

Collective Science: Magnetosphere-Ionosphere- Atmosphere Coupling and the Building of an Amateur Radio Citizen Science Community

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The University of Scranton



Understanding Ionospheric Variability

2

- Here at CEDAR, we are very interested in the dynamics of atmospheric regions and how they couple together.
- The **ionosphere** is of particular interest to many of us...
 - Region that links the neutral atmosphere and the magnetosphere
 - Has interesting physics in its own right
 - Dramatically impacts many technological applications, including radio communications and satellite navigation.

Ionosphere Frontier Topics

- **Coupling from above vs. below**

- Space weather drives the ionosphere from above
- Terrestrial weather drives from below

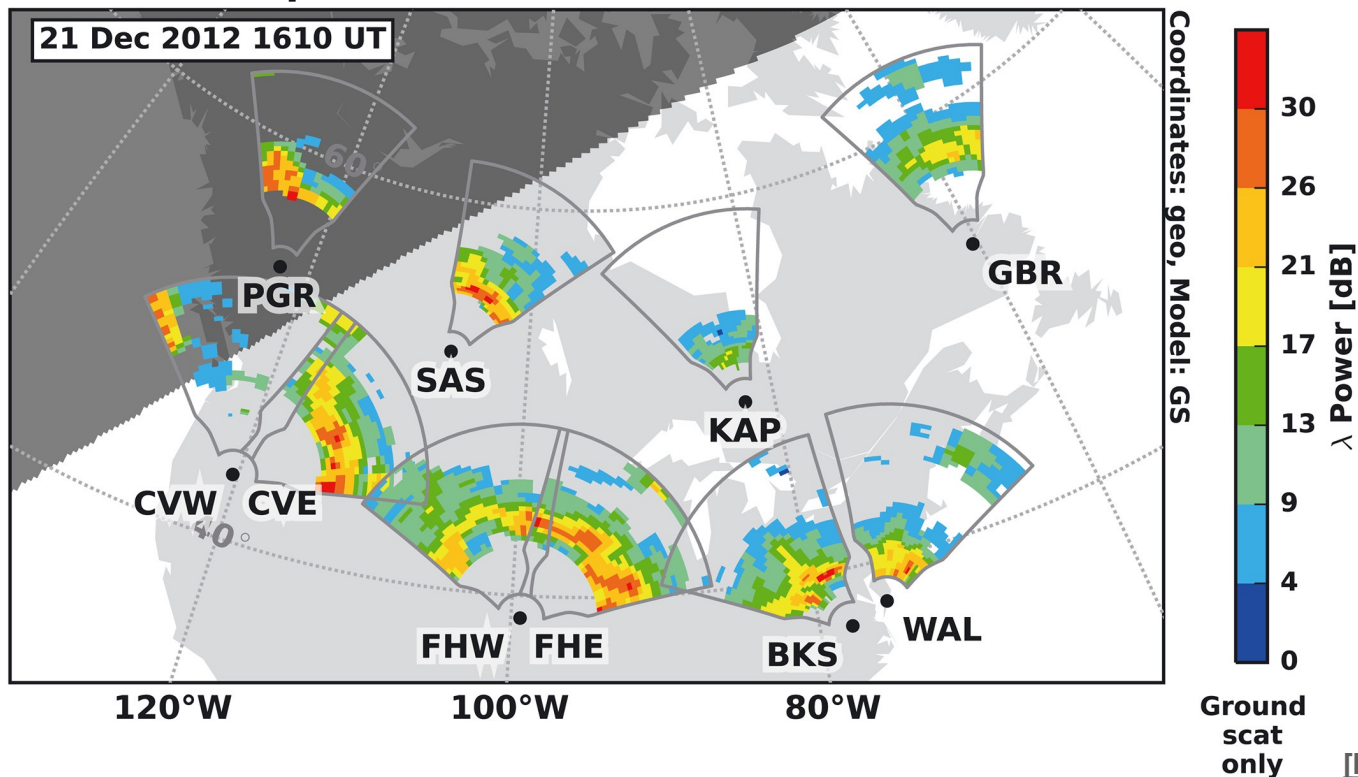
- **Weather vs. Climate**

- We have some reasonable understanding of ionospheric climate
- Many, many open questions about ionospheric weather

- **How to make progress?**

MSTIDs Observed By SuperDARN

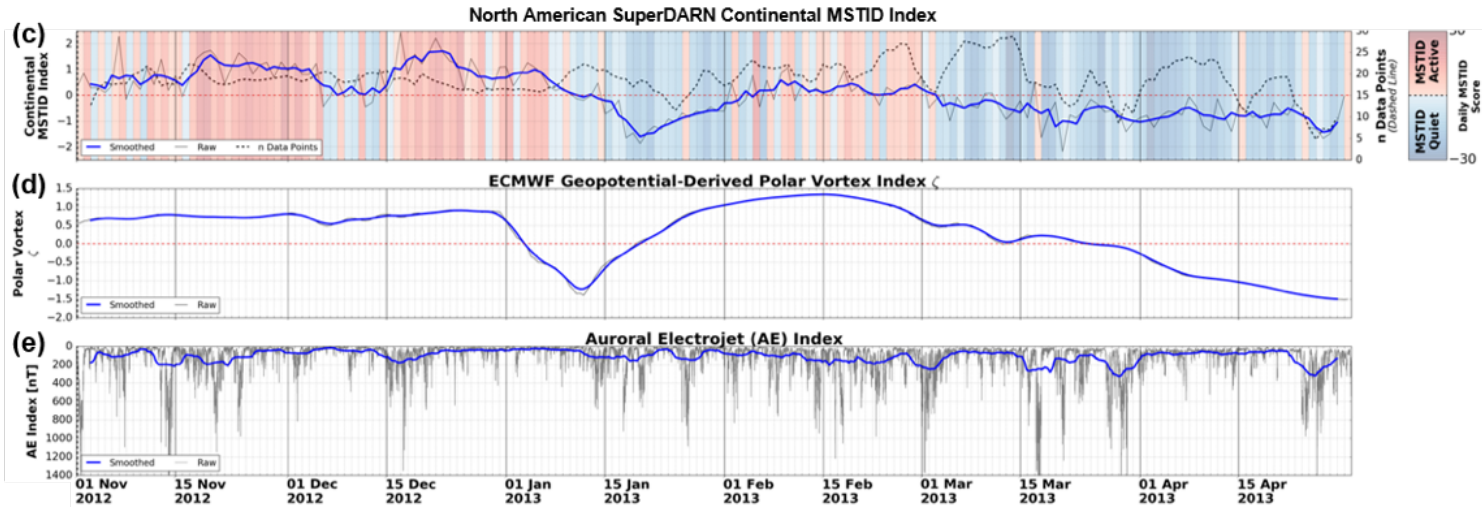
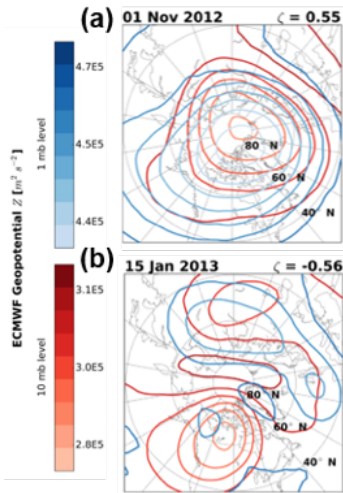
SuperDARN Ground Scatter Data



[Frissell et al., 2016]

SuperDARN MSTID Index

Polar Vortex Index



(Frissell et al., 2016, <http://dx.doi.org/10.1002/2015JA022168>)

What is Amateur (Ham) Radio?

