Seismic, Acoustic, and Electromagnetic Background Assessments for Future Cosmic Explorer Site Tests: Final Report

Research Student: Carlos Campos
Mentors: Michael Landry, Robert Schofield

9/27/24

1 Abstract

From June 11th to August 16th, we worked on preparing equipment, field kits, and action plans in order to be used for Cosmic Explorer, CE, site testing. This needed to be done so that the CE site surveyors are prepared and know what to do and look for when they get to potential sites. We worked on calibrating and configuring seismometers and magnetometers. These are used to read the environmental background noise. When configuring the seismometer, we discovered that it has an electronic lock that is controlled digitally. Its other functions are controlled via the same software. This differs from prior models where they lock and unlock without the need for user inputs. With the magnetometer, we found some limitations with the digital to analog converter (ADC)'s software. To mend this issue, a Python code was written to widen our data analysis capabilities. We also had to construct hardware in order to connect our seismometer to the ADC as they were not compatible. After getting the equipment working, we set out to identify transient and other environmental noise in the area. We did this so the surveyors know what to look for when at potential sites. We also worked on constructing travel-ready kits in order to easily transport the equipment and sensors. These surveys will greatly decrease the amount of trouble shooting and calibrating that Cosmic Explorer will have to undergo as they will be made familiar with the transient noise in the area.

2 Introduction

The purpose of this project is to test and prepare instruments intended to be used for Cosmic Explorer. Cosmic Explore, or CE, is a proposed third generation gravitational wave observatory to be located in North America. The site will consist of two 40km arms, and 1-3 interferometers comprised in said arms. These interferometers may be 40 km or 20 km in length. However, the exact location of CE has not yet been determined. There are currently hundreds of potential sites. These sites must have low levels of background and environmental noise; this being seismic, acoustic, and electromagnetic noise. To help reduce the number of sites, data from NOAA and Google Maps will be used to get a sense of the terrain without actually going to the proposed location. This will be done through meteorological and geographical data, i.e, wind, rain, ground level. As well as seeing if there are any man-made structures in the surrounding areas that may affect the interferometer(s) and other site sensors.

After the sites have been narrowed down to a handful, is when the surveyors will go to the sites. They will perform day long testing as well as yearlong testing. This is to observe noise sources which occur over the span of hours as well as months. These two testing methods will prevent noise levels from being averaged down or up. To perform these tests, seismometers, microphones, and magnetometers will be implemented.

This is where our project comes in. This kind of testing was not done when the original two LIGOs were built. In addition, all the equipment to be used for these tests is new. So, we were tasked with testing and preparing the instruments for use as well as developing a method of efficiently surveying environmental noise at sites. We also worked on constructing kits for the equipment to travel in as well as any hardware or software required for the equipment.

3 Instrument Setup

3.1 Magnetometer

The magnetometer's setup was simple and followed what the provided pamphlet laid out. The magnetometer connected to the computer through a device called a WebDAQ. This device is an analog to digital converter (ADC). It turns the sensor's analog signal into a digital signal which the computer can read. We ran initial tests in the lab, checking it against different metal framed objects and furniture. As well as testing it along power outlets and cords.

The WebDAQ worked well for recording data, but we quickly ran into issues when viewing live data. In the WebDAQ's program, there is a window where you can view live time series data and Fast Fourier Transform (FFT) data. However, when we looked at this page the live data was very delayed and choppy. The FFT data plot parameter could also not be changed. We could alter the plot limits but could not change the length of the FFT from 1 second.

Through reading literature and going through the different program menus, we were able to fix the live data issue, giving us the ability to properly read data in the field. However, we could not change the length of the FFTs. Since the built in program could not give us the resolution we wanted, we would have to rectify the issue ourselves.

3.2 Seismometer

Like the magnetometer, the initial setup of the seismometer went smoothly and according to the setup manual. Unlike the magnetometer, it did not use the WebDAQ. It ran off its own ADC called a Minimus. When initially testing the seismometer, it was properly responding to our inputs and the data was reflected through the software. However, we could not get everything running properly in the lab because the seismometer's GPS could not connect inside to the building. So, once we felt comfortable with the seismometer, we took it outside to test the GPS. When we did this, the seismometer did not turn on. This problem was quickly fixed as the power cord had come undone.

