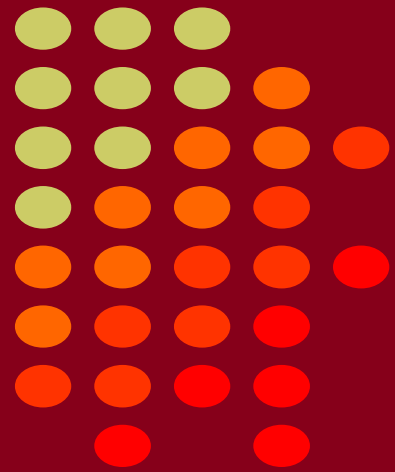
CTU Presents

Contesting for Ionospheric Science During the 2023 and 2024 North American Solar Eclipses



Nathaniel A. Frissell W2NAF

Gary Mikitin AF8A, Gareth Perry KD2SAK, Joe Huba, Bill Engelke AB4EJ, Rachel Boedicker AC8XY, Kristina Collins KD8OXT, John Gibbons N8OBJ, David Kazdan AD8Y, Phil Erickson W1PJE, Bob Gerzoff WK2Y, Mary Lou West KC2NMC, Ward Silver N0AX, and the HamSCI Community

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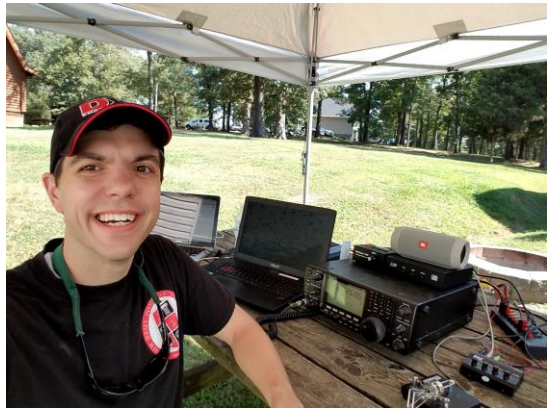
Ham radio Science Citizen Investigation

hamsci.org/dayton2022



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.

Festivals of Eclipse Ionospheric Science

- **Annular: Saturday, Oct 14, 2023**
- **Total: Monday, April 8, 2024**

https://hamsci.org/eclipse

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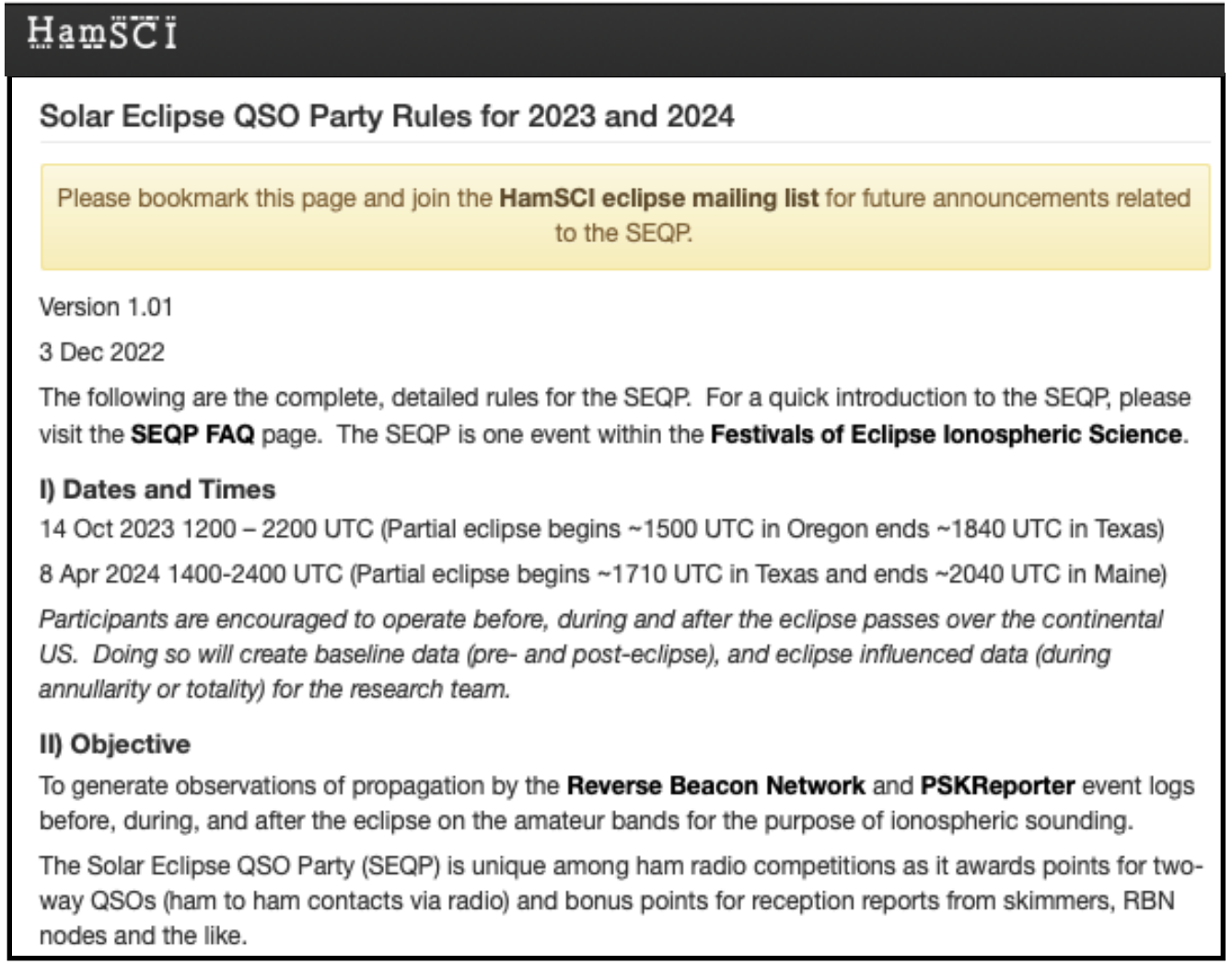
Solar Eclipse QSO Party 2.0

- 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/contest-info
- https://hamsci.org/seqp-faqs
- https://hamsci.org/seqp-rules
- Results will be published



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Solar Eclipse QSO Party Rules for 2023 and 2024

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

Version 1.01

3 Dec 2022

The following are the complete, detailed rules for the SEQP. For a quick introduction to the SEQP, please visit the **SEQP FAQ** page. The SEQP is one event within the **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 annullarity or totality) for the research team.

II) Objective

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

The Solar Eclipse QSO Party (SEQP) is unique among ham radio competitions as it awards points for two-way QSOs (ham to ham contacts via radio) and bonus points for reception reports from skimmers, RBN nodes and the like.

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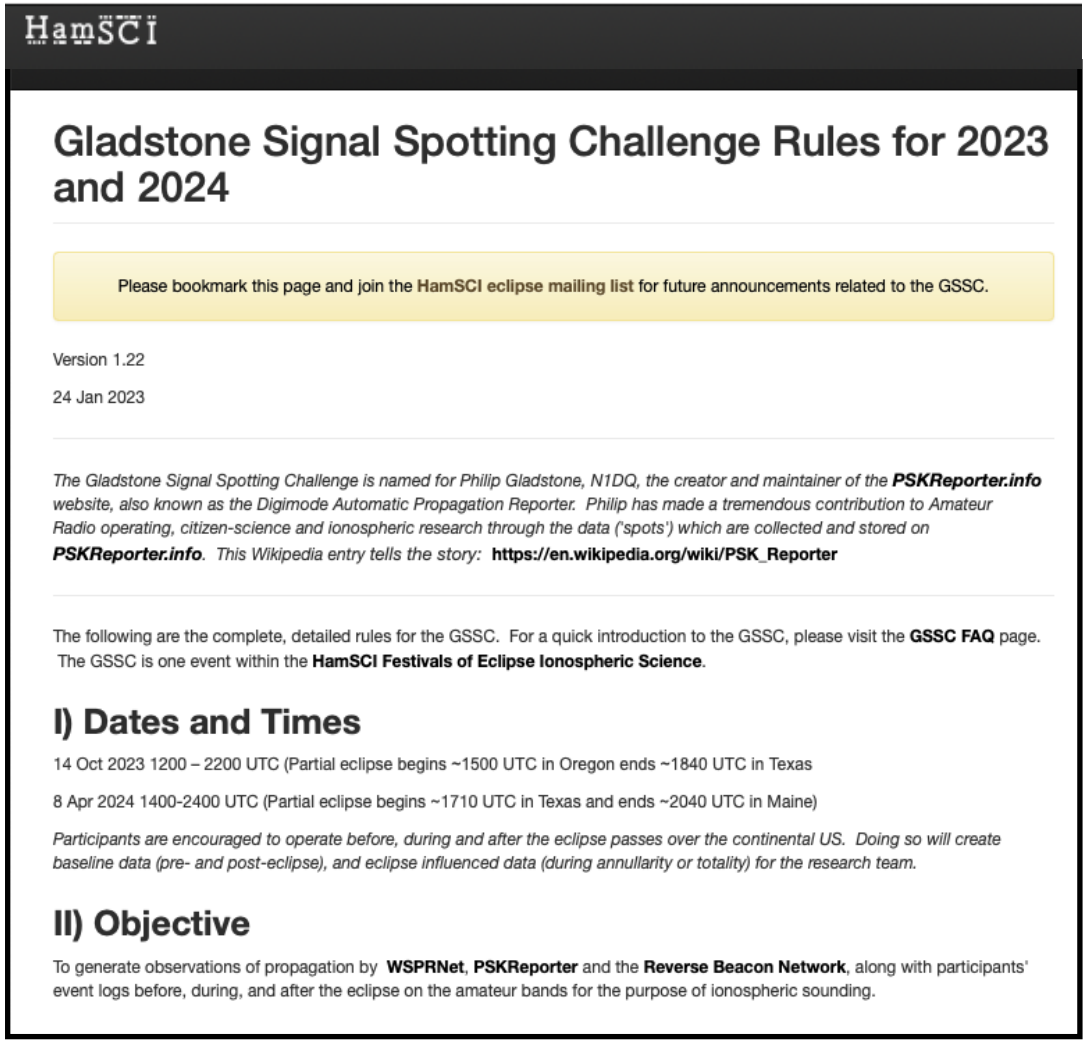
Gladstone Signal Spotting Challenge

- A contest for people who like running skimmers, using FT8, FST4W, and WSPR!
- The HamSCI website has details on the Challenge and links to WSPR and FST4W information
- https://hamsci.org/contest-info
- https://hamsci.org/gssc-faqs
- https://hamsci.org/gssc-rules
- Results will be published



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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 annullarity 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.

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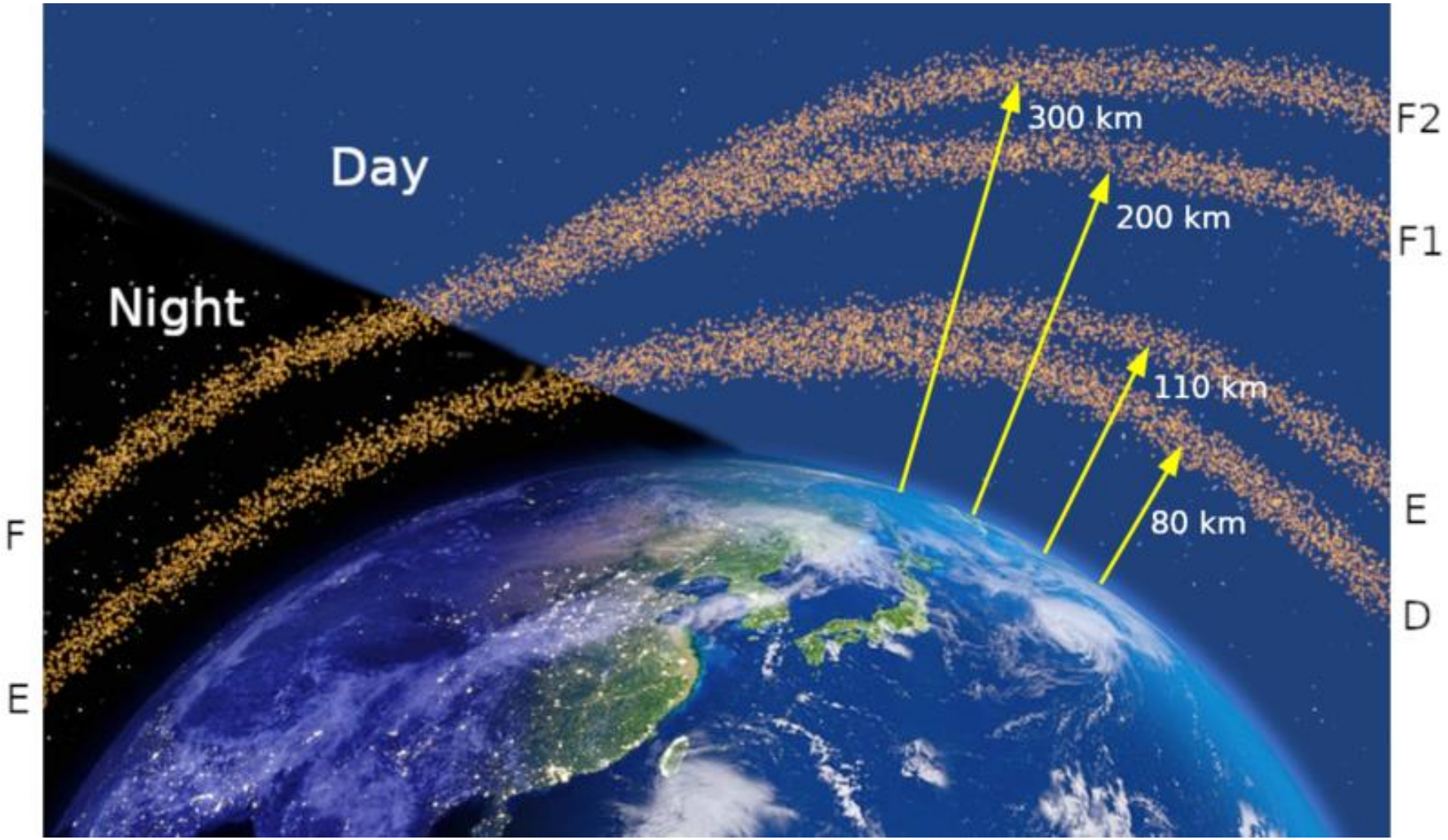
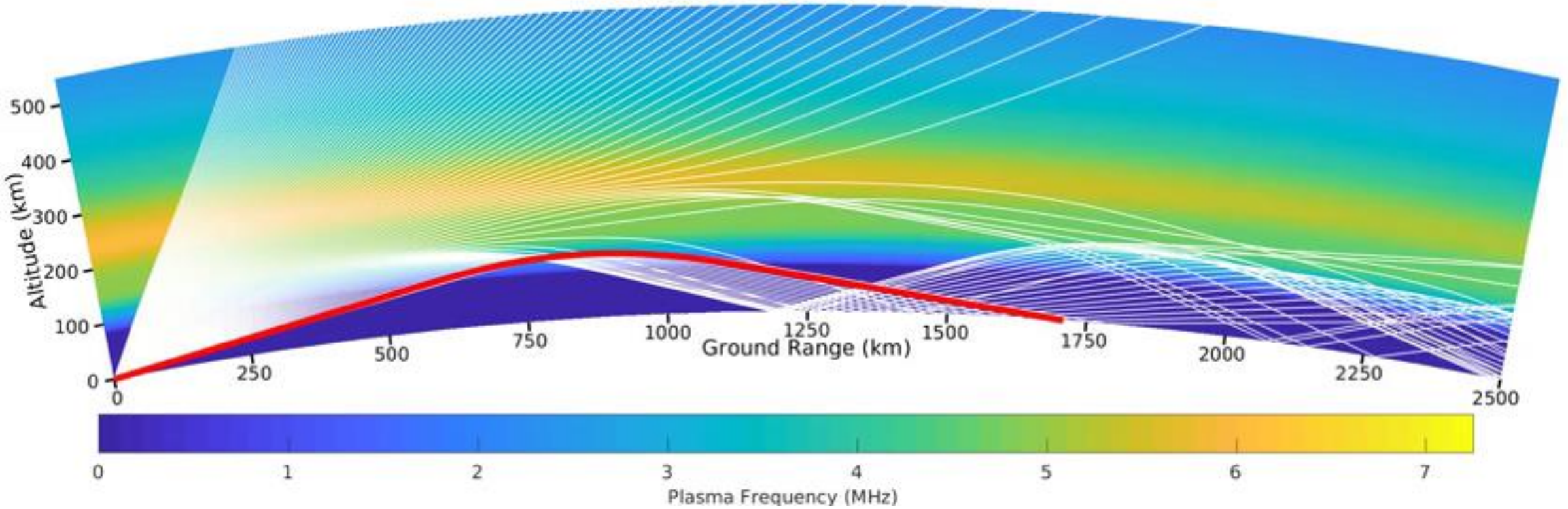
The Ionosphere



