HamSCI and the 2023 and 2024 Solar Eclipses

Nathaniel A. Frissell W2NAF and the HamSCI Community

The University of Scranton

Hamvention Antenna Forum 2023

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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.

The Ionosphere

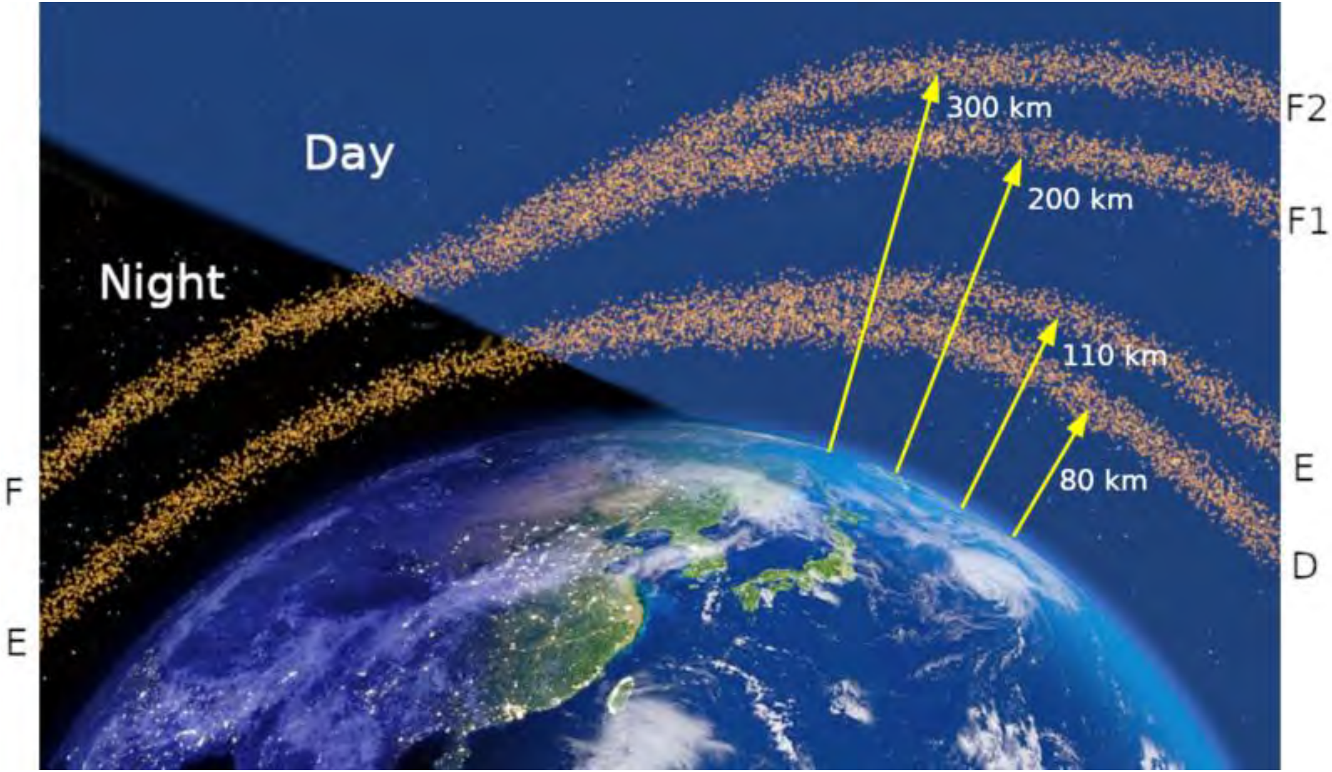

Figure by Carlos Molina (https://commons.wikimedia.org/wiki/File:Ionospheric_layers_from_night_to_day.png)

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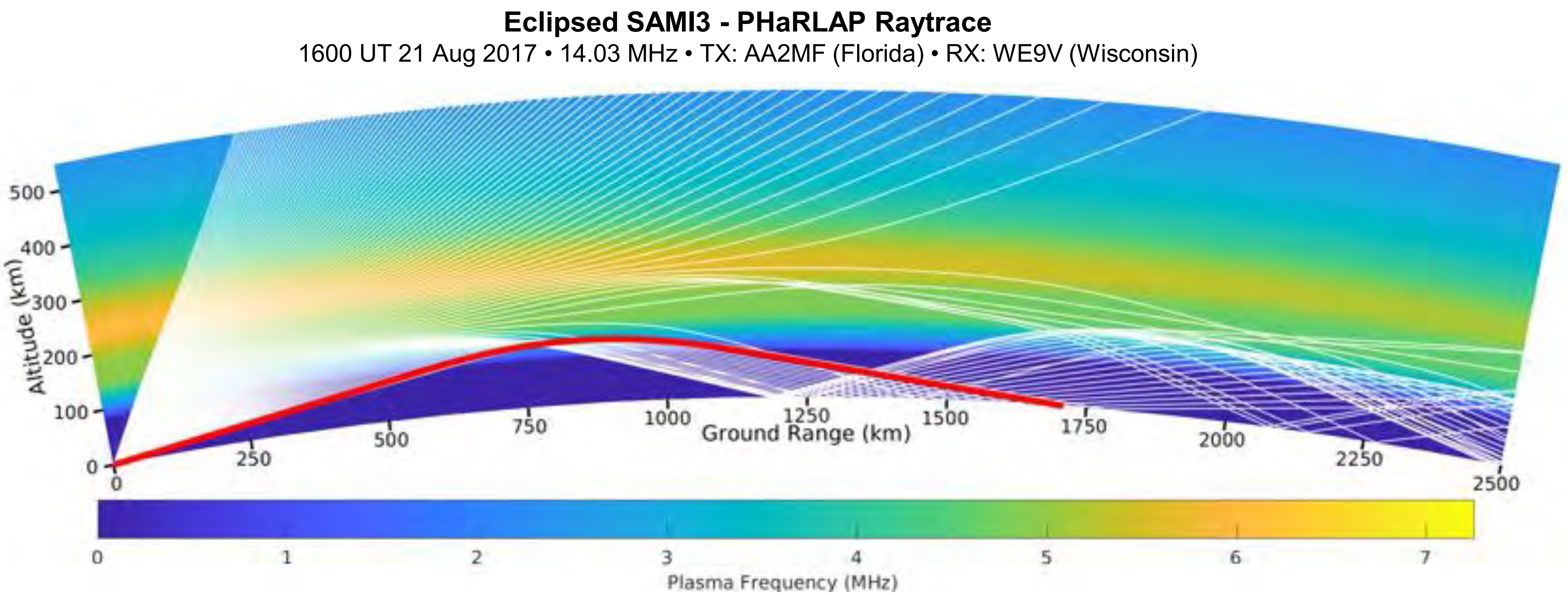
Refraction as a Function of Electron Density



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

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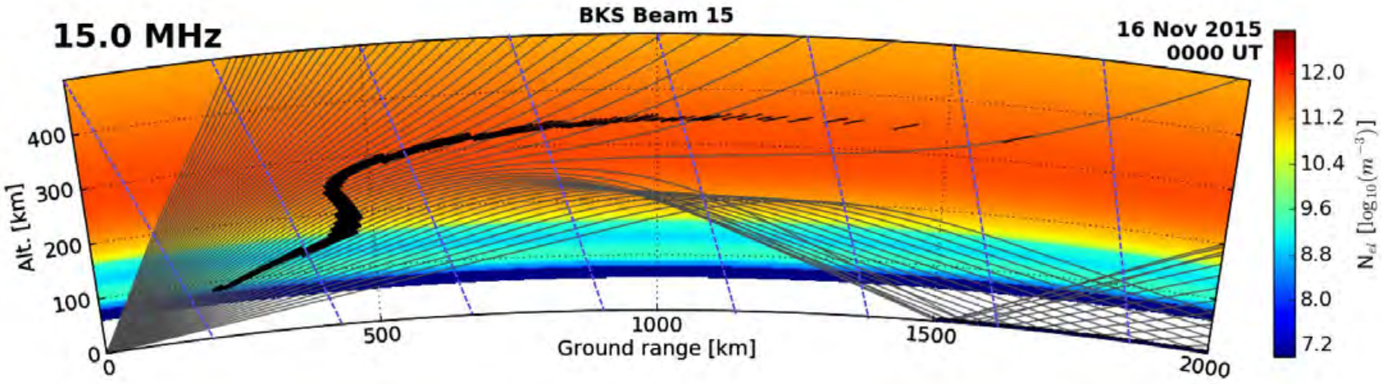
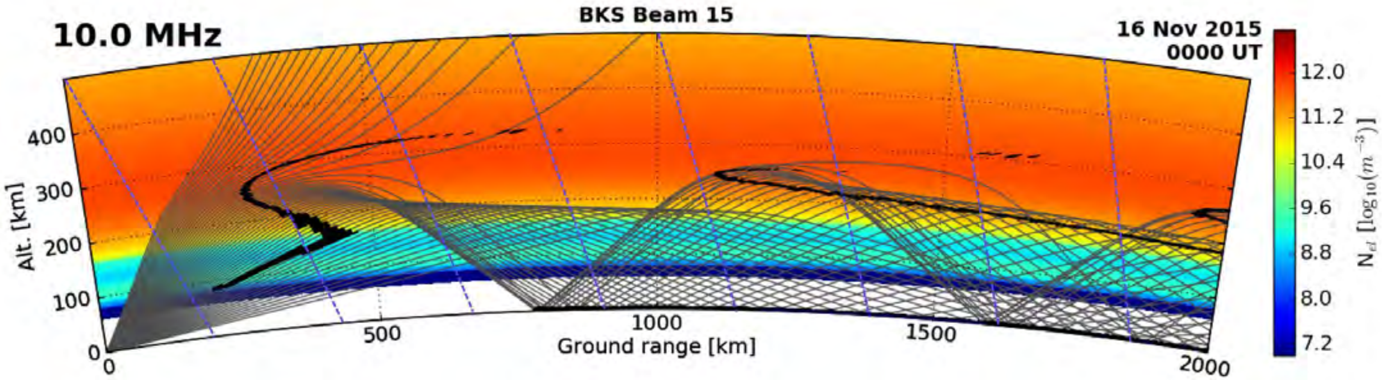
Refraction as a Function of Frequency





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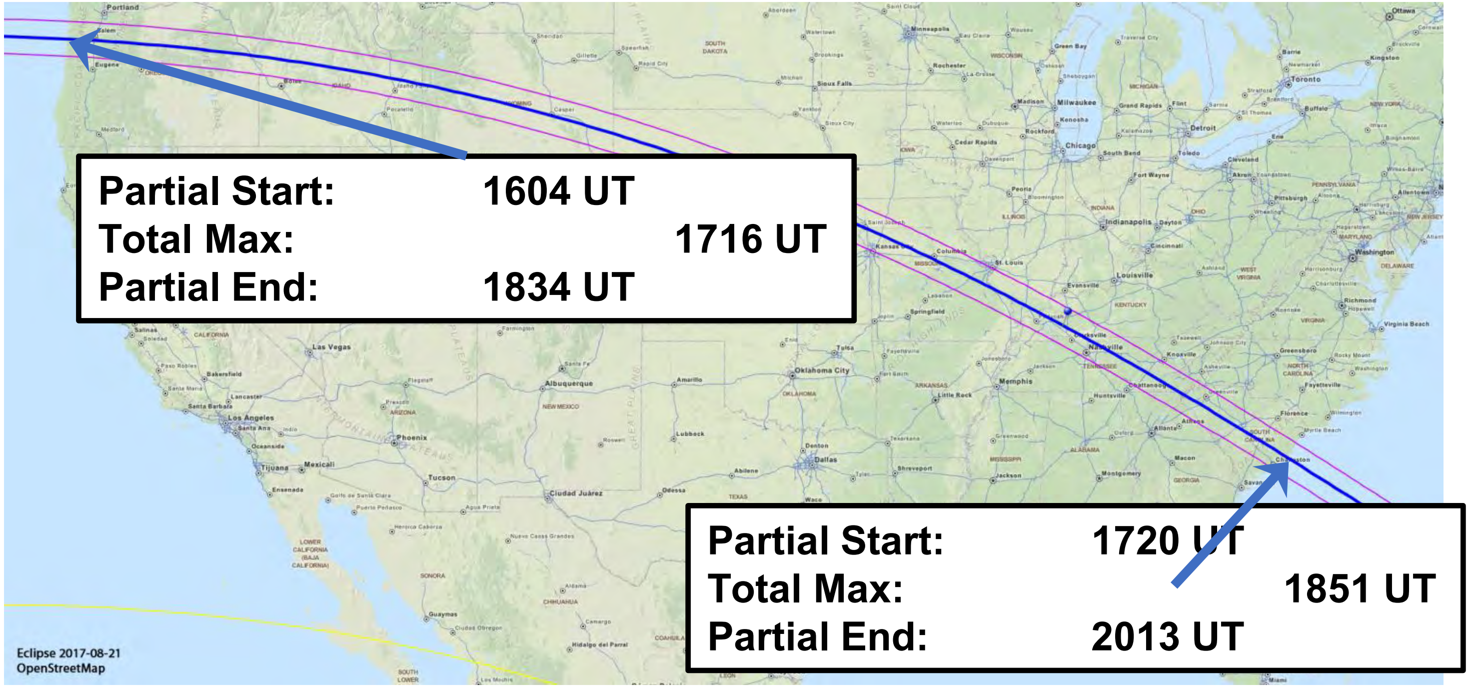
2017 Total Solar Eclipse

21 August 2017



Partial Start: 1604 UT
Total Max: 1716 UT
Partial End: 1834 UT

Partial Start: 1720 UT
Total Max: 1851 UT
Partial End: 2013 UT

Figure: W. Strickling, Wikipedia

Eclipses as Controlled Experiments

- Aside from dusk, dawn, and the seasons, there are very few cases where we know a priori how much solar energy will be input into the upper atmosphere.
- Solar flares, geomagnetic storms, and others are random events we cannot predict.
- We can calculate eclipses with great accuracy ahead of time, and so can be considered a “controlled” ionospheric experiment.

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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?

