HF PROPAGATION EXPERIMENT UTILIZING CHU BEACON DURING THE APRIL 2024 SOLAR ECLIPSE: A COLLABORATIVE APPROACH TO IONOSPHERIC RESEARCH

CASE WESTERN RESERVE UNIVERSITY

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BACKGROUND

The 8 April 2024 total solar eclipse presented an extraordinary natural experiment in ionospheric physics. The ionosphere is comprised of ions and thus reacts to changes in solar radiation, the effect of which can be seen through high-frequency (HF) radio communications. Many long-distance radio communications rely on properties of the ionosphere to send signals beyond the horizon (via refraction). As the day-night cycle progresses, certain bands of long-distance communication may or may not be viable as a result of ionospheric changes. However, these changes are slow. During a total solar eclipse, the Moon's shadow provides a much quicker change in solar radiation as it moves across Earth's surface. Hypothetically, the same quick change could appear in the ionosphere and thus in radio propagation. When the experiment was conceived, this was one of the primary ideas the research group planned to test.

Coincidentally, the April eclipse's path included a great circle segment from Austin, Texas through Toronto, Ontario. The great-circle continued to time-standard radio station CHU, operated by the Canadian National Research Council and maintained accurate by atomic clock reference. CHU transmits amplitude-modulated ticks every second, synchronized to a "trio of atomic clocks" [1]. The experiment made use of the path and these signals in an attempt to measure changes in radio propagation.

This poster is primarily concerned with the development, deployment, and maintenance of a network of data collection devices to record GPS-synchronized time-series data during the eclipse. The data collected were and are intended to be analyzed for the eclipse effects on the ionosphere.

