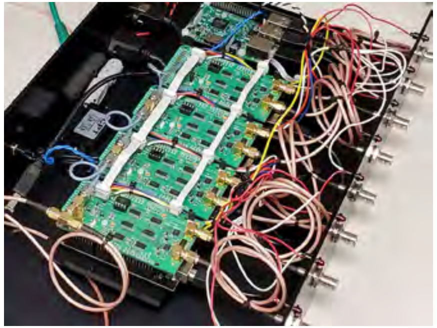
HamSCI:
The Ionosphere from Your Backyard

Nathaniel A. Frissell, W2NAF
The University of Scranton

Sterling Park Amateur Radio Club
September 2, 2020

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

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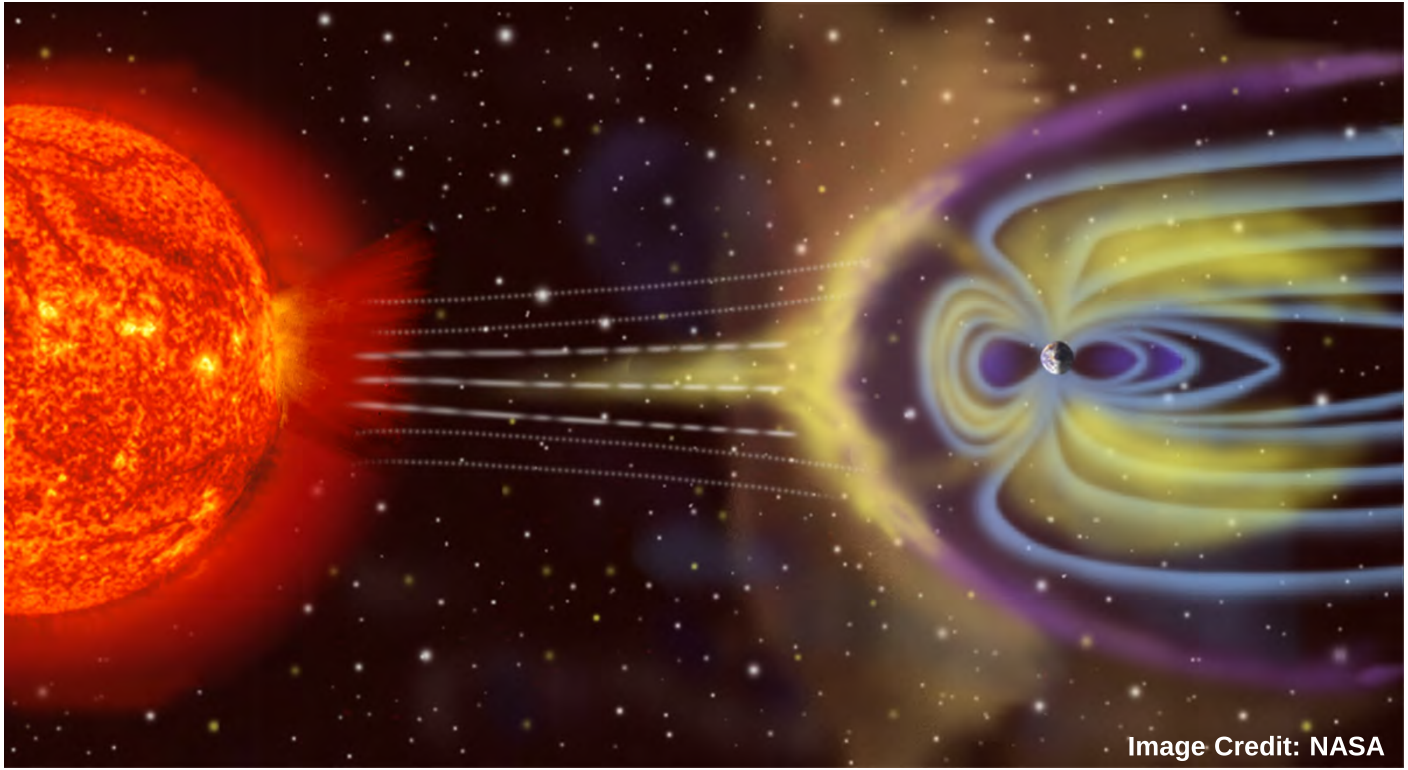
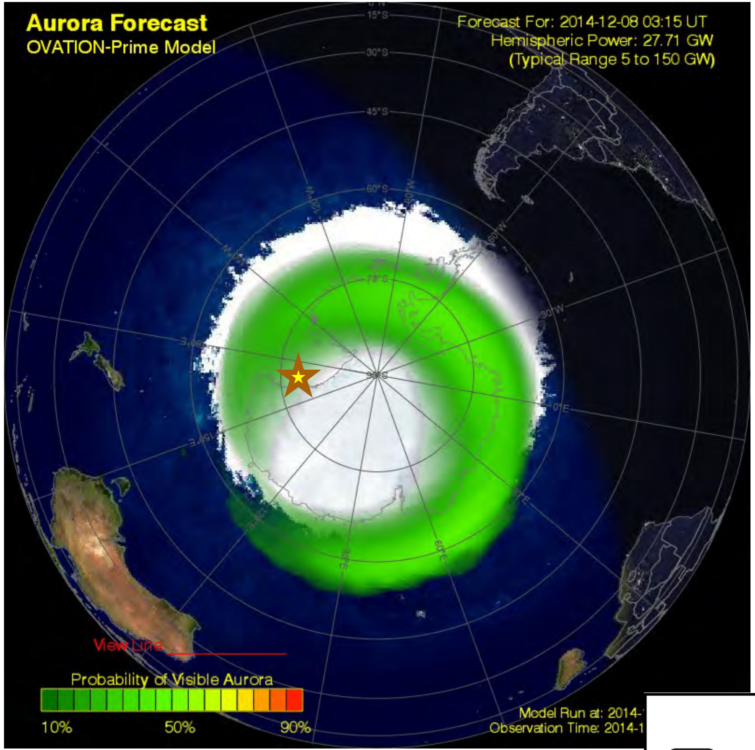
Hams & Space Weather



Space Weather and Ham Radio



20141227 0746 UT Aurora @ KC4USV 14010 kHz

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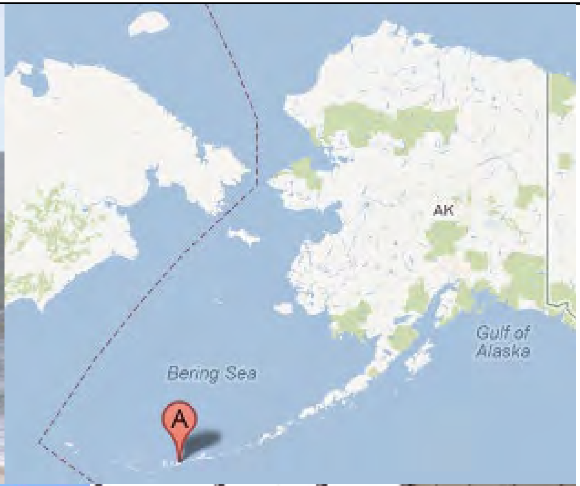
Adak Island SuperDARN/DXPedition



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:

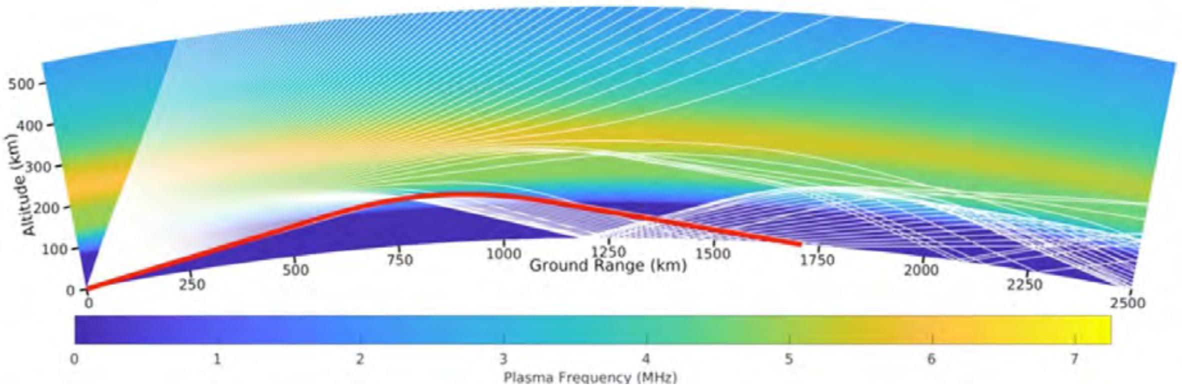
1. **Advance** scientific research and understanding through amateur radio activities.
2. **Encourage** the development of new technologies to support this research.
3. **Provide** educational opportunities for the amateur radio community and the general public.

Large citizen science community organized through e-mail lists, regular telecons, and the annual HamSCI workshop. See https://hamsci.org/get-involved.

