HamSCI Distributed Array of Small Instruments Personal Space Weather Station (DASI-PSWS): Architecture and Current Status

N. A. Frissell[1], D. Joshi[1], K. Collins[2], A. Montare[2], D. Kazdan[2], J. Gibbons[2], S. Mandal[3], W. Engelke[4], T. Atkison[4], H. Kim[5], A. J. Gerrard[5], J. S. Vega[5], S. H. Cowling[6], T. C. McDermott[6], J. Ackermann[6], D. Witten[6], H. W. Silver[7], W. Liles[7], S. Cerwin[7], P. J. Erickson[8], E. S. Miller[7,9]

[1]The University of Scranton
[2]Case Western Reserve University
[3]University of Florida
[4]University of Alabama
[5]New Jersey Institute of Technology

[6]TAPR
[7]HamSCI
[8]MIT Haystack Observatory
[9]Systems & Technology Research

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.

- In addition, the PSWS design **takes into account the needs of professional researchers** who might want to deploy these devices for their own specific purposes.

- 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.

What is the purpose of the PSWS?

The **PSWS aims to support two primary groups of users, space scientists and amateur radio operators**. Each of these groups have different but related needs:

- **Space Science Researchers**
  - Observe, characterize, and understand ionospheric variability on small temporal and spatial scales
  - Understand coupling between the neutral atmosphere, ionosphere, and magnetosphere
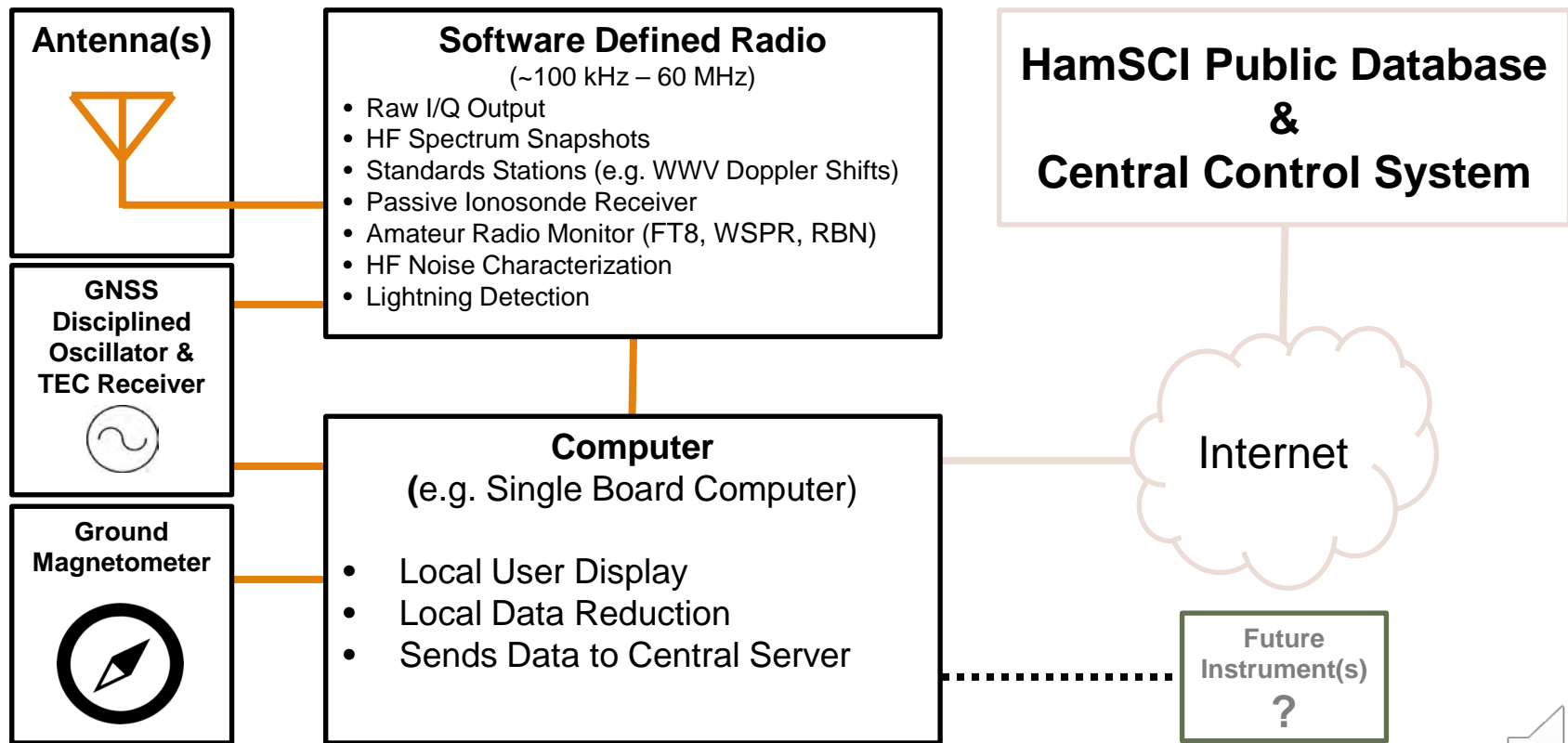 - Validate and improve models with the goals of prediction and understanding

