VLF Natural Radio Emissions CEDAR Workshop 2023 Student Day

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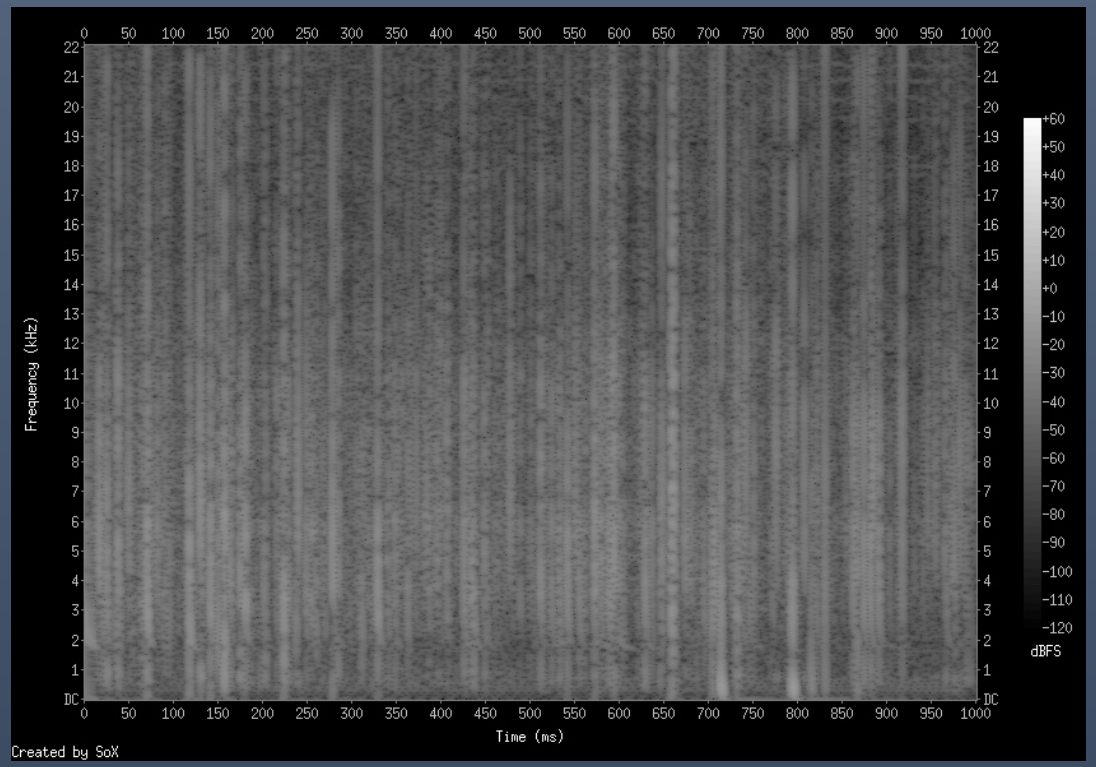
VLF/ULF Band

- Very Low Frequency Band: ITU designation for frequencies between 3kHz to 30kHz.
- Ultra Low Frequency Band: ITU designation for frequencies between 300Hz to 3kHz.
- Waveguide Propagation: VLF/ULF propagation behavior is similar to propagation through a waveguide, due to the spherical waveguide formed by the ionosphere and earth's surface, commonly referred to as the Earth-Ionosphere Waveguide (EIWG)
- Natural Radio Emissions: Naturally occurring radio emissions from lightning discharges and magnetospheric plasma interactions can detected in the VLF/ULF band.
- Sonification: Because these radio emissions occur at mostly audible frequencies, they can be converted to sound and listened to as they are.

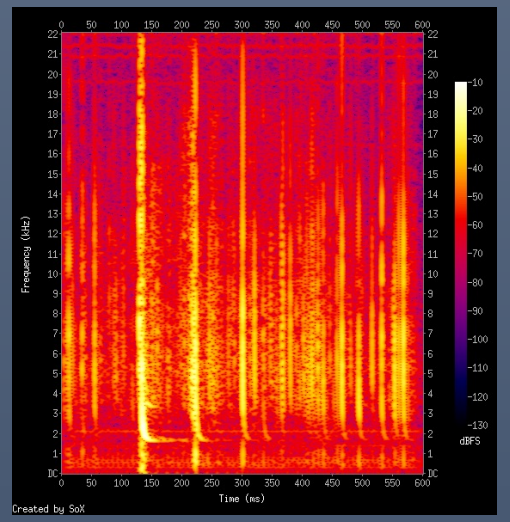
Sferics

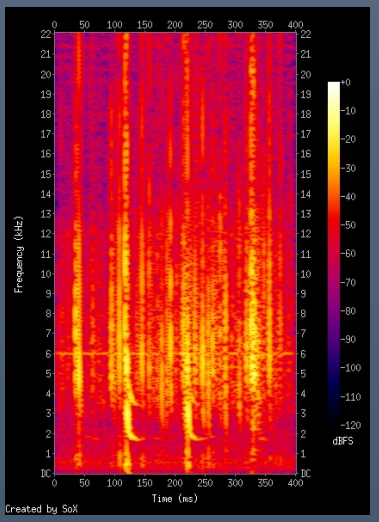
- Called radio atmospherics, or more commonly known as sferics.
- Most common type of VLF Natural Radio emission.
- Generated by lightning strokes.
- Very broadband and impulsive in nature.
- Occur almost constantly and can be detected anywhere on Earth.
- Lightning detection systems use sferics for lightning location using the Time of Group Arrival (TOGA) method.

