- John Ackerman N8UR (Clock Module)
- David Witten KD0EAG (Magnetometer)
- Jules Madey K2KGJ (Magnetometer)
- David Larsen KV0S (FPGA Code/Website)

Responsibilities
- TangerineSDR (High Performance)
- 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
- **Kristina Collins KD8OXT**
- **David Kazdan AD8Y**
- **John Gibbons N8OBJ**
- Christian Zorman (PI)
- Skylar Dannhoff KD9JPX
- Aidan Montare KB3UMD

Responsibilities
- Low Cost PSWS System

MIT Haystack Observatory
- **Phil Erickson W1PJE**

Responsibilities
- Science Collaborator

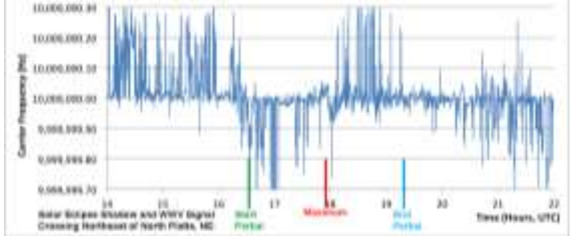
New Jersey Institute of Technology
- **Hyomin Kim KD2MCR (PI)**
- Gareth Perry KD2SAK
- Andy Gerrard KD2MCQ

Responsibilities
- Ground Mag Oversight & Testing
- Science Collaborators

Low-Cost "Grape" PSWS

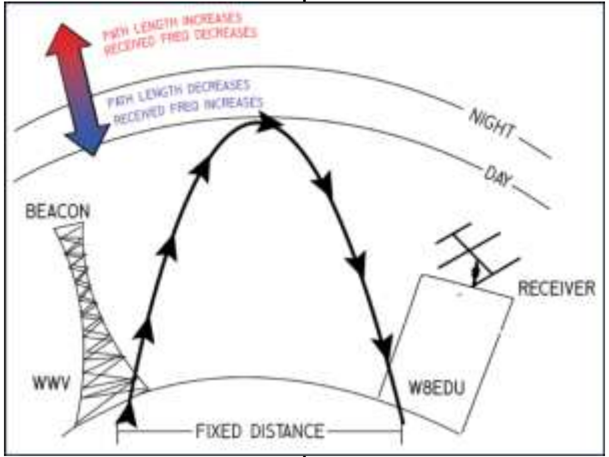
- HF "Doppler Shift" Monitoring
- Main components: Raspberry PI, GPSDO, Custom Direct-conversion receiver board
- Cost: ~$300
- Developed by Case Western

10 MHz Doppler During 2017 Eclipse
TX: WWV RX: WA9VNJ (Milwaukee)



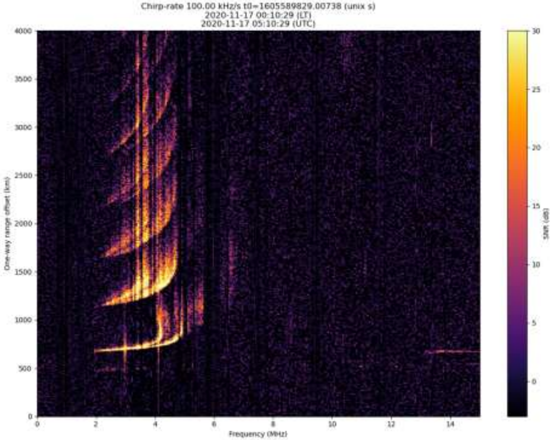
SDR-Based "Tangerine"

- HF FPGA-based Software Defined Radio
- Precision timing and frequency measurement
- 2 to 4 coherent, phase-locked receive channels
- Cost ~$500 to $1000
- Developed by Amateur Radio Group TAPR



[Collins et al., 2021]

Oblique Ionograms
(Currently on Ettus N200 but will be ported to Tangerine)



Movie by Dev Joshi
GNUChirpsounder2 by Juha Vierinen

PSWS Control Software and Database

Developed by University of Alabama

Primary objective

- Local Control Software for Tangerine SDR

Network

ations

Bill Engelke AB4EJ demonstrates early versions of the TangerineSDR Local Control Software and Simulator at 2020 HamCation in Orlando, FL.