- **Amateur Radio Operators**
  - Understand and predict radio propagation to support amateur radio communications, including public/emergency service operations, contesting, and DX (long distance) communications.
  - Study space weather and propagation for personal edification and to contribute back to science and the radio art.
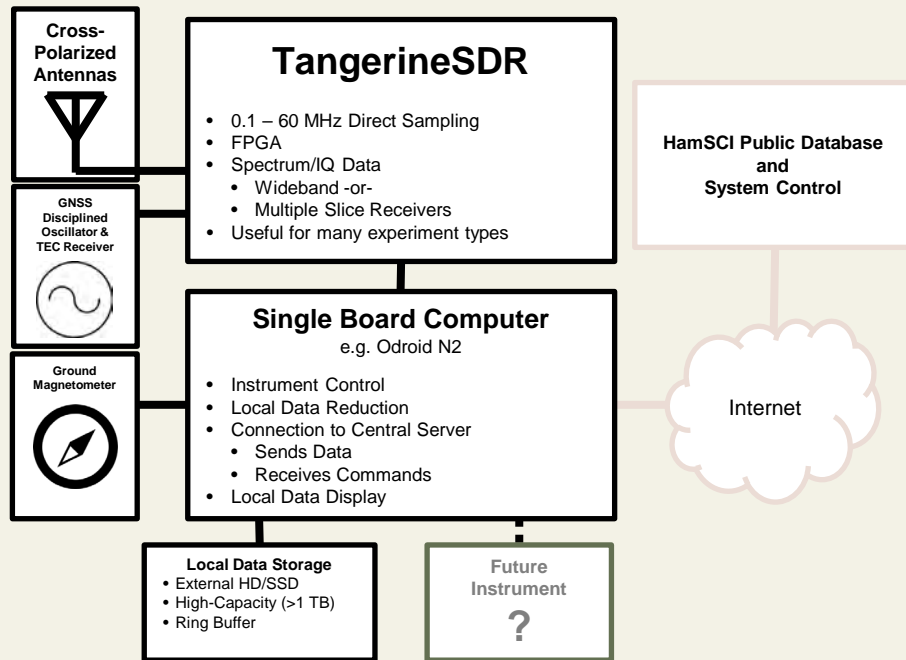
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nathaniel.frissell@scranton.edu

What makes up a PSWS?

Antenna(s)

Software Defined Radio
(~100 kHz – 60 MHz)
- Raw I/Q Output
- HF Spectrum Snapshots
- Standards Stations (e.g. WWV Doppler Shifts)
- Passive Ionosonde Receiver
- Amateur Radio Monitor (FT8, WSPR, RBN)
- HF Noise Characterization
- Lightning Detection

GNSS Disciplined Oscillator & TEC Receiver

Ground Magnetometer

**Computer
(**e.g. Single Board Computer)

- Local User Display
- Local Data Reduction
- Sends Data to Central Server

**HamSCI Public Database
&
Central Control System**

Internet

**Future Instrument(s)
?**

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Where will the PSWSs be deployed?

- Currently, the PSWS is funded on a DASI Track 1 to develop prototypes, rather than deploy a network.

- There is significant interest from the amateur radio community in this project. So, we will be looking to encourage voluntary adoption of these devices by amateurs to create an ad-hoc network.