- **Hobby for Radio Enthusiasts**

- Communicators
- Builders
- Experimenters

- **Wide-reaching Demographic**

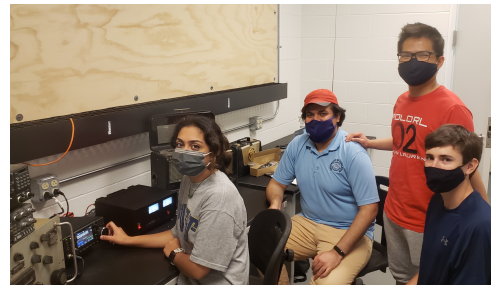
- All ages & walks of life
- Over 760,000 US amateurs; ~3 million Worldwide
(<http://www.arrl.org/arrl-fact-sheet>)

- **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”

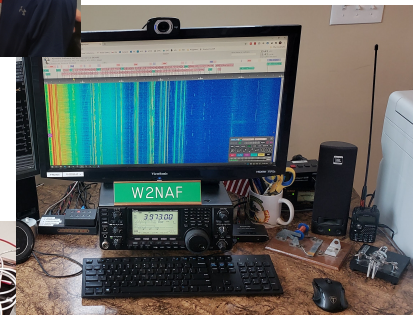
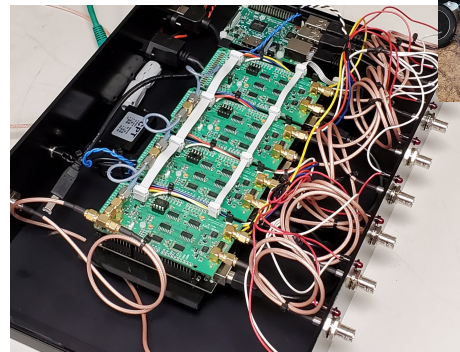
- **Ideal Community for Citizen Science**

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



University of Scranton
Students at W3USR

W2NAF Home Station

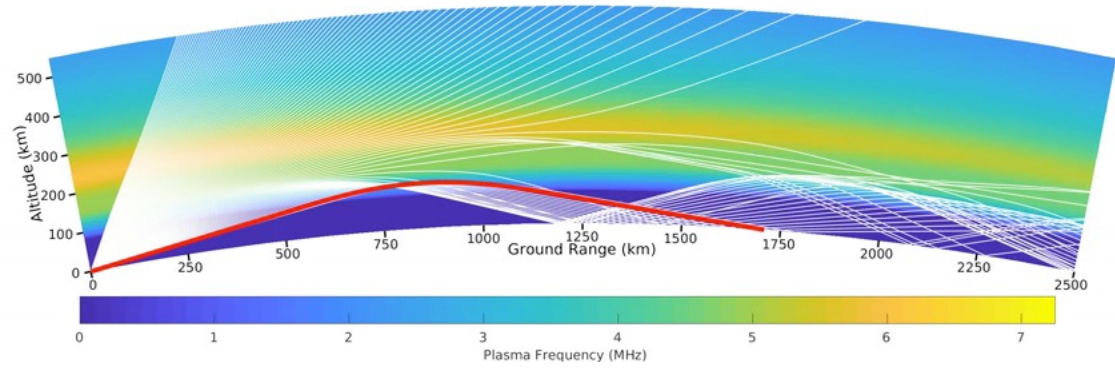


N8UR multi-TICC:
Precision Time Interval
Counter

Amateur Radio Frequencies and Modes

Eclipsed SAMI3 - PHaRLAP Raytrace

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

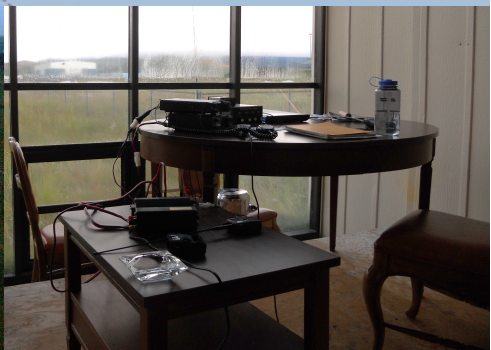
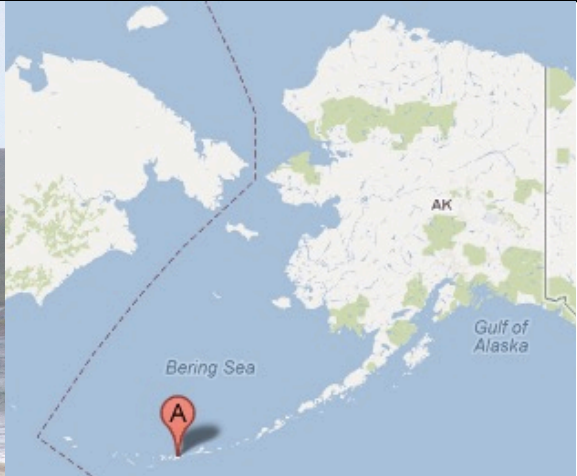


PHaRLAP: Cervera & Harris (2014), <https://doi.org/10.1002/2013JA019247>
 SAMI3: Huba & Drob (2017), <https://doi.org/10.1002/2017GL073549>
 Amateur Radio and the Eclipse: Frissell et al. (2018), <https://doi.org/10.1029/2018GL077324>

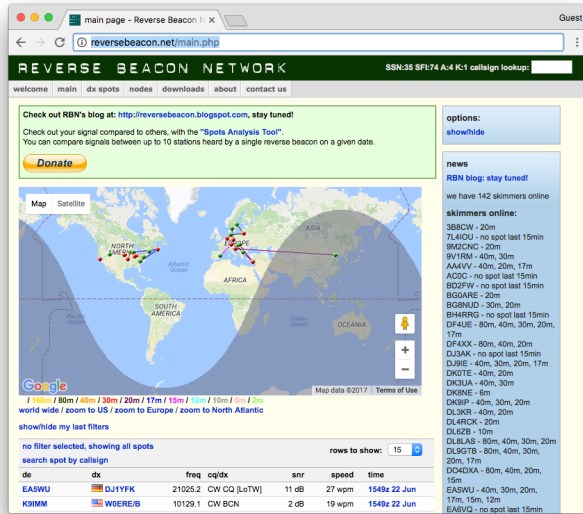
- **Amateurs routinely use HF-VHF transionospheric links.**
- **Often ~100 W into dipole, vertical, or small beam antennas.**
- **Common HF Modes**
 - Data: FT8, PSK31, WSPR, RTTY
 - Morse Code / Continuous Wave (CW)
 - Voice: Single Sideband (SSB)

	Frequency	Wavelength
LF	135 kHz	2,200 m
	473 kHz	630 m
MF	1.8 MHz	160 m
	3.5 MHz	80 m
HF	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
	50 MHz	6 m
VHF+	And more...	

