HamSCI Personal Space Weather Station (PSWS): Architecture and Current Status

N. A. Frissell[1], D. Joshi[1], V. Romanek[1], K. Collins[2], A. Montare[2], D. Kazdan[2], J. Gibbons[2], W. Engelke[4], T. Atkison[4], H. Kim[5], S. H. Cowling[6], T. C. McDermott[6], J. Ackermann[6], D. Witten[6], J. Madey[6], H. W. Silver[7], W. Liles[7], S. Cerwin[7], P. J. Erickson[8], E. S. Miller[7,9], J. Vierinen[10]

[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
[10]University of Tromsø

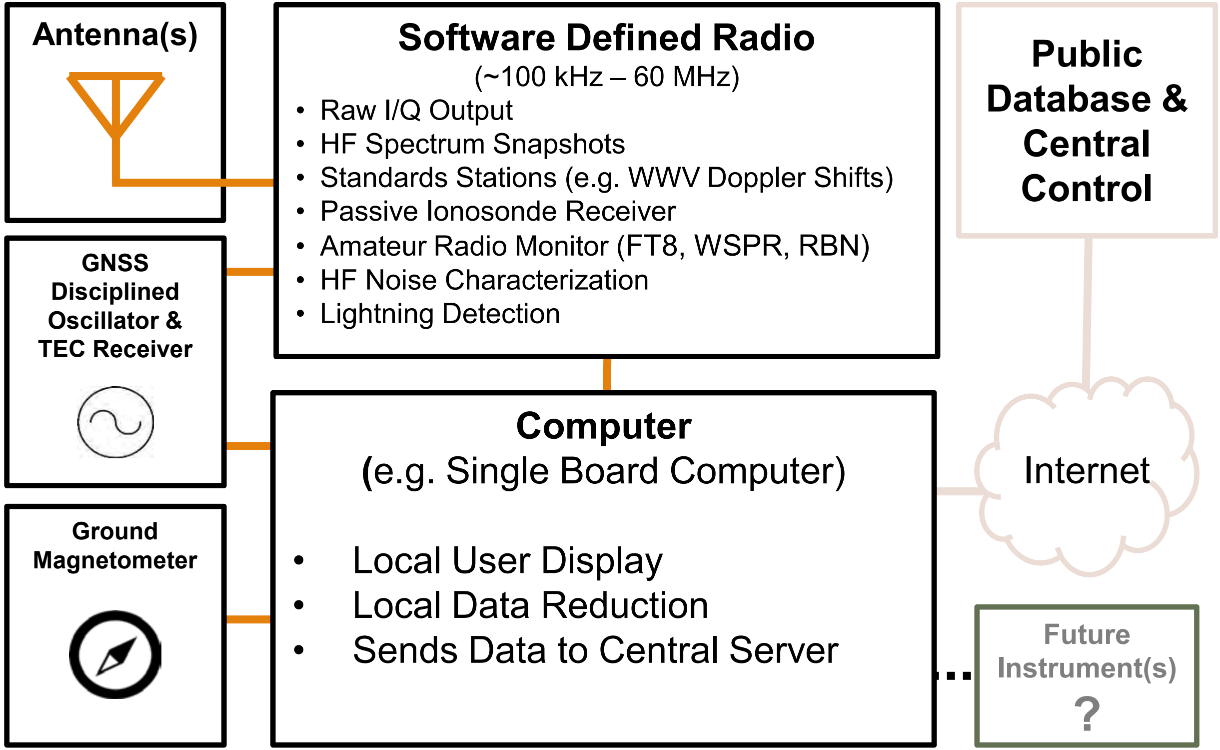
HamSCI
http://hamsci.org

NSF CEDAR Workshop
June 2021

nathaniel.frissell@scranton.edu

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

nathaniel.frissell@scranton.edu

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.

nathaniel.frissell@scranton.edu

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.

nathaniel.frissell@scranton.edu

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

Zephyr Engineering Inc.