Amateur Radio Frequencies and Modes

Eclipsed SAMI3 - PHaRLAP Raytrace

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

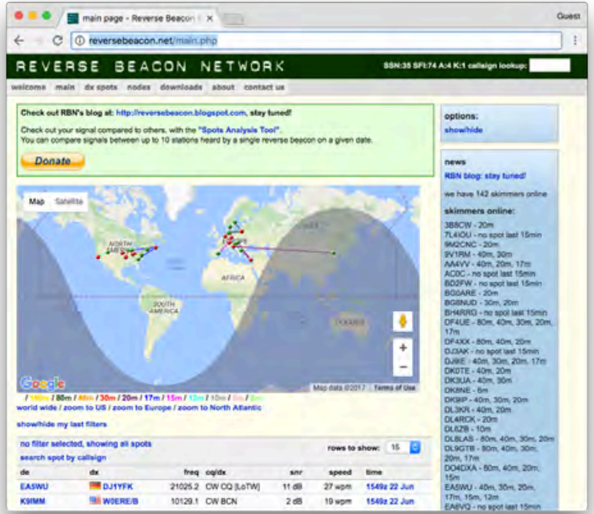


PHaRLAP: Cervera & Harris, 2014, https://doi.org/10.1002/2013JA019247
SAMI3: Huba & Drob, 2017, https://doi.org/10.1002/2017GL073549

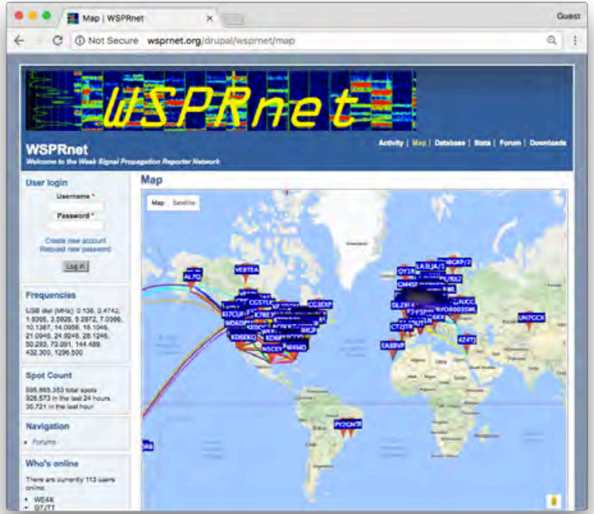
- **Amateurs routinely use HF-VHF transionospheric links.**
- **Often ~100 W into dipole, vertical, or small beam antennas.**
- **Common HF Modes**
  - Data: FT8, PSK31, WSPR, RTTY
  - Morse Code / Continuous Wave (CW)
  - Voice: Single Sideband (SSB)

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

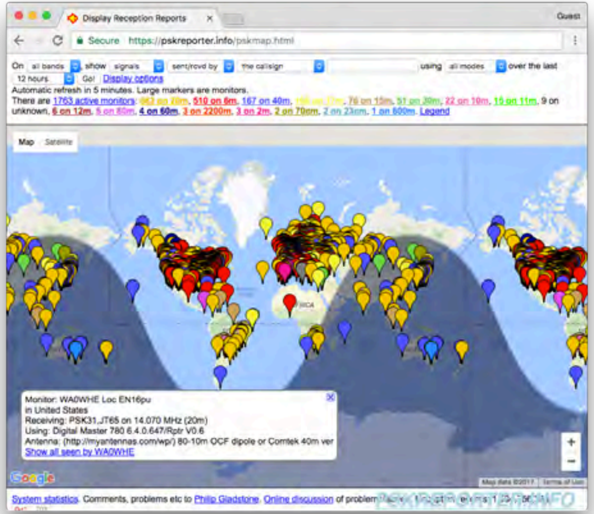
Current Amateur Radio Observation Networks



Reverse Beacon Network (RBN)
reversebeacon.net



WSPRNet
wsprnet.org

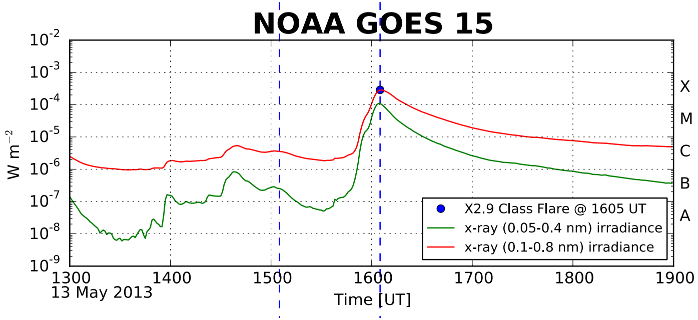


PSKReporter
pskreporter.info

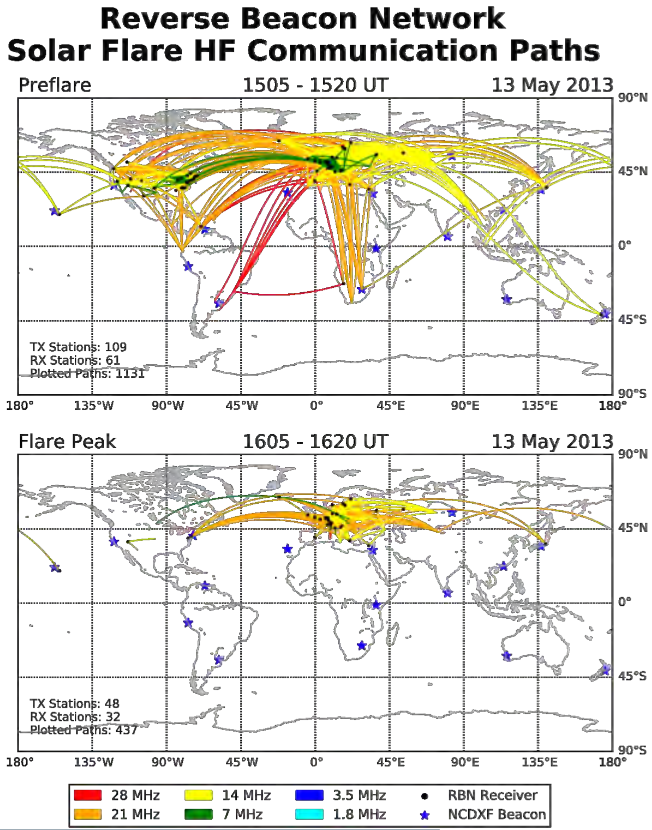
- Quasi-Global
- Organic/Amateur Radio Run
- Unique & Quasi-random geospatial sampling

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

RBN/PSKReporter/WSPRNet RX

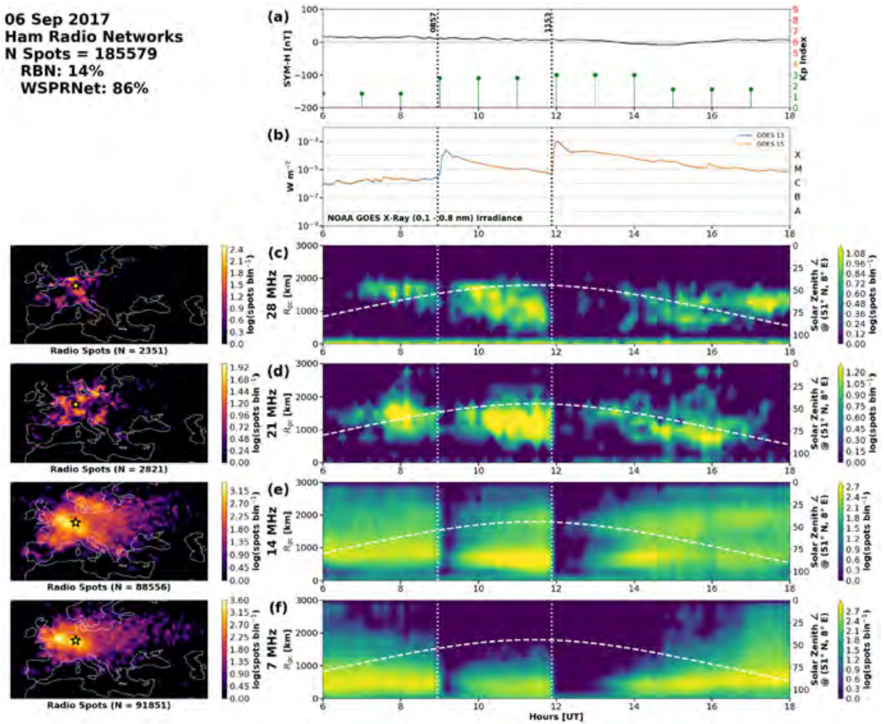


[*Frissell et al.*, 2014, *Space Weather*]