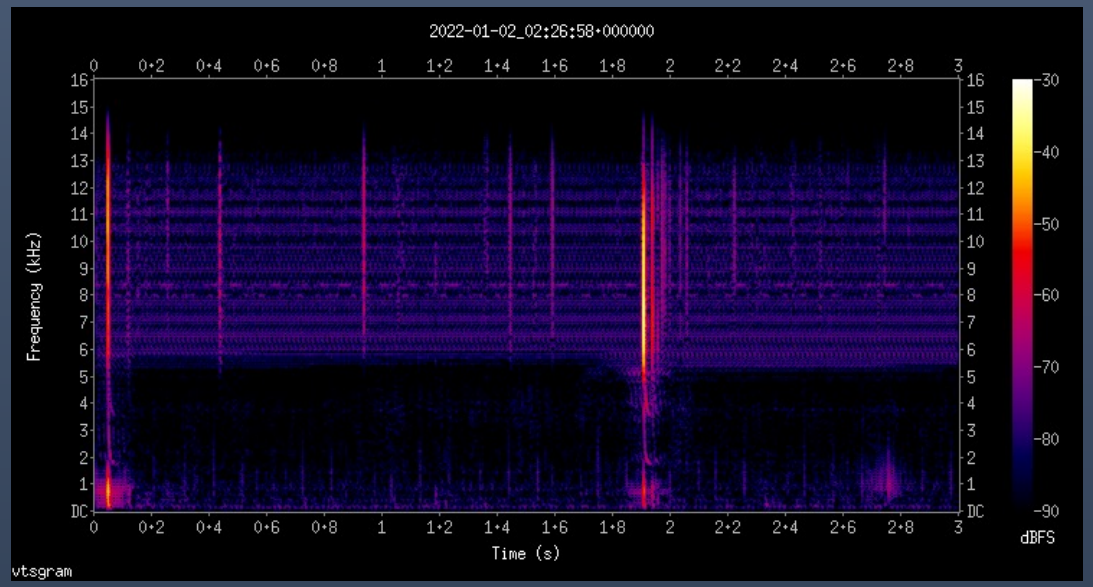


Tweeks

- Some sferics have some of their frequency components dispersed in time due to the resonant modes of the EIWG. These sferics are often called Tweeks, or Tweek atmospherics.
- Frequency dispersion occurs at ~1.7kHz and at multiple harmonics thereof (e.g. 3.4kHz, 6.8kHz, etc.) and often classified by mode (e.g. mode 0 is the fundamental of 1.7kHz, mode 1 is 3.4kHz, etc.)
- Frequency dispersion occurs on the range of a few milliseconds.
- It is possible to calculate the reflection height of tweeks.
- Tweeks have a distinctive pinging sound.







~1.7 kHz and ~3.4 kHz modes observed in all spectrograms

Whistlers

- When sferics propagate out of the ionosphere, they can take a propagation path of thousands of miles though ducts that form in the magnetosphere, as illustrated on the right. This duct consists of solar wind plasma that has aligned itself along one of Earth's magnetic field lines.
- As the sferic propagates through this duct, its frequency components get dispersed in time, ranging from less than a second to a few seconds.
- Lower frequencies propagate slower than higher frequencies, so higher frequencies arrive at the end point sooner.
- Since the ducts follow the Earth's magnetic field lines, the propagation path terminates in the opposite hemisphere.
- The frequency dispersion produces a long, wavering tone that is characteristic of a whistler.
- This propagation mode is often called whistler-mode propagation.
- The electron density of the duct determines the amount of frequency dispersion, which is called the dispersion measure.
- Whistlers that have very discretely-sounding frequency components are called pure note whistlers.
- Whistlers can also sound breathy or swishy and have more diffuse frequency components.
- From the perspective of the terminating endpoint, the originating point is located at the geomagnetic conjugate point.

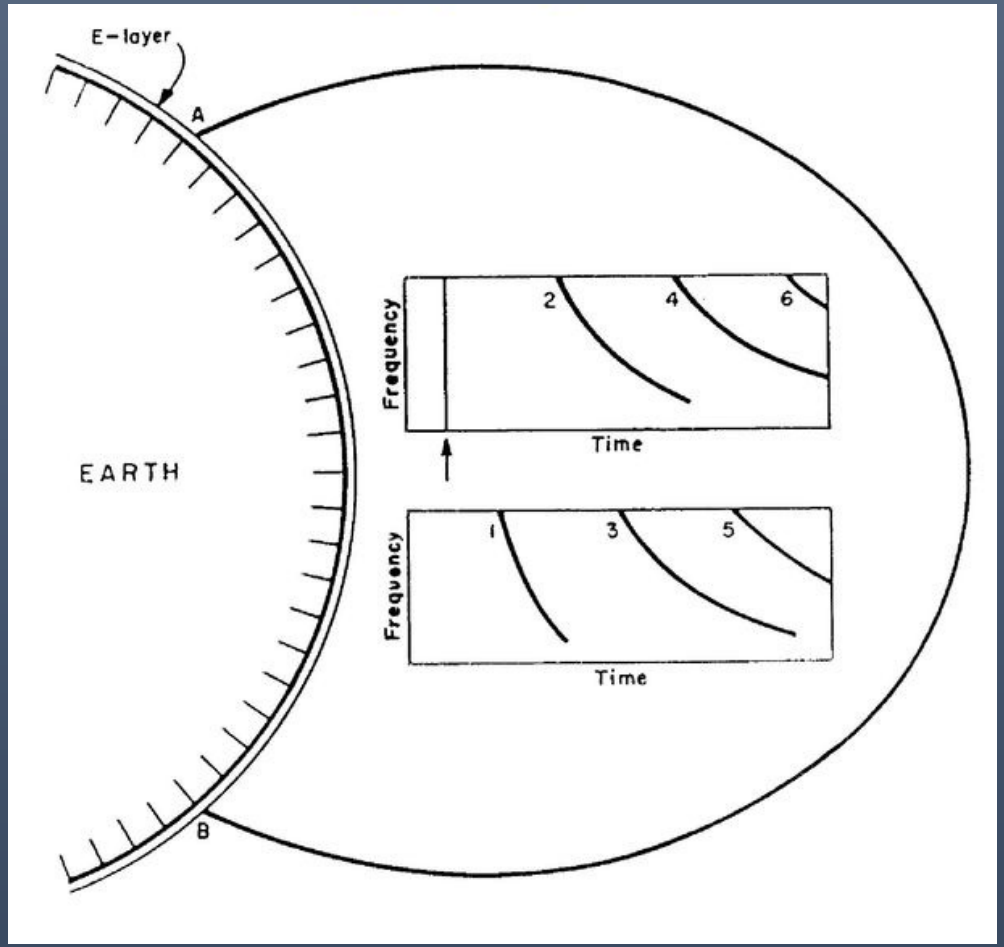
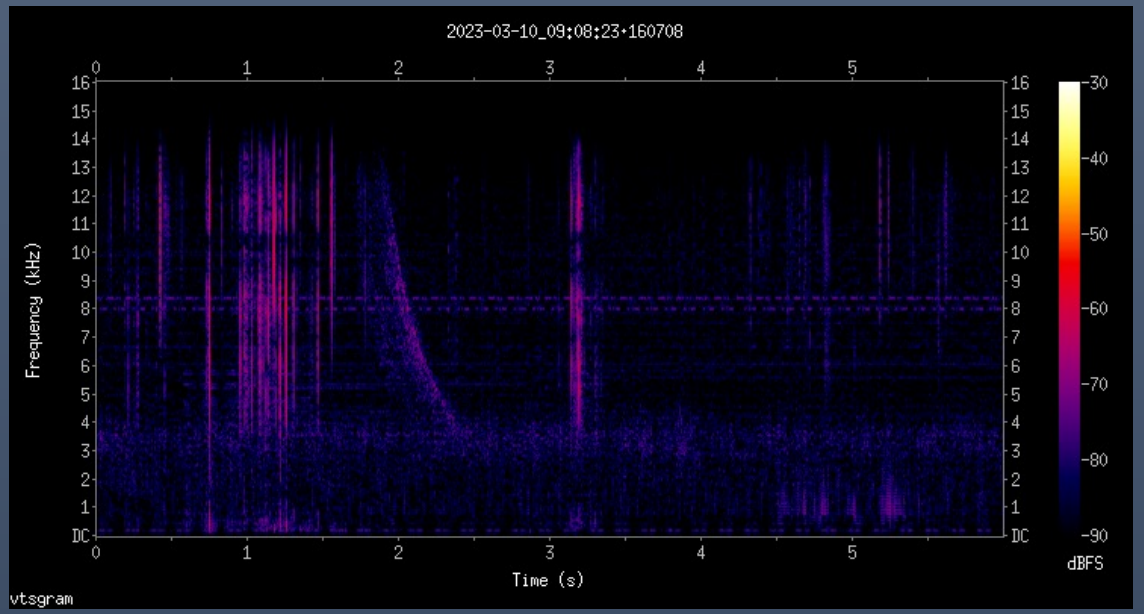


