THE UNIVERSITY OF SCRANTON
A JESUIT UNIVERSITY

Multi-Band GNSS-Disciplined WSPR and HF Doppler Ionospheric Observations Using the RX-888, KA9Q-Radio, WSPRDaemon, and the WSPRSonde

***Nathaniel A. Frissell W2NAF[1★]**, Rob Robinett AI6VN[2★], Paul Elliott WB6CXC[3★], Gwyn Griffiths G3ZIL[2★], Phil Karn KA9Q[★], John Gibbons N8OBJ[4★], William D. Engelke AB4EJ[5★], Stephen Cerwin WA5FRF[★], and the HamSCI Community*

[1]The University of Scranton, Scranton, Pennsylvania, USA
[2]wsprdaemon.org, Half Moon Bay, CA, USA
[3]Turn Island Systems, Friday Harbor, WA, USA
[4]Case Western Reserve University, Cleveland, OH, USA
[5]The University of Alabama, Tuscaloosa, AL, USA
[★]HamSCI Community

HamSCI http://hamsci.org

nathaniel.frissell@scranton.edu

Need for an Affordable Scientific SDR

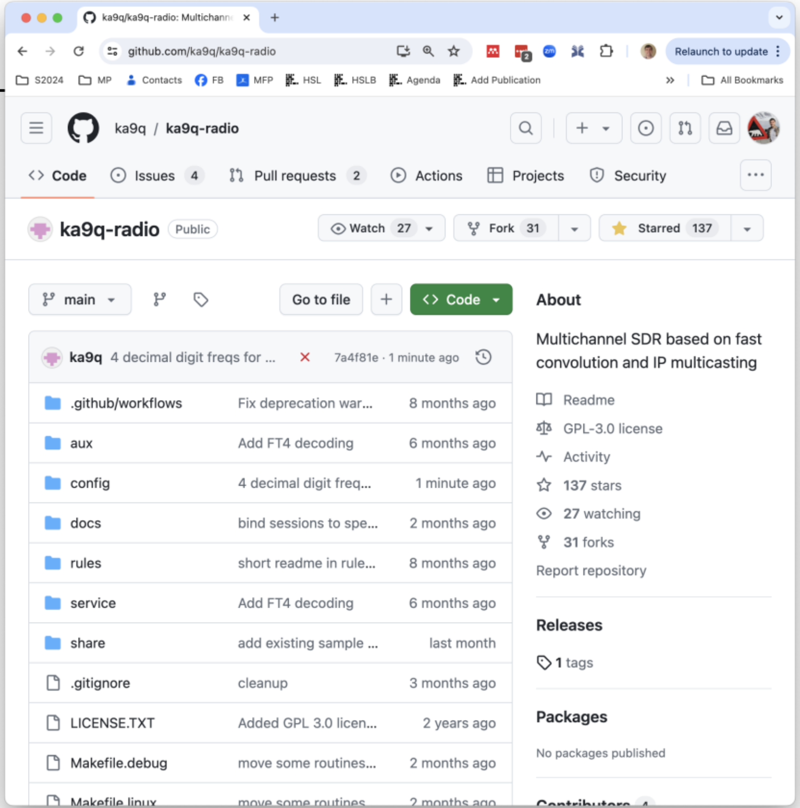
- HamSCI observations primarily rely on passive receivers.
- Ideal receivers could sample full bandwidth from DC through 50 MHz with precision frequency and timing measurements.
- IQ data from such a system could be derived into multiple types of measurements.
- Commercial receivers with this capability (e.g., Ettus USRP) are prohibitively expensive for amateurs (> US $3000).
- Amateur receivers are often affordable, but do not meet bandwidth or frequency/timing precision requirements.
- Grape v1/v2 provide precision frequency measurements, but are specialized, narrowband receivers specifically for HF Doppler measurements.

First Approach: TangerineSDR

- HamSCI/TAPR tried addressing these issues with the FPGA-based TangerineSDR.
- Needed FPGAs were expensive, difficult to obtain, difficult to program, and required proprietary programming software.
- This approach did not work.

KA9Q-Radio

- **TAPR/HamSCI member Phil Karn KA9Q developed KA9Q-radioKA9Q-radio using fast convolution for multichannel reception**
  - Code is fast enough to run well on a low- to moderate performance conventional CPU
  - Can produce hundreds of arbitrary bandwidth slice receivers from the input bandwidth.
  - Does this by computing FFT of the A/D input stream, selecting ranges of frequency bins and computing the inverse FFT
  - The forward FFT is shared by all slices. Individual slices are computationally cheap.



https://github.com/ka9q/ka9q-radio

GPL v3

RX-888 MkII SDR

- Rob Robinett AI6VN realized that KA9Q-radio with the RX-888 MkII and a GPSDO could meet many of the requirements for the HF SDR Receiver.
    1. LTC2208 16bit ADC @ 130 MSPS
    2. HF Input Frequency Range: 1 kHz-64 MHz
    3. HF Maximum Bandwidth: 64 MHz
    4. External 27 MHz reference clock support

    https://www.cqdx.ru/ham/new-equipment/sdr-receiver-rx-888-mkii/
- ~US $250 on Amazon

https://www.amazon.com/Receiver-Luminum-Industrial-Beautiful-1kHz-64Mhz/dp/B09FZW89L8

