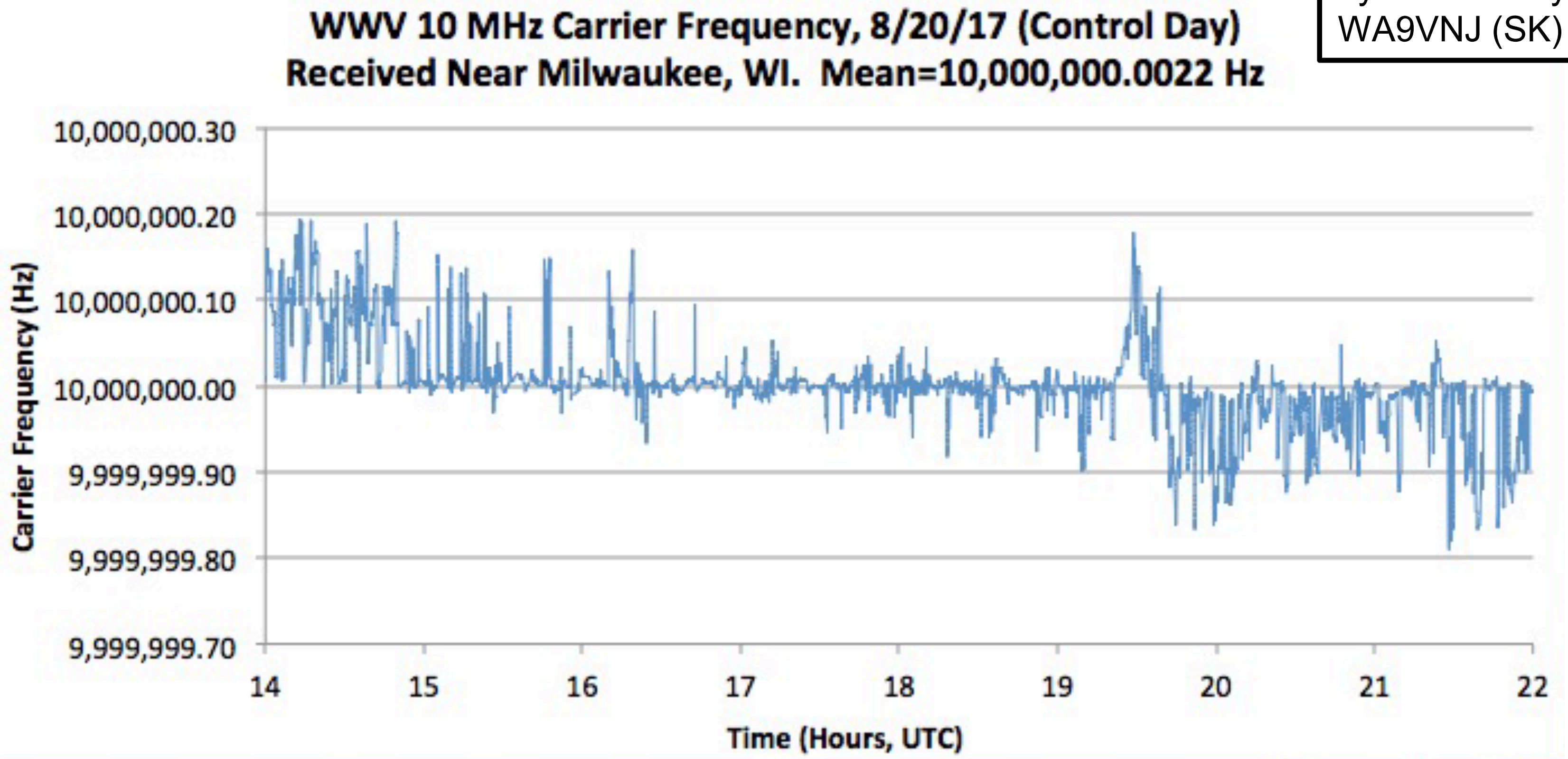
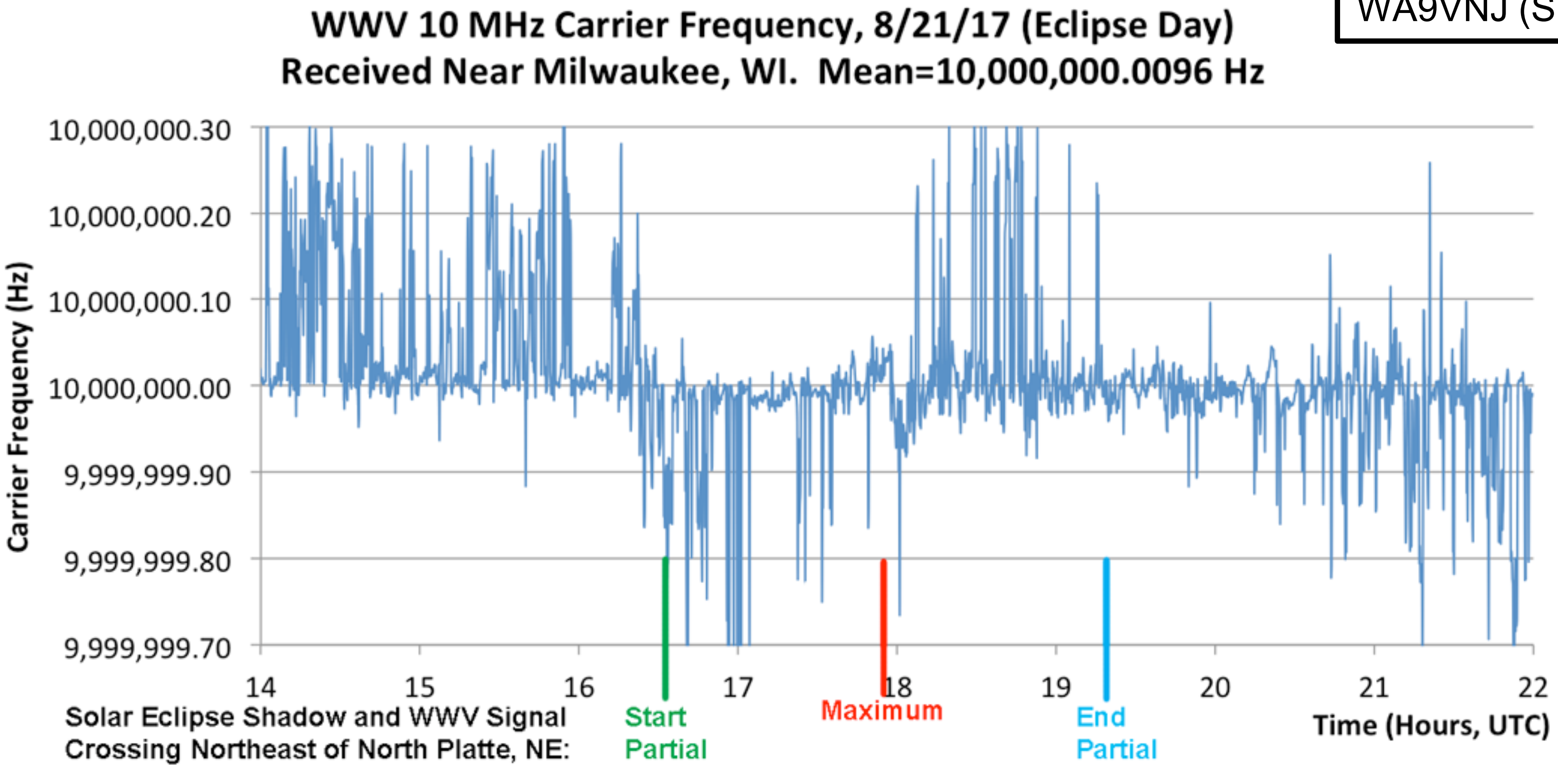
Example Doppler Measurements

Measurements by Steven Reyer WA9VNJ (SK)