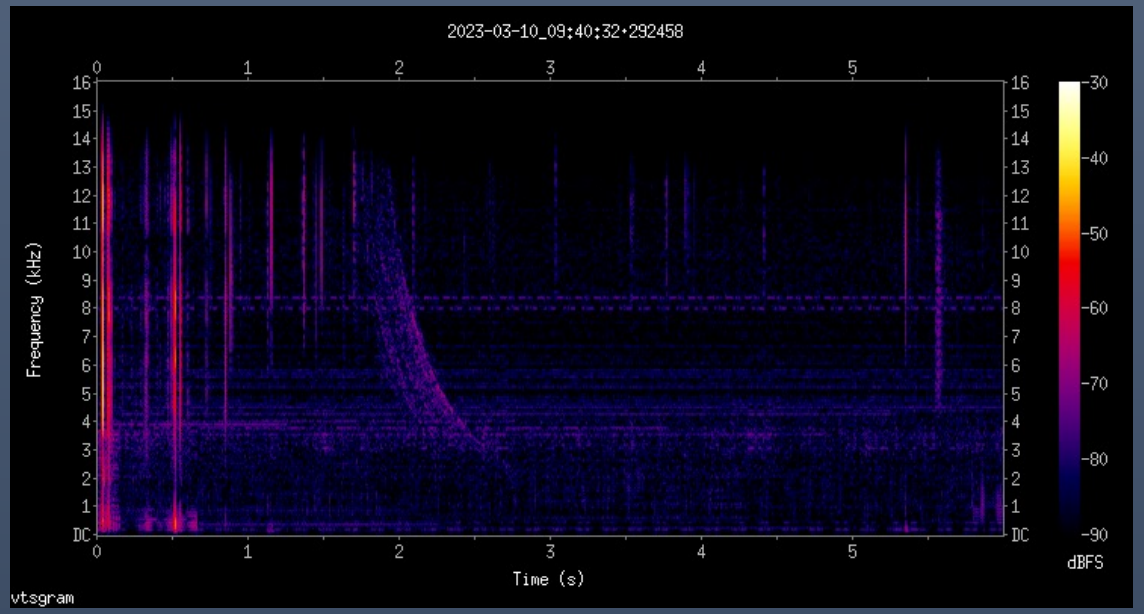
Image taken from *Whistlers and Related Ionospheric Phenomena* pp. 6