Current Status

- Prototype of local control software exists
- Runs on Odroid N2 Single Board Computer
- Uses data from a TangerineSDR Simulator
- Can monitor up to 16 band segments at a time
- 4 types of data collection
  - **Snapshotter:** wideband high frequency spectrograms at a 1 second cadence.
  - **Ring Buffer:** Continuous local storage of IQ samples for 24 hours, then upload on request from Central Control (with throttling)
  - **Firehose:** Continuous transfer IQ samples to a local computer
  - **Propagation Monitoring:** Decoding of FT8 and WSPR amateur radio digital modes on up to 8 bands at a 1 minute cadence

nathaniel.frissell@scranton.edu

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

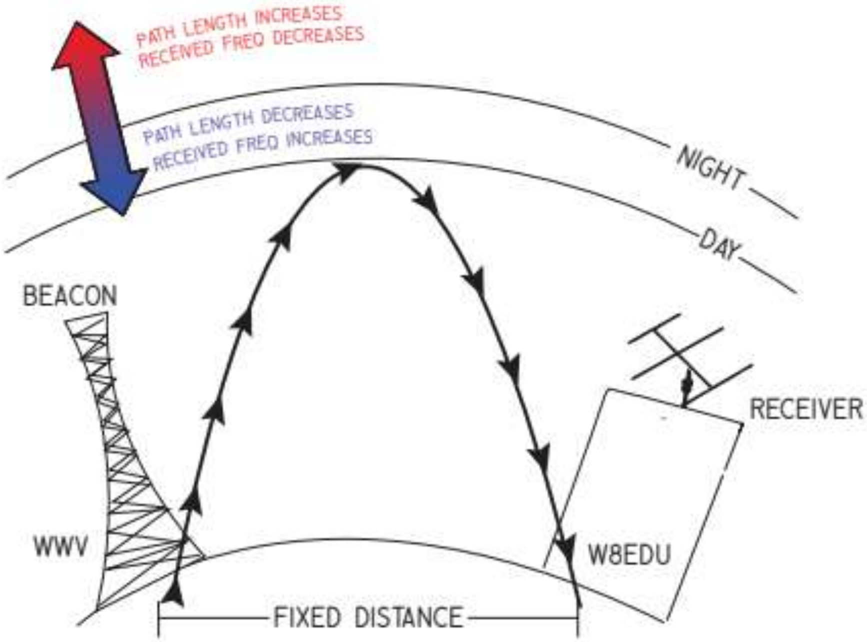


Figure by Kristina Collins, KD8OXT

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.

nathaniel.frissell@scranton.edu

GPS Disciplined Oscillators (GPSDO)

•

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

Icom IC-7610

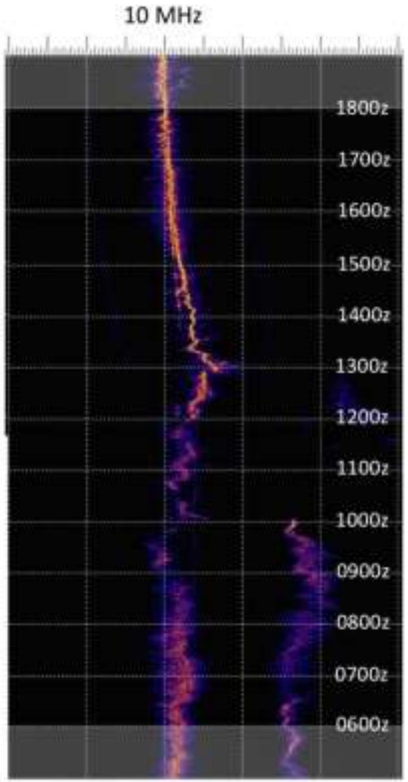
nathaniel.frissell@scranton.edu

Icom IC-7610

nathaniel.frissell@scranton.edu

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.