WSPRDaemon-Grape System Goals

AI6VN’s Goal: Create an SDR system that

- Measures WWV/H and CHU propagation with same sensitivity and accuracy as the HamSCI GRAPE 1/2 receivers
- Has end-to-end frequency accuracy and stability must be much better than the doppler shift introduced by ionospheric motion
- Simultaneously measures WSPR-2 frequency and doppler shift on all 15 WSPR bands, and upload to wsprnet.org and wsprdaemon.org
- Simultaneously records all 10 WWV/CHU carrier frequencies and upload to the HamSCI GRAPE servers

http://wsprdaemon.org/

nathaniel.frissell@scranton.edu

WSPR and WSPRDaemon

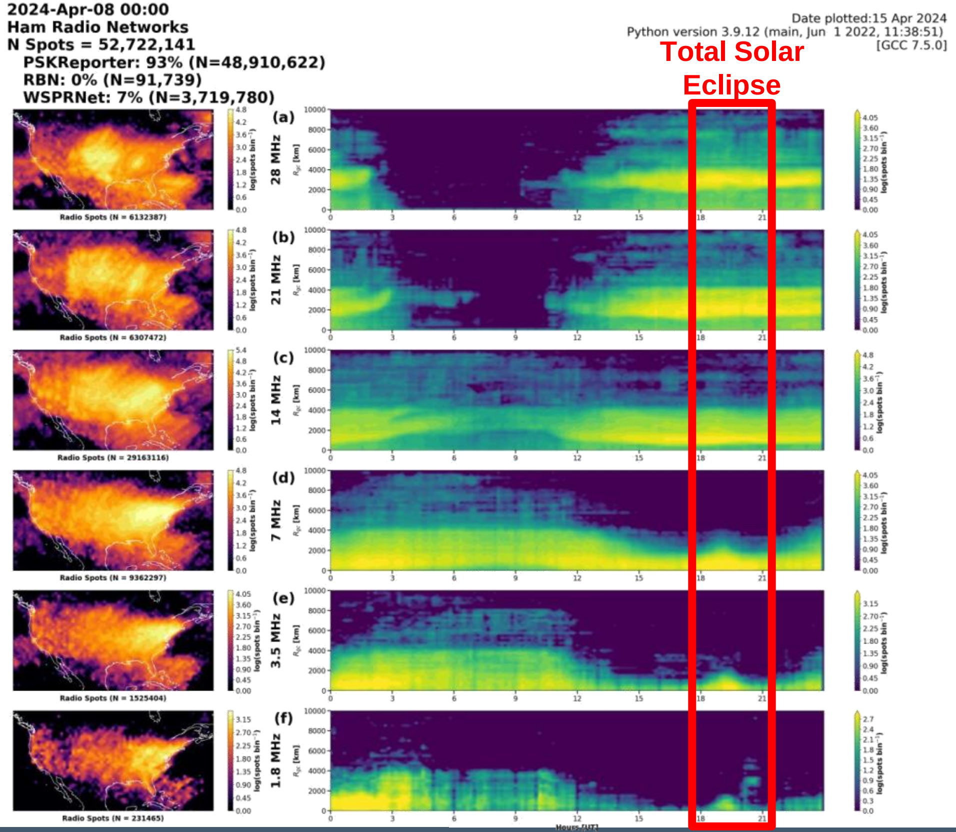
- Weak Signal Propagation Reporter (WSPR) is an amateur radio digital digital mode developed by Joe Taylor that can probe lower-power HF paths through the ionosphere.
- WSPRDaemon is an advanced WSPR decoder developed by Rob Robinett AI6VN, Gwyn Griffiths G3ZIL, et al.
- Unlike the standard WSPR decoder, WSPRDaemon can
  - Measure Noise
  - Derive true signal strength from SNR and measured noise
  - Use GNSS-disciplined receivers to measure Doppler spread on FST4W spots

power decoding
wspr daemon

http://wsprdaemon.org/

WSPR, RBN, & PSKReporter Eclipse 2024 Observations

- WSPRNet (along with PSKReporter & RBN) provide real-time, quasi-global views of HF propagation and ionospheric dynamics.
- This example shows impacts of the 8 April 2024 Total Solar Eclipse on CONUS HF propagation.

