The HamSCI Personal Space Weather Station

Development, Deployment and Data

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A modular system, not a box

Four components, usable alone or in combination — roughly $100–1,000 each.

HF Receiver

HFRx

0.1–60 MHz, GPS-disciplined Doppler and time-of-flight.

Ground Magnetometer

GMag

Three-axis, noise level lower than 10 nT at 1 Hz.

VLF Whistler Catcher

VLF-WC

Whistlers, chorus, and lightning location.

WSPRsonde Transmitter

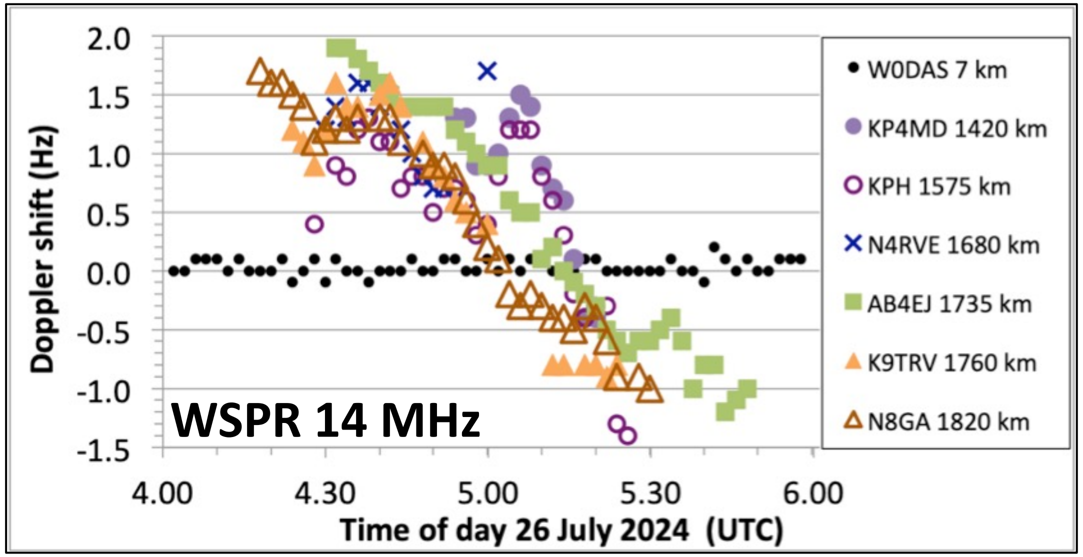
WS8

Eight bands at once, GPS-locked, 1 W per band.

https://hamsci.org/psws-overview

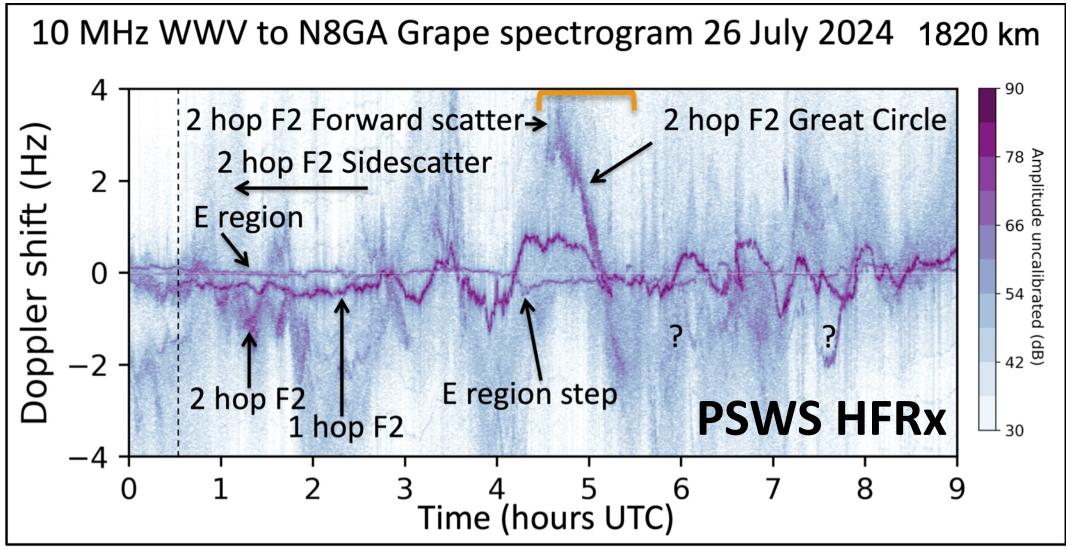
The questions the PSWS is designed to answer

Amateur radio



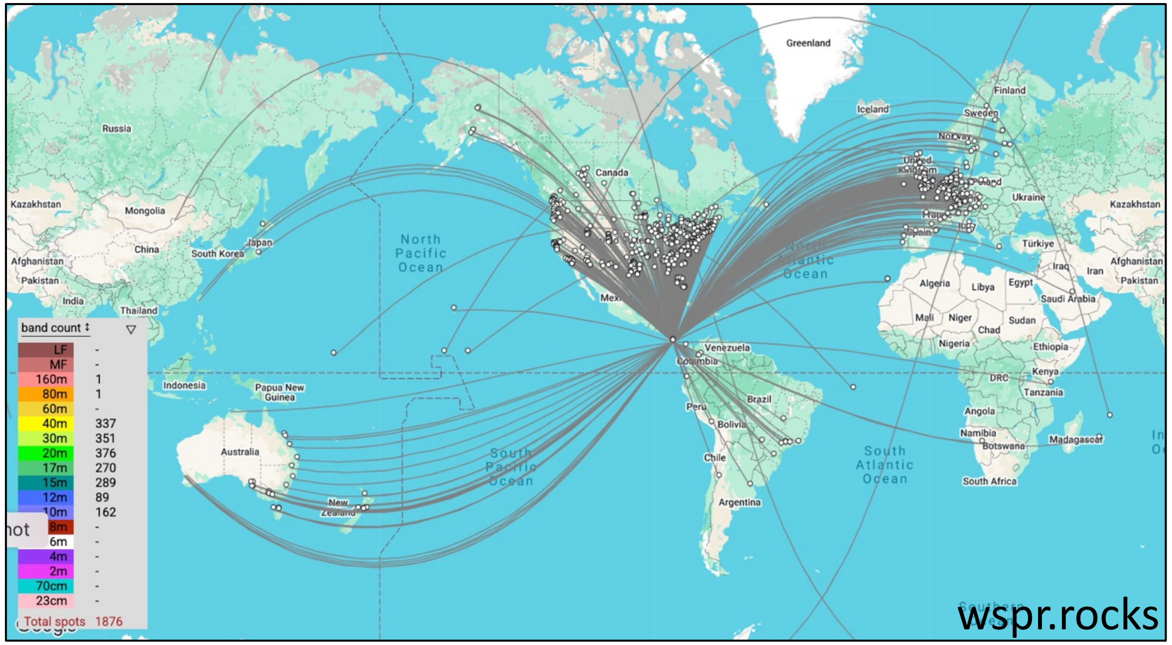
- How do flares, storms and Travelling Ionospheric Disturbances (TIDs) affect propagation?
- How can this science make us better operators?
- What can I measure in my own backyard?

Science



- How does the ionosphere respond to space and atmospheric inputs?
- What drives Travelling Ionospheric Disturbances?
- What causes Sporadic E?

Why an amateur radio network, not a handful of observatories



A professional network buys a few excellent sites; HamSCI uses thousands of good ones.

1876 WSPR stations reporting reception of WSPRsonde at TI4JWC, Costa Rica.
24 hours on 22 July 2026

- **Scale** —Thousands of WSPR stations already on the air, denser data than any research programme could fund.
- **Coverage** — Oceanic islands, poles, sparse regions, often someone lives there and enjoys the hobby.
- **Durability** — Operators maintain their own stations because they want to.

Higher spatial density is the unique aspect

HamSCI PSWS HFRx locations and status 22 July 2026.

https://pswsnetwork.eng.ua.edu/home

- High cost research and operational ionospheric sounders such as Ionosondes and Doppler Radar (e.g. SuperDARN) instruments are sparse.
- Densely-spaced mid-latitude Doppler, VLF and geomagnetic observation has never been done. (*There is a dense network of GPS receivers for ionosphere Total Electron Content measurements*).
- Density, not per-instrument precision, is what this network buys.

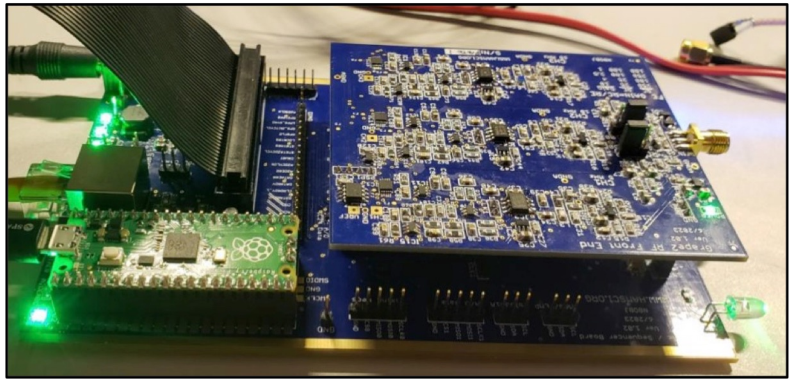
Development — the GRAPE line

GRAPE = **G**reat **R**adio **A**mateur **P**ropagation **E**xperiment

Original GRAPE Receivers led by John Gibbons N8OBJ, Case Western Reserve University / Case Amateur Radio Club W8EDU.

- **GRAPE v1**: Single Frequency, build it yourself direct conversion
- **GRAPE v2**: Three frequencies, triplicated analogue RF preassembled
  30 deployed for the April 2024 Total Eclipse
- **Through-Hole GRAPE**, an initiative of Bob Reif W1XP as an introductory/training/build route.

v1



v2

Images: N. Frissell / HamSCI — used with permission.

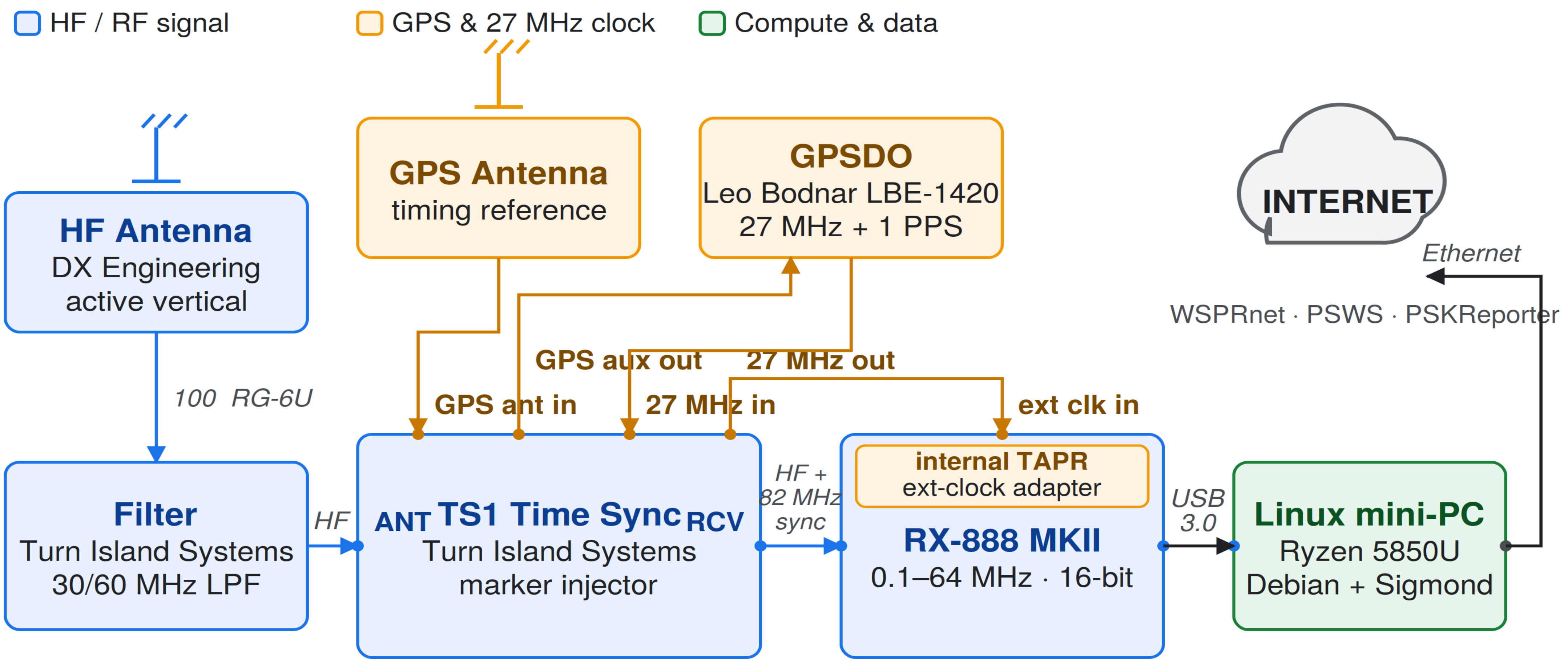
The HFRx Receiver — What it does

0.1–60 MHz	≤ 1 mHz	≤ 1 µs
continuous coverage	frequency accuracy	timing accuracy

- Dozens-to-hundreds of signals decoded simultaneously, unattended, 24/7.
  - Time/Frequency Standard stations: WWV/WWVH/BPM
  - Amateur transmissions: WSPR & FST4W · FT8/FT4 · Meteor Scatter MSK144.
  - CODAR (Ocean Currents radar) · HF Data Link (HFDL) Aircraft signals
- Science-grade HFRx station ≈ $1,500. Entry level ≈ $700.