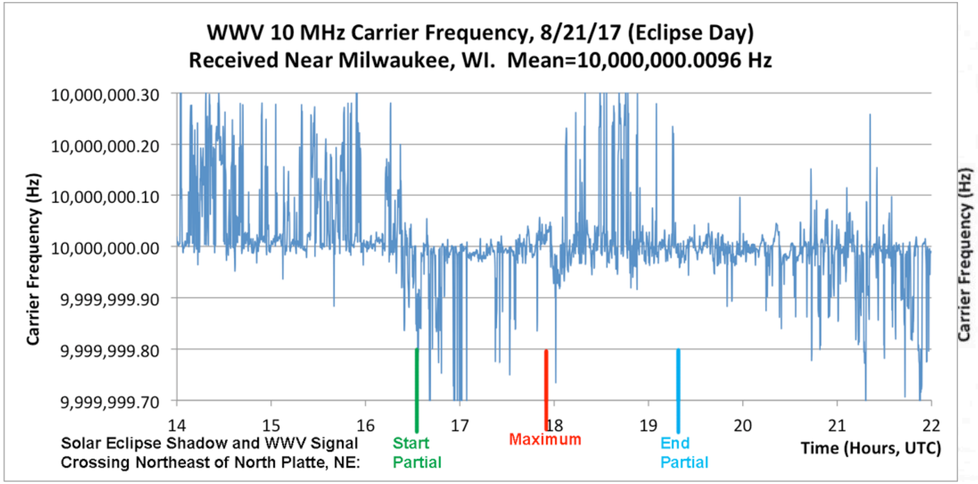
Example Doppler Measurements

Measurements
by Steven Reyer
WA9VNJ (SK)

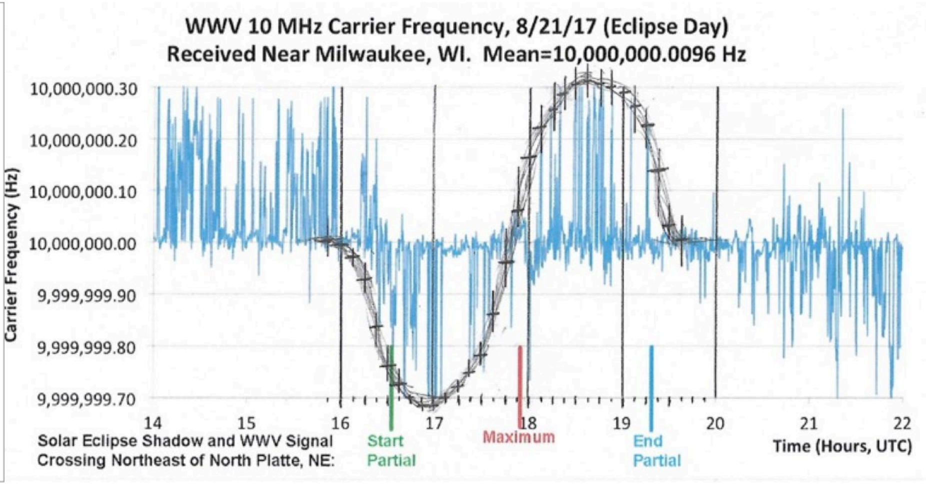


Example Doppler Measurements

Analysis by
Steve Cerwin
WA5FRF



WA9VNJ Frequency Record



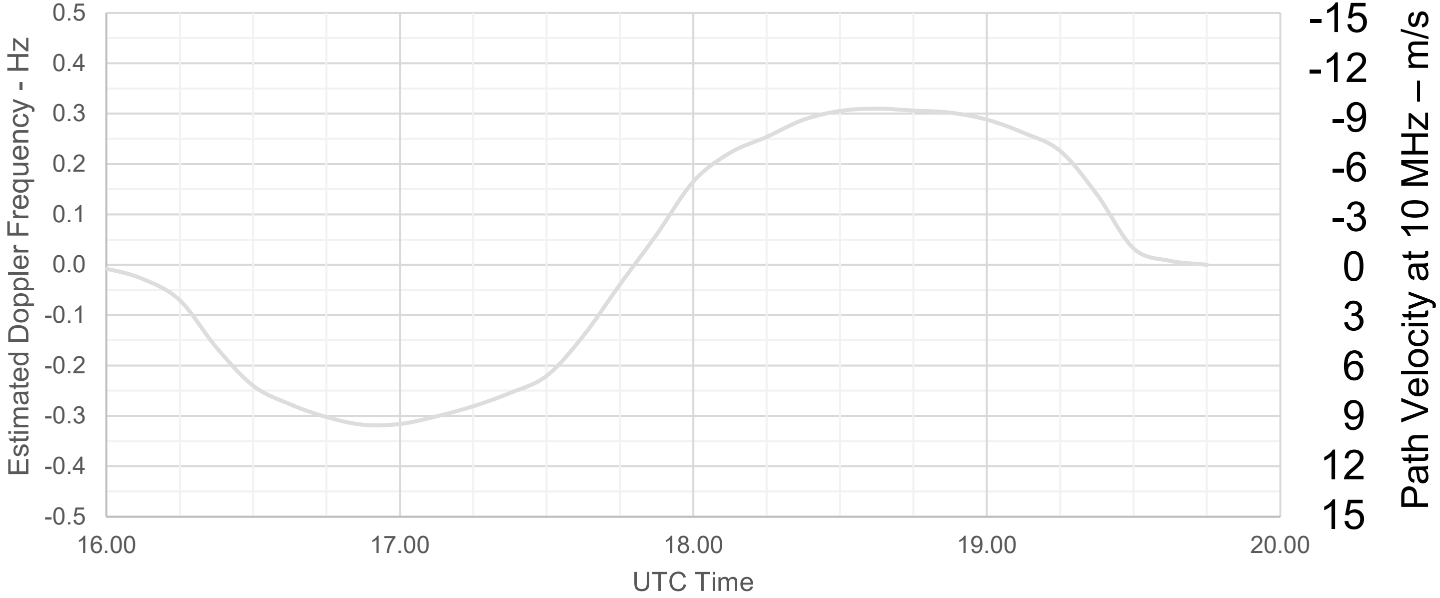
WA9VNJ Frequency Record with Superimposed Envelope Estimation

Envelope estimation with 7.5 minute timing markers superimposed over data record to allow manual digitization for computer analysis.

Estimated Doppler Frequency Envelope Imported to Excel Spreadsheet and Calculated Velocity of Path Length Change

Analysis by
Steve Cerwin
WA5FRF

WA9VNJ 08/21/17 Eclipse Data
Digitized Representation of Estimated Doppler Shift Envelope



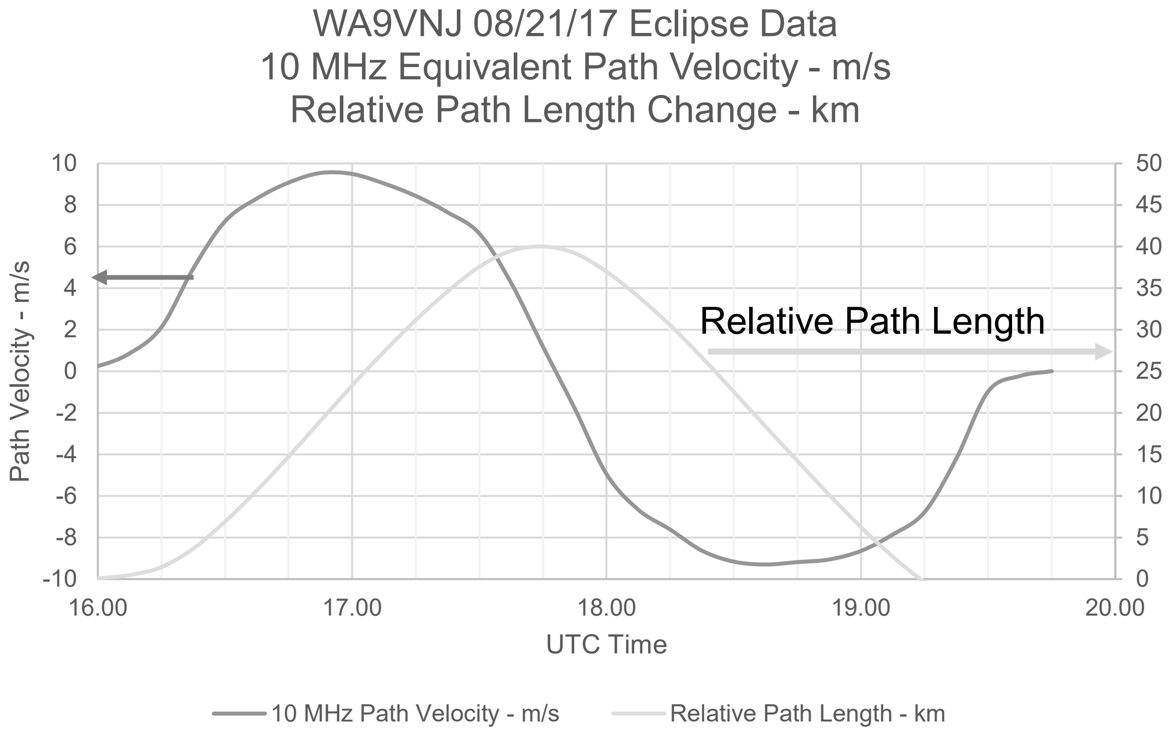
Note sign and scale change. Positive velocity values Indicate Increasing Path Length from Ascending Ionization Layer

