

# A New VLF Reception System for Professional and Citizen Science Applications

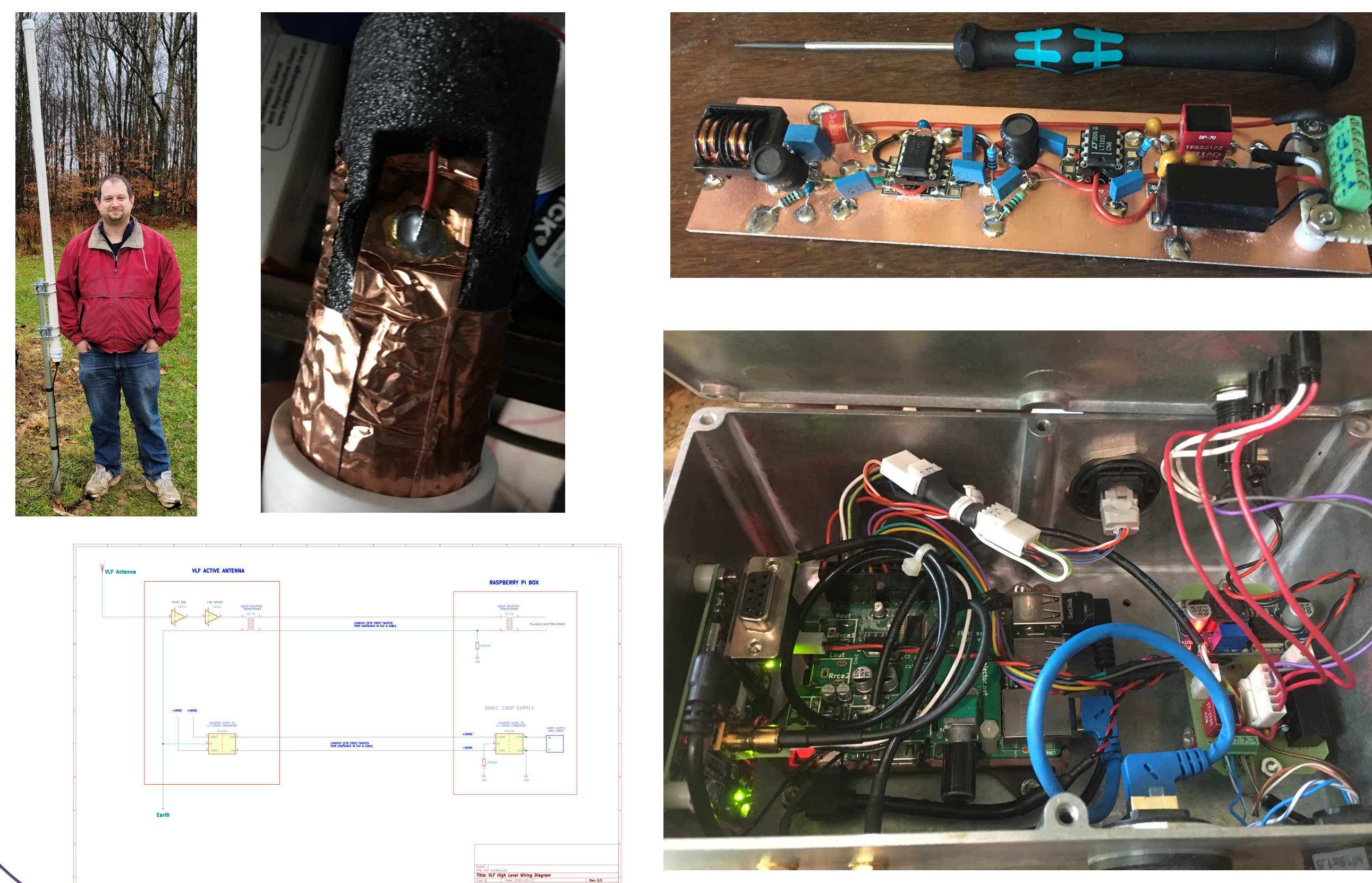
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## Abstract

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 vlfrc-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 lightning with continuing currents suggesting a link between ELVES transient luminous events (TLEs) and extremely low frequency (ELF) tails.