- The amateur radio community is global, but is heavily weighted towards North America and Europe. Initial adoption will likely be in these regions.

- A number of amateurs at high latitudes (Alaska, Northern Canada, Norway and Svalbard) have also expressed interest in the project.

- Low cost and SDR-based versions of the PSWS are being designed to help maximize adoption.
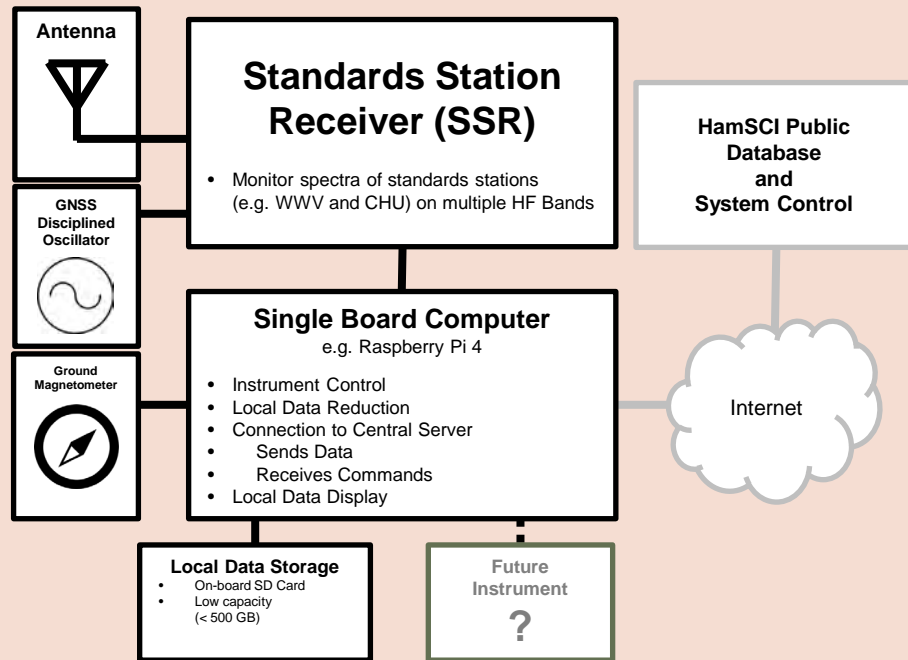
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SDR-Based and Low-Cost PSWS Versions

(a) **SDR-Based PSWS (Tangerine)**

Cross-Polarized Antennas

TangerineSDR
- 0.1 – 60 MHz Direct Sampling
- FPGA
- Spectrum/IQ Data
  - Wideband -or-
  - Multiple Slice Receivers
- Useful for many experiment types

GNSS Disciplined Oscillator & TEC Receiver

Ground Magnetometer

HamSCI Public Database and System Control

Single Board Computer
e.g. Odroid N2
- Instrument Control
- Local Data Reduction
- Connection to Central Server
  - Sends Data
  - Receives Commands
- Local Data Display

Internet

Local Data Storage
- External HD/SSD
- High-Capacity (>1 TB)
- Ring Buffer

Future Instrument ?

(b) **Low-Cost PSWS (Grape)**

Antenna

Standards Station Receiver (SSR)
- Monitor spectra of standards stations (e.g. WWV and CHU) on multiple HF Bands

GNSS Disciplined Oscillator

Ground Magnetometer

HamSCI Public Database and System Control

Single Board Computer
e.g. Raspberry Pi 4
- Instrument Control
- Local Data Reduction
- Connection to Central Server
  - Sends Data
  - Receives Commands
- Local Data Display

Internet

Local Data Storage
- On-board SD Card
- Low capacity (< 500 GB)

Future Instrument ?

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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!