Velocity of path length change $= - c/f_0$ * Doppler Shift
$= -30$ * Doppler Shift at 10 MHz

nathaniel.frissell@scranton.edu

Path Length Change from Eclipse Computed Through Numerical Integration Procedure on Velocity Envelope

Analysis by
Steve Cerwin
WA5FRF



Relative path length obtained from a cumulative sum of path length increments computed from:

$\Delta P = \Delta v * \Delta t$,   where
ΔP = Incremental change in path length
Δv = Path velocity increment from velocity envelope
Δt = Time increment = 7.5 min = 450 sec

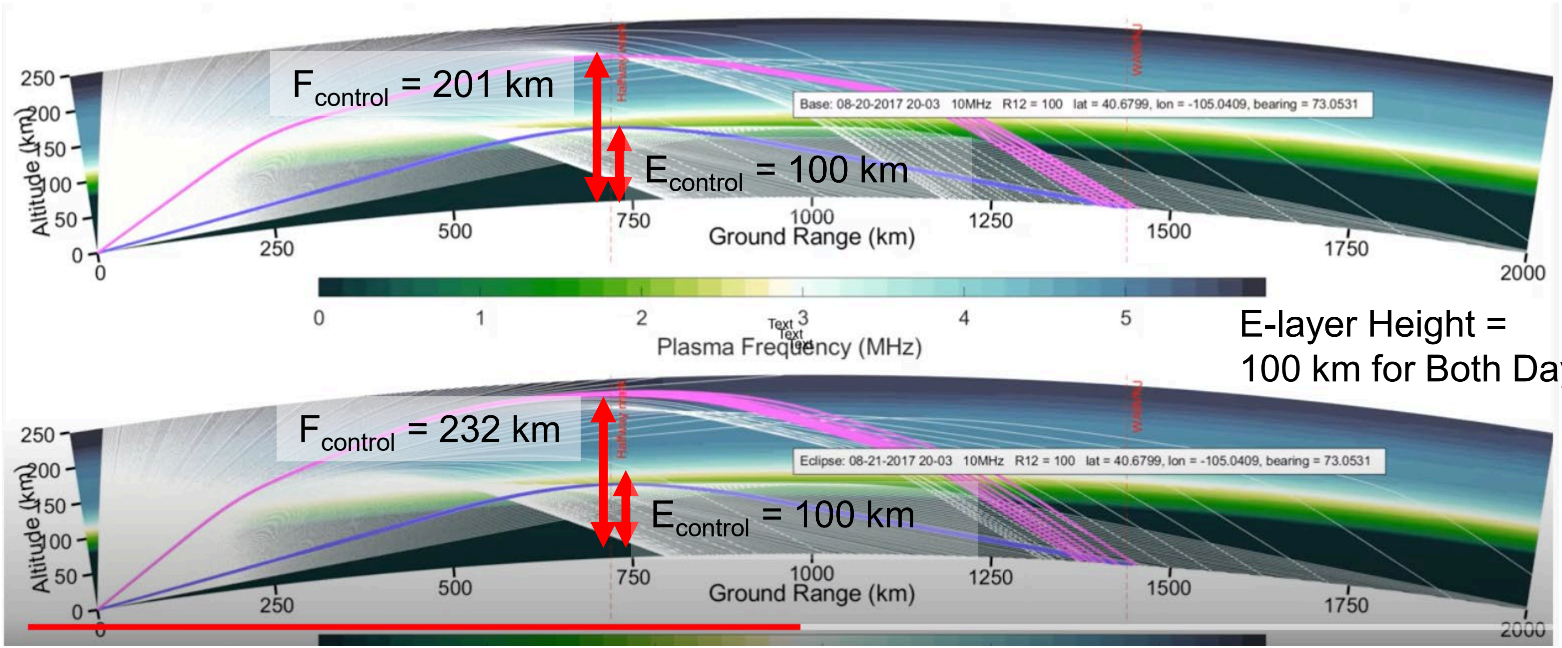
$P = \Delta P_1,\ \Delta P_1+\Delta P_2,\ \Delta P_1+\Delta P_2+\Delta P_3, \ldots$

KD8OXT SAMI3 Simulation Shows an F-layer Height Increase of 31 km From the Eclipse but No Change in E-layer Height

Control Day
F-layer Height
= 201km

Eclipse Day
F-layer Height
= 232 km

E-layer Height =
100 km for Both Days



SAMI3 simulation generated by Kristina Collins KD8OXT using:

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

nathaniel.frissell@scranton.edu

Eclipse Study – Initial Observations

Analysis by
Steve Cerwin
WA5FRF

- **The eclipse-induced increase in layer height inferred from WA9VNJ Doppler data was 40 km. The SAMI3 simulations performed by KD8OXT showed the increase to be 32 km.** Possible causes for the difference include:
  - Error in the manually drawn Doppler envelope estimation.
  - Inaccuracies in the actual Doppler data reported by the FLDIGI frequency measuring program.
  - Error in the “flat earth” ray trace model used to calculate layer height from path length. This model does not take into account the curvature of the earth and assumes straight line propagation paths with geometric reflection from a virtual reflection height instead of curved ray paths and a rounded refraction in the ionization layer.
  - The F layer depictions in the SAMI3 simulations were not continuous in the video from which they were captured. It is possible the frame captures were not taken at the right time and did not reflect the actual minimum height on the control day or the maximum height during the eclipse day. Also the maximum height on the simulations was 250 km and it is possible higher layer predictions were there but not displayed.
  - The solar-terrestrial forecasts used for the simulation may not have been the actual numbers present during the eclipse.
- **The data presented here assumes the measured frequency shift data resulted only from Doppler shift caused by the ascending-then-descending refraction layer. It is possible that the extra frequency shift may have been caused by wave velocity modulation.** The passage of the eclipse shadow over the propagation path causes both layer height changes and rapid changes in free electron density that can decelerate and accelerate wave velocity.
- **The SAMI3 simulations showed an eclipse-induced increase in F-layer height but no change in the E-layer.** This prediction ties in nicely with many spectral recordings that show a steady frequency track along with mode splitting into multiple higher order modes during daily dawn and dusk transitions. This suggests that the frequency swings and mode splitting occur in the F layer while the steady track comes from the E-layer.

Festival of Frequency (FoF) Measurements

- Kristina Collins KD8OXT has been leading the charge to run global campaigns to monitor HF Doppler shifts using both PSWS Grapes and Amateur gear.
- Initial results from October 1, 2019 FoF now submitted to IEEE GRSL.
- Preparing for December 4, 2021 Southern Hemisphere Eclipse

DRAFT FOR IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, AS OF NOVEMBER 27, 2020 1

Citizen Scientists Conduct Distributed Doppler Measurement for Ionospheric Remote Sensing

Kristina Collins, Aidan Montare, Nathaniel Frissell, David Kazdan

Abstract—Doppler shift measurement using time standard stations as passive radar beacons is well-established as a means of estimating virtual ionospheric height. A community science experiment in distributed Doppler shift measurement was conducted in October 2019 using the time station WWV, on the event of that station's centennial. Participants were asked to collect Doppler shift data from the WWV 5MHz carrier via the open source software program fldigi. This experiment garnered participation from stations across the country, demonstrating considerable volunteer interest: 45 recordings of WWV's 5 MHz beacon were collected. The novel element of this study is the use of distributed low-fidelity sensors in this geophysical domain, and the robust participation of the amateur radio community was enabled by inexpensive and readily available instrumentation. In this letter, we present an initial correlation analysis of the resultant data and discuss its implications for future long-term distributed Doppler networks. The data collected are in good agreement and, when examined together, offer some insight into regional trends. Despite the variety of equipment used by the amateur community, this community science approach shows promise for addressing the problem of undersampling in the geospace system.