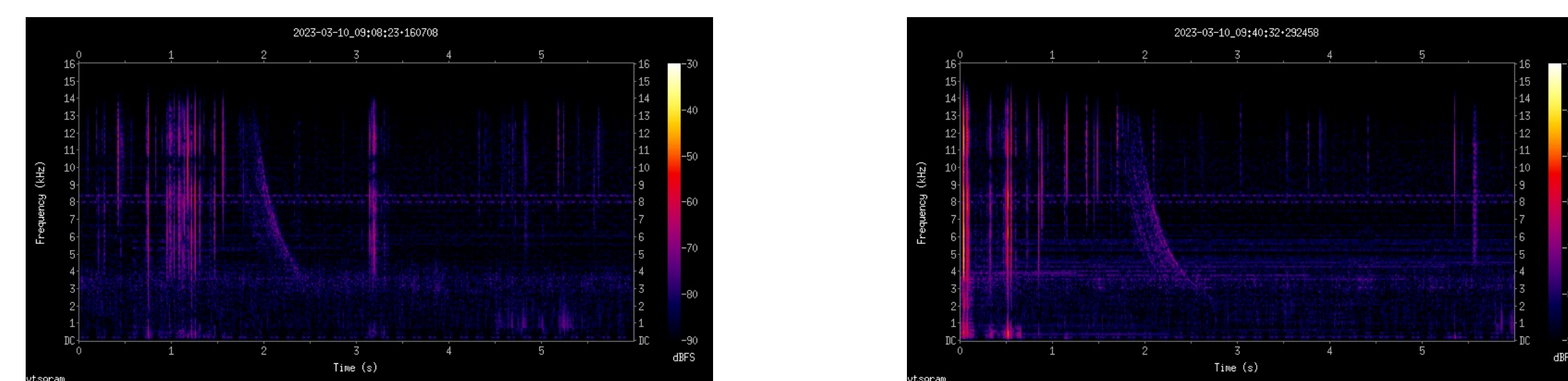
## VLF Reception System

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 vlfrc-tools software and GPS Daemon. It captures, stores, monitors, and processes the VLF spectrum.

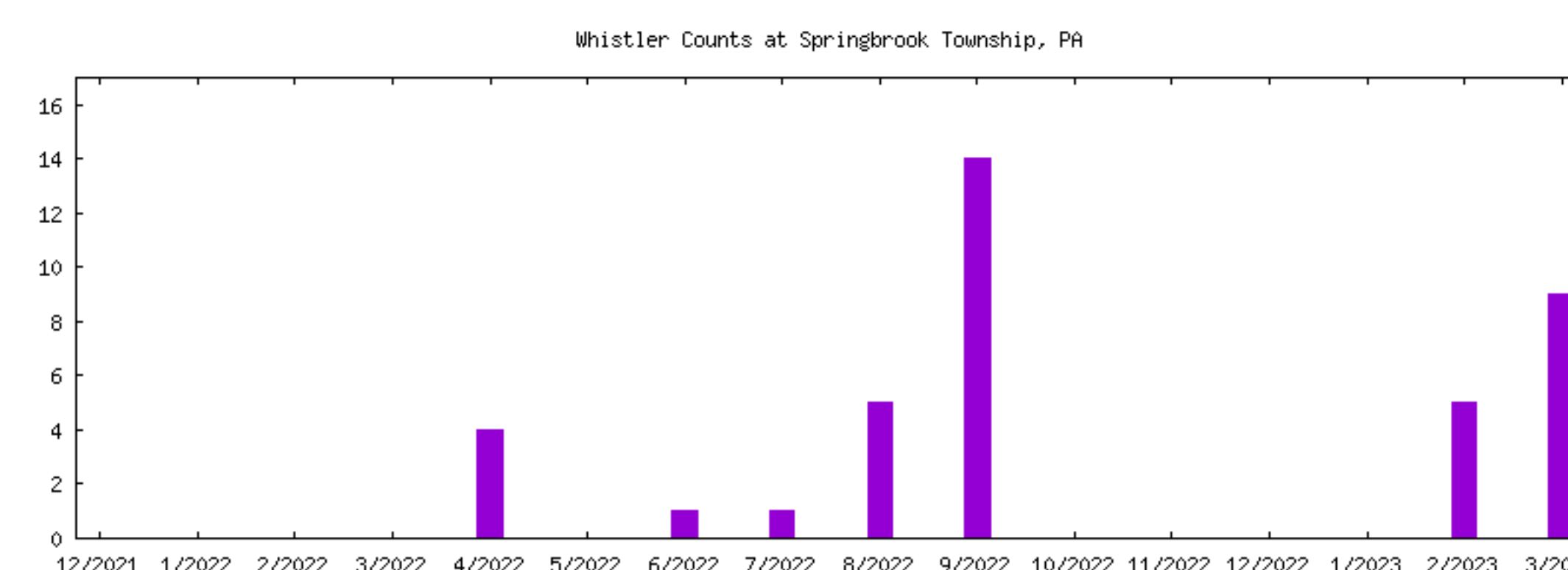


## Whistlers

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.

