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

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HamSCI

http://hamsci.org

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Understanding Ionospheric Variability

- 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.

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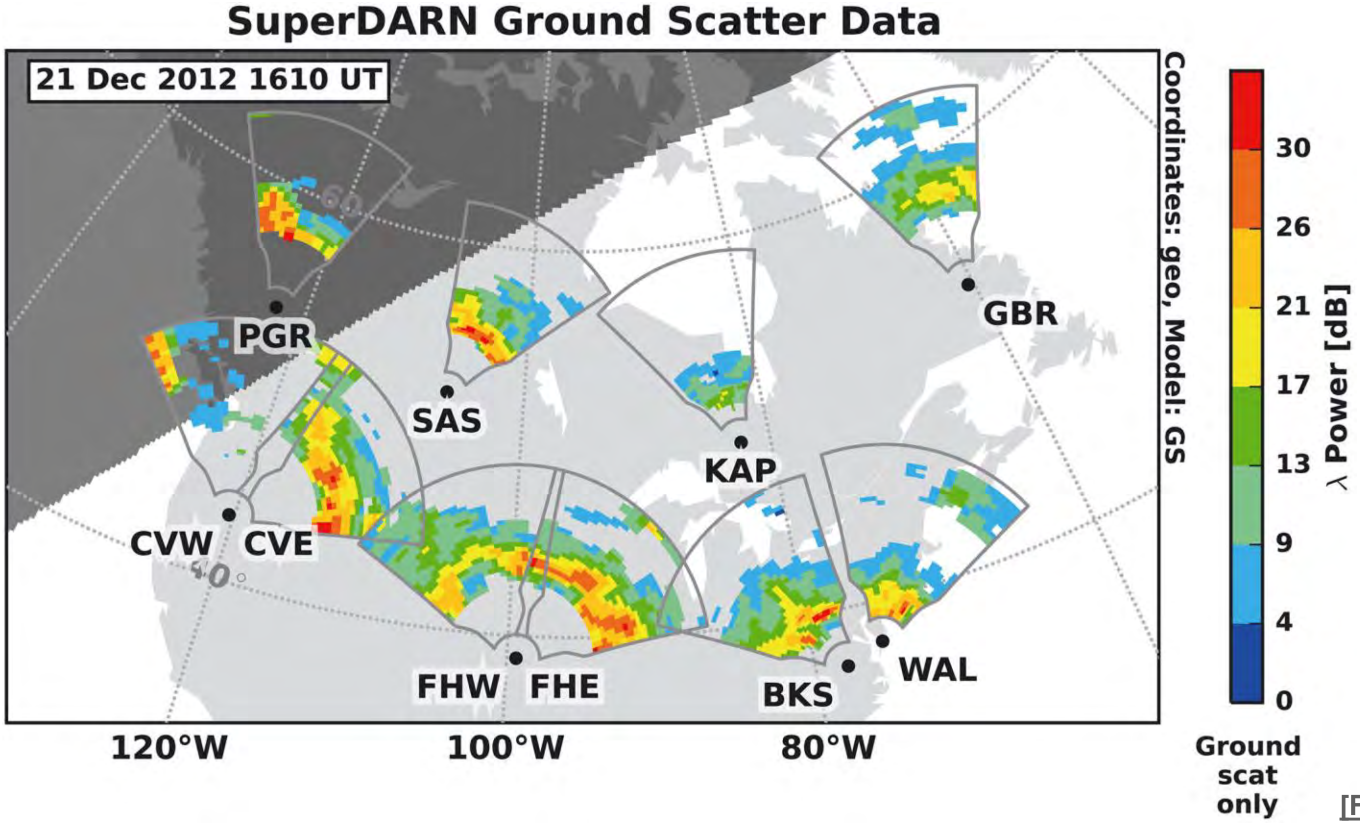
Ionosphere Frontier Topics

- **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



[Frissell et al., 2016]

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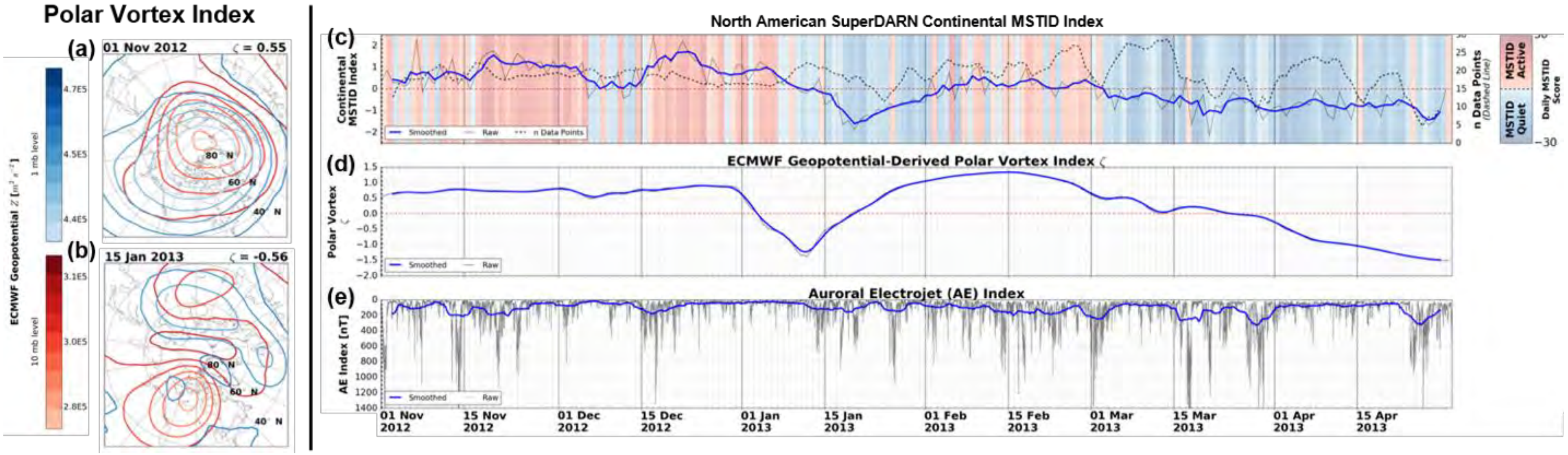
SuperDARN MSTID Index



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

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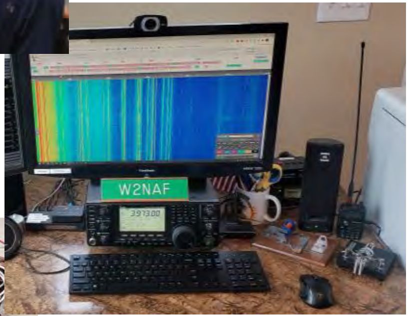
What is Amateur (Ham) Radio?