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

nathaniel.frissell@scranton.edu

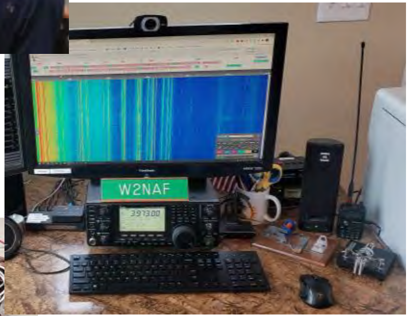
What is Amateur (Ham) Radio?

- **Hobby for Radio Enthusiasts**
  - Communicators
  - Builders
  - Experimenters
- **Wide-reaching Demographic**
  - All ages & walks of life
  - Over 760,000 US amateurs; ~3 million Worldwide

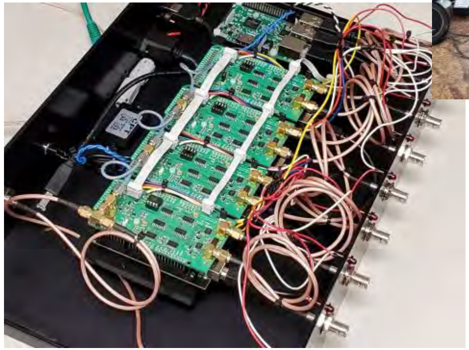
    (http://www.arrl.org/arrl-fact-sheet)
- **Licensed by the Federal Government**
  - Basic RF electrical engineering knowledge
  - Licensing provides a path to learning and ensures a basic interest and knowledge level from each participant
  - Each amateur radio station has a government-issued "call sign"
- **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

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:

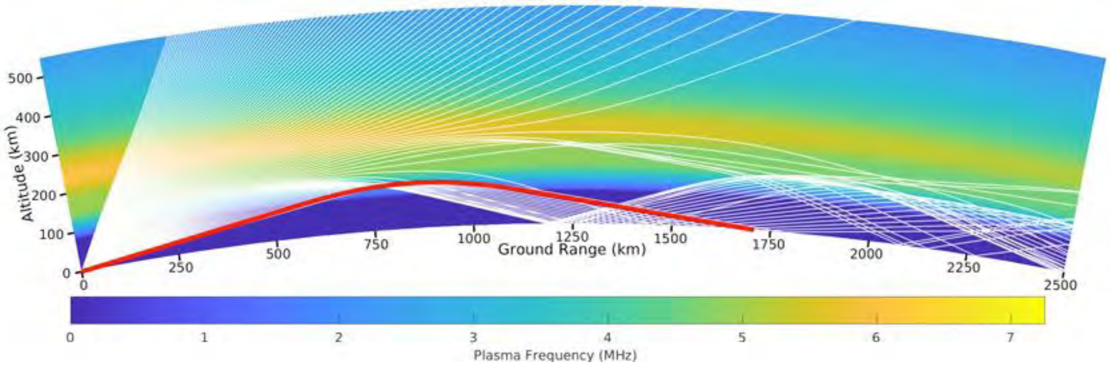
1. **Advance** scientific research and understanding through amateur radio activities.
2. **Encourage** the development of new technologies to support this research.
3. **Provide** educational opportunities for the amateur radio community and the general public.

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
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)

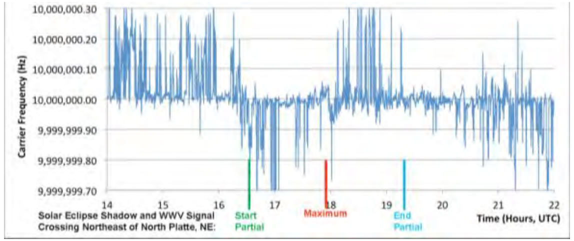
	Frequency	Wavelength
LF	135 kHz	2,200 m
MF	473 kHz	630 m
	1.8 MHz	160 m
HF	3.5 MHz	80 m
	7 MHz	40 m
	10 MHz	30 m
	14 MHz	20 m
	18 MHz	17 m
	21 MHz	15 m
	24 MHz	12 m
	28 MHz	10 m
VHF+	50 MHz	6 m
	And more…	