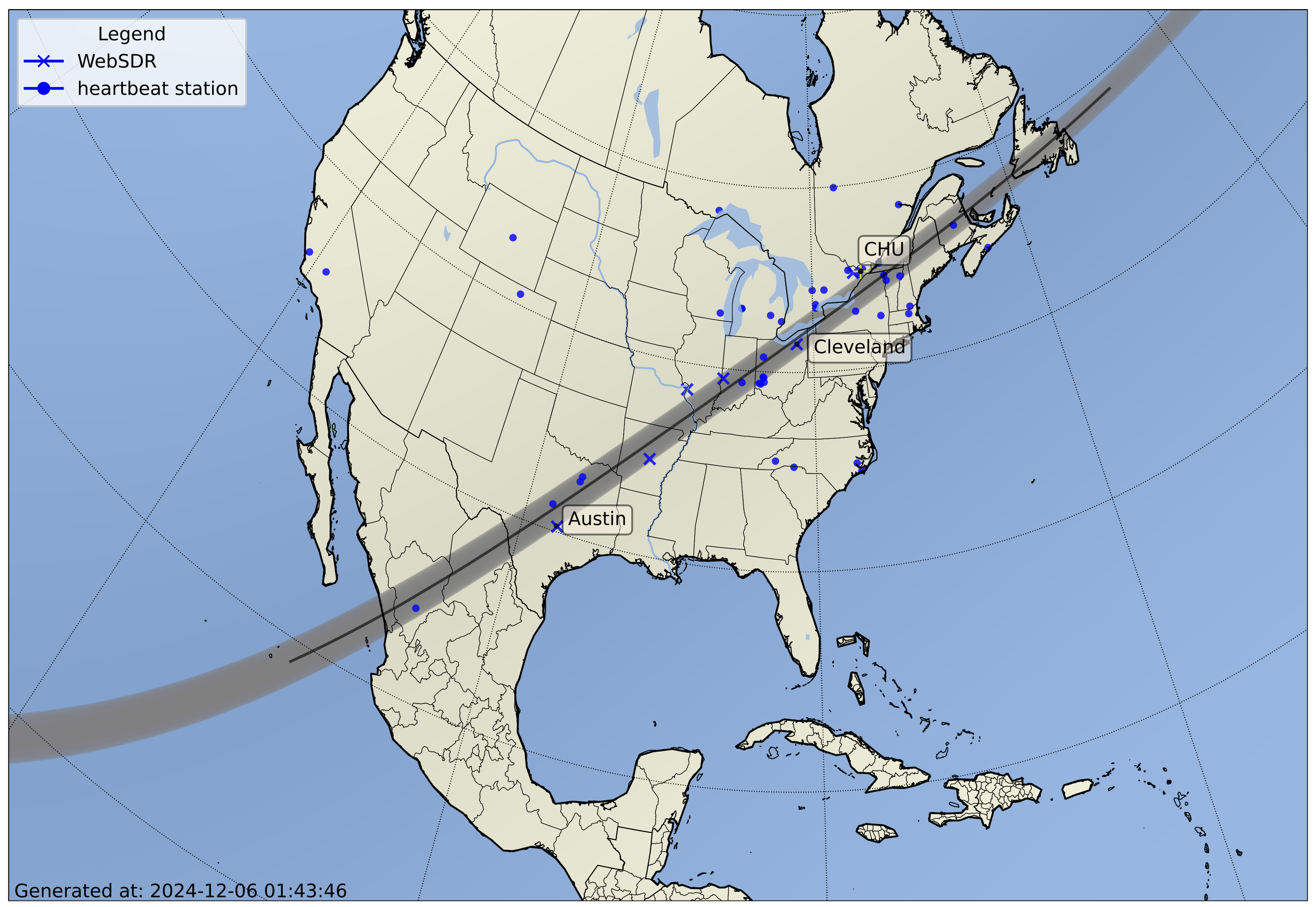

Figure 1: Eclipse path and receiving stations for the April 8 eclipse

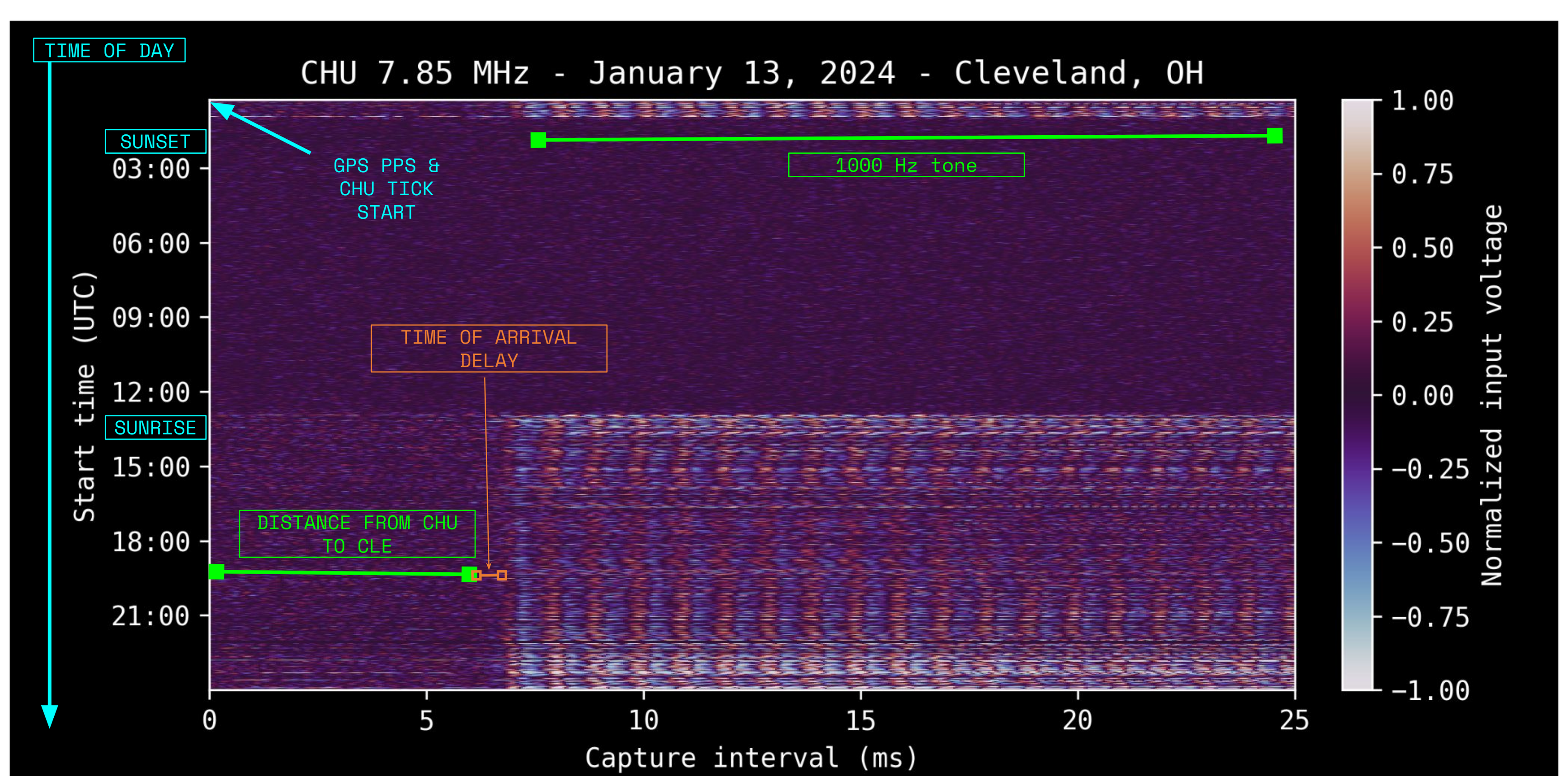

Figure 2: Waterfall of data collected in January describing different parts of the graph

METHODS & IMPLEMENTATION

The primary goal of the experiment was to measure changes in time-of-flight of radio signals propagating via the ionosphere as the Moon's shadow passed over the Earth. Radio station CHU sends a 1000 Hz tone, 300ms in duration, at the start of every second. With a reliable common-view clock source, changes in time-of-flight from one second to another can be measured. Using GPS synchronization, the time-of-flight can be measured directly.

CHU broadcasts on multiple frequencies: 3.33, 7.85, and 14.67 MHz, each of which interacts with the ionosphere differently.

Every eclipse is unique. To take advantage of this opportunity, the research group decided to amass as much data as possible from as many locations as possible. This resulted in two primary data collection sources:

Eclipse Tracking (ET) units

CHU uses single-sideband, full-carrier AM modulation [1]. The primary signal of interest is the 1000 Hz tone at the start of every second. Using GPS-synchronization one can obtain a common-view start of the UTC second which can then be compared to the reception time of the tone. A system was designed to take advantage of this.

The ET unit is equipped with a Teensy 4.0, GPS module, Rasbperry Pi 4.0, and a custom PCB built by John Gibbons (N8OBJ) that connects the components. At the start of every UTC second, the GPS module outputs a pulse on the 1PPS line, triggering an interrupt service routine (ISR) on the Teensy 4.0 to capture 300ms of audio from the audio jack. After capture, the software appends a checksum to the end of the data and sends a packet of data over the serial port to the Raspberry Pi. Upon receiving the data, the Raspberry Pi decodes the packet, and verifies that the checksum matches. If the checksum matches, the Raspberry Pi appends the data to a local file. At a user-configurable period, the Raspberry Pi sends the data to a central server.