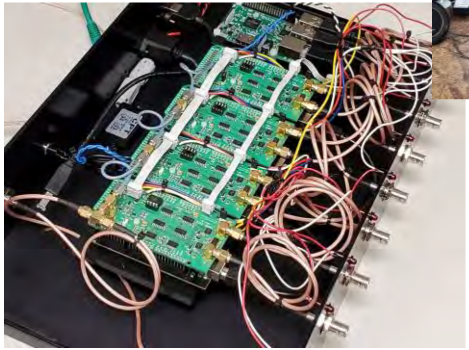
- **Hobby for Radio Enthusiasts**
  - Communicators
  - Builders
  - Experimenters
- **Wide-reaching Demographic**
  - All ages & walks of life
  - Over 760,000 US amateurs; ~3 million Worldwide (http://www.arrl.org/arrl-fact-sheet)
- **Licensed by the Federal Government**
  - Basic RF electrical engineering 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

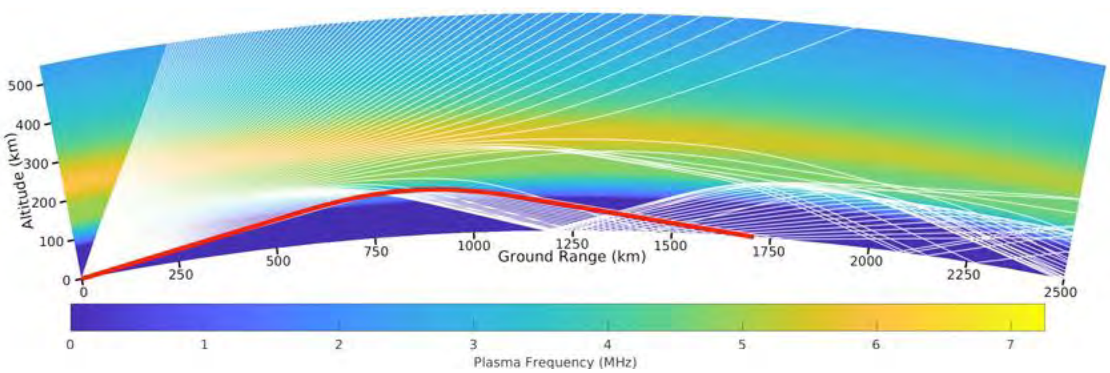


N8UR multi-TICC: Precision Time Interval Counter

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
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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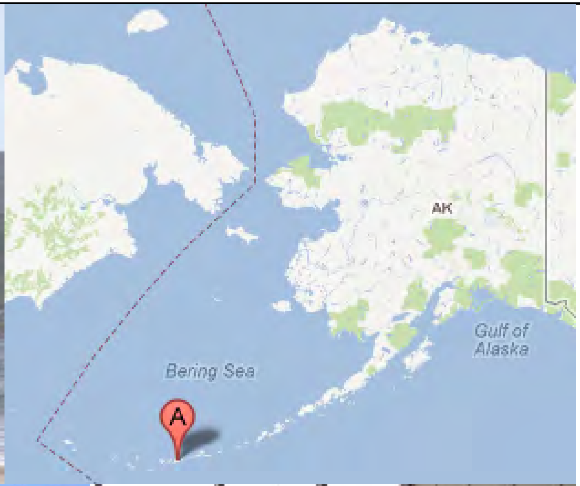
Adak Island SuperDARN/DXPedition



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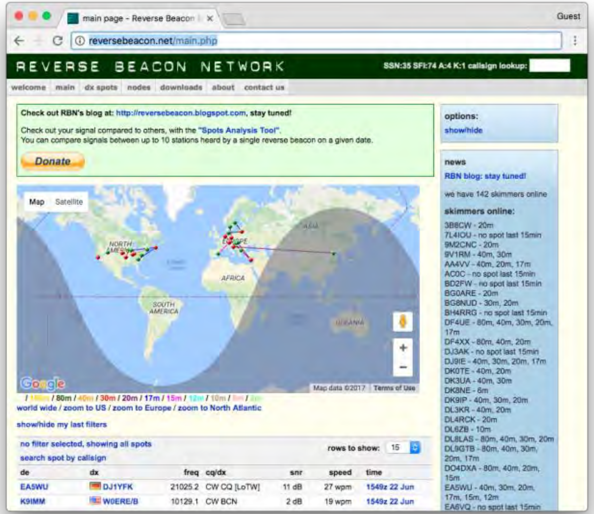
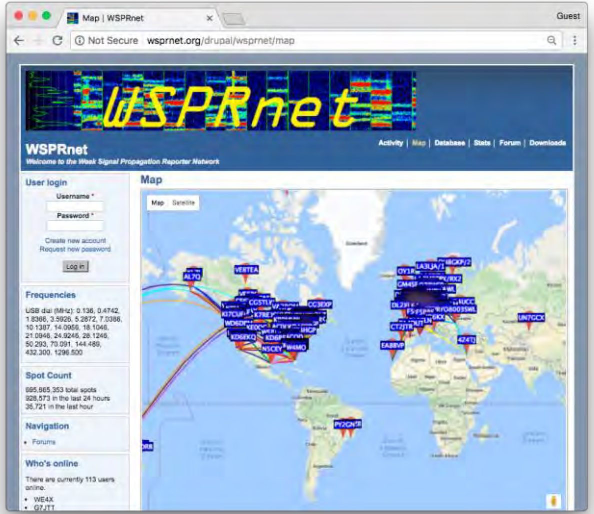
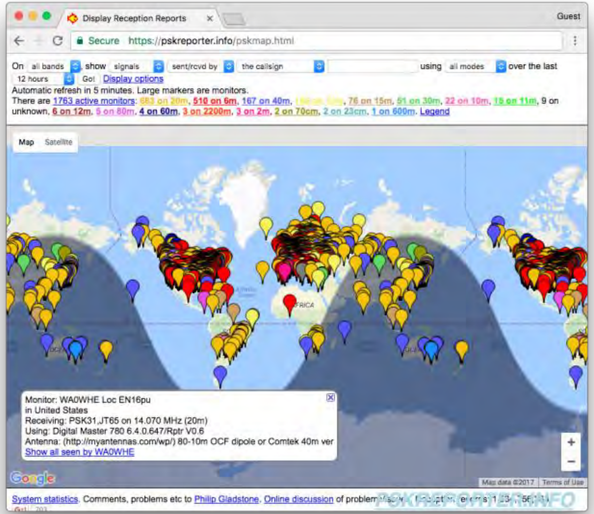
Amateur Radio Observation Networks