***Index Terms*—Doppler shift, citizen science, time standard, GPS-disciplined oscillator (GPSDO), distributed sensing.**

I. Introduction

AMATEUR radio is a proven resource for the collection of scientific data in ionospheric physics [1]. The population of amateur radio operators is widely distributed, largely technically literate, and socially inclined, making the community well-suited for citizen science. As amateur radio has become more computerized, the number of licensed operators has increased; the same trend enables greater sophistication in scientific data collection at lower cost. The experiment discussed herein, undertaken in October 2019, leveraged the instrumentation and goodwill of the amateur community for a large-scale data collection exercise [2]. The event sought citizen scientists from the amateur radio community as well as those with HF listening equipment. Instructions were provided at https://hamsci.org/wwv-centennial-festival-frequency-measurements and publicized widely in the amateur radio community. Data was made available in a public archive [3]. This exercise was a pilot experiment for the Personal Space Weather Station project, an effort by the Ham Radio Science Citizen Investigation (HamSCI) collective to create a distributed network of instruments which will gather scientific-grade observations of signals of opportunity across the HF bands from volunteer citizen observers.

K. Collins (kd8oxt@case.edu), A. Montare (kb3umd@case.edu) and D. Kazdan (ad8y@case.edu) are in the Department of Electrical Engineering at Case Western Reserve University. N. Frissell is in the Physics and Engineering Department at the University of Scranton.

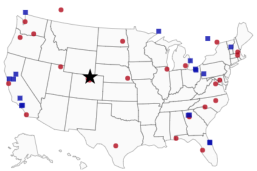


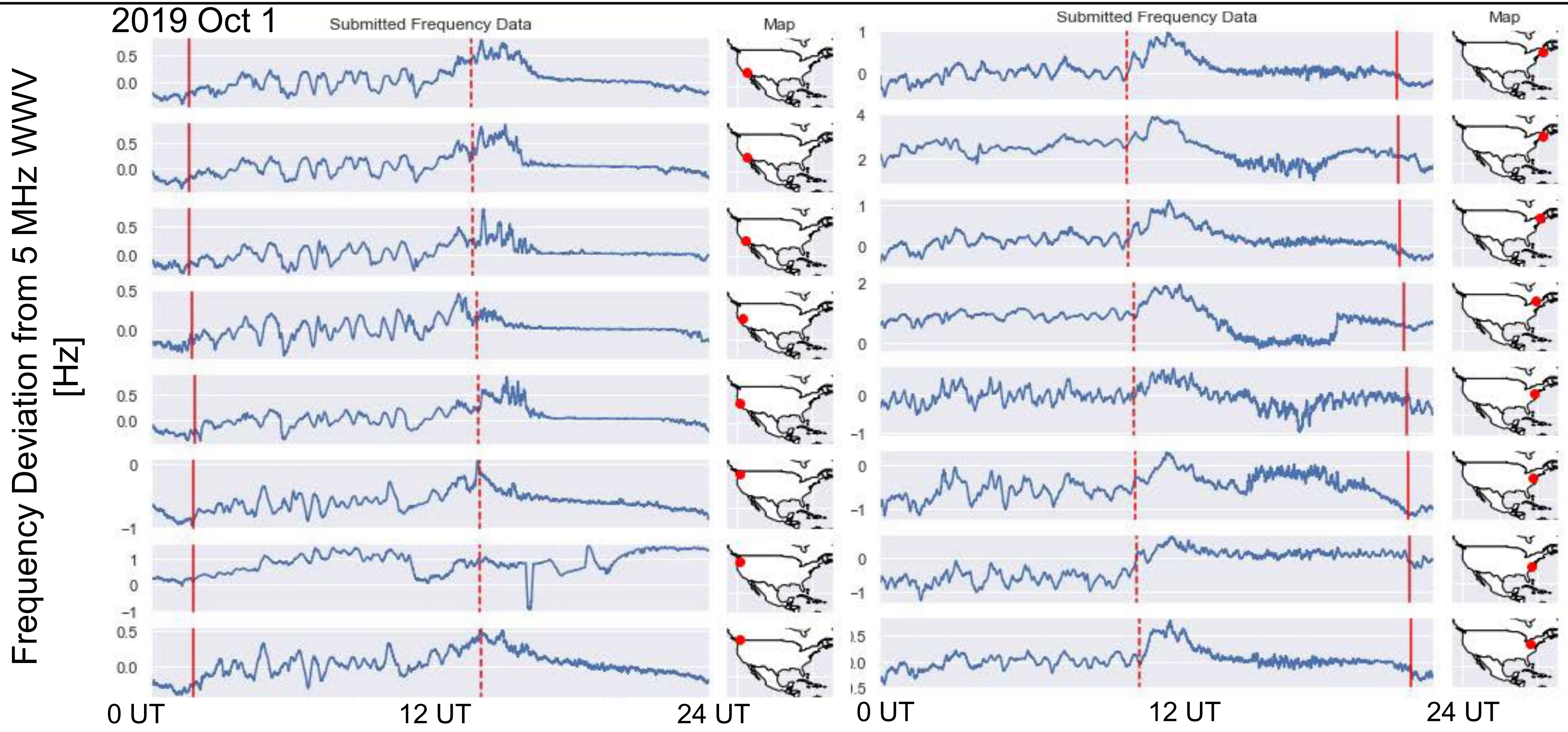
Fig. 1: Map of participants in North America, some international stations not shown. Squares denote stations with GPSDOs. The star indicates the location of WWV.

II. Methodology

A. Doppler Measurement Via WWV

WWV is a radio station of the U.S. National Institute of Standards and Technology (NIST) that transmits standard time and frequency information. Located in Fort Collins, Colorado since 1966, WWV provides a stable, reliable, and traceable reference for frequency and time that can be received with simple equipment. Signals from HF time standards stations like WWV propagate via the ionosphere, and the path length of the signal changes with ionospheric conditions. These variations occur on a daily basis, with the virtual ionospheric height at a given location dropping during the day and rising during the night; they also undergo variation on longer (e.g., seasonal) and shorter (e.g., minute) timescales. The frequency of the received signal is affected by Doppler shift, as shown in Figure 2. For a ray undergoing a single hop, a movement upwards in the virtual ionospheric height at the point of reflection results in a drop in received frequency as the wavefronts are stretched farther apart. Conversely, if the virtual height decreases, the wavefronts move closer together and the received frequency is increased. Since WWV's carrier is extraordinarily precise, the change in received frequency may be used as a proxy for change in path length, and therefore change in virtual

Festival of Frequency Measurement

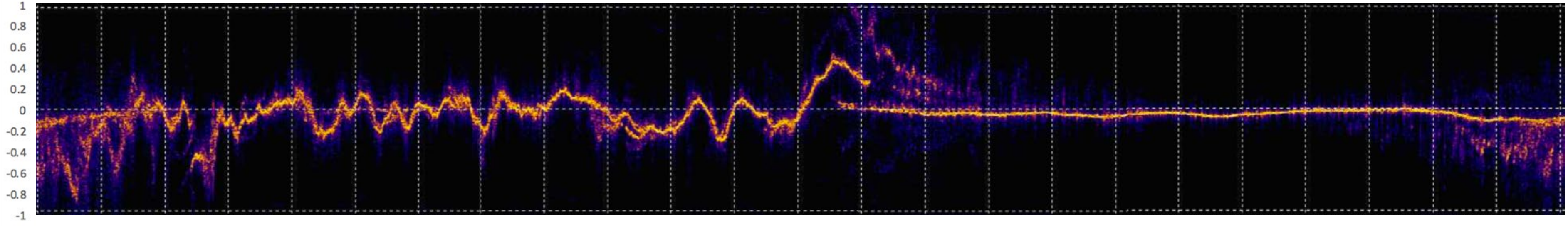


[*Collins et al.*, 2020, Submitted IEEE GRSL]

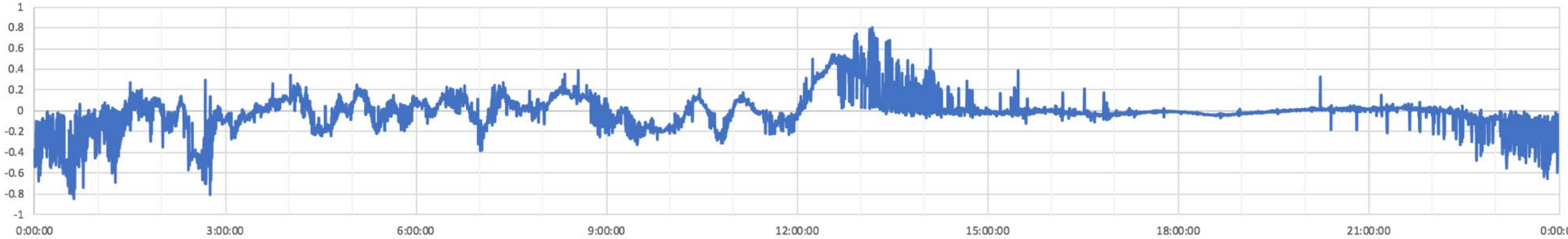
nathaniel.frissell@scranton.edu

WA5FRF Comparison Between Spectrogram and Single Frequency Formats During HamSCI Festival of Frequency Measurements