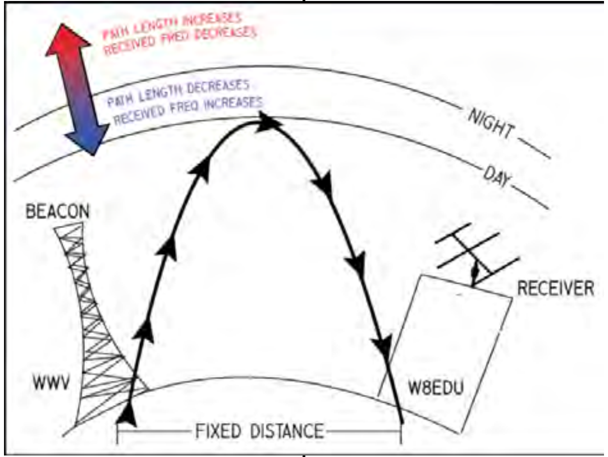
nathaniel.frissell@scranton.edu

Low-Cost "Grape" PSWS

- HF "Doppler Shift" Monitoring
- Main components: Raspberry PI, GPSDO, Custom Direct-conversion receiver board
- Cost: ~$300
- Developed by Case Western

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



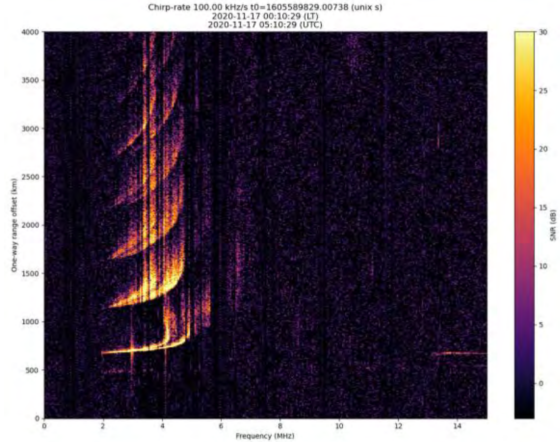


[Collins et al., 2021]