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

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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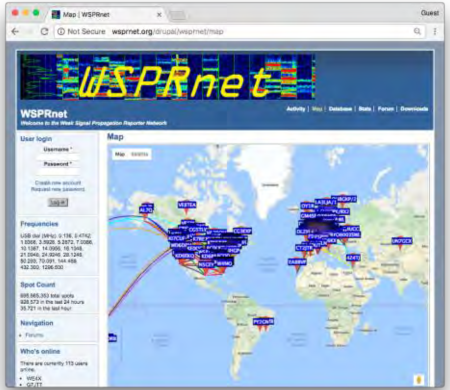
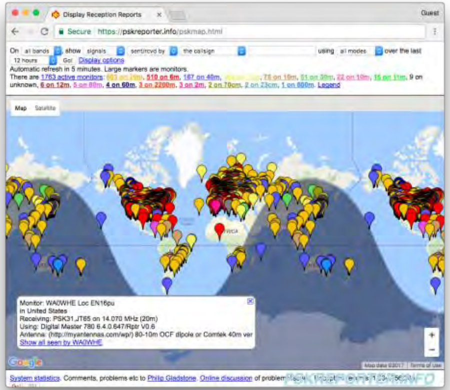
SEQP Observations

RBN
reversebeacon.net



WSPRNet
wsprnet.org



PSKReporter
pskreporter.info

Observations from 21 August 2017 1400 – 2200 UT

Network	# Spots / QSOs
RBN	618,623
WSPRNet	630,132
PSKReporter	1,287,962
Participant Logs	29,809

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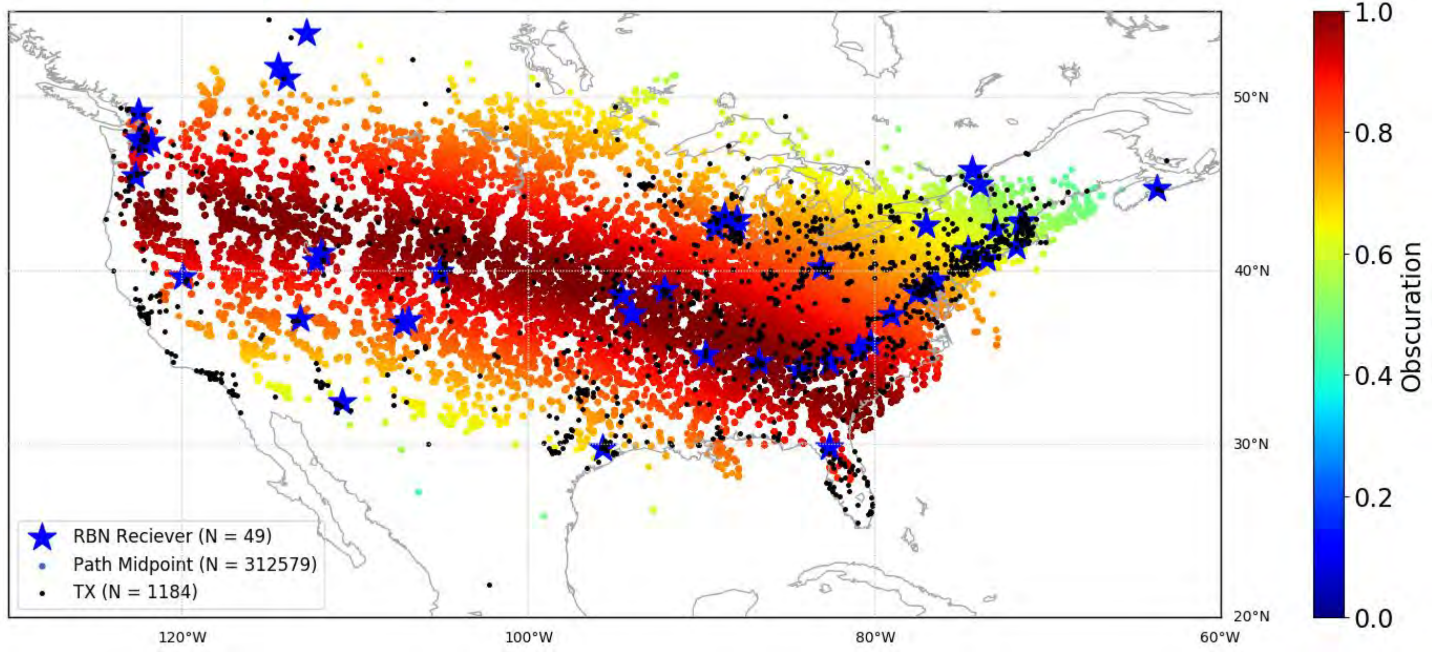
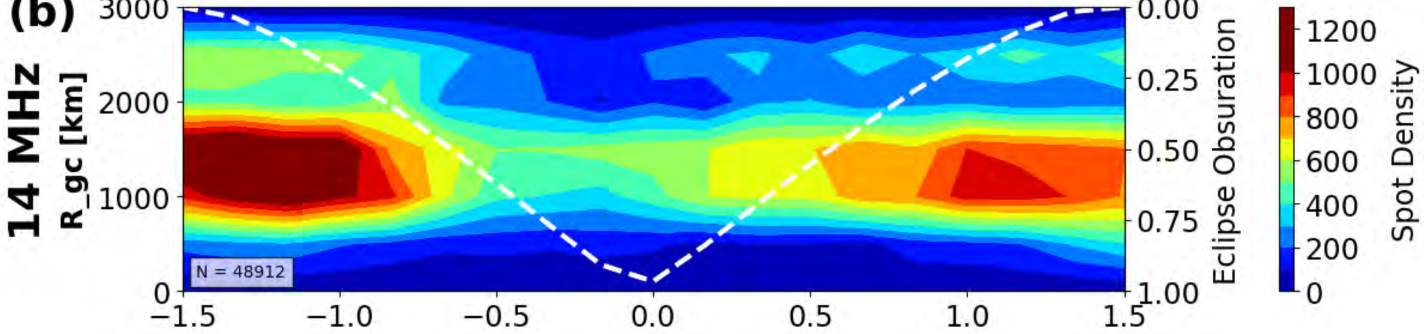
Solar Eclipse QSO Party RBN Observations



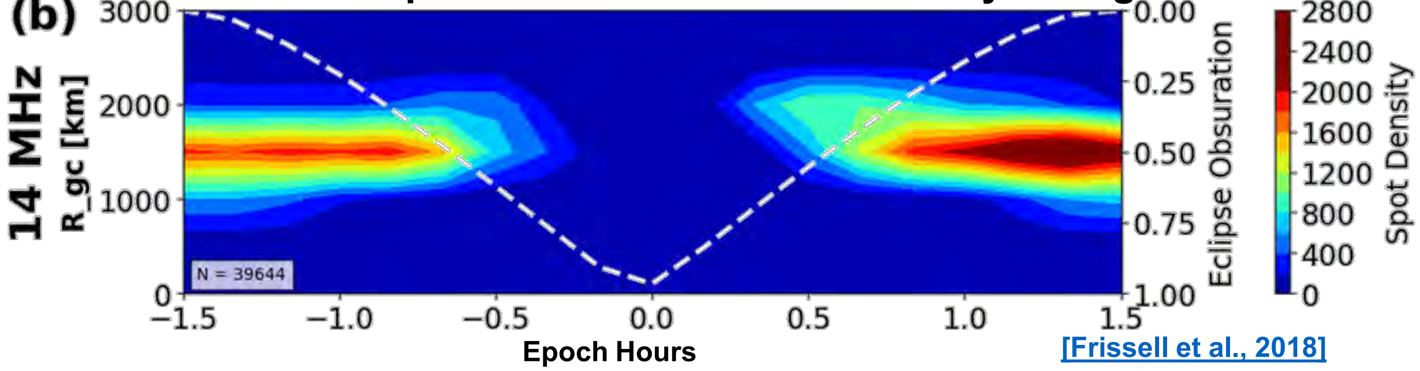
[Frissell et al., 2018]

Observations and Model Results

Ham Radio Observations

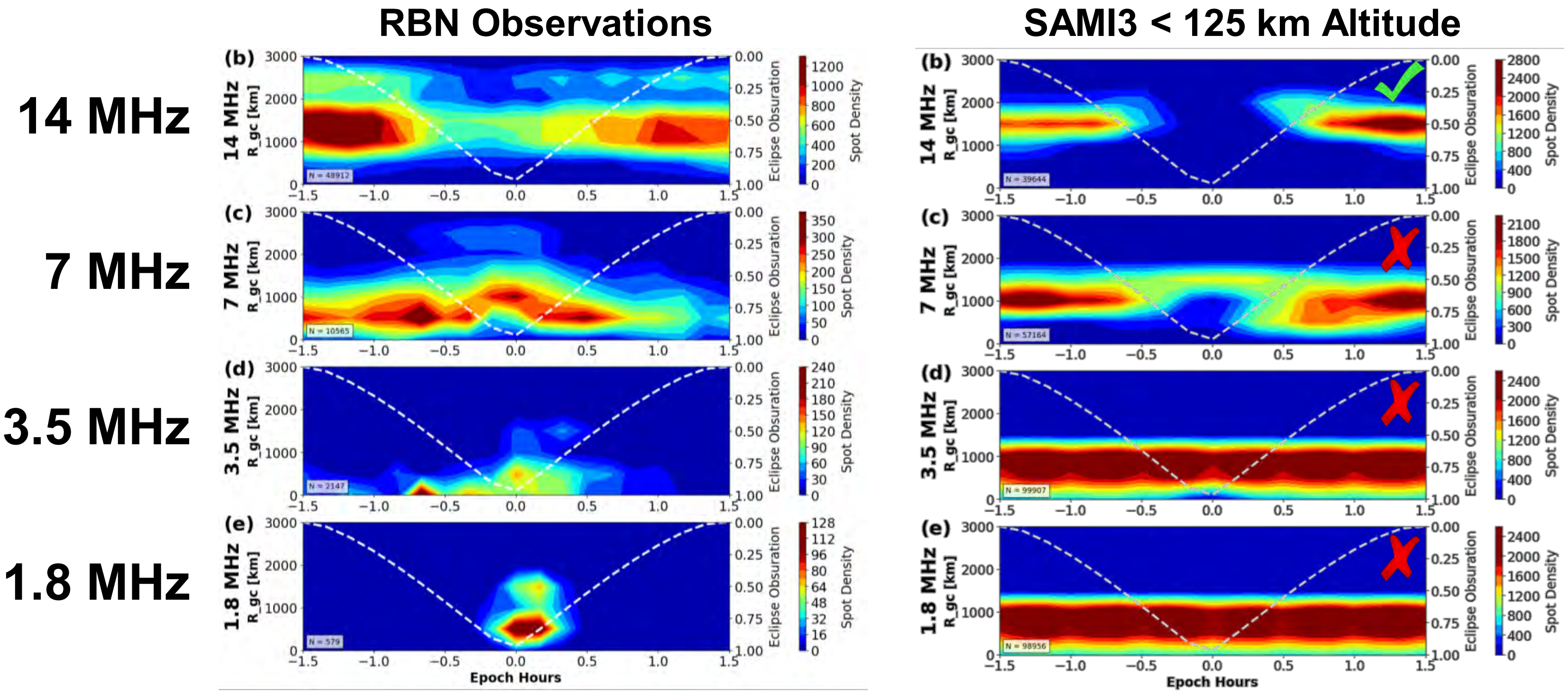


Model – Eclipsed SAMI3 with PHaRLAP Raytracing



[Frissell et al., 2018]

SAMI3 < 125 km alt



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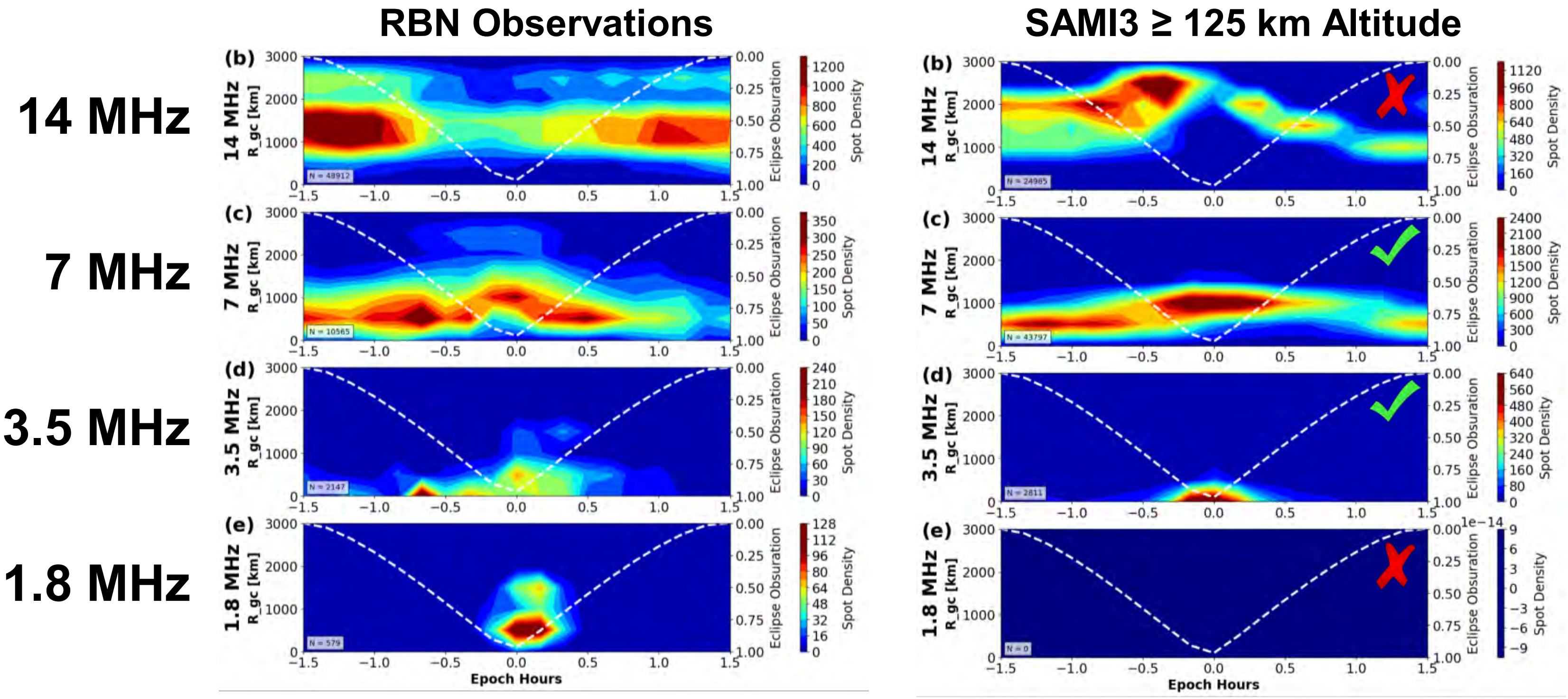
SAMI3 ≥ 125 km alt



http://hamsci.org
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2017 Eclipse Conclusions: 14 MHz

Raytracing suggests 14 MHz refracted at h < 125 km

- This means E-layer ionosphere!
- Mean elevation angle was < 10˚
- Higher frequency meant D-layer absorption was not a problem, even at low elevation angles.
- Low-angle rays could be refracted by E-layer (secant law)
- Higher elevation angles penetrated both the E and F layers.