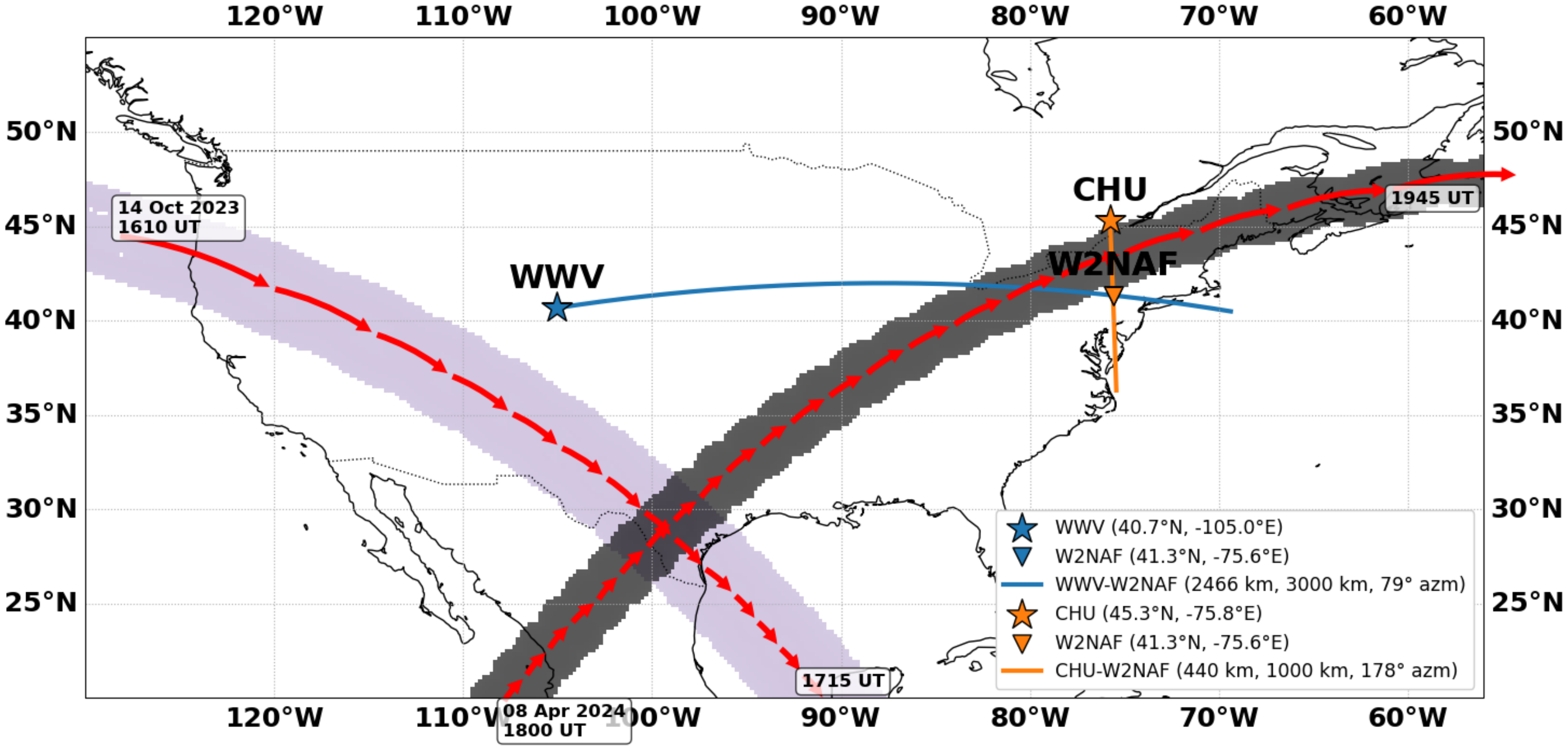


A complete WSPR+GRAPE Receive Station

- **GPSDO**
  - Leo Bodnar mini GPSDO $175 https://v3.airspy.us/product/lb-gpsdo-mini/
  - TAPR GERT (target) $100
- **HF SDR: RX888 MkII**
  - Amazon (next day) $250 https://www.amazon.com/dp/B09FB425CQ
  - AliExpress (China) $160 https://www.aliexpress.us/item/3256803776884712.html
- **Linux x86 server**
  - Lenovo Thinkcentre Tiny i5-6500T for $120 https://www.amazon.com/dp/B07XFH6YXZ
  - Beelink SER 5 with Ryzen 5 5560U for $240 https://www.amazon.com/dp/B0CRL3PL4X
- **GPSDO Interface Kit**
- **Turn Island System 30 MHz Low Pass Filter**
- **LNA & Antenna**