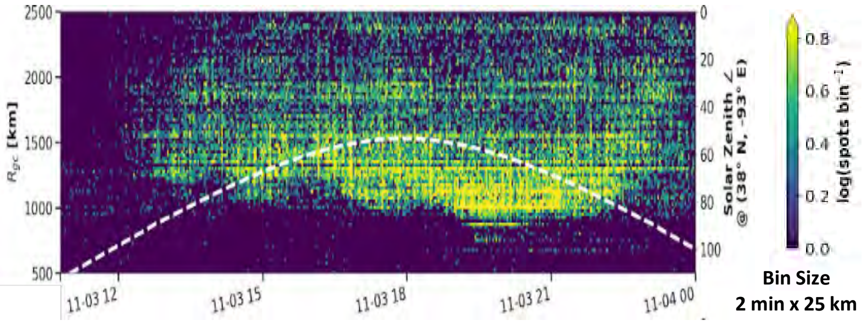
Examples of Amateur Radio Research

HF Amateur Radio Response to Solar Flares



[*Frissell et al.*, 2019, https://doi.org/10.1029/2018SW002008]

HF Amateur Radio (RBN & WSPR) TID Observations



Bin Size
2 min x 25 km

$\lambda_h \approx$ 1,100 km
$v_p \approx$ 950 km/hr
$T \approx$ 70 min
$\Phi_{Azm} \approx$ 135°

TEC Courtesy of
A. Costar /
MIT Haystack

2017 Total Solar Eclipse

21 August 2017

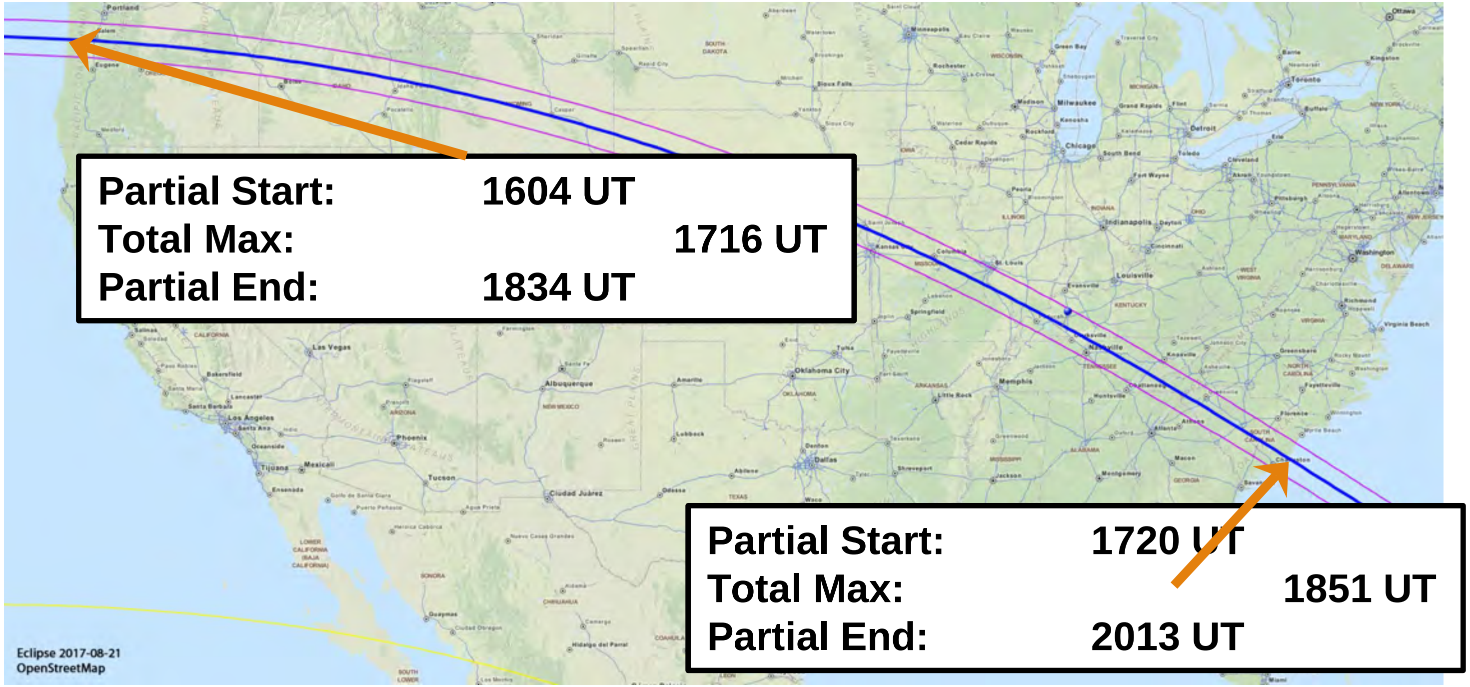


Figure: W. Strickling, Wikipedia

HamSCI Eclipse Research Questions

- Can we use HF ham radio communications to observe eclipse effects on the ionosphere?
- Can we use data-model comparisons to:
  - Better understand the ham radio data?
  - Constrain or calibrate the model?

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Solar Eclipse QSO Party (SEQP)

- **August 21, 2017 from 1400 – 2200 UT**
- **Contest-like**
  - 2 Points CW or Digital
  - 1 Point for Phone
  - Multiply Score by # of Grids
- **Exchange**
  - RST + 6 Character Grid Square
- **Data sources**
  - Reverse Beacon Network
  - PSKReporter
  - WSPRNet
  - Participant-submitted logs

SEQP

http://hamsci.org/seqp

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Solar Eclipse QSO Party

- 570 parsed logs
- 29,809 QSOs
- 4,929 unique callsigns
- 649 4-char grid squares
- 80 DX Entities

(from logs submitted to hamsci.org)

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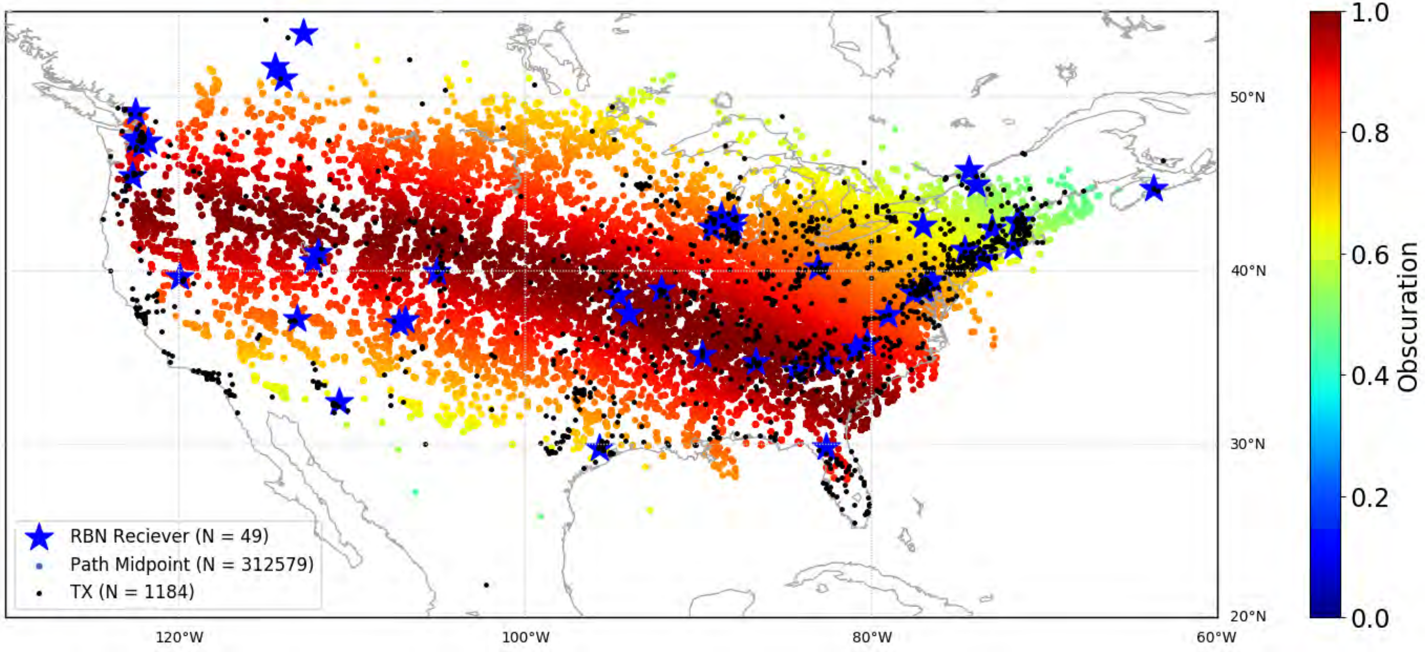
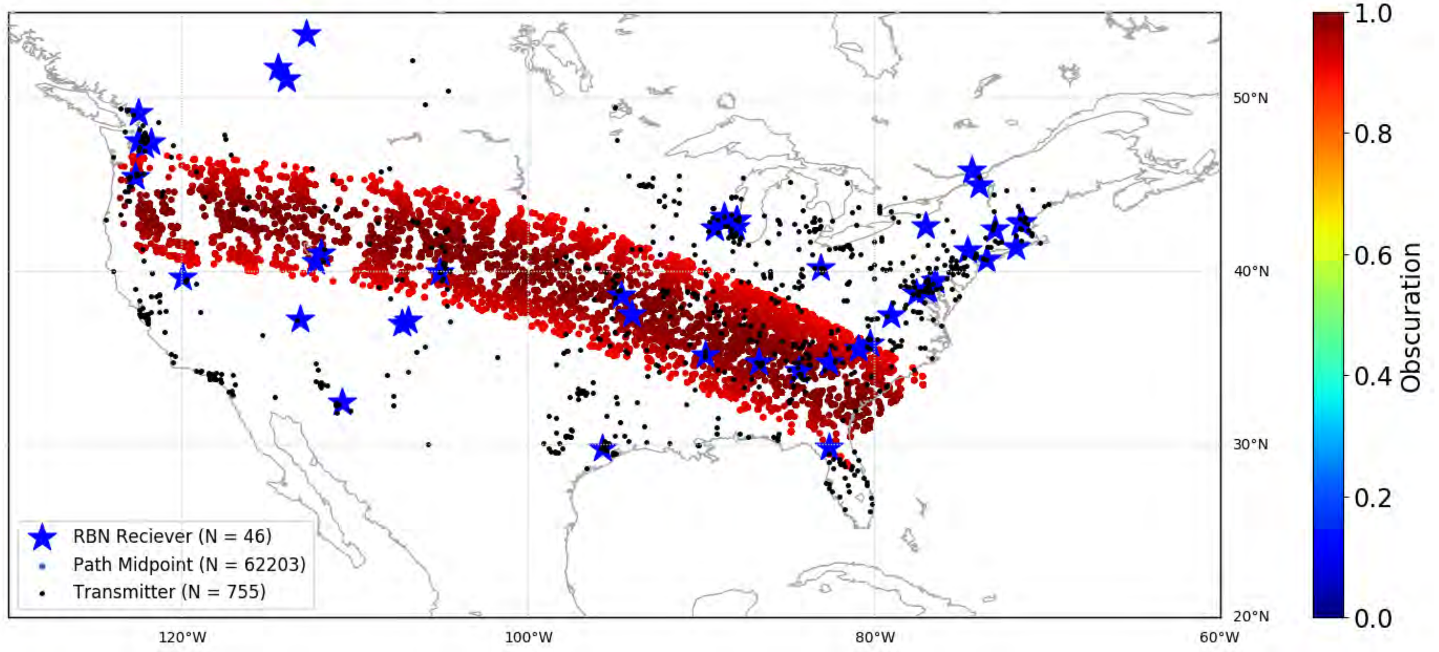
SEQP RBN Observations