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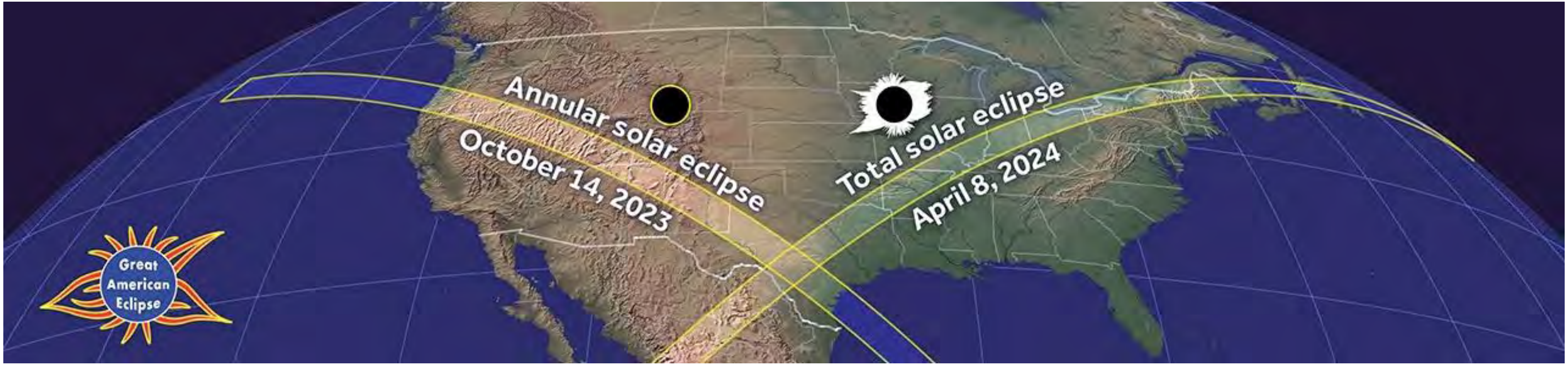
2017 Eclipse Conclusions: 1.8 - 7 MHz

Raytracing suggests 1.8 - 7 MHz refracted at h ≥ 125 km

- This means F-layer ionosphere!
- Elevation angle was > 60˚
- Low-angle rays were likely absorbed by the D-region and not observed.
- Higher elevation angles penetrated the E-layer but could be refracted by F-layer.

Eclipses 2023 and 2024



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

Total and Annular Solar Eclipses

Total

Photo by Jim Sackerman, KC2ZFK

Partial

Photo By Yurakum
(https://commons.wikimedia.org/wiki/File:Sun_eclipse_25_oct_2022_in_Saratov.jpg)

Annular

Photo By
Smrgeog~commonswiki
(https://commons.wikimedia.org/wiki/File:Annular_Eclipse._Taken_from_Middlegate,_Nevada_on_May_20,_2012.jpg)

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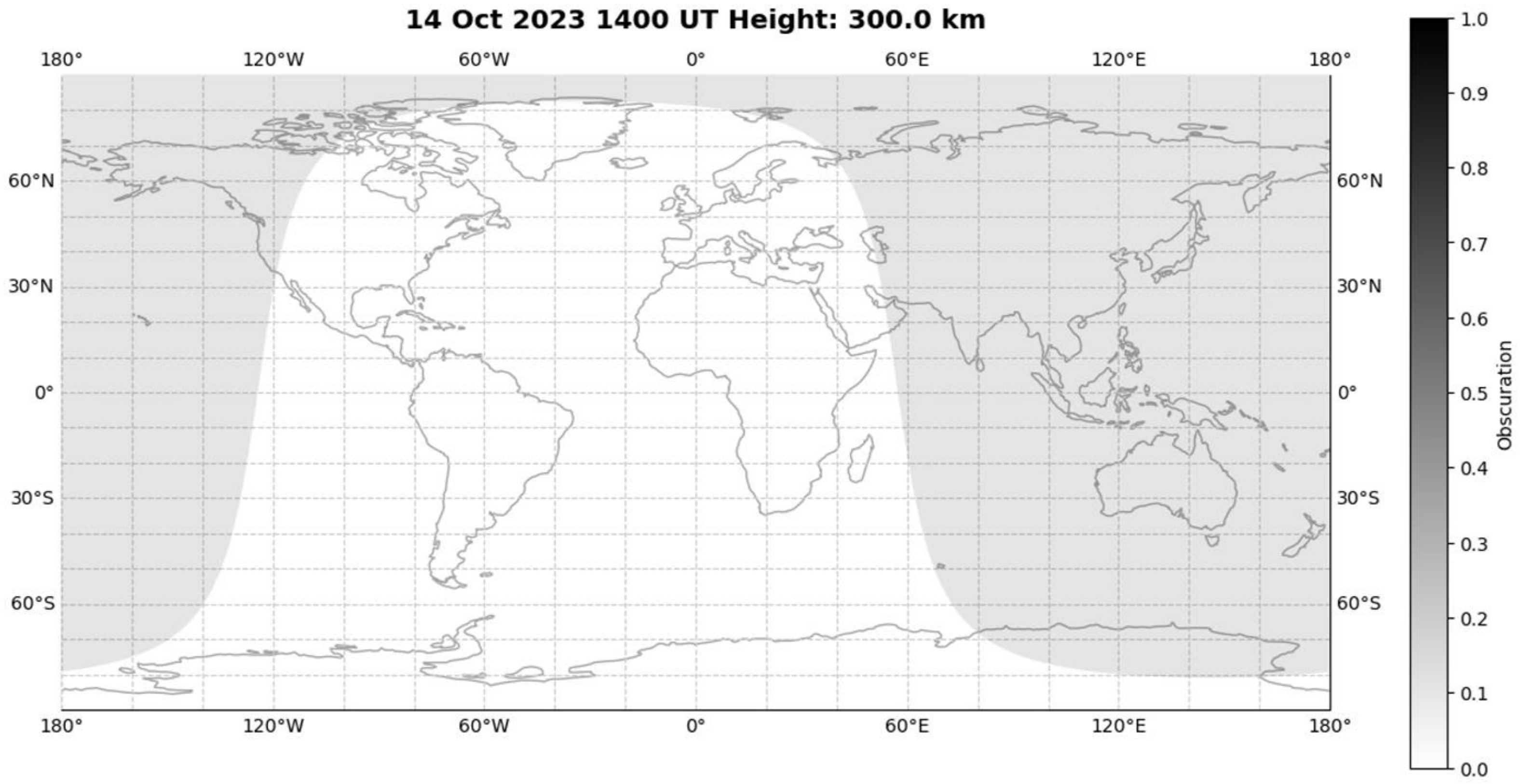
Annular Solar Eclipse: October 14, 2023



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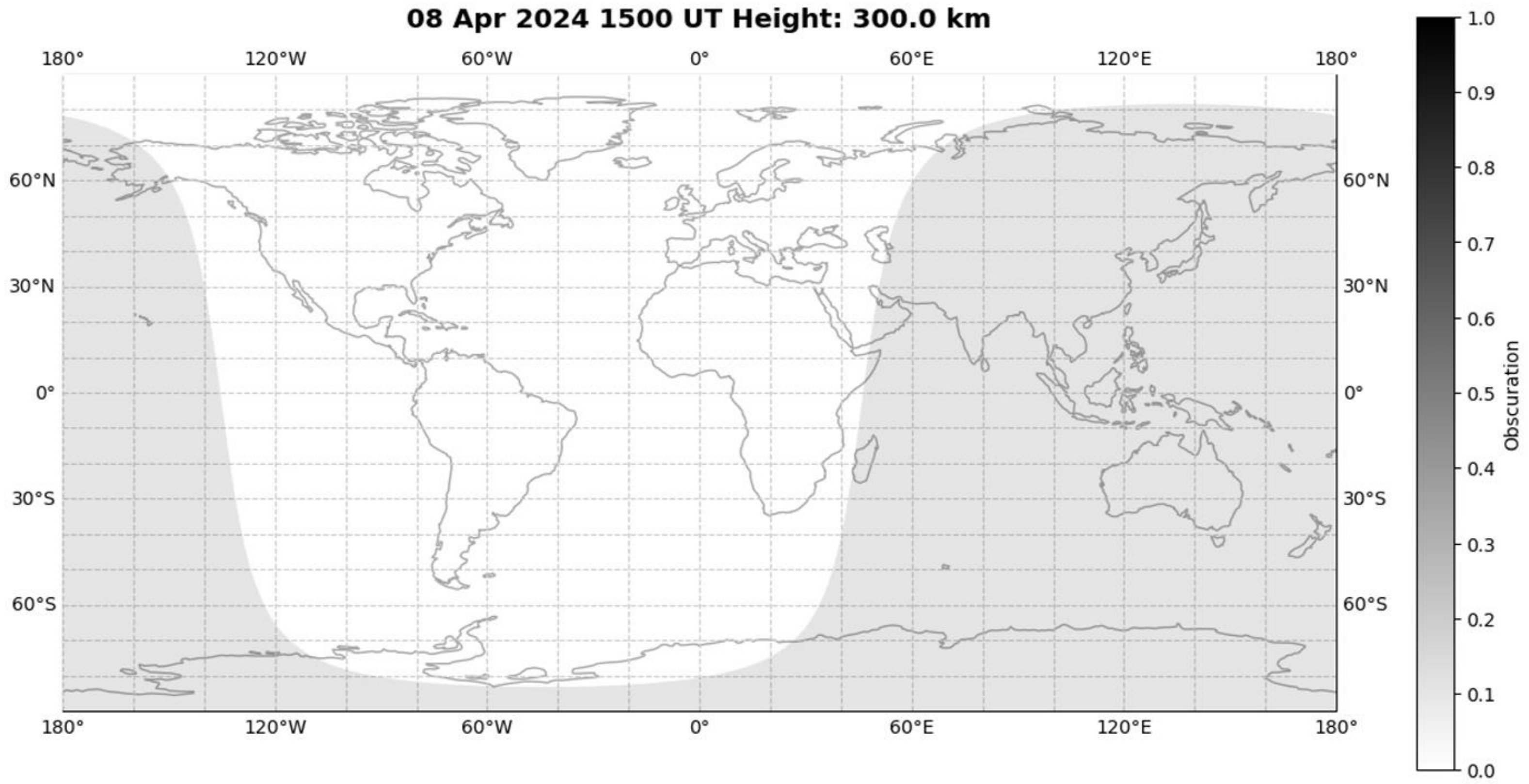
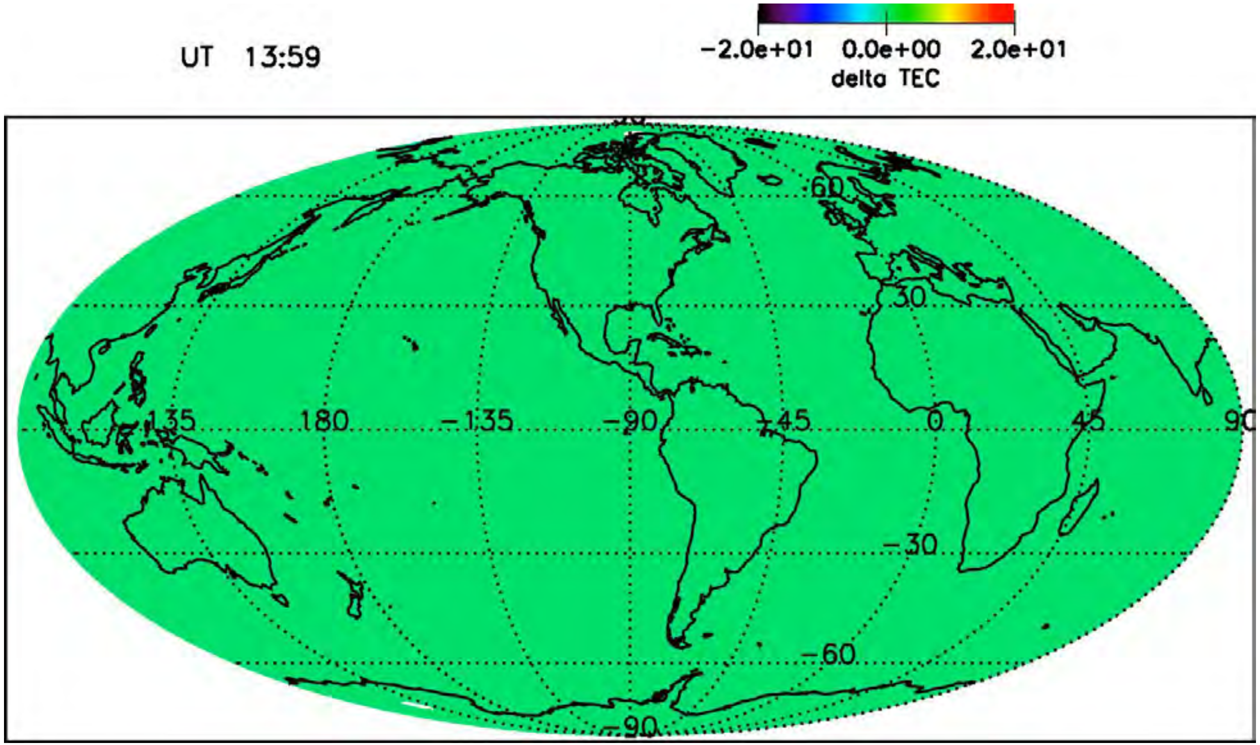
Total Solar Eclipse: April 8, 2024



SAMI3 Annular Eclipse Ionospheric Prediction



Courtesy of Dr. Joseph Huba, Syntek Technologies

Festivals of Eclipse Ionospheric Science

Festivals of Eclipse Ionospheric Science

- **Solar Eclipse QSO Party (SEQP)**
  - "Traditional" Ham Radio Contest
- **Gladstone Signal Spotting Challenge (GSSC)**
  - A contest for skimmers and spotters!
- **Grape HF Doppler Experiment**
  - Study ionospheric variability by observing Doppler shifts of the WWV, WWVH, and CHU carriers
- **Time Difference of Arrival Experiment**
  - Experiment Using TDOA measurements to Profile Ionospheric Layer Height Changes
- **And more!**

https://hamsci.org/eclipse

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2023/2024 Science Questions

- Can the annular eclipse be observed in HF communications?
- How large is the disturbance?
- How long before and after maximum eclipse are eclipse effects observed?
- Is an onset-recovery asymmetry observed?
- Will results again suggest E-layer propagation for 14 MHz and F-layer for 1.8 – 7 MHz?
- How similar are the eclipse effects to dawn and dusk (grayline)?

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SEQP/GSSC Dates and Times

- **October 14, 2023, 1200 – 2200 UTC**
  - Partial Eclipse Begins ~1500 UTC in Oregon
  - Partial Eclipse Ends ~1840 UTC in Texas

- **April 8, 2024, 1400-2400 UTC**
  - Partial Eclipse Begins ~1710 UTC in Texas
  - Partial Eclipse Ends ~2040 UTC in Maine

Solar Eclipse QSO Party 2.0

- Taking the best concepts from the 2017 event yielded a fresh set of rules, FAQs, etc.
- The HamSCI website is the ultimate resource:

  https://hamsci.org/eclipse

Bands, Frequencies, and Modes

- **Modes:** Digital (all varieties), CW, and Phone
- **Bands:** 160, 80, 40, 20, 15, 10, and 6 Meter Bands

Reminder: By international agreements, the 60, 30, 17, and 12 meter bands may not be used for two-way contest QSOs.

- For CW and SSB, call "CQ SEQP" on the '38s:
  - CW +/-10kHz from 3538, 7038, 14038, etc.
  - SSB +/-25kHz 3838, 7238, 14328, 21338, 28338
- For digital modes, use usual activity centers, but please spread out!