Whistler Storm Bielefeld

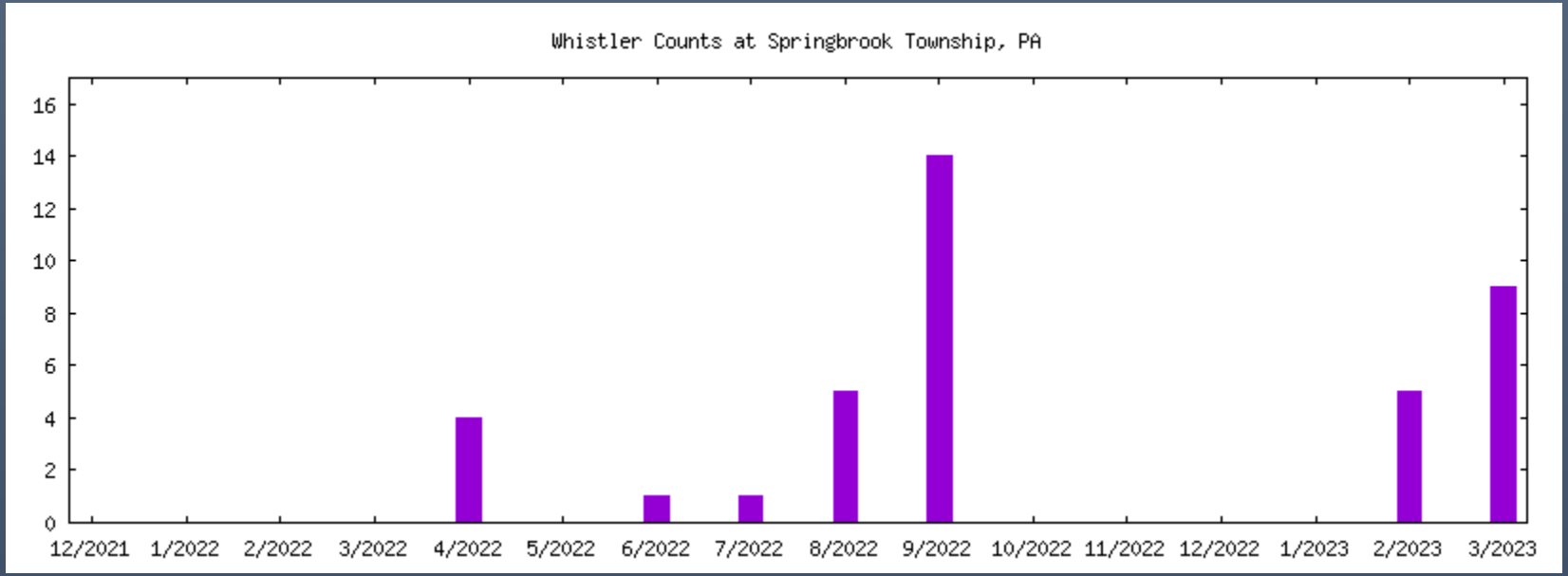
Whistler examples recorded in Bielefeld

3/10/2023 Whistler Events





Observed Whistler Counts 12/2021-3/2023



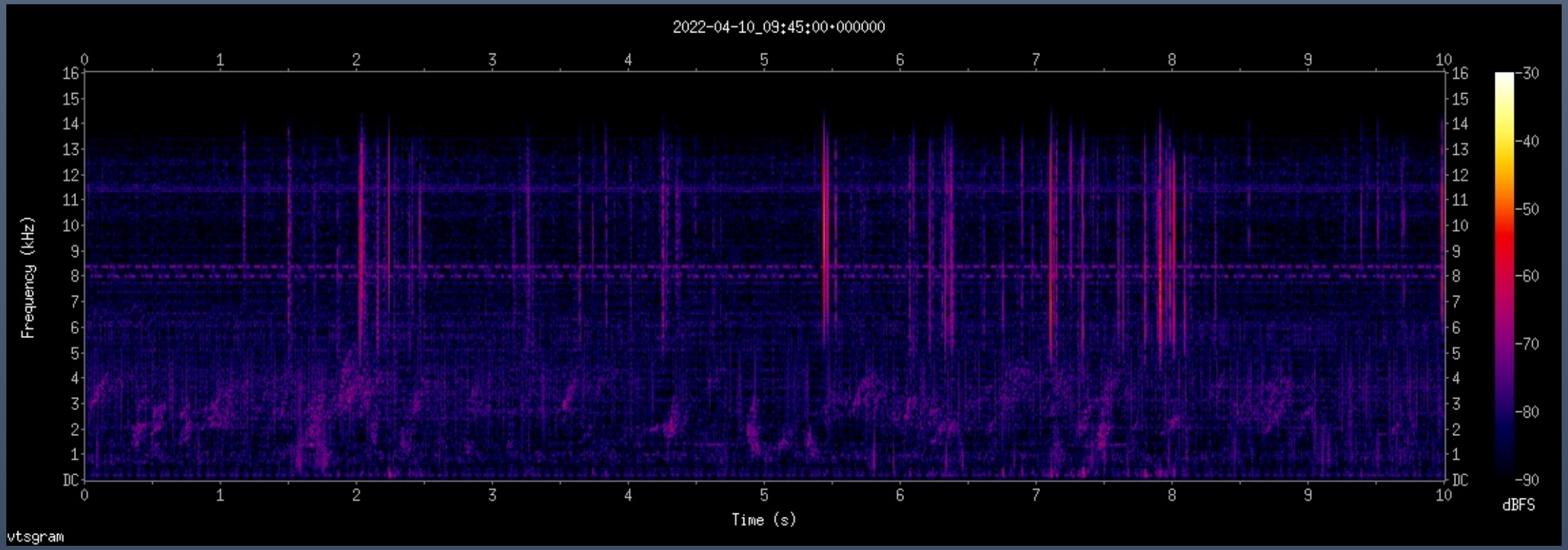
Science questions worth investigating:

- How much of the conjugate point's climatology had an influence on early Spring and Fall whistler counts?
- How much of an influence did geomagnetic activity have in creating and maximizing conditions for ducts to form?
- How did this effect the whistler's dispersion measure?

Dawn Chorus/Auroral Chorus

- When solar wind interacts with the magnetosphere, emissions are produced due to cyclotron interaction. Dawn chorus emissions are discrete events that often overlap and are spaced closely together.
- These emissions often sound like tree frogs or peepers and much resembles birdsong at dawn.
- Dawn chorus often occurs during geomagnetic storms and in the early morning hours of dawn.
- Discrete dawn chorus events can be spaced out on the order of a few seconds or more. These are called periodic emissions or risers.
- Dawn chorus also occurs during auroral display events and is called auroral chorus.
- It is possible to use a VLF receiver to listen to auroral chorus while watching an auroral display!