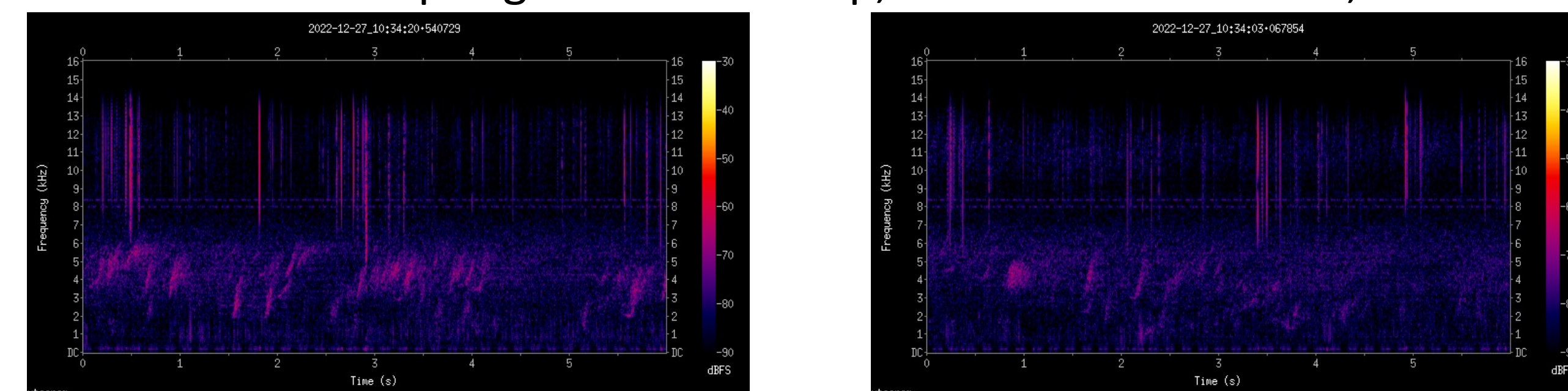


Below is a histogram of whistler events by month, from December 2021 to March 2023, received at Spring Brook Township, PA. It indicates an uptick of whistlers in both the Spring and Fall seasons.