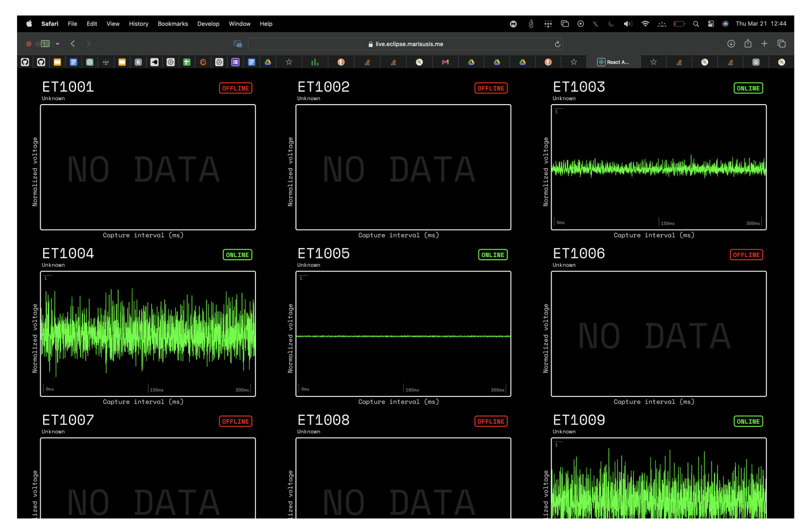

Figure 3: Real-time monitoring dashboard

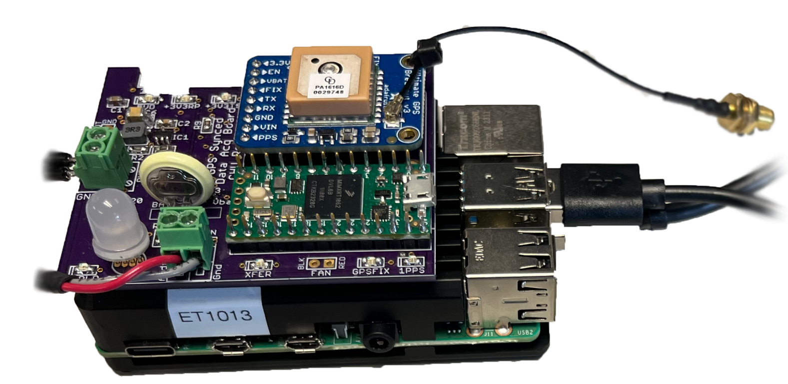

Figure 4: Assembled ET unit

WebSDR scraping

WebSDRs (such as the KiwiSDR) are a package of hardware (including a software-defined radio) and a web interface that is usually open to the public. With the permission of their operators, data was scraped from WebSDR stations across North America. The communication protocol between the front and backend was reverse-engineered and a SDR scraping tool was written in Rust [2]. The research group targeted KiwiSDRs in particular as they are a fairly popular product and many are listed on `https://rx.skywavelinux.com/`.

Data collection

The ET units were deployed along the path of totality such that the received signal would be likely to interact with affected areas of the ionosphere. The research group chose 6 locations to send these units: Ottawa, ON, CA, Cleveland, OH, Terre Haute, IN, St. Louis, MO, Little Rock, AR, and Austin, TX (see Figure 1). These locations were chosen based on the availability of local amateur radio operators. Each was provided with three ET units: one for each of the CHU frequencies. They were also provided a setup manual which helped standardize the process [3].

The operators were directed to operate their ET units for a week before and after the eclipse. This was to establish a baseline of normal operation and to provide lead time to ensure that the units were functioning correctly. Additionally, a monitoring system was built and integrated to identify issues during setup and operation (a screenshot of the monitoring system is shown in Figure 5).

REFERENCES

[1] National Research Council Canada, *CHU Broadcast Codes*, Accessed: 2024-12-01, National Research Council Canada, 2023. [Online]. Available: `https://nrc.canada.ca/en/certifications-evaluations-standards/canadas-official-time/chu-broadcast-codes`.

[2] M. Usis, *marisusis/sdr-scraper: v1.0.0*, version v1.0.0, Dec. 2024. DOI: `10.5281/zenodo.14272006`. [Online]. Available: `https://doi.org/10.5281/zenodo.14272006`.

[3] M. Usis, L. Schwartz, A. Goodman, D. Kazdan, and J. Gibbons, *ET Station Setup Instructions for CHU Measurement, April 8, 2024 Solar Eclipse*, Aug. 2024. DOI: `10.5281/zenodo.13293307`. [Online]. Available: `https://doi.org/10.5281/zenodo.13293307`.

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[5] S. Golomb and H. Taylor, "Constructions and properties of Costas arrays," *Proceedings of the IEEE*, vol. 72, no. 9, pp. 1143–1163, 1984. DOI: `10.1109/PROC.1984.12994`.

OCTOBER 2, 2024 ANNULAR ECLIPSE

To continue the research, arrangements were made to measure the ionospheric effects of the October 2, 2024 annular eclipse. This experiment focused on WWVH in Hawaii (WWV/WWVH are the United States' equivalent of CHU, and are maintained by NIST), which was along this eclipse's path. Improvements were made to the ET units based on feedback and experience from the April 8 eclipse:

- The ET software was improved to write directly to an H5 file with compression enabled. This reduced the file size, often by a factor of 5 or more, when compared to the CSV files.
- A local monitoring program, `ekg`, was developed. This allowed the users to plug the Raspberry Pi into a monitor and see a live view of the signal. Issues arose during calibration of equipment using the live monitoring dashboard for the April 8, eclipse. This was due to Internet connectivity issues. The local monitoring program was developed to address this.

Units were sent to three different locations for this experiment:

- 2 ET units were sent to Walker Creek Farm, Falkland Islands where Bobby and Lyn Short operate their amateur radio station.
- 4 ET units were sent with a member of the research group, Maris Usis, to southern Chile. He traveled a small fishing village, Caleta Tortel, that was in the path of annularity.
- 2 ET units were sent to the Puerto Montt area of Chile, where César Cérdenas runs the CE7DE Radio Club.

Figure 5: View from recording location in Caleta Tortel, Chile

Figure 6: Photo of the October 2, 2024 annular eclipse from Caleta Tortel, Chile

RESULTS & CONCLUSIONS

2TB of data was collected in total. There is still a great deal of data cleaning that must be done before it is ready to be properly distributed, however, the raw data is currently available on Zenodo [4]. The group is actively working on cleaning and converting the data to the NetCDF/H5 format, which is more efficient for storage and analysis.