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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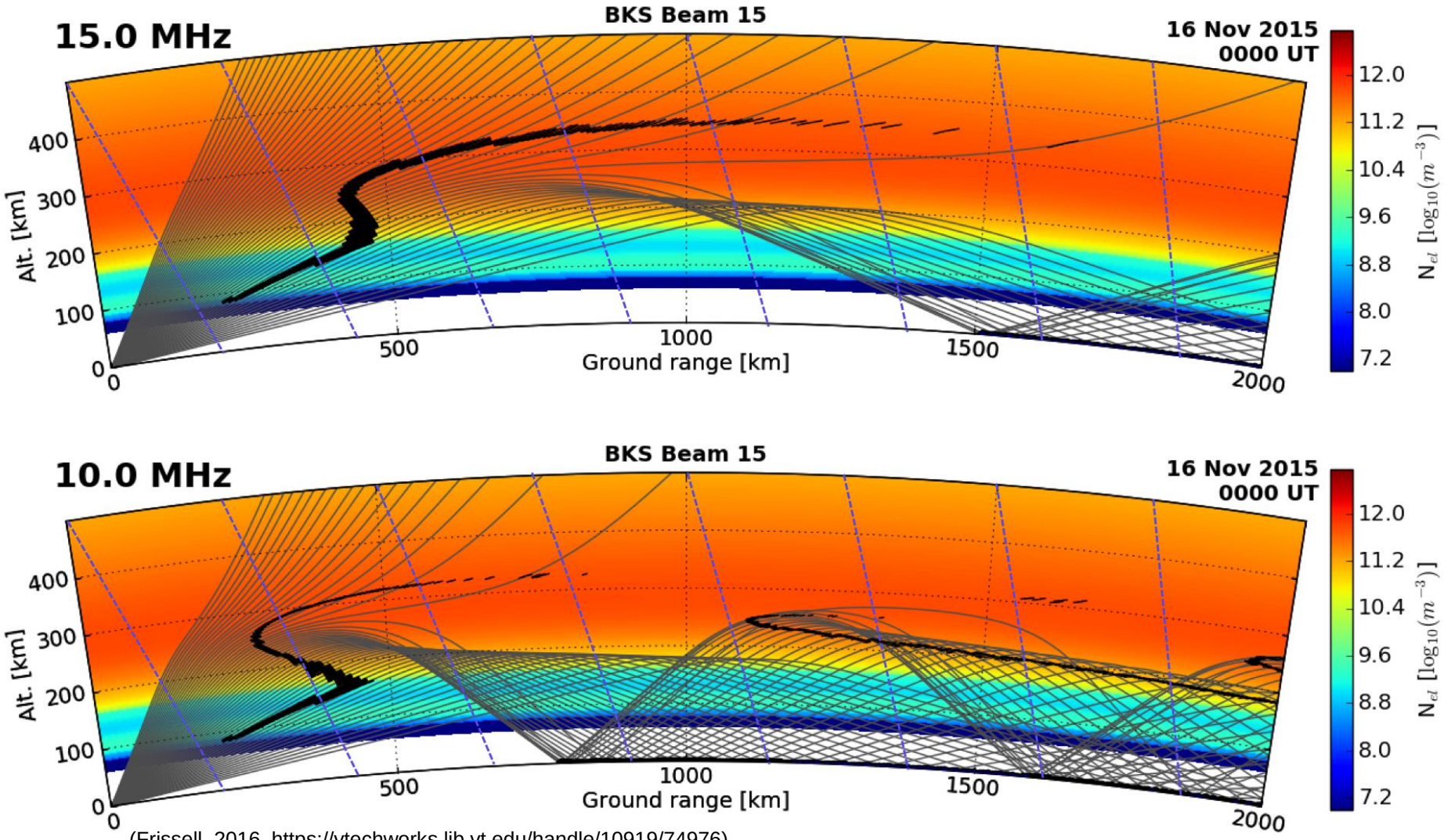
Refraction as a Function of Frequency



(Frissell, 2016, https://vtechworks.lib.vt.edu/handle/10919/74976)

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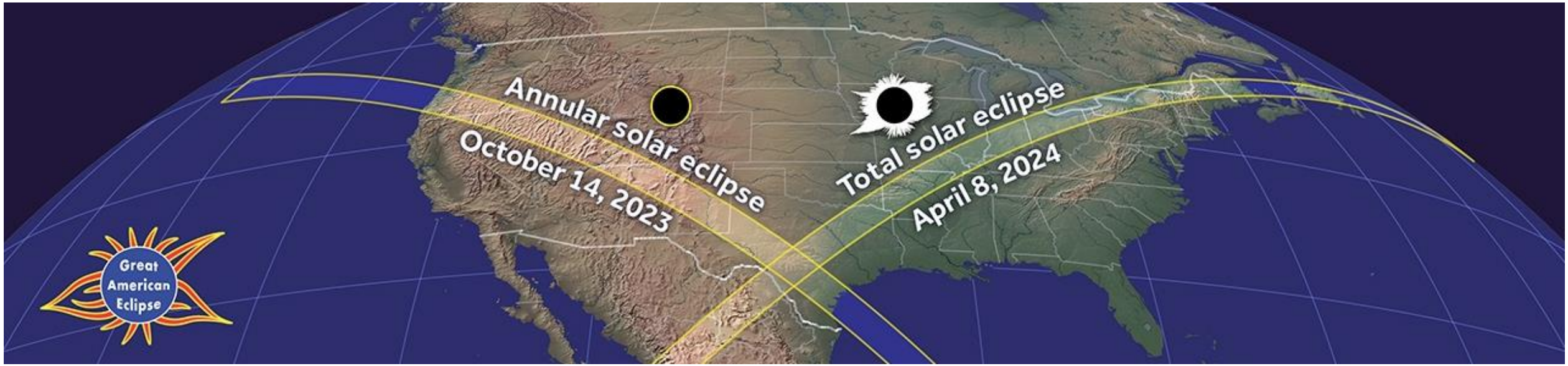
Eclipses 2023 and 2024



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

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Umbra and Penumbra

Moon's shadow has 2 parts:

- **Umbra:** innermost region of the shadow; Sun fully hidden & objects in total shadow.
- **Penumbra:** outermost region of the shadow; Sun partially hidden & objects still receive some sunlight.

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Total and Partial Eclipse

- **Total Eclipse:** Observer is located in the umbra.
- **Partial Eclipse:** Observer is located in the penumbra.

*A Total Solar Eclipse is **much** more dramatic than a partial solar eclipse. During a total solar eclipse, you can even see the Sun's Corona! If you have a chance to be in the path of totality during a solar eclipse, you should take the opportunity!*

Total and Annular Solar Eclipses

- The Moon appears larger in the sky at perigee compared to apogee.
- By coincidence, when the Moon is at or near perigee, it is sized to completely cover the solar disk during an eclipse. This results in a **Total Solar Eclipse.**
- At apogee when the Moon is farthest from the Earth, it will fit inside the Solar disk rather than totally obscure it. This creates an **Annular Solar Eclipse.**

Total and Annular Solar Eclipses

Total

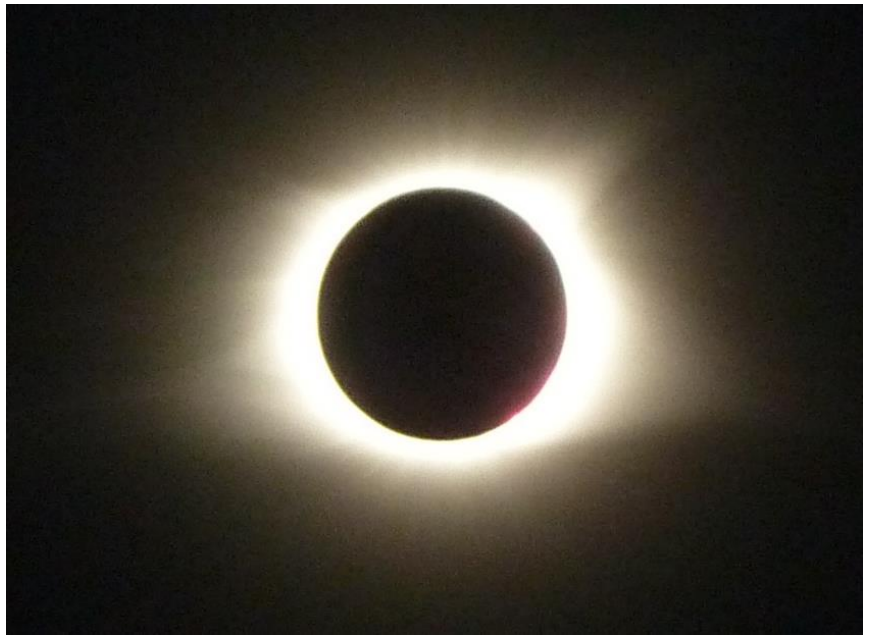

Photo by Jim Sackerman, KC2ZFK

Partial

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

Annular

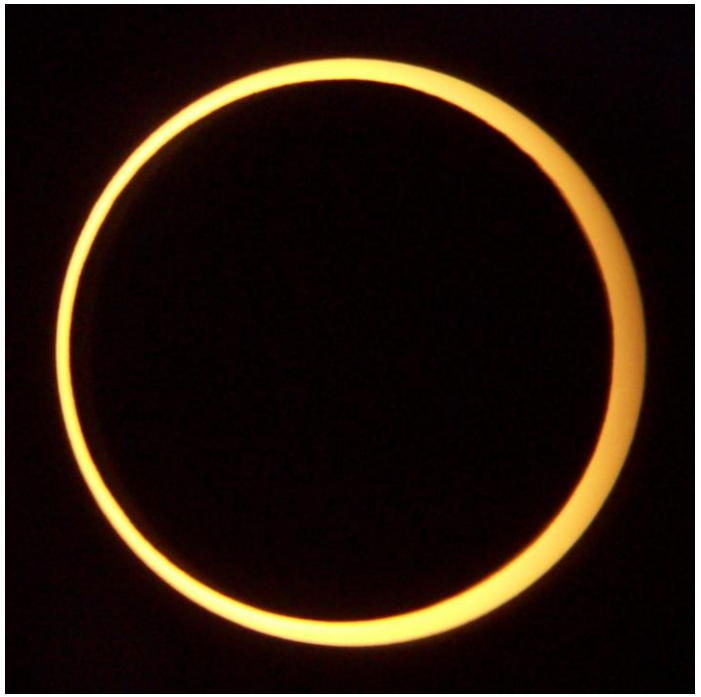

Photo By Smrgeog~commonswiki (https://commons.wikimedia.org/wiki/File:Annular_Eclipse._Taken_from_Middlegate,_Nevada_on_May_20,_2012.jpg)

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Eclipse Ionospheric Effects

- Because solar radiation is blocked from the atmosphere during an eclipse, we can expect the ionosphere to respond similarly to day and night.
- But, there are differences…

What are those differences?

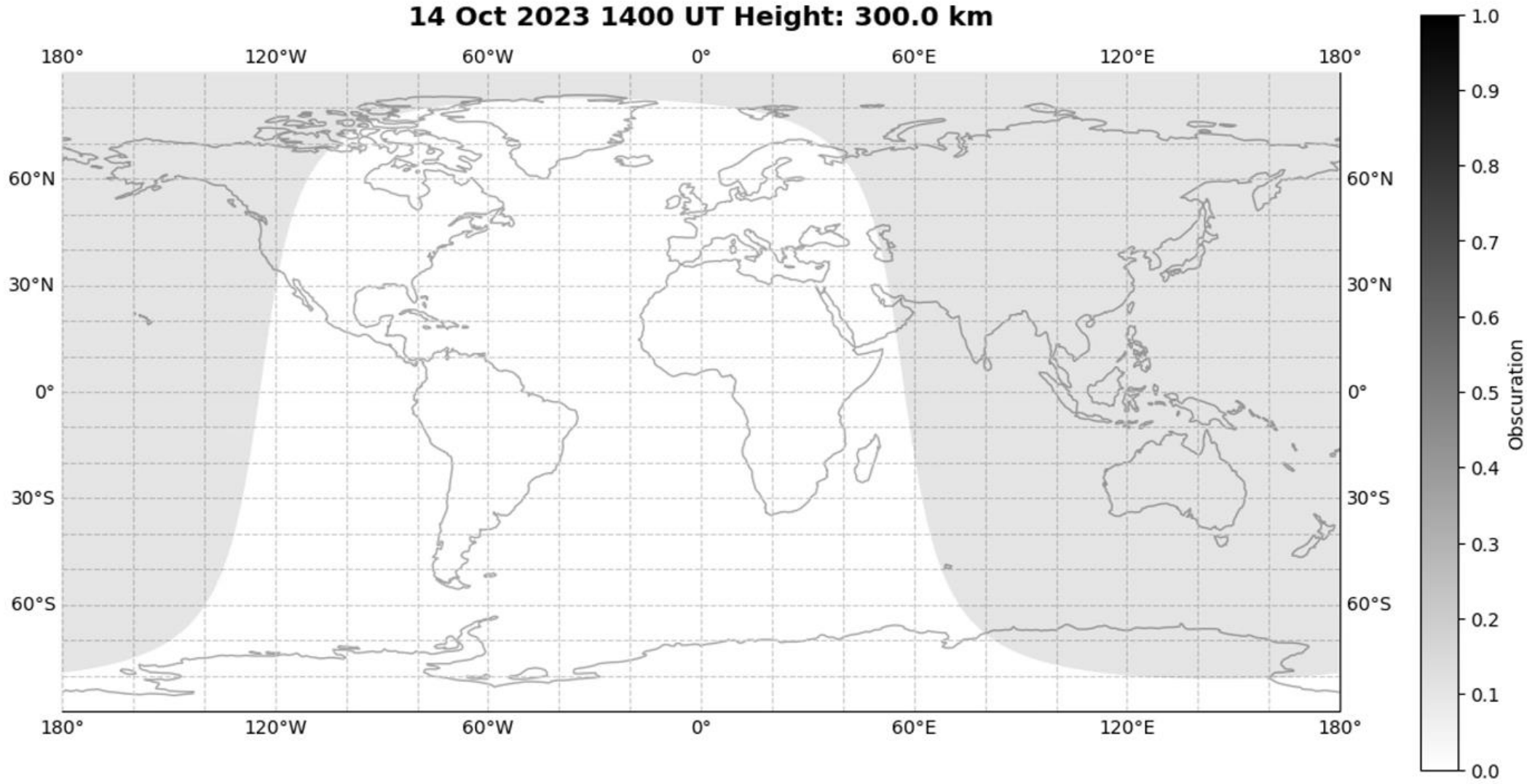
Differences Between Eclipses and Day-Night

- Eclipse is shorter duration.
- More localized.
- Travels at supersonic speeds.
- Travels in directions that are different from westward motion of dawn and dusk terminators.