Exchange for Two-Way QSOs

- **Accurate Signal Report, 4-Character Grid Square.**
- *Example Exchange:*
  - W1AW: *CQ CQ SEQP de W1AW W1AW*
  - N0AX: *N0AX*
  - W1AW: *N0AX 579 FN31*
  - N0AX: *589 EM48*
- If you miss any of the information, simply ask for a repeat (on SSB), or send AGN? (on CW). Be sure to log what you receive.

SEQP Scoring

Score = (QSO Points x Multipliers) + Bonus Points

1. QSO Points: CW and Digital QSOs, 2 points each; SSB QSOs, 1 point each
2. Multipliers: 4-character grid squares, counted once per band.
3. The same station may be worked for QSO points on all SEQP bands and modes.
4. **Dupes are allowed every 10 minutes!** This is to monitor changes in propagation due to the eclipse.

Gladstone Signal Spotting Challenge

- A contest for people who like running skimmers or operating WSPR and FST4W!
- Named after PSKReporter Founder/Operator Philip Gladstone N1DQ.

https://hamsci.org/eclipse

HamSCI

Gladstone Signal Spotting Challenge Rules for 2023 and 2024

Please bookmark this page and join the **HamSCI eclipse mailing list** for future announcements related to the GSSC.

Version 1.22

24 Jan 2023

The Gladstone Signal Spotting Challenge is named for Philip Gladstone, N1DQ, the creator and maintainer of the ***PSKReporter.info*** *website, also known as the Digimode Automatic Propagation Reporter. Philip has made a tremendous contribution to Amateur Radio operating, citizen-science and ionospheric research through the data ('spots') which are collected and stored on* ***PSKReporter.info****. This Wikipedia entry tells the story:* **https://en.wikipedia.org/wiki/PSK_Reporter**

The following are the complete, detailed rules for the GSSC. For a quick introduction to the GSSC, please visit the **GSSC FAQ** page. The GSSC is one event within the **HamSCI Festivals of Eclipse Ionospheric Science**.

I) Dates and Times

14 Oct 2023 1200 – 2200 UTC (Partial eclipse begins ~1500 UTC in Oregon ends ~1840 UTC in Texas

8 Apr 2024 1400-2400 UTC (Partial eclipse begins ~1710 UTC in Texas and ends ~2040 UTC in Maine)

Participants are encouraged to operate before, during and after the eclipse passes over the continental US. Doing so will create baseline data (pre- and post-eclipse), and eclipse influenced data (during annularity or totality) for the research team.

II) Objective

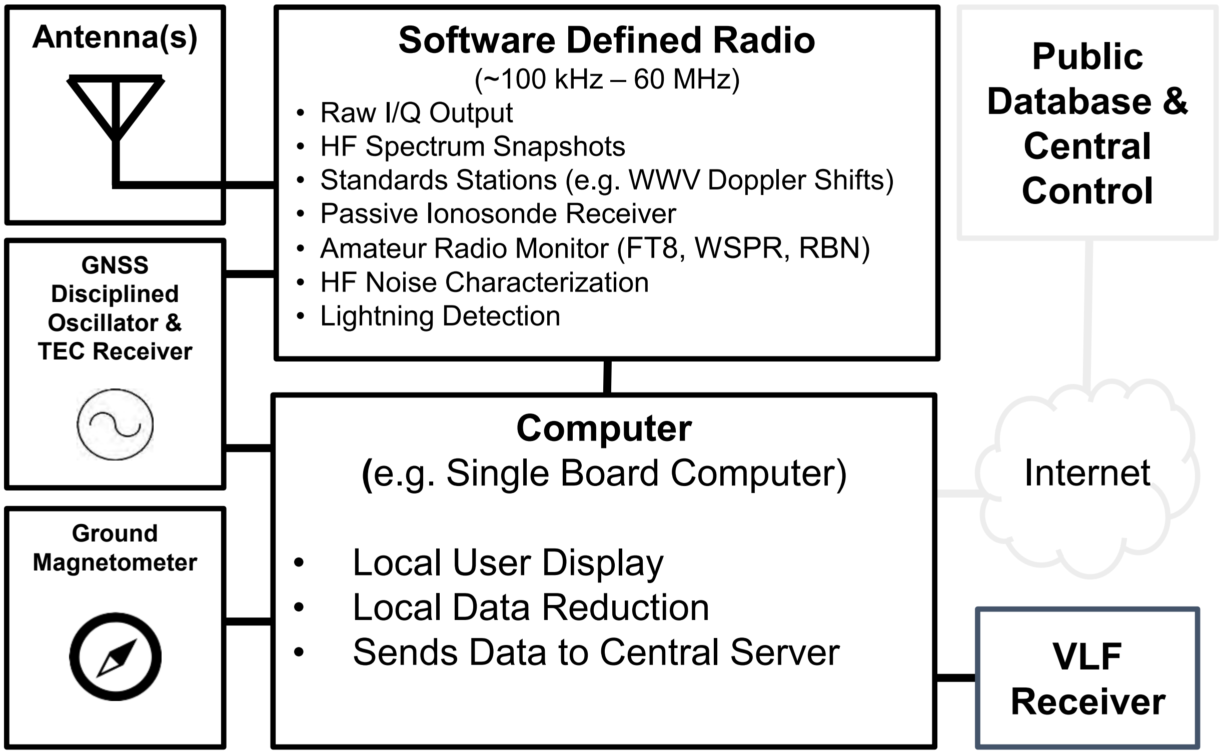
To generate observations of propagation by **WSPRNet**, **PSKReporter** and the **Reverse Beacon Network**, along with participants' event logs before, during, and after the eclipse on the amateur bands for the purpose of ionospheric sounding.

GSSC Scoring

- 1 Point for every spot received
- 1.25 Multiplier for Operating FST4W-120
- 1.10 Multiplier for uploading PDFs of station design
- 1.05 Multiplier for uploading photos of station

Personal Space Weather Station Eclipse Experiment

HamSCI Personal Space Weather Station



For more information, visit http://hamsci.org/psws

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PSWS Teams

University of Scranton
- **Nathaniel Frissell W2NAF (PI)**
- Devin Diehl
- Rachel Frissell W2RUF
- Cuong Nguyen KC3UAX
- Gerard Piccini KC3ZHK
- Veronica Romanek KC2UHN
- Jonathan Rizzo KC3EEY
- Simal Sami KC3UAW
- Bob Spalletta KC3QOB
- Nisha Yadav
- Dev Joshi KC3PVE (Now at Iowa)

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)
- Rachel Boedicker AC8XY
- Skylar Dannhoff KD9JPX
- Aidan Montare KB3UMD

Responsibilities
- Low Cost PSWS System

MIT Haystack Observatory
- **Phil Erickson W1PJE**

Dartmouth College
- David McGaw N1HAC

AMATEUR RADIO DIGITAL COMMUNICATIONS

New Jersey Institute of Technology
- **Hyomin Kim KD2MCR (PI)**
- Gareth Perry KD2SAK
- Diego Sanchez KD2RLM
- Andy Gerrard KD2MCQ

Responsibilities
- Ground Mag Oversight & Testing
- Science Collaborators

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)
- Total cost ~$100-$150

Sensors

- PNI RM3100 magnetometer module
    - 3 axis magneto-inductive measurement module
    - Very small (25.4 x 25.4 x 8 mm)
- MCP9808 temperature sensor

Now available from TAPR!

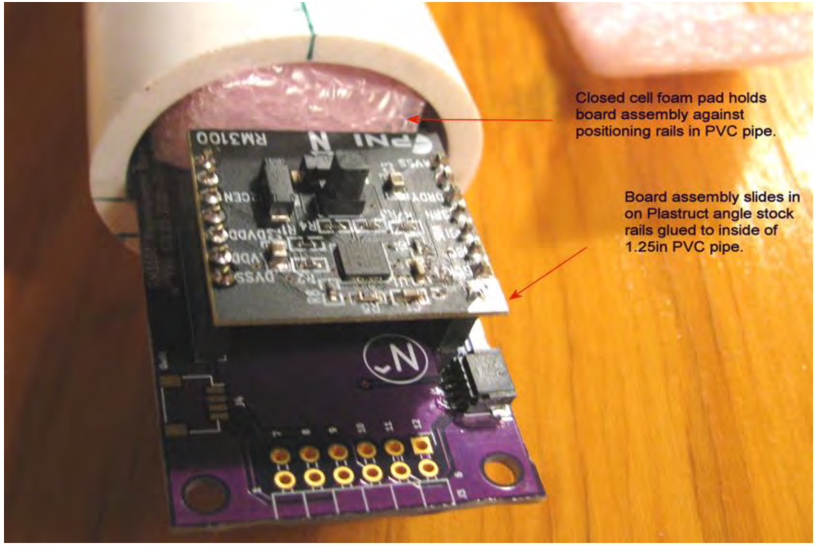


Photo by Jules Madey, K2KGJ

Whistler Catcher VLF LEAF Module

Developed by Jonathan Rizzo KC3EEY

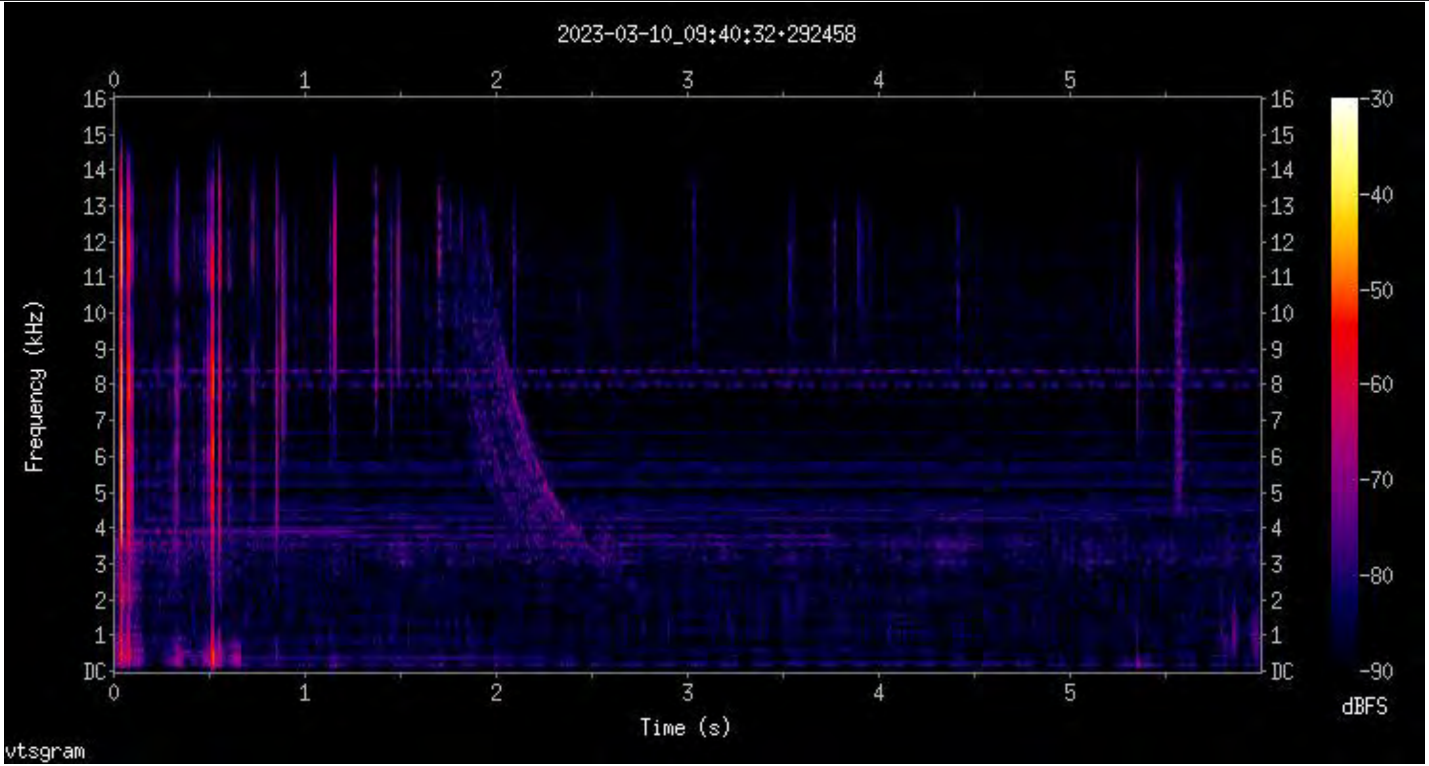
Purpose

- A 4-channel VLF SDR module to record the VLF spectrum up to 100 kHz for purposes of capturing Natural Radio emissions, Sudden Ionospheric Disturbances in VLF transmitters, and VLF amateur transmissions.

Features

- Uses the Texas Instruments TLV320ADC6140: Quad-channel 768-kHz Burr-Brown™ audio analog-to-digital converter
- Up to a 384 kHz sample rate, 112 dB dynamic range
- Clocking provided by SynthDO module
- 4-channel input
- Outputs spectrum in a vlfrx-tools-compatible stream.

Whistler Catcher VLF Observations



Whistler Observations – Spring Brook Twp, PA – 10 March 2023

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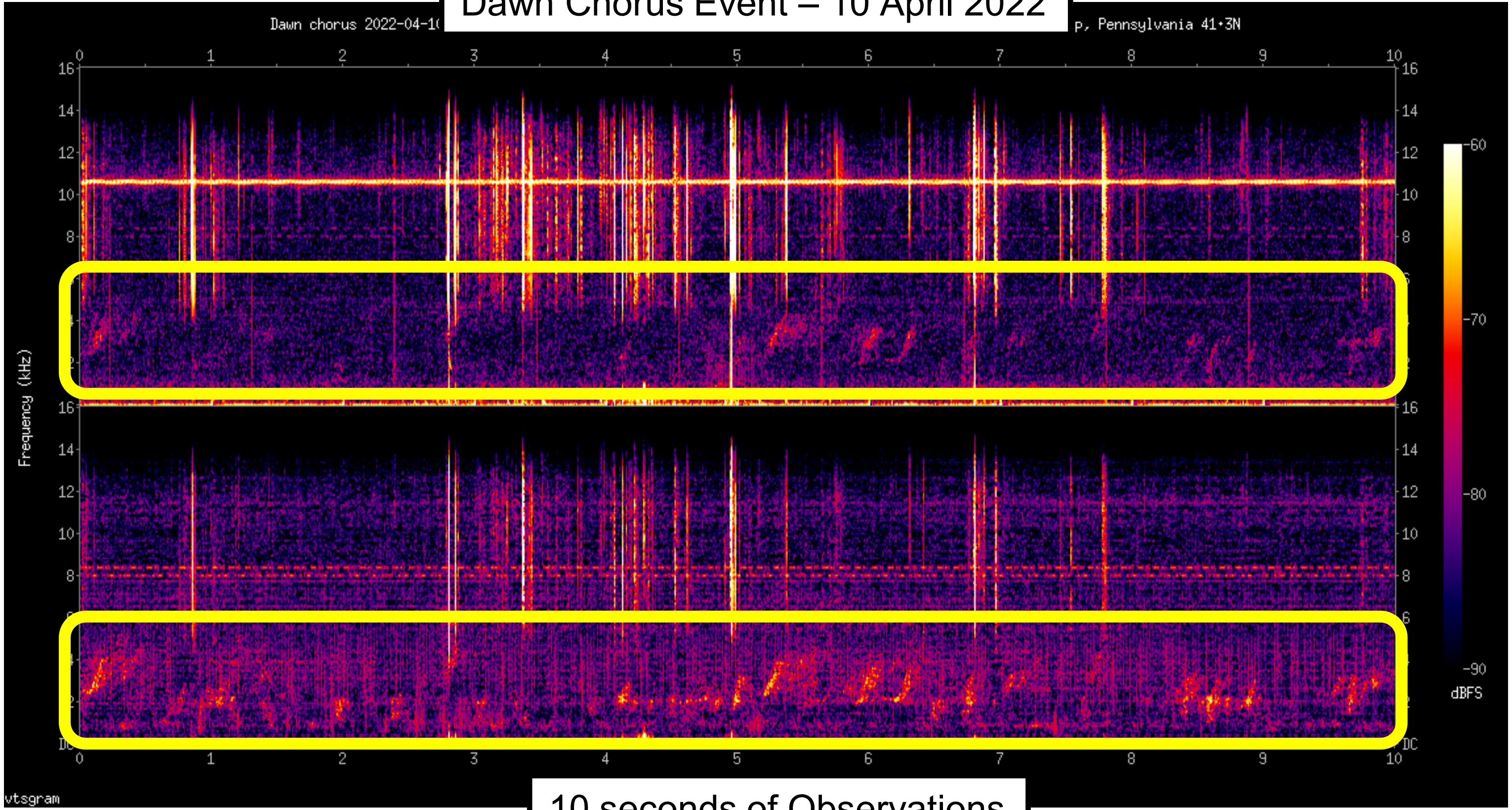
Whistler Catcher VLF Observations