As shown in Figure 2, the data is visualized using waterfall plots, where each horizontal line represents a 300 millisecond capture window, stacked chronologically from top to bottom. However, many of the plots show a zoomed-in view of the first 30-90ms to better see the 1000Hz tone.

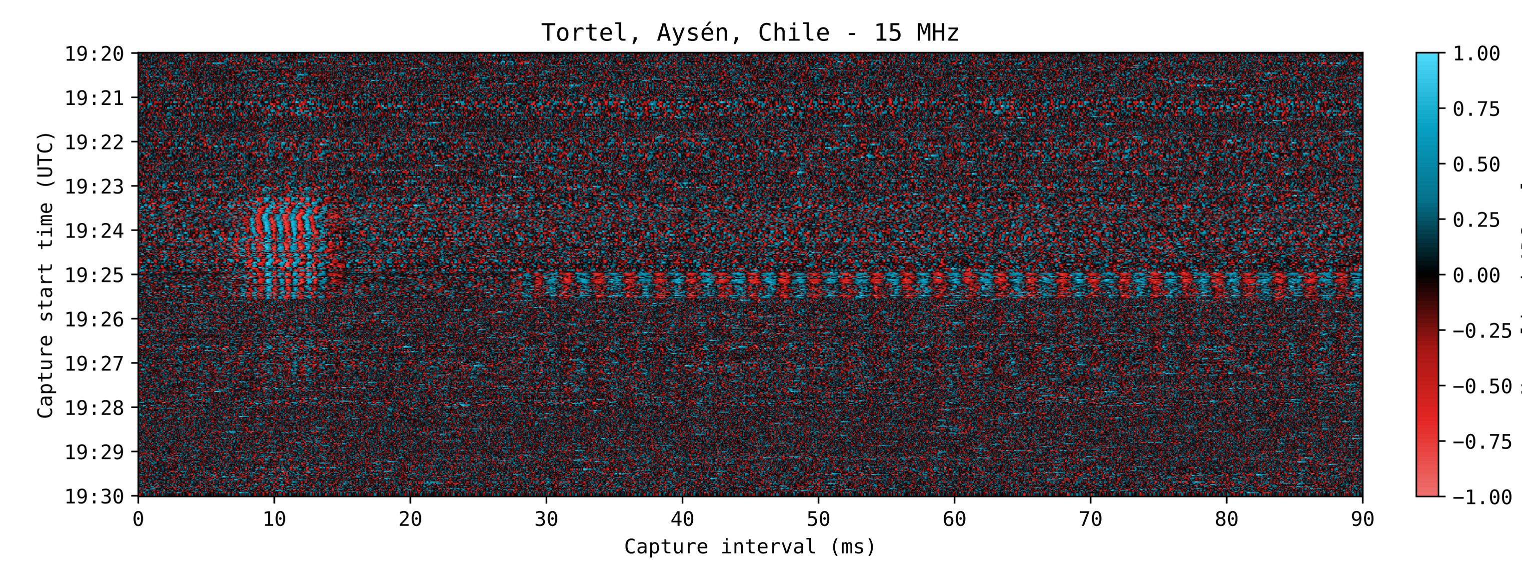

Figure 7: Possible transmission of signal during the October 2, 2024 eclipse

Some preliminary investigation has been done on both the April, 8, and October 2 data. An interesting example is shown in Figure 7. This waterfall plot was generated using data from the October 2, 2024 annular eclipse from 1920 to 1930 UTC. It shows what appears to be a period of brief reception of signal when the moon's shadow was over Rapa Nui (Easter Island). More investigation will be done to determine, firstly, whether the signal is WWVH, Hawaii, or WWV, Fort Collins, CO.

FUTURE WORK

There are many continuations of this body of work, one of which could be an investigation of the 2026 total solar eclipse across Greenland. Because the path of this eclipse doesn't coincide with an existing time-standard radio station, work may be done to design a custom signal that could be transmitted across the path of the eclipse. This could incorporate innovations such as the Costas array, which provides an optimum ambiguity function [5], ideal for locking on to the delay of a signal. This work is also relevant outside ionospheric research. The techniques and systems employed here to conduct data collection at scale with citizen scientists could be applied to other ventures.