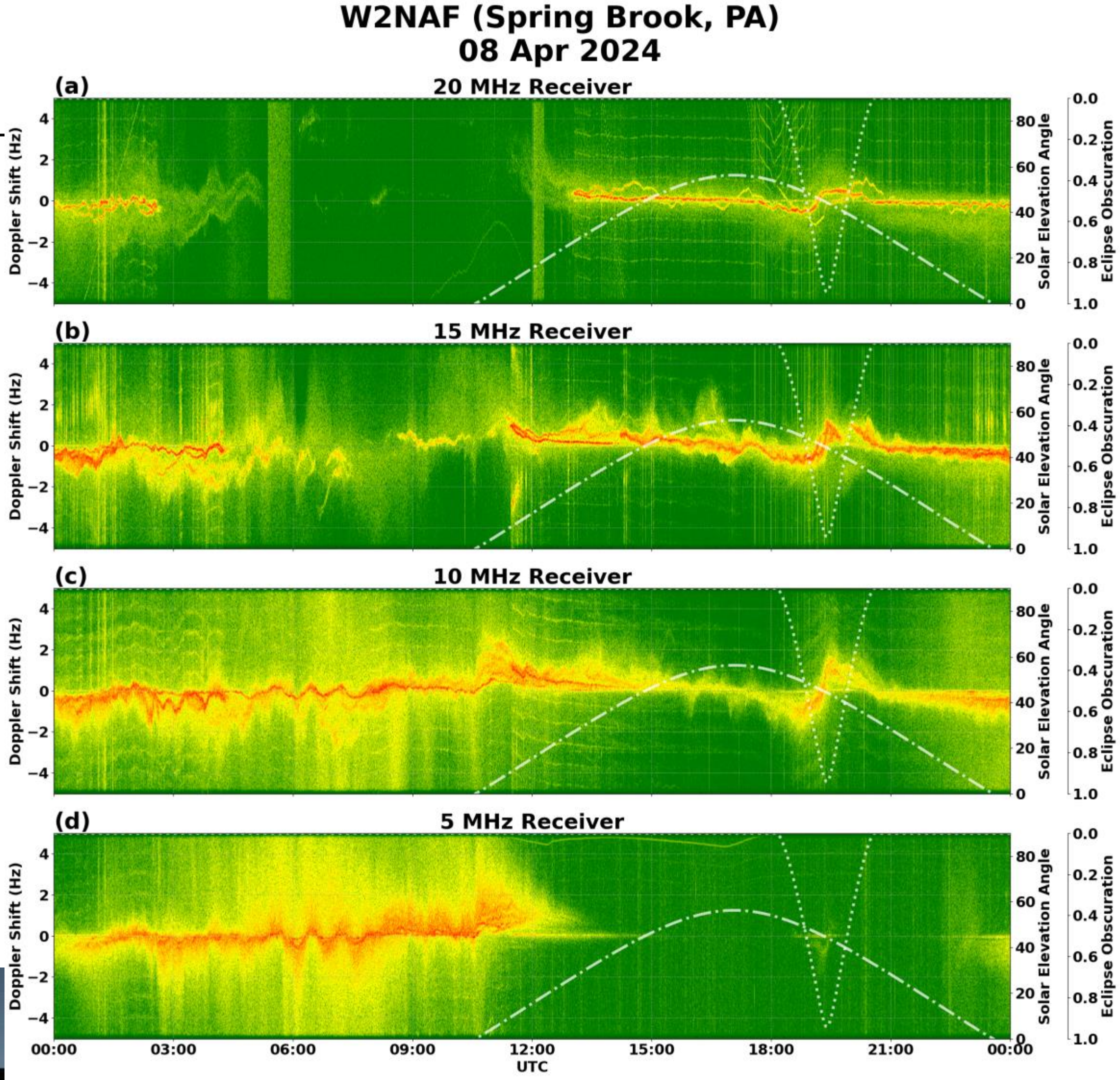
nathaniel.frissell@scranton.edu

WWV-CHU-W2NAF

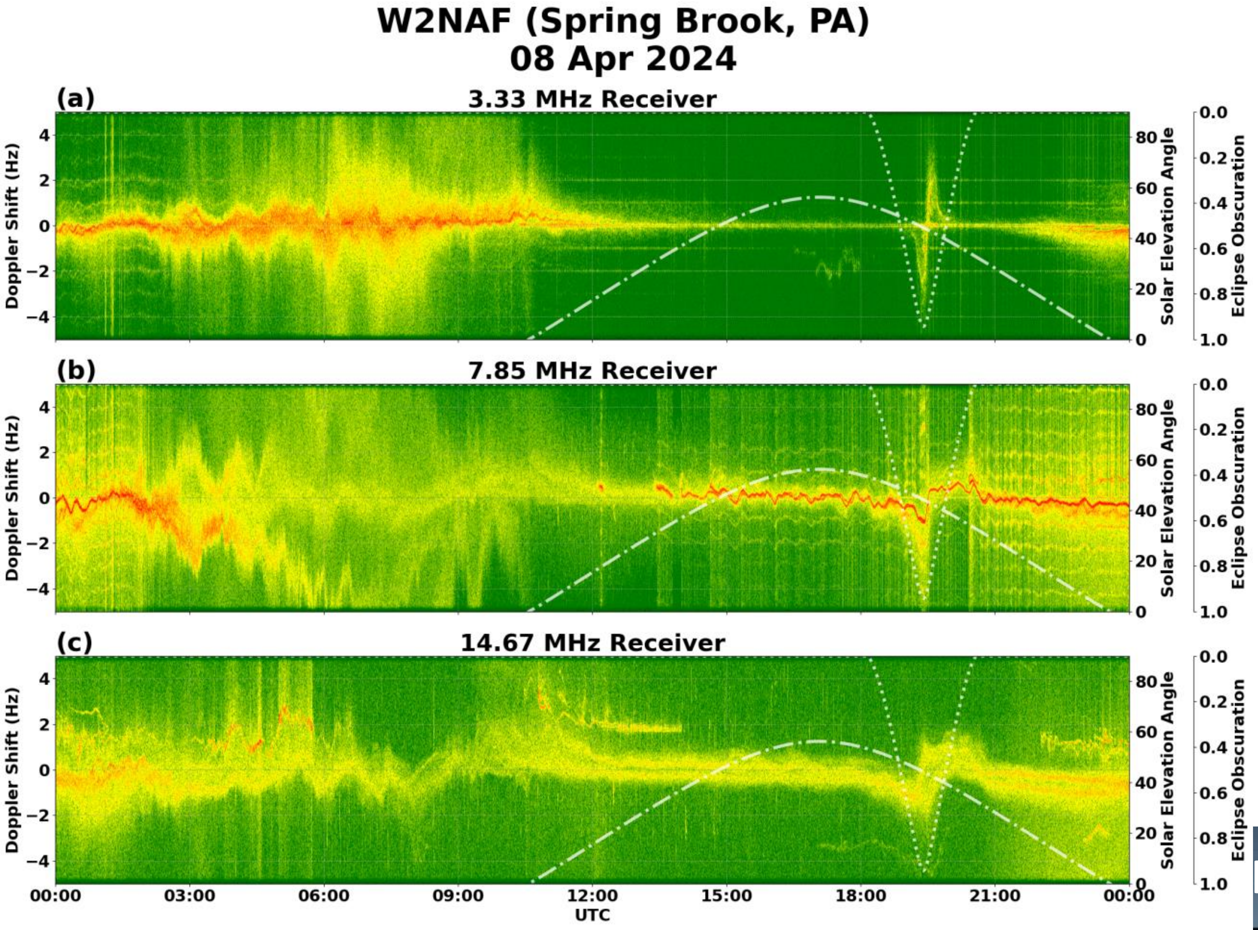


WWV → W2NAF

8 April 2024
HF Doppler

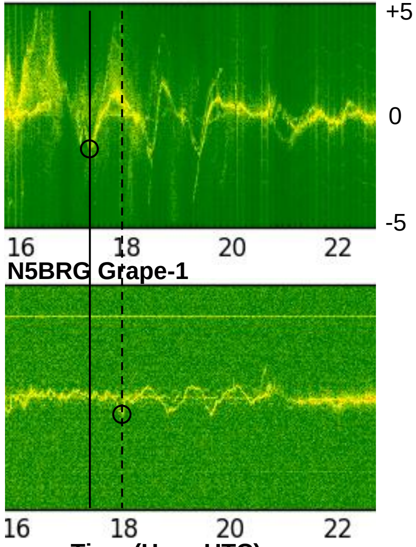


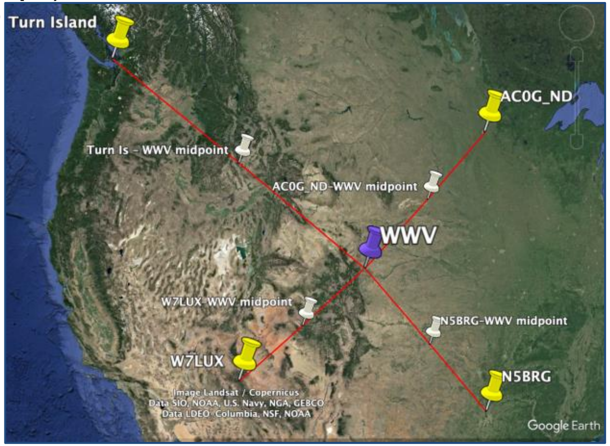
CHU → W2NAF 8 April 2024 HF Doppler

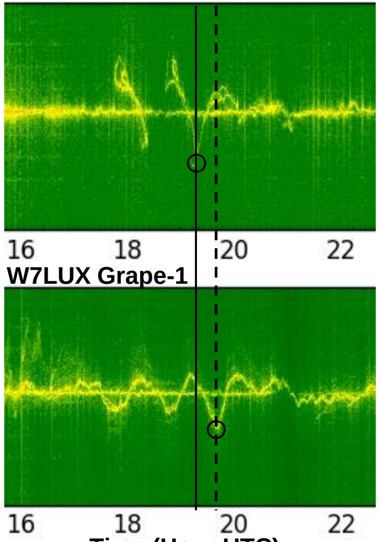


Spectacular Large Scale Travelling Ionospheric Disturbance across N. America
19:00 UTC 17 May 2024

Provisional graphical analysis of period, velocity and wavelength from 10 MHz Grape & RX888 spectrograms



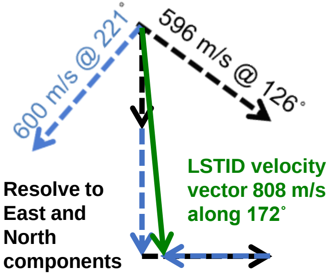




Vector sums:
V_{north} = -803 m/s
V_{east} = +88 m/s
to give
TID phase speed vector:
~808 ±80 m/s along 174˚±6˚

Period from spectrograms:
~ 57–61 minutes