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.

Annular Solar Eclipse: October 14, 2023



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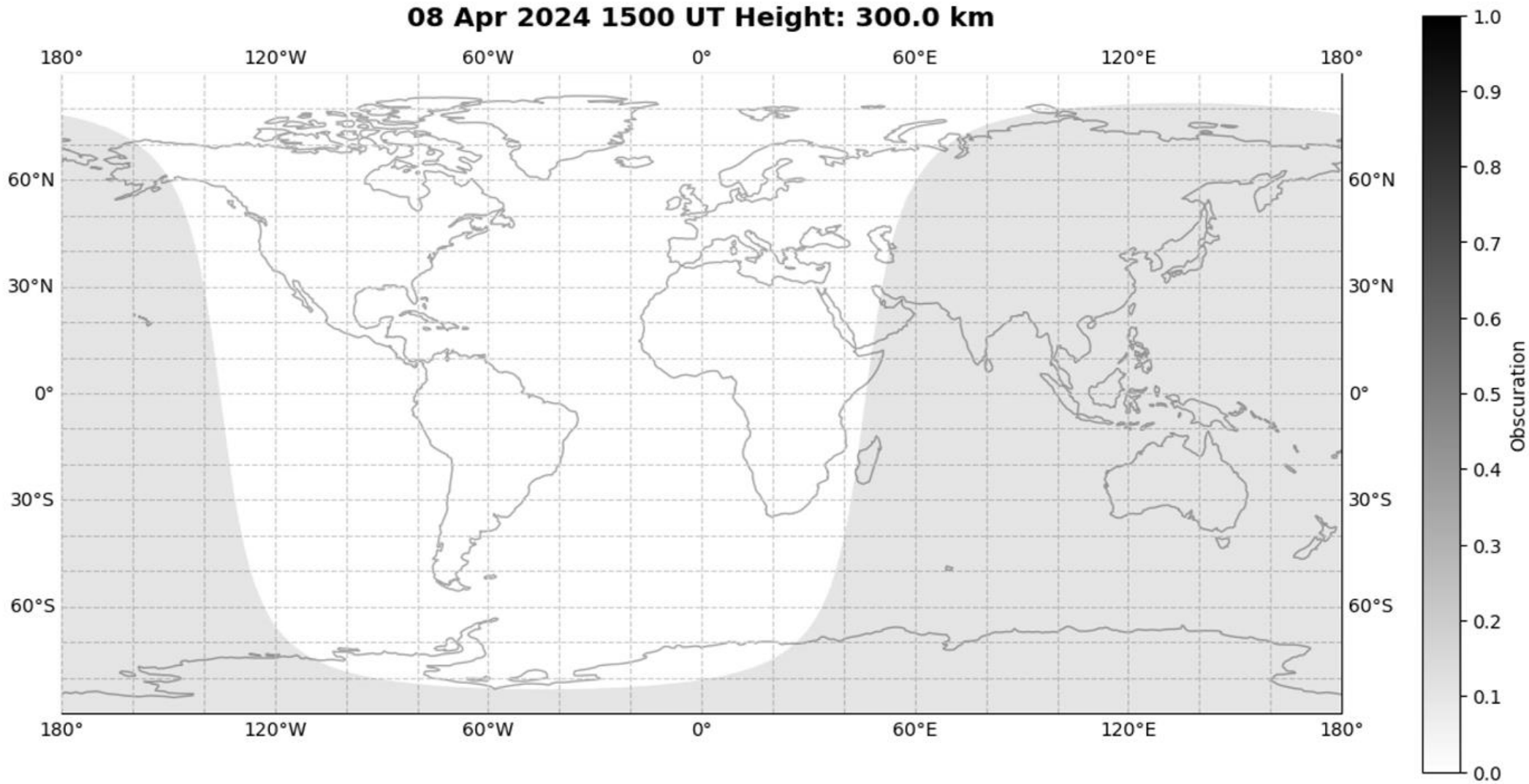
Total Solar Eclipse: April 8, 2024



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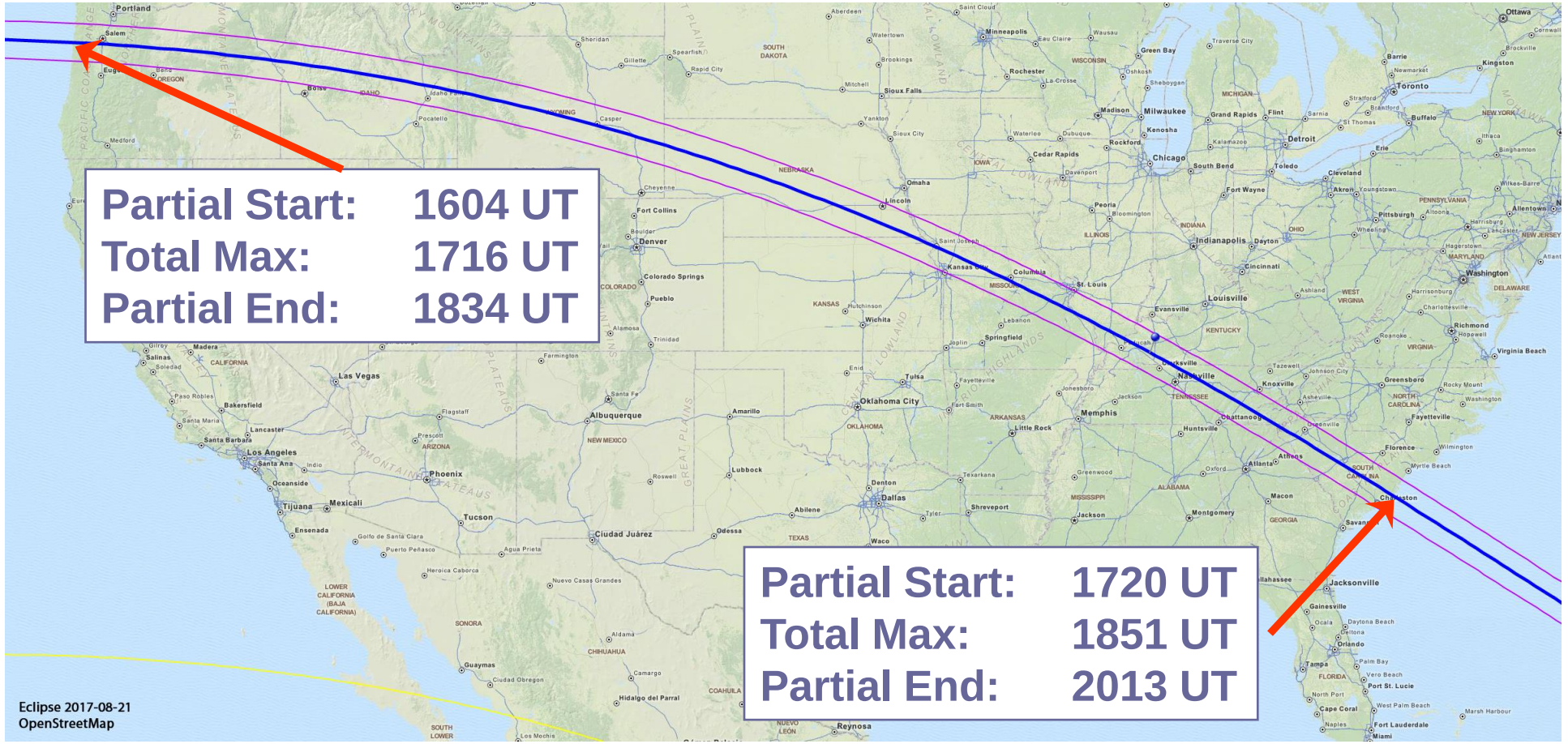
2017 Total Solar Eclipse



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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?

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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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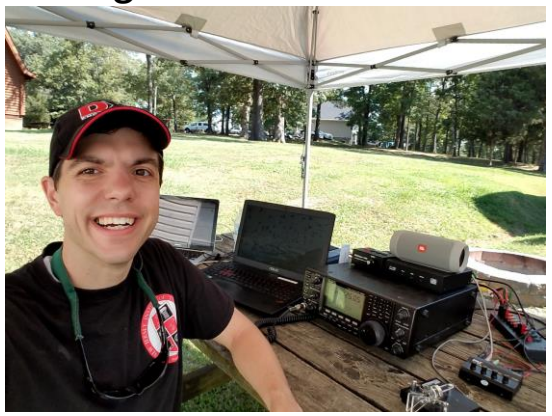
Solar Eclipse QSO Party

- 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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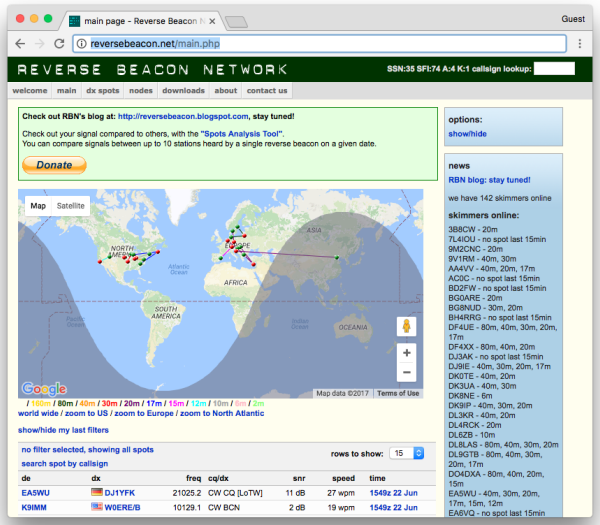
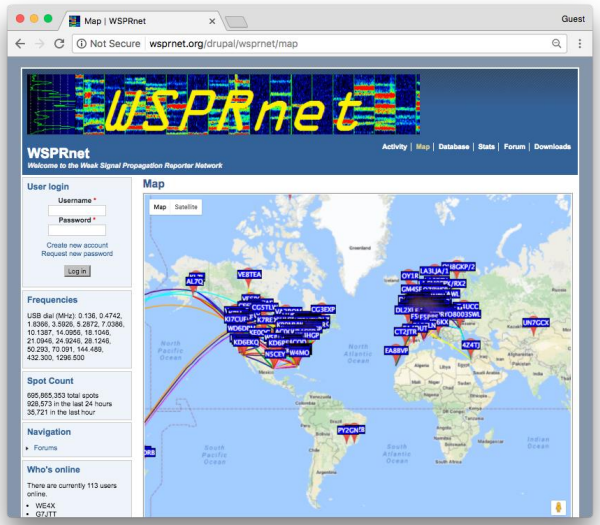
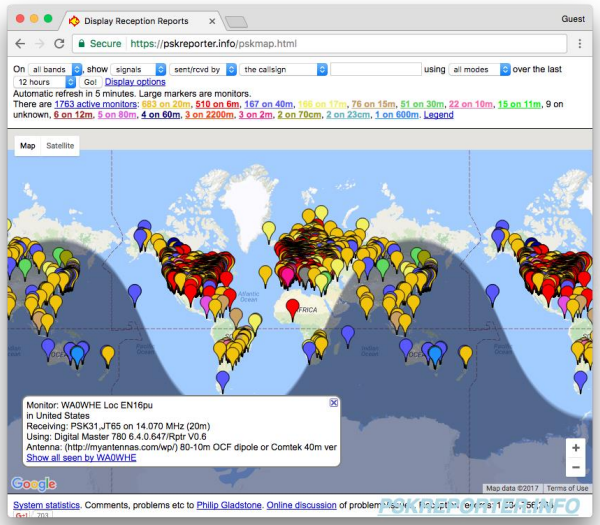
SEQP Observations



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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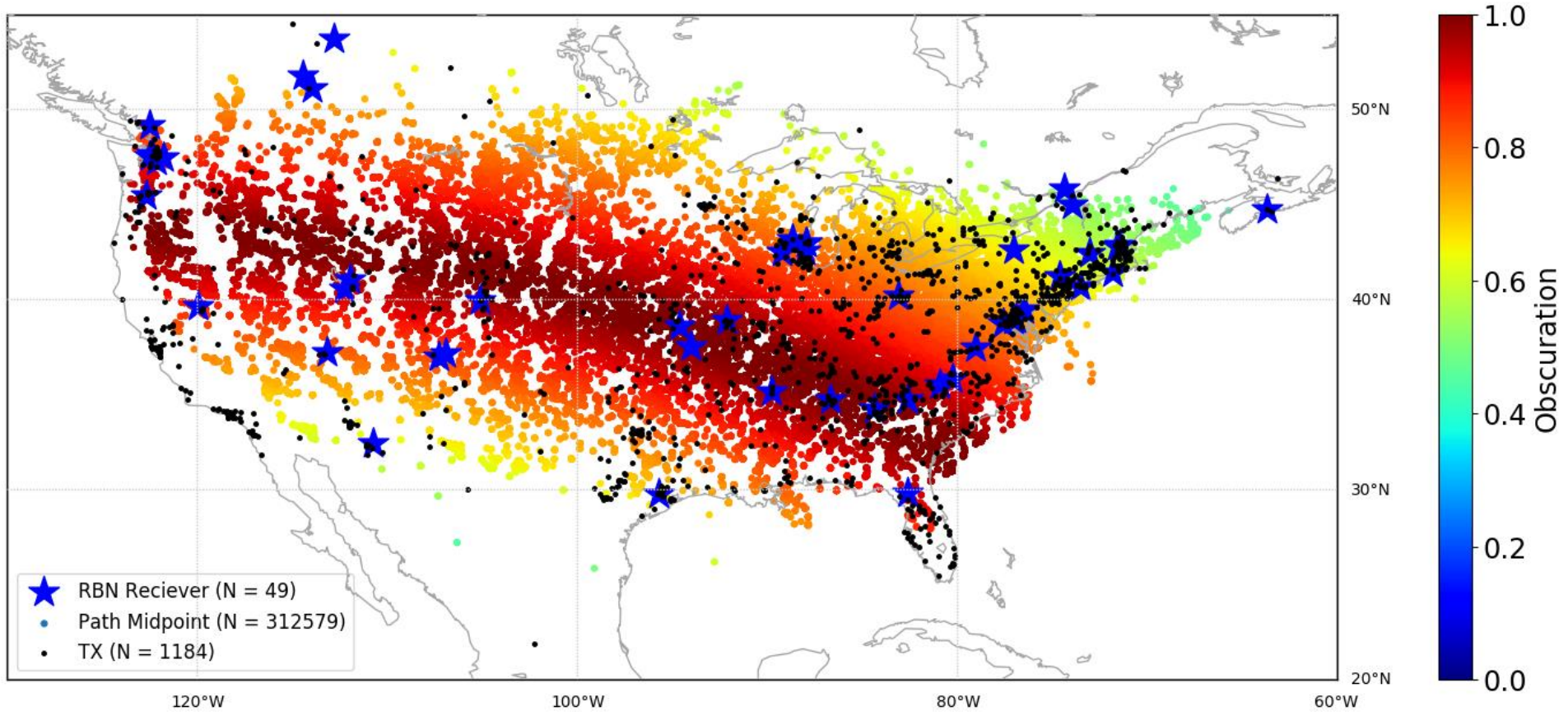
Solar Eclipse QSO Party RBN Observations