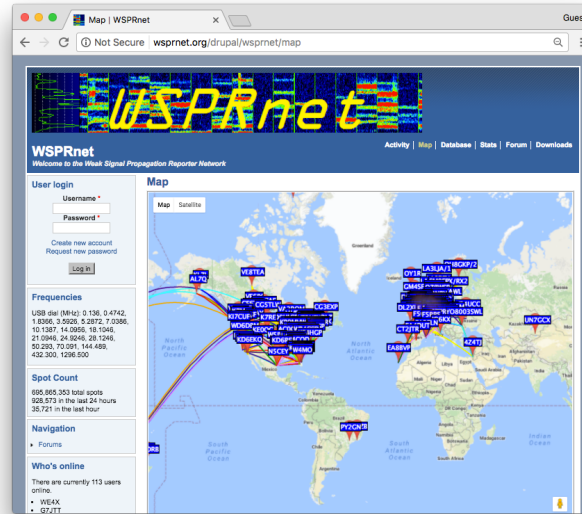
Adak Island SuperDARN/DXPedition



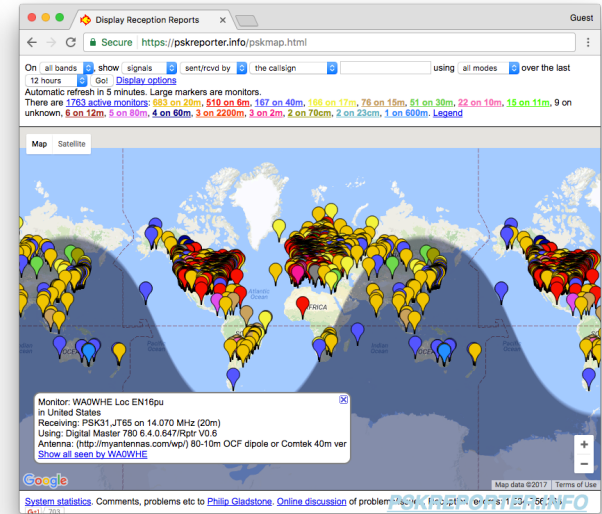
Amateur Radio Observation Networks



Reverse Beacon Network (RBN)
reversebeacon.net



WSPRnet
wspnet.org



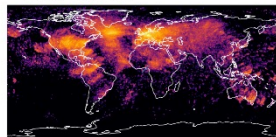
PSKReporter
pskreporter.info

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

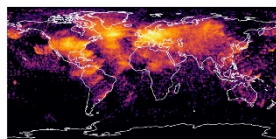
- Data back to 2008 (A whole solar cycle!)
- Available in real-time!

RBN/WSPR 2009-2020

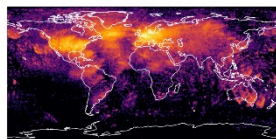
01 Jan 2009-
01 Jan 2020
Ham Radio Networks
N Spots = 1924315496
Data Sources:
RBN
WSPRnet



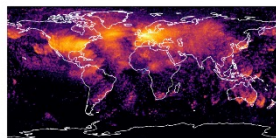
Radio Spots (N = 45142226)



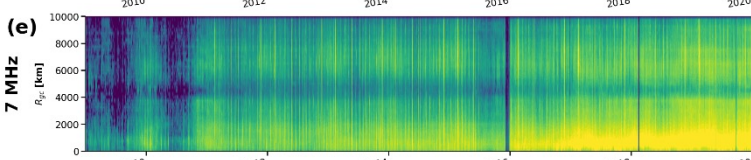
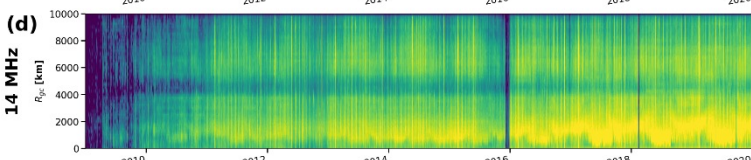
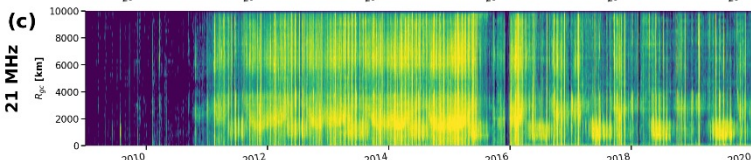
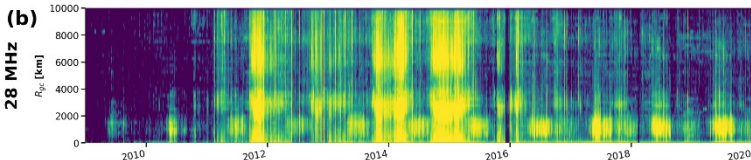
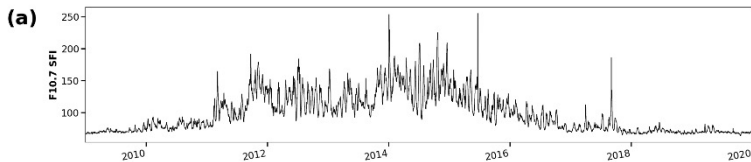
Radio Spots (N = 70444256)



Radio Spots (N = 627673930)

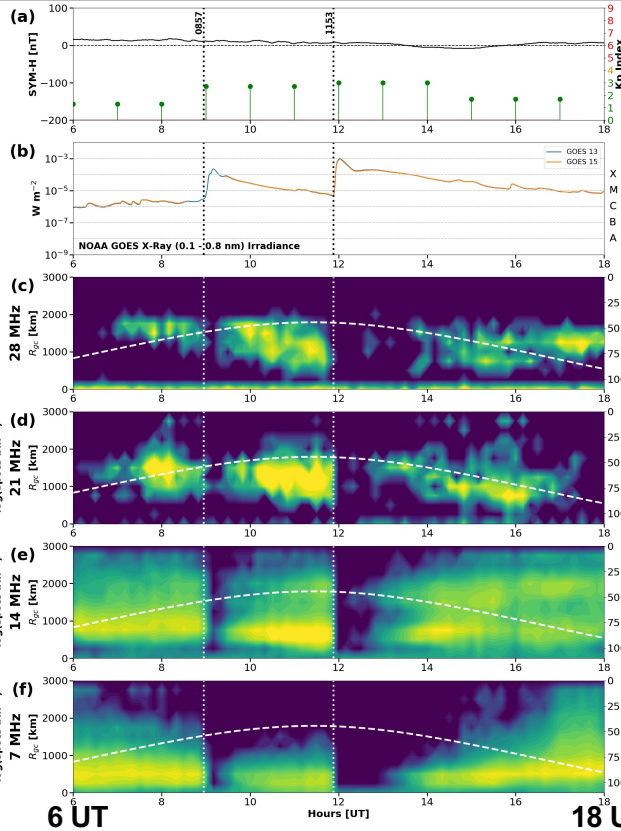


Radio Spots (N = 831317452)