However, once we did turn it back on in the lab, the seismometer's readings were incredibly noising and erratic. We immediately started reading further manuals. This is when we learned the seismometer had an electronic lock, which was controlled digitally. We also learned that moving it while unlocked can damage the equipment inside the seismometer. We tried troubleshooting the issues by giving it physical inputs and using different menus and functions. However, they were not reported in the data displayed; nor was it responding to our digital commands. It would not lock, center, or calibrate itself. However, throughout the week the data was slowly becoming less noisy, and it would occasionally report our physical input. This upturn is what kept us from believing the sensor was broken and using a different seismometer.

Then, by accident, I kicked the cord connecting the seismometer to the computer. This created a spike in the data. I was able to replicate this by repeatedly tapping the cord. Because of this we figured there was an issue with the connection. To see if this was true, we unplugged the seismometer and cleaned the port out with compressed air, then reconnected the instrument. Once we did this, the seismometer worked properly. The signal was no longer erratic and was responding to our inputs. It would show us walking around and tapping on different pieces of furniture. It also received our electronic requests. We were able to lock, unlock, and execute all its other functions. After this we were able to learn how to properly lock and transport it. We also were able to test the GPS and its supporting functions working.

4 Equipment Construction

4.1 Hardware

As previously stated, we ran the seismometer off a device called a Minimus, a combined digitizer and communication unit made by Guralp, the maker of our seismometer instrument. The Minimus is used not only to display the found data, but also control all the seismometer's digital functions. However, we did not want to use this set up long term. This is because the WebDAQ has functions and abilities that the Minimus does not. Namely, displaying FFT data, as well as other data analysis techniques, and the ability to easily download recorded data to computers for further offline analysis. The Minimus does not store data for each testing session individually. It concatenates all the data into one file, for each function. This creates large files and causes us to dive into the files to find the data we want. It also uses a mseed data format. Forcing us to spend time using third party software to get it into a format we can use. The WebDAQ stores data on an internal hard drive which can be accessed digitally through a graphical user interface (GUI). With this GUI, we can easily select the data we want the download it as a CSV file. It also has the capability to have an additional SD card inserted, giving it a far greater storage capacity than the Minimus.

The issue is that the WebDAQ and Minimus are incompatible. The WebDAQ uses BNC cables to connect to devices, while the Minimus has its own unique connector cord. We could not abandon the Minimus outright, due to the fact that we could not operate the seismometer without it. Guralp did have the foresight to make a device called a breakout box. This allows the seismometer to connect to a third-party ADC, or something similar, as well as control the seismometer via physical buttons. Unfortunately, this breakout box would not be delivered until the end of our summer research. This meant we had to make our own version of the breakout box.

To create this breakout box, I cut into the seismometer's connection cord. This cord is what connects the seismometer to the Minimus. In it are 26 different wires that have their own unique function as well as ground wires place throughout. However, we only needed 6 of these wires. Seismometers operate off of three pendulums swinging between sensor coils to infer seismic movement. Each of these test masses, the pendulums, use two of these wires to send signals out. I used a multimeter and probes to find the 6 we needed. I then used a box with BNC connectors along its sides as a housing for the cord and a base for our breakout box. I then connected the 6 wires to the BNCs via solder. Each direction gets its own connector; meaning, 2 of the 6 wires were soldered to each of the 3 connectors. I then applied putty along the interior and exterior where the cord is to try and prevent it from sliding out and breaking the soldering. However, the putty was not able to adhere to the box when exposed to the outside heat. As a result, I removed the putty and replaced it with electrical tape and two worm gear clamps. This new setup was able to withstand the heat when performing field testing as well as providing a greater degree of flexion in the cord. We have dubbed this breakout box PERRY, the Physical Environmental Readings RelaY.