KD2JAO & WB2JSV at NJIT Station K2MFF

AB4EJ Home Station
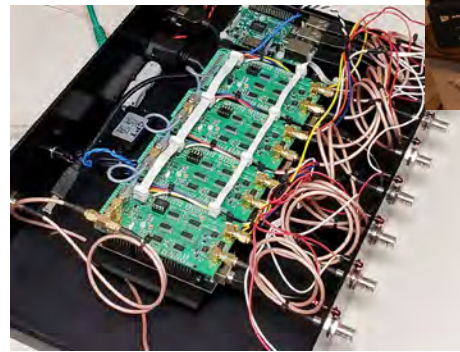
N8UR multi-TICC: Precision Time Interval Counter

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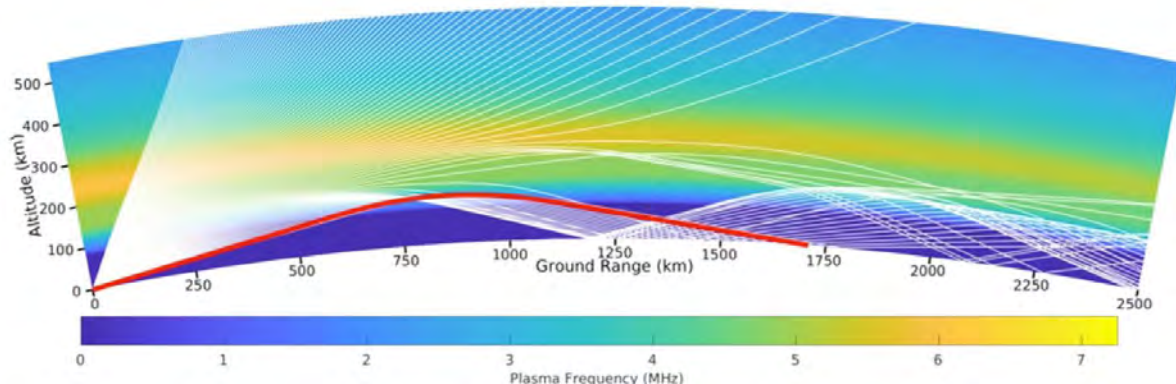
PHaRLAP: Cervera & Harris, 2014, https://doi.org/10.1002/2013JA019247
SAMI3: Huba & Drob, 2017, https://doi.org/10.1002/2017GL073549

	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…	

- **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)

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Ham Radio Observation Networks
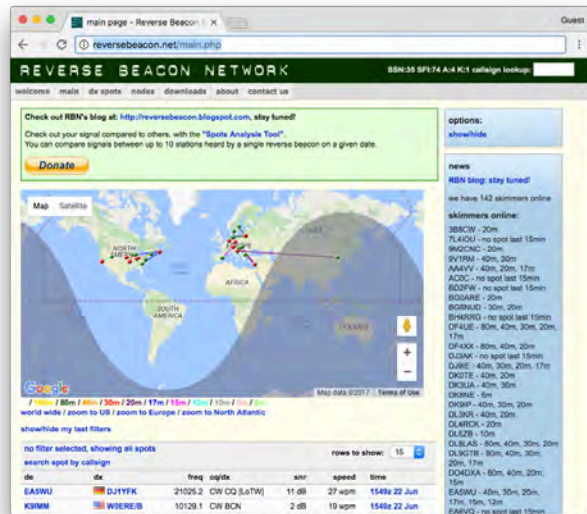
Reverse Beacon Network (RBN)
reversebeacon.net
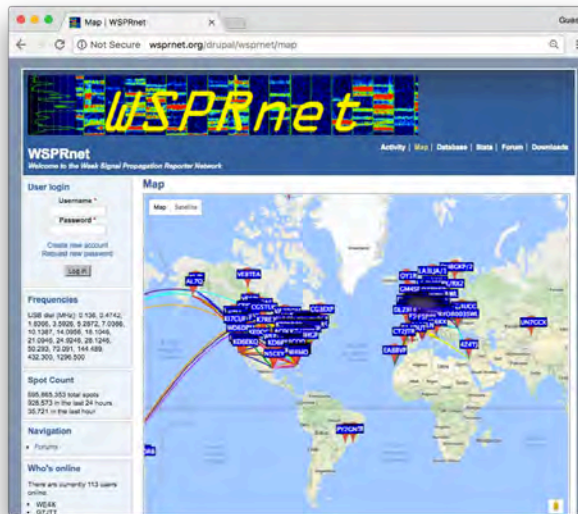
WSPRNet
wsprnet.org
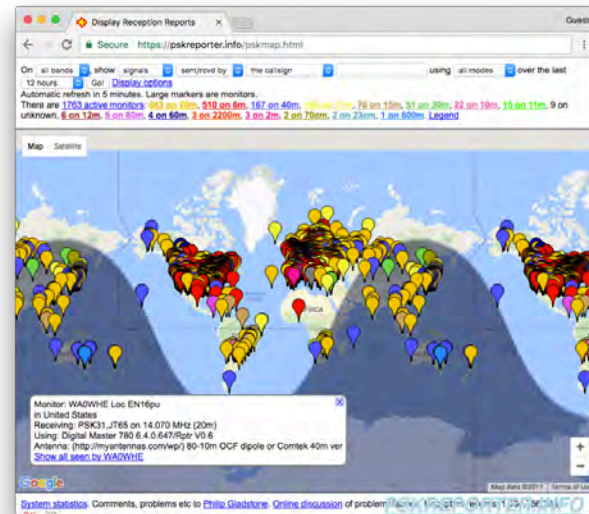
PSKReporter
pskreporter.info