[Frissell et al., 2018]

SEQP RBN ($O_{300} \geq 0.9$)



[Frissell et al., 2018]

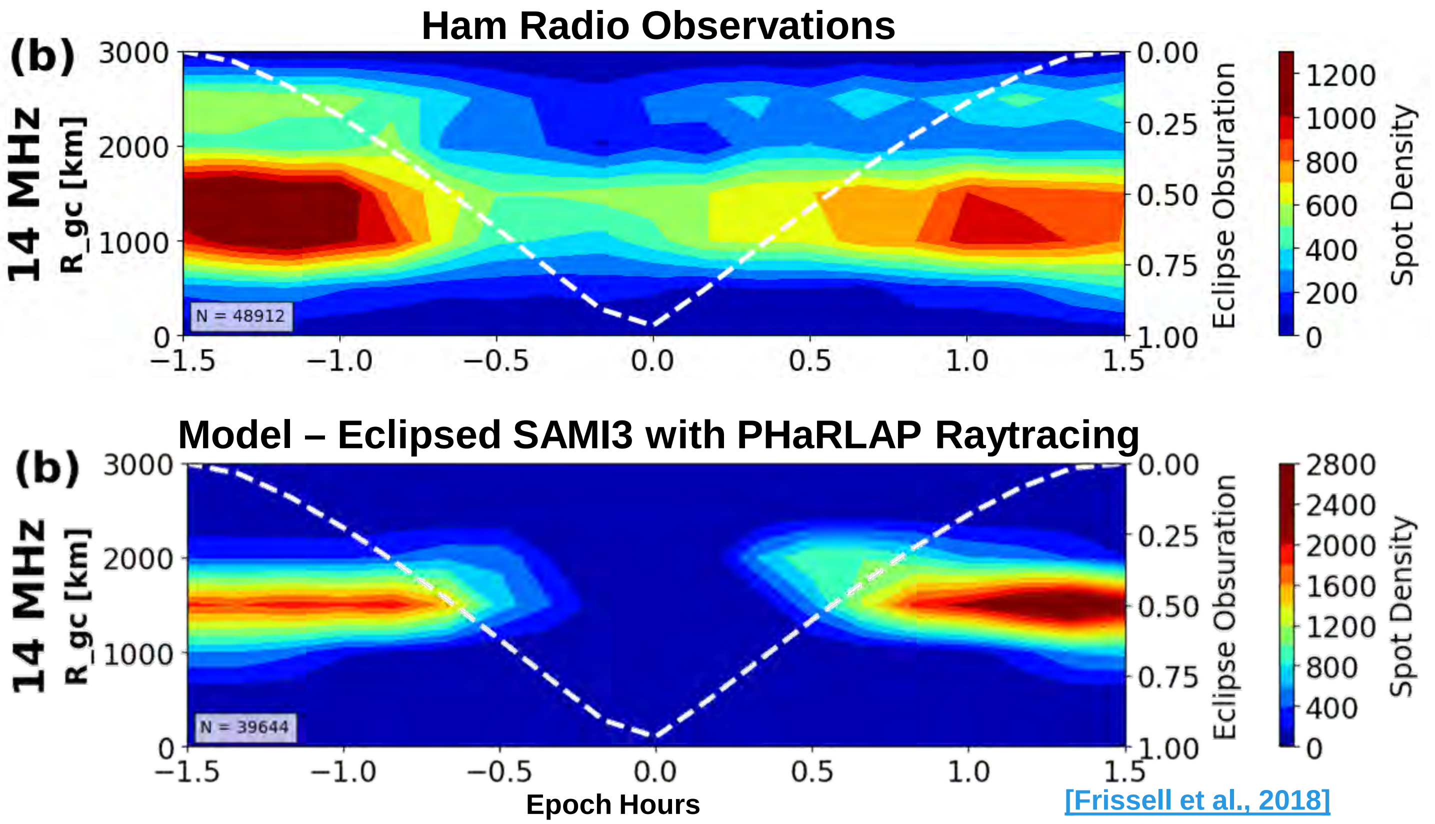
SAMI3-PHaRLAP Raytrace

1600 – 2200 UT 14.03 MHz
TX: AA2MF (Florida) RX: WE9V (Wisconsin)