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

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



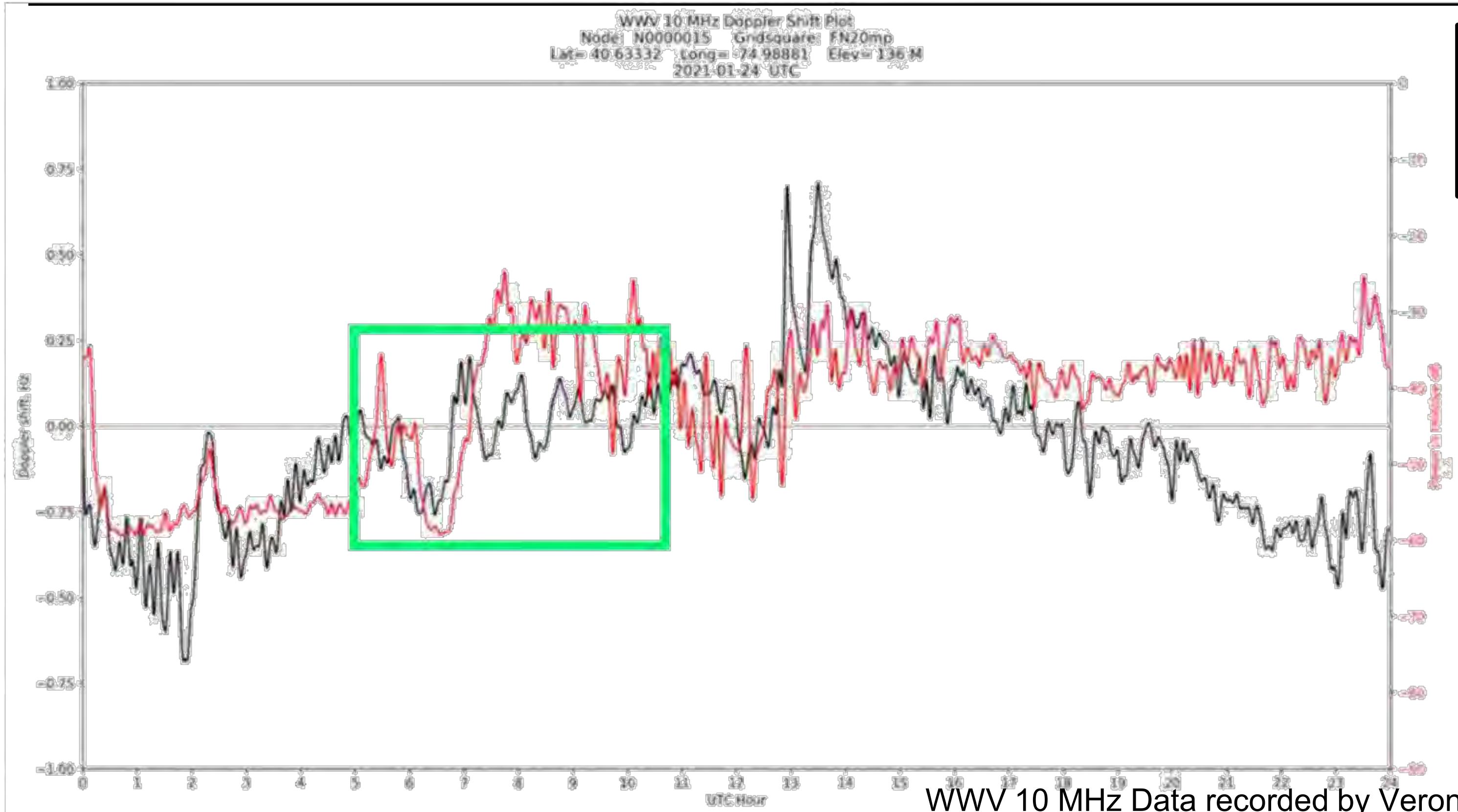
Movie by Dev Joshi
GNUChirpsounder2 by Juha Vierinen

PSWS Current Engineering Status

- **Tangerine Data Engine (MAX10)**
  - Schematic capture: 100% complete
  - BOM: 100% complete
  - Component placement: 100% complete
  - Almost all parts delivered
  - Next step: Waiting for FPGA and USB chip delivery
- **Tangerine RF Module (dual-channel 0.1-54MHz)**
  - Schematic capture: 100% complete
  - BOM: 100% complete
  - Component placement and routing: 100% complete
  - Update will be required for DE compatibility
- **Tangerine Clock Module (ZED-F9T SynthDO)**
  - Schematic capture: 100% complete
  - BOM: 100% complete
  - Component Placement: 100% complete
- **MagnetoPi Hat**
  - Schematic capture: 100% complete
  - BOM: 100% complete
  - PC Board placement and layout: 100% complete
  - Compatibility review with LC-PSWS: 100% complete
  - Prototype build of 50 units: 100% complete
- **Low Cost PSWS (Grape)**
  - Grape Generation 1 consists of
    - Leo Bodnar GPSDO frequency standard
    - low IF receiver
    - USB based A/D converter
    - RaspberryPi running a modified version of FLDIGI
  - Several Grape V1 stations operational, and build instructions available at hamsci.org/grape1.
  - Grape v2 Design in Progress, will be capable of receiving 4 HF channels simultaneously.
- **Control Software and Database**
  - Prototype of local control software exists
  - Runs on Odroid N2 Single Board Computer
  - Uses data from a TangerineSDR Simulator (FlexRadio with GPSDO + DAX IQ output)
  - Can monitor up to 16 band segments at a time
  - 4 types of data collection: Snapshotter, Ring Buffer, Firehose(L+R), and FT8/WSPR Propagation Monitoring
  - Proof of concept code working for all modes except WSPR and Firehose L (supercomputer interface)