[Frissell et al., 2018, https://doi.org/10.1029/2018GL077324]

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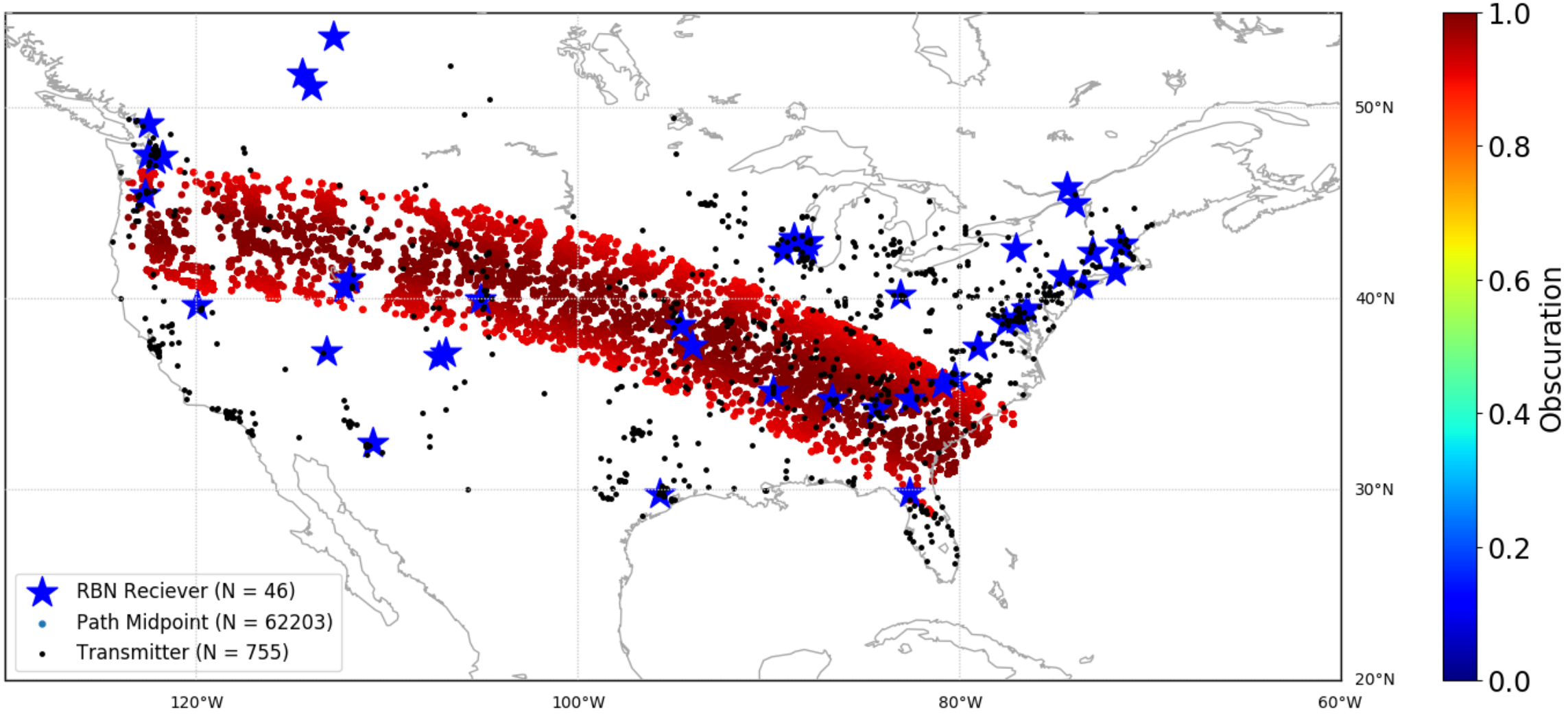
SEQP RBN ($O_{300} \geq 0.9$)



[Frissell et al., 2018, https://doi.org/10.1029/2018GL077324]

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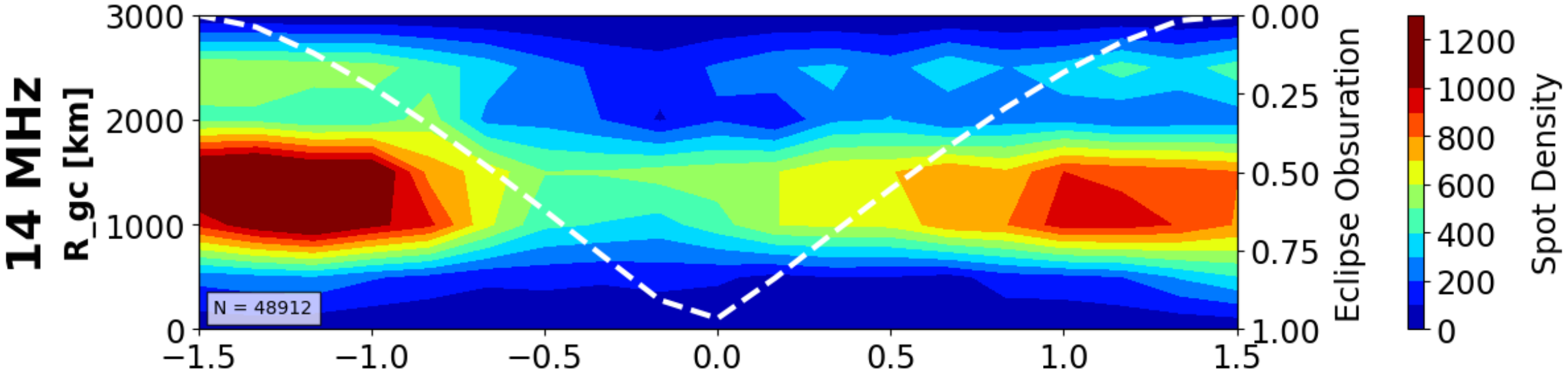
14 MHz 2017 SEQP RBN ($O_{300} \geq 0.9$)



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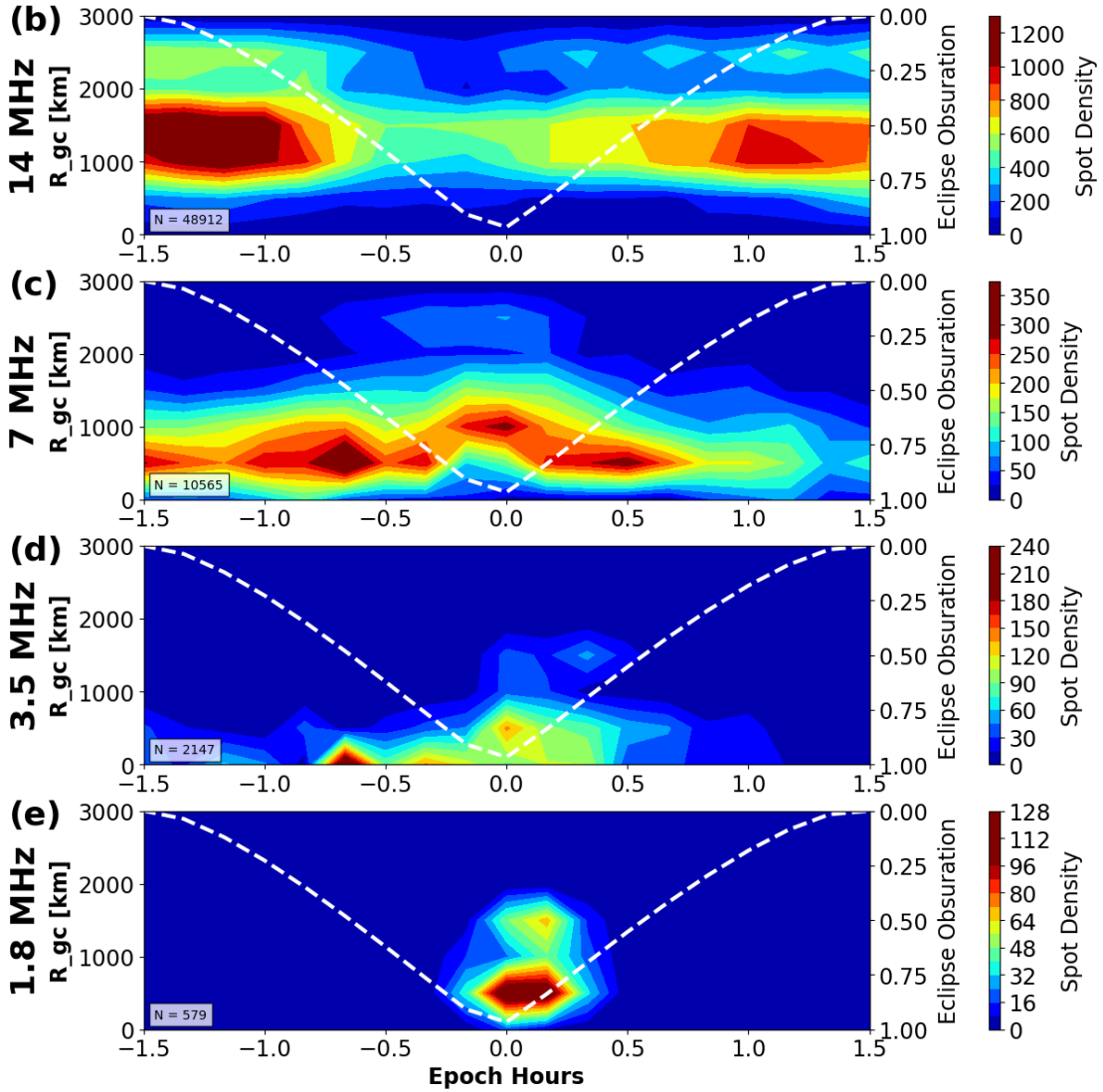
2017 SEQP RBN ($O_{300} \geq 0.9$)



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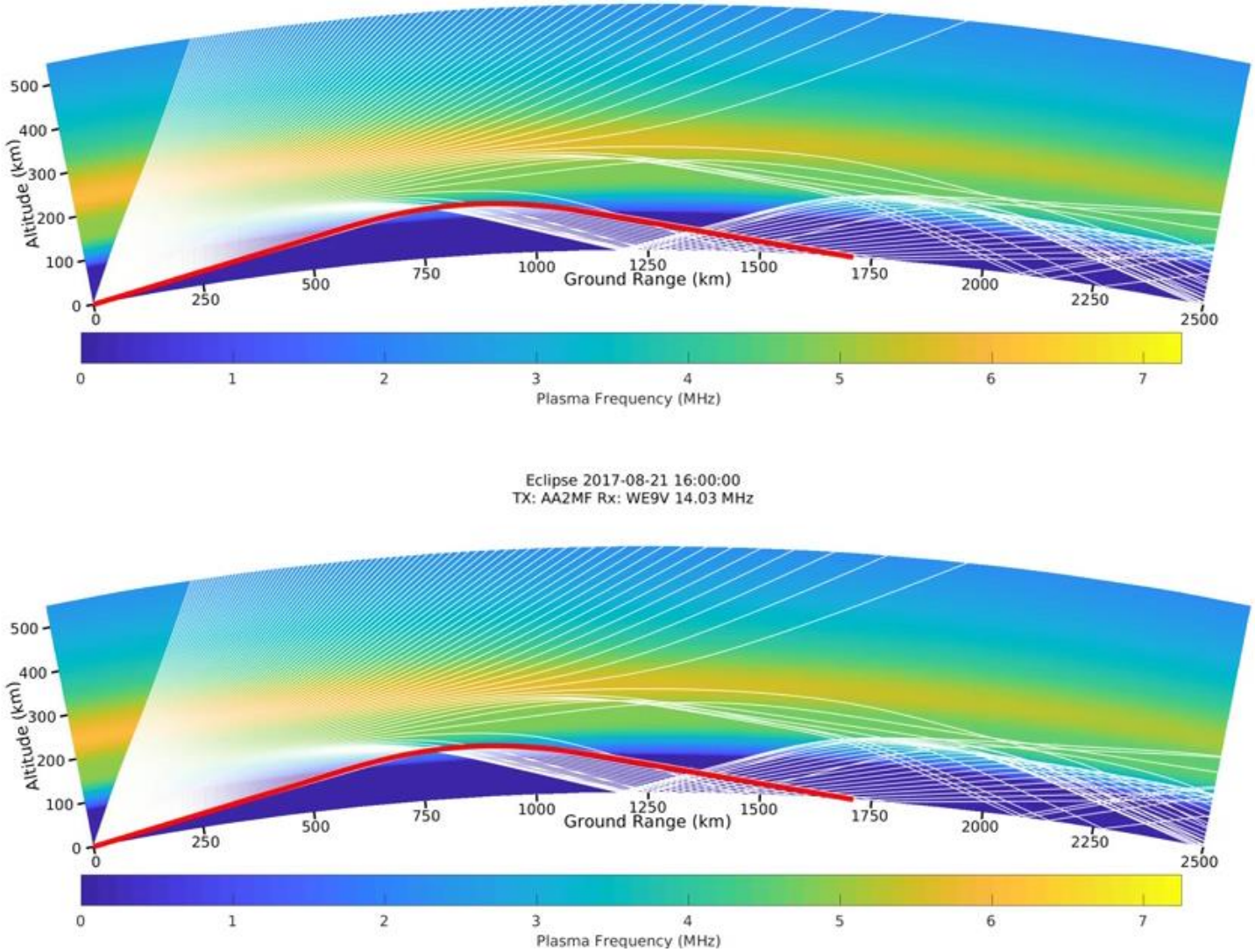
Modeling the Solar Eclipse QSO Party

SAMI3-PHaRLAP Raytrace
1600 – 2200 UT 14.03 MHz
TX: AA2MF (Florida)
RX: WE9V (Wisconsin)