Non-Eclipsed

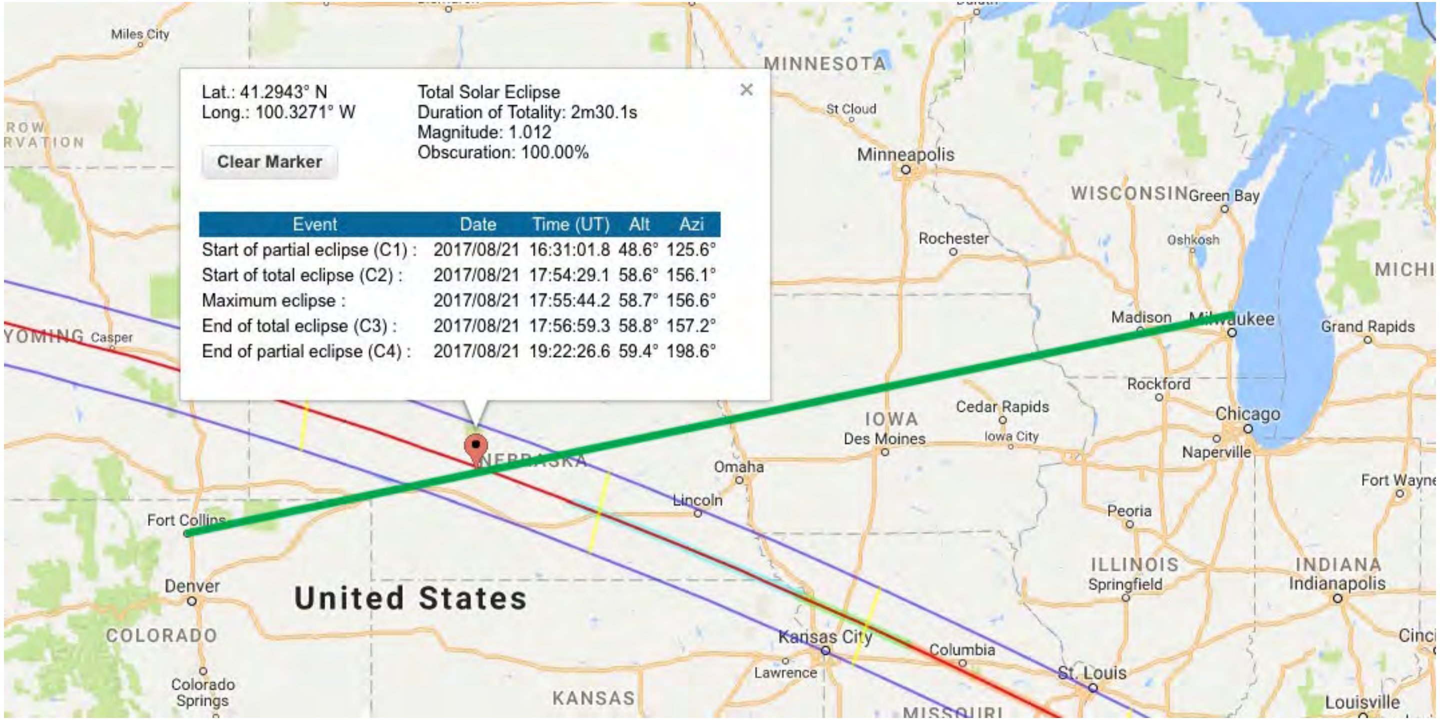
Eclipsed

14 MHz SEQP RBN ($O_{300} \geq 0.9$)

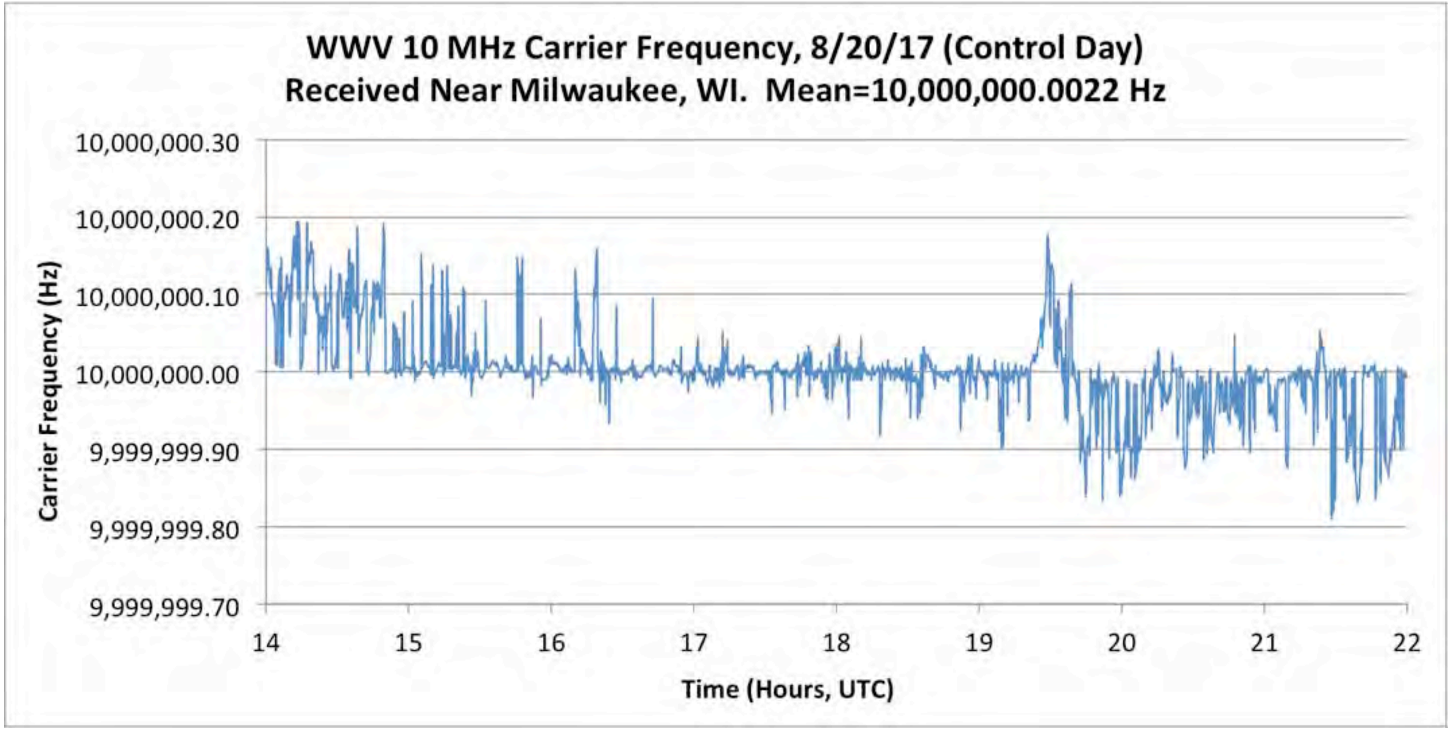


[Frissell et al., 2018]