Hardware signal chain: One antenna, one SDR, one PC.

GPS / clock along the top · HF signal through the middle



Antenna $250 · Filter $60 · TS1 $170 · GPSDO $210 · RX-888 $250 · mini-PC $410

Total ≈ $1,350

RX-888 MKII — The enabling component

Figure: N. Frissell / HamSCI — used with permission.

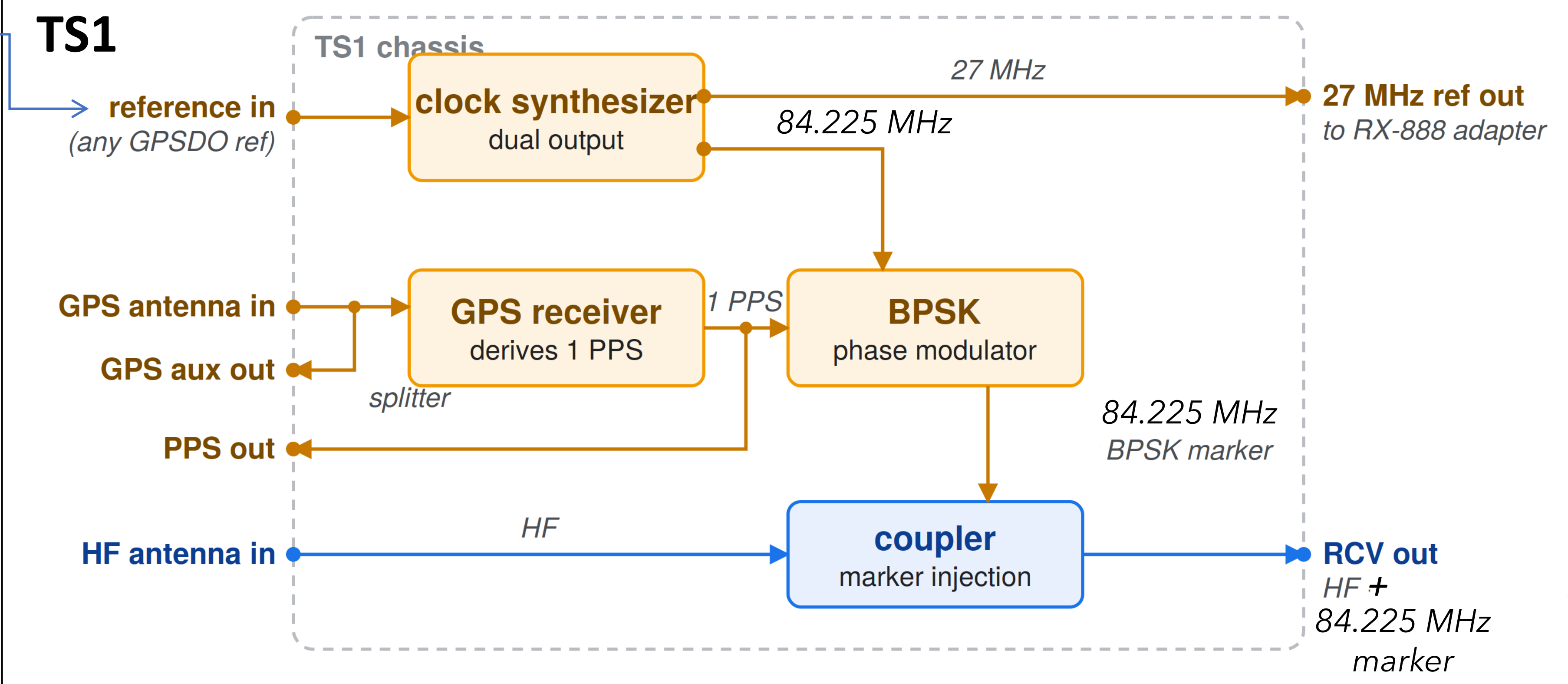
- 16-bit direct sampling (LTC2208 ADC), ~130 Msps.
- 0.1–64 MHz over USB 3 — the whole of HF at once.
- ~$250: nothing else matches bandwidth × bits for the price.
- Downside – unknown manufacturer of units on Aliexpress, Amazon etc., but clones and scams
- Compute: ~$400 mini-PC (e.g. Beelink Ryzen 5850U, 8 Core/16 Thread).

Getting to 1 mHz and 1 µs: GPSDO and TS1 Time Sync Injector

The timestamp rides through the same ADC, filters and signal processing as the signals being measured.

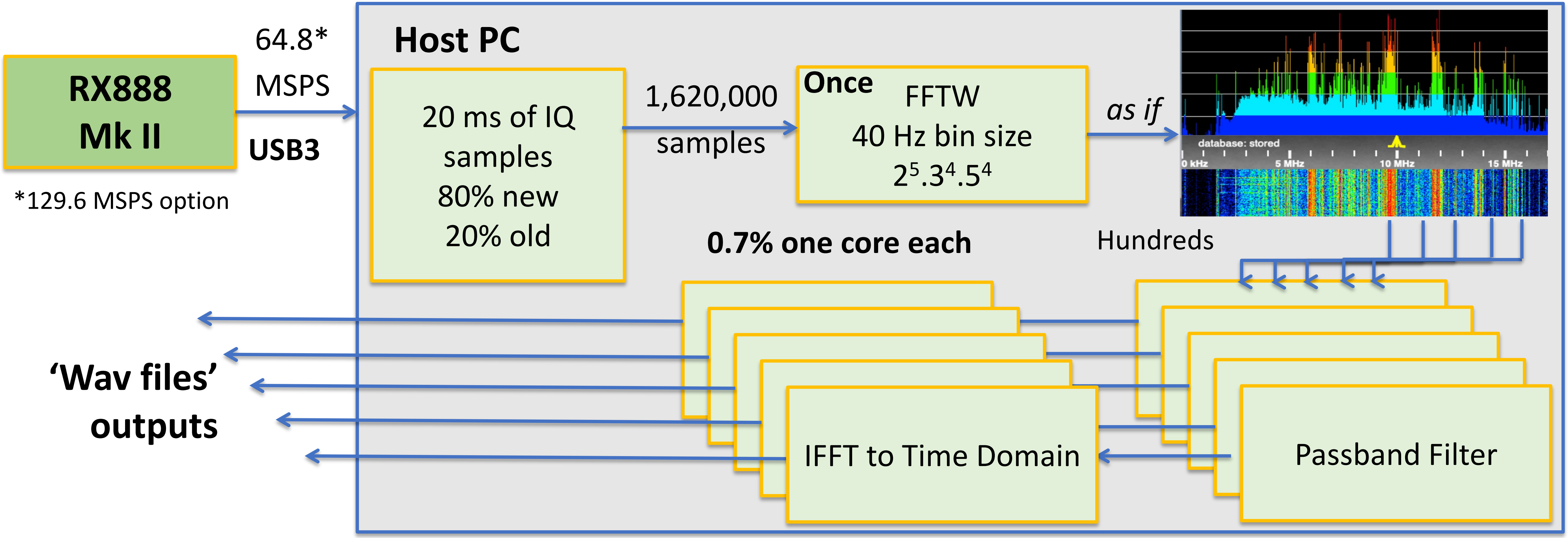
GPS Disciplined Oscillator, e.g. MiniGPS Reference from Leo Bodnar.

TS1 from Turn Island Systems



Physical TS1 front panel carries PPS OUT · REF OUT · RCV · ANT; drawn left→right here for signal-flow clarity.
Both clocks are generated by the synthesizer from whatever reference frequency the GPSDO supplies.

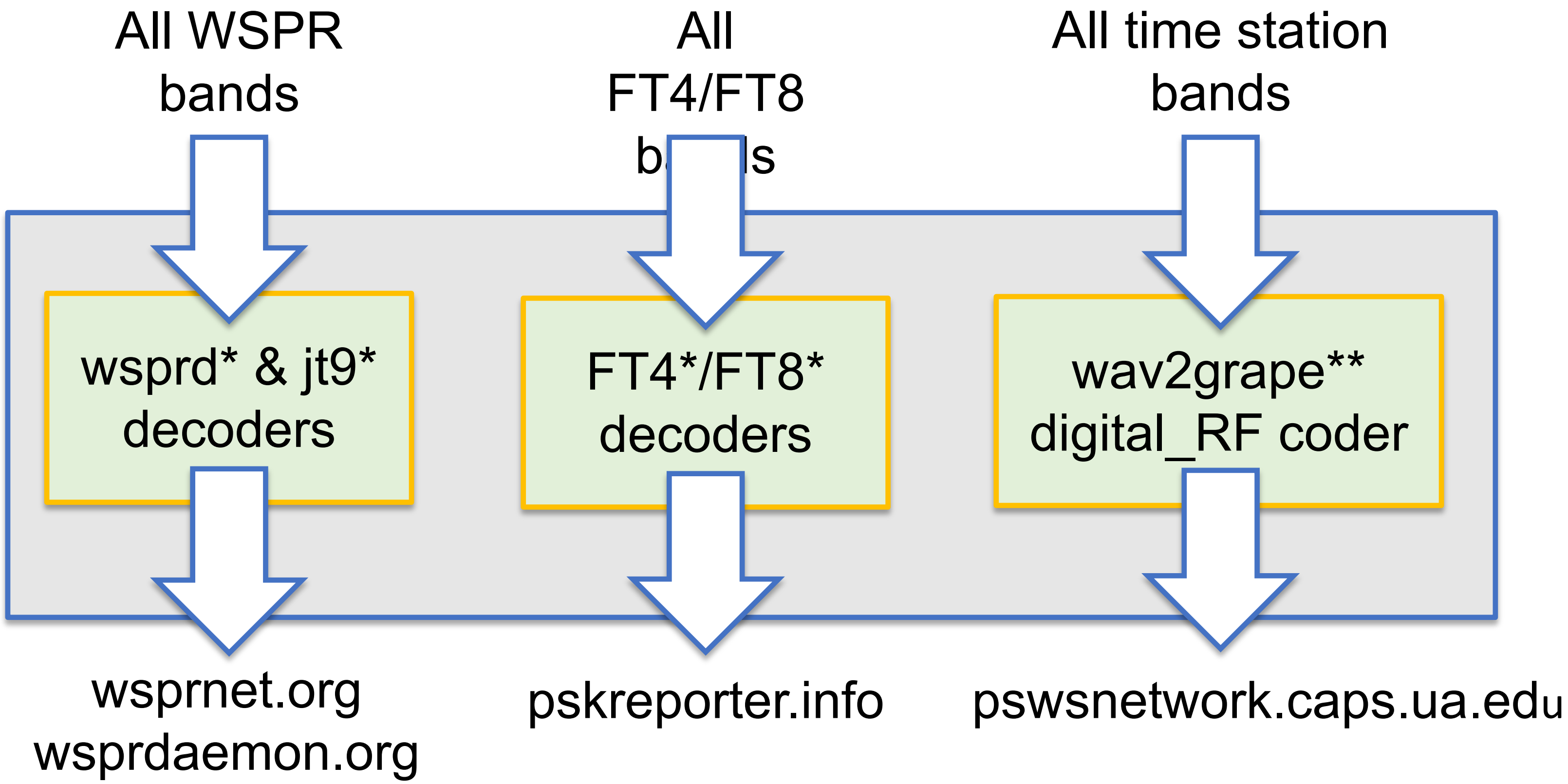
How one SDR receives hundreds of signals