Reverse Beacon Network (RBN)
reversebeacon.net



WSPRNet
wsprnet.org

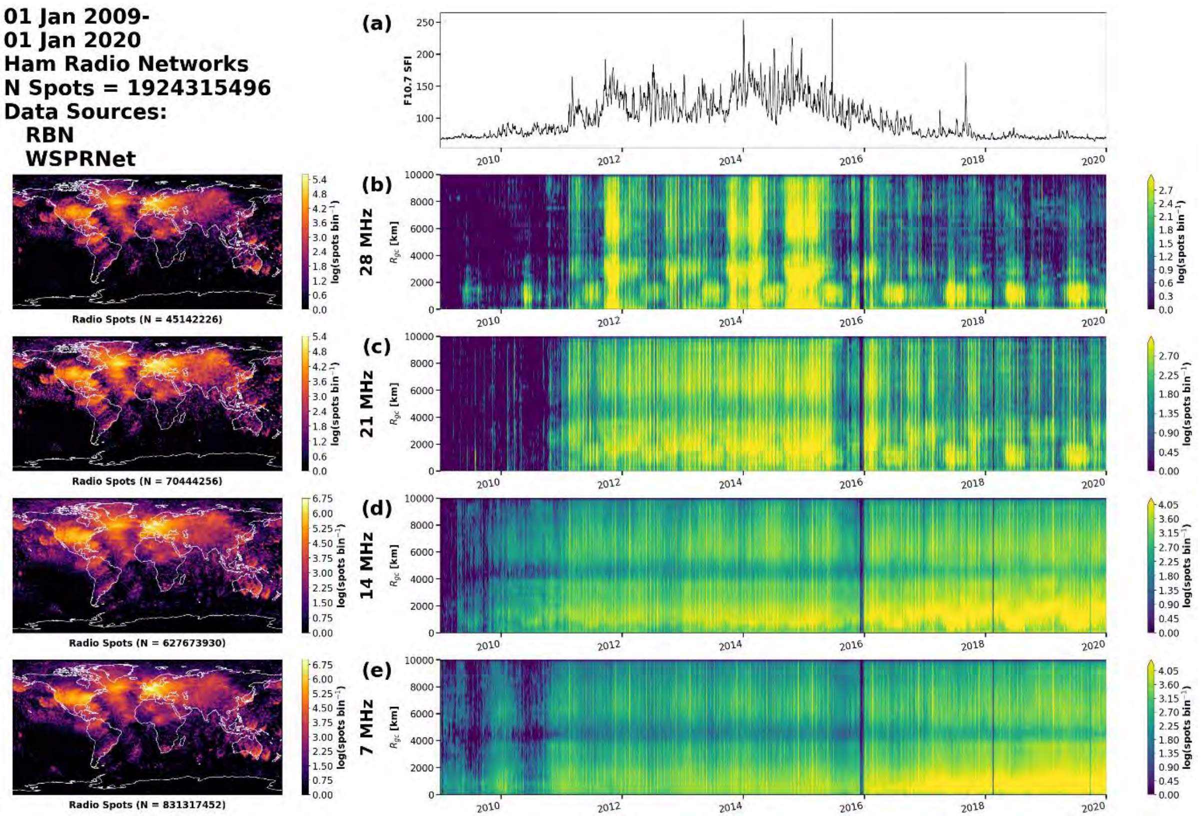


PSKReporter
pskreporter.info

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

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

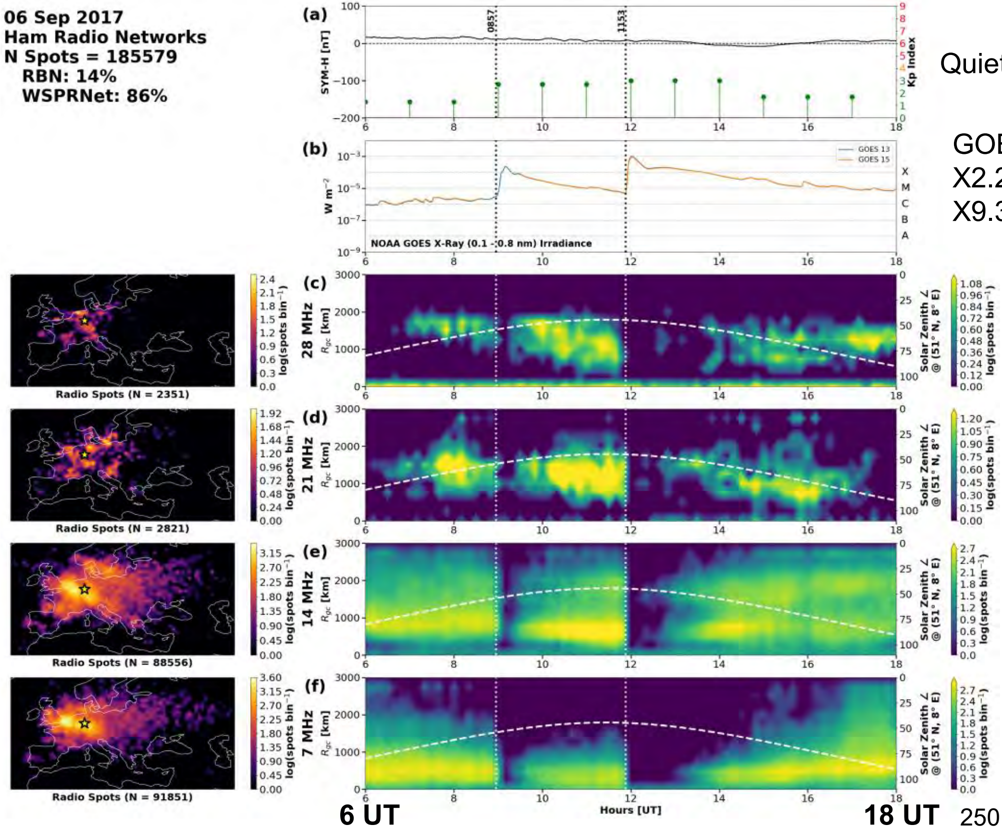
RBN/WSPR 2009-2020



EU Response to Solar Flares