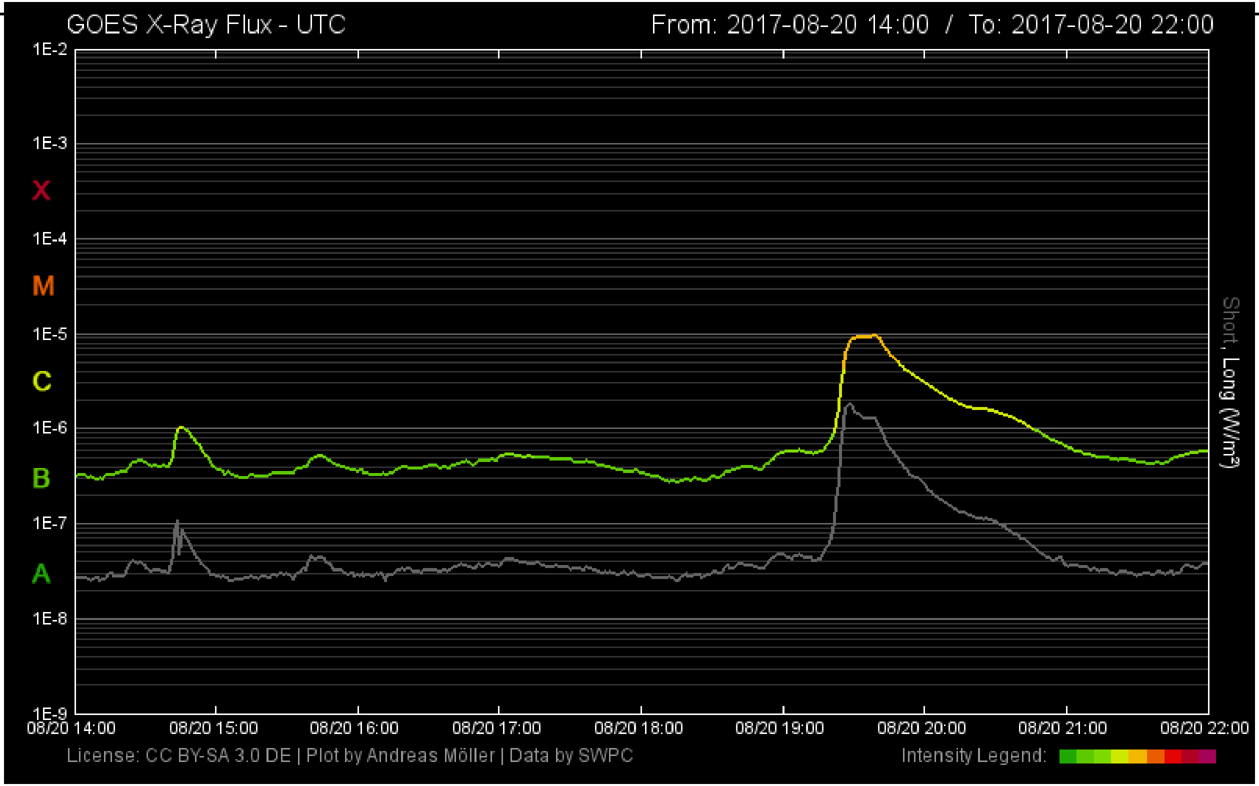
WA9VNJ 10MHz WWV Observations



WA9VNJ 10MHz WWV Observations



GOES X-Ray Flux – Control Day



http://www.polarlicht-vorhersage.de/goes_archive

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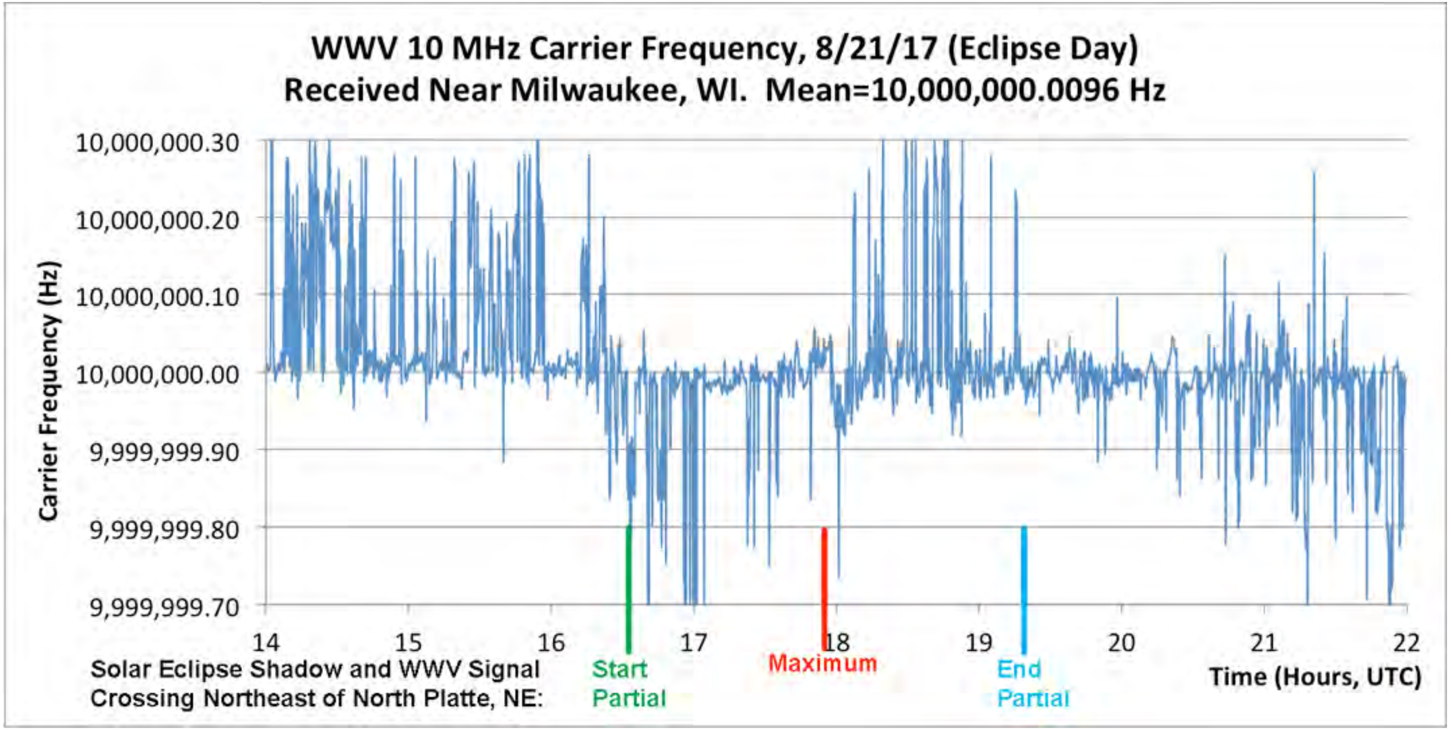
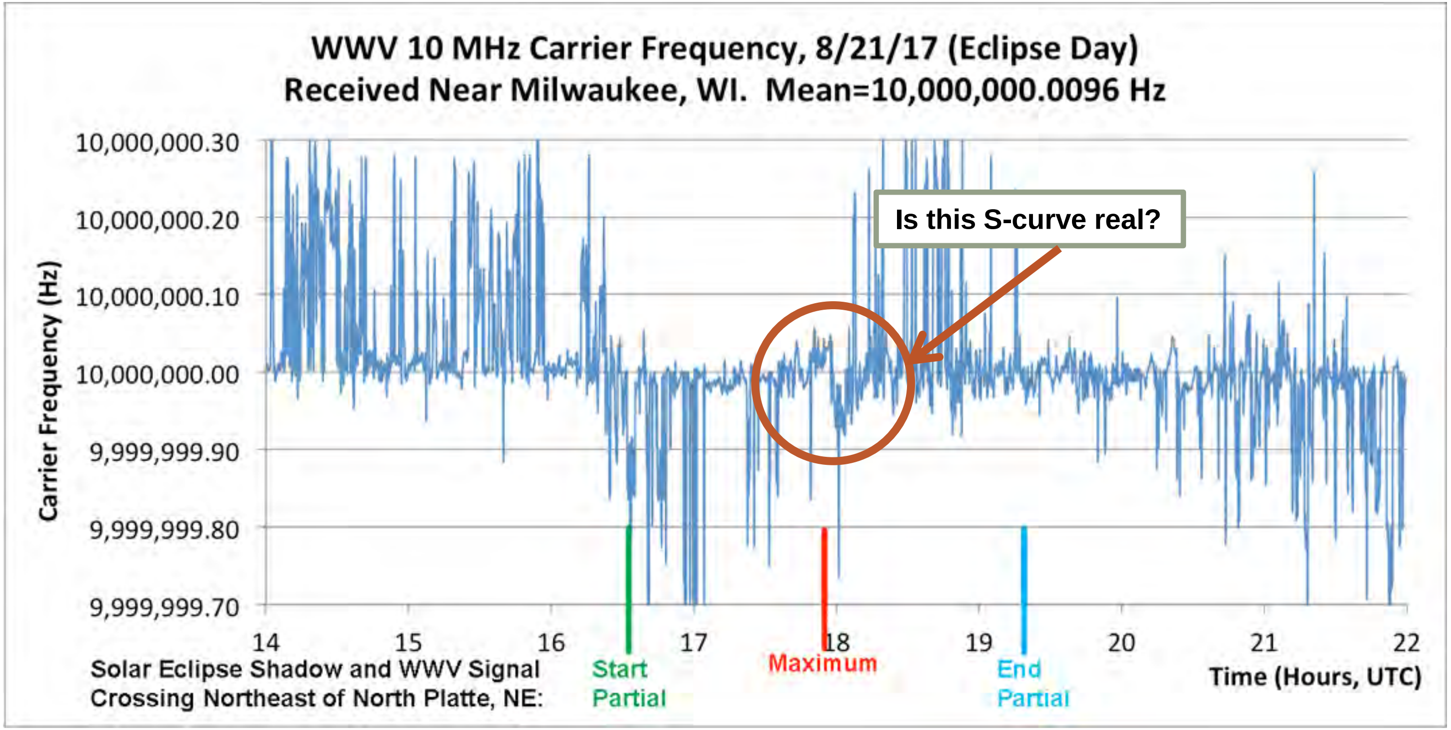
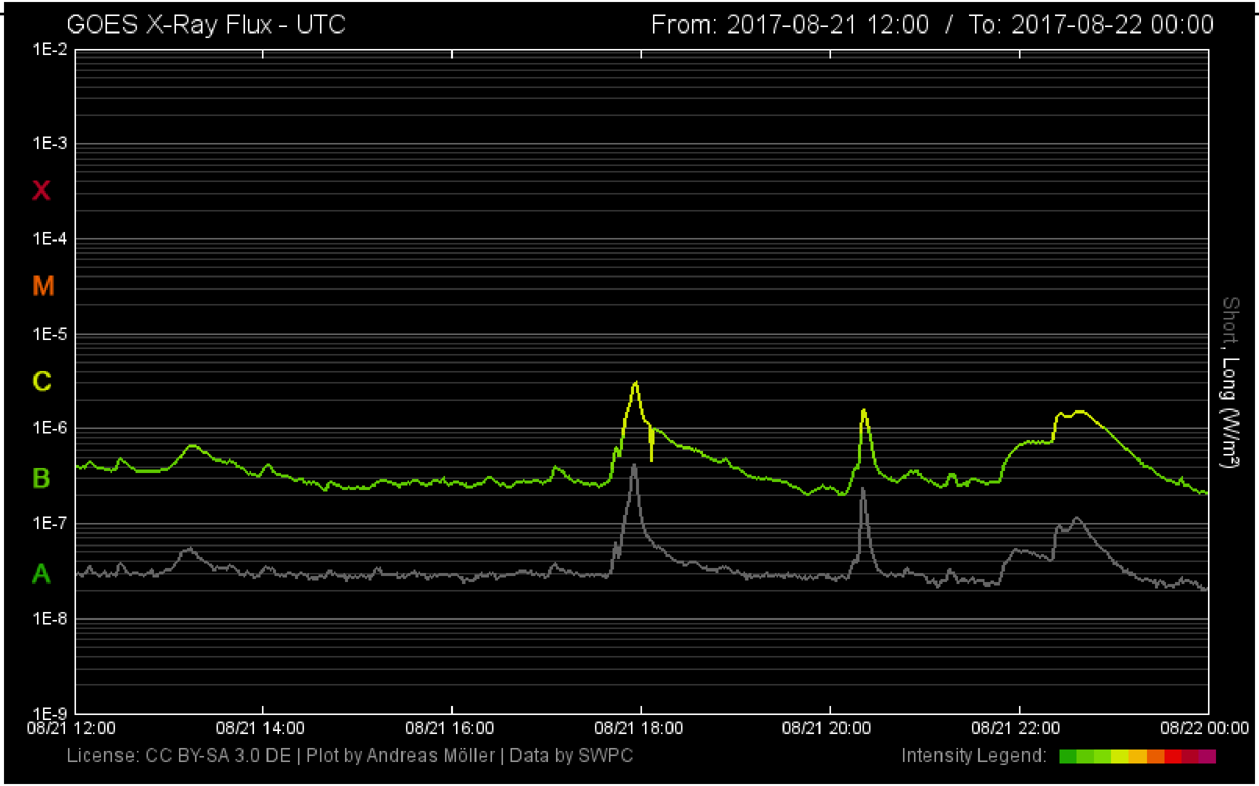
WA9VNJ 10MHz WWV Observations