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

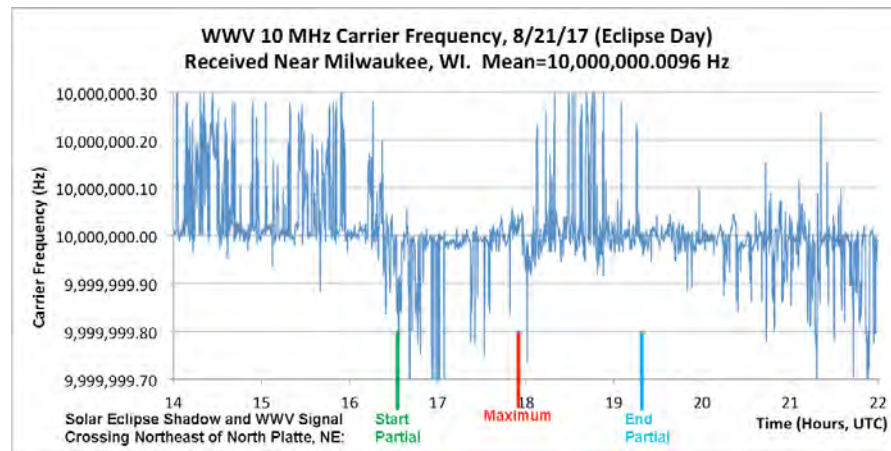- Data back to 2008 (A whole solar cycle!)
- Available in real-time!

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Examples of Amateur Radio Research

- Existing amateur radio observations networks, not specifically designed for scientific use, have already enabled ionospheric observations using amateur radio.

2017 Eclipse Continental US Observations

[Frissell et al., 2018, https://doi.org/10.1029/2018GL077324]
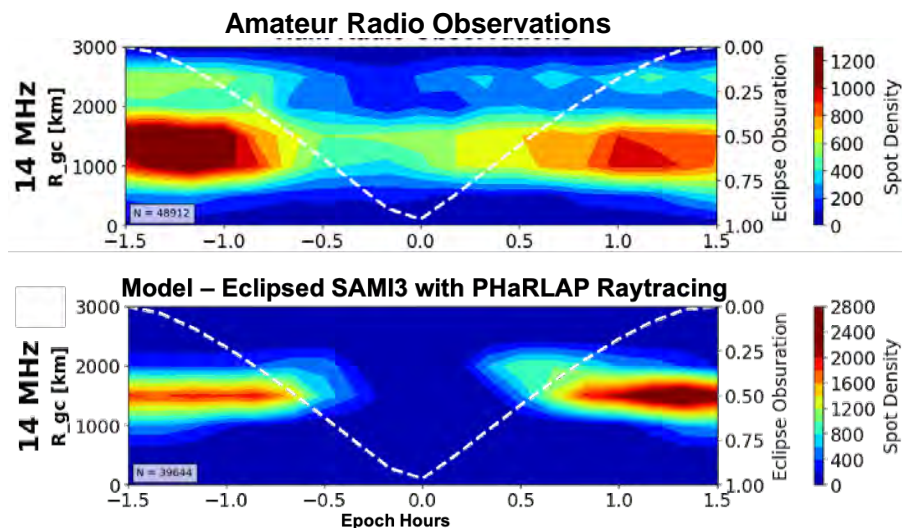
2017 Eclipse WWV Doppler Shift Observations

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Examples of Amateur Radio Research