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

[Frissell et al., 2019]



Quiet Kp/Sym-H

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

28 MHz

21 MHz

14 MHz

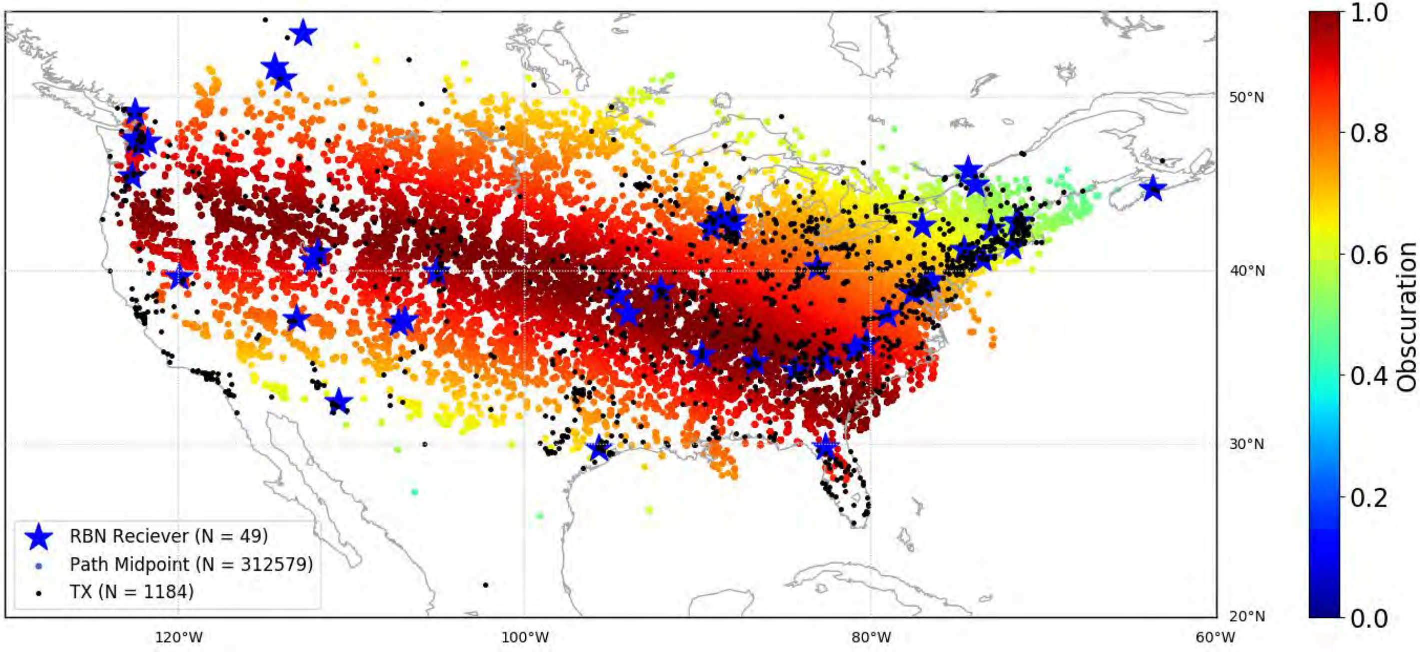
7 MHz

6 UT

18 UT

250 km × 10 min bins

Solar Eclipse QSO Party RBN Observations



[Frissell et al., 2018]