WA9VNJ 10MHz WWV Observations



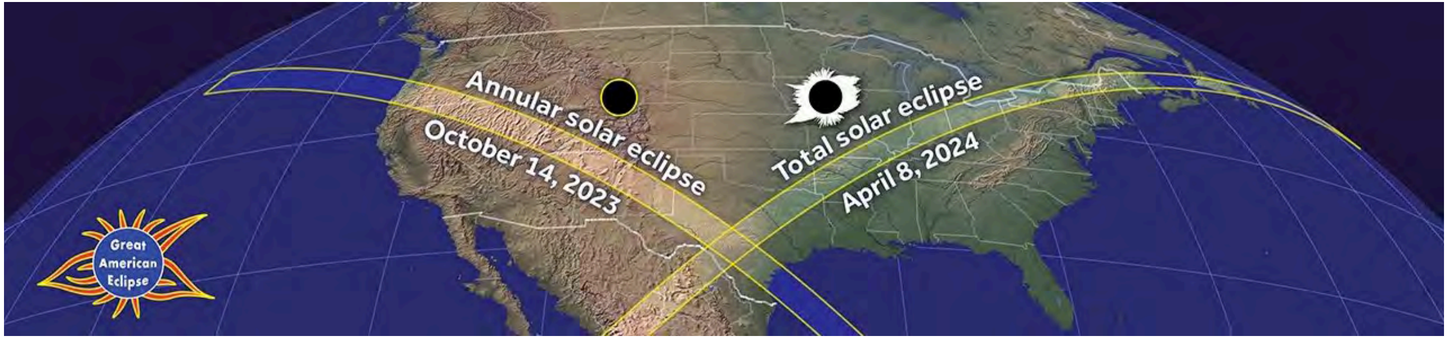
GOES X-Ray Flux



http://www.polarlicht-vorhersage.de/goes_archive

Eclipses 2023 and 2024

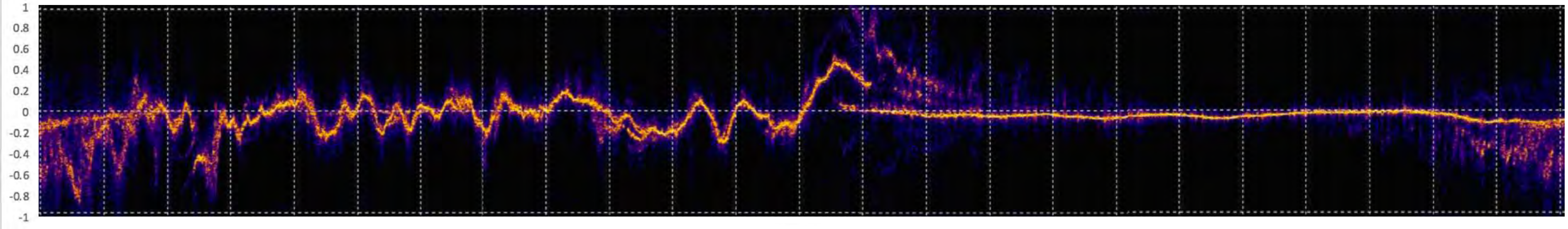
- Eclipses in 2023 and 2024 are great targets for the Personal Space Weather Station
- Example Science Goal
  - Look for TID wave signatures in both GPS-TEC and the HF receiver?



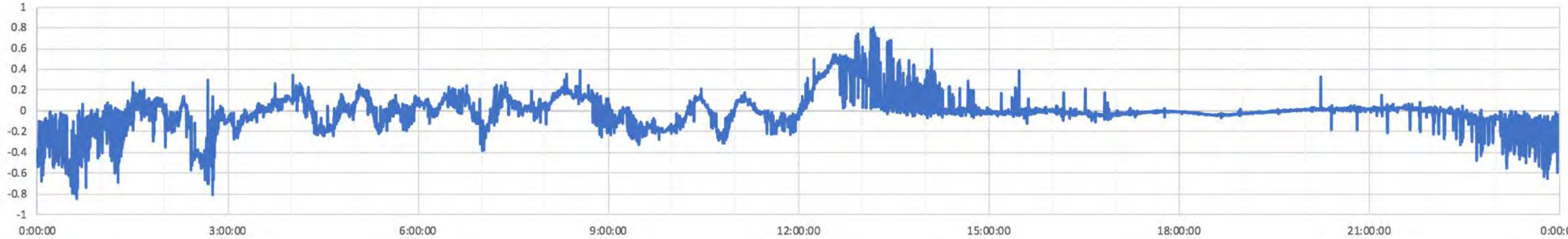
[https://www.greatamericaneclipse.com/]

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

Can we do better?

- This is all great, but ham radio receiver networks weren’t designed for science.
- What if we could create a network of Personal Space Weather Stations that were designed for both science (and ham radio!) from the ground up?
- That is the idea behind the HamSCI Personal Space Weather Station project.

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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.
- The PSWS is being developed as a collaborative project under the **Ham Radio Science Citizen Investigation (HamSCI)** collective, led by the University of Scranton with collaborators at Case Western Reserve University, the New Jersey Institute of Technology (NJIT), the University of Alabama, the MIT Haystack Observatory, **TAPR**, and volunteers from additional universities and the amateur radio community.