How multiple wav files are processed and reported: WsprDaemon

Rob Robinett AI6VN

Wav files input



Outputs to databases

* Decoders from WSJT-X under GNU GPLv3

** Franco K4VZ & Rob AI6VN & MIT Haystack

https://github.com/rrobinett/wsprdaemon

How multiple wav files are processed and reported: Sigmond

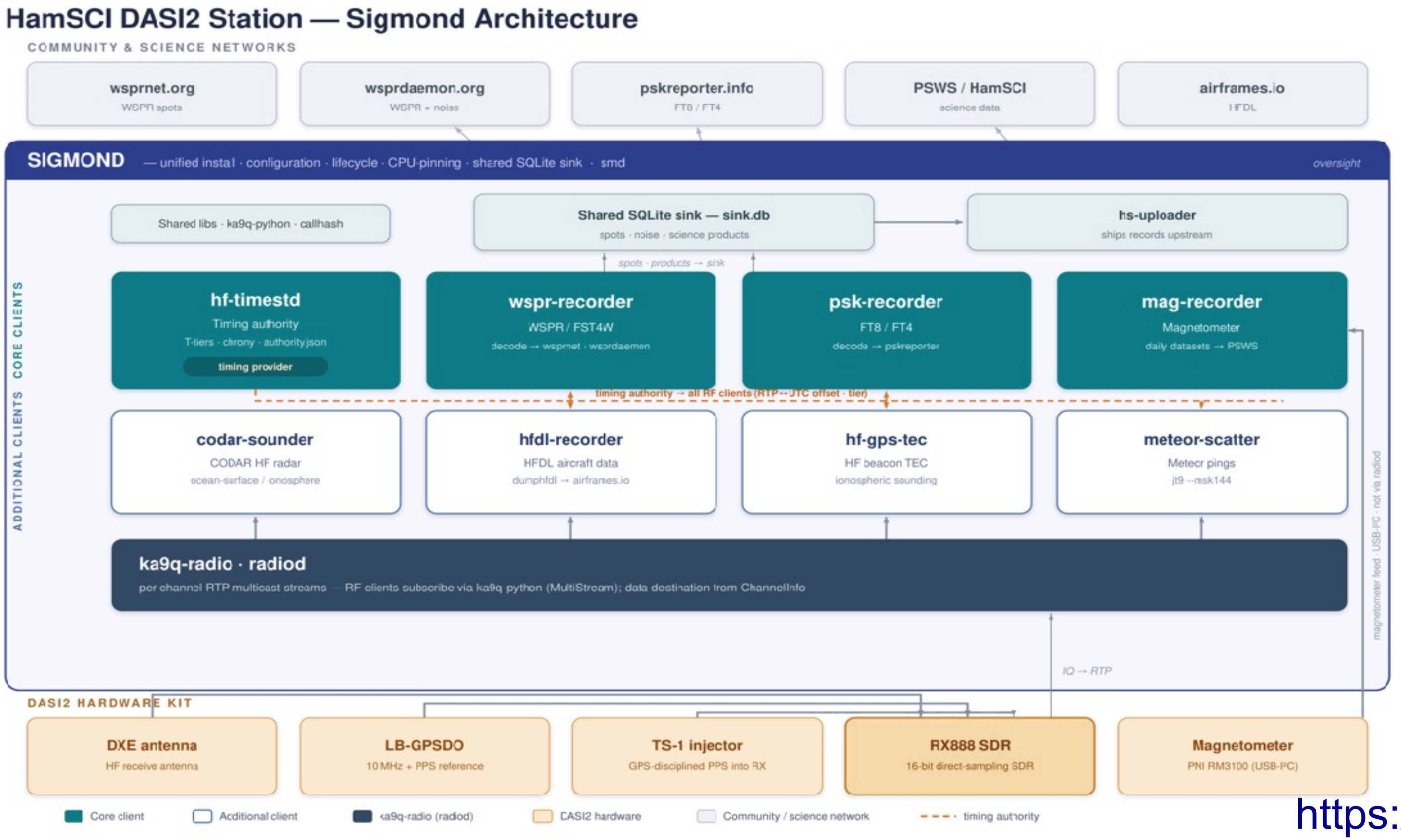


Figure: Sigmond project (R. Robinett).

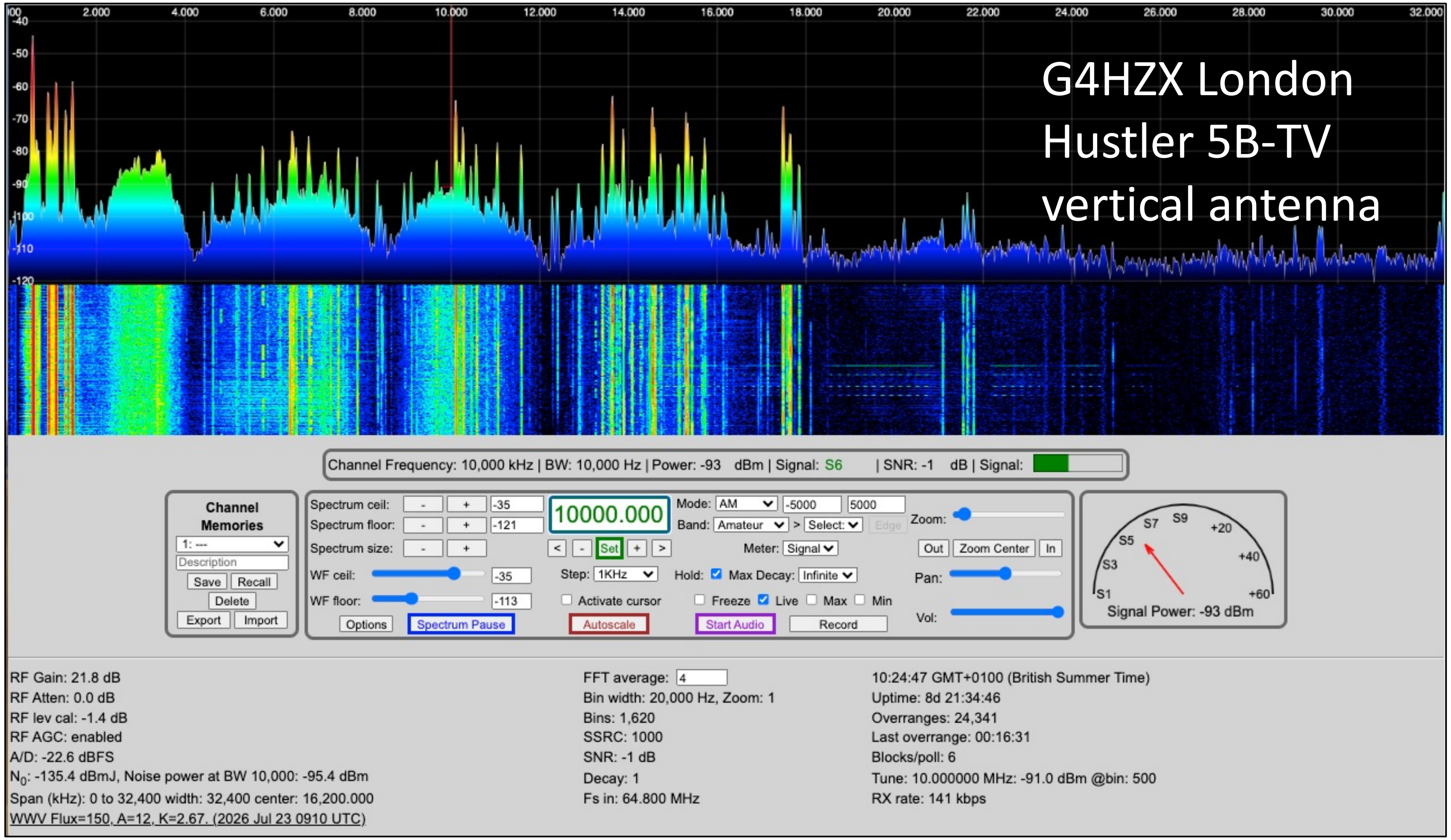
An initiative of Rob Robinett AI6VN, Michael Hauan AC0G, Phil Karn KA9Q and many fellow amateurs, with Anthropic’s Claude AI.

Adds:

- Time of Flight
- Magnetometer
- CODAR ocean radar
- HFDL aircraft comms
- Other decoders as required

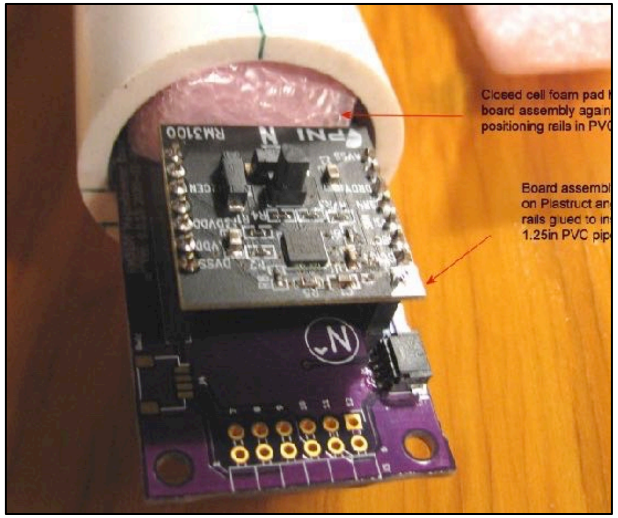
https://github.com/HamSCI/sigmond

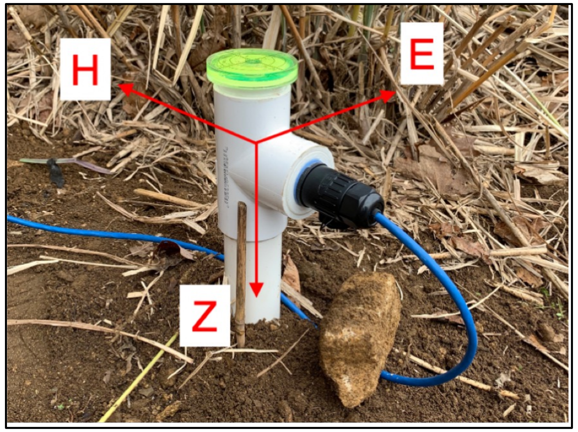
In addition… the ka9q_web user interface



The Ground Magnetometer

- RM3100 magneto-inductive sensor, three axes.
- Buried sensor, minimises daily temperature changes.
- Quiet site away from mains wiring, ideal >50-100 m.
- Noise level lower than 10 nT at 1 Hz
- Aim for stations 50–100 miles apart.
- No separate computer —uses same mini-PC as HFRx.





Images: N. Frissell / HamSCI — used with permission.

Why a dense amateur array matters

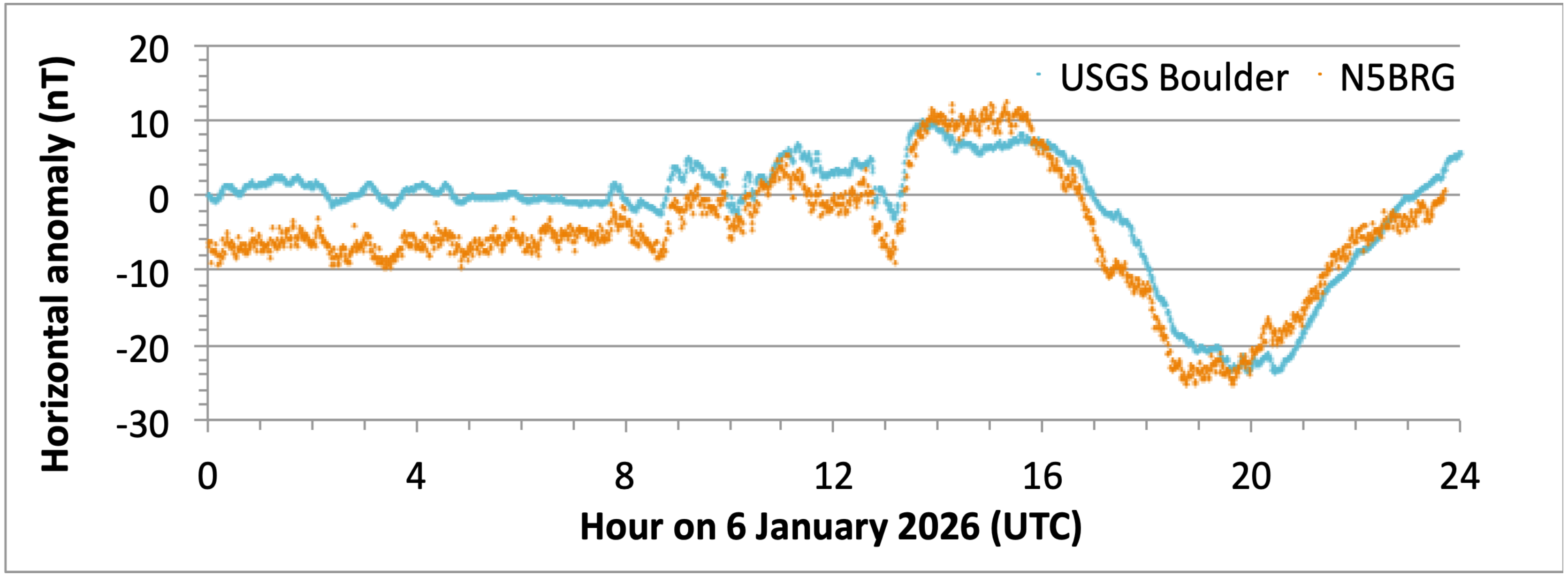
Graphic by Claude AI

USA: 13 magnetometers maintained by the US Geological Survey, of which 6 in lower 48 states.
Finland: 11 magnetometers over an area about 1/30th that of the USA.

- Storms and sub-storms cause variations of tens-to-hundreds of nT — well within HamSCI magnetometer range.
- More sites → better ionospheric current maps, fewer assumptions.
- Complements, not competes with, sparse government observatories.

Reading the magnetometer

1. Find a list of HamSCI magnetometers reporting on the day of interest at: https://pswsnetwork.eng.ua.edu/observations/observation_list
2. Download csv file, or zip file and extract JSON data
3. Plot results, usually as a *magnetic anomaly*, that is, difference from the day's average.



Boulder data credit to US Geological Survey and Intermagnet

Horizontal magnetic field anomaly for HamSCI Magnetometer of Bob Stricklin N5BRG near Dallas, Texas (orange) alongside that from the US Geological Survey magnetometer at Boulder, Colorado (cyan) 1080 km NW.

The VLF Whistler Catcher

- Developed by Jonathan Rizzo KC3EEY (right, with antenna behind).
- Open hardware, open software, open data VLF receiving system.
- Whistlers, dawn chorus, 8270 / 5710 Hz bands.
- Locates lightning strokes by sferic timing.

Whistler

Dawn Chorus

Sound files courtesy British Antarctic Survey, recorded at Halley, available at http://www.nerc-bas.ac.uk/uasd/programs/wave/wavesamp.html

Image courtesy Jonathan Rizzo

Hardware and software chain

Antenna

E-field probe + preamp (open hardware, *right*).

Acquisition

Interface board (*left*) → Audio ADC → thin-client PC.

Timing

GNSS box supplies PPS for calibration and timestamps.

Software

vlfrx-tools: ~48 utilities — capture to plotting, lightning location and more.