HF Amateur Radio Response to Solar Flares

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

[*Frissell et al.*, 2019, https://doi.org/10.1029/2018SW002008]
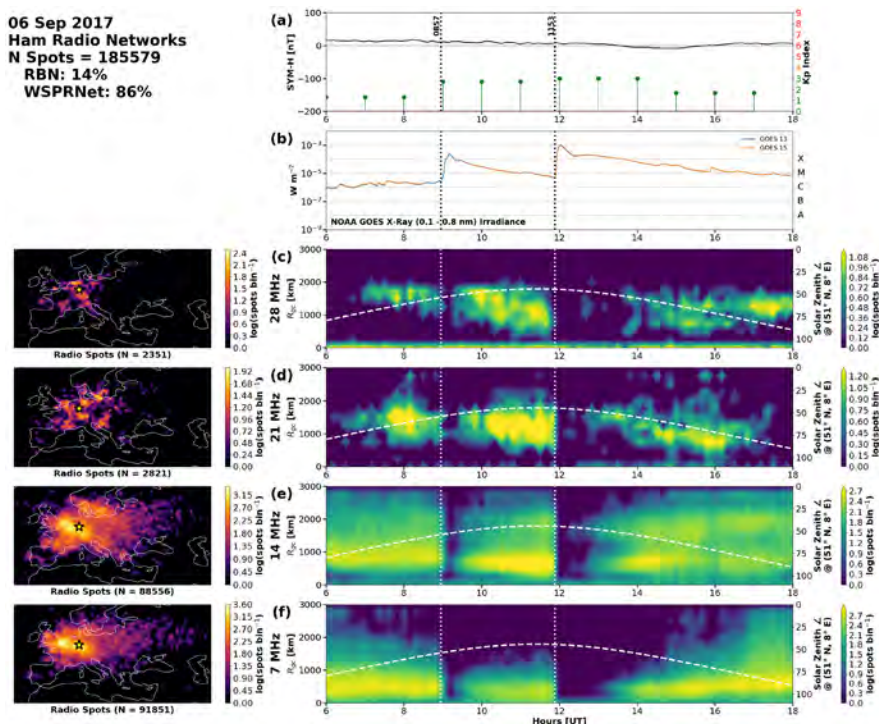
HF Amateur Radio (RBN & WSPR) TID Observations

Bin Size
2 min x 25 km
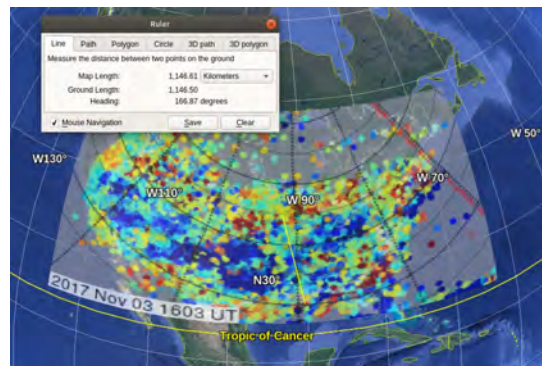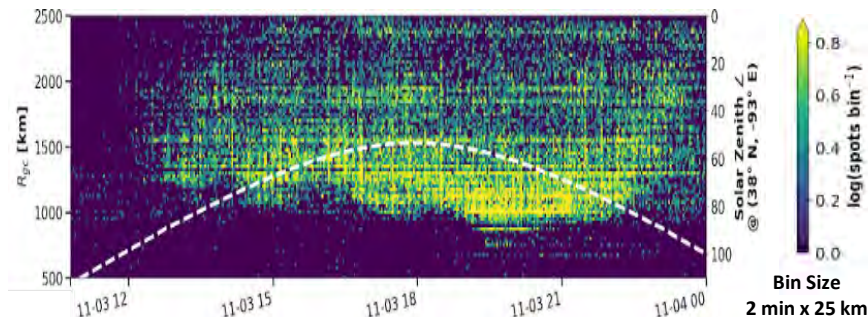
$\lambda_h \approx 1{,}100$ km
$v_p \approx 950$ km/hr
$T \approx 70$ min
$\Phi_{Azm} \approx 135°$

TEC Courtesy of
A. Costar /
MIT Haystack

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PSWS Teams

University of Scranton
- **Nathaniel Frissell W2NAF (PI)**
- Dev Joshi (Post-Doc)