Horizontal wavelength from product of phase speed and period: ~ 2860 ±300 km



Resolve to East and North components then add.

Path 1 WWV to Turn Island, WWV to N5BRG

1360 km between midpoints along 126˚
First max. negative Doppler 38 minutes later at N5BRG than at Turn Island.
Velocity 596 ±60 m/s along 126˚

Path 2 WWV to AC0G_ND, WWV to W7LUX

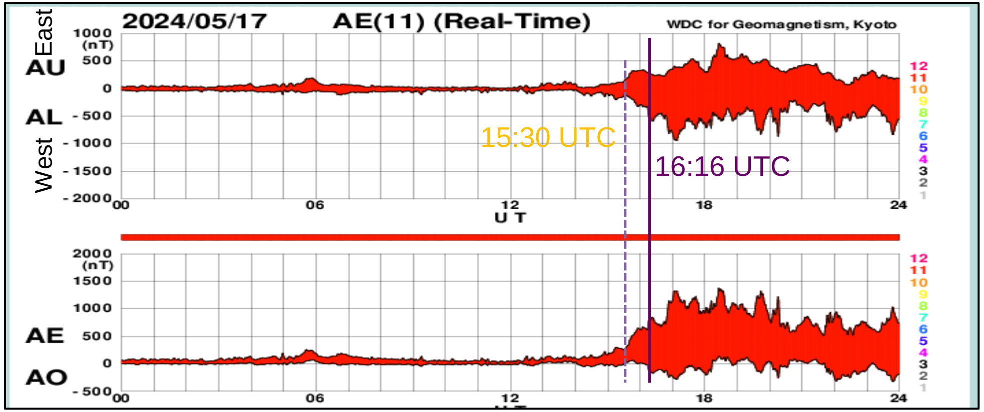
900 km between midpoints along 221˚
Matching negative Doppler 25minutes later at W7LUX than at AC0G_ND.
Velocity 600 ±60 m/s along 221˚

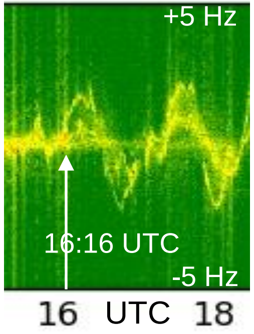
With thanks to Paul Elliott, Rob Robinett, Michael Hauan, Joe Hobart, Robert Stricklin Jr. and the HamSci PSWS database.

Analysis V1 by Gwyn Griffiths G3ZIL.