HamSCI recognises the contributions of Paul Nicholson, G8LMD (SK) — Author of vlfrx-tools, pioneer of amateur VLF reception

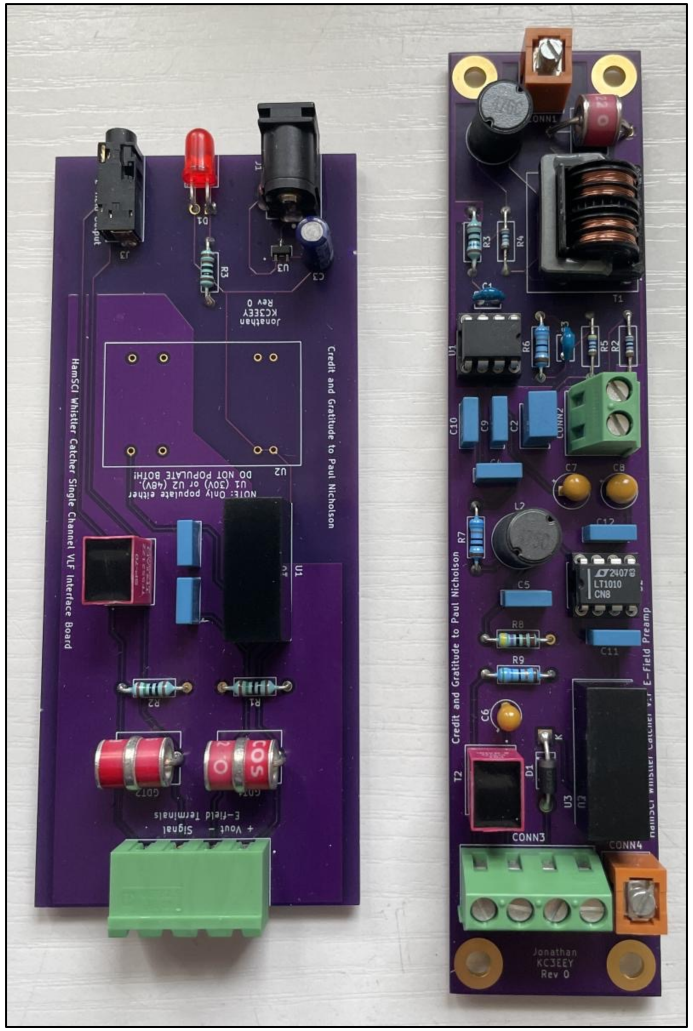
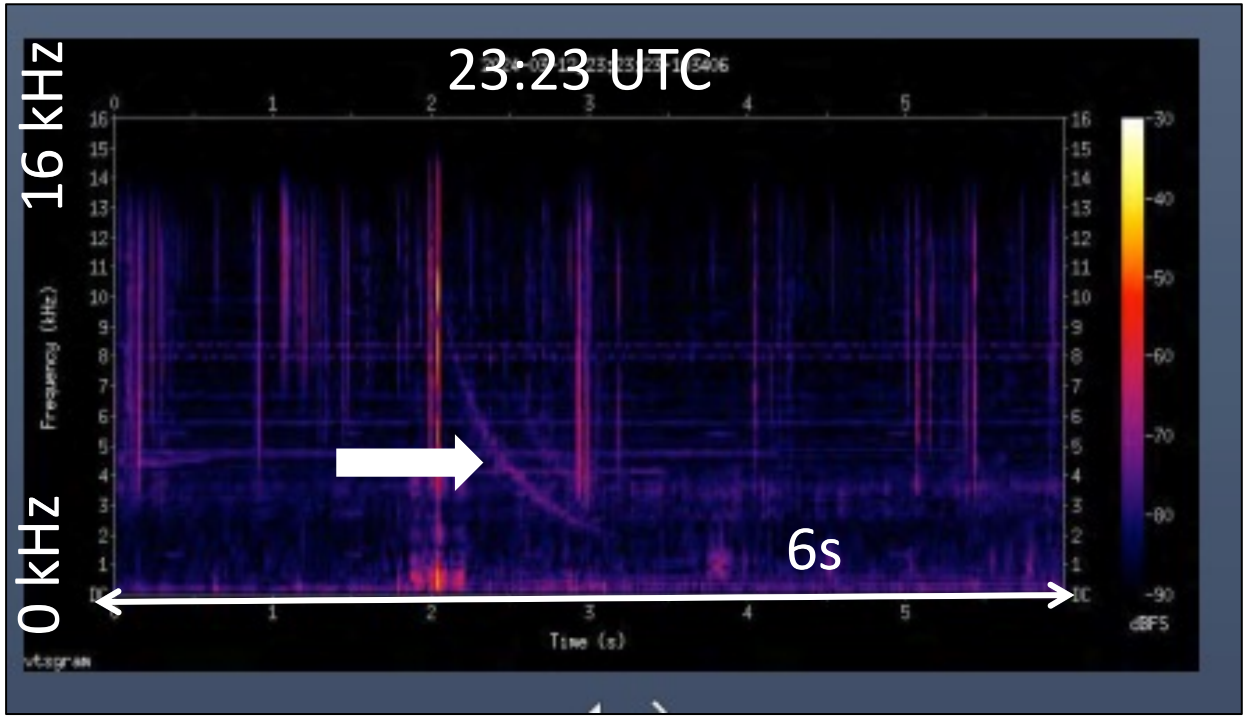


Image courtesy Jonathan Rizzo

Siting and Example Whistler Spectrogram

- Ideally 60 metres or more from anything carrying mains harmonics.
- 10 metres from overhanging branches, ideally open ground.
- Compromises are inevitable — HamSCI will advise what can relax.



WSPRsonde-8 — The Transmit side

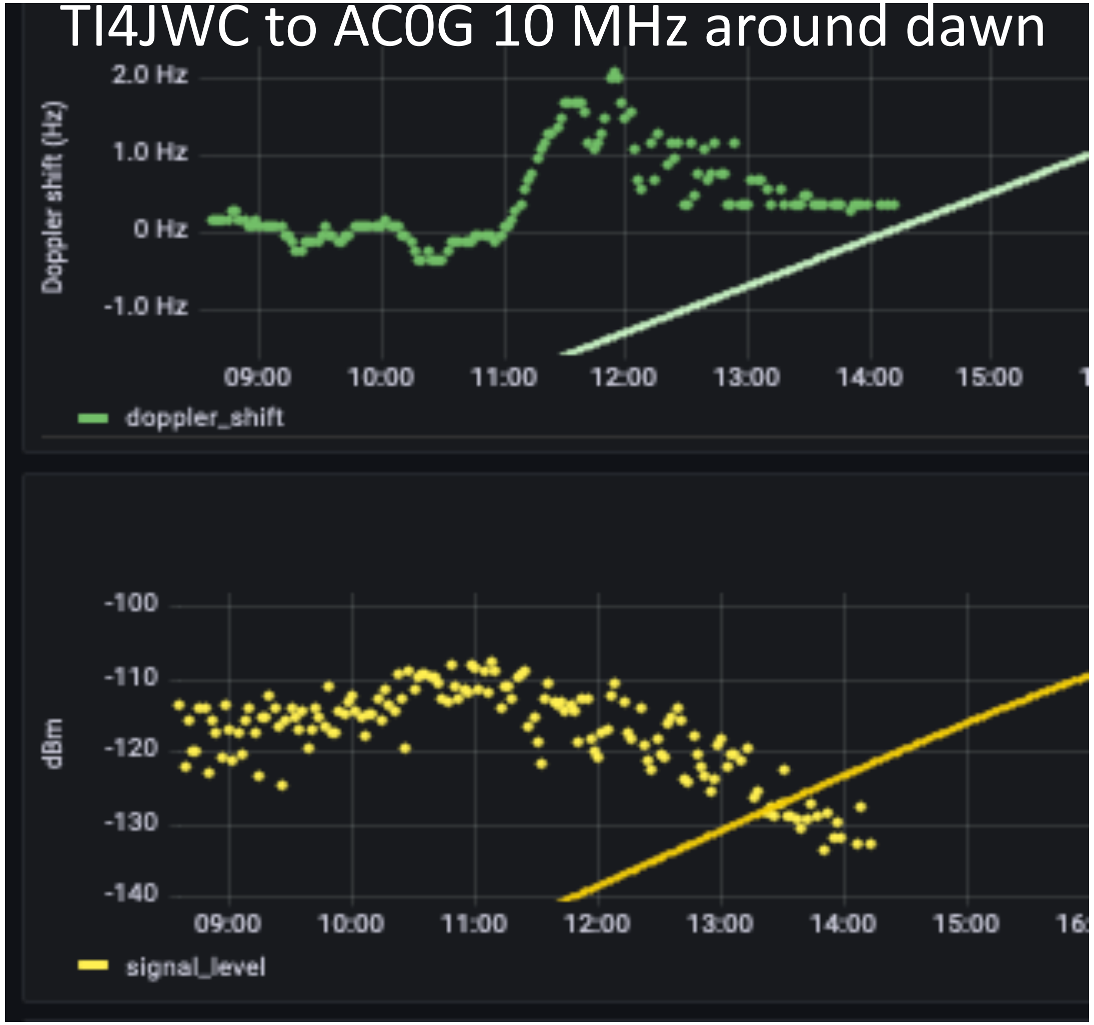
https://turnislandsystems.com/

- Eight bands simultaneously, WSPR or FST4W, GPS-locked (10 MHz Leo Bodnar GPSDO).
- 1 W output per band
- Developed by Paul Elliott, WB6CXC. Shown with the six-band filter/combiner. A nine-band filter-combiner is available for all bands 80 through 6 metres.

Figure: N. Frissell / HamSCI — used with permission.

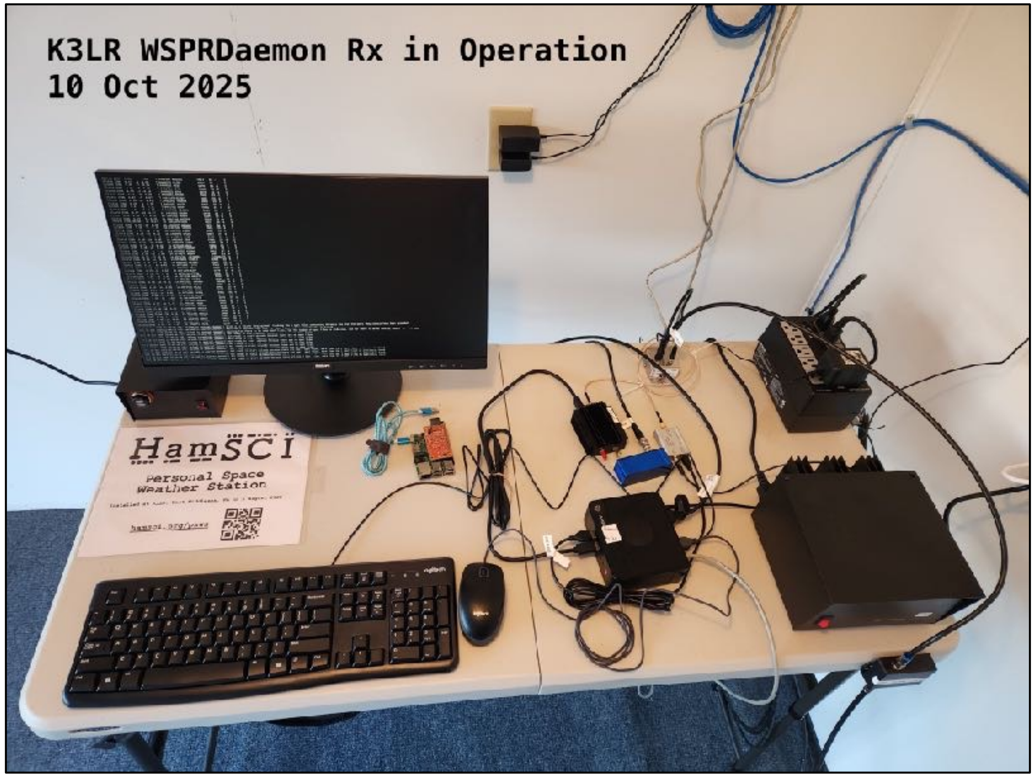
Why a transmitter completes the observatory

- Receive-only networks measure whatever happens to be on the air.
- Known transmitters turn listening into a designed experiment.
- Both endpoints known; time and frequency known to GPS accuracy.
- All bands sounded at once — multi-band Doppler and Time of Flight comparable.