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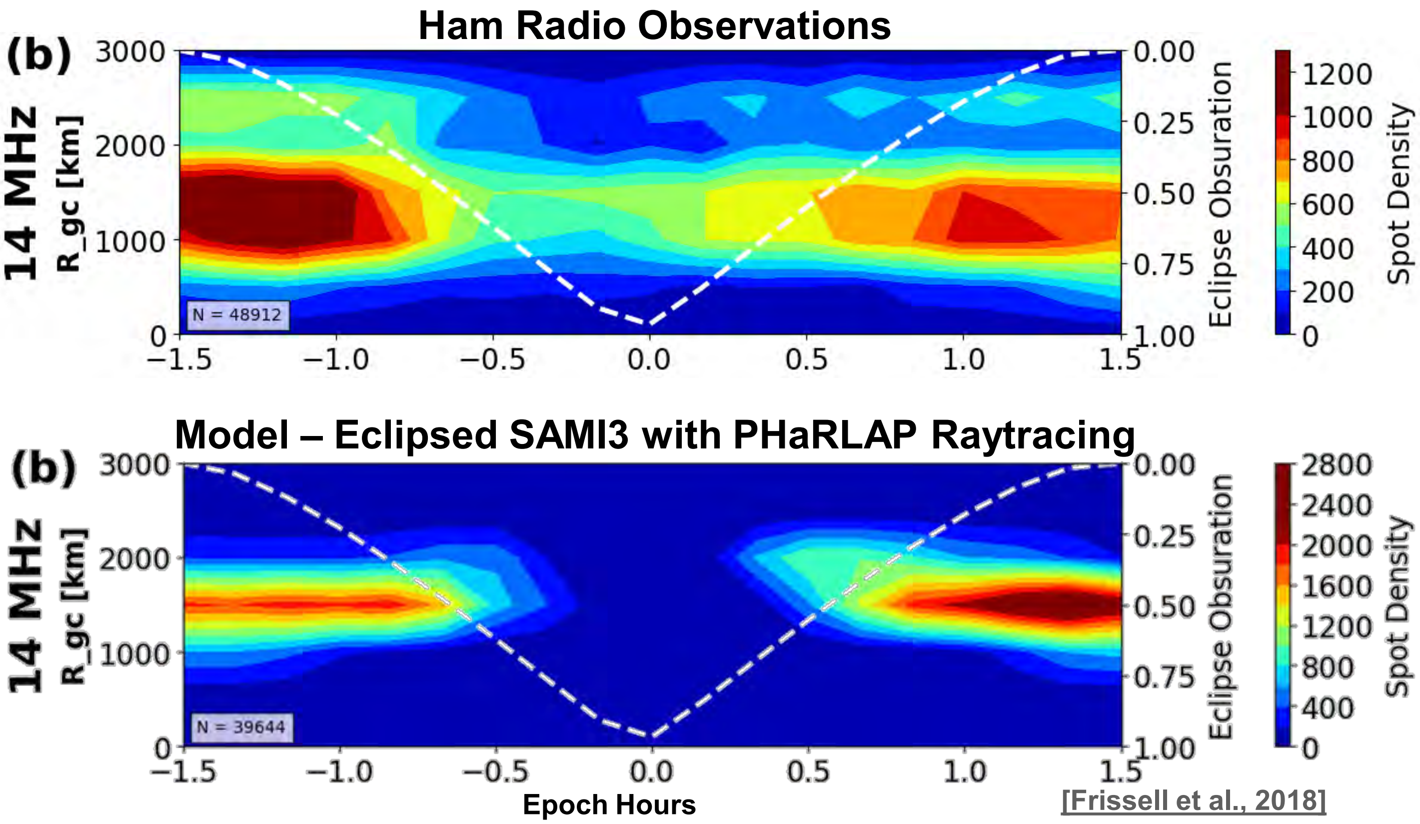
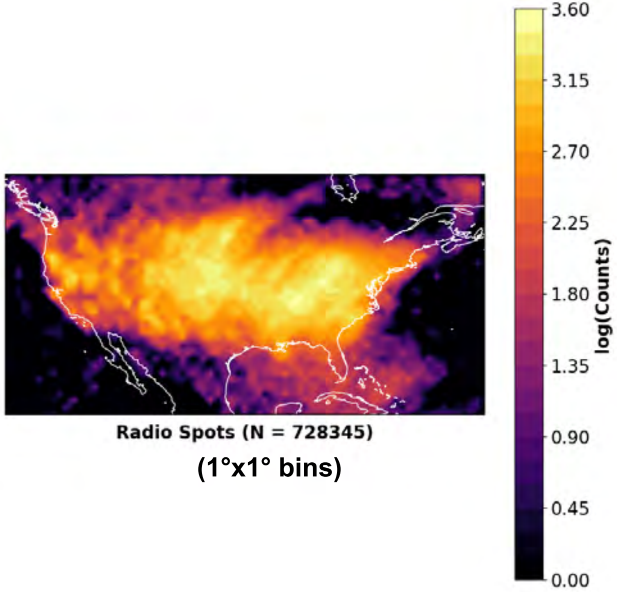
Linking Radio Observations to Physics with Modeling



[Frissell et al., 2018]