EU Response to Solar Flares

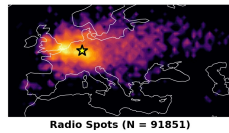
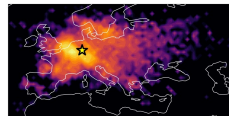
06 Sep 2017
 Ham Radio Networks
 N Spots = 185579
 RBN: 14%
 WSPRNet: 86%



Quiet Kp/Sym-H

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

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



28 MHz

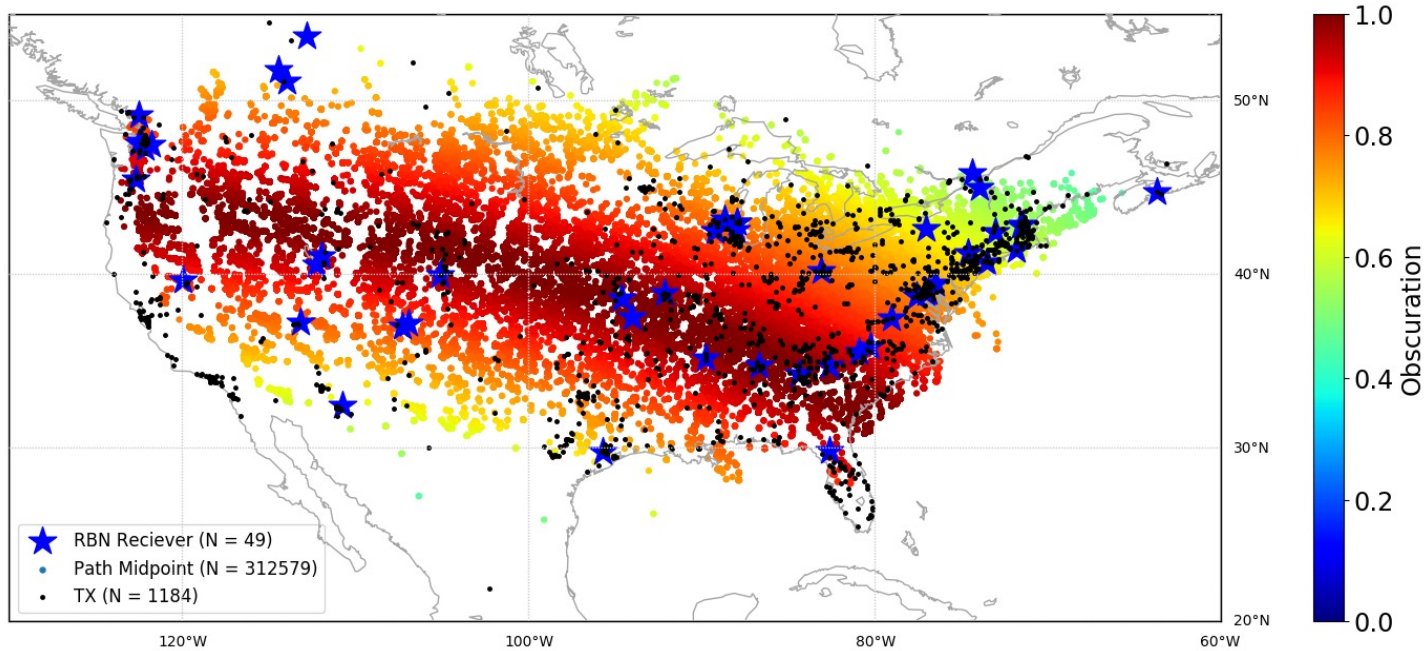
21 MHz

14 MHz

7 MHz

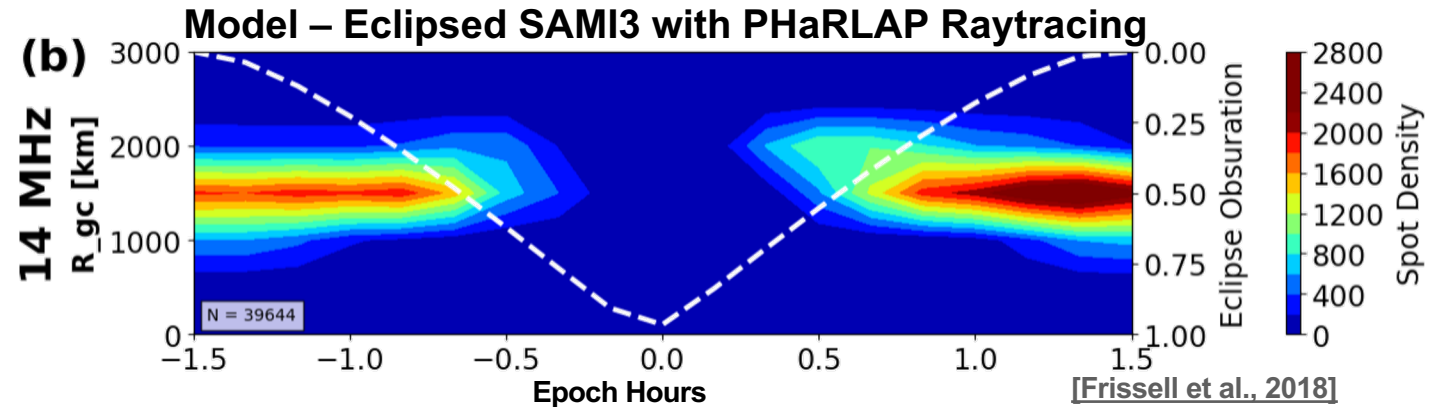
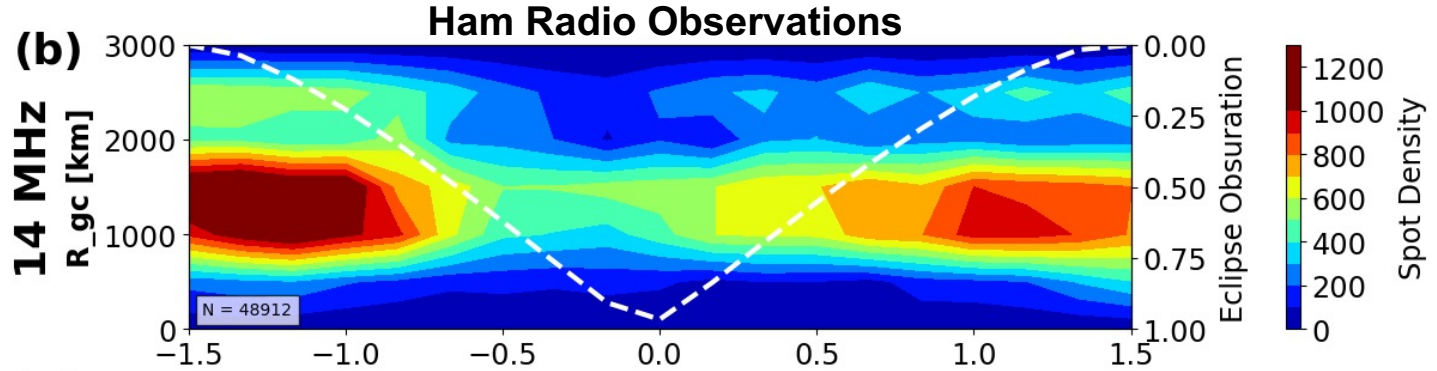
[Frissell et al., 2019]