Example of Doppler shift (top) and signal level (bottom) from the WSPRsonde at TI4JWC, Costa Rica received by AC0G Missouri, USA on 10 MHz

A station at home: Most new stations start with the RX888 HFRx

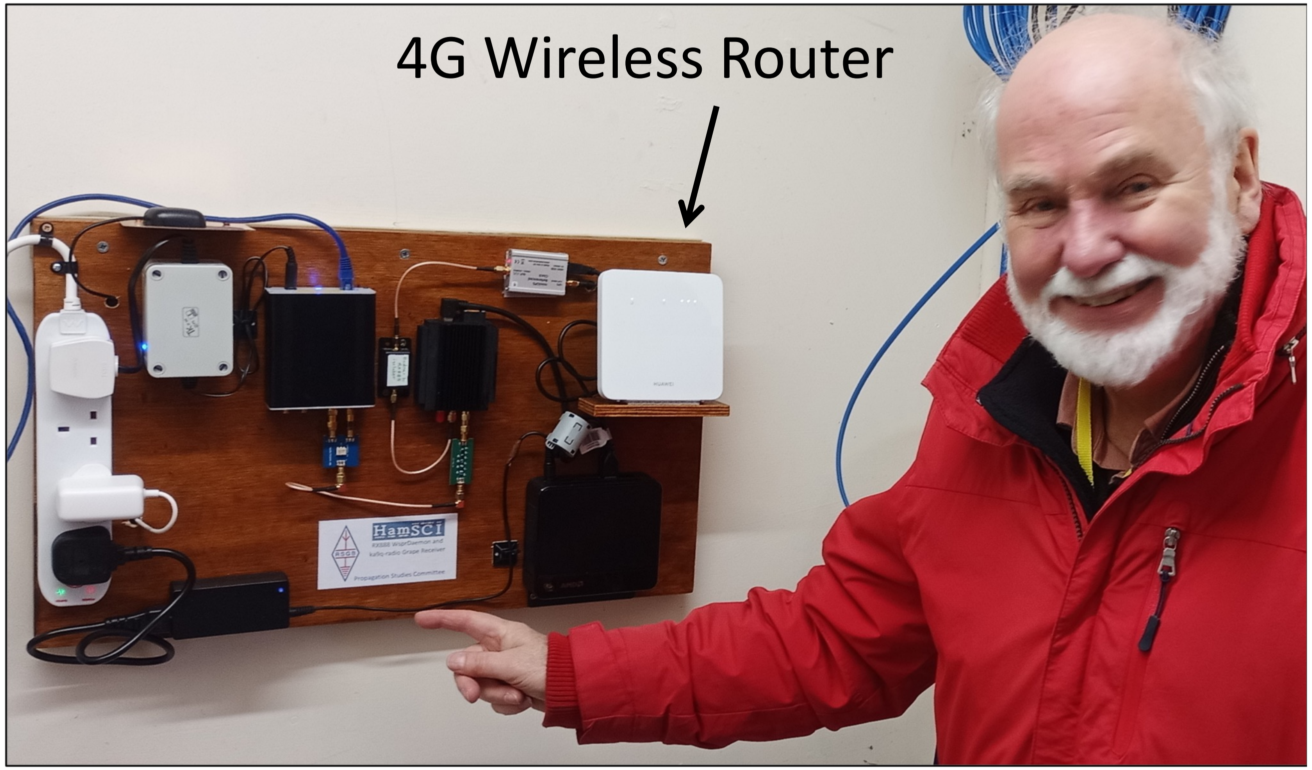


K3LR Western Pennsylvania, USA

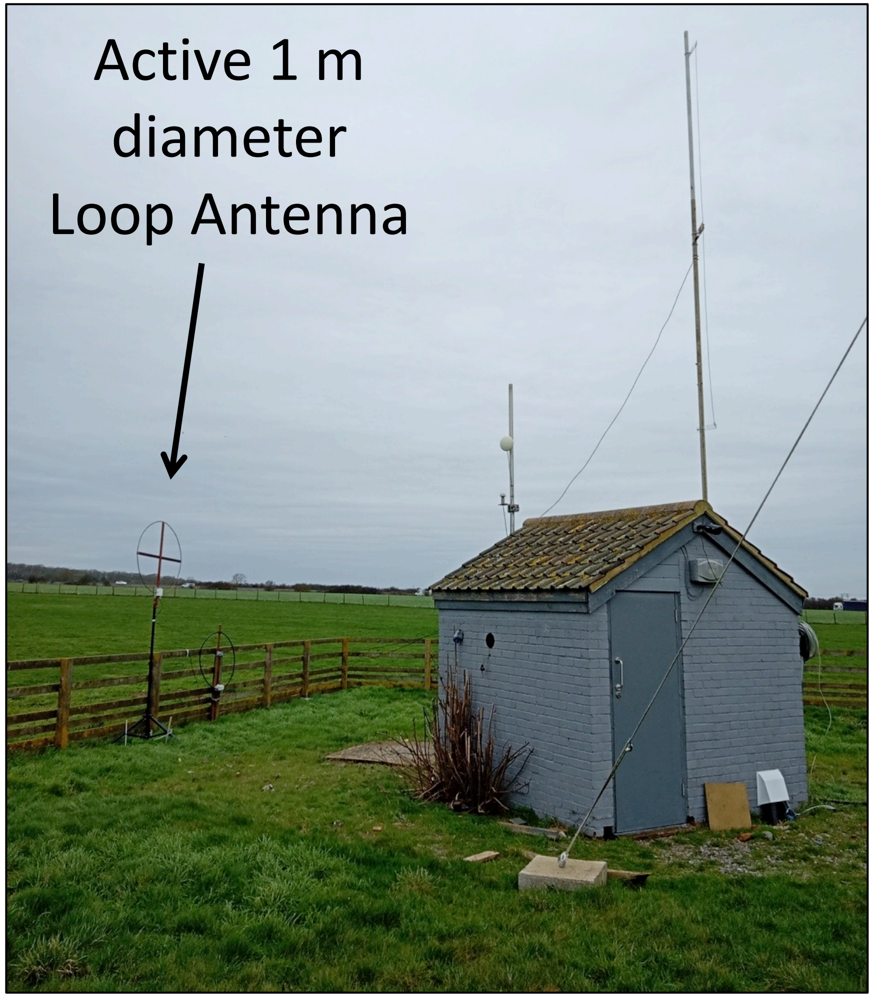
Figure: N. Frissell / HamSCI — used with permission.

- Understand the systems, see https://hamsci.org/psws-overview
- Software quick-start guide https://wsprdaemon.readthedocs.io/en/master/getting_started/quick_start.html
- A broadband antenna you can put up, e.g.
  - Active vertical or loop
  - End-fed wire
  - Off-centre fed dipole
- An Internet connection

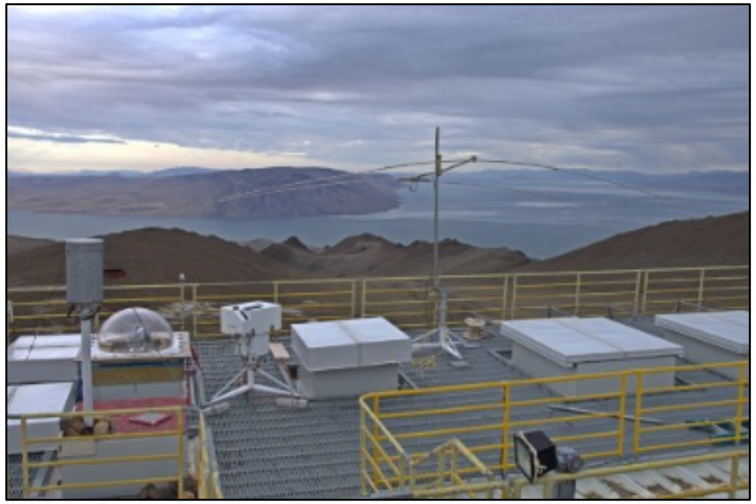
A remote HF receiver in practice: GB0PSC, Baldock, UK



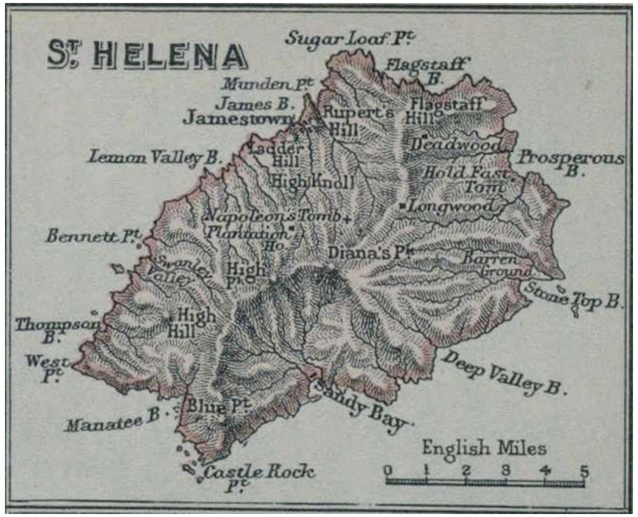
All the modules mounted on a wooden back-board and tested at home prior to remote installation. About 2 GB data per month.



Pole to Pole deployments



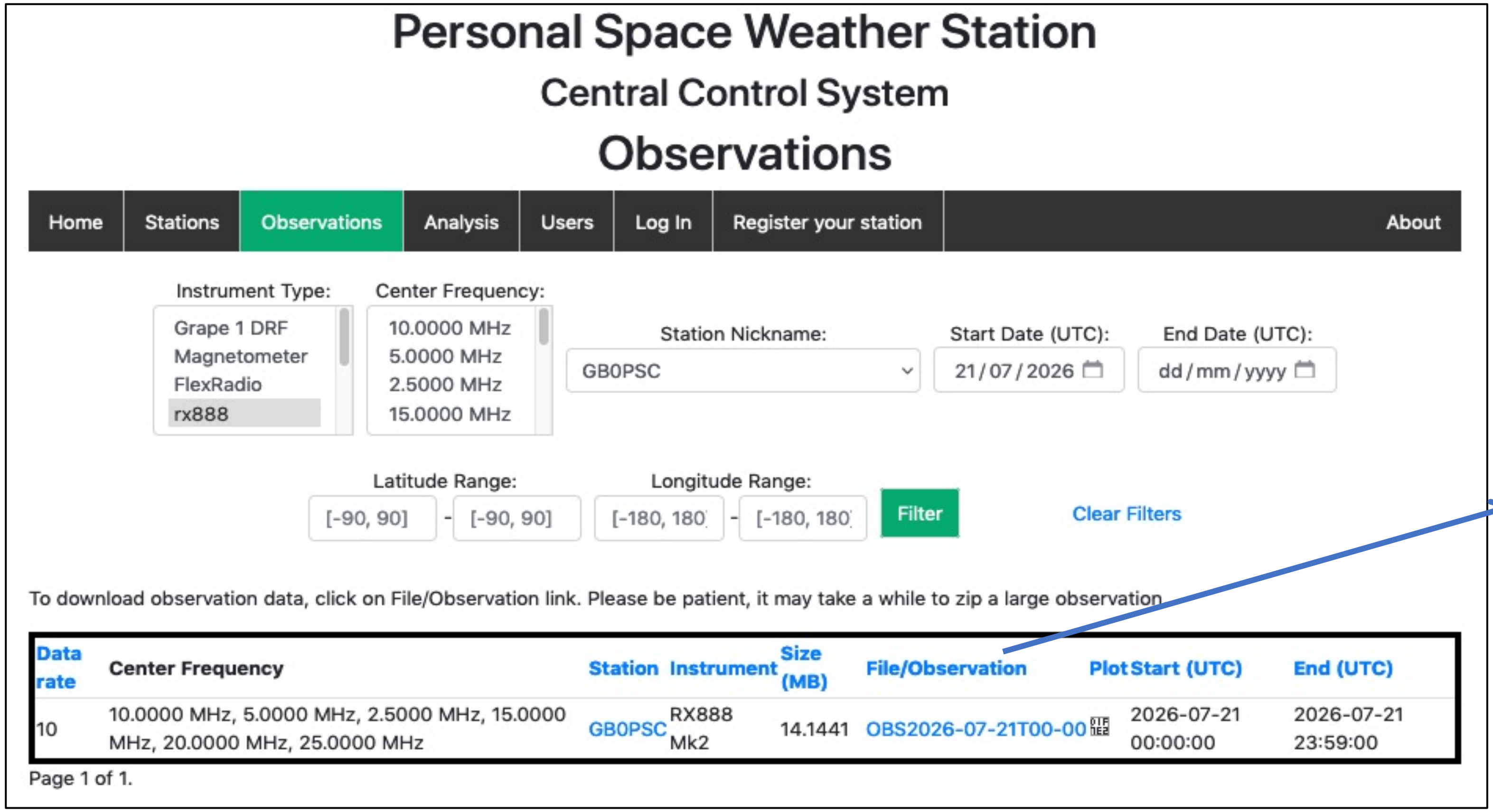
HFRx VY0ERC, PEARL Ridge Lab., Eureka, Ellesmere Island, Nunavut at 80˚N. Photo courtesy Pierre Fogal.



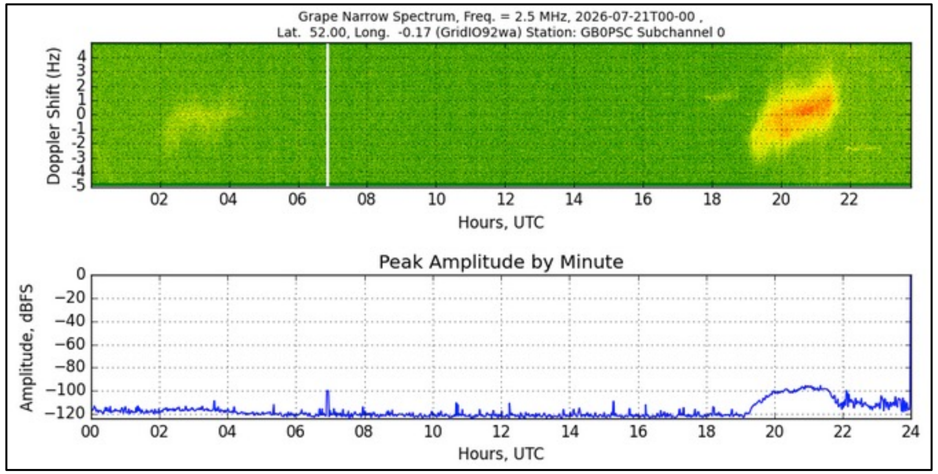
WSPRsonde ZD7GWM using a Yaesu multiband fan dipole. Equipment provided by Gerry Bulger G3WIP. An RX888 HFRx is also on the island but not currently operational.