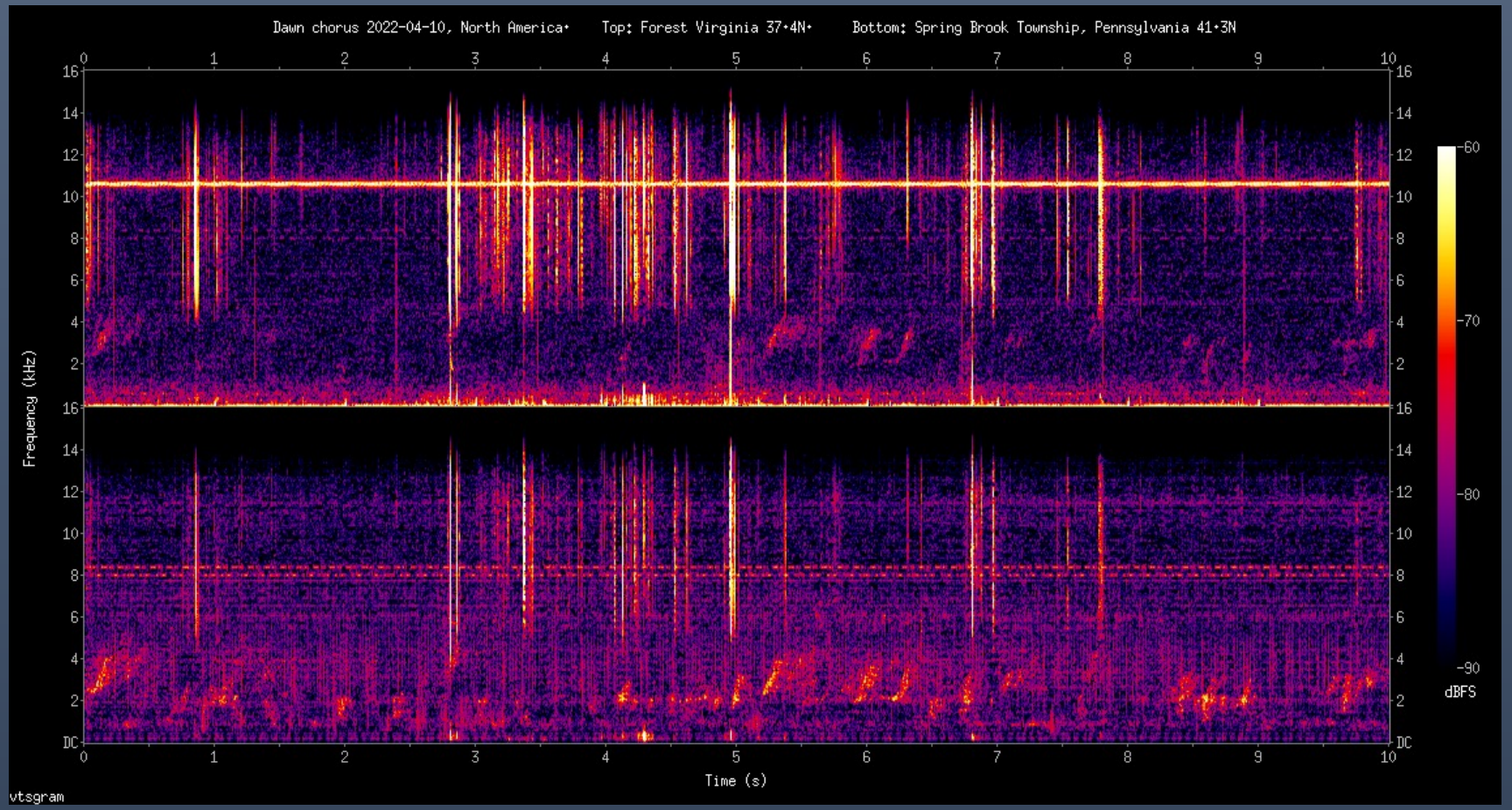
4/10/2022 Dawn Chorus Event



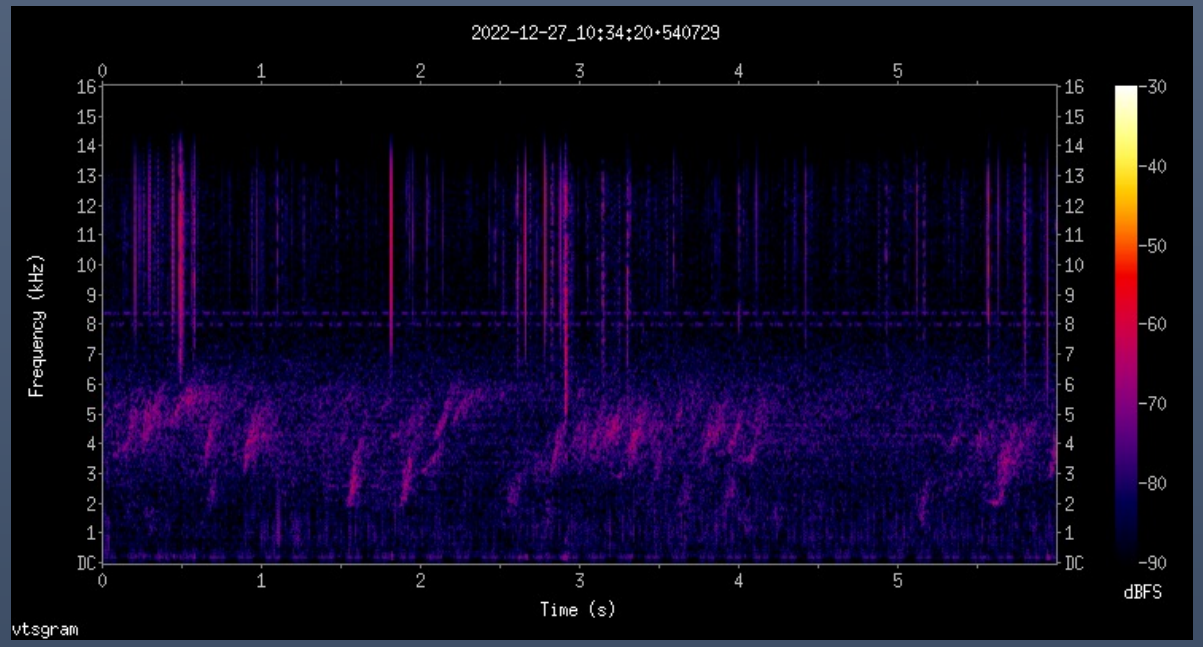
4/10/2022 Dawn Chorus Event Spring Brook, PA and Forest, VA