Solar Eclipse QSO Party RBN Observations

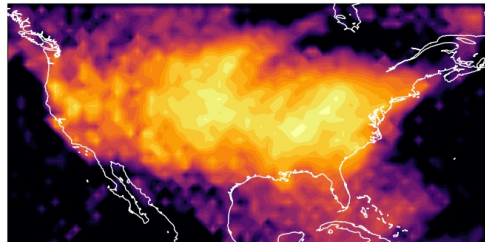


[Frissell et al., 2018]

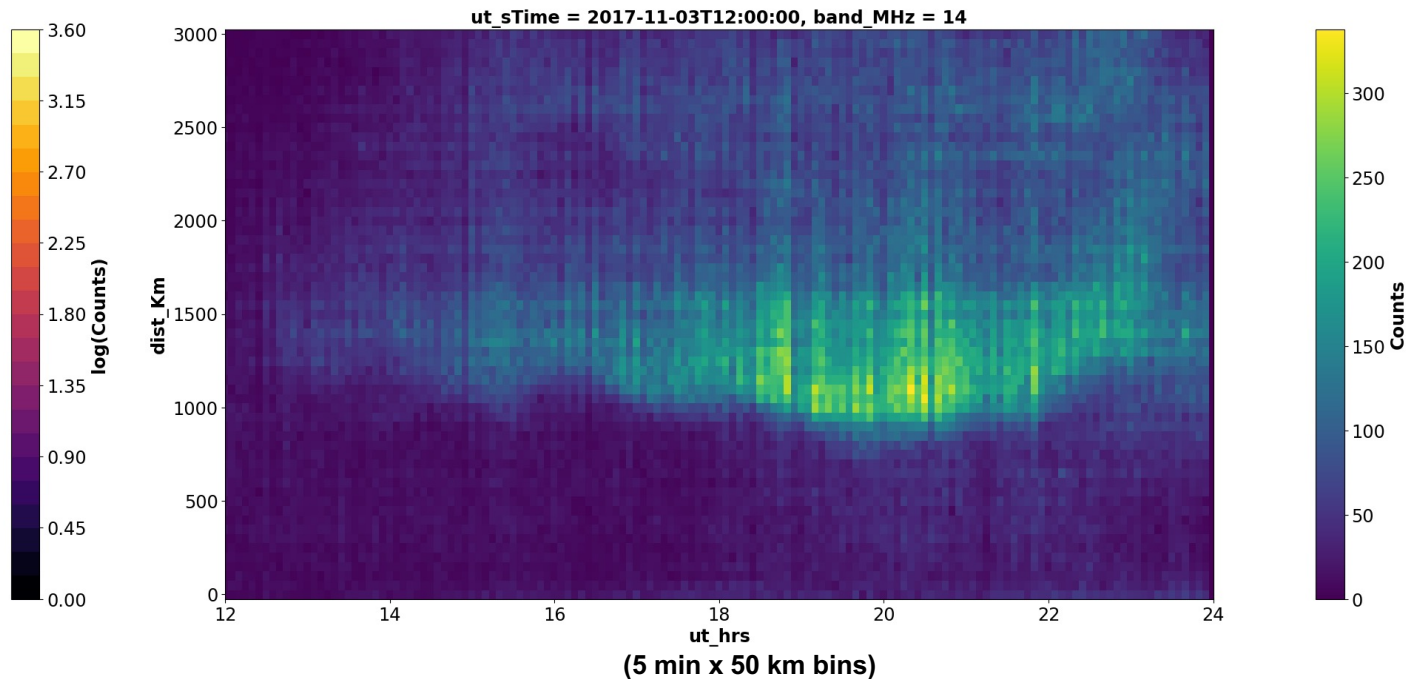
Linking Radio Observations to Physics with Modeling

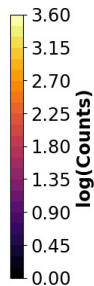
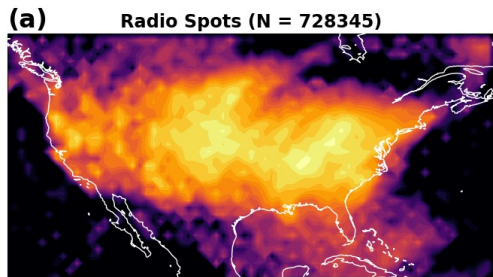


20171103.1200-20171104.0000_timeseries.png

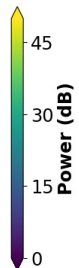
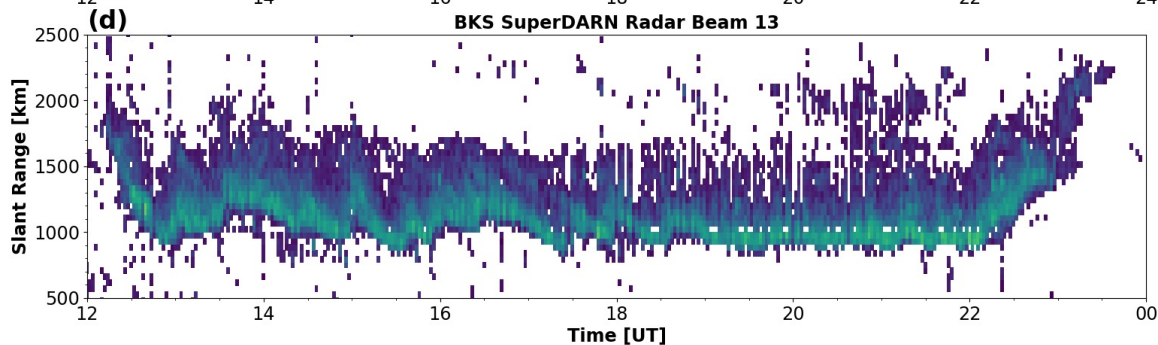
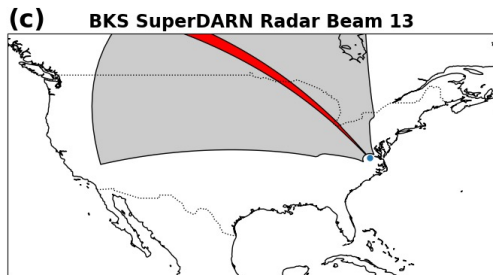
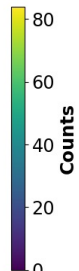
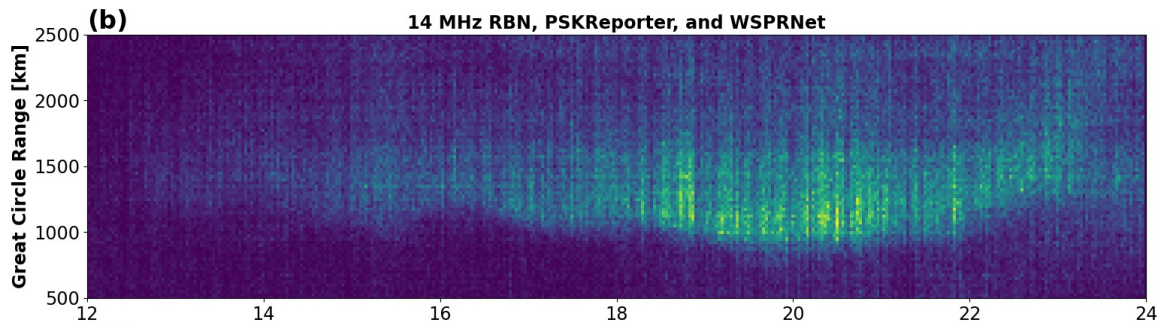