HFRx and WSPRsonde DP0GVN, Neumayer III station, Antarctica. Photo courtesy Pablo Conrat Fuentes (Alfred Wegener Institut).

Where the data lives and how to see and get it



https://pswsnetwork.eng.ua.edu



Click on File/Observation to get immediate, on-screen HFRx Doppler spectrograms and amplitude plots.

If interested in further processing, toolbox at https://github.com/g3zil/grapeDRF_doppler_model

An Atlas of HamSCI PSWS Doppler Spectrograms

- An initiative of Bob Mattaliano N6RFM.
- Brief introduction to Doppler shift and HamSCI GRAPE receivers
- Main content:
  - **Feature Spectrograms**: Examples of propagation features one-by-one
  - **Event Spectrograms**: e.g. Eclipse, Ionospheric Storm, which include multiple propagation modes

https://spectrogram-docs.readthedocs.io

Spectrograms

Search Go

Navigation

Spectrogram Interpretation

The Ionosphere and HF Propagation

Principles of Operation

GRAPE-1
GRAPE-2
WSPRDaemon GRAPE

Feature Spectrograms

Typical Spectrogram
Surface Wave
One-hop E region propagation
Sporadic E (Es)
One-hop F Region Propagation
Two Hop F Region Side Scatter
Prolonged Two Hop F Region Side Scatter
Dawn Doppler
Travelling Ionospheric Disturbance
SID and Doppler Flash
Solar Eclipse

Prolonged Two Hop F Region Side Scatter

Title: Prolonged Two Hop F Region Sidescatter

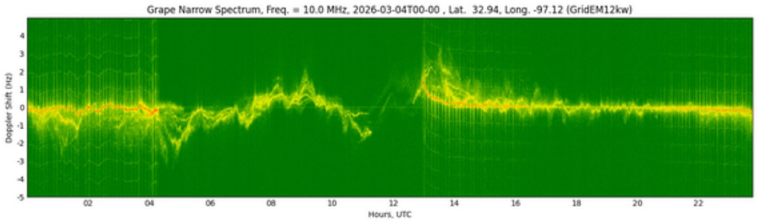
Contributed by: Bob Mattaliano N6RFM with Gwyn Griffiths G3ZIL

Reviewed by:

Receiving Station Location: EM12kw, near Fort Worth, TX 4 March 2026

Receiving Station Details: Grape-1 DRF

Feature Description



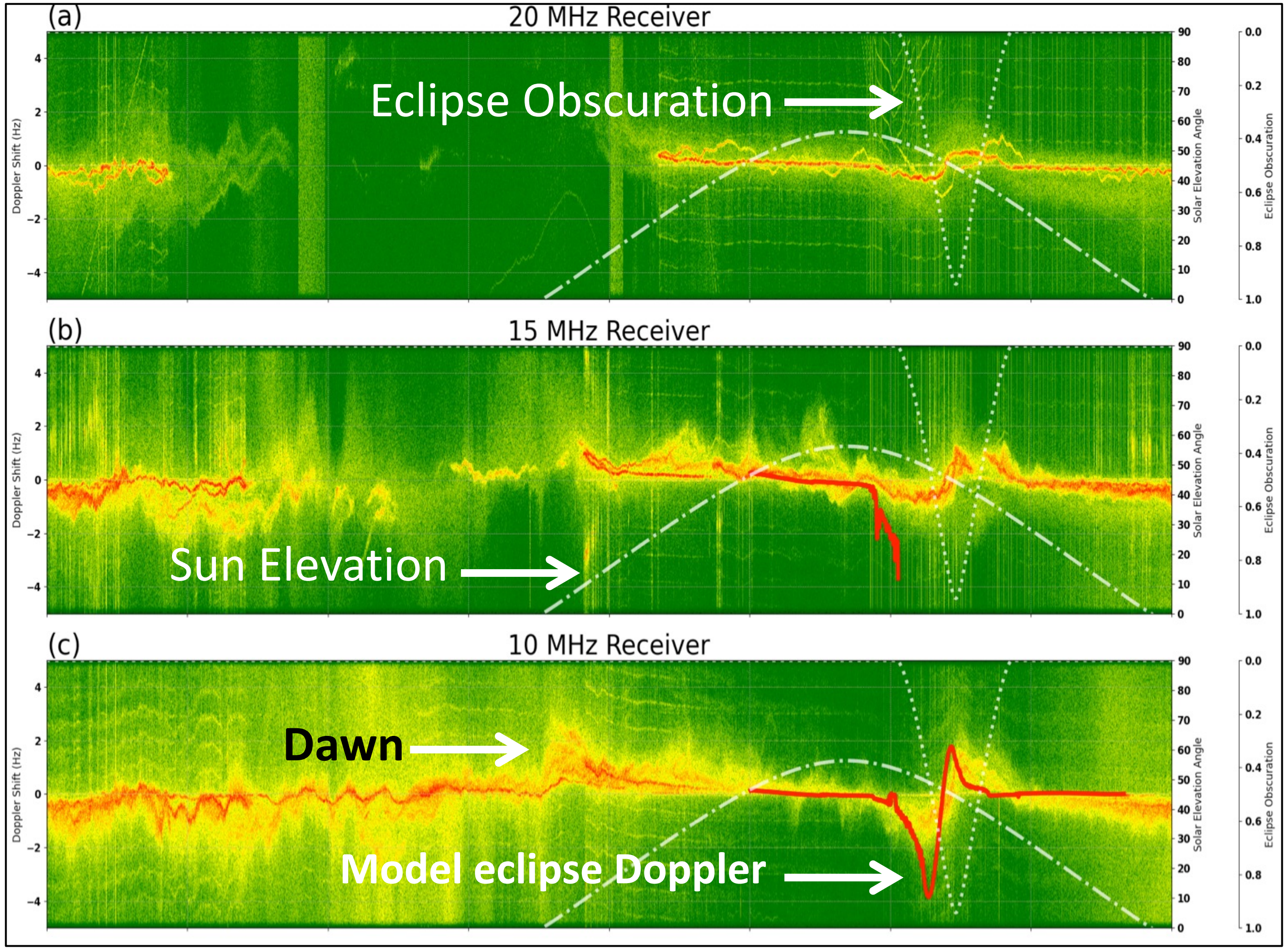
The "Typical Spectrogram" shown elsewhere illustrates the band closing and then opening. This example shows that even when the band is "closed", weak propagatgion can persist. In this case, two-hop F region sidescatter predominates from ~0415Z onward. This mode continues even until after the band re-opens. Since the Doppler shift through the local night is not near zero, it is unlikely to E region propagation.

3D PyLap ray trace modeling can be used to show the likely geographical regions from which two hop sidescatter between a pair of stations could occur. In this case, the maps below show six frames from an animation covering 0300 UTC to 1730 UTC. In these frames the intensity of the red contours relate to likelihood of sidescatter. However, factors such as weather from the sea or land also affect the strength of the sidescatter. At

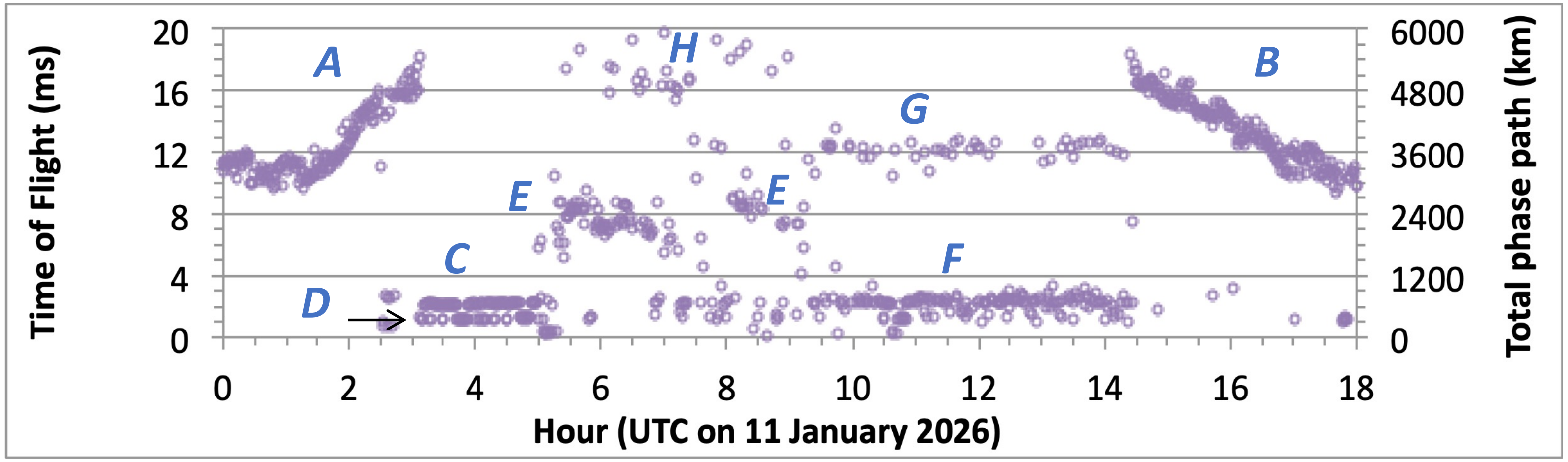
Eclipse Doppler: W2NAF Spring Brook, Pennsylvania, USA

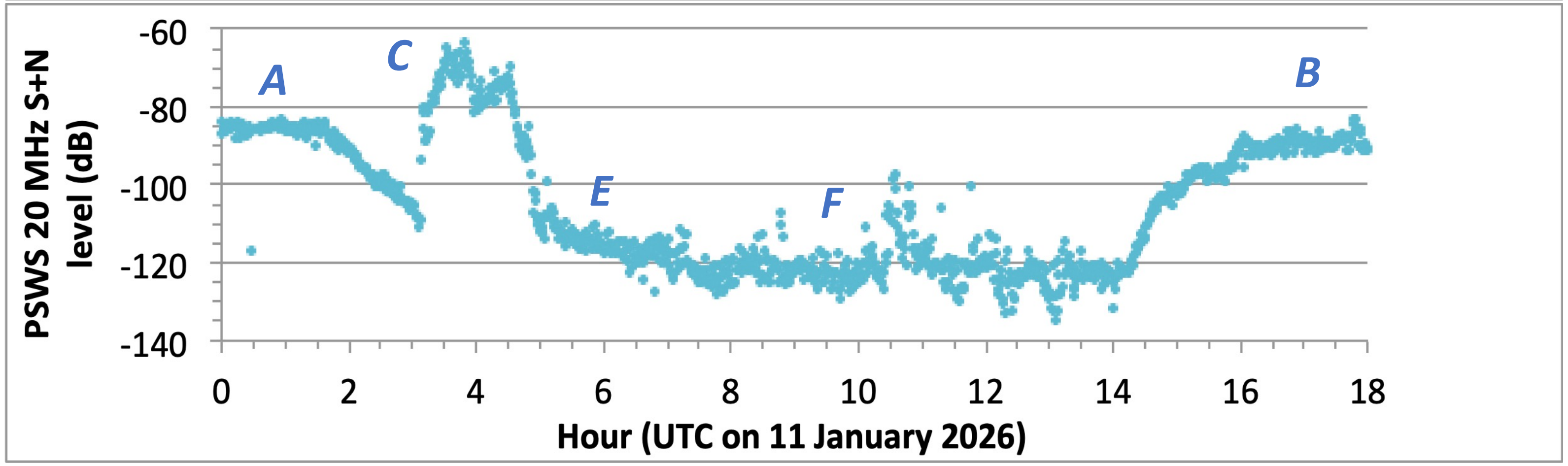
WWV Colorado to W2NAF Pennsylvania, a 2460 km path, on 20, 15 and 10 MHz during the 8 April 2024 total eclipse. Showing:

- **Dawn** - Positive Doppler, reducing, as height of reflection falls.
- **Eclipse** – Negative Doppler as height of reflection rises due to reduced insolation. Followed by positive Doppler as insolation returns and reflection height falls.



Time-of-flight case study: 20 MHz WWV to KA7OEI, 617 km path





Time of flight (top) adds information to signal level (bottom) to deduce propagation modes:

A, B, H: Two-hop sidescatter

C: Sporadic E

D: Bad data, ToF less than minimum possible.

E: Two-hop sidescatter via sporadic E

F: Great circle path forward scatter

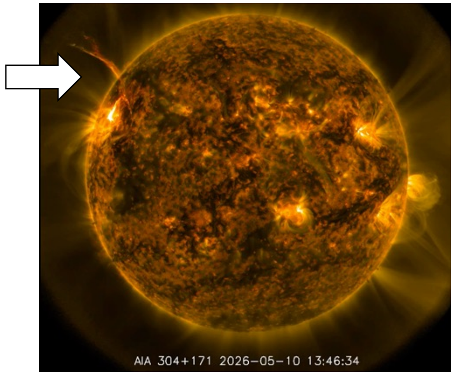
G: Half-hop ionospheric backscatter?

From a precursor to the Turn Island Systems TS1, same principles.