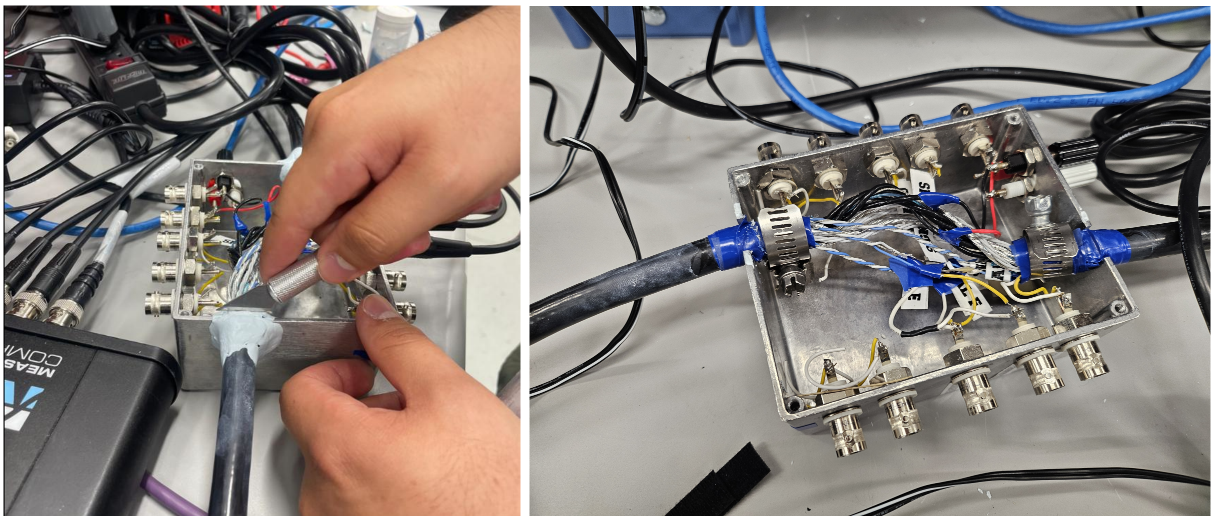

Figure 1:
Left: A student cleaning off excess putty from PERRY's hull *Right:* A picture of the update version of PERRY

4.2 Software

As aforementioned, the WebDAQ software could not display the FFT data the way we needed. It could only perform FFTs with a length of 1 second, needed at least 100 seconds. This lesser time results in lower resolution data. To mend this problem, I wrote a Python script to analyze the data from the WebDAQ. I had already started writing a code when we ran into the issue with the live time series display. Luckily, I was able to easily modify it to work as a base for this analytical code.

The main functions the code needed were the abilities to plot the collected data, analyze the data with more precision than the WebDAQ, as well as plot the analyzed data. Additional capabilities I wanted the code to have were to have it be able to detect the frequencies found in the data, plot them, and output them into a data file. I already had written how to upload and plot the data. However, I needed to figure out how to analyze the data via an FFT, or a like process. The first thing I needed to do was be able to bin the data. I did this by looping through the data to find the index of the time I wanted, then slicing the data file. This allows me to vary how large the bin is. This is opposed to the WebDAQ where it could only create bins in terms of one second. The advantage of using larger bins is that the quality is improved. The frequency peaks become narrower, making it easier to differentiate different frequencies. After I figured that out, I needed to actually analyze the data. We decided to use a Power Spectral Density (PSD) process instead of a FFT to be uniform with process parallel to us. I ended up using SciPy for this process. *Welch* was used to perform the PSD, while *find_peaks* was used to find the frequencies and their amplitudes. I also used SciPy in order to make spectrograms of the data.

5 Instrument Testing

Before going out and looking for transient noises, we had to test the equipment and code to make sure they were operating correctly. We did this by creating a rhythmic noise for both equipment, starting with the seismometer. We used a Piezo shaker to create harmonic noises starting at 15 Hertz (Hz). This is reflected in *Figure 2*. We found frequency peaks more or less within the 15 Hz harmonic. However, there is some discrepancy with some of the peaks. This is most likely due to the age of the shaker equipment and driver. We also can see that the harmonics are more powerful than the 15 Hz wave itself. There are also peaks at 57 and 85 Hz. We believe the 57 maybe the resident frequency of the springs inside the seismometer. However, we are still trying to figure out the cause of the 85 Hz.