Dawn Chorus Event – 10 April 2022

Forest, VA
(Mike Smith, N4VLF)

Spring Brook Twp, PA
(KC3EEY & W2NAF)



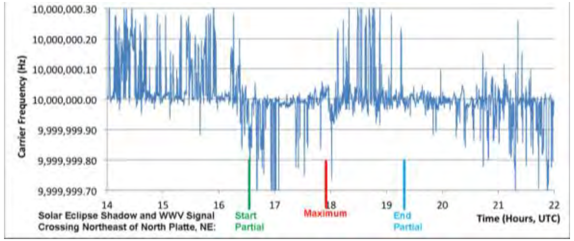
10 seconds of Observations

Spectrogram by Paul Nicholson

Low-Cost "Grape" PSWS

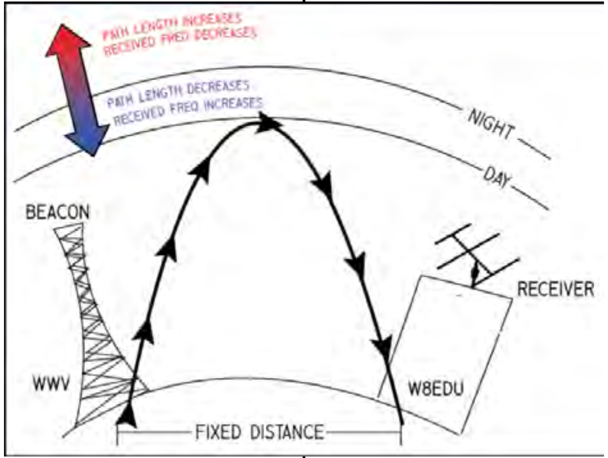
- HF "Doppler Shift" Monitoring
- Main components: Raspberry PI, GPSDO, Custom Low-IF receiver board
- Cost: ~$300
- Developed by Case Western

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



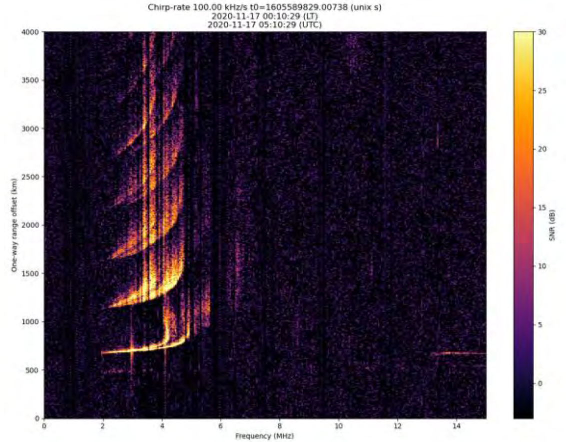
SDR-Based "Tangerine"

- 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



[Collins et al., 2021]

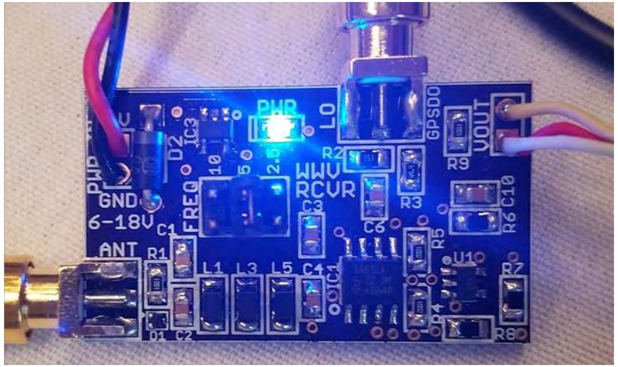
Oblique Ionograms
(Currently on Ettus N200 but will be ported to Tangerine)



Movie by Dev Joshi
GNUChirpsounder2 by Juha Vierinen

Grape Low-Cost PSWS

- **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.
- **Grape v1.12**
  - Single Frequency
  - Build it yourself
  - Available now!
- **Grape v2**
  - 3 Frequency
  - Preassembled
  - Prototypes Currently Being Built



"Grape Receiver" Generation 1 by J. Gibbons N8OBJ

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

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HF Doppler Shift

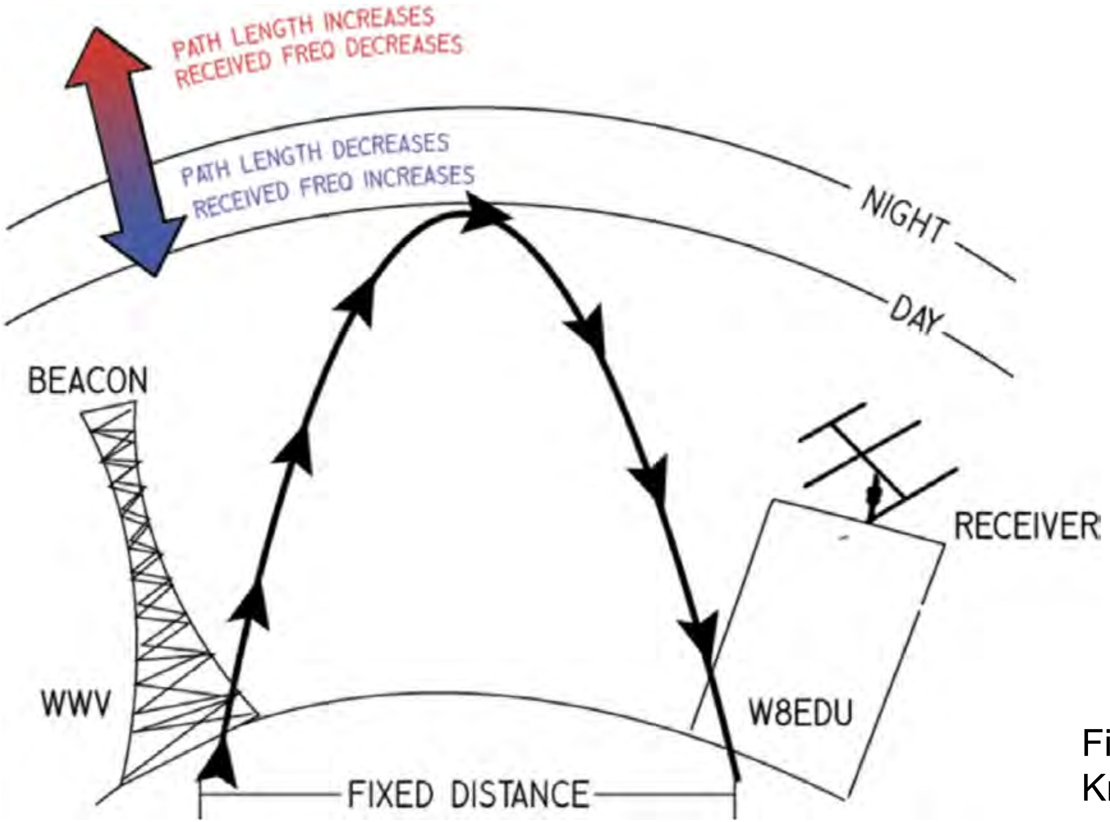
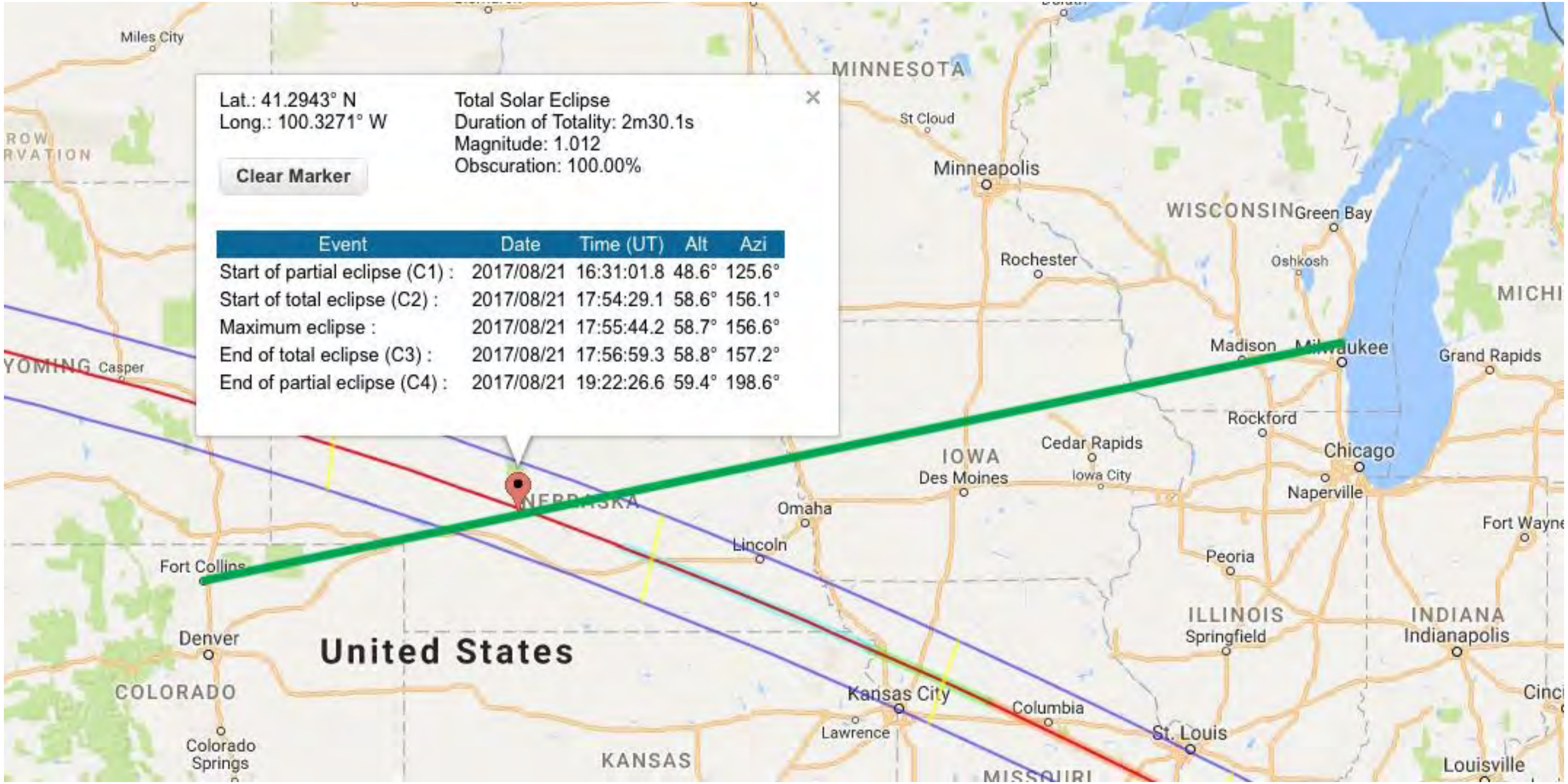
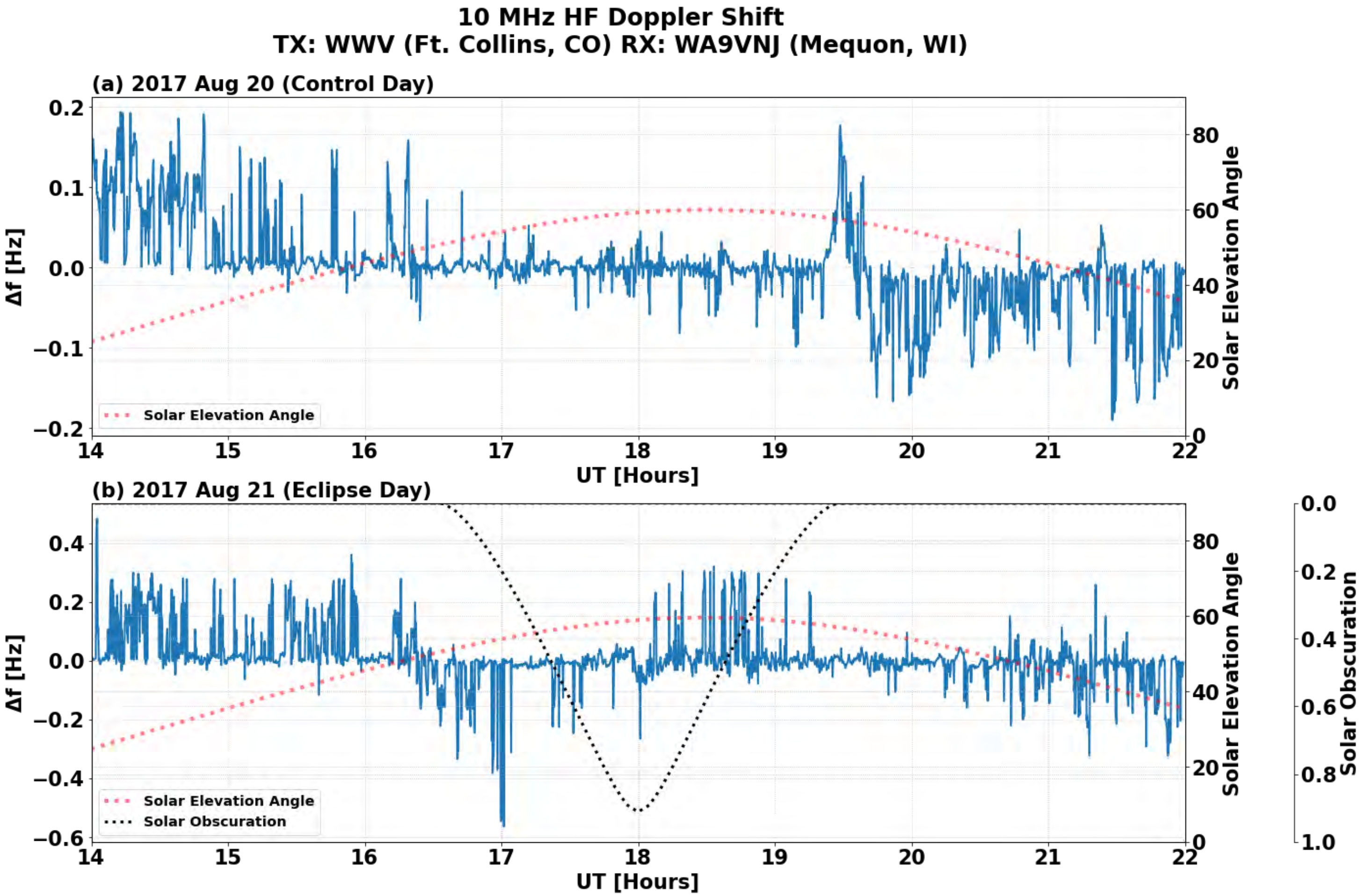