Radio Spots (N = 728345)
(1°x1° bins)





2017 Nov 03 1200 UT - 2017 Nov 04 0000 UT



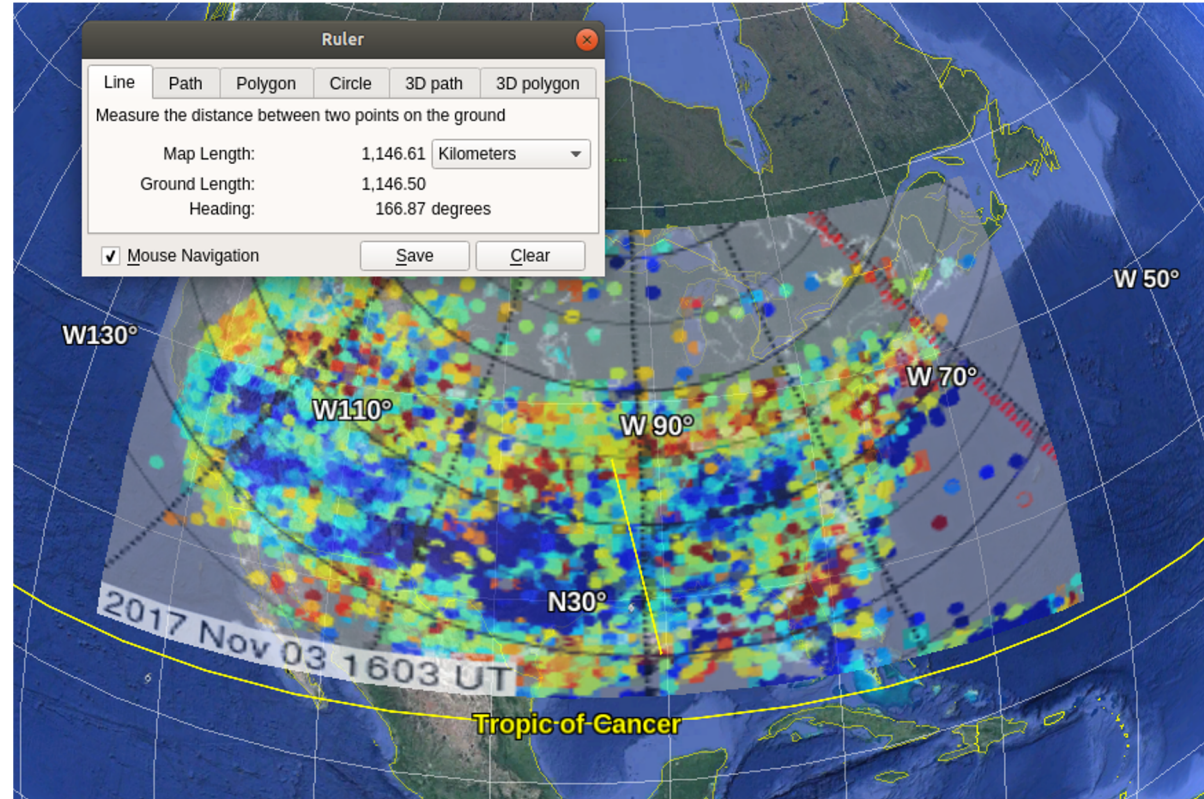
Estimated GNSS TEC LSTID Parameters

$$\lambda_h \approx 1,100 \text{ km}$$

$$v_p \approx 950 \text{ km/hr}$$

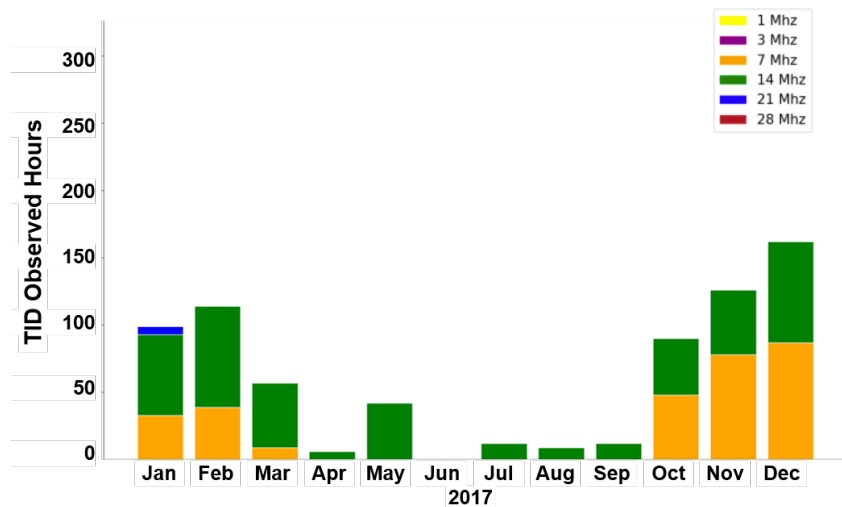
$$T \approx 70 \text{ min}$$

$$\Phi_{\text{Azm}} \approx 135^\circ$$



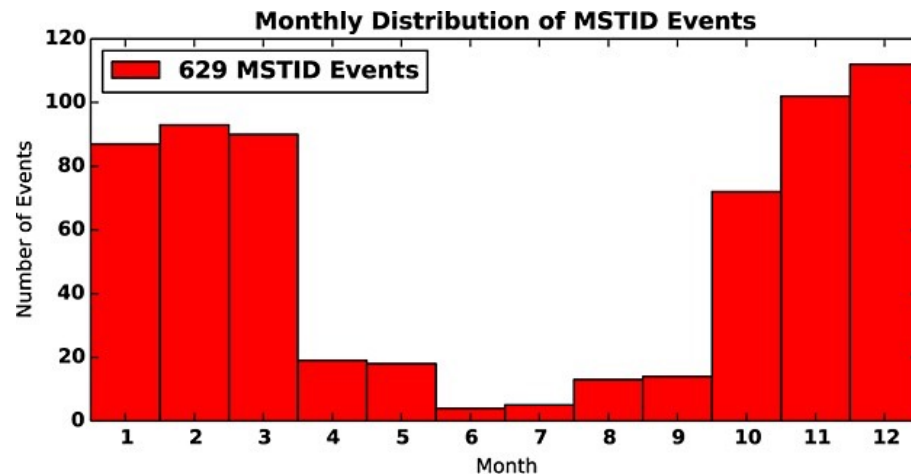
Comparison with SuperDARN MSTID Statistics