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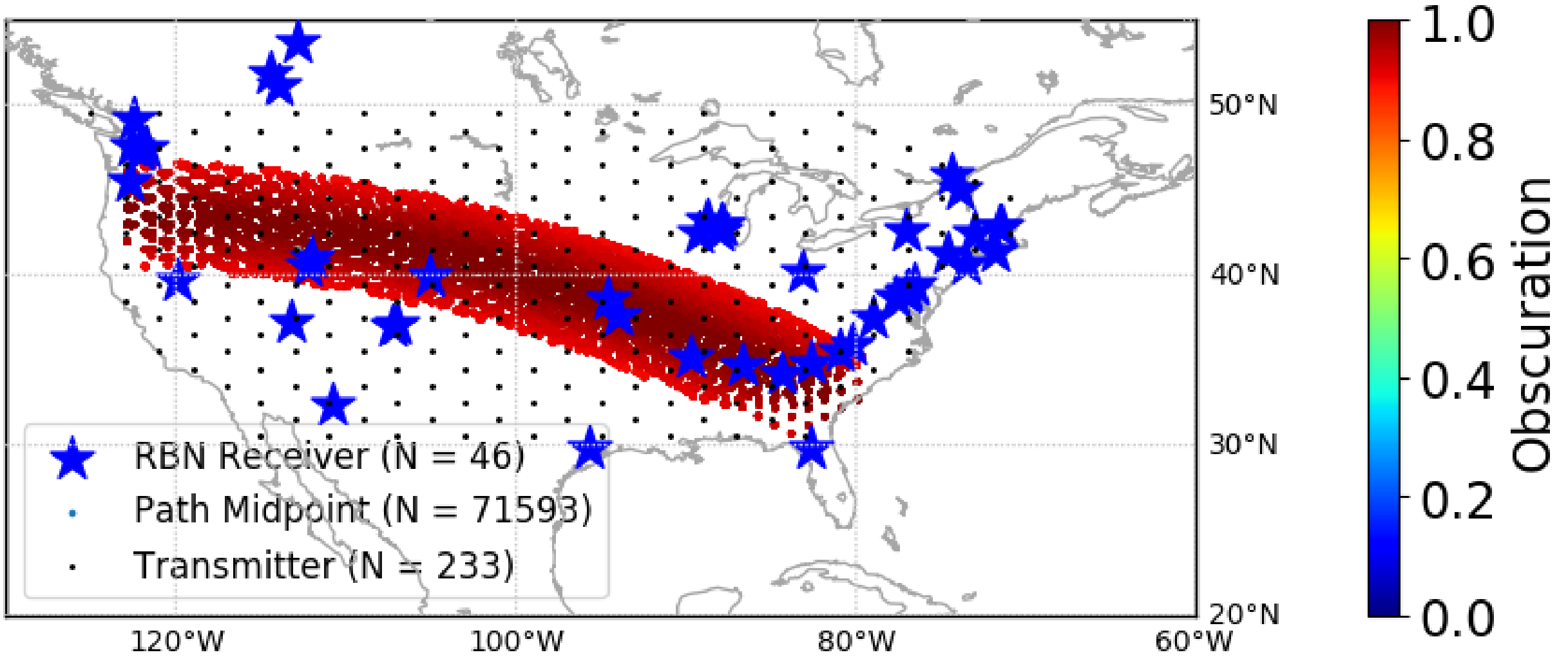
Modeling the Solar Eclipse QSO Party



[Frissell et al., 2018, https://doi.org/10.1029/2018GL077324]

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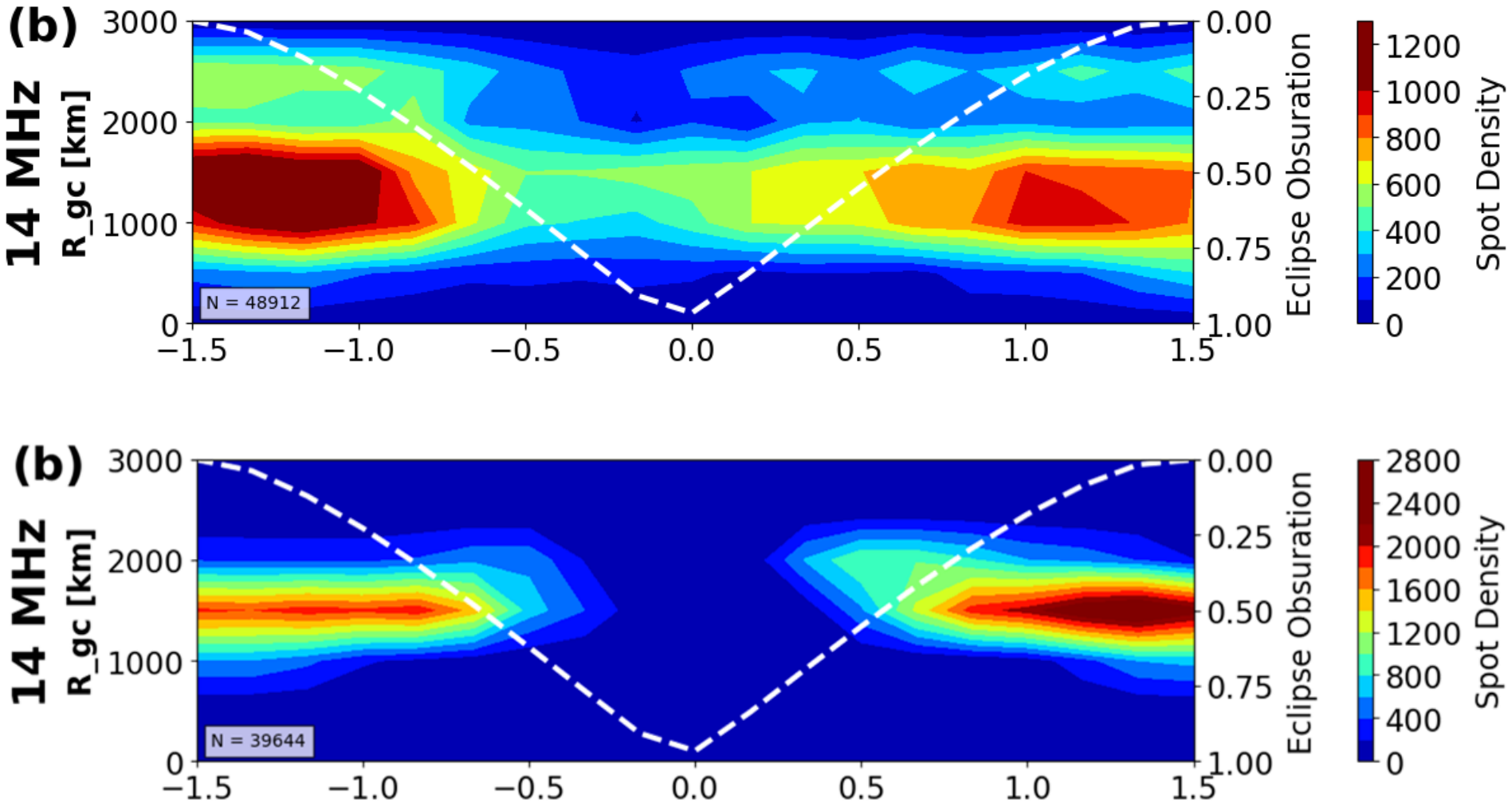
Observations and Model Results



[Frissell et al., 2018, https://doi.org/10.1029/2018GL077324]

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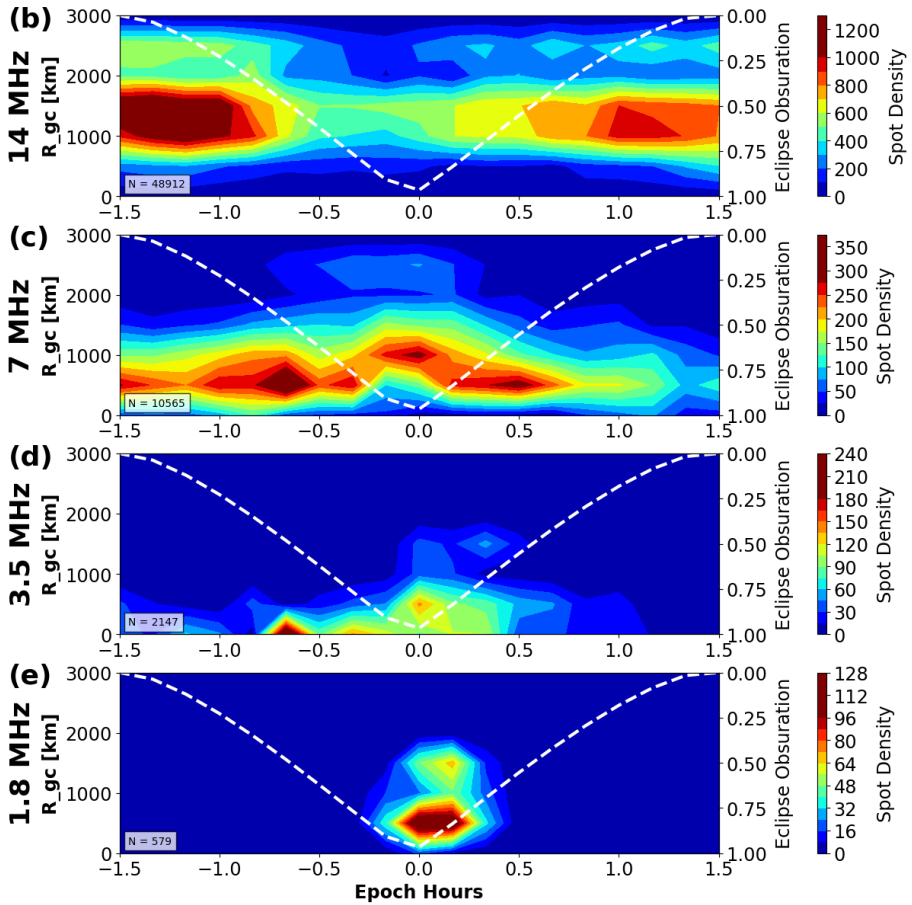
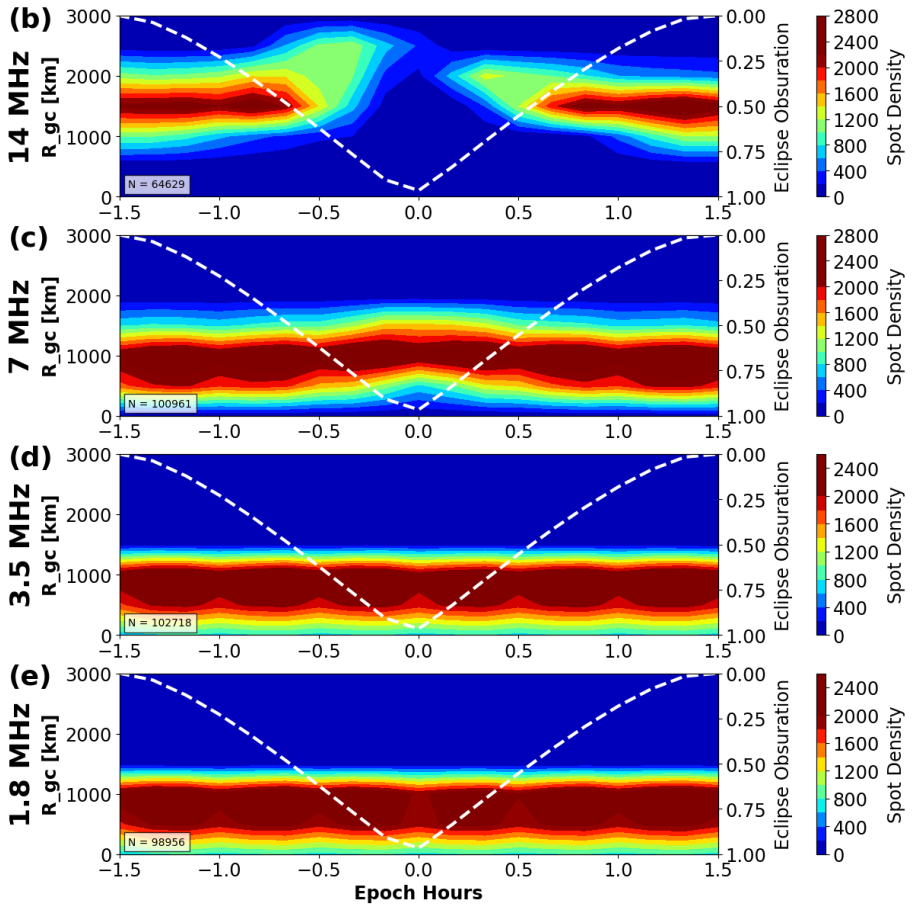
RBN Observations – SAMI3 Simulation





[Frissell et al., 2018, https://doi.org/10.1029/2018GL077324]