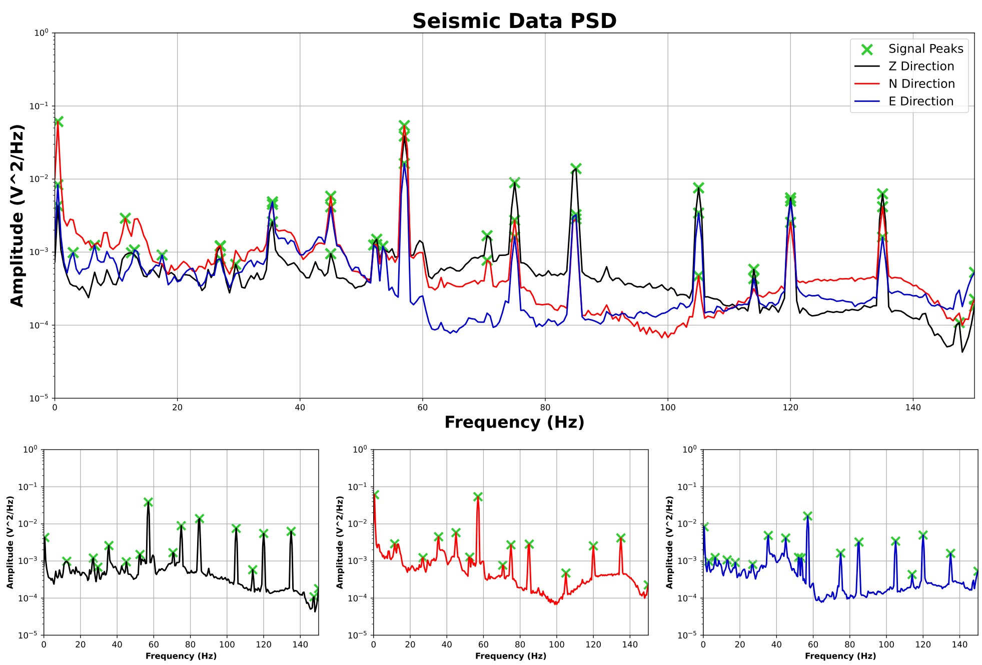

Figure 2:
Top: The seismometer data is displayed in a power spectral density plot. Each different directional plane is reflected by a unique color. The black is the Z direction, while the red and blue are N and E. The green x's are the different frequencies found during these tests.
Bottom: These display each of the directional plane in their own respective plots. They also display the frequencies found.

For the magnetometer, a laptop and a smartwatch were used to create this noise. Both of these devices create periodic electromagnetic noise when they are operating. We were able to see this periodic noise on the time series and then we were able to display the data in a PSD plot, this is *Figure 3*. Unlike the seismometer, we did not know beforehand what the frequencies would be. But we were still able to get data. It seemed the main frequency we found was 240 Hz and its harmonics. We also found some at lower frequencies as well.

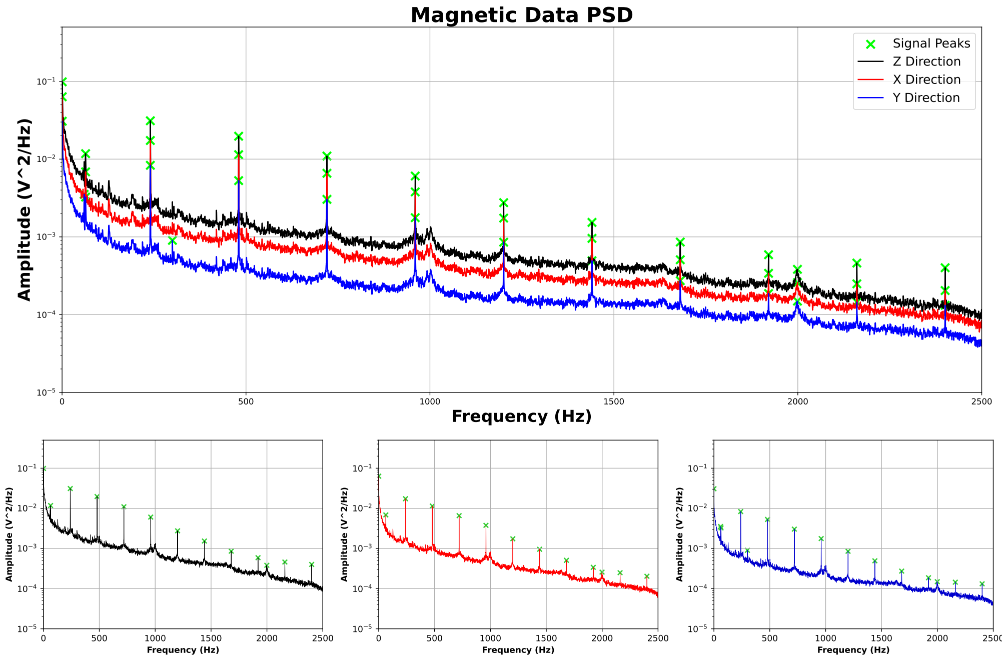

Figure 3:
Top: A power spectral density plot of the data we collected while testing the magnetometer. Each color represents a different directional plane. The black is the Z direction, while the red and blue are X and Y respectfully. The green x's are the different frequencies found during these tests.
Bottom: These are each directional plane in their own respective plots. They also display the frequencies found.