nathaniel.frissell@scranton.edu

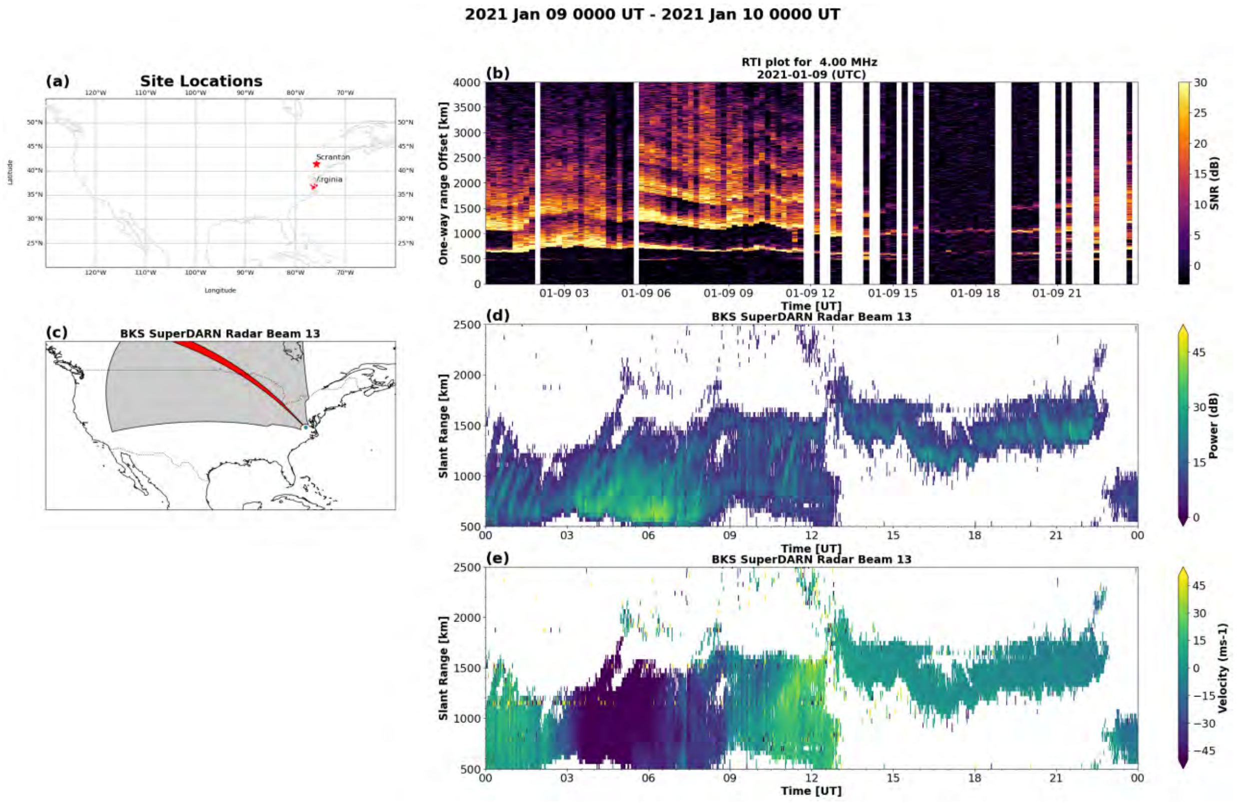
Grape Data Example



See
Veronica Romanek's
poster this afternoon
3:30-5:00 PM MT

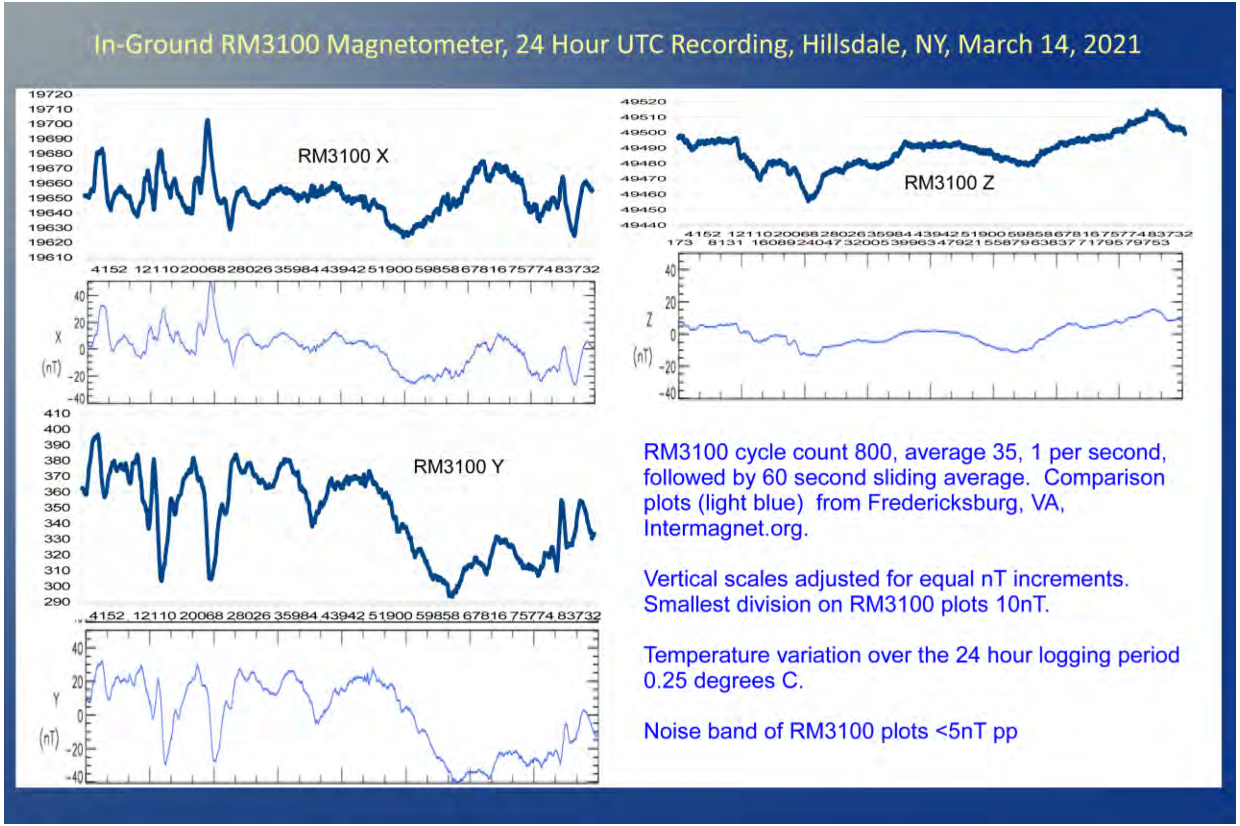
WWV 10 MHz Data recorded by Veronica Romanek, Hampton, NJ

Chirpsounder Example



See
Dev Joshi's poster
Thursday afternoon
3:30-5:00 PM MT

Ground Mag Example



Hillsdale, NY data and data comparison by Jules Madey

nathaniel.frissell@scranton.edu

Summary

- HamSCI is a collective that aims to bring together the amateur radio and professional space science research communities for mutual benefit.
- 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 $300 - $1000, depending on capabilities.

nathaniel.frissell@scranton.edu

Acknowledgments

We are especially grateful for the

- the support of NSF Grant AGS-2002278, AGS-1932997, and AGS-1932972.
- amateur radio community volunteers who have contributed engineering, testing, and data collection efforts to the PSWS project.
- 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).

nathaniel.frissell@scranton.edu

Thank You!

This project is supported by NSF Grants AGS-2002278, AGS-1932997, and AGS-1932972.

nathaniel.frissell@scranton.edu

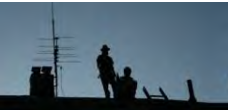
Abstract

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.

nathaniel.frissell@scranton.edu

Glossary and Acronyms

- **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



nathaniel.frissell@scranton.edu