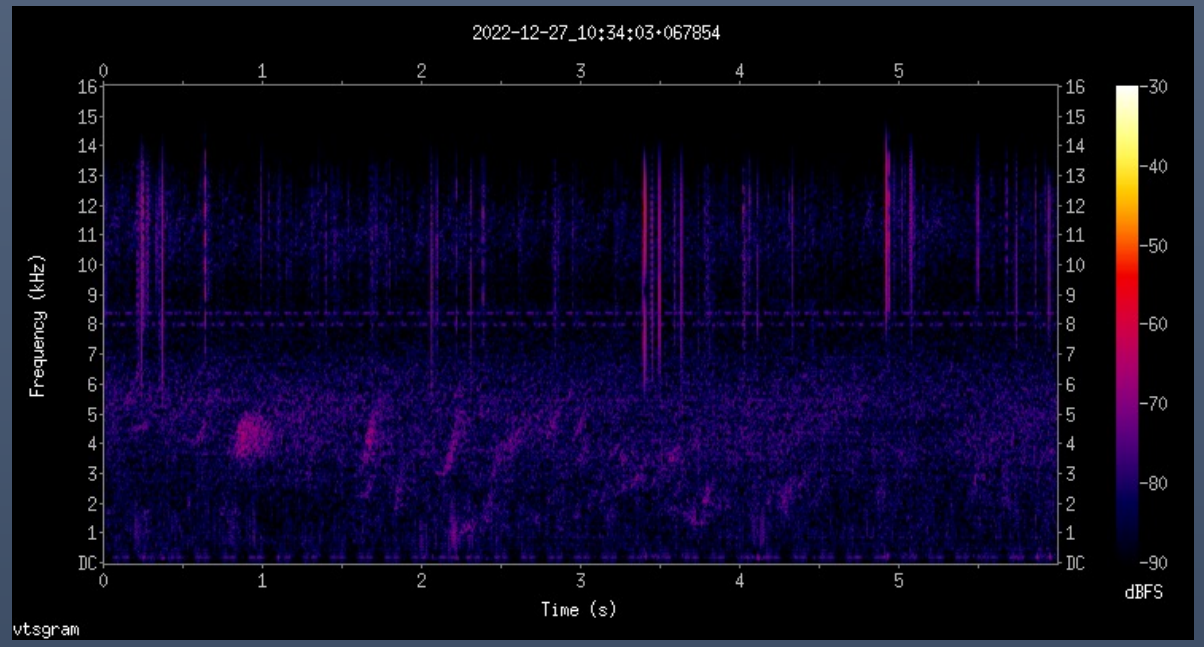
Forest, VA

Spring Brook Township, PA

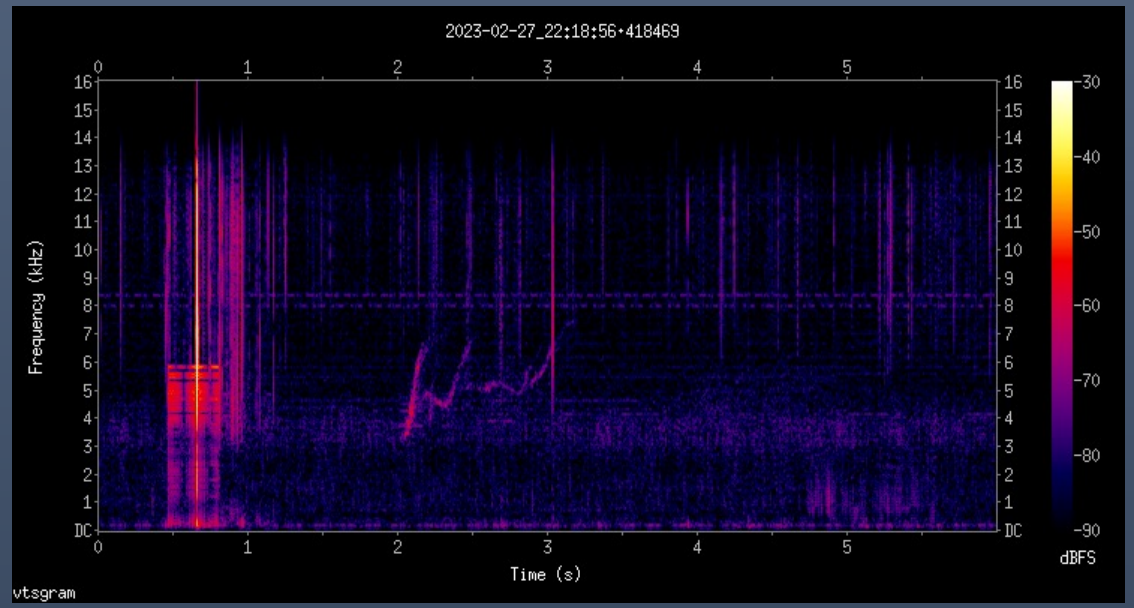


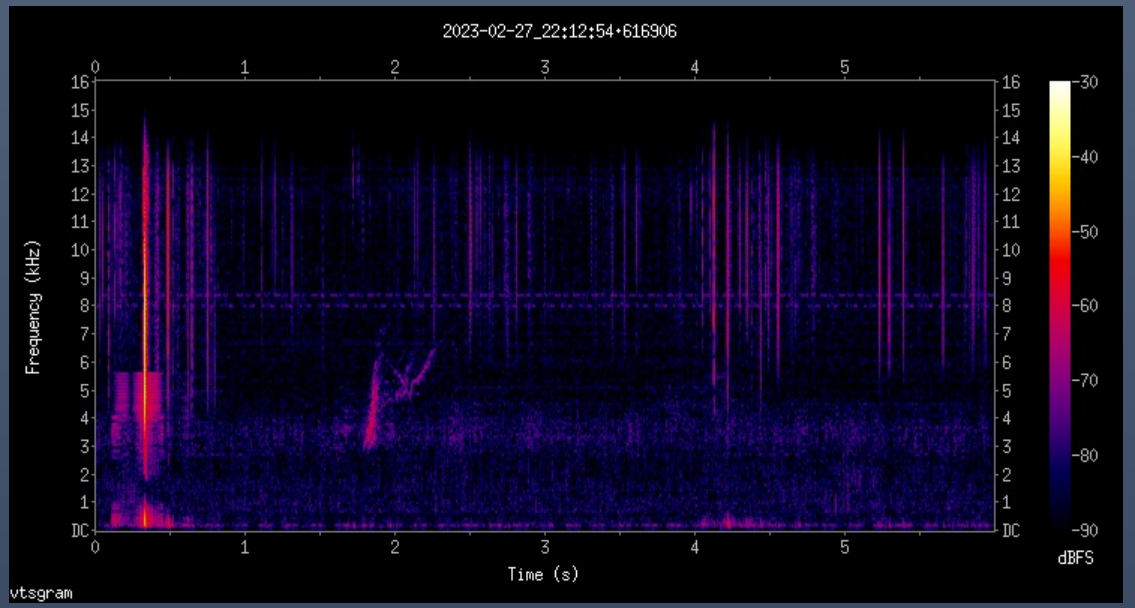
12/27/2022 Dawn Chorus Event



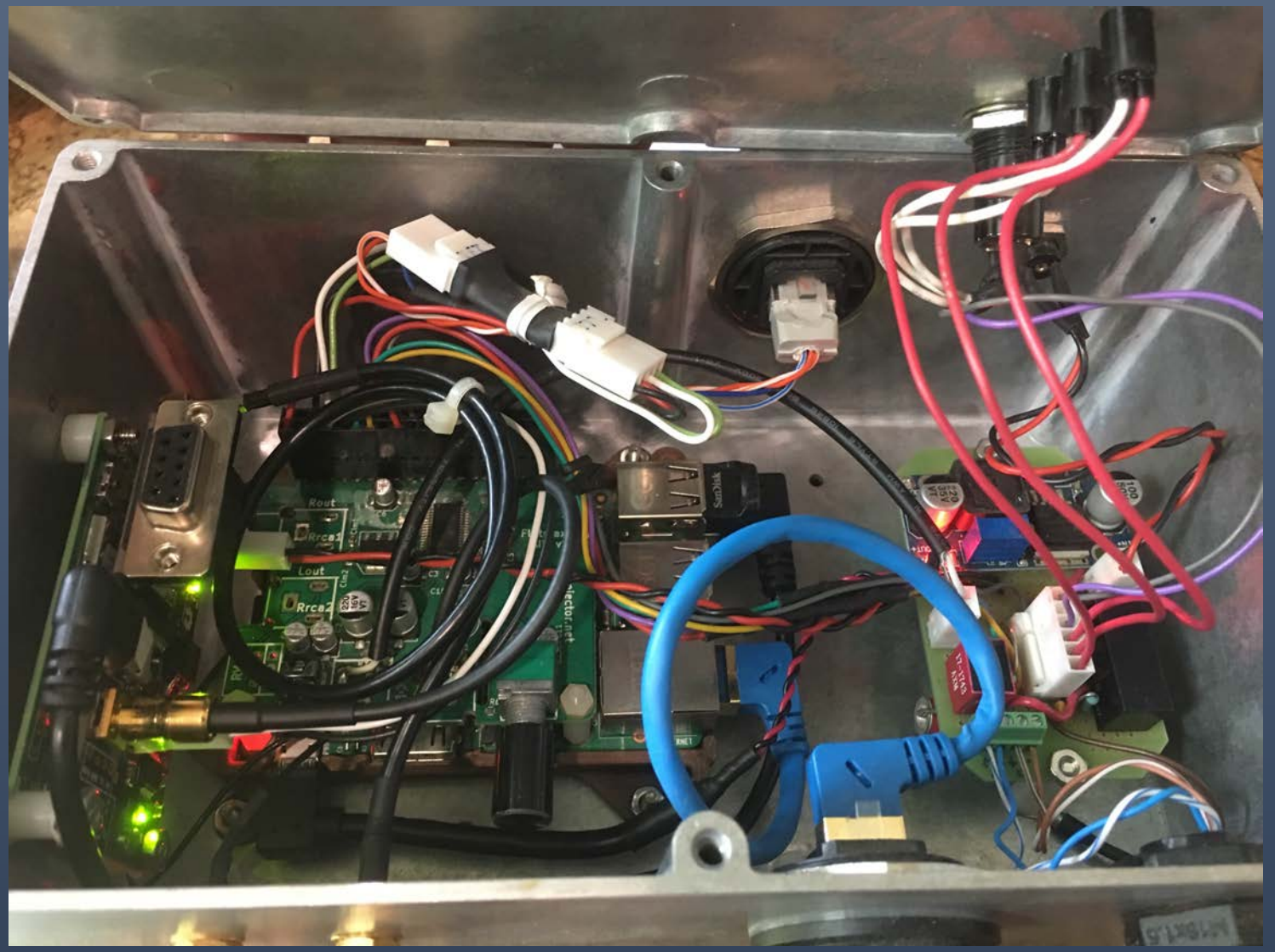


02/27/2023 Riser Events



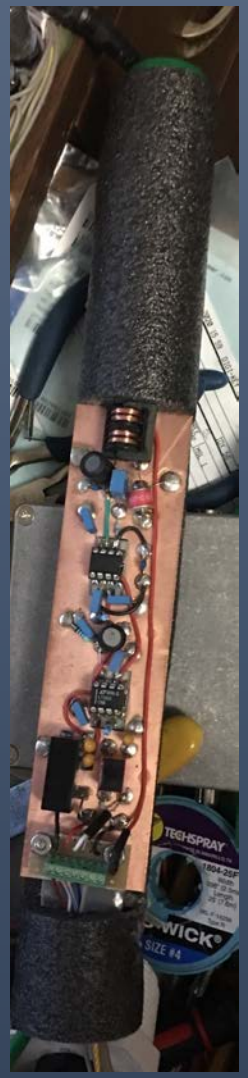