6 Field Work

After getting all the equipment up and running we could start field testing. We knew our end goal was to construct travel kits for the instruments and all their supporting gear. But we did not know what we would need to achieve that. We knew we needed some kind of carrying case for the sensors and their supporting equipment. In addition, we also needed a way to power everything. To figure these specifics out, we decided to trial and error the process. We set out in a van down the Y-arm of the observatory. We were carrying the support equipment and the magnetometer in a plastic storage box, the seismometer by hand, and a granite slab. The granite slab is what the seismometer is placed on in the field. We do this because when the seismometer expands due to the heat the movement can appear in the readings. Using a polished granite slab reduces this noise. We then setup all our equipment on the ground we were able to get everything powered by our van's battery. Our goal wasn't to collect environmental data, but to simply learn what we needed and to see if the instruments worked properly in the field. During this process we learned three important things. One, we need some way to protect the seismometer from the wind. If the seismometer tilts due to the wind, our readings will all be askew. We had a similar issue with the magnetometer. To make sure the magnetometer doesn't move we either have to bury it or set it up on a tripod. Lastly, we need some way to protect the Minimus, WebDAQ, and the other equipment. Due to being on the ground in the sun, they became very hot. They also were exposed to the elements, meaning they would not survive the site testing time frame.

For the seismometer, we ordered a medium size trash can to be placed over it to serve as this needed protection. While we were waiting for it to arrive we used a wooden crate. We decided on a plastic trash can because it would be easy to transport and the site surveyors would be able to easily get one when they get to the site. We also got a support for the magnetometer. It's not a full tripod, but it's secure enough so that the magnetometer doesn't move. Lastly, we ordered Pelican cases for the equipment. This way everything is protected and easy to travel with. Each team of surveyors will be given three Pelican cases. One will contain the Minimus, WebDAQ, a breakout box, and the magnetometer and its box. The other will carry the connection cords and any other pieces of equipment we need. The third case will carry the seismometer.

Figure 4:
Left: Students placing a wooden cover over the seismometer to protect it from wind.
Right: Student packing holes beneath the cover with sand

As for data collection, we had two approaches. For the seismometer, we set up along the either of the two arms insight of a nearby road. We had one person in the van running the computer and two people on a hill watching the road. We would collect data for 30 minutes. During that time, the two people on the hill would take note of the different vehicles passing by and the time which they passed. While the person in the van made sure everything was running properly. For the magnetometer, we could not stay stationary. We were testing against a nearby power line to see how the electromagnetic field changes with distance. We set up close to the power line then move further and further away.

7 Data Analysis

7.1 Seismometer

After collecting the field data, we set out to analyze the data. Before we did any work to identify any transient noise, we perform a sanity test of sorts. We compared the data we collected against the data from the seismometers at the end stations. We did this via a spectrogram. This was because it would tell us when the different vehicles went by and if something were wrong, we could see went it happened. When we did this comparison, we observed correlation between the two, showing they were agreeing. However, there was an issue. On the spectrogram of the data we collected, there were data drop offs. The signal was so low that it got caught in the noise filter. This meant we would have to make a pre-amp for the WebDAQ to boost the signal by at least a factor of 10.