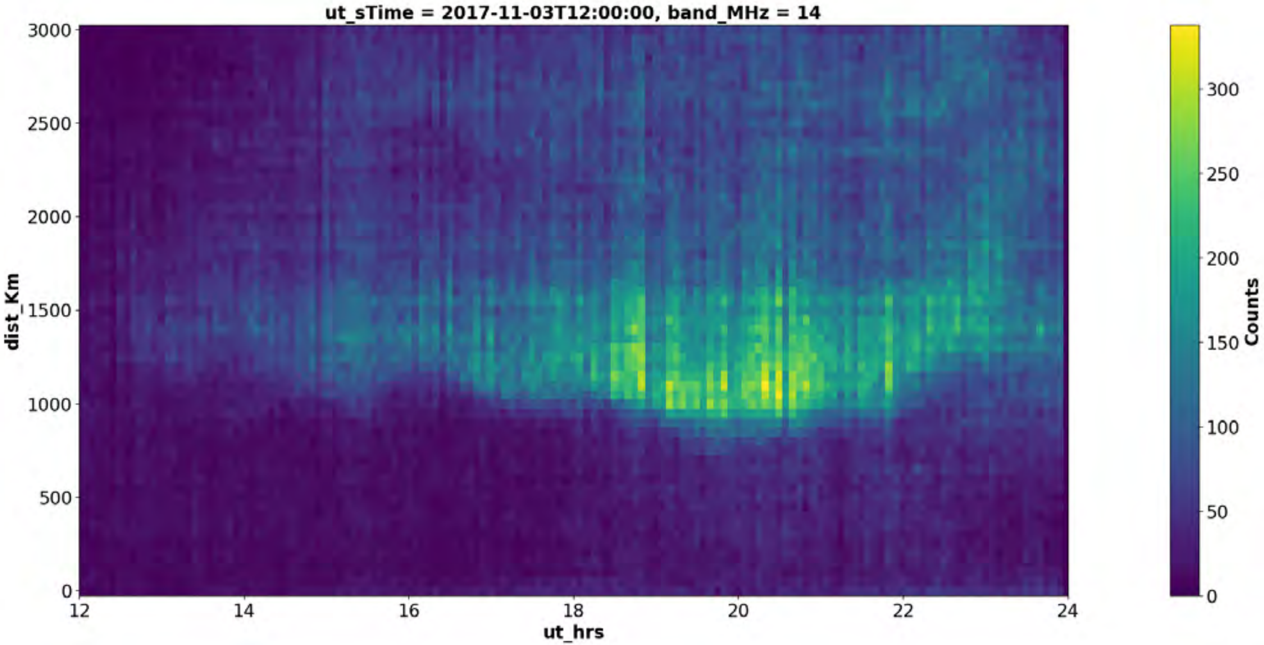
November 3, 2017

20171103.1200-20171104.0000_timeseries.png



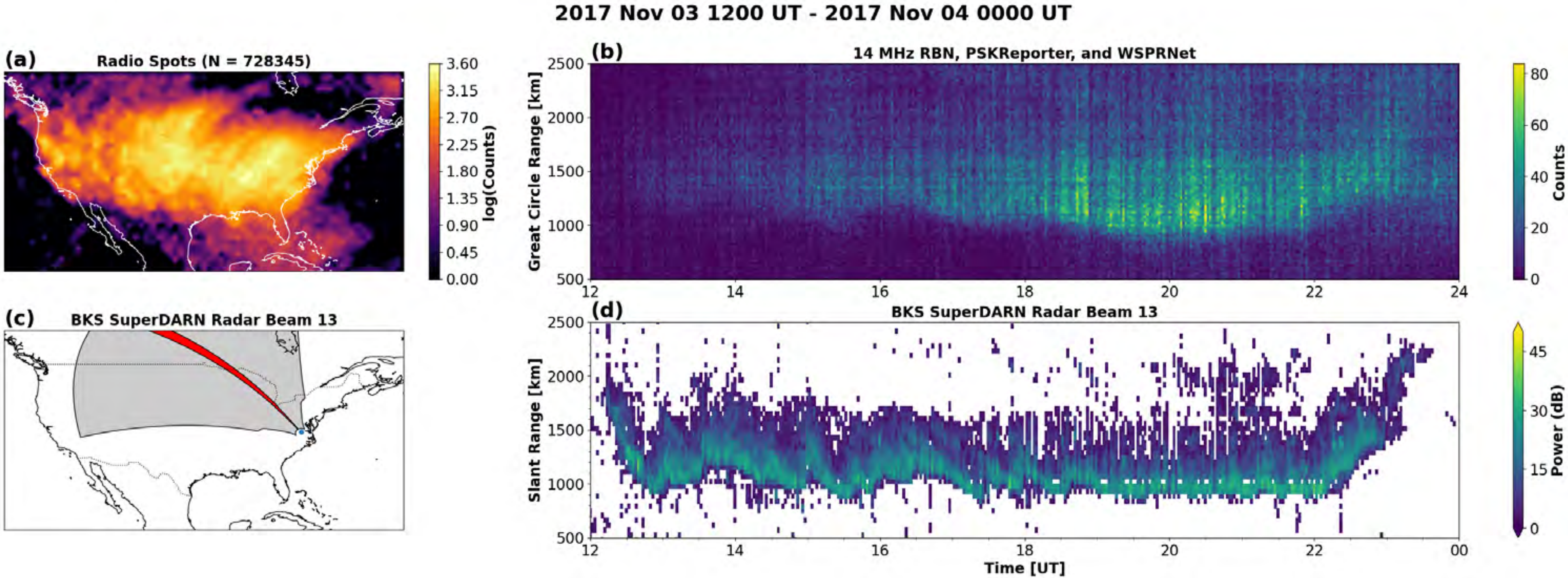
Radio Spots (N = 728345)

(1°x1° bins)



(5 min x 50 km bins)