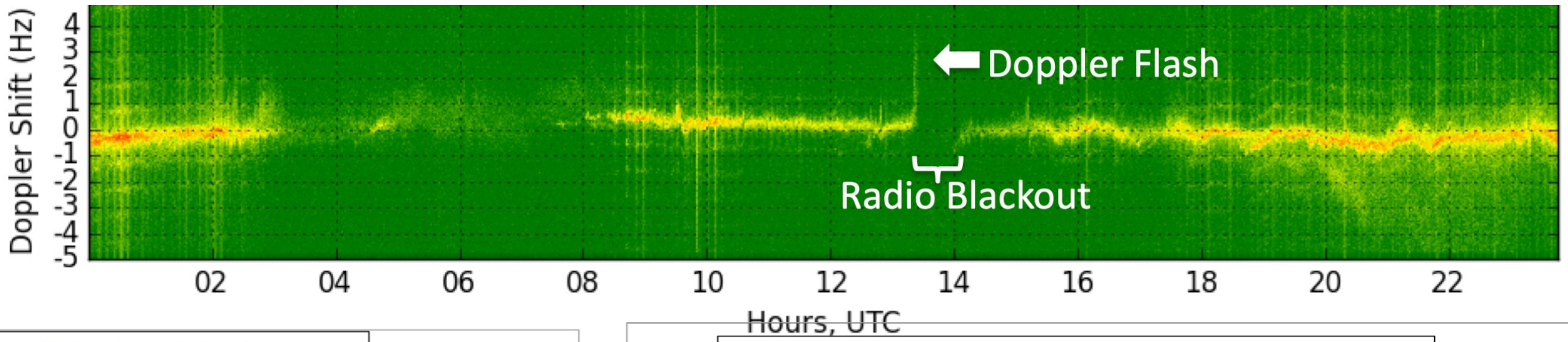
More details at tinyurl.com/mvcp8zkb

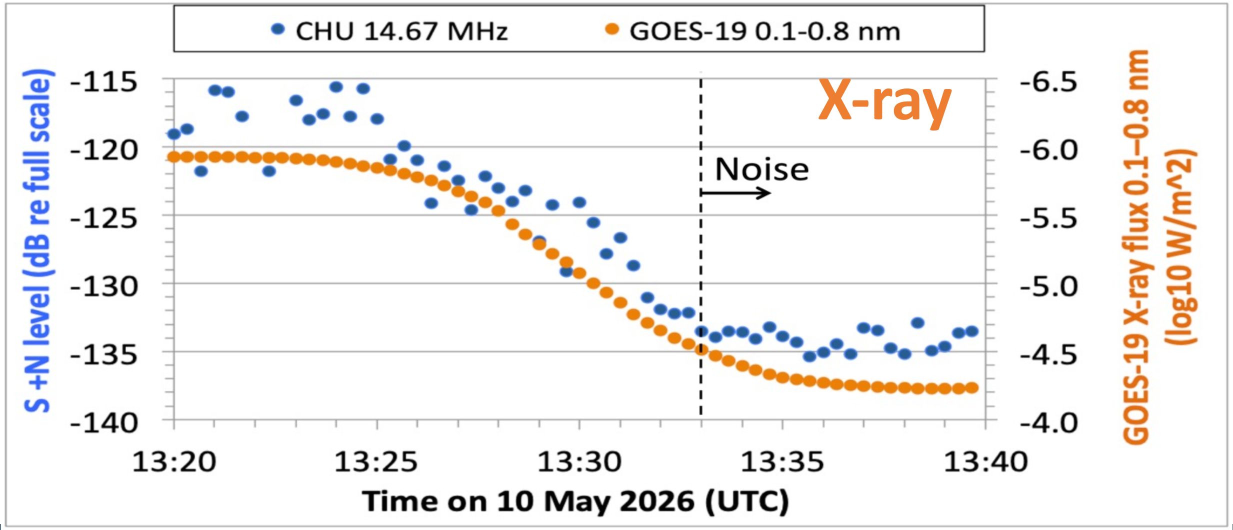
Impacts of Solar Flare on Signal Level and Frequency

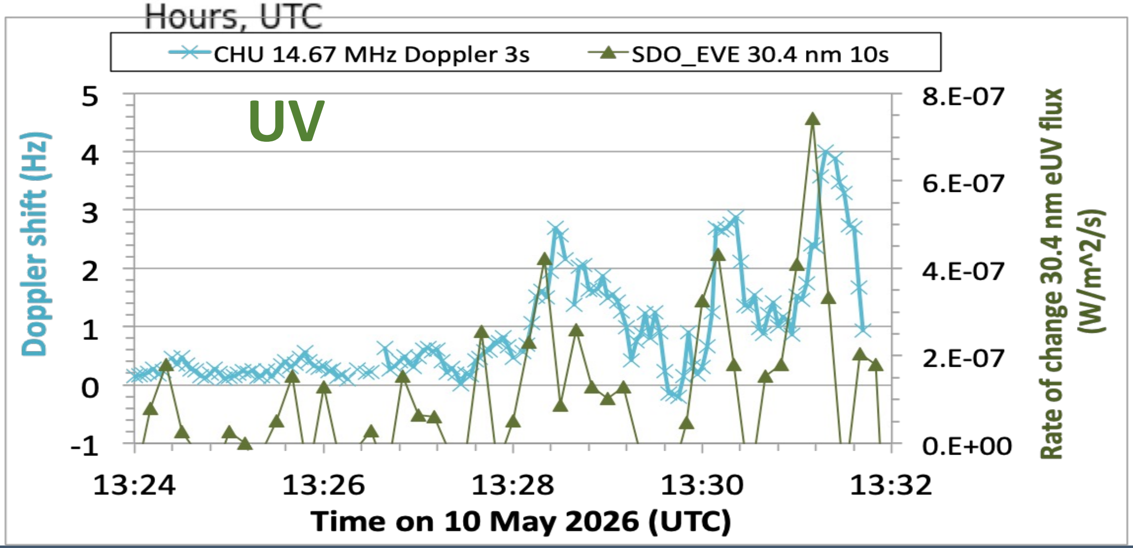
M5.7 Flare 10 May



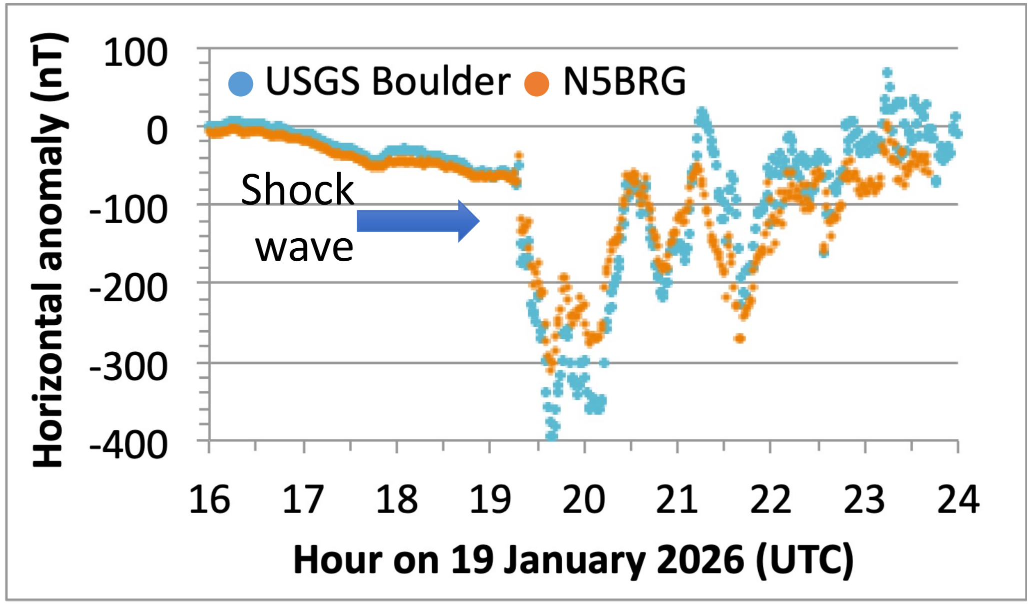
PSWS Doppler spectrogram of CHU, Canada on 14.67 MHz at GB0PSC, Baldock UK







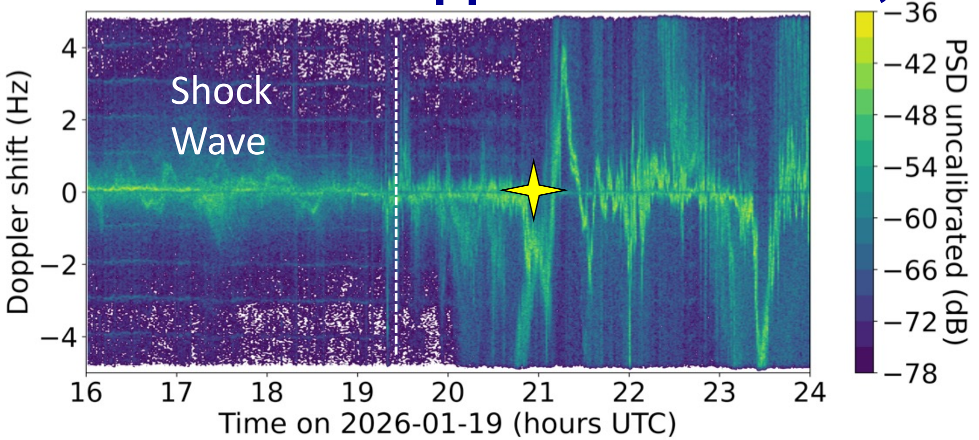
Geomagnetic storm: Magnetometer and Doppler shift



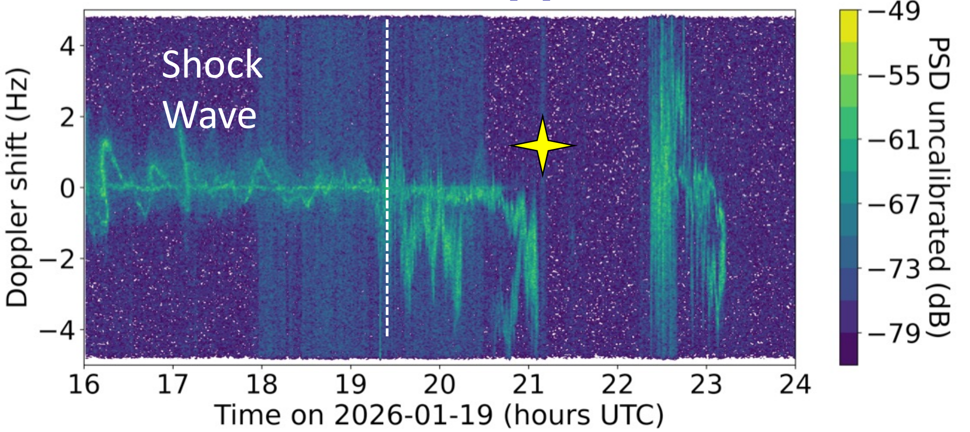
Step-down in horizontal magnetic field anomaly at 19:19 UTC as Coronal Mass Ejection shock wave impacts Earth's magnetosphere. Followed by G4 geomagnetic storm with Kp6-8.

Ionospheric storm (Doppler shift) begins at shock-wave but **major impacts delayed** .

10 MHz WWV Doppler shift N5TNL, Arkansas



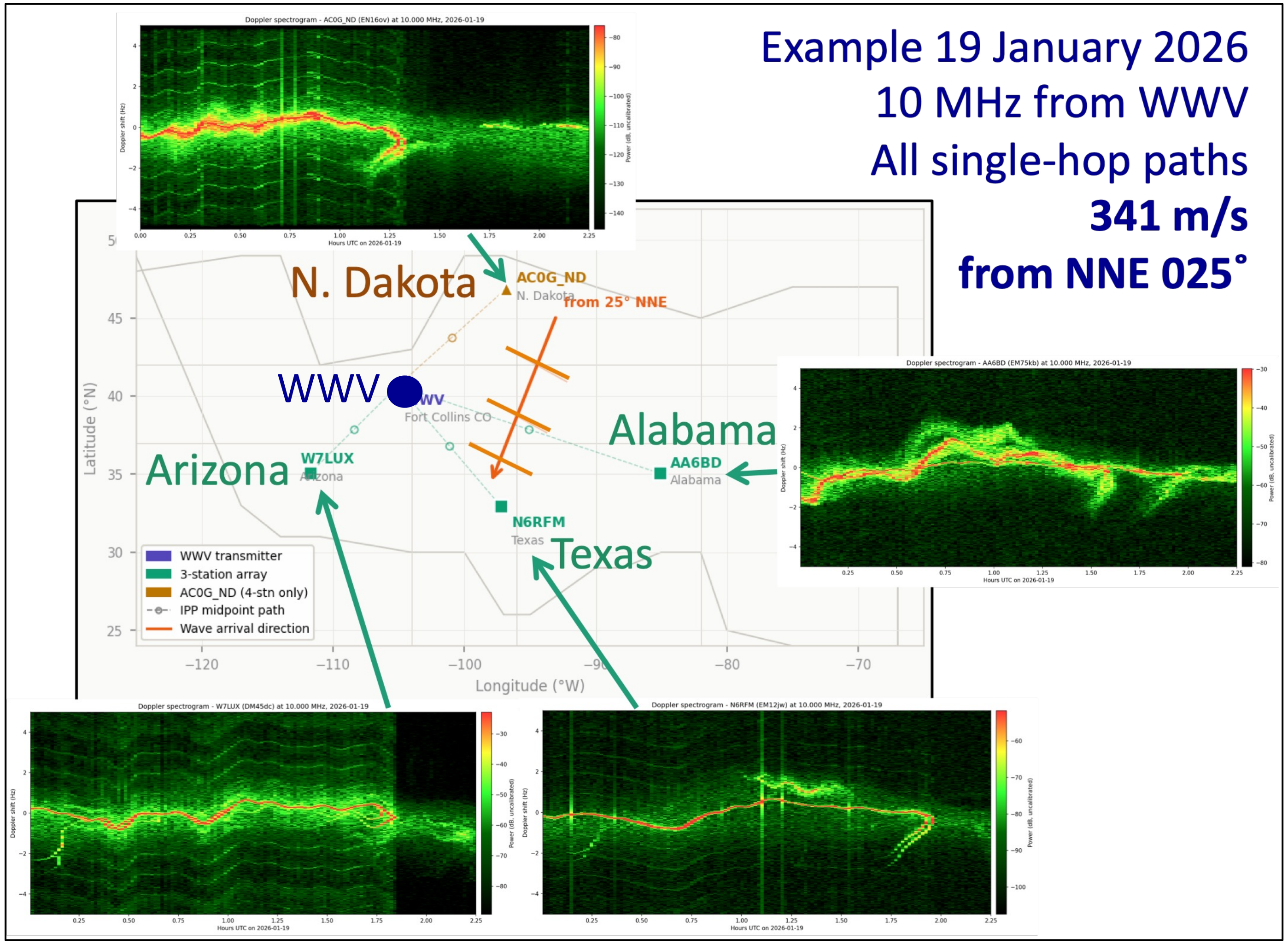
14.67 MHz CHU Doppler shift N5TNL, Arkansas