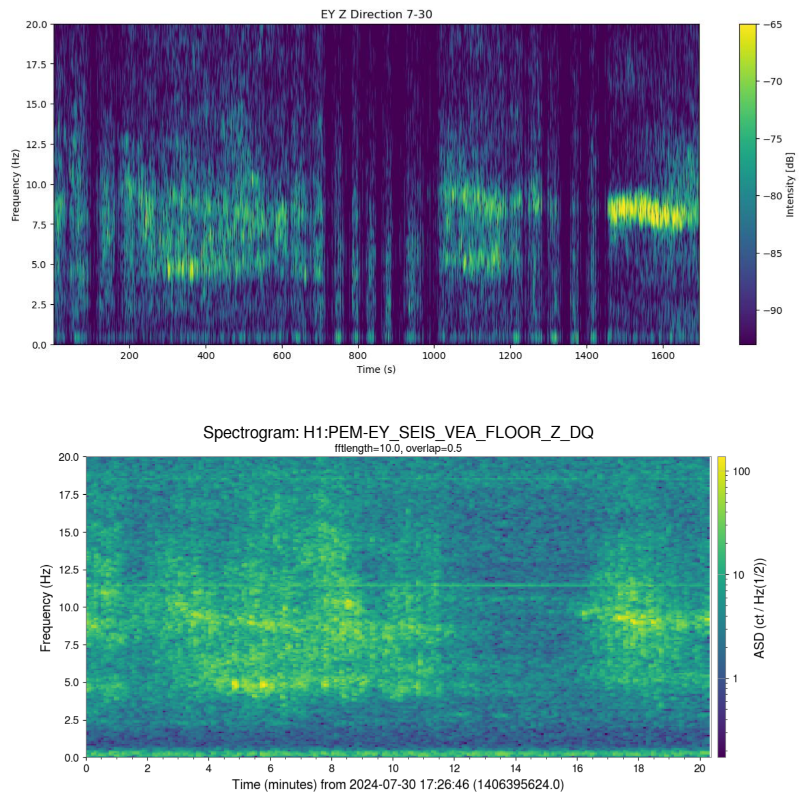

Figure 5:
Top: A spectrogram of the field data we collected with our seismometer via the WebDAQ
Middle: A spectrogram from the seismometer at End Y

Luckily, the Minimus has a pre-amp built into it, allowing us to continue testing while waiting for the pre-amp parts. However, when looking at the Minimus data we discovered another issue. The spectrogram showed electronic noise interference. This again, made the data unusable. We figured that the issue was due to the fact we were splitting the signal between the WebDAQ and the Minimus. So, I did a test where I ran the signal solely to the Minimus, then halfway through I connect the WebDAQ, if our theory is correct the signal should get noisy when I connect the two. Luckily, this is exactly what happened.

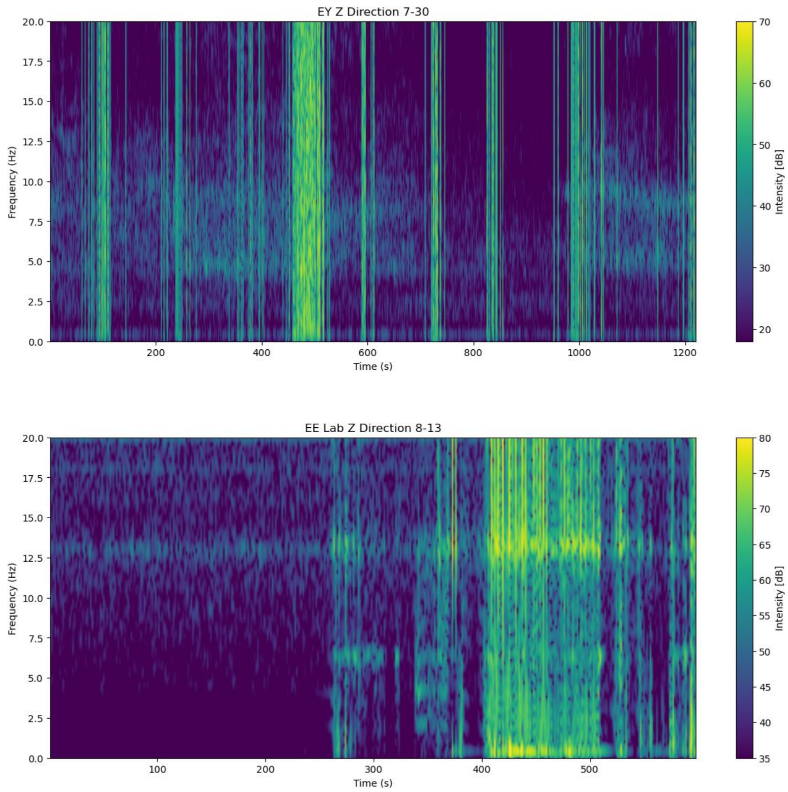

Figure 6:
Top: A spectrogram of the field data we collected with our seismometer via the Minimus
Bottom: A spectrogram showing of the results of the Minimus-WebDAQ test

Now that we got setup on the right track we had to perform a huddle test. A huddle test is where two or more seismometers are set next to each other. This is done to calibrate the seismometer to make sure it is reporting correct data. The reason we didn't do this sooner is because the calibration factor will change depending on the equipment in the system. Meaning a future huddle test will have to be done with the WebDAQ and its pre-amps. The reason we wanted to do it with the Minimus was as a proof of concept and the learn the process. I performed this test in the LVEA next to one of the seismometers in the vertex. Fortunately, there were no issues when administrating the huddle test.