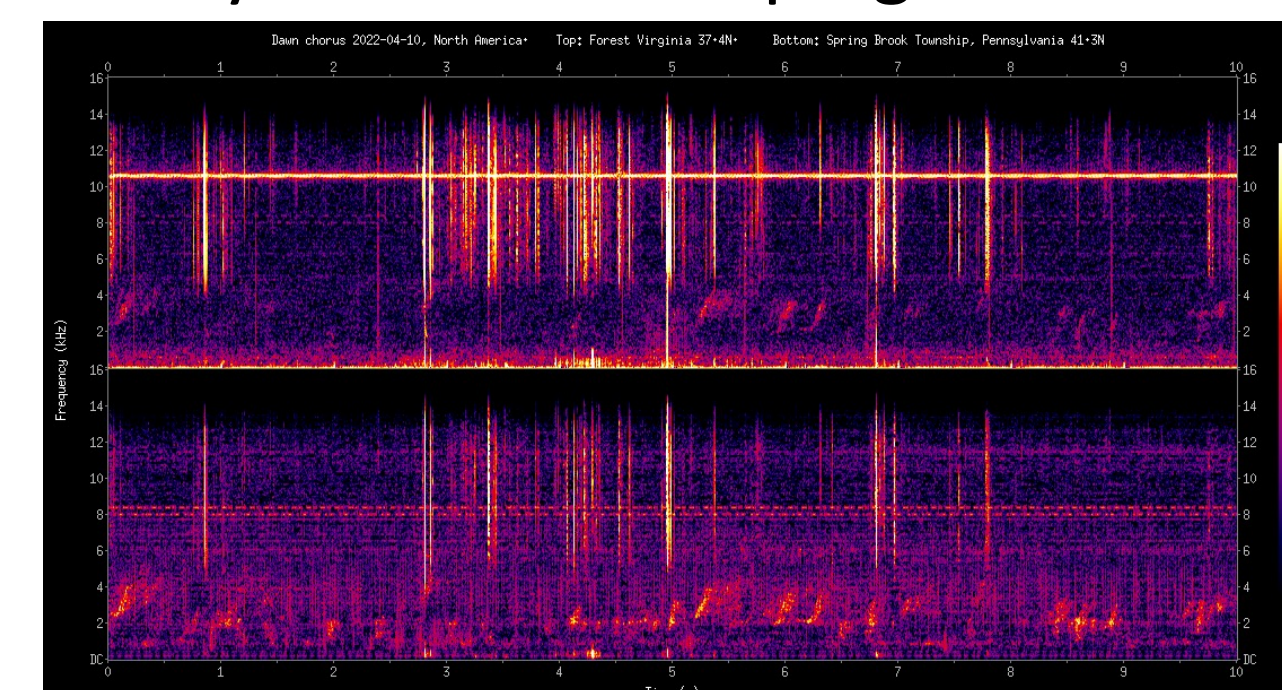


## Dawn Chorus

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

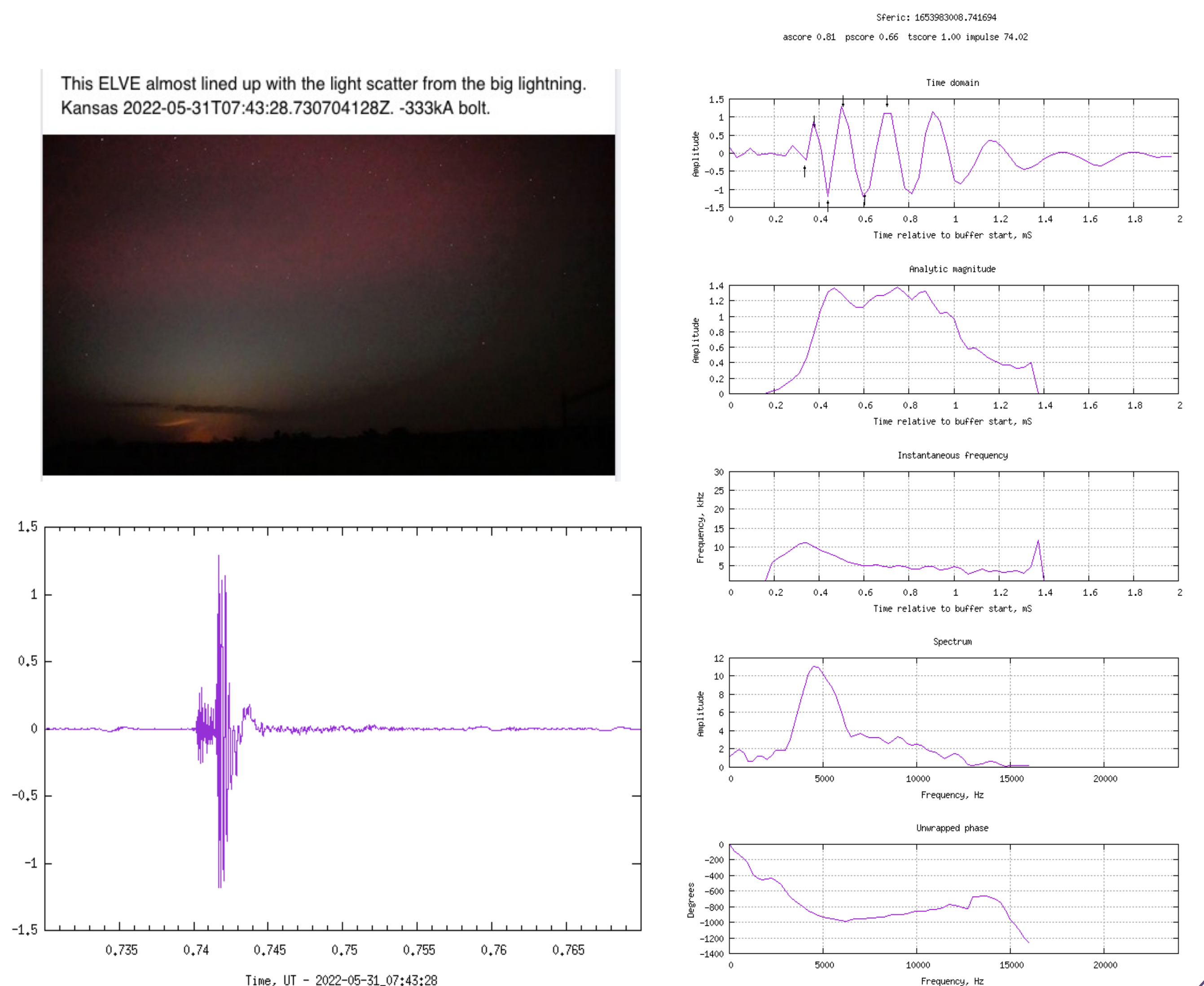


Below is a stacked spectrogram of a dawn chorus event at Forest, VA (top) and Spring Brook Township (bottom) on April, 10<sup>th</sup> 2022 showing the footprint of the event in both locations. The time alignment of sferics is accomplished by GPS timestamping on both VLF receivers.



## 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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