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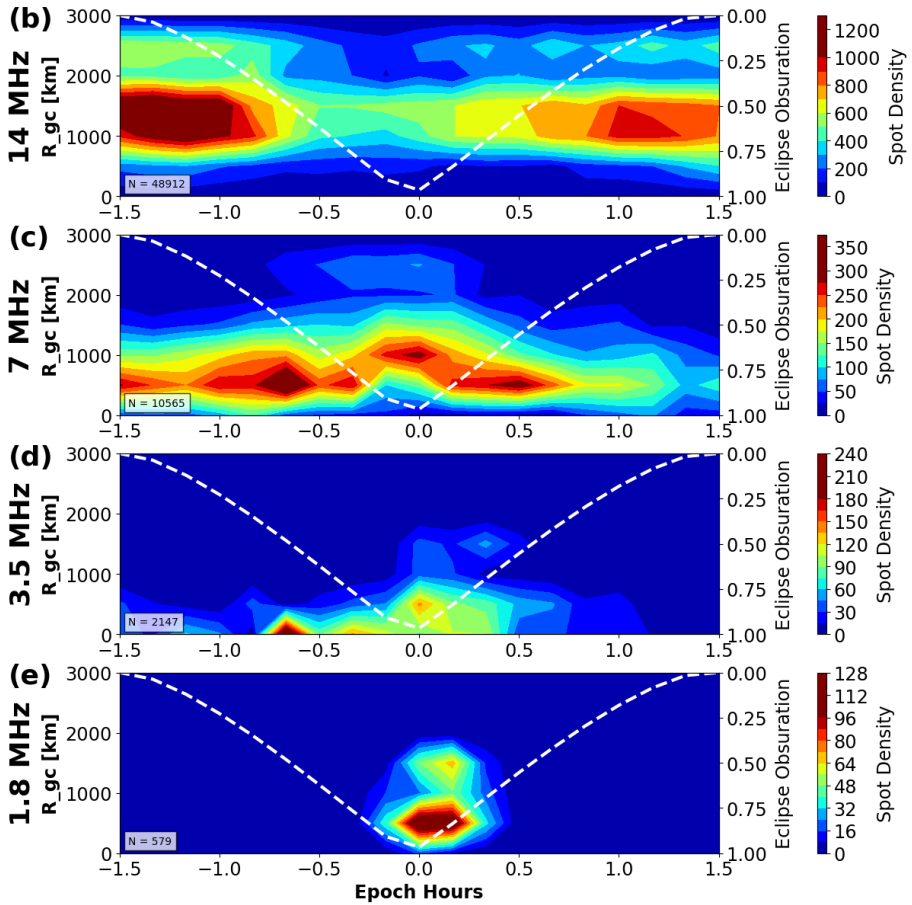
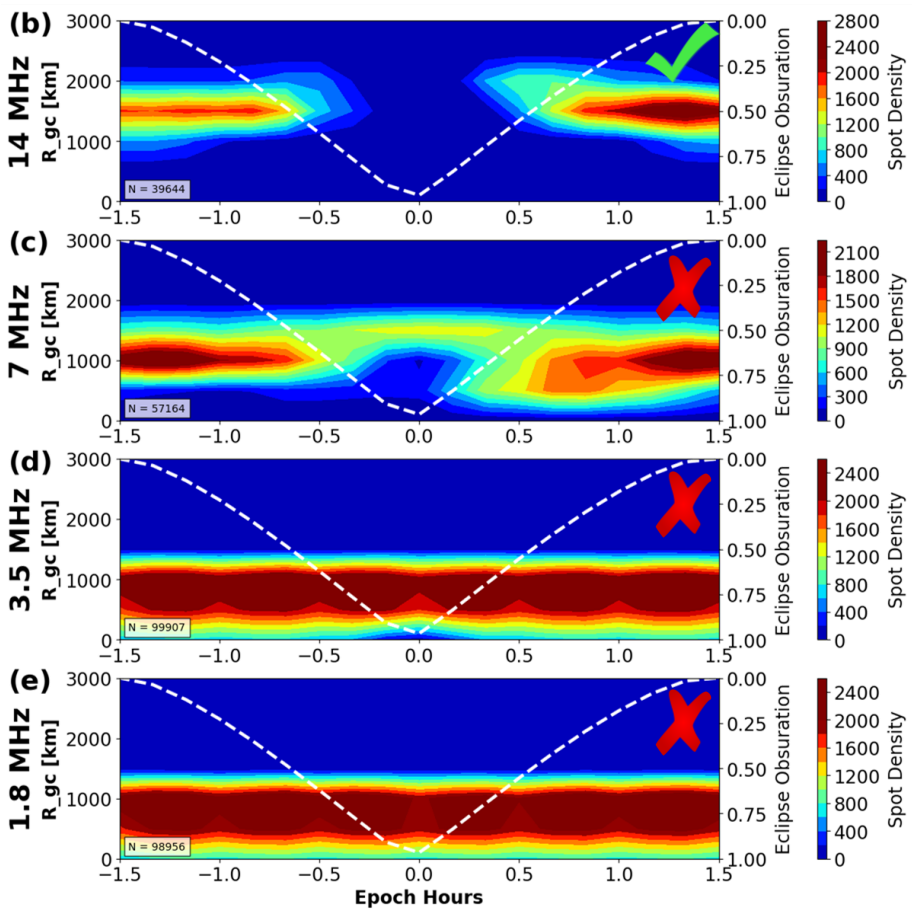
SAMI3 < 125 km alt





[Frissell et al., 2018, https://doi.org/10.1029/2018GL077324]

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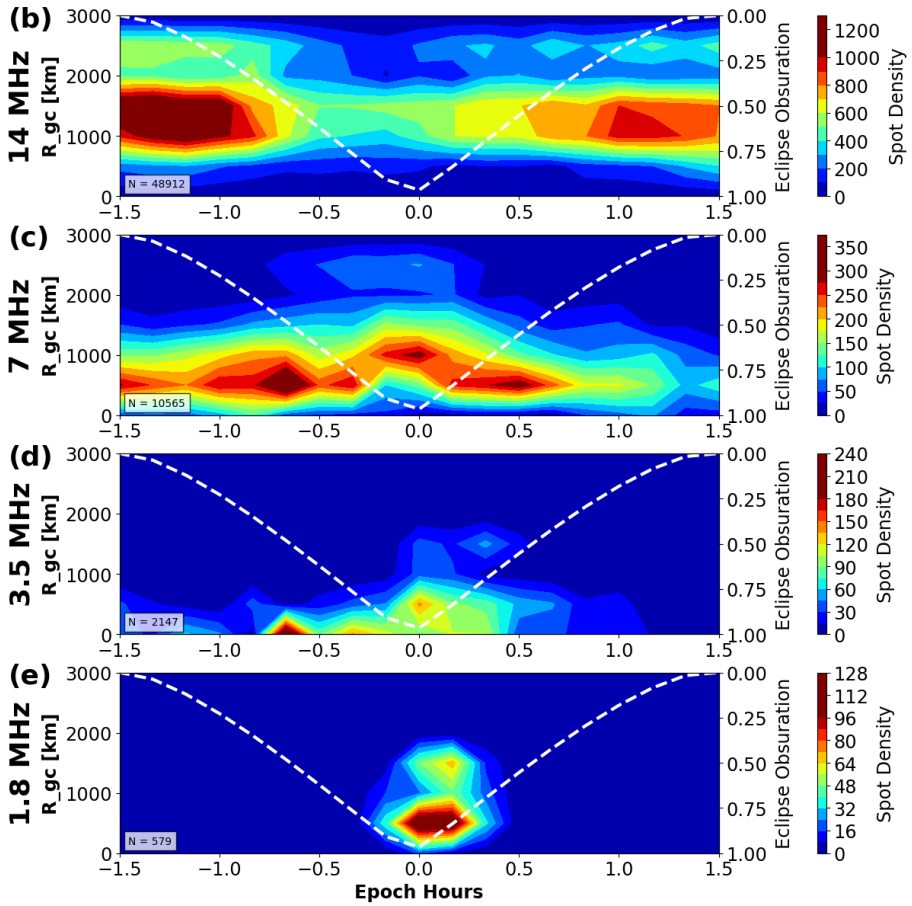
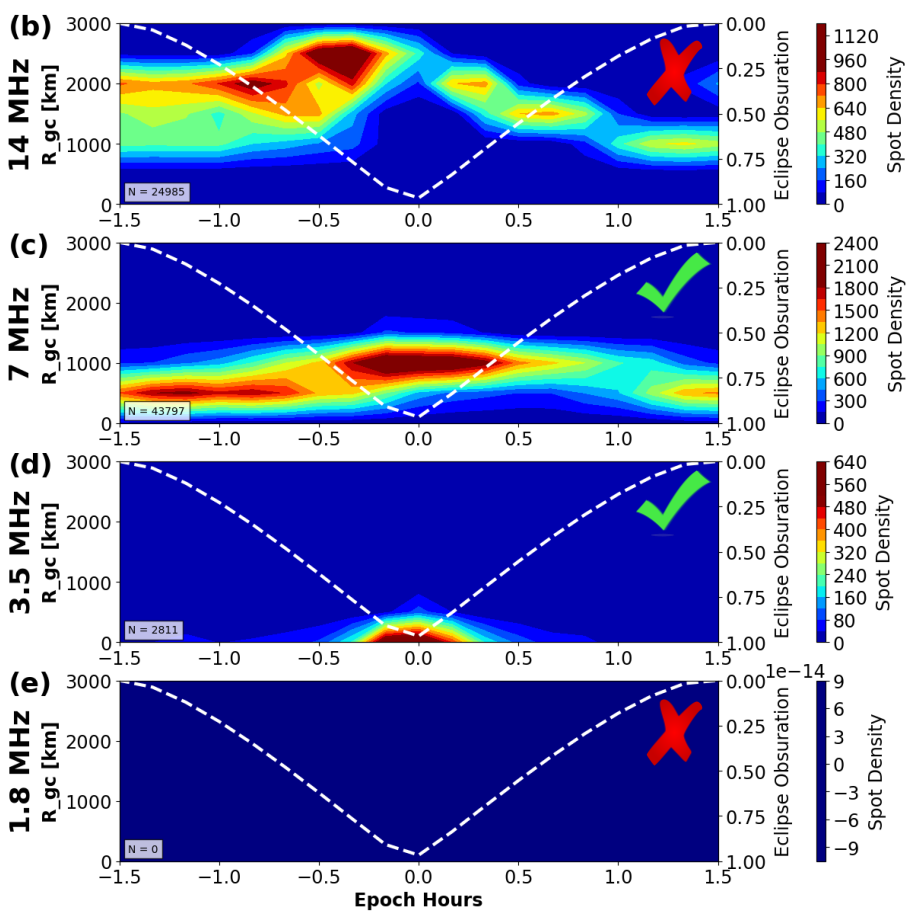
SAMI3 ≥ 125 km alt





[Frissell et al., 2018, https://doi.org/10.1029/2018GL077324]

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2017 Eclipse Conclusions

- SEQP generated over 2.5 million link soundings.

- Eclipse effects are observed:
  - ±0.3 hr on 1.8 MHz
  - ±0.75 hr on 3.5 and 7 MHz
  - ±1 hr on 14 MHz

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.

2017 Eclipse Conclusions: 1.8 - 7 MHz

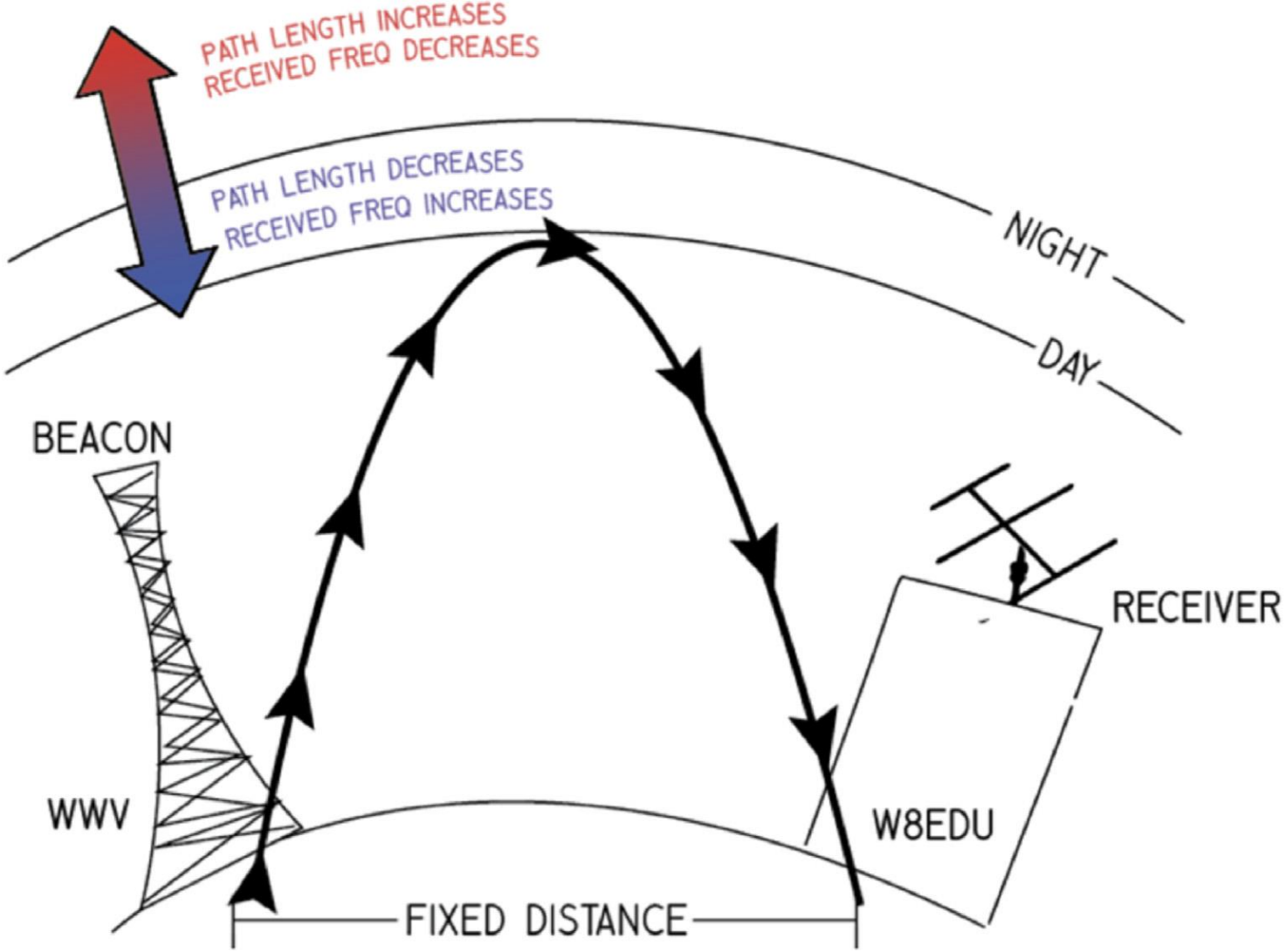
Raytracing suggests 1.8 - 7 MHz refracted at h ≥ 125 km

- 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.

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)?

HF Doppler Shift



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Steve Reyer, PhD, WA9VNJ (SK)

- Professor Emeritus of Electrical Engineering at the Milwaukee School of Engineering
- Teacher and Industry Consultant
  - digital signal processing
  - communications
  - microprocessors
  - circuits
  - Senior Design
- Active in FMT Community
- Very important for HamSCI 2017 Eclipse Frequency Measurement Experiment

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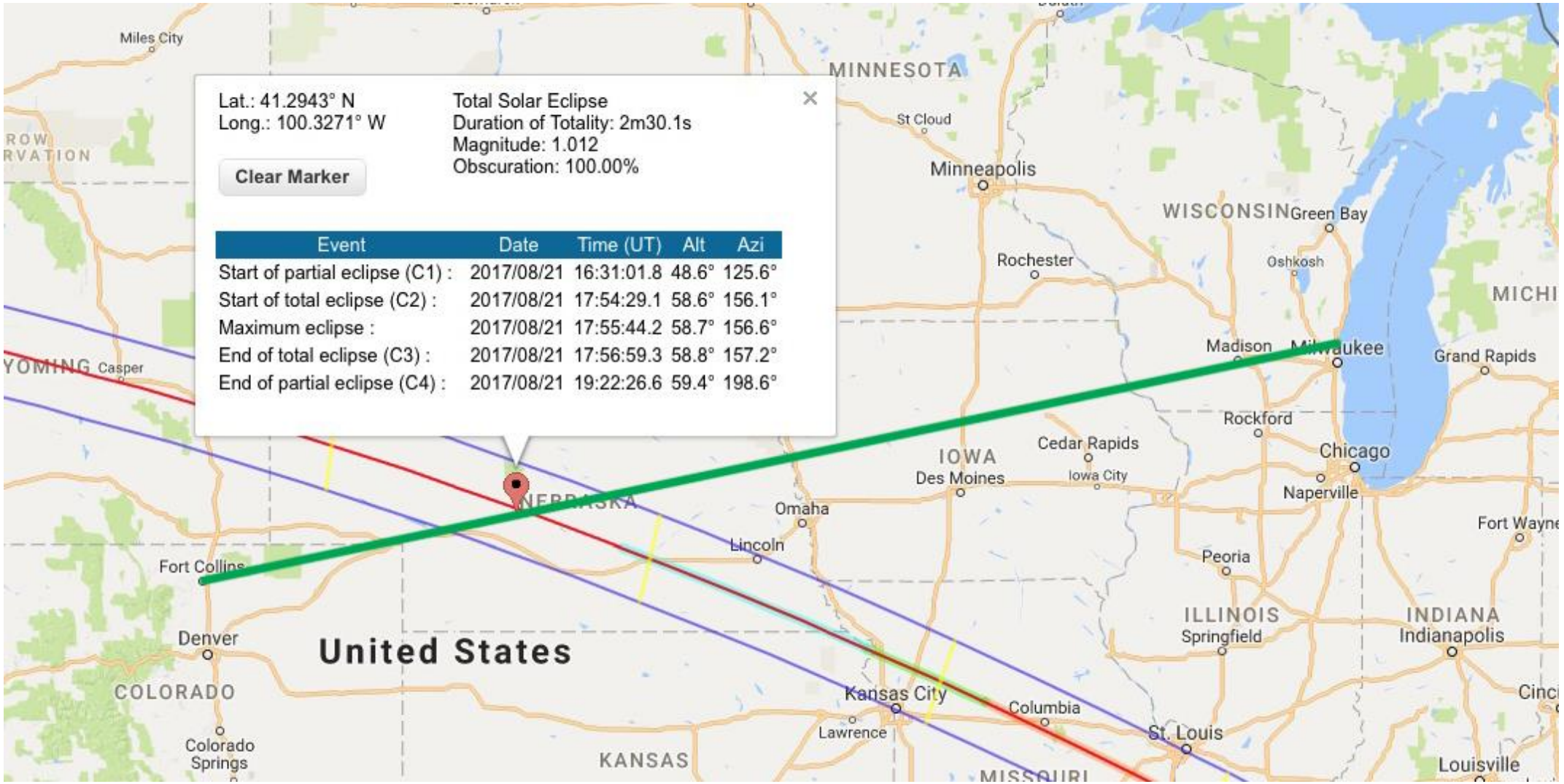
WA9VNJ 10 MHz WWV Observations