Spectrogram Format using Spectrum Lab



Single Frequency Detector using FLDIGI



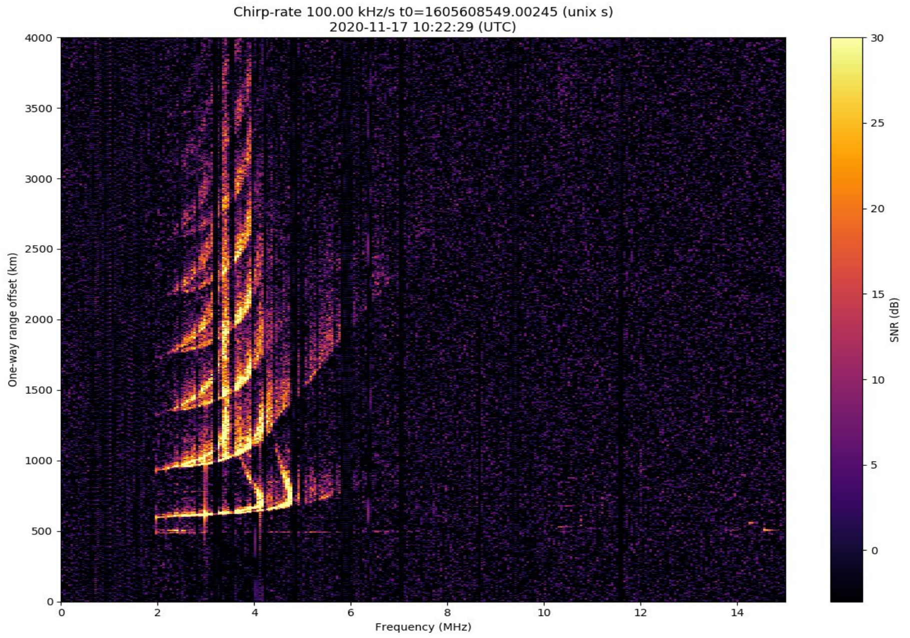
Dusk Transition ------------------ > Night -------------------------- > Dawn Transition ------------------- > Day ------------------ > Dusk Transition

Path: WWV, Ft. Collins CO to WA5FRF, near San Antonio, TX 0000z – 2359z October 1, 2019

Slide Courtesy of Steve Cerwin, WA5FRF

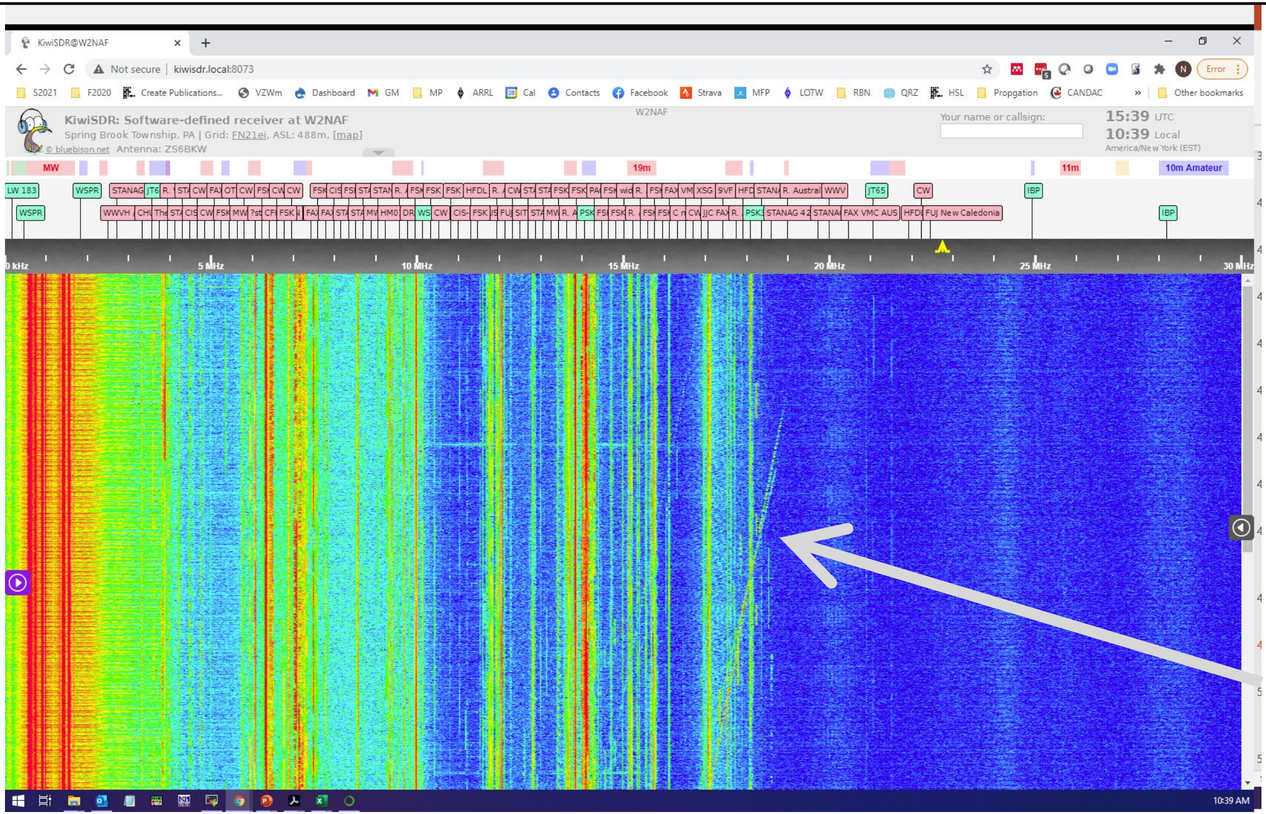
Chirp Ionosonde Studies

- 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.

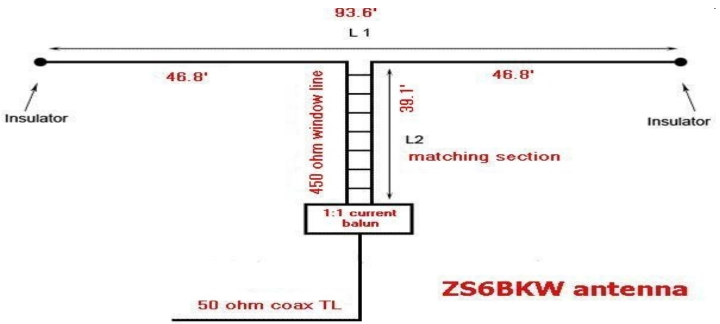
KiwiSDR Capture of Chirp Ionosonde



Chirp Ionosonde

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

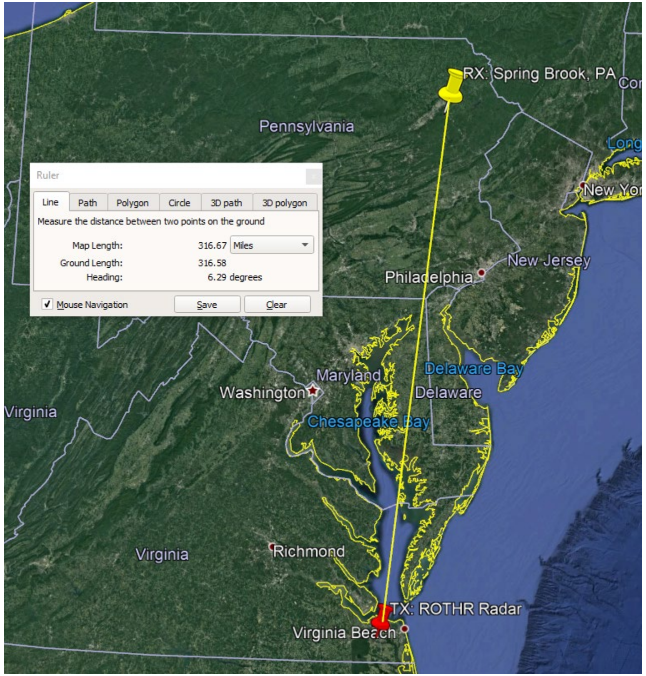
- **The** software **Chirpsounder2 (**https://github.com/jvierine/chirpsounder2**)** can be used to detect chirp sounders and over-the-horizon radar transmissions over the air, and to calculate ionograms from them. The software relies on Digital RF recordings of HF.
- This is a new implementation of 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]