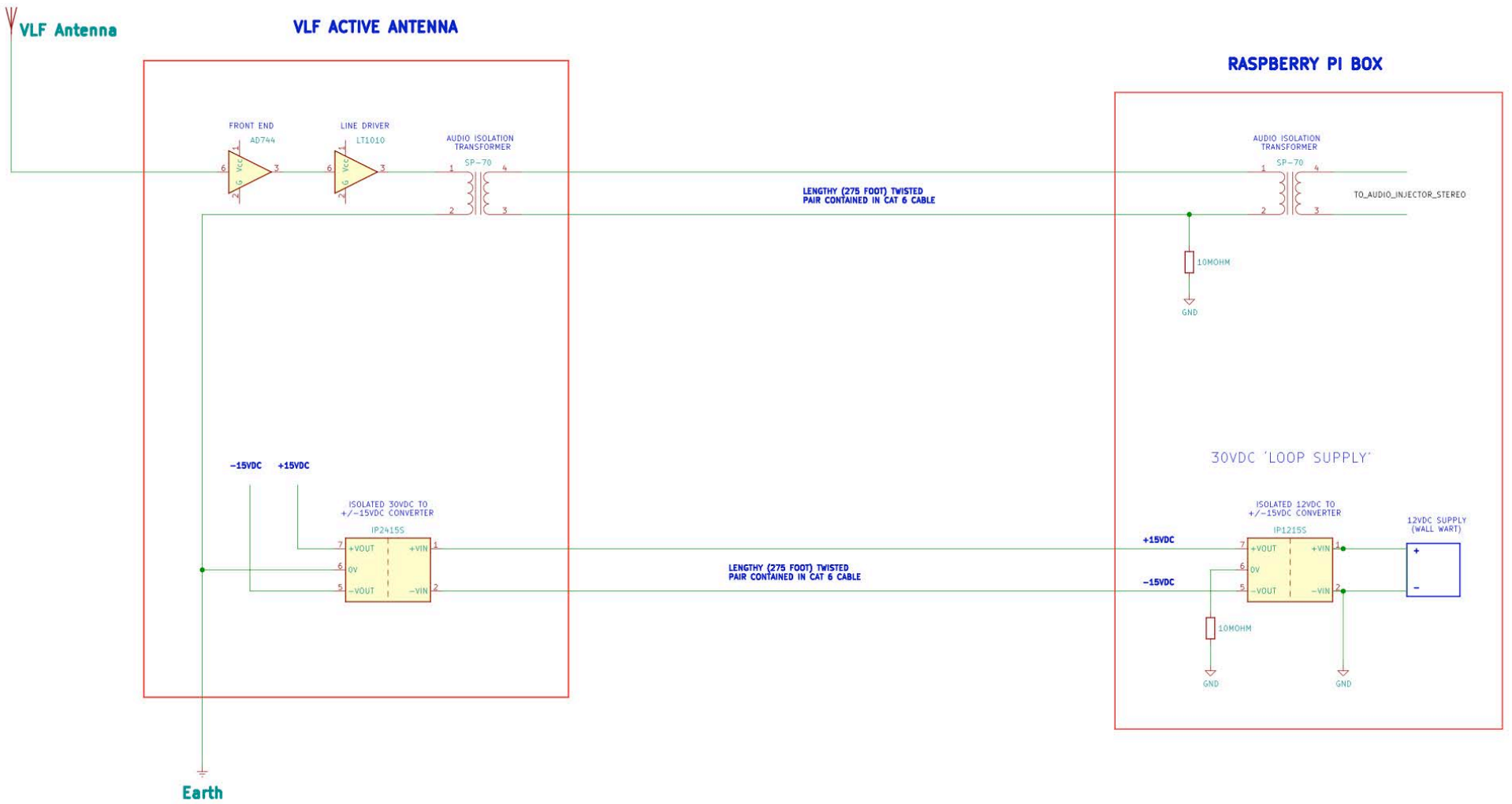
Whistler Catcher VLF Reception System



VLF Active Antenna

VLF Active Antenna





Credit to Gary Mikitin AF8A

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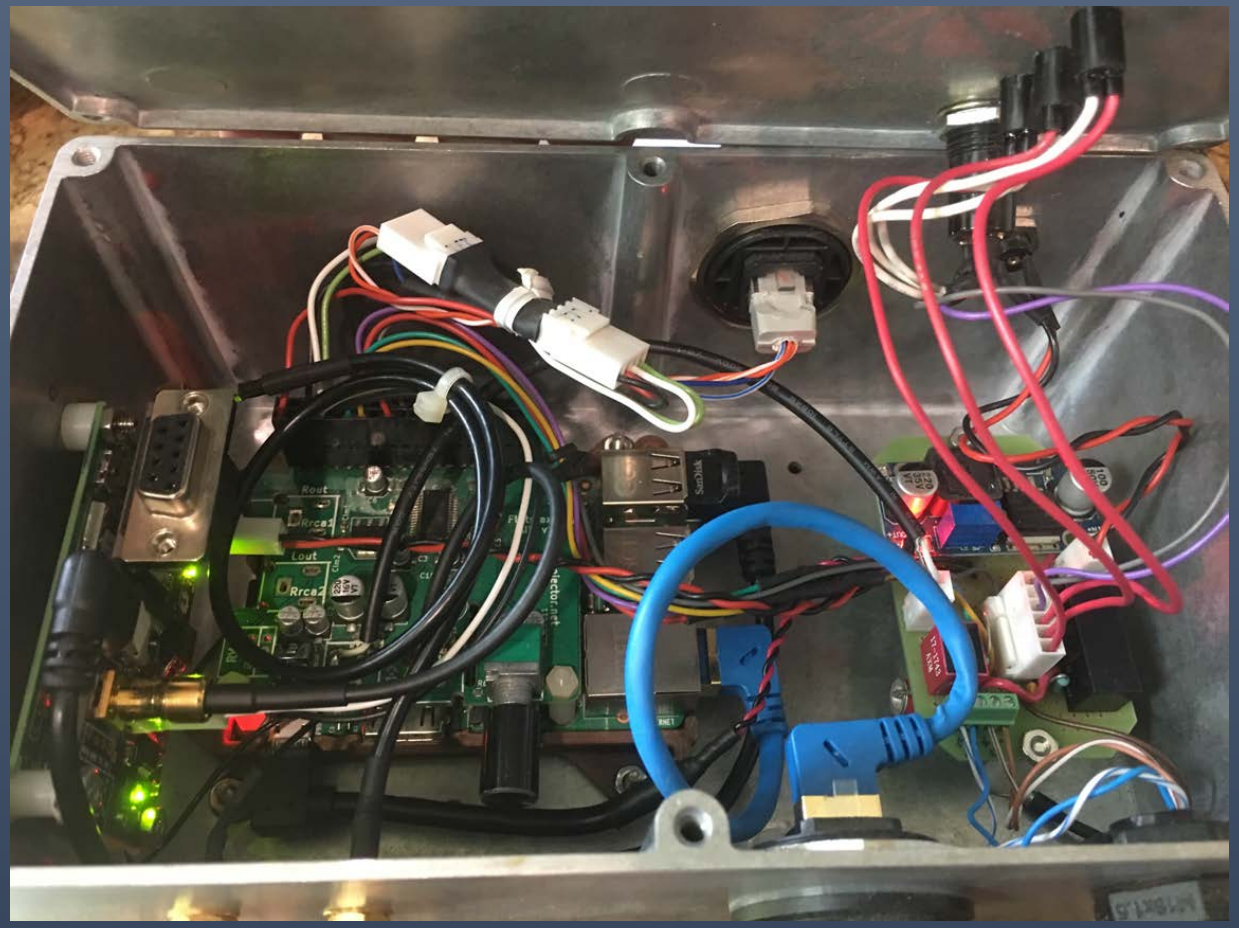
Raspberry Pi Enclosure