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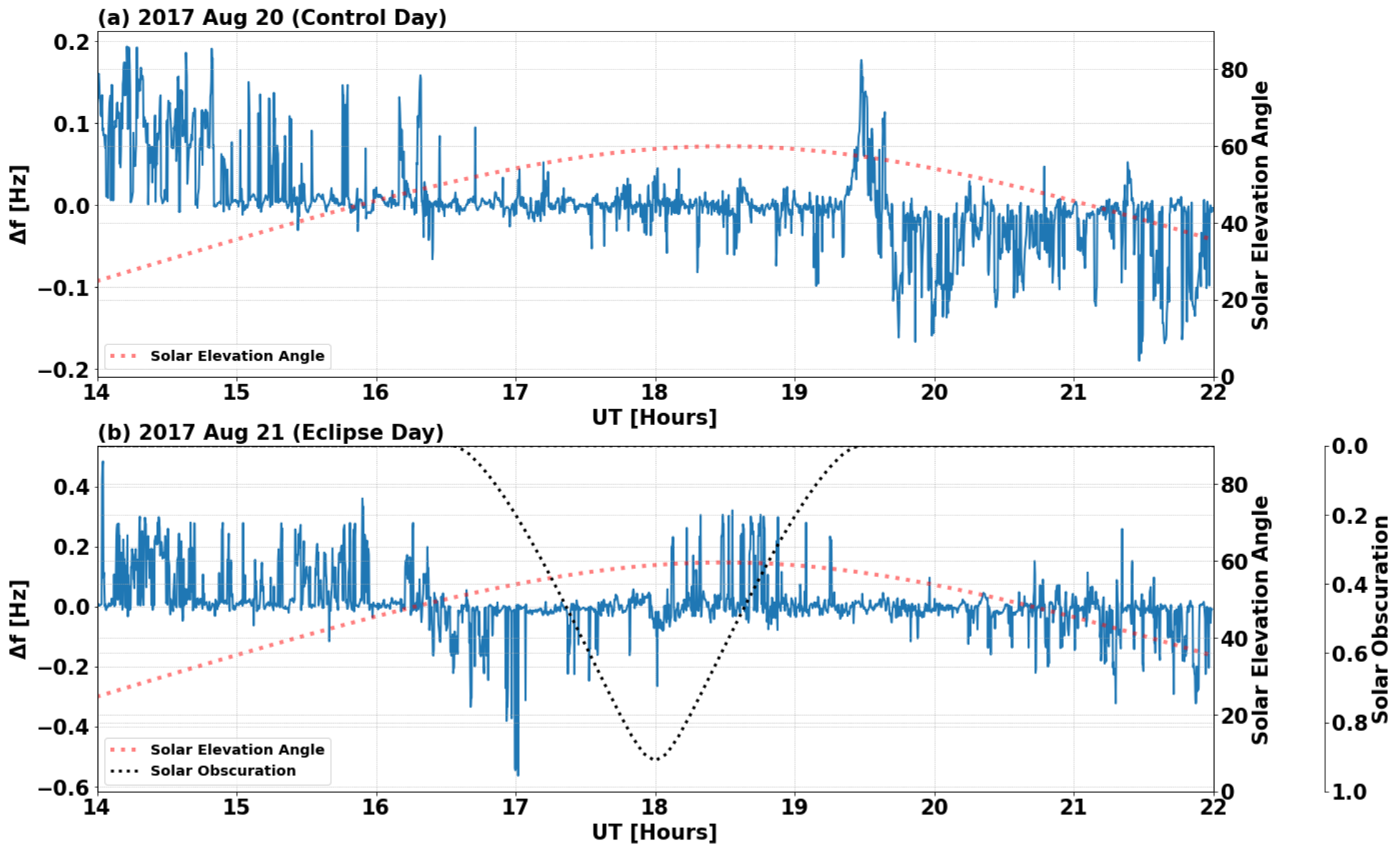

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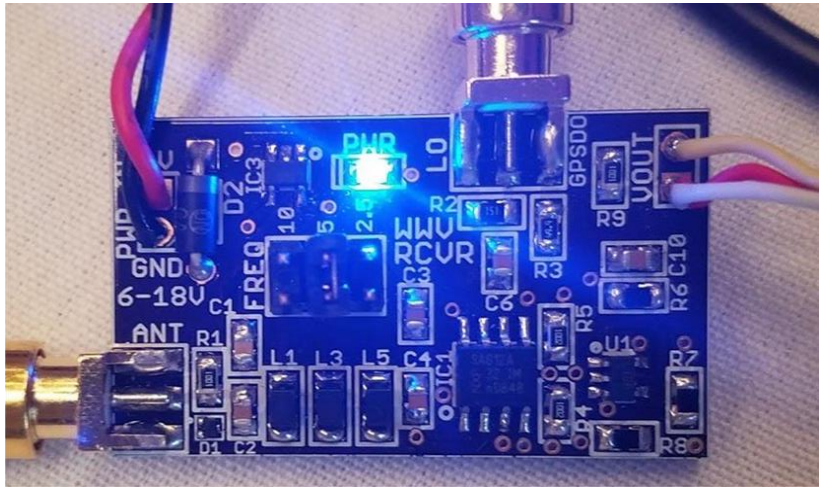
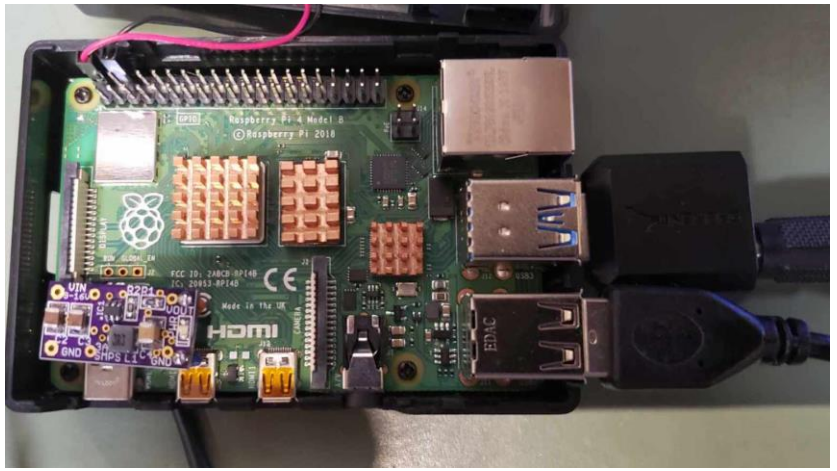
Grape Low-Cost PSWS Status

- **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 of Grape v1 is ~$300 (not including antenna).**
- **Several stations** are currently deployed.
- Grape v1 build documentation is available at hamsci.org/grape1.
- Doppler shift data is collected via spectrographs and frequency estimation algorithms**.**
- Grape V2 will be capable of monitoring 3 HF channels simultaneously.





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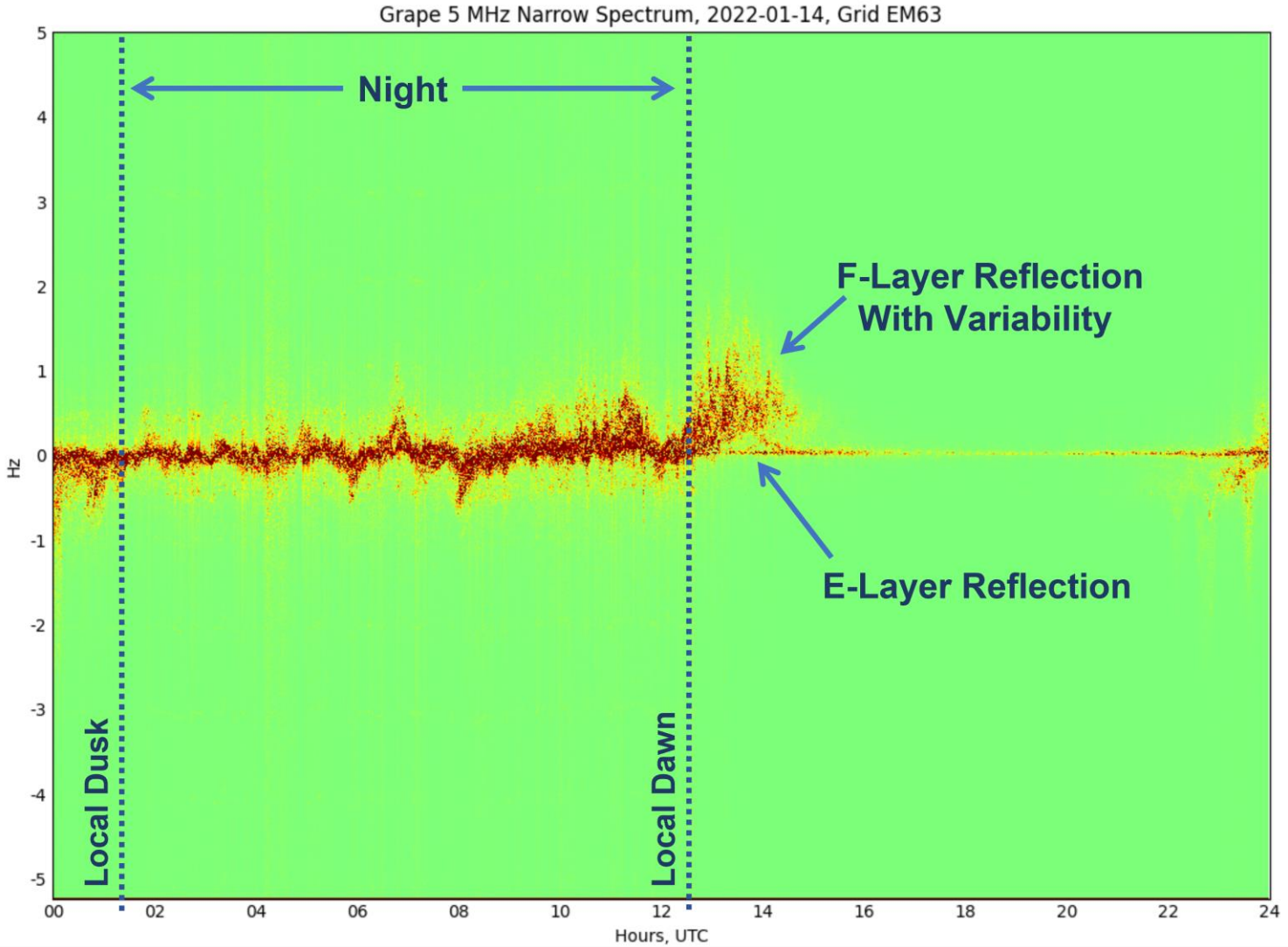
5 MHz WWV-AB4EJ Doppler Shifts



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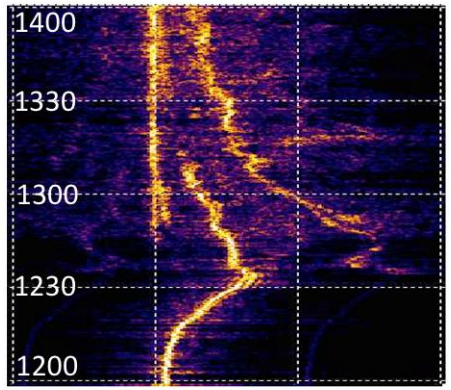
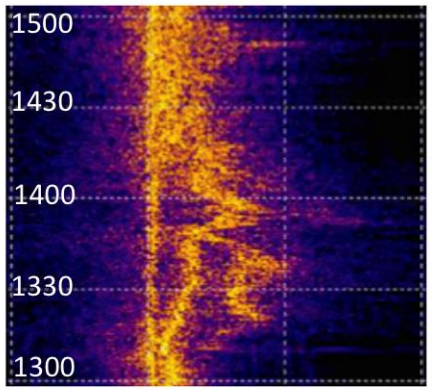
5 MHz WWV-WA5FRF Doppler Shifts

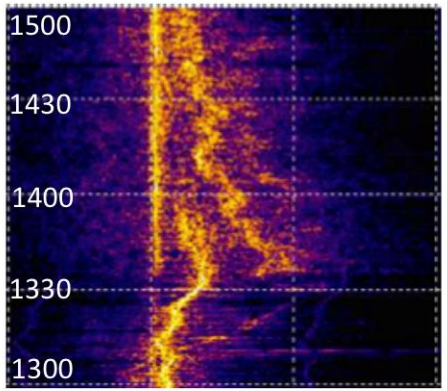
Positive Frequency Excursions During Sunrise



2020-10-03



2020-02-07



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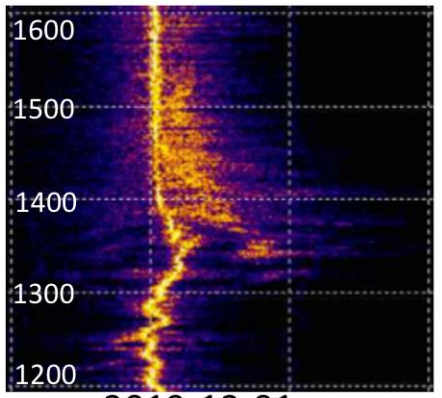
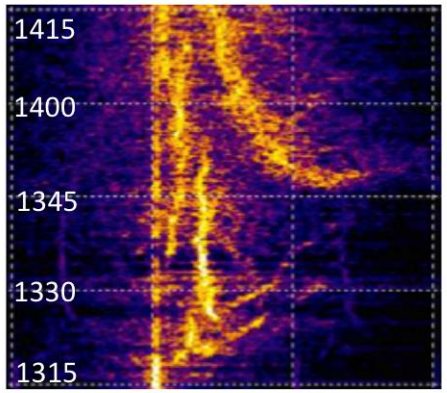
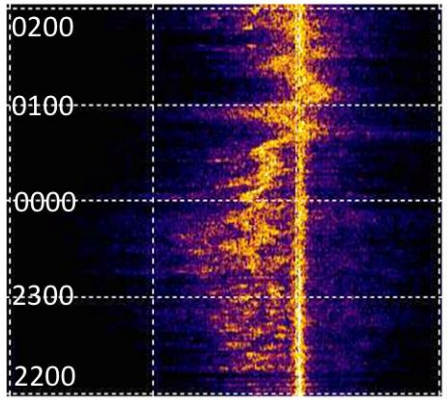