Amateur Radio TID Statistics 2017



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

Blackstone, VA SuperDARN MSTID Statistics 2010



[Frissell et al., 2014]

HamSCI Ham radio Science Citizen Investigation



hamsci.org/dayton2017



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

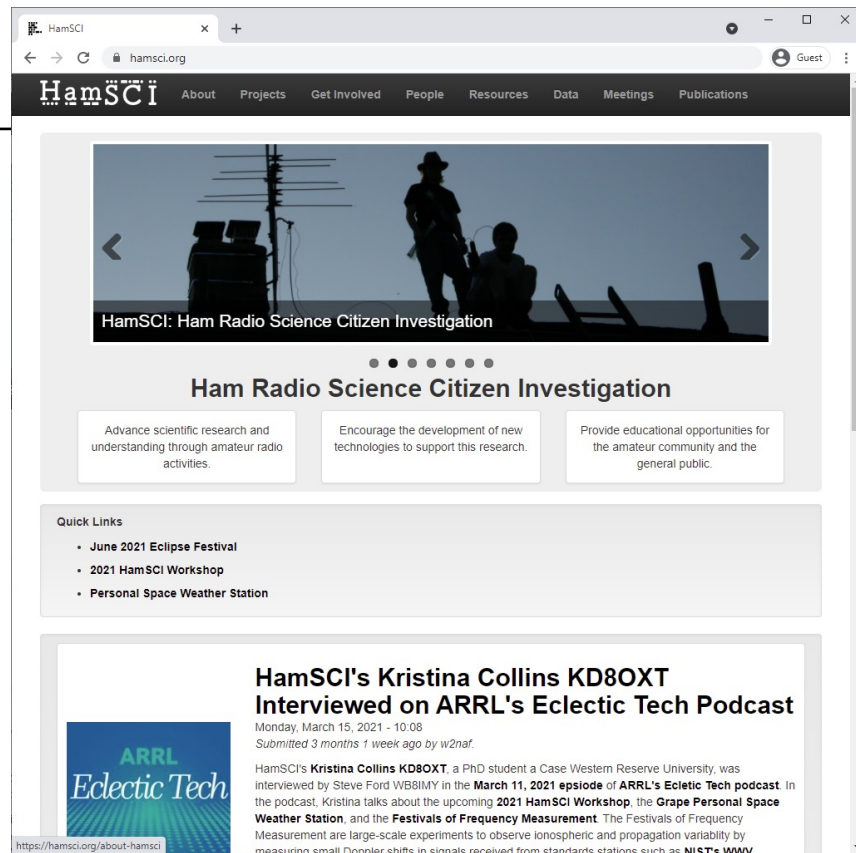
A collective that allows university researchers to collaborate with the amateur radio community in scientific investigations.

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.

HamSCI Activities

- **Google Group (Over 450 Members!)**
- **Weekly Telecons**
- **Participation in**
 - Professional Science Meetings
 - Amateur Radio Conventions
- **Annual HamSCI Workshop**



The screenshot shows the HamSCI website homepage. At the top is a navigation bar with the HamSCI logo and links for About, Projects, Get Involved, People, Resources, Data, Meetings, and Publications. Below the navigation bar is a large banner image showing silhouettes of people at a radio station. The banner text reads "HamSCI: Ham Radio Science Citizen Investigation". Below the banner is a section titled "Ham Radio Science Citizen Investigation" with three columns of text: "Advance scientific research and understanding through amateur radio activities.", "Encourage the development of new technologies to support this research.", and "Provide educational opportunities for the amateur community and the general public." Below this is a "Quick Links" section with three items: "June 2021 Eclipse Festival", "2021 HamSCI Workshop", and "Personal Space Weather Station". At the bottom is a featured article titled "HamSCI's Kristina Collins KD8OXT Interviewed on ARRL's Eclectic Tech Podcast" with a date of Monday, March 15, 2021 - 10:08 and a submission date of 3 months 1 week ago by w2nar. The article text mentions that Kristina Collins KD8OXT is a PhD student at Case Western Reserve University and was interviewed by Steve Ford WB8IMY on the March 11, 2021 episode of ARRL's Eclectic Tech podcast. The article also mentions the upcoming 2021 HamSCI Workshop, the Grape Personal Space Weather Station, and the Festivals of Frequency Measurement.

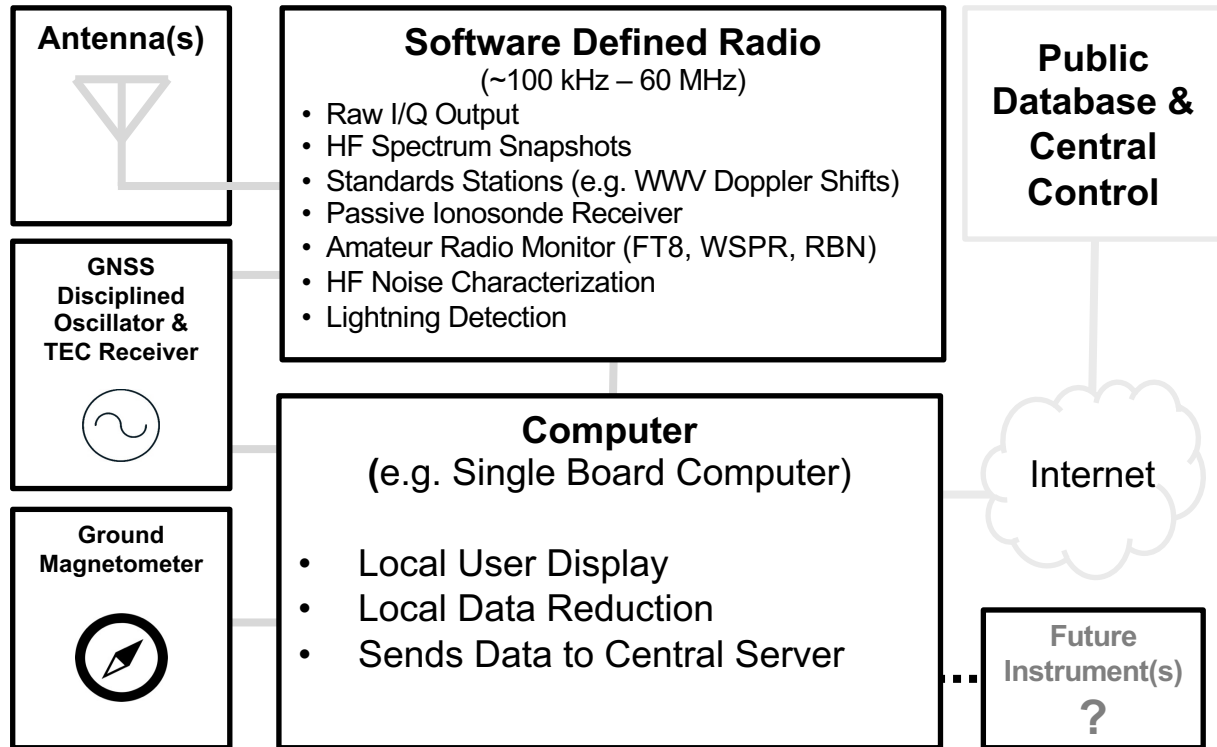
Join us at <https://hamsci.org>

Benefits of Amateur Radio Citizen Science

- Access to broad expertise and different perspectives
- Ability to collect data on a large scale that can complement and augment existing space science datasets
- Widespread outreach
- Mechanism for reaching and involving youth in space science, well before graduate school
- Unique opportunity for community members with significant experience to mentor younger generation