Large Scale Travelling Ionospheric Disturbance across the network

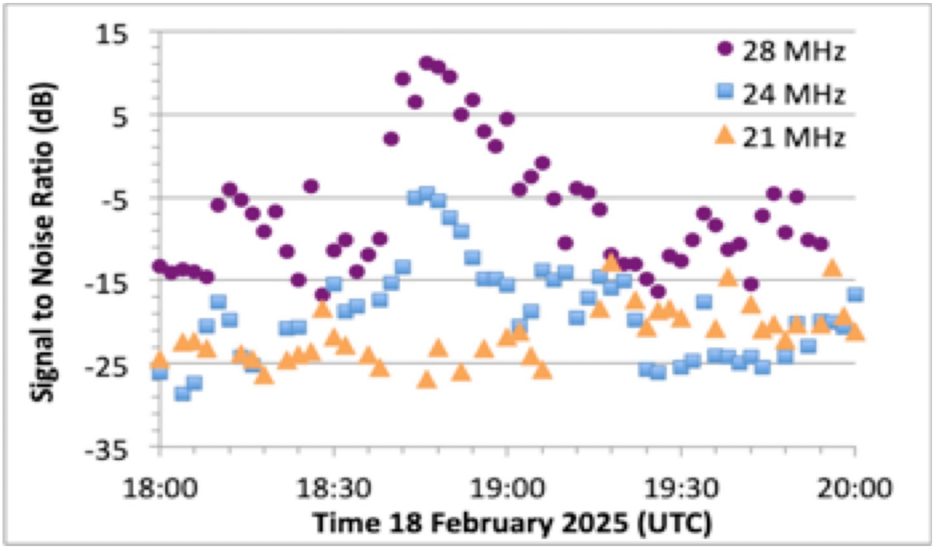
- Bob Mattaliano, N6RFM has an *experimental* Python toolbox to analyze Doppler shift across a *network* of PSWS stations.
- Doppler is extracted from multiple spectrograms and cross correlation finds most likely time delays between station pairs.
- Geometry, and assuming plane wave, gives estimates of speed and direction.

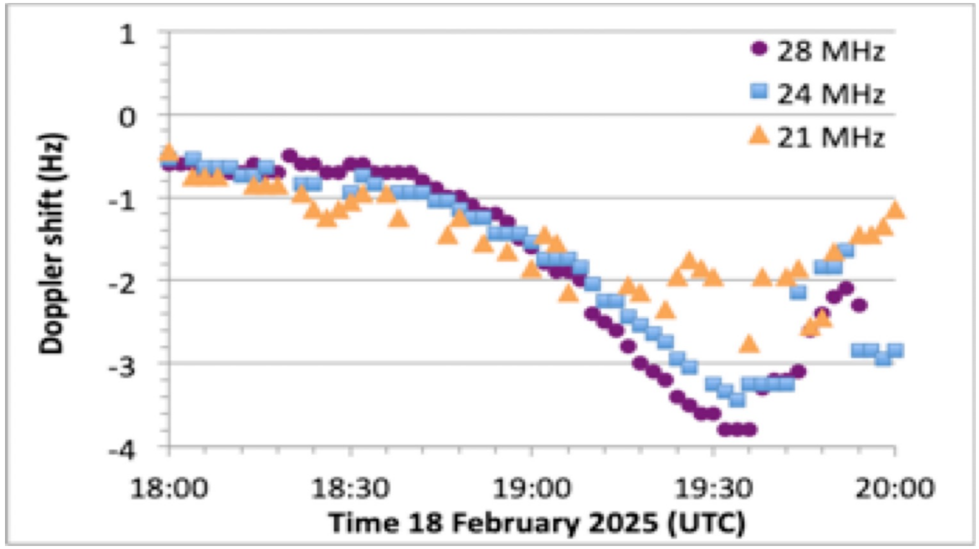
https://github.com/N6RFM/psws-drf-tid-tools

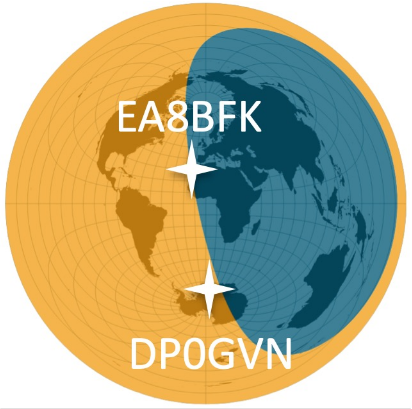


Advantages of WSPRsonde: Multiband and every two minutes

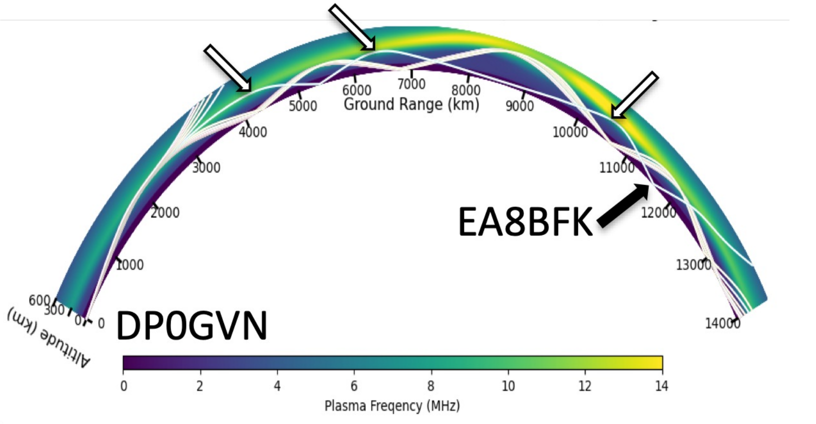
DP0GVN, Antarctica to EA8BFK, Canary Islands







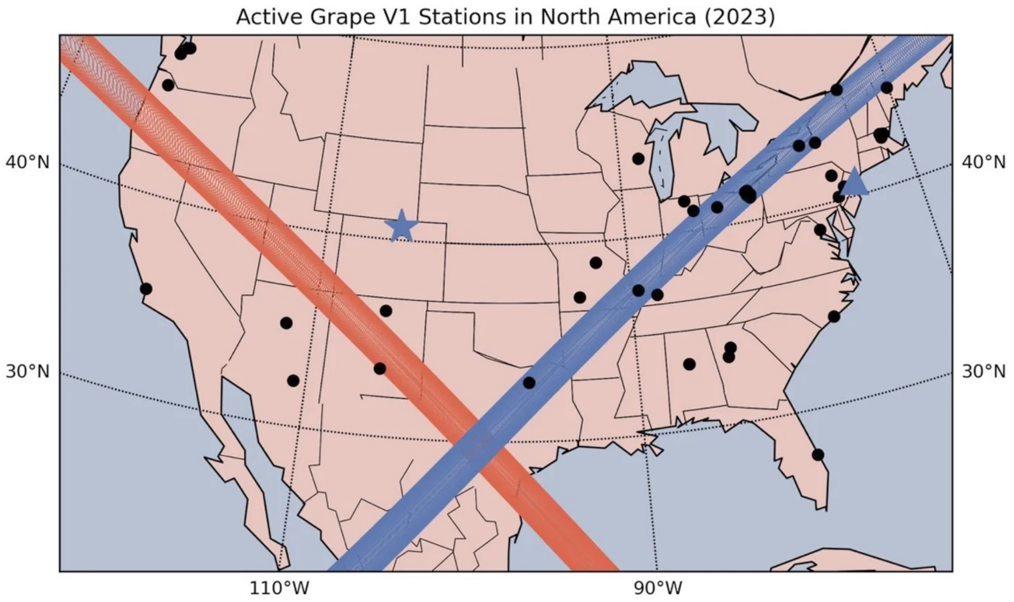
WSPRSonde transmissions each 2-minutes simultaneously on multiple bands capture detail on a short-lived ducted and chordal-hop grey-line propagation event.



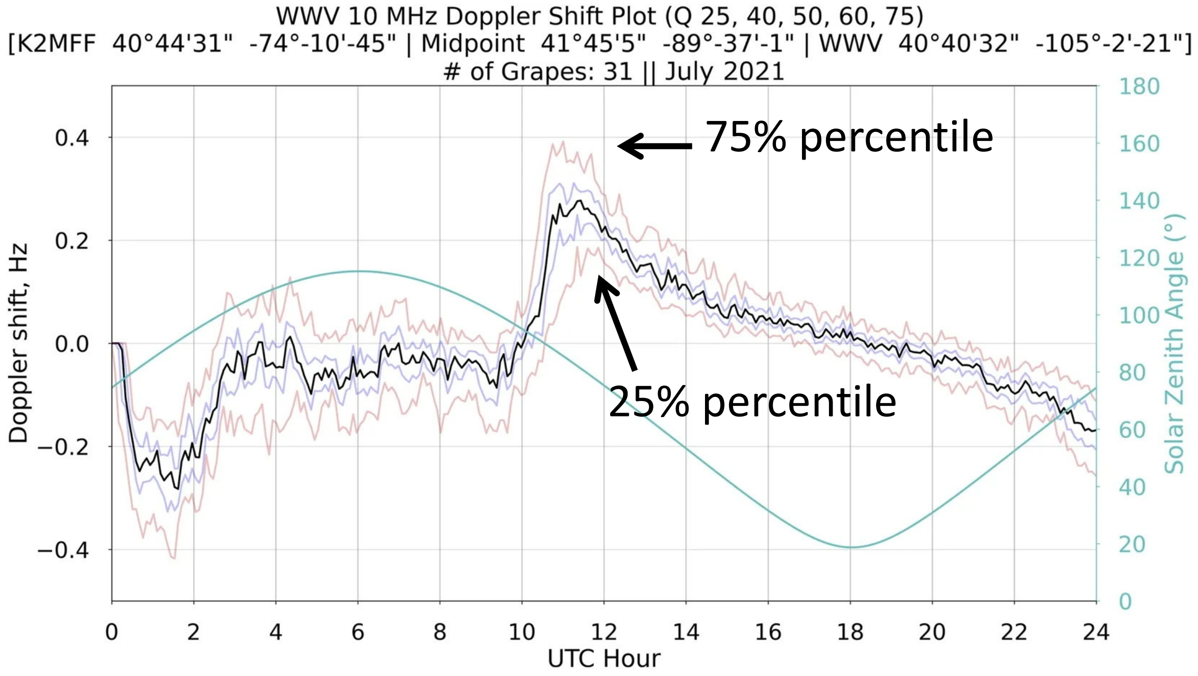
Published science: https://hamsci.org/publications

Fernandes, S., Perry, G.W., Trigo, T., Frissell, N.A., Gibbons, J. and Collins, K., 2026. Characterizing ionospheric variability through HF Doppler measurements: a statistical and numerical ray tracing analysis. *Frontiers in Astronomy and Space Sciences*, 13, p.1713968.

Open access at: https://www.frontiersin.org/journals/astronomy-and-space-sciences/articles/10.3389/fspas.2026.1713968/pdf



HamSCI receivers (black dots) reporting during the October 2023 (red) and April 2024 (blue) eclipses.



Doppler statistics across month of July 2021

Roadmap: Projects in the Pipeline

- RX-888 successor (WB6CXC for TAPR)
  - Truly open source from TAPR
  - Better anti-alias filter and MF/LF performance
  - Improved heat management and proper input for external clock
- GitHub code migration to HamSCI org repository — Sigmond development in the open.
- Time-referenced WSPR/FST4W beacons for network-wide ToF.

Image courtesy Paul Elliott, TAPR, WB6CXC

CLOSE

Build one — Join HamSCI — Join the Network

- Join the HamSCI Community
- Start with any single component.
- Resources:
  - hamsci.org/get-involved
  - hamsci.org/psws-overview
  - pswsnetwork.eng.ua.edu
  - wsprdaemon.org
  - hamsci-psws Google Group.

≈ $700
entry HF receiver

≈ $1,500
science-grade station

Delegates, HamSCI Annual Workshop, Newark, New Jersey, 2025

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