2019-12-01



2020-01-28

Negative Frequency Excursions During Sundown



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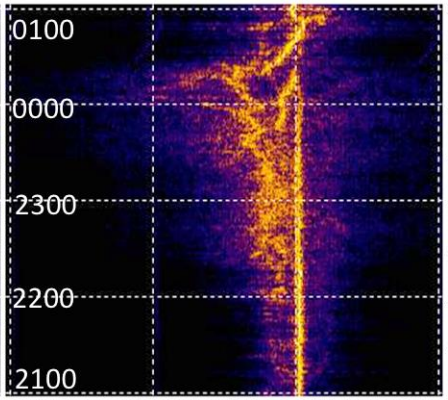

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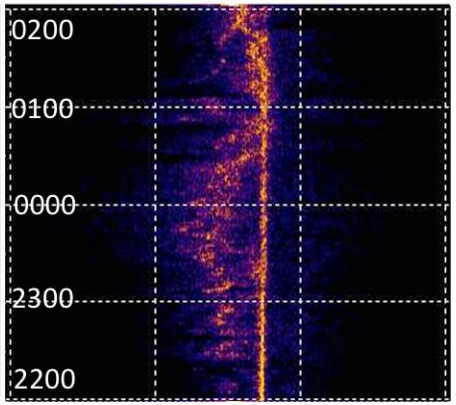

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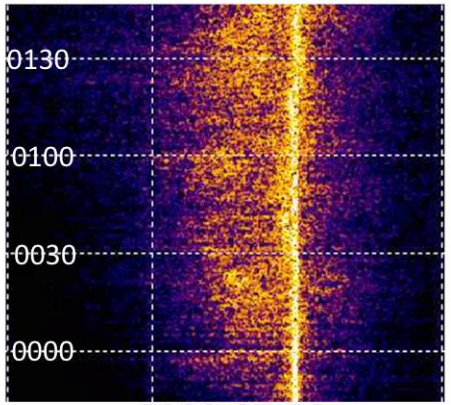
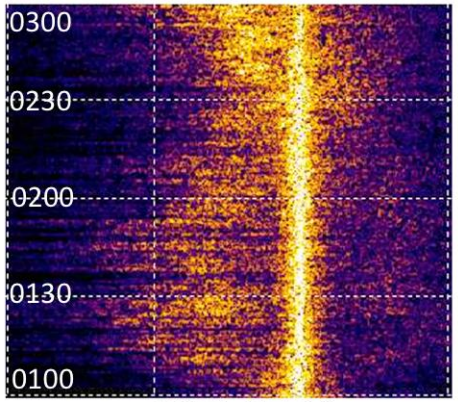


2020-07-08



2020-07-13

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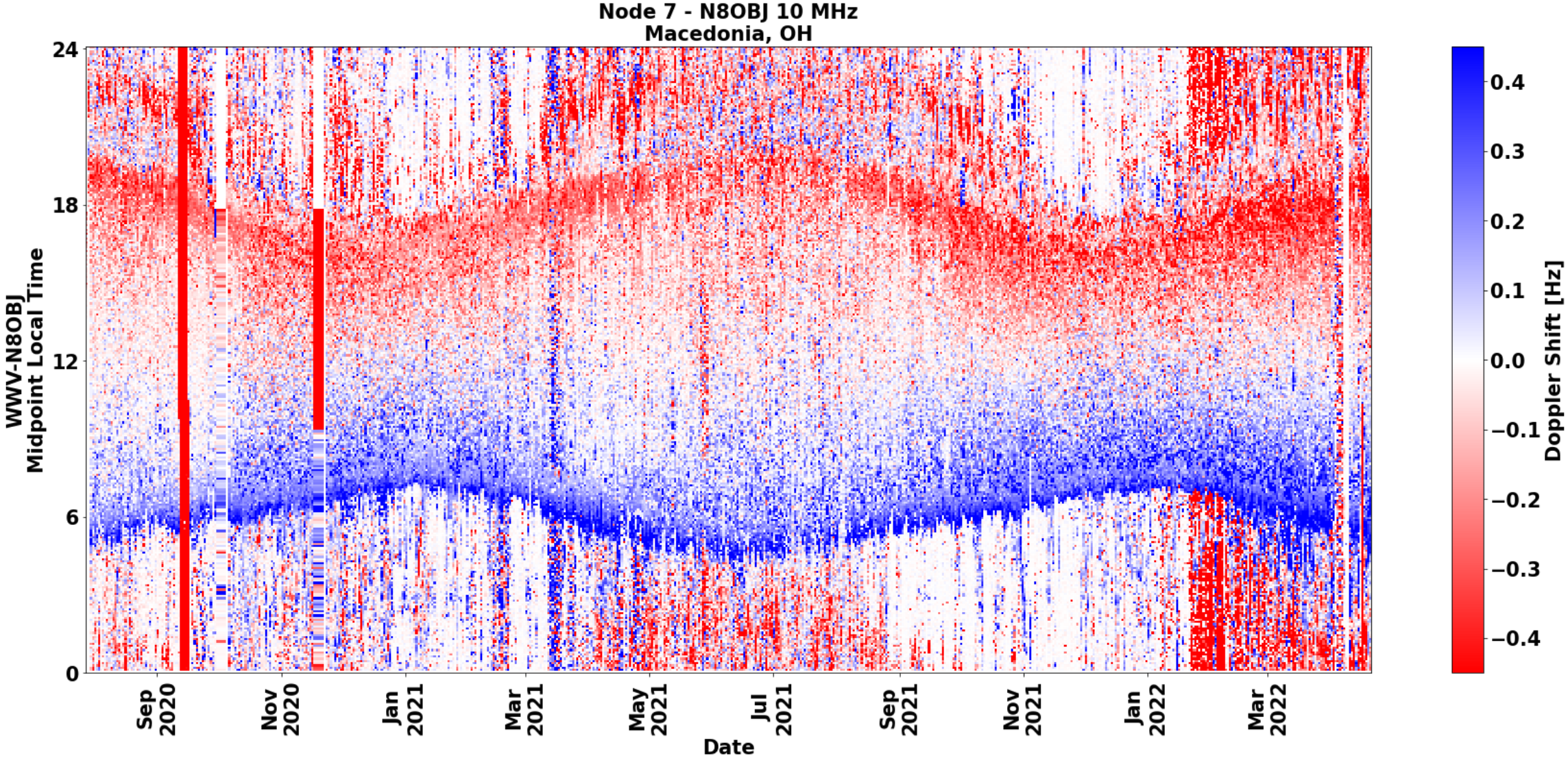
10 MHz WWV-N8OBJ (Cleveland, OH)



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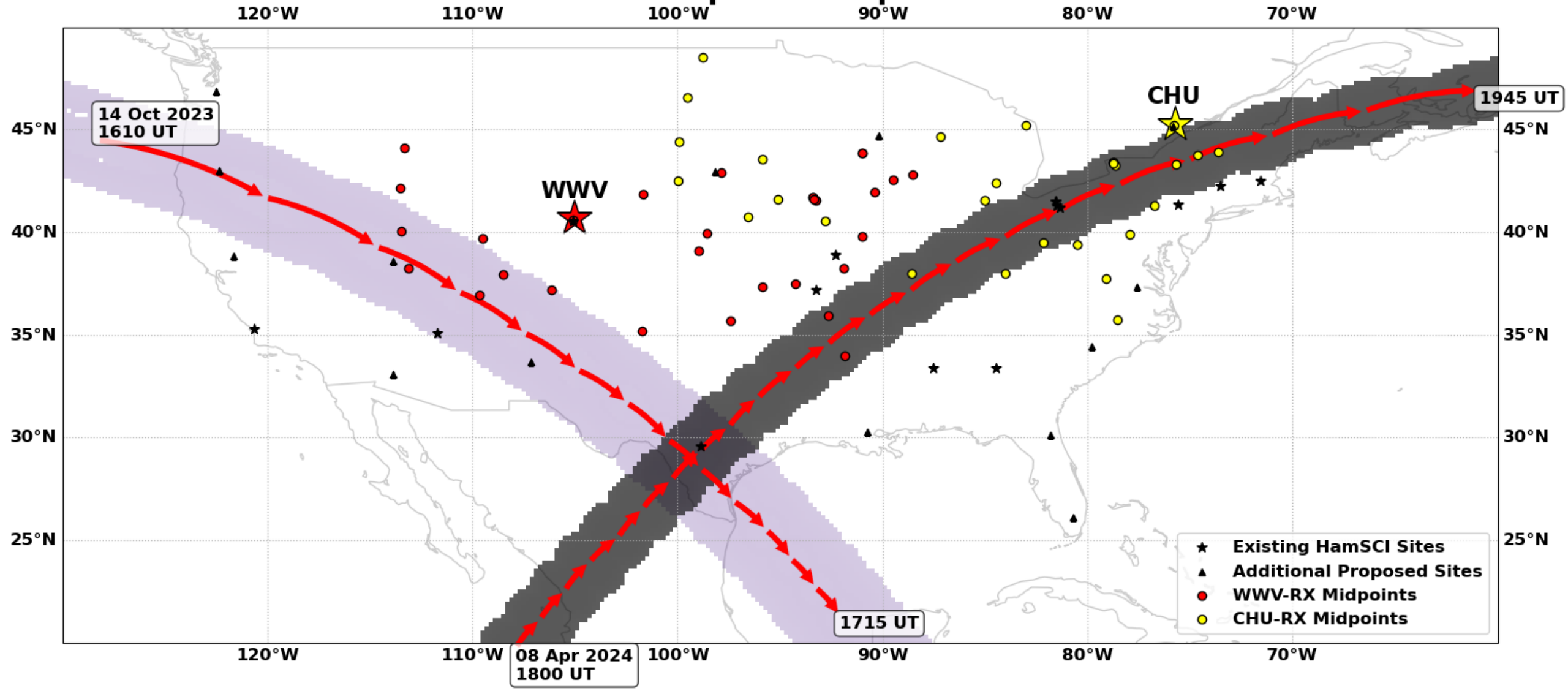
Locations of Proposed Grape 2 Receivers



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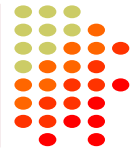
Solar Eclipse Grape Doppler Science Questions



1. How do dawn and dusk ionospheric variability as observed by HF Doppler shift measurements vary with local time, season, latitude, longitude, frequency, distance, and direction from the transmitter?
2. Is eclipse ionospheric response symmetric with regard to onset and recovery timing?
3. How similar is the eclipse to daily dawn and dusk terminator passage?
4. Do we observe multipath HF mode-splitting in the post-eclipse interval that is similar to dawn events?
5. How is the response different for the southward Annular eclipse in 2023 compared to the northward Total eclipse of 2024?

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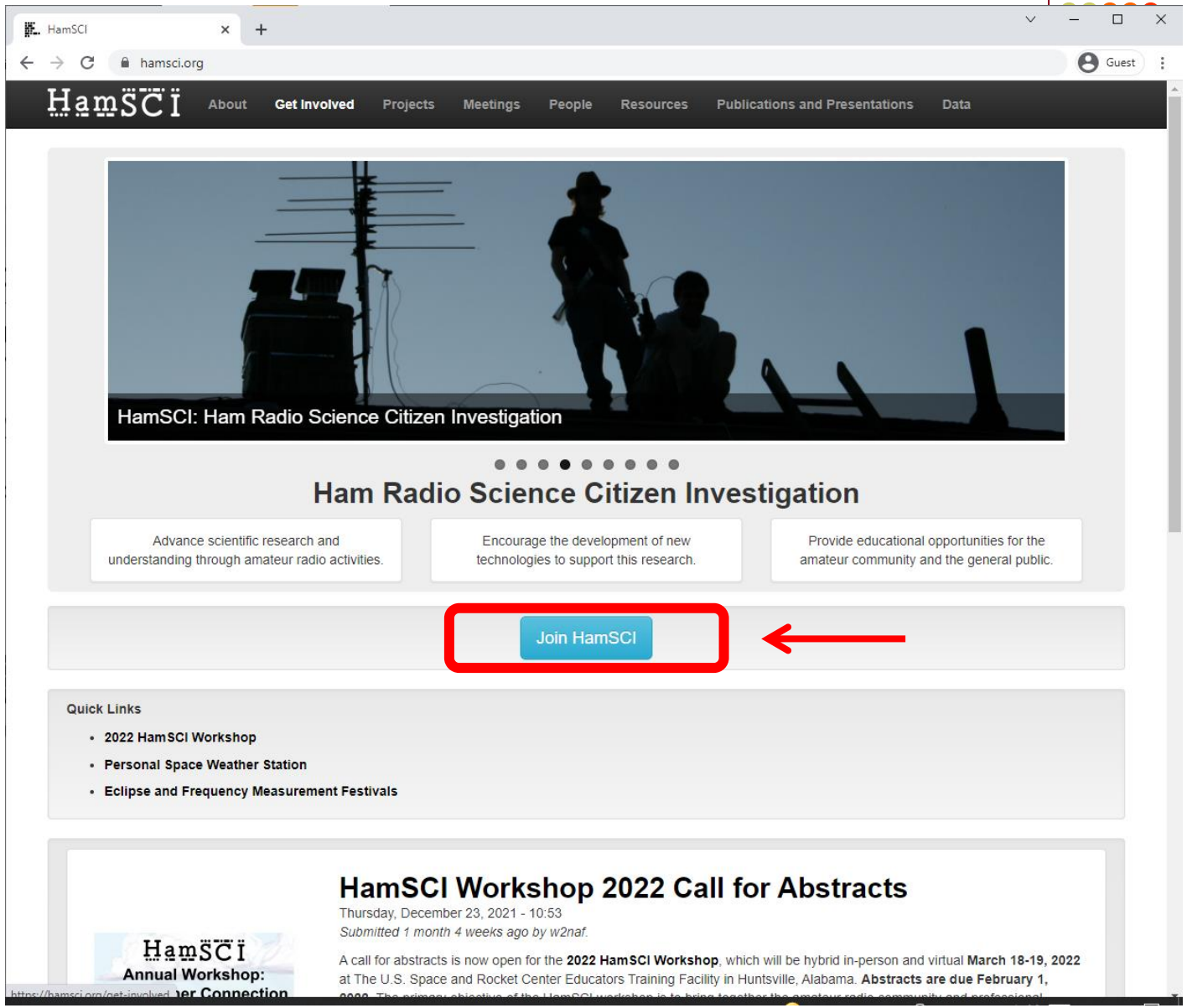
Getting Involved

- **HamSCI now has over 750 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!
- Visit Booth 5008 (with TAPR)!



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Visit us in Booth 5008 (with TAPR)!

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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 Grant 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).

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