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)
- 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

Responsibilities
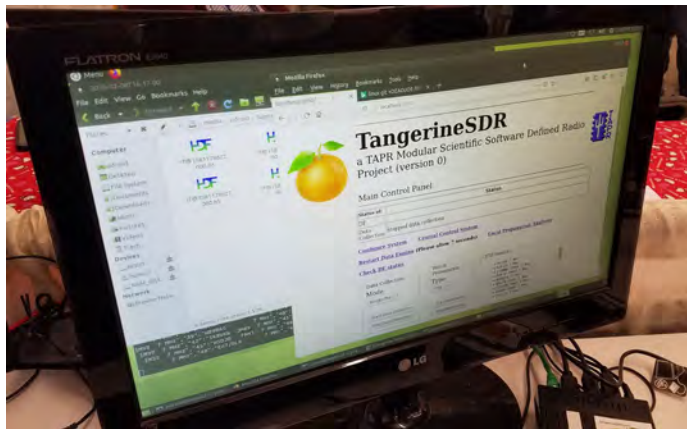- Ground Mag Oversight & Testing
- Science Collaborators

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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

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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.
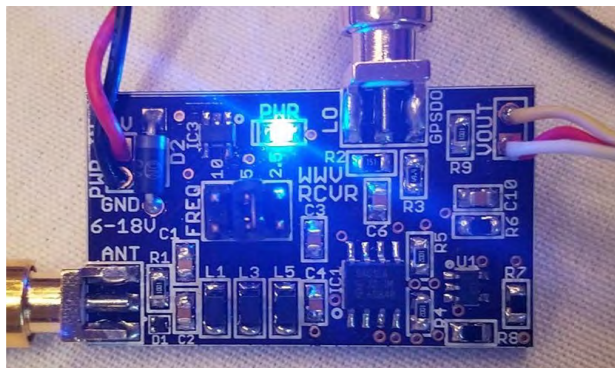
"Grape Receiver" Generation 1 by J. Gibbons N8OBJ

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

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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.

Acknowledgements

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http://hamsci.org

nathaniel.frissell@scranton.edu

Thank You!

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nathaniel.frissell@scranton.edu

Abstract

Recent advances in geospace remote sensing have shown that large-scale distributed networks of ground-based sensors pay large dividends by providing a big picture view of phenomena that were previously observed only by point-measurements. While existing instrument networks provide excellent insight into ionospheric and space science, the system remains undersampled and more observations are needed to advance understanding. In an effort to generate these additional measurements, the Ham Radio Science Citizen Investigation (HamSCI, hamsci.org) is working with the Tucson Amateur Packet Radio Corporation (TAPR, tapr.org), an engineering organization comprised of volunteer amateur radio operators and engineers, to develop a network of Personal Space Weather Stations (PSWS). These instruments that will provide scientific-grade observations of signals-of-opportunity across the HF bands from volunteer citizen observers as part of the NSF Distributed Array of Small Instruments (DASI) program. A performance-driven PSWS design (~US$500) will be a modular, multi-instrument device that will consist of a dual-channel phase-locked 0.1-60 MHz software defined radio (SDR) receiver, a ground magnetometer with (~10 nT resolution and 1-sec cadence), and GPS/GNSS receiver to provide precision time stamping and serve as a GPS disciplined oscillator (GPSDO) to provide stability to the SDR receiver. A low-cost PSWS (< US$100) that measures Doppler shift of HF signals received from standards stations such as WWV (US) and CHU (Canada) and includes a magnetometer is also being developed. HF sounding algorithms making use of signals of opportunity will be developed for the SDR-based PSWS. All measurements will be collected into a central database for coordinated analysis and made available for public access.

Glossary and Acronymns

- **FT8:** Franke Taylor 8, an amateur radio digital mode

- **GNSS DO**: Global Navigation Satellite System Disciplined Oscillator

- **HF:** High Frequency (3 – 30 MHz)

- **MF:** Medium Frequency (300 kHz – 3 MHz)

- **RBN:** Reverse Beacon Network, an automated network of receivers for monitoring amateur radio Morse code and radio teletype

- **RTTY:** Radio Teletype

- **TEC:** Total Electron Content

- **WSPR:** Weak Signal Propagation Reporting, an amateur radio digital mode