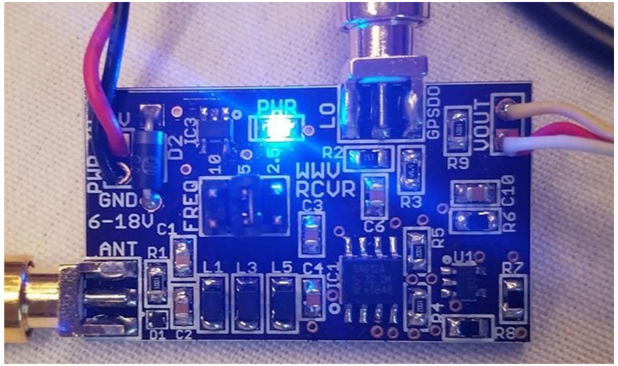
nathaniel.frissell@scranton.edu

Monday Night TangerineSDR Telecons

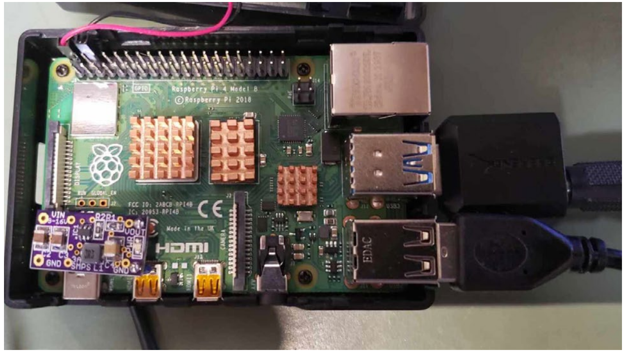
- Engineering-focused telecon to support
  - TangerineSDR development
  - Magnetometer module development
  - TangerineSDR-based PSWS
- Monday nights at 9 PM Eastern
- Hosted by TAPR and The University of Scranton
- Zoom link, calendar, and archives at https://hamsci.org/get-involved

nathaniel.frissell@scranton.edu

Thursday Morning Grape Telecons



“Grape Receiver” Generation 1 by J. Gibbons N8OBJ



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

- Engineering-focused telecon to support
  - Low-cost PSWS engineering and science
- Thursday mornings at 10 AM Eastern
- Hosted by Case Western Reserve University and Case ARC W8EDU
- Zoom link and calendar available at https://hamsci.org/get-involved

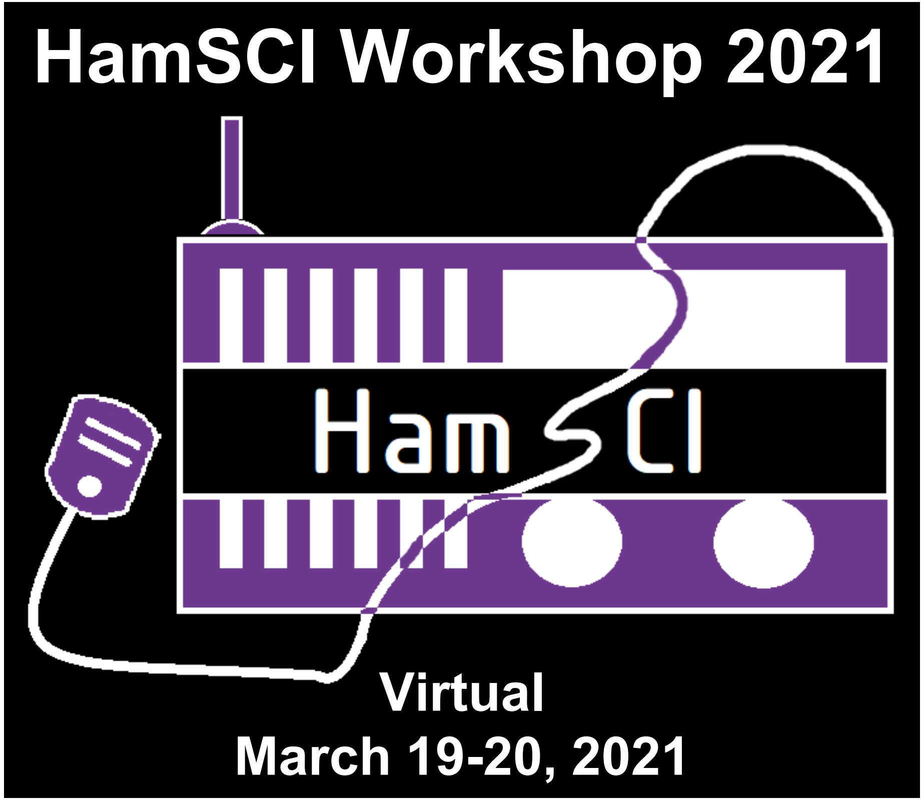
nathaniel.frissell@scranton.edu

Thursday Bi-Weekly HamSCI Telecons

- Science-focused telecon to support HamSCI Science
- Every other Thursday 3 PM Eastern
- Hosted by The University of Scranton
- Contributed speakers are welcome!
- Zoom link, calendar, and archives at https://hamsci.org/get-involved

nathaniel.frissell@scranton.edu

HamSCI Workshop 2021 – Virtual!



We welcome papers related to:

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

Theme: Midlatitude Ionospheric Science

Abstracts are due February 15, 2021.

Visit hamsci.org/hamsci2021 for details.

nathaniel.frissell@scranton.edu

Virtual HamSCI Workshop (March 19-20, 2021)

Friday AM

PSWS Engineering Orals

Lunch Discussion

Friday PM

Science Orals

Friday 2200z (6 PM EST)
Keynote: “History of Radio”

Saturday AM 1
Invited Tutorials

Saturday AM 2
Experiment Co-Design

Lunch Discussion

Saturday PM

iPosters and Breakout Rooms

nathaniel.frissell@scranton.edu

Invited Scientist Tutorial

Invited Scientist Tutorial

Midlatitude Ionospheric Physics

Dr. J. Michael Ruohoniemi

The midlatitudes are where the bulk of humanity live and radio amateurs operate, however this region has traditionally been considered “quiet” compared to the auroral zone and equatorial region and therefore has received less scientific attention.

In this tutorial, Dr. Ruohoniemi will present a review of the physics of the midlatitude ionosphere, discuss recent advancements and open questions at the frontiers of research, and consider means by which the amateur radio community can contribute to advancing scientific understanding and technical capabilities.

Dr. J. Michael Ruohoniemi is a professor of electrical engineering at Virginia Tech and Principal Investigator of the Virginia Tech SuperDARN Laboratory.

Invited Amateur Tutorial

Invited Amateur Tutorial

Amateur Radio Observations and The Science of Midlatitude Sporadic E

Joseph Dzekevich K1YOW

Amateurs may ask, “How are sporadic-E transatlantic VHF communications possible between North America and Europe?”

In his tutorial, Joe K1YOW will explain what Sporadic E is, how amateur operators use Sporadic E to enable long-distance VHF communications, current theories of Sporadic E formation, and how we might be able to better understand Es formation by examining amateur radio propagation logs.

Joe’s studies of Sporadic E using amateur radio have been published both in QST (2017) and CQ Magazine (2020).

Keynote Address

Keynote Address

History of Radio

Dr. Elizabeth Bruton

This talk will explore developments in the history, science, technology, and licensing of radio amateur communities from the early 1900s through to the present day, exploring how individuals and communities contributed to “citizen science” long before the term entered popular usage in the 1990s.

Dr. Brunton will also explore how these community-led developments can inspire the next generation’s interest in science, technology, engineering, and mathematics (STEM), citizen science, and amateur radio.

Dr. Bruton is Curator of Technology and Engineering at the Science Museum, London, specializing in the history of communications. Her PhD dissertation is entitled *Beyond Marconi: the roles of the Admiralty, the Post Office, and the Institution of Electrical Engineers in the invention and development of wireless communication up to 1908*.