A New VLF Reception System for Professional and Citizen Science Applications

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[1]HamSCI, [2]University of Scranton, HamSCI

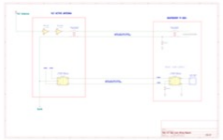
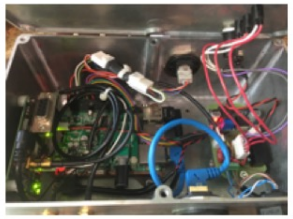
Abstract

Very Low Frequency (VLF, 300 Hz – 30 kHz) natural radio emissions originate from lightning discharges and interactions with solar wind particles and the magnetosphere. Studying these natural emissions, as well as man-made VLF transmissions, gives insight to the D and E layers of the ionosphere and magnetosphere. A science-grade VLF reception system can be constructed using a simple active antenna, Raspberry Pi, soundcard, Global Navigation Satellite System (GNSS) receiver, and free, open-source vlfrx-tools software. This instrument can be utilized by both professional researchers and citizen scientists to capture and analyze these radio emissions for further study. By recruiting both professionals and citizen scientists, a network of these VLF reception systems can be used for global study of Natural Radio Emissions using common off-the-shelf (COTS) components with free open source software (FOSS). A VLF reception system has been installed in a radio-quiet location in Spring Brook Township, PA and has been in operation for over a year, capturing and analyzing natural radio emissions and man-made VLF transmissions with a goal to add more VLF reception systems to the network. In this presentation, we present the design of this system, as well as observations of dawn chorus events, whistler events, and signatures of lighting with continuing currents suggesting a link between ELVES transient luminous events (TLEs) and extremely low frequency (ELF) tails.

VLF Reception System

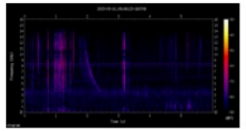
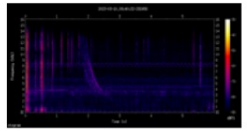
The VLF Reception System consists of a VLF Active Antenna and a backend processing system. The VLF active antenna is a general purpose E-field VLF receiver with antenna element. It contains a VLF preamp and microphonically-dampened antenna probe. The backend processing system is a Raspberry Pi with Audio Injector Stereo soundcard and GNSS timing receiver. The Raspberry Pi runs vlfrx-tools software and GPS Daemon. It captures, stores, monitors, and processes the VLF spectrum.



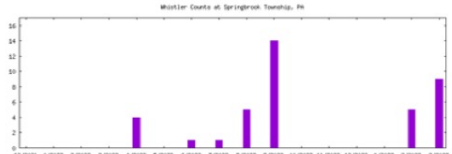




Whistlers

Whistlers are lightning sferics that propagate through magnetospheric ducts and undergo frequency dispersion on the order of ~1s or more due to the electron density of the duct. The following spectrograms are captured whistler events at Spring Brook Township, PA.

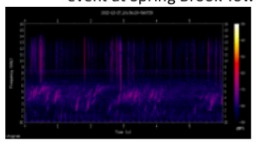
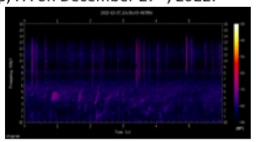



Below is a histogram of whistler events by month, from December 2021 to March 2023, received at Spring Brook Township, PA. It indicates an uptick of whistlers in both the Spring and Fall seasons.

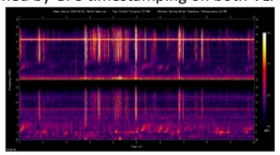


Dawn Chorus

Dawn chorus is a natural radio emission created by the interaction of geomagnetic storms and the magnetosphere. It consists of multiple rising and wavering tones. The following spectrograms are a captured dawn chorus event at Spring Brook Township, PA on December 27th, 2022.

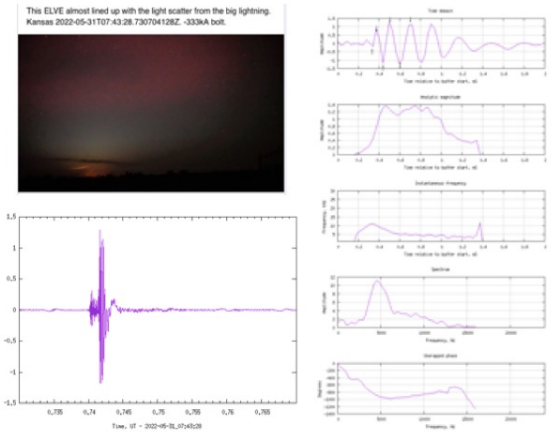



Below is a stacked spectrogram of a dawn chorus event at Forest, VA (top) and Spring Brook Township (bottom) on April, 10th 2022 showing the footprint of the event in both locations. The time alignment of sferics is accomplished by GPS timestamping on both VLF receivers.



Lightning Strokes with Continuing Currents and ELF Tails Associated with Mesospheric Lightning

There is evidence that TLEs are often generated by lightning strokes with continuing currents (Reising 1996) and it was observed that continuing current strokes produce a delayed ELF component of the sferic (Pierce 1960). With the help of Amateurs with an interest in photographing TLEs (mesospheric lightning) using GPS-timestamped photography, it is possible to correlate these events with sferics received at Spring Brook Township, PA and observe not only the delayed ELF component, but extract various parameters of the sferic, such as the magnitude of frequency content, analytic magnitude, skywave component, instantaneous frequency, and unwrapped phase from recorded Time of Group Arrival (TOGA) measurement.



References

1] S. C. Reising, U. S. Inan, T. F. Bell, and W. A. Lyons, "Evidence for continuing current in sprite-producing cloud-to-ground lightning," Geophysical Research Letters, vol. 23, no. 24, pp. 3639–3642, 1996. doi:10.1029/96gl03480
[2] E. T. Pierce, "Some ELF Phenomena," Journal of Research of the National Bureau of Standards, Section D: Radio Propagation, vol. 64D, no. 4, p. 383, 1960. doi:10.6028/jres.064d.045

Acknowledgements

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Thank you!

- I'd like to offer my gratitude to the following:
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  - The VLF Community (VLF Natural Radio groups.io group, VLF Facebook Groups)
  - Gary Miller for his amazing support and updates to gpsd that includes Trimble timing receiver support.
  - Nathaniel Frissell W2NAF for endless support and motivation for this project.
  - Carl F. Eddy AA3WR for the countless support and inspiration he was to me.
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