November 3, 2017



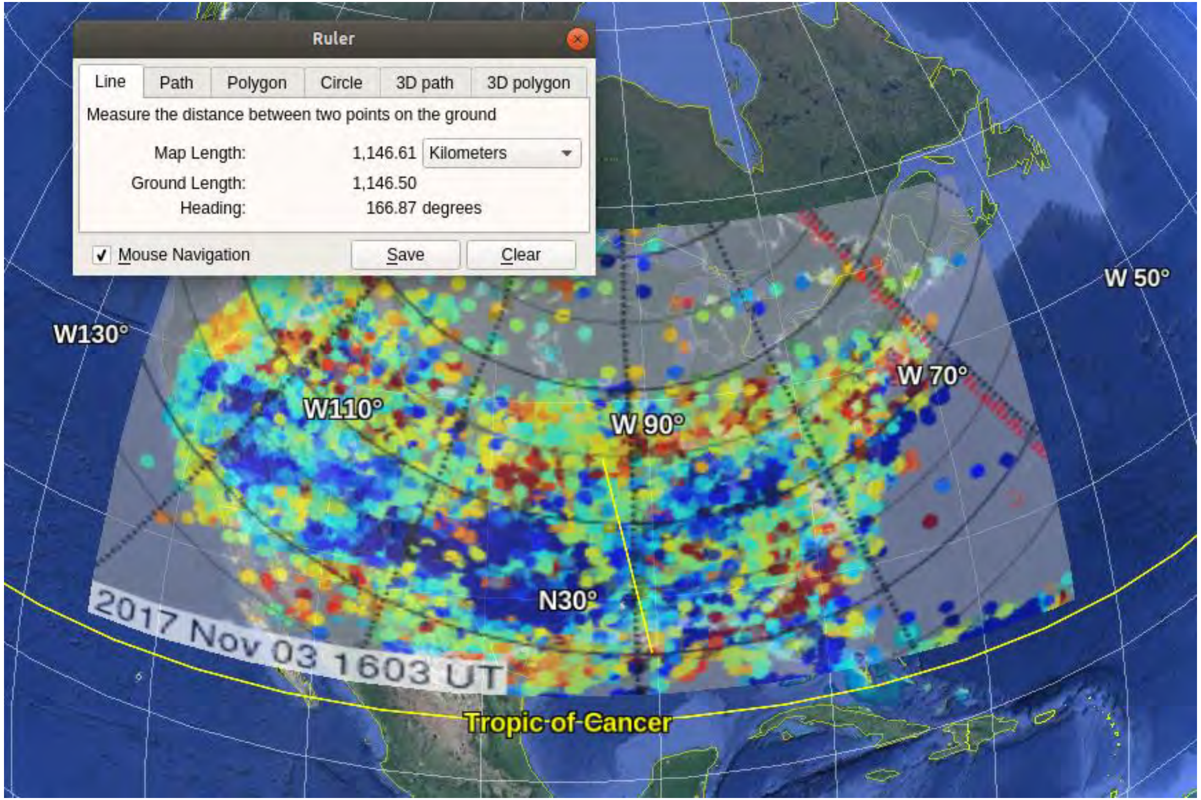
Estimated GNSS TEC LSTID Parameters

$\lambda_h \approx$ 1,100 km

$v_p \approx$ 950 km/hr

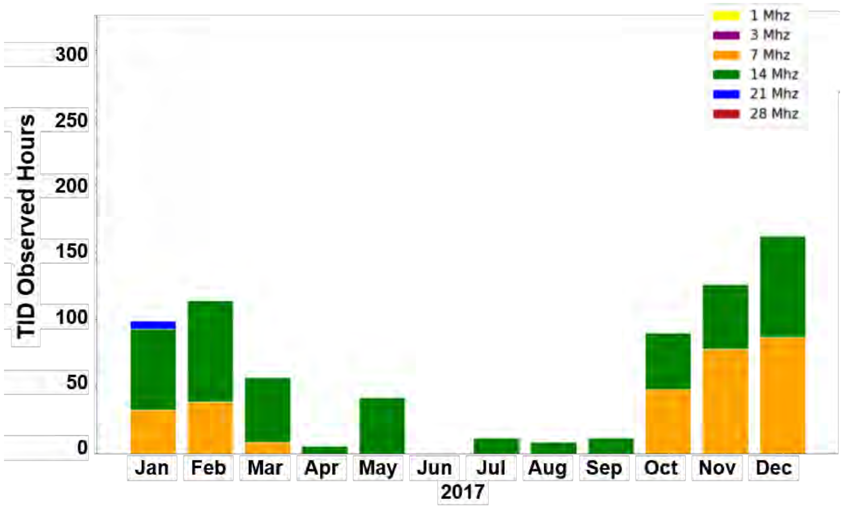
$T \approx$ 70 min

$\Phi_{Azm} \approx 135°$



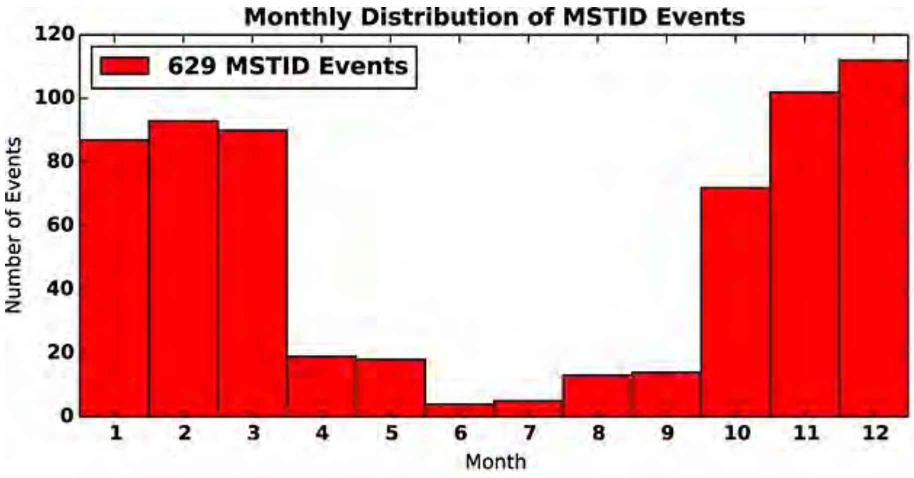
Comparison with SuperDARN MSTID Statistics

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 **S**cience **C**itizen **I**nvestigation

hamsci.org/dayton2017

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

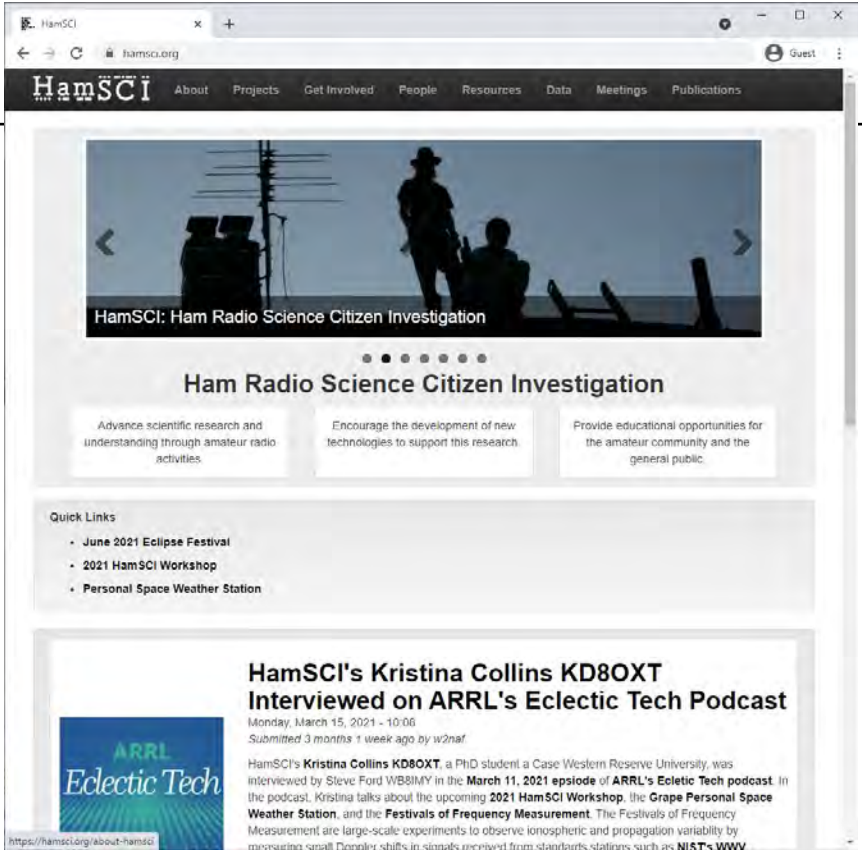
A collective that allows university researchers to collaborate with the amateur radio community in scientific investigations.