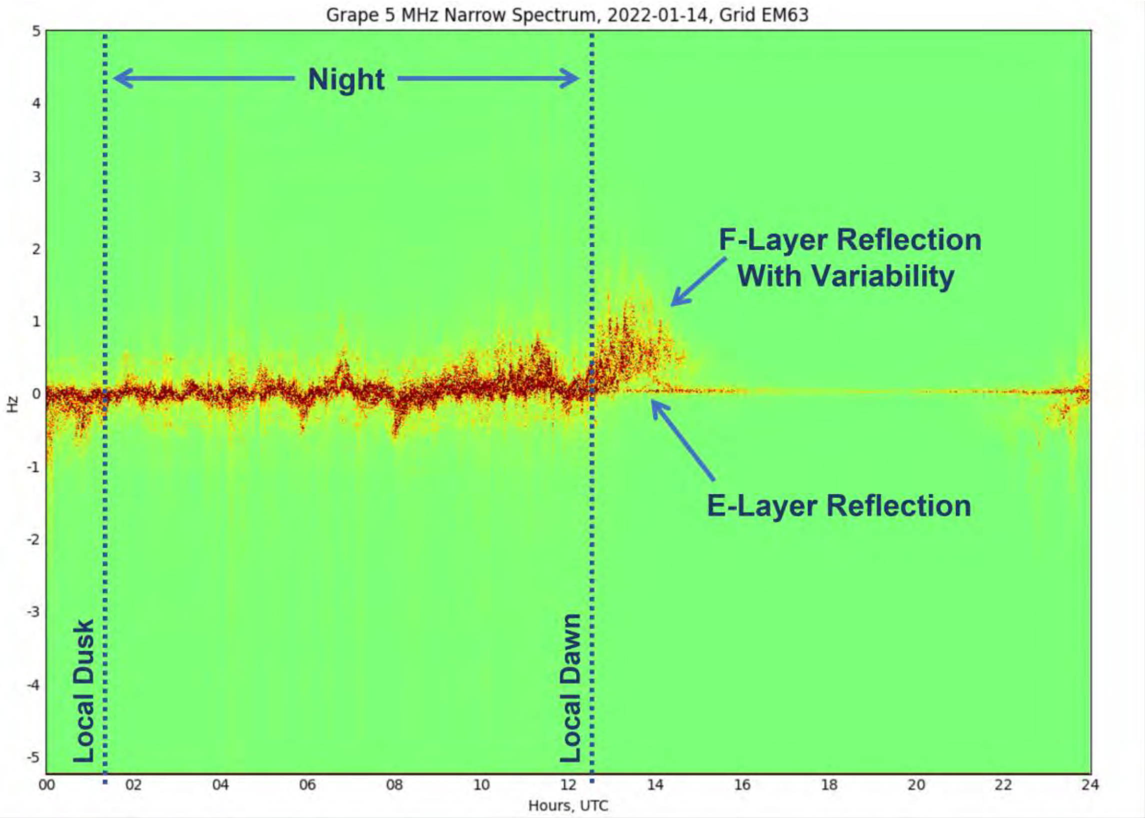
Figure by
Kristina Collins KD8OXT

WA9VNJ 10 MHz WWV Observations




10 MHz HF Doppler Shift
TX: WWV (Ft. Collins, CO) RX: WA9VNJ (Mequon, WI)
(a) 2017 Aug 20 (Control Day)
Δf [Hz]
Solar Elevation Angle
UT [Hours]
(b) 2017 Aug 21 (Eclipse Day)
Solar Obscuration

5 MHz WWV-AB4EJ Doppler Shifts



Data by
Bill Engelke AB4EJ

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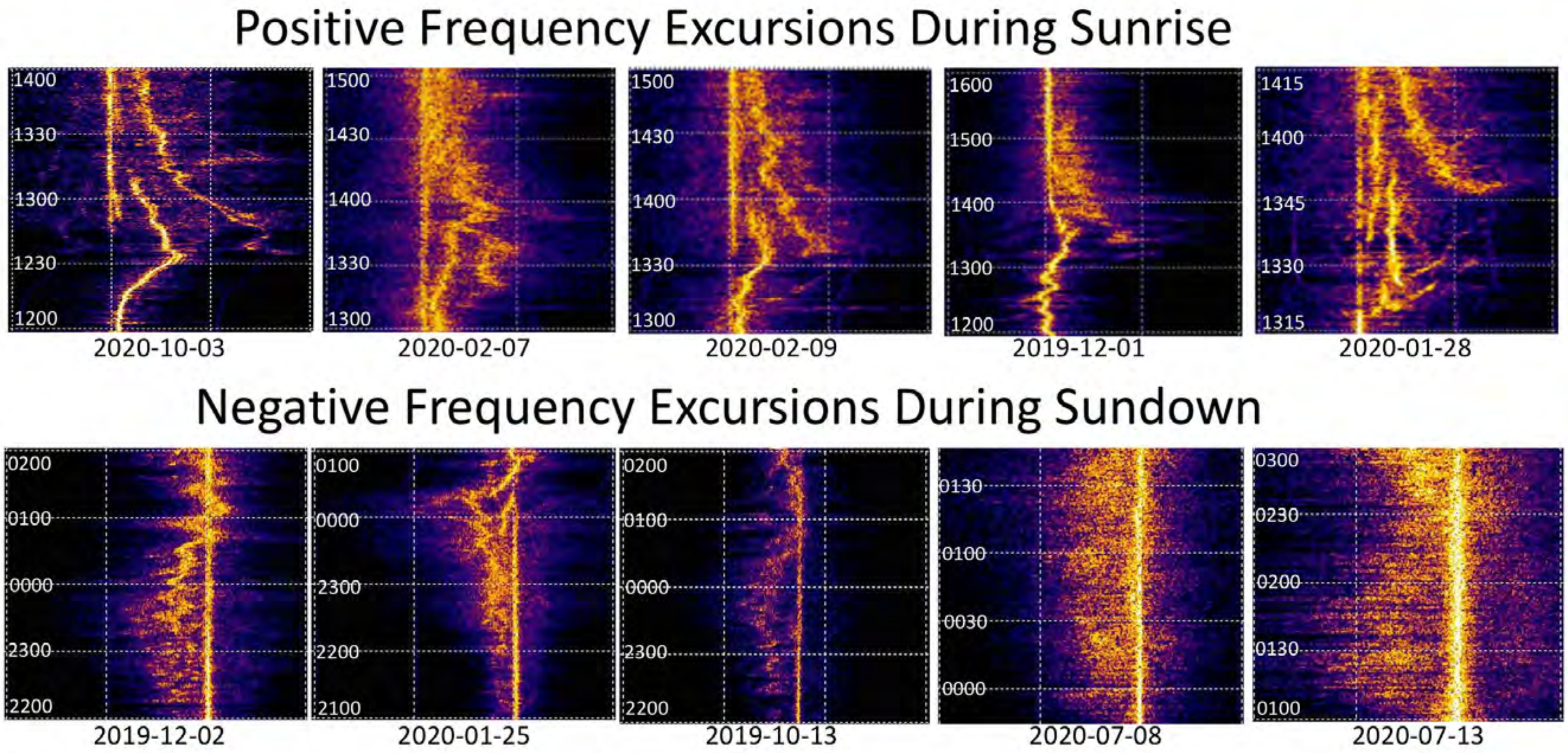
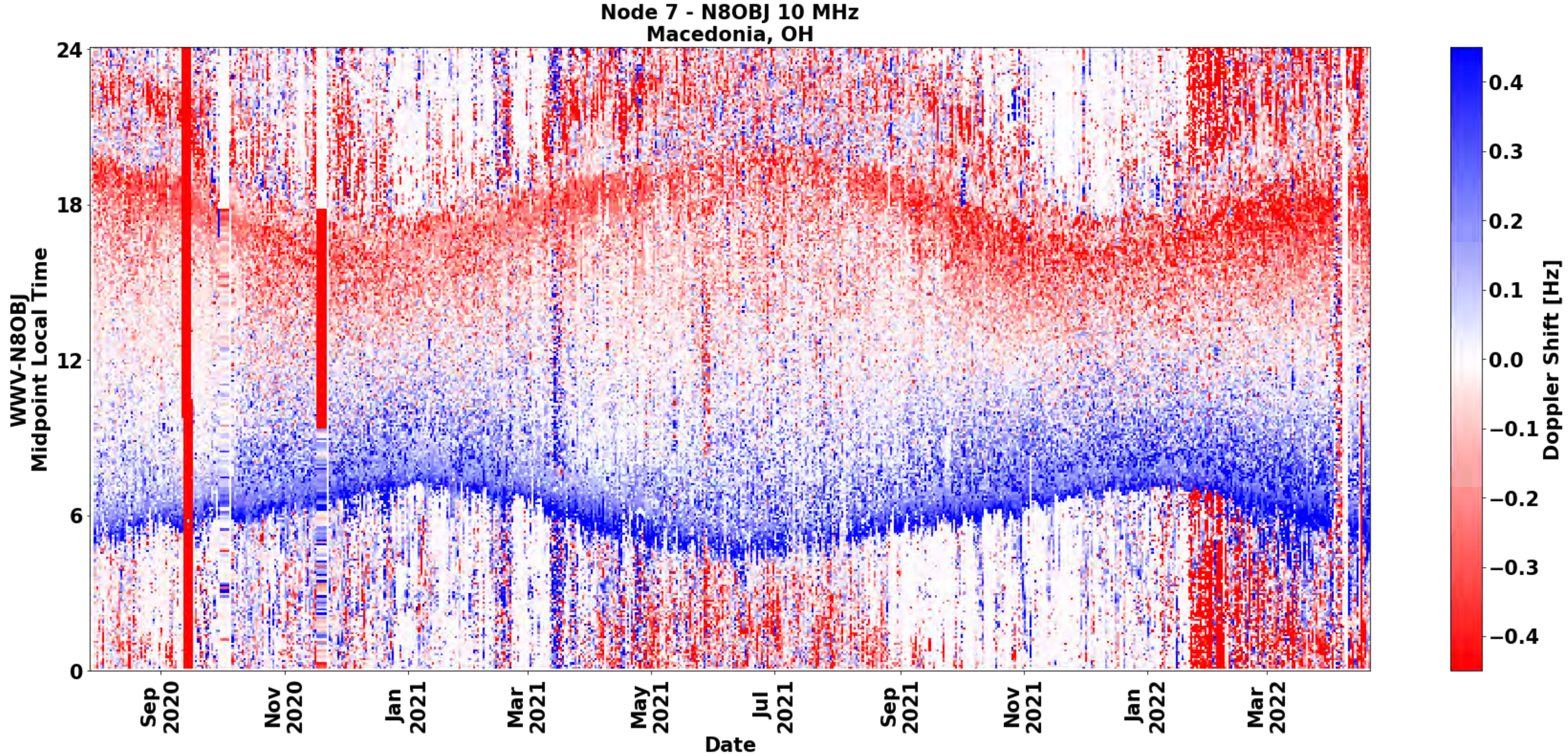
5 MHz WWV-WA5FRF Doppler Shifts



Data by Steve Cerwin WA5FRF

10 MHz WWV-N8OBJ (Cleveland, OH)



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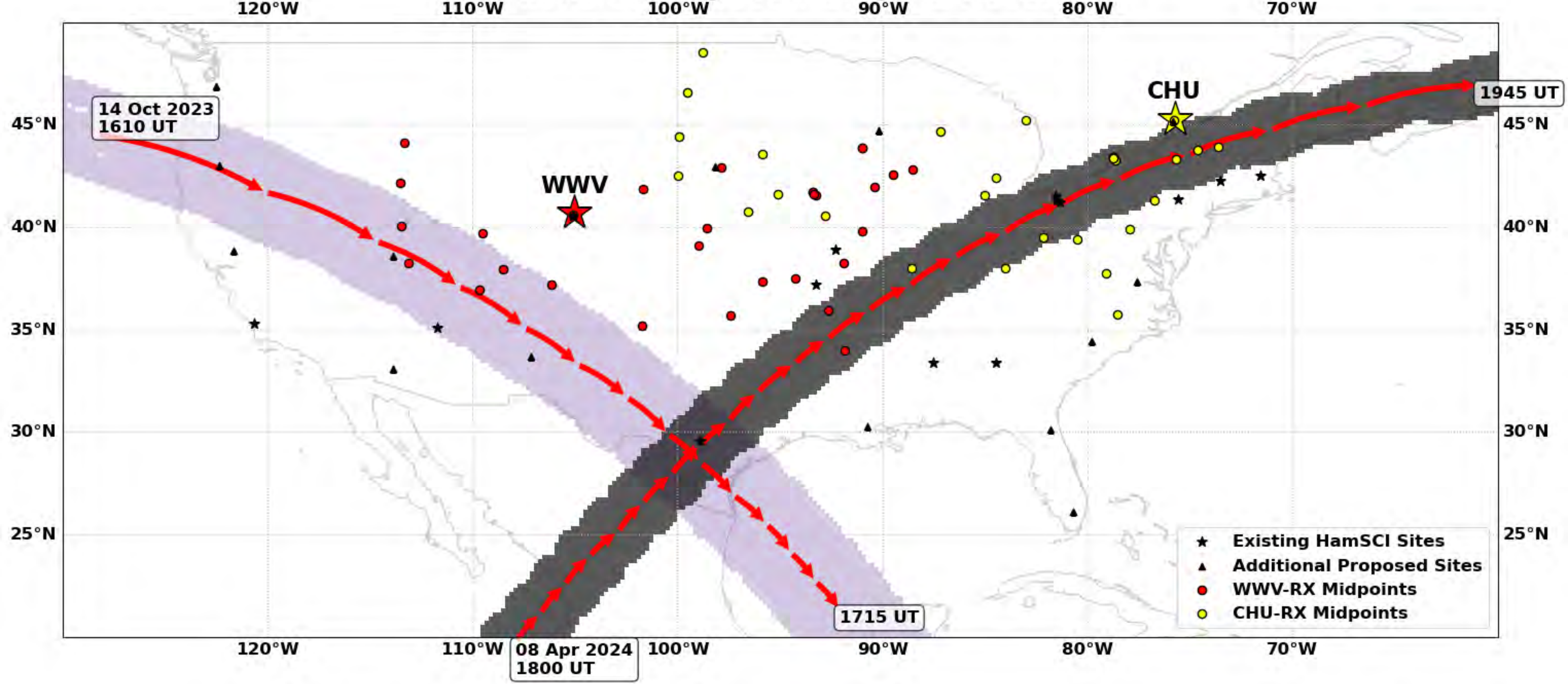
Locations of Proposed Grape 2 Receivers



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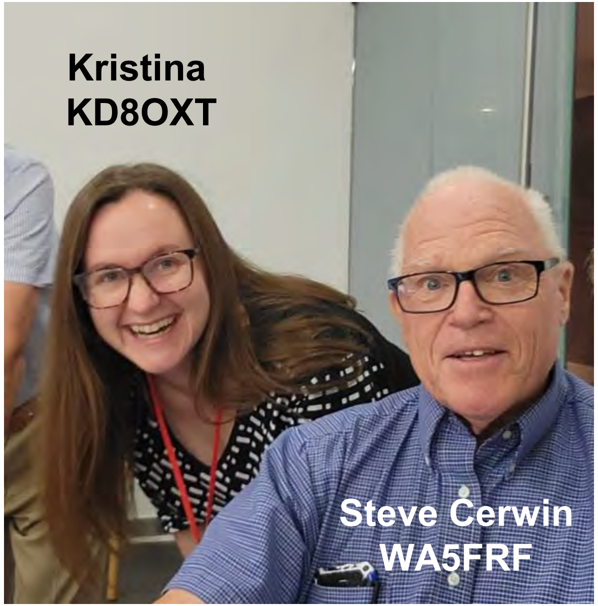
Time Difference of Arrival (TDOA) Experiment

Solar Eclipse TDOA Experiment

- Using a chirp waveform, it is possible to get relative path length measurements even without GPSDO.
- In the Eclipse TDOA Experiment, we ask pairs of stations to team up in small groups to systematically transmit and receive customized chirp waveforms to make these measurements.