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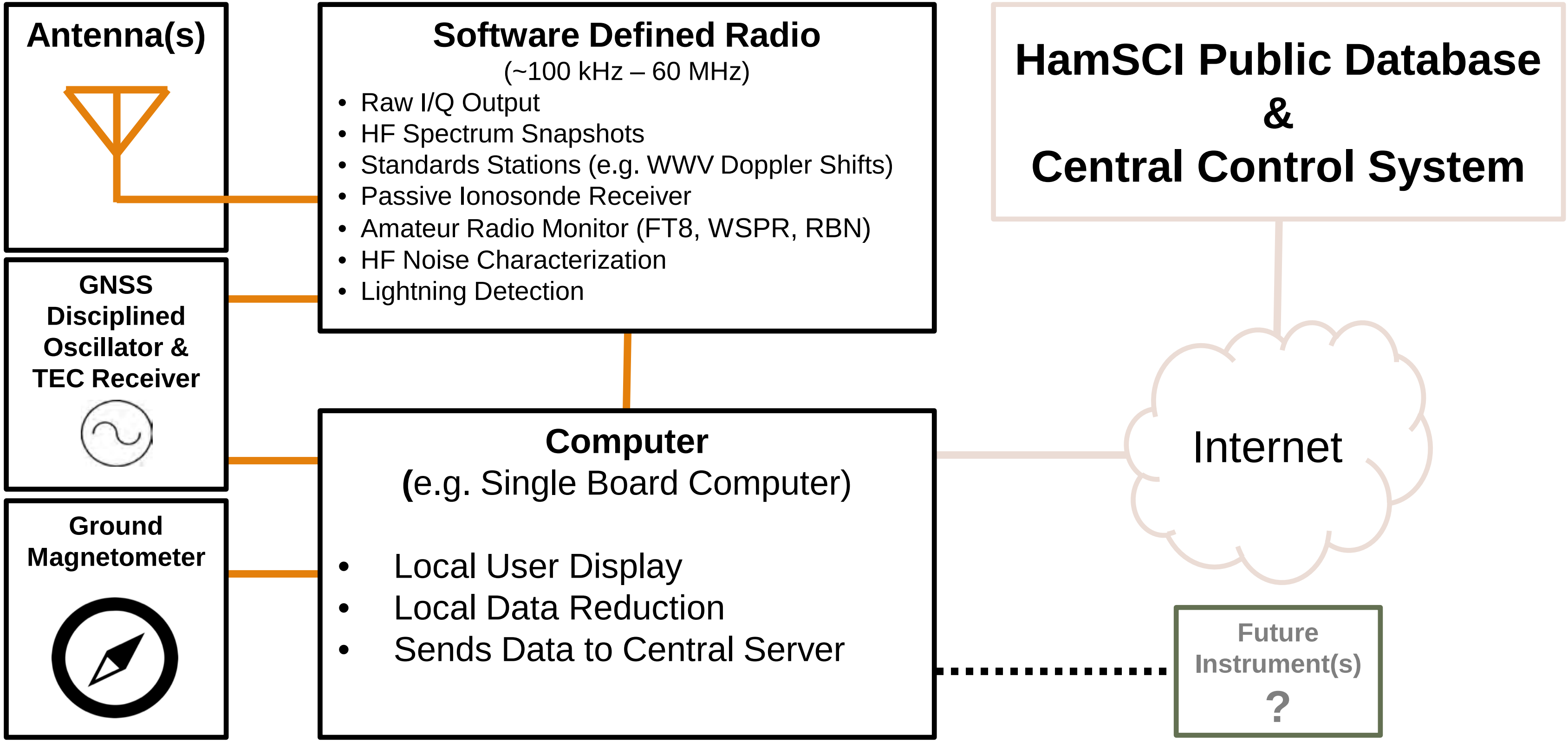
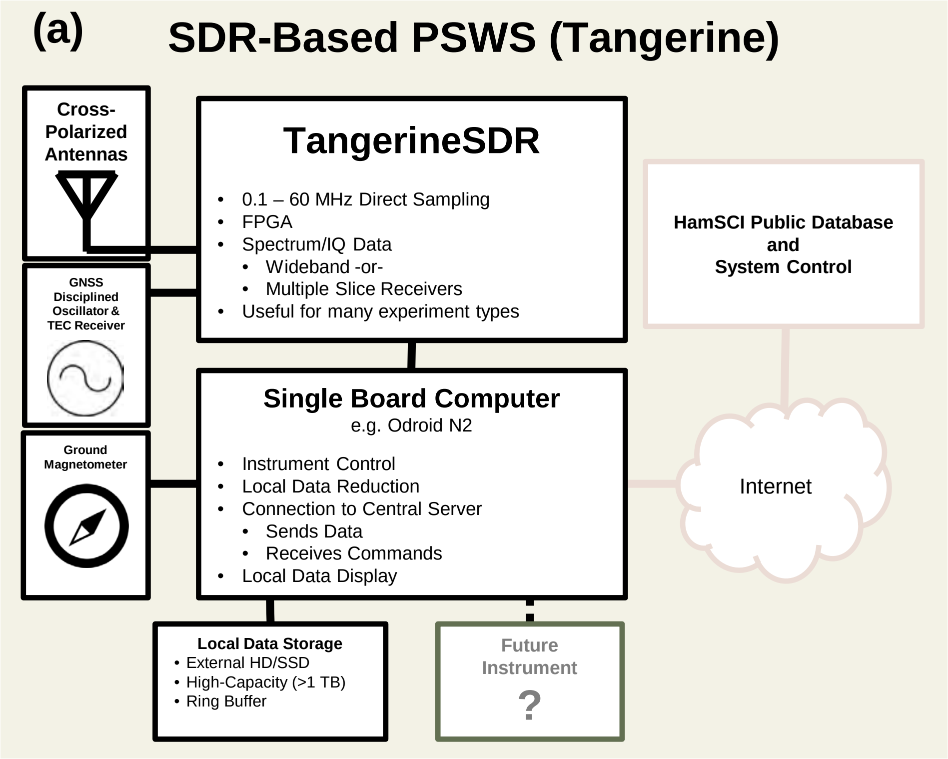
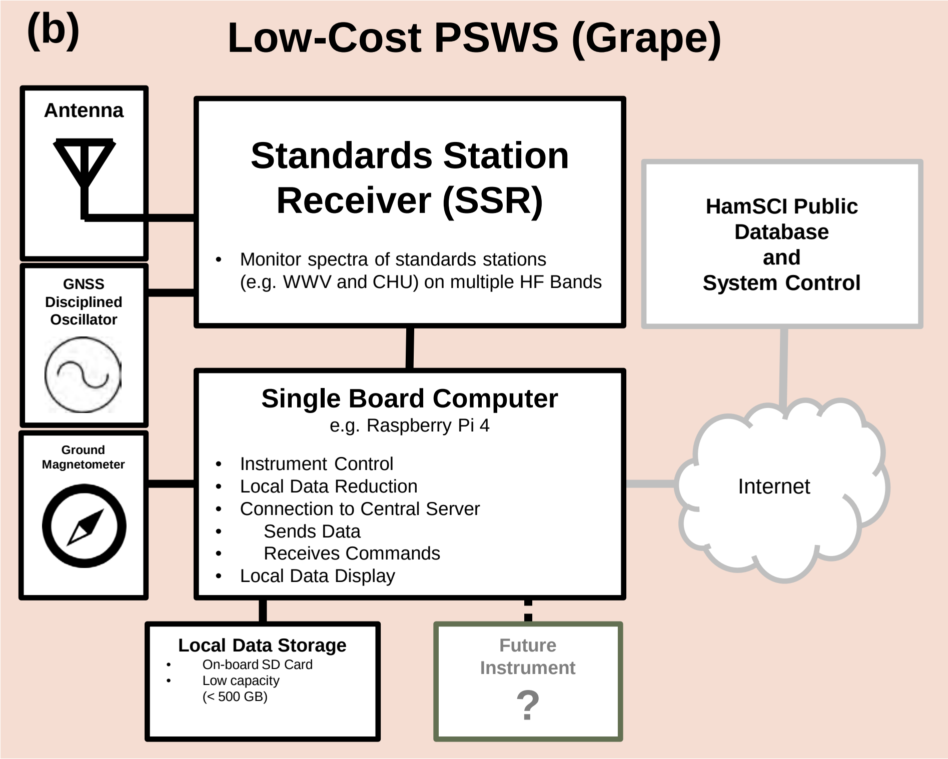
What makes up a PSWS?



SDR-Based and Low-Cost PSWS Versions





PSWS Teams

University of Scranton

- **Nathaniel Frissell W2NAF (PI)**
- Dev Joshi KC3PVE(Post-Doc)
- Jonathan Rizzo KC3EEY
- Veronica Romanek KD2UHN

Responsibilities

- Lead Institution
- HamSCI Lead
- Radio Science Lead

TAPR & Zephyr Engineering

- **Scotty Cowling WA2DFI (Chief Architect)**
- Tom McDermott (RF Board)
- John Ackerman N8UR (Clock Module)
- David Witten KD0EAG (Magnetometer)
- Jules Madey K2KGJ (Magnetometer)
- David Larsen KV0S (Website)

Responsibilities

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

University of Alabama

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

Responsibilities

- Central Database
- Central Control Software
- Local Control Software

Case Western Reserve University
Case Amateur Radio Club W8EDU

- **David Kazdan AD8Y (Lead)**
- Kristina Collins KD8OXT
- John Gibbons N8OBJ
- Rob Wiesler AC8YV
- Soumyajit Mandal (PI)
- Matt McConnell KC8AWM
- Skylar Dannhoff KD9JPX
- Aidan Montare KB3UMD

Responsibilities

- Low Cost PSWS System

MIT Haystack Observatory

- **Phil Erickson W1PJE**

Responsibilities

- Science Collaborator

New Jersey Institute of Technology

- **Hyomin Kim KD2MCR (PI)**
- Gareth Perry KD2SAK
- Andy Gerrard KD2MCQ
- Diego Sanchez KD2RLM

Responsibilities

- Ground Mag Oversight & Testing
- Science Collaborators

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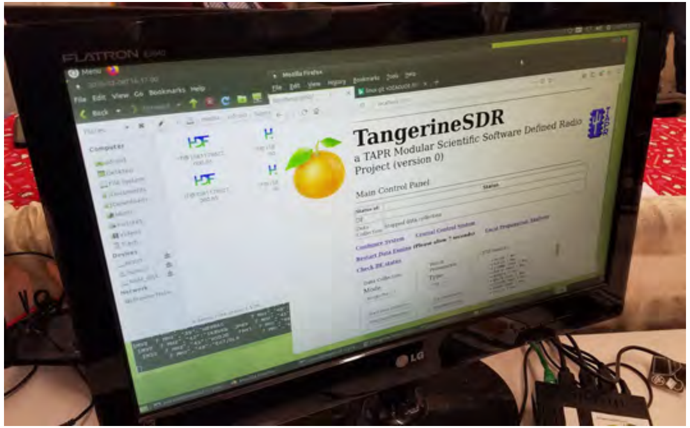
PSWS Control Software and Database

Developed by University of Alabama

Primary objective

- Local Control Software for Tangerine SDR
- Central Control System for PSWS Network
- Central Database to collect observations



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

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

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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.

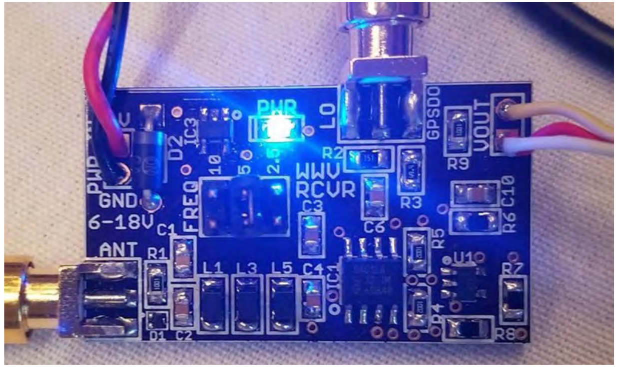
Planned Testing

- 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

Summary

- HamSCI is a collective that aims to bring together the amateur radio and professional space science research communities for mutual benefit.
- Peer-reviewed studies of ionospheric effects generated by solar flares, solar eclipses, and geomagnetic storms using data from propagation observation networks created and run by the amateur radio community have already been published.
- 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 $100 - $1000, depending on capabilities.

TAPR DCC – Next week!!!

https://tapr.org/conferences/

Acknowledgements

The authors gratefully acknowledge the support of NSF Grant 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), 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. The results in this presentation include those obtained using the HF propagation toolbox, PHaRLAP, created by Dr Manuel Cervera, Defence Science and Technology Group, Australia (manuel.cervera@dsto.defence.gov.au). This toolbox is available from https://www.dst.defence.gov.au/opportunity/pharlap-provision-high-frequency-raytracing-laboratory-propagation-studies. 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!

This project is supported by NSF Grants AGS-2002278, AGS-1932997, and AGS-1932972, and many volunteers in the amateur radio community.

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