Objectives:

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

HamSCI Activities

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



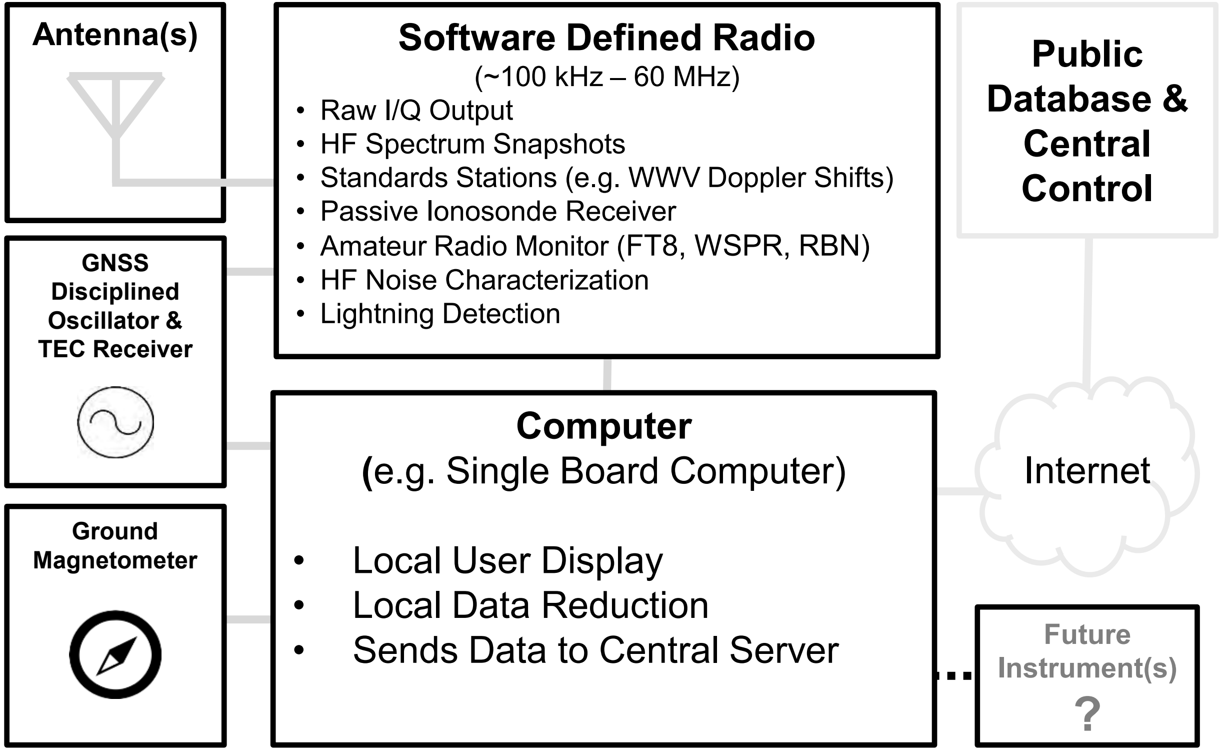
Join us at *https://hamsci.org*

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

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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

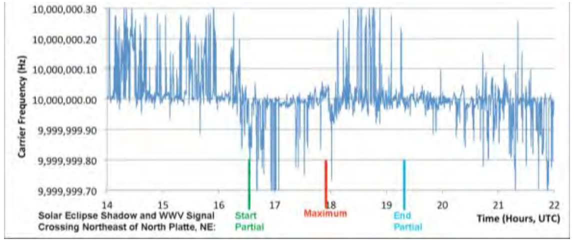
New Jersey Institute of Technology
- **Hyomin Kim KD2MCR (PI)**
- Gareth Perry KD2SAK
- Andy Gerrard KD2MCQ

Responsibilities
- Ground Mag Oversight & Testing
- Science Collaborators

Low-Cost "Grape" PSWS

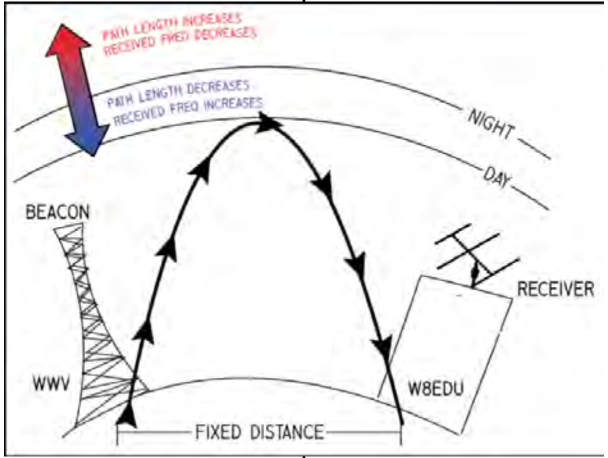
- HF "Doppler Shift" Monitoring
- Main components: Raspberry PI, GPSDO, Custom Direct-conversion receiver board
- Cost: ~$100 to $200
- Developed by Case Western

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



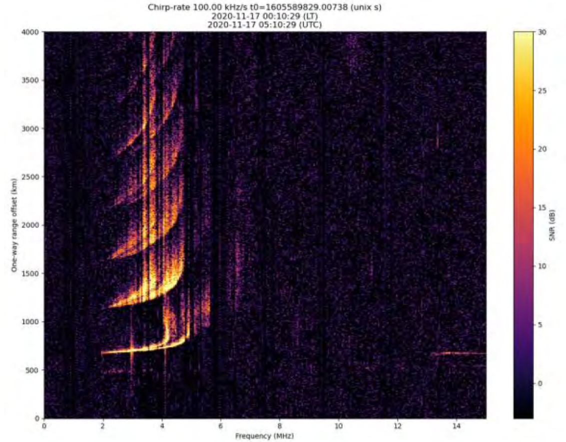
SDR-Based "Tangerine"

- 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

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.

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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

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Thank You!

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Acknowledgments

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- 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).

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