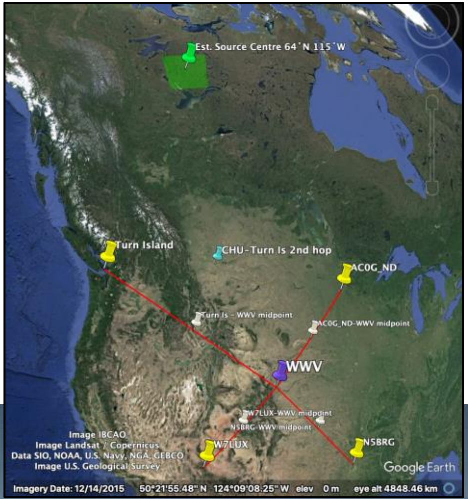
nathaniel.frissell@scranton.edu

LSTID across N. America 19:00 UTC 17 May 2024
Auroral Electrojet Index and *provisional* graphical backtrack trace to possible source region





CHU 14.67 MHz at Turn Island



- Line at 16:16 UTC is positive-Doppler step on two-hop ~3600 km path CHU to Turn Island RX888 at 14.67 MHz. This is the most northerly path. Estimated refractions at 47˚53'N 86˚50'W and 49˚33'N 111˚15'W.
- Auroral Electrojet index *AE* (*AU-AL*) rose from ~260 nT to ~630 nT between 15:30 and 15:54 UTC.
- Assuming LSTID initiated mid-rise at 15:42 UTC, seen at 49˚33'N 111˚15'W at 16:16 UTC and velocity 808 m/s at 174˚ estimate initiated at 64˚N 115˚W, with error estimates leading to wider source region.
- But this assumes parallel wave fronts over the measurement area, more likely to be curved.

Auroral electrojet graphic from https://wdc.kugi.kyoto-u.ac.jp/ae_realtime/202405/index_20240517.html
Contact on AE: Prof. Ayako Matsuoka (wdc-service@kugi.kyoto-u.ac.jp)
Analysis by Gwyn Griffiths G3ZIL

Need for a GPSDO Amateur Beacon TX

- Precision frequency measurements require precision frequency on both transmit and receive.
- Grape receivers rely on government standards stations such as WWV, WWVH, and CHU.
- These are great, but they are only at fixed locations.
- We need an amateur beacon transmitter with precision frequency that can be easily deployed.

WSPRSONDE-8

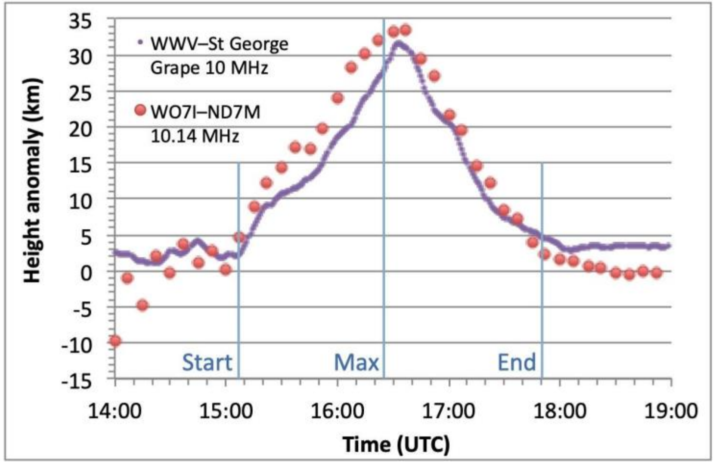
GPS-Disciplined 8-Band Simultaneous Amateur HF Beacon Transmitter
Developed by Paul Elliott WB6CXC

- WS-8 Shown with the Six-Band Filter / Combiner (80 / 40 / 30 / 20 / 15 / 10 meter bands)
- Leo Bodnar GPSDO provides the 10 MHz reference clock
- The WS-8 includes a passive antenna splitter, which lets the GPSDO share the antenna
- +12VDC (2A) power input

https://turnislandsystems.com/wsprsonde-8/

GRAPE and WSPRSONDE: Measuring ionospheric refraction height change, October 2023 Eclipse

Excellent agreement GRAPE and WSPRSONDE in height of refraction measurement, requiring high stability, low phase noise, and absolute frequency accuracy.