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.

nathaniel.frissell@scranton.edu

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.

References

Cervera, M. A., and Harris, T. J. (2014), Modeling ionospheric disturbance features in quasi-vertically incident ionograms using 3-D magnetoionic ray tracing and atmospheric gravity waves, J. Geophys. Res. Space Physics, 119, 431– 440, doi:10.1002/2013JA019247.

Collins, K., Montare, A., Frissell, N. A., & Kazdan, D. (2020). Citizen Scientists Conduct Distributed Doppler Measurement for Ionospheric Remote Sensing. IEEE Geosci. Remote Sens. Lett., (under review).

Frissell, N. A., Baker, J. B. H., Ruohoniemi, J. M., Gerrard, A. J., Miller, E. S., Marini, J. P., West, M. L., and Bristow, W. A. (2014), Climatology of medium-scale traveling ionospheric disturbances observed by the midlatitude Blackstone SuperDARN radar, J. Geophys. Res. Space Physics, 119, 7679– 7697, doi:10.1002/2014JA019870.

Frissell, N. A., Vega, J. S., Markowitz, E., Gerrard, A. J., Engelke, W. D., Erickson, P. J., et al. (2019). High-frequency communications response to solar activity in September 2017 as observed by amateur radio networks. Space Weather, 17, 118– 132. https://doi.org/10.1029/2018SW002008.

Huba, J. D., and Drob, D. (2017), SAMI3 prediction of the impact of the 21 August 2017 total solar eclipse on the ionosphere/plasmasphere system, Geophys. Res. Lett., 44, 5928– 5935, doi:10.1002/2017GL073549.

Joshi, DR, Frissell NA, Liles, W, Vierinen, J, Miller, ES (2020). Developing an Ionospheric Sounding Mode Using Chirp Ionosondes of Opportunity for the HamSCI Personal Space Weather Station : Status and Early Results. AGU Fall Meeting. Virtual.

Sanchez, D., Frissell, NA, Perry, GW, Coster, A, Erickson, PJ, Engelke, WD, Ruohoniemi, JM, and Baker, JBH (2020). A Climatology of Traveling Ionospheric Disturbances Observed by High Frequency Amateur Radio Networks. AGU Fall Meeting. Virtual.

nathaniel.frissell@scranton.edu

Backup Slides

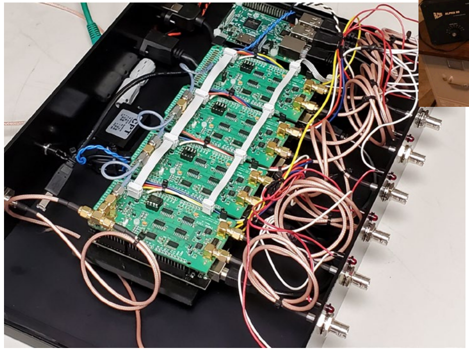
What is Amateur (Ham) Radio?

- **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 only!