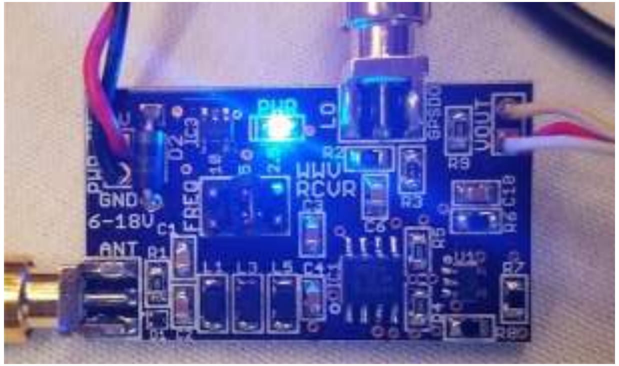
13 Oct 2019

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.



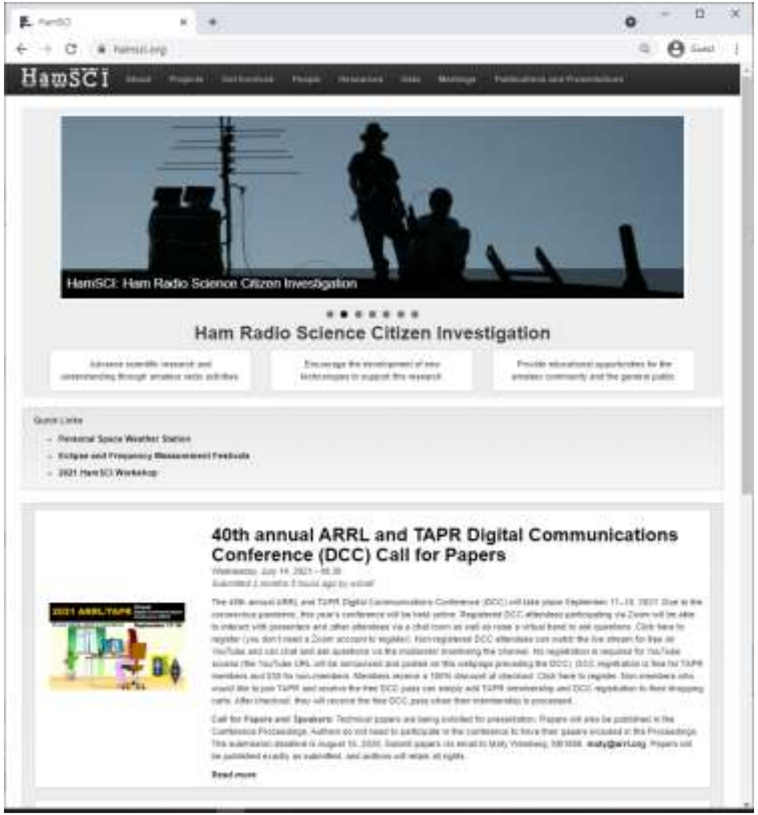
“Grape Receiver” Generation 1 by J. Gibbons N8OBJ

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

Other HamSCI or Community Projects

- **Festivals of Frequency Measurement** (KD8OXT, AD8Y)
- **WWV Modulation Experiment** (KD8OXT, AD8Y, WA5FRF, NQ6Z, W0DAS, N0RGT, et al…)
- **WSPRDaemon / WSPRNet Noise and Propagation Studies** (AI6VN and G3ZIL)
- **Simulation and Comparison of Weak-Signal VHF Propagation** (KE8KCT and Kate Duncan)
- **e-POP RRI Observations of the ARRL FMTs** (KD2SAK et al.)
- **40 m Trans-Pacific Propagation Studies** (N6NC et al.)