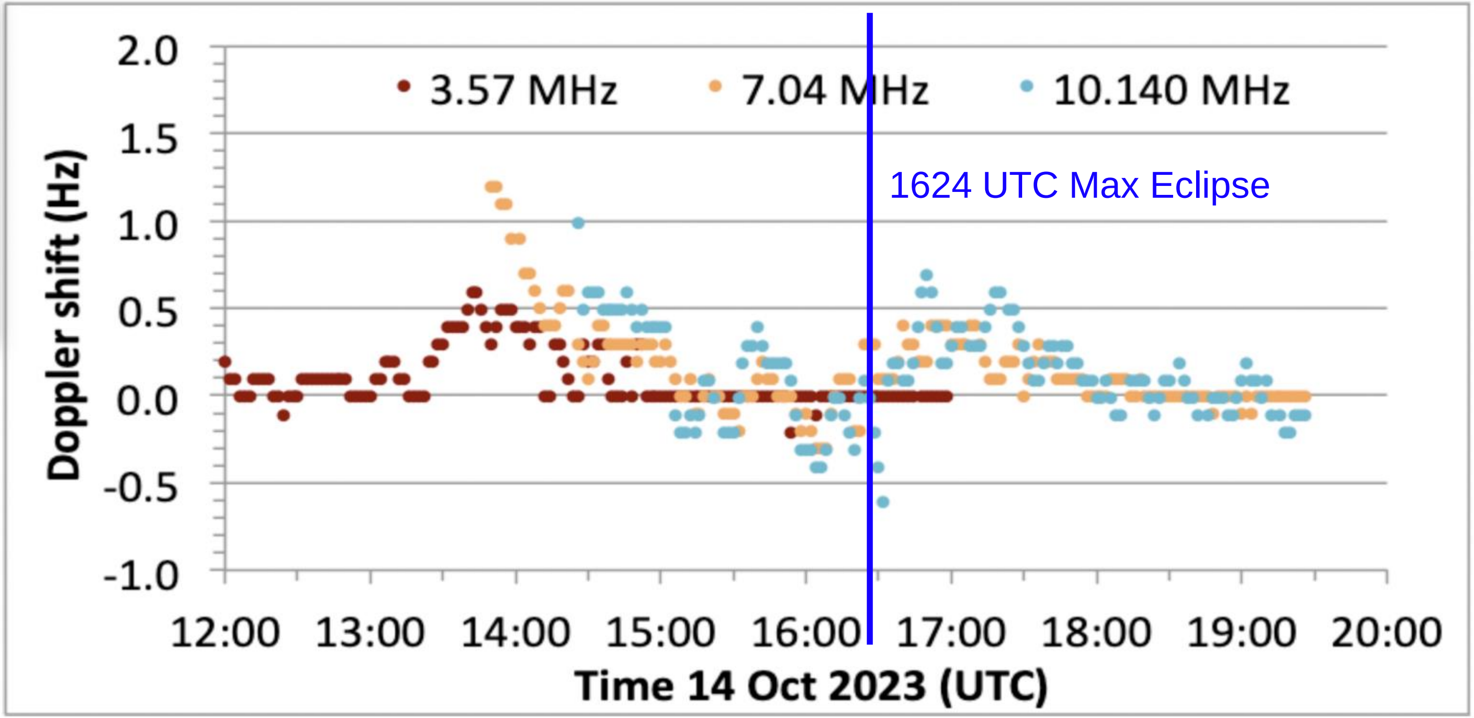


HamSci **GRAPE** receiver at St. George, Utah receives **WWV** 10 MHz.

KiwiSDR at ND7M, Nevada receives **WSPRSONDE** on 80, 40 and 30 m from WO7I

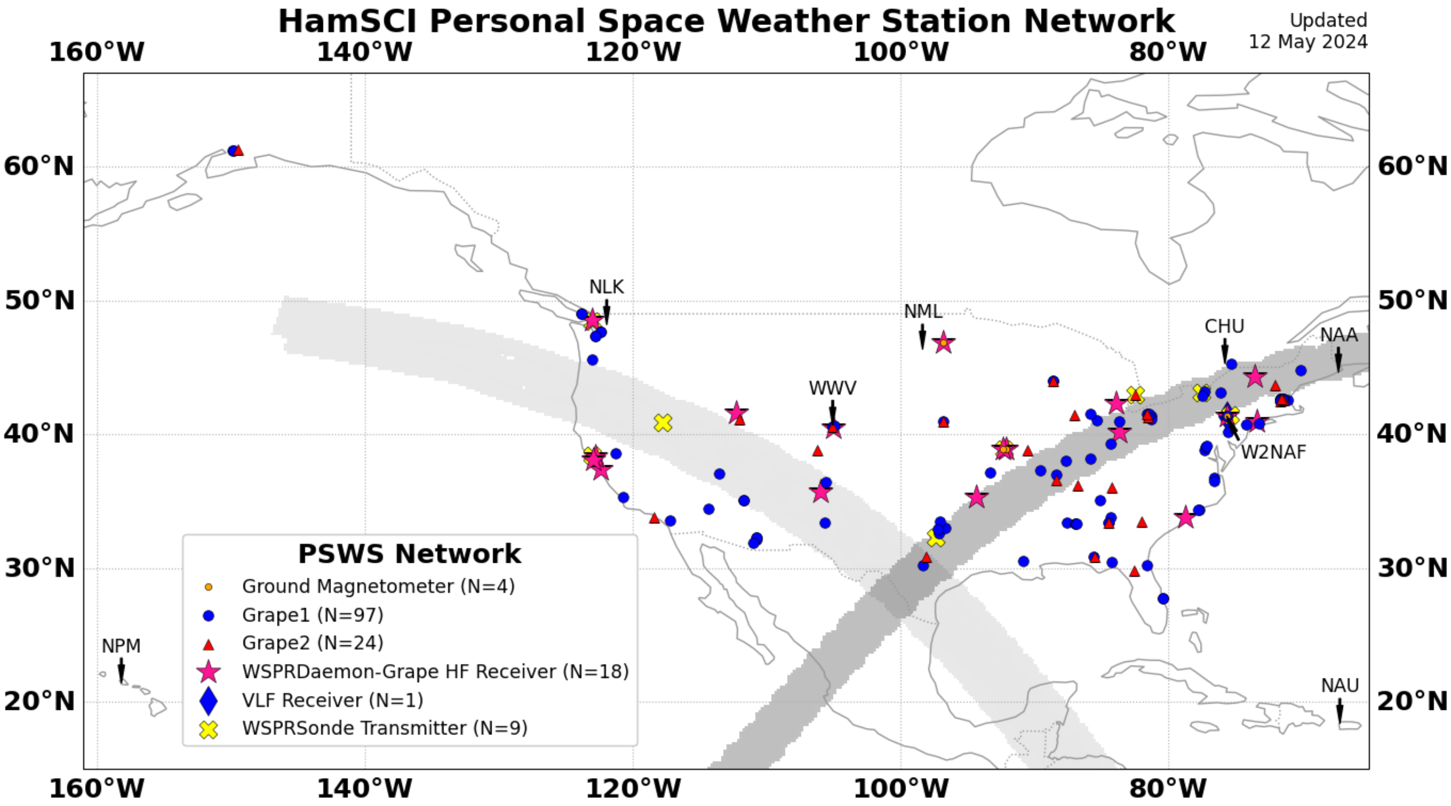
Analysis by Gwyn Griffiths G3ZIL from a presentation at 2024 HamSci.