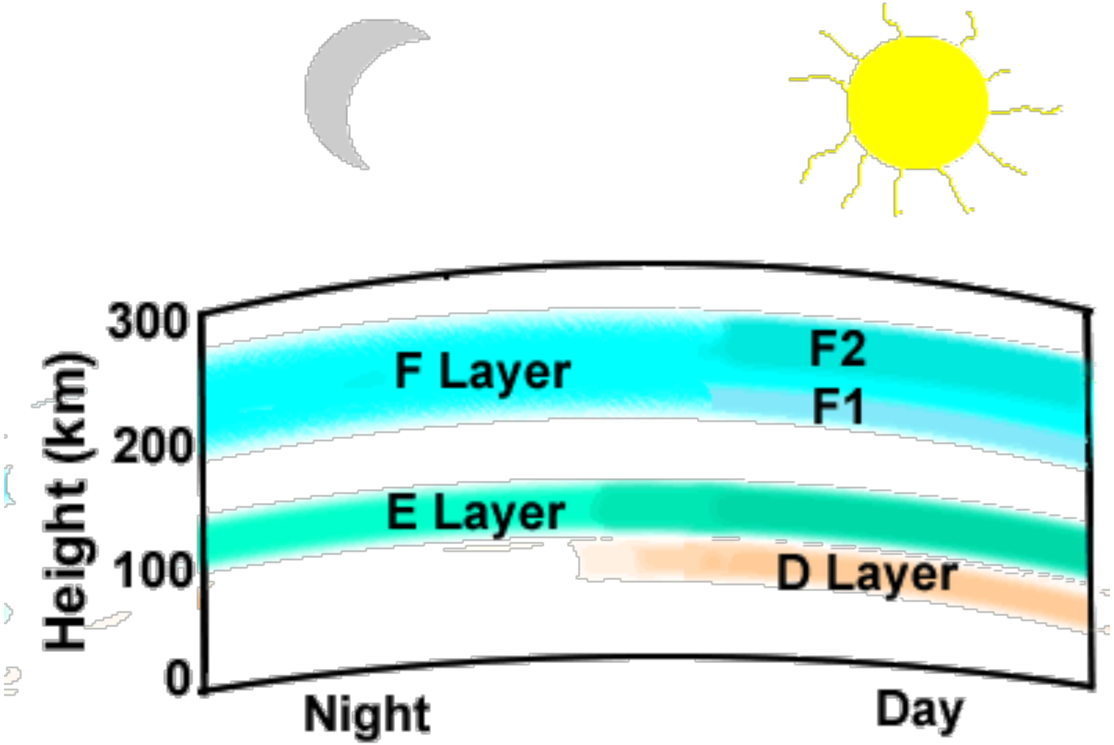
KD2JAO & WB2JSV at NJIT Station K2MFF

AB4EJ Home Station



N8UR multi-TICC: Precision Time Interval Counter

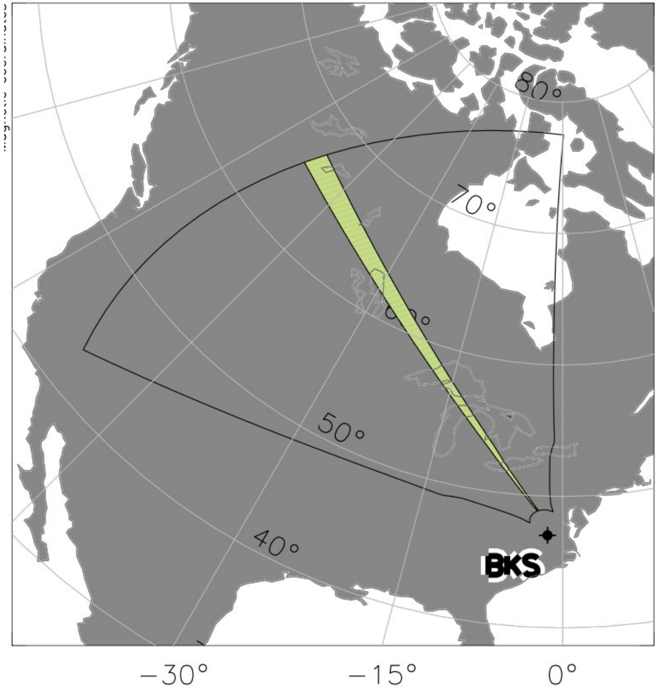
The Ionosphere

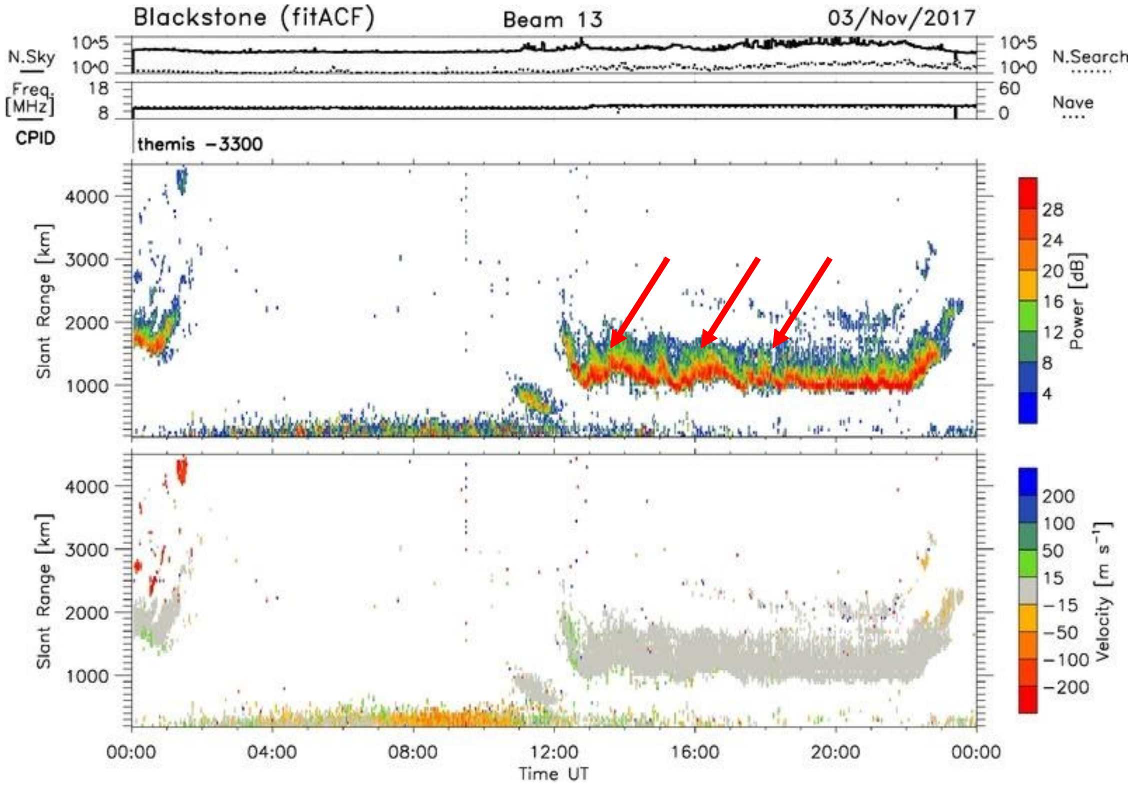


https://commons.wikimedia.org/wiki/File:IonosphereLayers-NPS.gif

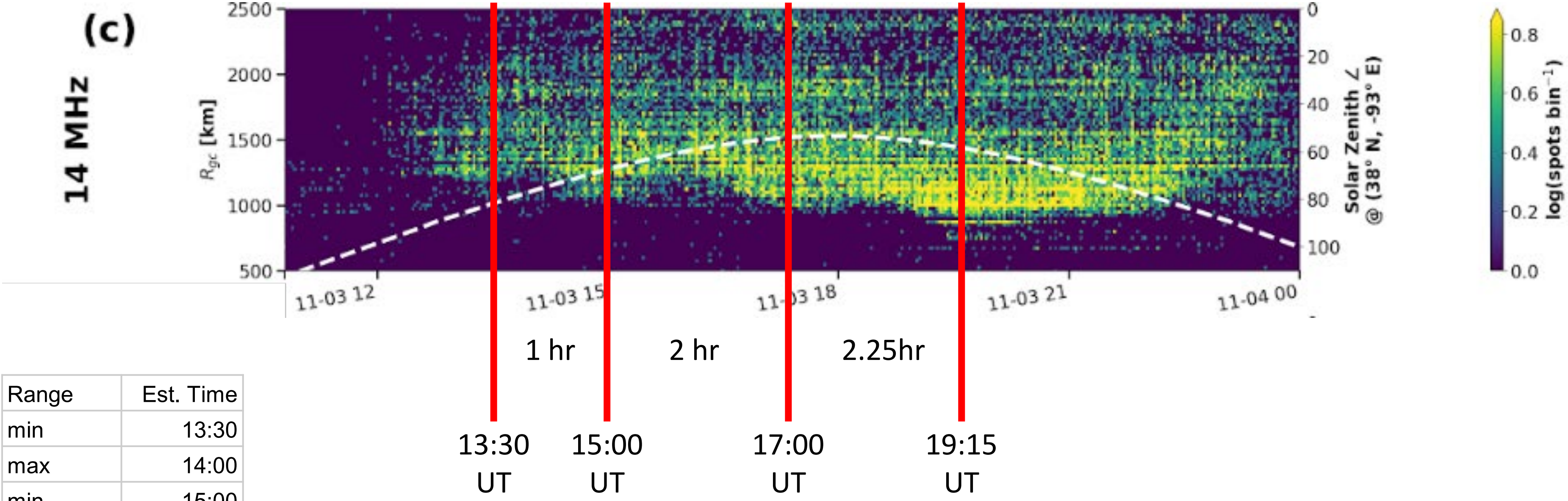
nathaniel.frissell@scranton.edu

TIDs in Blackstone SuperDARN





Periods get longer…



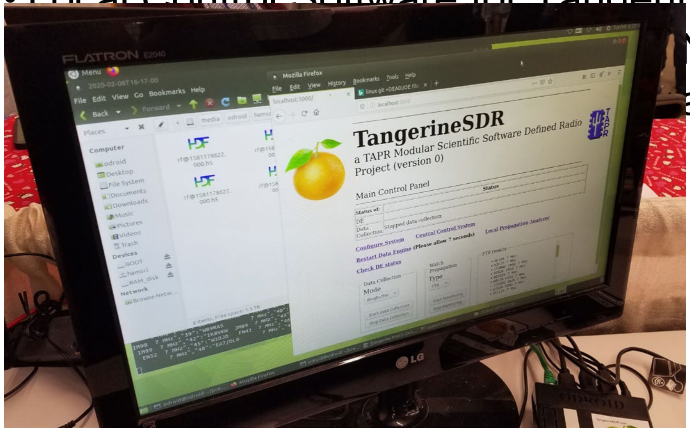
Range	Est. Time
min	13:30
max	14:00
min	15:00
max	16:15
min	17:00
max	18:30
min	19:15

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

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)

Current Status

- Prototypes expected by Fall 2020
- More information at tangerinesdr.com

nathaniel.frissell@scranton.edu

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

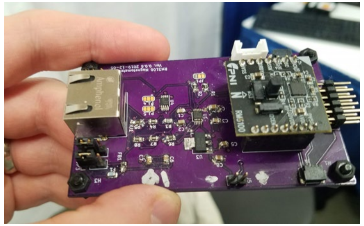
Prototypes have been made

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

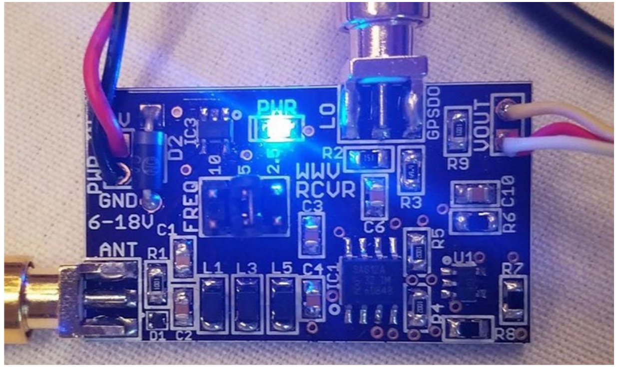
- Testing at established quiet sites.
- Comparison with calibrated sensors of established quality.



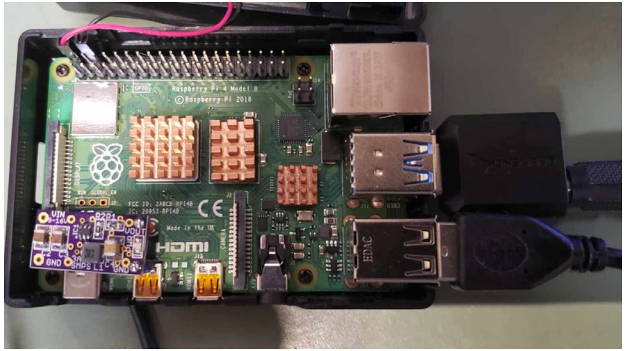
Magnetometer prototype designed by David Witten KD0EAG at the 2020 HamCation conference in Orlando, FL

Low-Cost PSWS Status

- **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 target is ~$100.**
- **Four stations** are currently deployed, some with prototype receivers and some with amateur transceivers. Preparations are also underway to set up stations with several aspiring data collectors.
- Doppler shift data is collected via spectrographs and frequency estimation algorithms.
- The low-cost PSWS team is currently fine-tuning metadata formats and automatic data upload.



“Grape Receiver” Generation 1 by J. Gibbons N8OBJ



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

nathaniel.frissell@scranton.edu

What is Total Electron Content (TEC)?

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

Slant TEC

Frequency Terms

Recorded carrier phases of the signal (converted to distance units)

Integer cycle ambiguities

Instrument (satellite and receiver) bias terms

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]