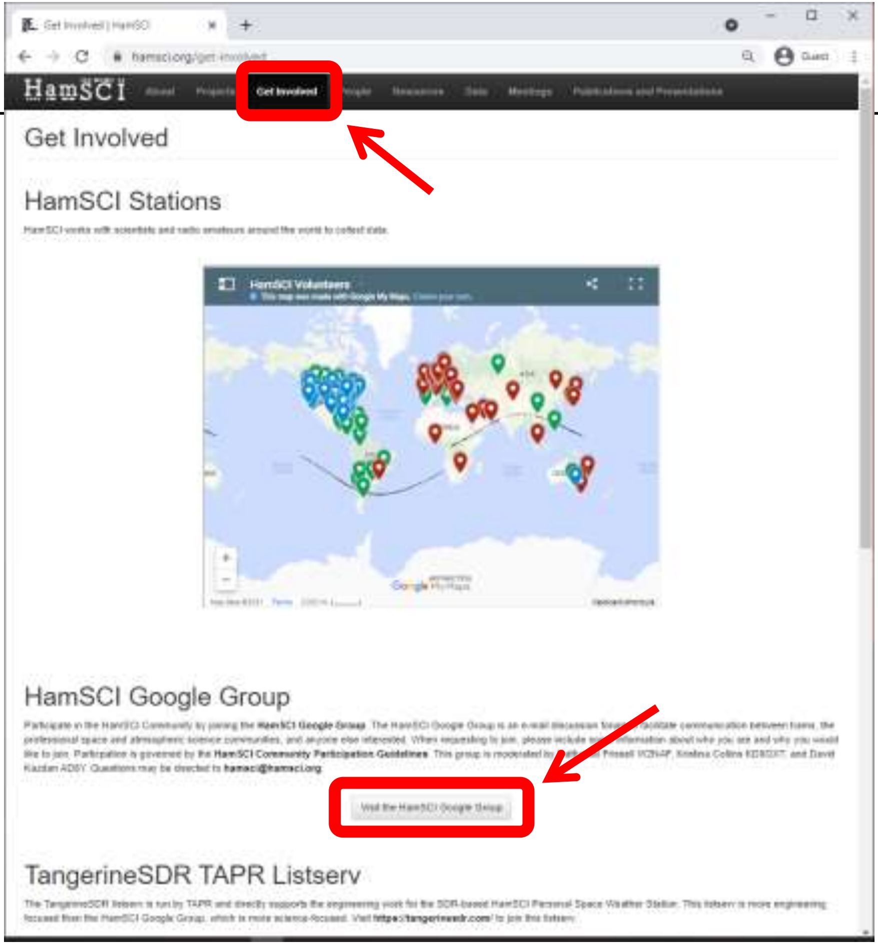
and many more…



nathaniel.frissell@scranton.edu

HamSCI Google Group

- The HamSCI Google Group now has over 450 members!
- Join by visiting https://hamsci.org/get-involved
- Open discussion for all things related to HamSCI.



HamSCI Zoom Telecons

TangerineSDR Telecon	**Engineering telecon to support the TangerineSDR and magnetometer board development.**	**Mondays at 9 PM Eastern**
Grape Telecon 	**Telecon to support engineering and science related to the Grape (low-cost) Personal Space Weather Station.**	**Thursdays at 10 AM Eastern**
HamSCI Telecon	**Science-focused telecon open to all HamSCI topics.**	**Every other Thursday at 3 PM Eastern during the academic year**

Zoom links and calendar at http://hamsci.org/get-involved.

nathaniel.frissell@scranton.edu

HamSCI Workshop 2022 – Hopefully in person!

HamSCI Workshop 2022

Scranton, PA
March 18-19, 2022

We welcome papers related to:

- Development of the PSWS
- Ionospheric Science
- Atmospheric Science
- Radio Science
- Space Weather
- Radio Astronomy

Theme: The Weather Connection

Watch hamsci.org/hamsci2022 and ARRL news for details.

nathaniel.frissell@scranton.edu