Steve Cerwin WA5FRF is leading the Eclipse TDOA Experiment

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Eclipse TDOA Science Questions

- What is the observed change in effective F2 ionization layer height caused by the momentary blockage of solar radiation?
- Is symmetry observed in layer height changes when comparing 'before eclipse' and 'after eclipse' layer heights?

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The Time Difference of Arrival (TDOA) Between 1 and 2 hop Modes Can be Used to Deduce Layer Height

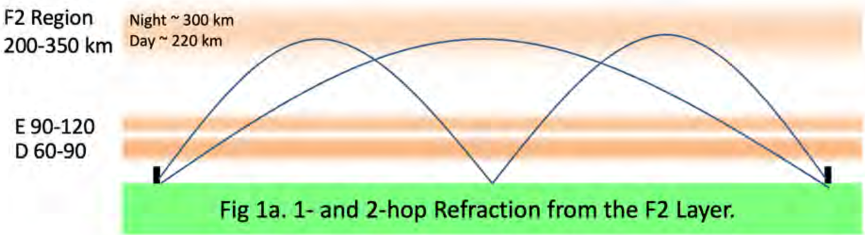


Fig 1a. 1- and 2-hop Refraction from the F2 Layer.

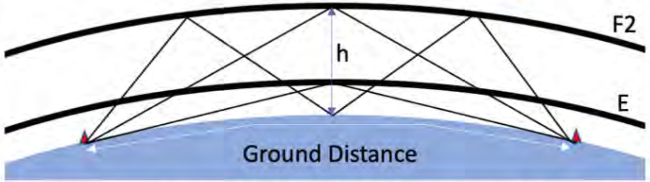


Fig 1b. Virtual Height model Used to Calculate Relationship between Virtual Height h and Path Length.
Time of Flight = Path Length / c

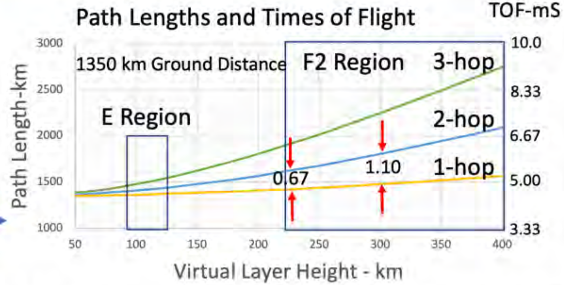


Fig 1c. TDOA Example: At 1350 km ground distance the Time Difference of Arrival between 1 and 2 hop modes is 0.67 ms at 225 km layer height and 1.10 ms at 300 km.

Courtesy of Steve Cerwin WA5FRF

An Audio Frequency Chirp Can be Used to Sense the TDOA of Simultaneous Multipath Signals

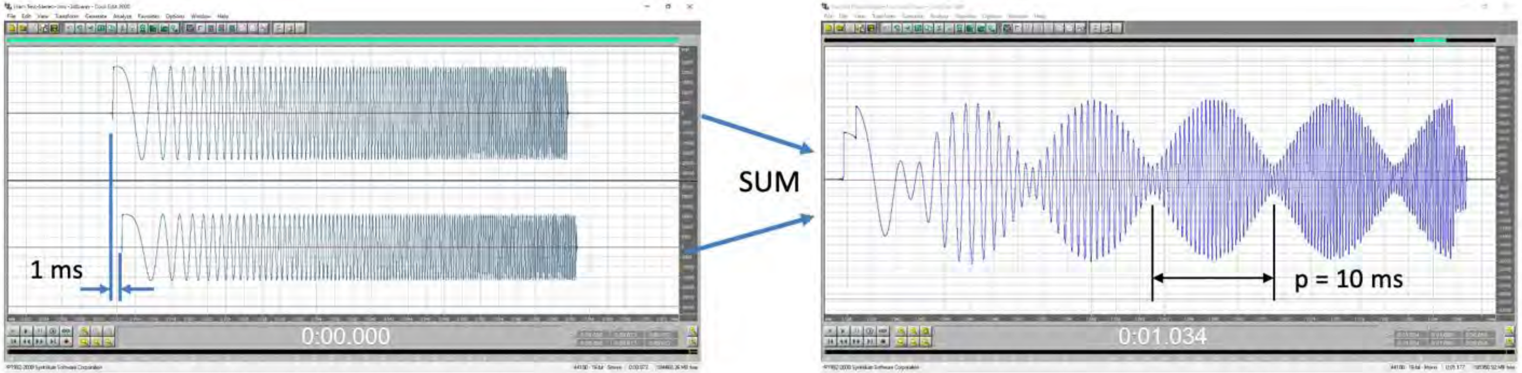


Fig 2a. Two 100 Hz/ms Chirps with 1 ms Time Delay. Delayed Chirp is 3 dB lower in Amplitude.

Fig 2b. Summation produces a Waveform with a Beat Note of Period p = 10 ms.

Summation of a linear chirp with a delayed copy of itself produces a difference frequency at Δf = Sweep Rate * Δt.
Beat pattern has a period p = 1/Δf. The Time Difference of Arrival (TDOA) can be calculated by:

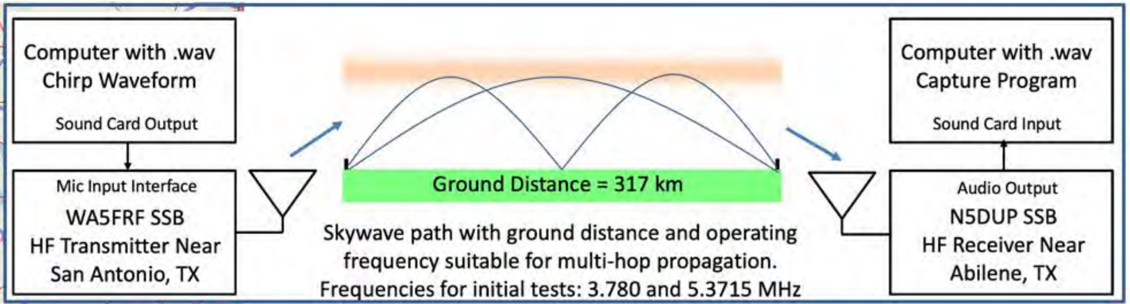
TDOA = 1/(p*Sweep Rate)

Example: two 100 Hz/ms chirps 1ms apart produce a difference frequency of 100Hz, which has a period of 10 ms.

TDOA = 1/(10 ms * 100 Hz/ms) = 1 s/1000 = 1 ms

Courtesy of Steve Cerwin WA5FRF

Geographic Layout TDOA Verification Experiment



Geometry and Setup for Initial TDOA On-Air Experiments
Using Amateur Radio Stations WA5FRF and N5DUP

Geometry is convenient for proximity to expected eclipse Path and to the Austin Ionosonde for ground truth data.

The 60 m and 75 m frequency bands were chosen for likelihood of both 1 hop and 2 hop propagation.

Courtesy of Steve Cerwin WA5FRF

The Results of the Texas TDOA Experiment were Consistent with Austin Ionosonde hmF2 Data

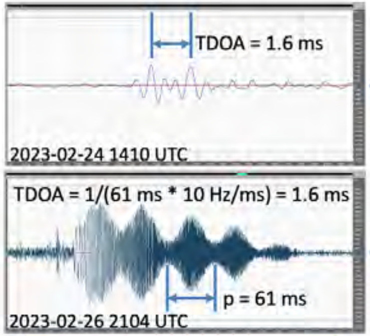


Fig. 4a Short Pulse and Chirp TDOA Measurements

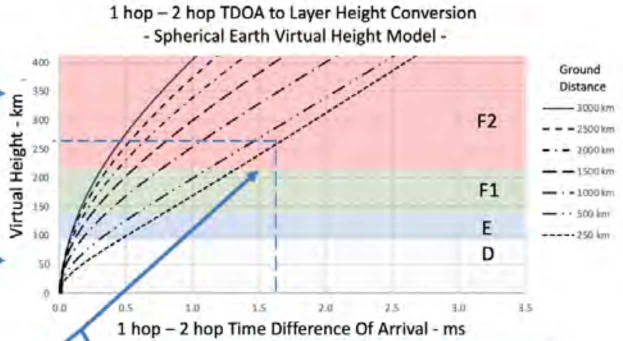


Fig. 4b Convert 1.6 ms TDOA Measurements to 270 km Layer Height

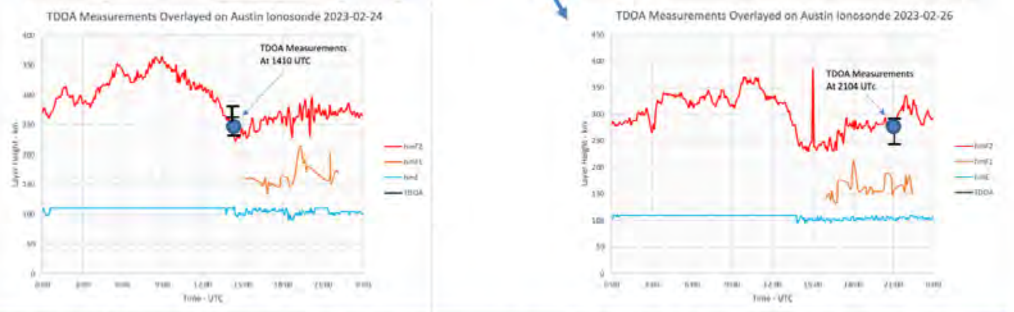
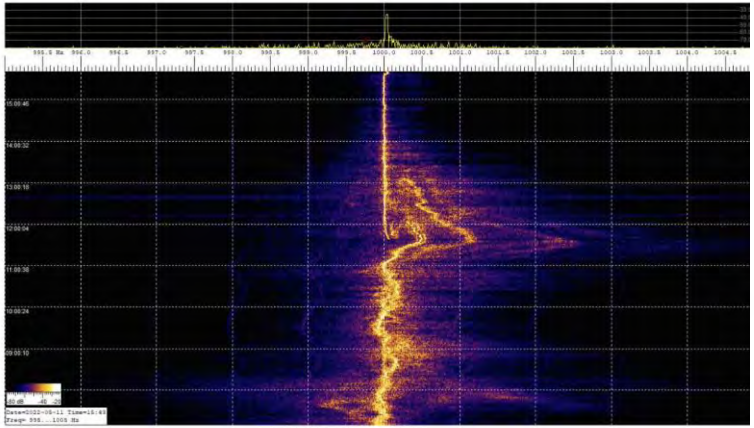


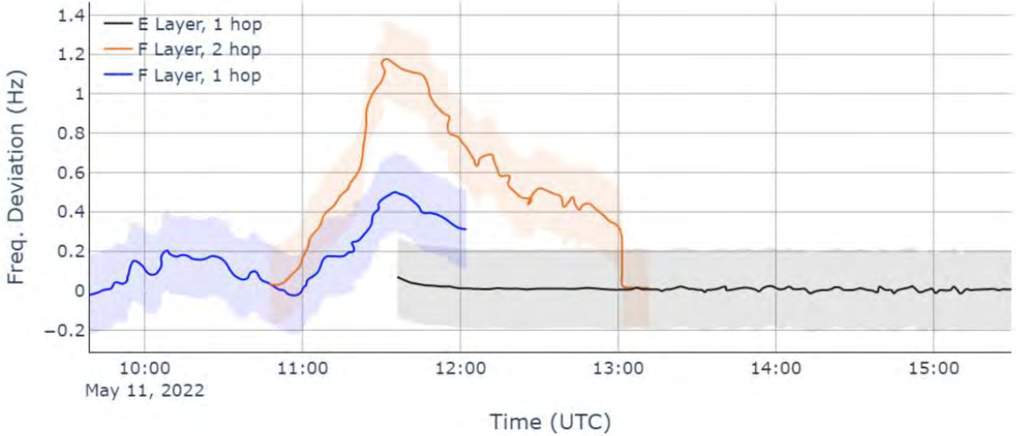
Fig. 4c Overlay Layer Height Estimation on Ionosonde hmF2 Data for Day and Time of Measurement. Error bars show range of 18 separate measurements using short pulses and 10-50 Hz/ms chirps.