HamSCI Personal Space Weather Station

- The 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.
- The PSWS design also works to take into account the needs of both amateur radio operators and professional researchers.



For more information, visit <http://hamsci.org/psws>

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)



Zephyr
Engineering
Inc.

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

HamSCI



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



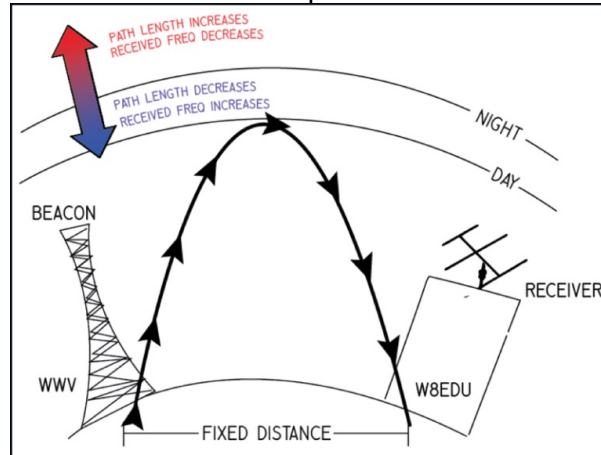
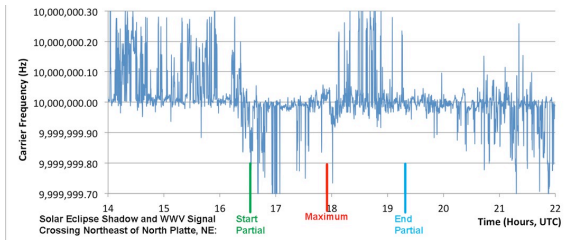
- HF “Doppler Shift” Monitoring
- Main components: Raspberry Pi, GPSDO, Custom Direct-conversion receiver board
- Cost: ~\$100 to \$200
- Developed by Case Western

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

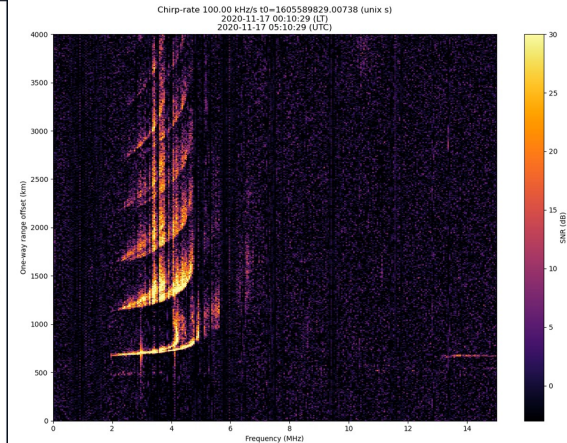
10 MHz Doppler During 2017 Eclipse TX: WWV RX: WA9VNJ (Milwaukee)



[Collins et al., 2021]

Oblique Ionograms

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



Movie by Dev Joshi
GNUChirpsounder2 by Juha Vierinen

Future Work - Science

What are the causes of the ionospheric variability we are observing?

- Combine amateur radio, SuperDARN, GNSS data, other sources, and model outputs together in a meaningful way.
- Develop PSWS network to generate new measurement techniques and data.
- Work with other professional researchers, students, and community members.

Future Work - Community

How do we best foster the HamSCI program so it truly does bring together the amateur and professional communities?

- Create opportunities for open, positive discussion
- Listen and respond to the needs of both communities
- Find ways for people to participate that match their interests and passions

Thank You!

Acknowledgments

We are especially grateful for the

- amateur radio community who voluntarily produced and provided the HF radio observations used in this paper, especially the operators of the Reverse Beacon Network (RBN, reversebeacon.net), the Weak Signal Propagation Reporting Network (WSPRNet, wsprnet.org), PSKReporter (pskreporter.info) qrz.com, and hamcall.net.
- support of NSF AGS-200227 and NASA 19-LWS19_2-0069.
- use of SuperDARN data. SuperDARN is a collection of radars funded by national scientific funding agencies of Australia, Canada, China, France, Italy, Japan, Norway, South Africa, United Kingdom and the United States of America.
- PyDARN Analysis Toolkit made available by the SuperDARN Data Analysis Working Group, Schmidt, M.T., Billett, D.D., Martin, C.J., Huyghebaert, D., Bland, E.C., ... Sterne, K.T. (2021, February 23). SuperDARN/pydarn: pyDARNio v2.0.1 (Version v2.0.1). Zenodo. <http://doi.org/10.5281/zenodo.4558130>.
- GNSS TEC data used is provided by the Millstone Hill Geospace Facility under NSF grant AGS-1952737.
- use of the Free Open Source Software projects used in this analysis: Ubuntu Linux, python (van Rossum, 1995), matplotlib (Hunter, 2007), NumPy (Oliphant, 2007), SciPy (Jones et al., 2001), pandas (McKinney, 2010), xarray (Hoyer & Hamman, 2017), iPython (Pérez & Granger, 2007), and others (e.g., Millman & Aivazis, 2011).

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](https://doi.org/10.1002/2013JA019247).

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](https://doi.org/10.1002/2014JA019870).

Frissell, N. A., Katz, J. D., Gunning, S. W., Vega, J. S., Gerrard, A. J., Earle, G. D., et al. (2018). Modeling amateur radio soundings of the ionospheric response to the 2017 great American eclipse. *Geophysical Research Letters*, 45, 4665– 4674. <https://doi.org/10.1029/2018GL077324>.

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](https://doi.org/10.1002/2017GL073549).

Sanchez, D. F., Frissell, N. A., Perry, G. W., Engelke, W. D., Coster, A., Erickson, P. J., Ruohoniemi, J. M., and Baker, J. B. H. (2020). A Climatology of Traveling Ionospheric Disturbances Observed by High Frequency Amateur Radio Networks, Fall American Geophysical Union Meeting (Virtual), <https://agu2020fallmeeting-agu.ipostersessions.com/?s=54-0E-51-AB-15-21-9A-6F-BC-57-16-81-81-0C-D8-37>.

Backup Slides