Preview of FST4W 2023 Annular Eclipse Observations



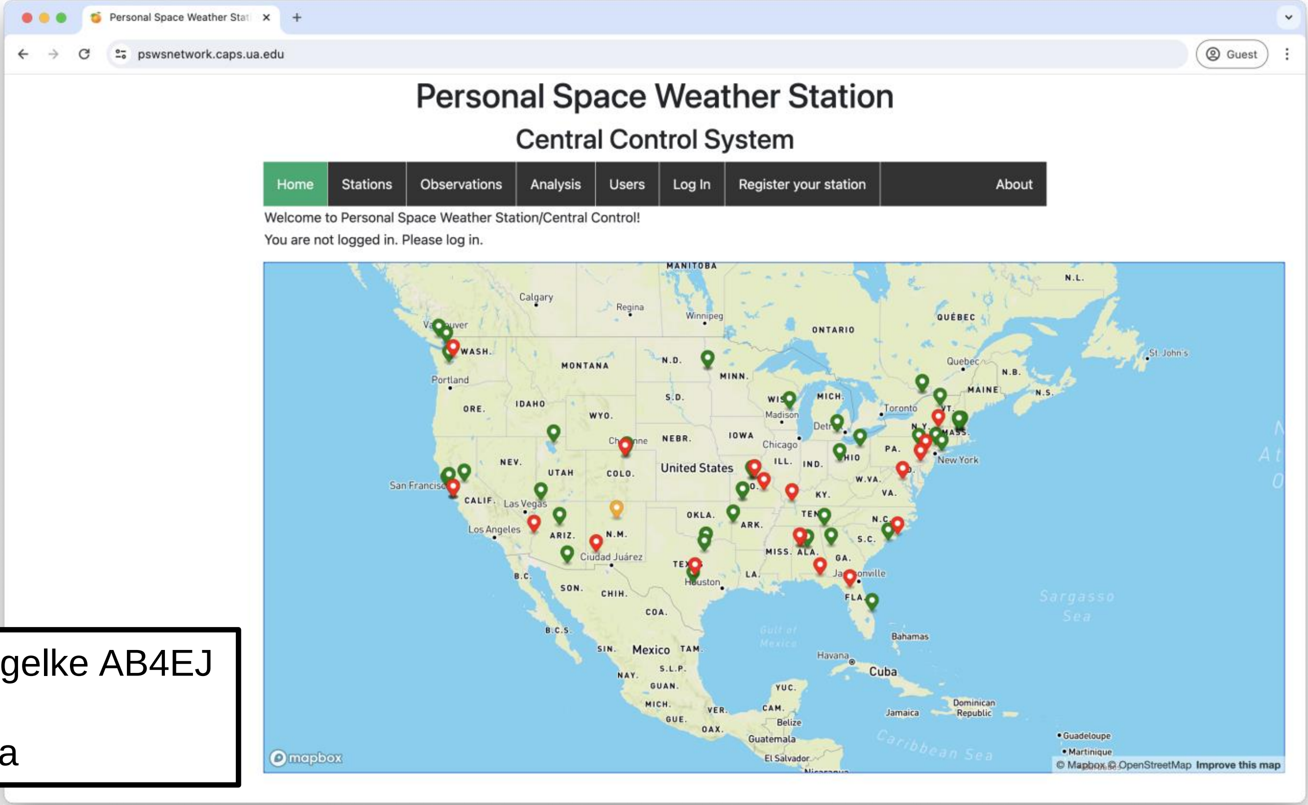
Doppler shift at three frequencies from simultaneous transmissions from WO7I to ND7M. 3.5 MHz was open during the night, 7 MHz, then 10 MHz, opened as the F2 layer critical frequency rose after dawn.

HamSCI PSWS Network – May 2024



nathaniel.frissell@scranton.edu

PSWS Data Website: psws.hamsci.org



Developed by Bill Engelke AB4EJ & team at the University of Alabama

Summary & Future Work

- KA9Q-Radio + RX-888 + GPSDO + WSPRDaemon software is an excellent and flexible HF SDR receiver for making low-cost ionospheric measurements.
- The WSPRSonde is an 8-band amateur HF beacon that can serve as a precision frequency transmitter.
- These systems are already deployed by the amateur radio community and collecting valuable ionospheric observations.
- The TAPR group is now working on developing a US-built alternative to the RX-888 with special attention to scientific needs.

Acknowledgments

We are especially grateful for the

- support of NSF Grants AGS-2002278, AGS-1932997, AGS-1932972, AGS-2045755, AGS-2230345, and AGS-2230346.
- support of the NASA SWO2R Grants 80NSSC23K1322 and 80NSSC21K1772.
- support of Amateur Radio Digital Communication (ARDC).
- amateur radio community volunteers who have contributed to HamSCI projects.
- 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.
- 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).
- Ann Marie Rogalcheck-Frissell KC2KRQ for the HamSCI silhouette photograph.

nathaniel.frissell@scranton.edu

Thank you!

nathaniel.frissell@scranton.edu