Courtesy of Steve Cerwin WA5FRF

Solar Eclipse WWV Doppler Shift Analyses

Colorado to Texas Path at 5 MHz



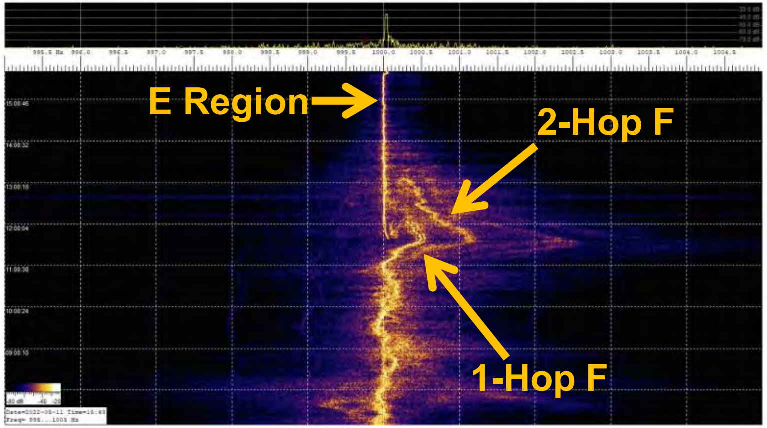


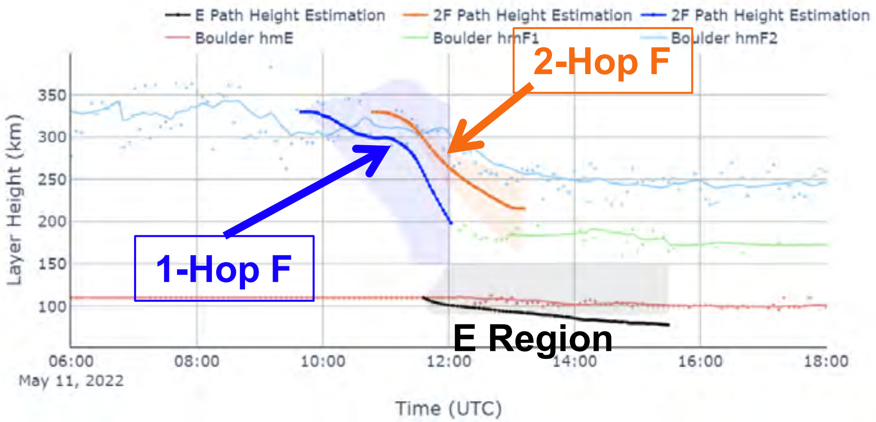
The lowering of the F2 layer height in the morning transition from night into day causes positive Doppler shifts in the 5 MHz WWV carrier. Mode splitting has been observed where the magnitude of the Doppler shifts appears to separate according to the number of hops between transmitter and receiver. A HamSCI science objective is to investigate if similar behavior occurs during an eclipse.

Courtesy of Steve Cerwin WA5FRF

Solar Eclipse TDOA Experiment

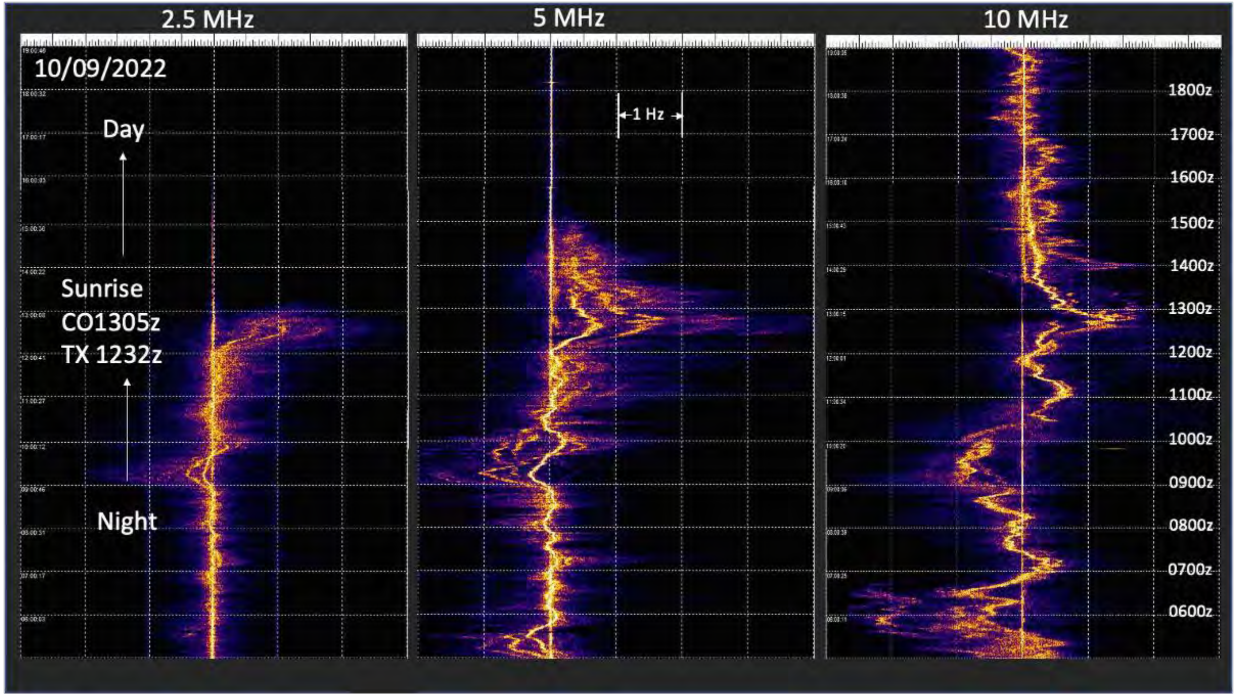
- Doppler splitting shows different propagation modes.
- This normally requires a GPSDO to get useful information





Courtesy of Steve Cerwin WA5FRF

Recording WWV Spectra at Multiple Frequencies Enables Analyses of Doppler Shift Frequency Dependencies

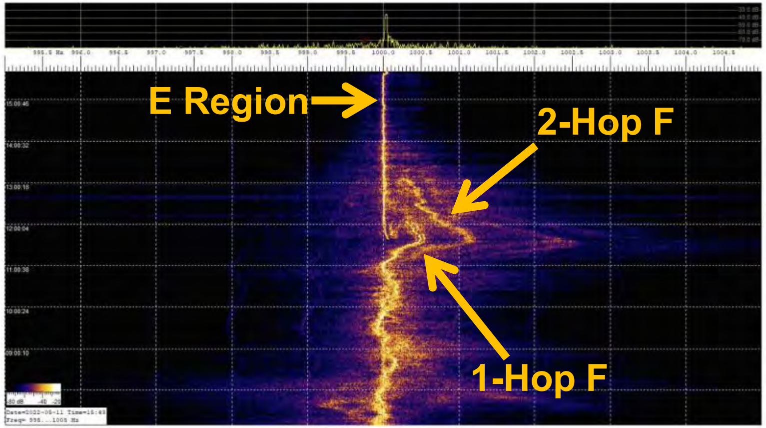


Courtesy of Steve Cerwin WA5FRF

Simultaneous 3-frequency WWV spectrograms over a Colorado to Texas Path (WWV – WA5FRF). The Experiment required three separate receivers and laptop computers at WA5FRF receive site.

TDOA Frequencies

- This type of multi-mode splitting most reliably occurs below 10 MHz.
- Therefore, the TDOA experiment will be concentrated on 40, 75, and 160 meters.

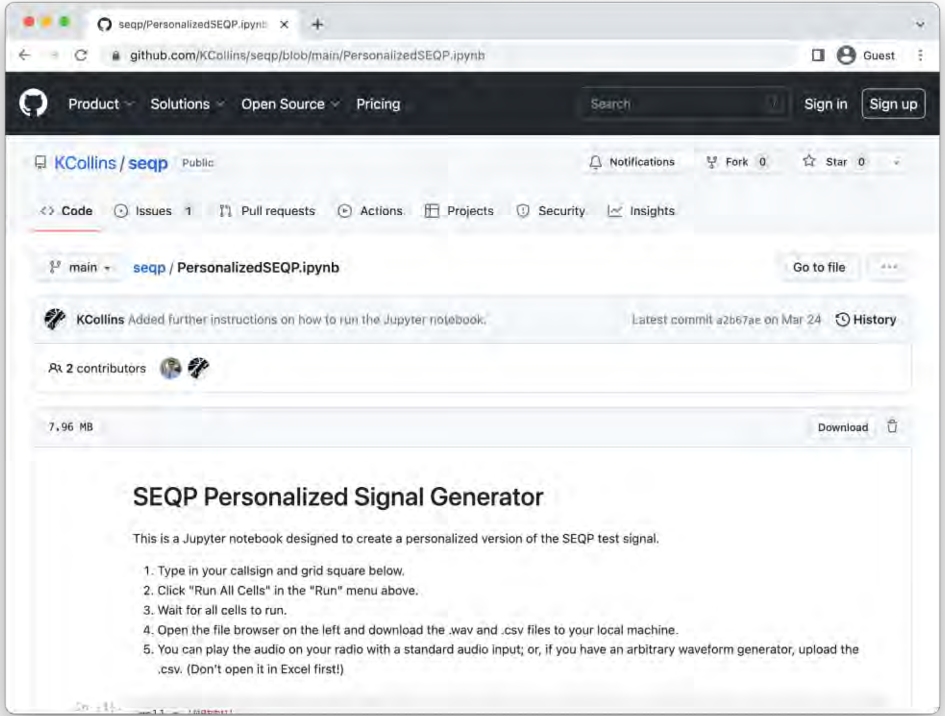


Courtesy of Steve Cerwin WA5FRF

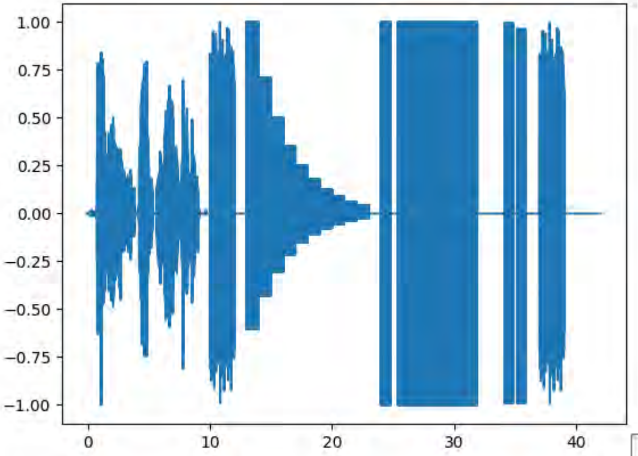
TDOA Procedure

1. Register at https://hamsci.org/tdoa-event-2023
2. Participants will be assigned to pairs or small groups.
3. Generate a custom chirp waveform using online Notebook.
4. Stations will take turns sending and receiving (recording) custom chirp waveforms every 6 to 10 minutes for at least 2 hours throughout the eclipse.
5. Return recordings to HamSCI website for analysis.
6. You can help with analysis! We will show you how.

Custom Waveform



- Custom chirp includes CW ID and Grid Square.
- Notebook developed by Kristina Collins KD8OXT and Aidan Montare KB3UMD.



Visit https://hamsci.org/tdoa-event-2023 to generate your custom waveform!

TDOA Test Run

- Join us in a 'dry run' approximately one month before the actual eclipse!
- This will give everyone a chance to check out their hardware and software, make adjustments and updates, well in advance.
- Proposed Test Run: September 16, 2023, at 0000 UTC.

Details have not been finalized.
Registered participants will be notified well in advance.

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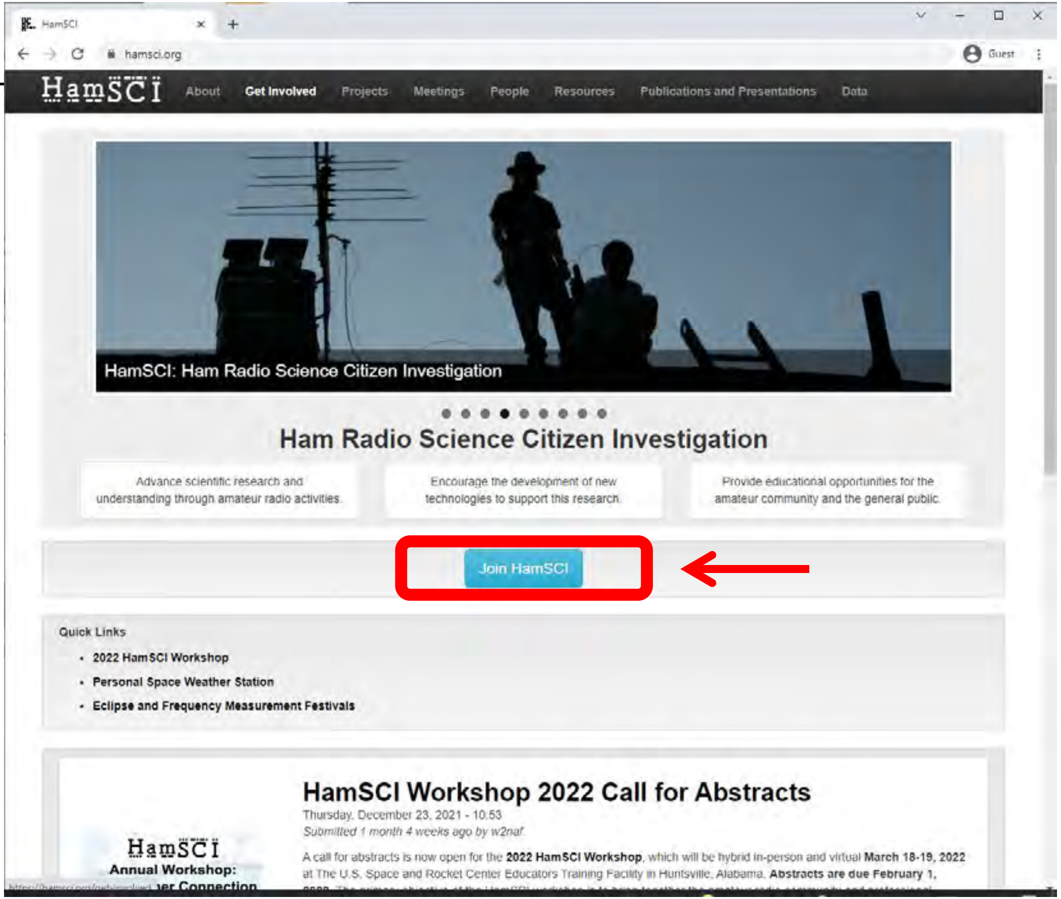
Getting Involved

- **HamSCI now has over 800 members!**
- Join by visiting **hamsci.org**
- Main Google group is open discussion for all things related to HamSCI.
- Many specialized email lists and telecons, too!



HamSCI Zoom Telecons

TangerineSDR Telecon	**Engineering telecon to support the TangerineSDR and magnetometer board development.**	**Mondays at 9 PM Eastern (Tuesdays 0100z)**
Grape Telecon 	**Telecon to support engineering and science related to the Grape (low-cost) Personal Space Weather Station.**	**Thursdays at 10 AM Eastern (1400z)**
SEQP Telecon	**Telecon to support the 2023 and 2024 Solar Eclipse QSO Parties.**	**Thursdays at 4 PM Eastern (2000z)**

Zoom links and calendar at http://hamsci.org/get-involved.

HamSCI Volunteer Ham Radio Community Coordinator

Gary Mikitin, AF8A

Visit us in Booth 5008 (with TAPR)!

- **HamSCI Booth Talks - Booth 4303 (YOTA)**
- **HamSCI Forum - Saturday 2:50 PM – Room 4**

Acknowledgments

We are especially grateful for the

- support of NSF Grants AGS-2002278, AGS-1932997, AGS-1932972, AGS-2045755, AGS-2230345, and AGS-2230346.
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- 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).

Thank you!

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