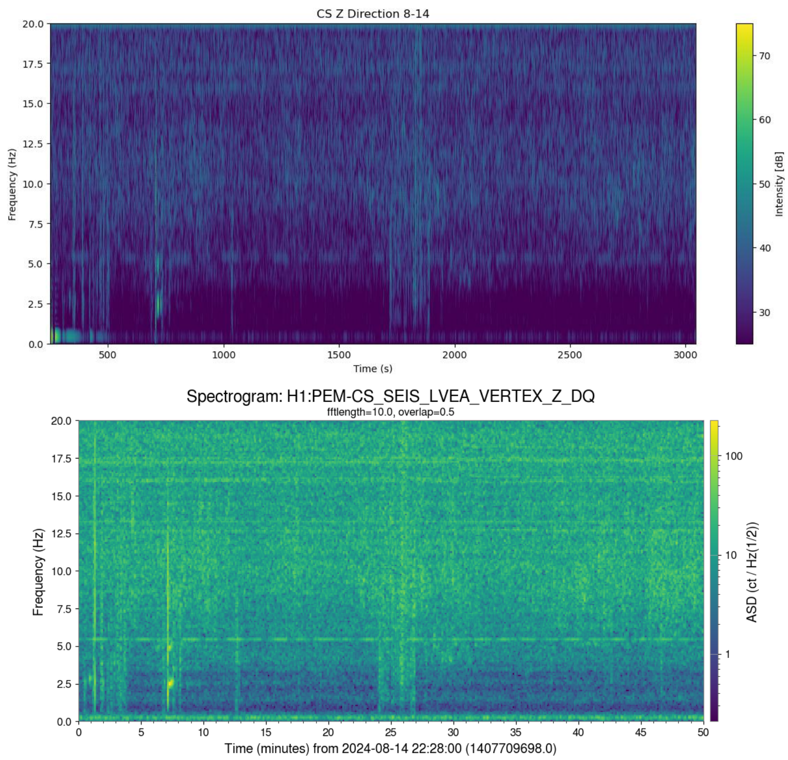

Figure 7:
Top: A spectrogram of the data we collected during the huddle test with our seismometer and Minimus
Bottom: A spectrogram of the data from the corner station seismometer

7.2 Magnetometer

For the magnetometer, the process went a lot smoother than with the seismometer. This is due to the fact that everything worked the first time. We didn't have any issues with the instrument, software, or hardware. The only thing of note we did was test the high pass filter. This eliminates the Earth's magnetic field from the data. There didn't seem to be any discrepancies on the y and z axes, but there was a noticeable difference on the x axis. This is definitely something that would have to be tested in the future. We will also have to calibrate the magnetometer in a similar process to the seismometer.

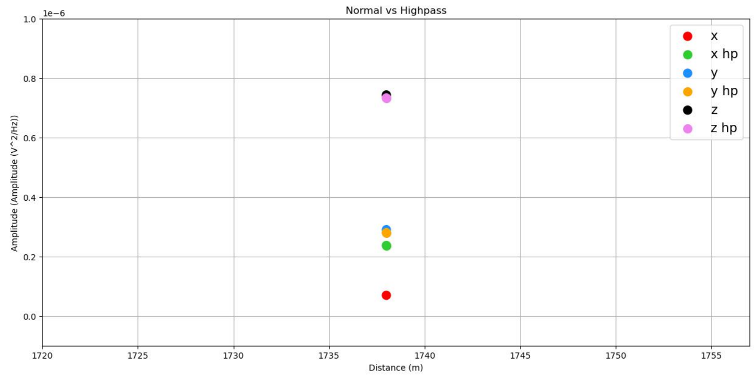

Figure 8:
A plot showing the difference from using and not using the high pass filter

8 Conclusion

The purpose of the project was to prepare instruments and a testing structure for future Cosmic Explore site surveying. In order to do that we had to become familiar with our instruments and their equipment, inside and out. We performed tests to learn their capabilities and limitations. We then set out to mend these limitations, be it hardware or software. After getting the instruments fully situated, we set out to do field test in order to learn how to identify transient and environmental noise. In addition, we learned what would be needed to transport and protect the equipment out in the field as well what other pieces of equipment could be used to make the process easier. Then, we learned the data analytical process. There we rectified more issues and smoothed the process. Through this process we have significantly reduce the learning curve of the site surveyors and solved a lot of the issues they would've faced in the field.