Searching for Dark Matter with Snipe Hunt Experiment

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Abstract

There are several theories proposed to explain the observed properties of dark matter, and for this research project, we look towards a theory of characterizing dark matter as axions, otherwise known as ultralight bosonic dark matter. Axions interact with the earth's magnetic field and create a distinct and measurable magnetic field oscillation in the 1Hz – 1kHz frequency range. Our research project, *The Search for Noninteracting Particles Experiment Hunt* (SNIPE Hunt), is an ongoing collaborative effort involving several universities across the globe. Our research team at Messiah University has been focusing on developing orders of magnitude higher sensitivity magnetometers. Our team focused mainly on calibration, noise sensitivity studies, and modeling of the performance of magnetometers. Current efforts are being made to limit input noise arising from ambient sources such as local power equipment.

Introduction

Dark matter axions propagate through space and interact with the ionosphere. This interaction creates a distinct magnetic field oscillation detectable in the 1Hz – 1kHz frequency ranges. Figure 1 shows a simulation of the motion of the ionosphere, useful in visualizing where the magnetic oscillations may congregate. Utilizing strategically placed magnetometers inscribed around the circumference of the earth, synchronized SNIPE Hunt collaborators will collect magnetic field sensitivity data. Location and time dependent readings are consolidated and compared against each other. From there, further data analysis is conducted to determine the significance of the field oscillations as it compares to the theoretical expectation.

The majority of the SNIPE Hunt experimental research teams, including our own, are focusing on data acquisition and instrumental efficiency. Our teams are iterating off previous results from the 2022 run. Figure 2 shows a selected plot of magnetic field sensitivity from the site at Oberlin College [1].

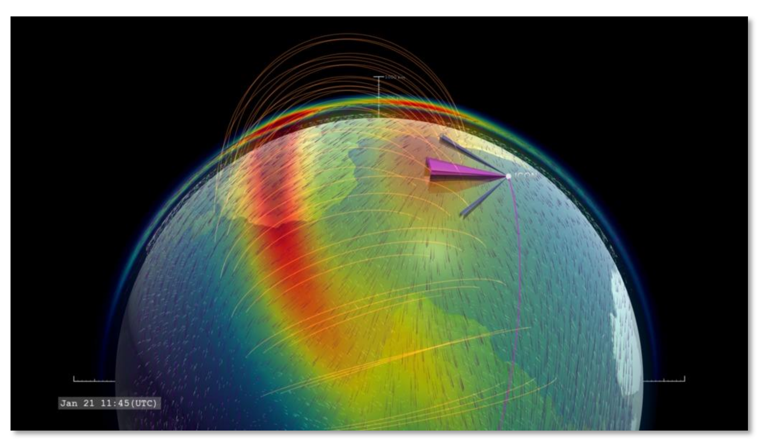

Figure 1: Image of Ionosphere Simulation

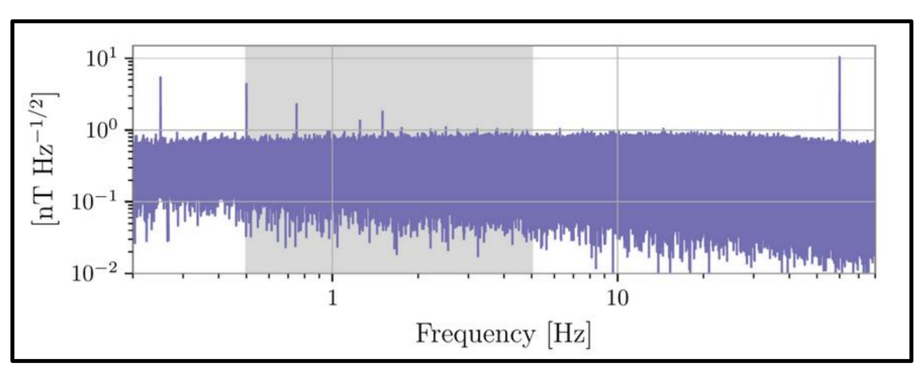

Figure 2: North-South Sensitivity Measurements of the Oberlin College Site

Approximately 3 days of data were recorded, and analysis from the resulting paper concluded several areas of contention:

- The data had too much noise
- The data was not sensitive enough

These issues were the main focal points that our research team looked to resolve over the past year. The following is the result of our collective efforts and refinement.

Experimental Method

The methods to make sensitive magnetic field measurements are the same that our teams used in the previous years. High loop count inductors measure ambient magnetic fields, and a current is sent through an amplifier(s). The amplifiers then send the signal to the DAQ board for data collection and then to the Raspberry PI for storage. [See Fig. 3]

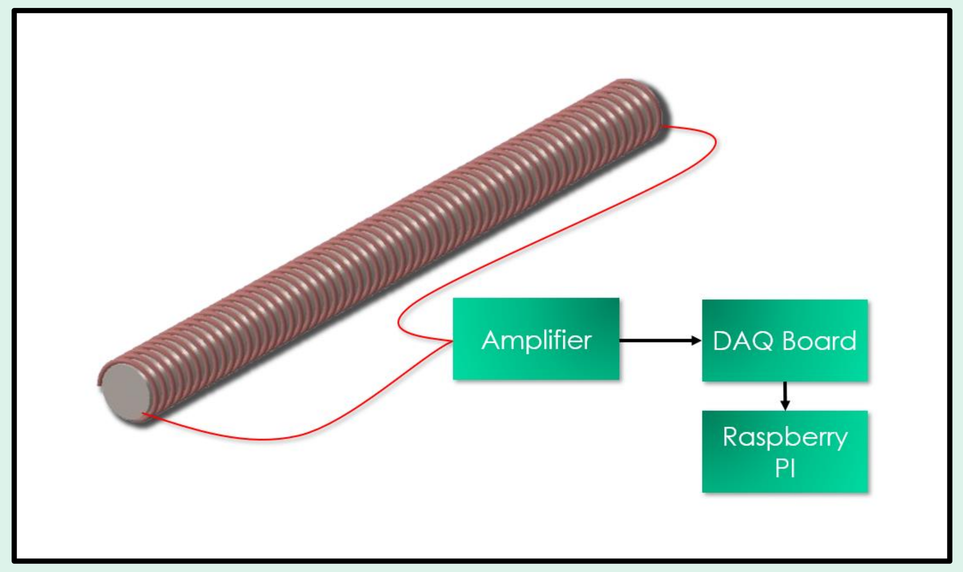

Figure 3: Simplified Diagram and Model of The Full Experimental Setup Used For Magnetic Field Measurements

Given the contentions previously mentioned, our team had to find ways to both lower noise and increase the sensitivity of our measurements. We looked at pieces of our setup to improve:

1. The coils. We ran a couple separate kinds of calibration testing to see how the coil responds to different magnetic fields of different frequencies. We built a large solenoid that the magnetometers could go inside of, to induce a nearly uniform magnetic field.

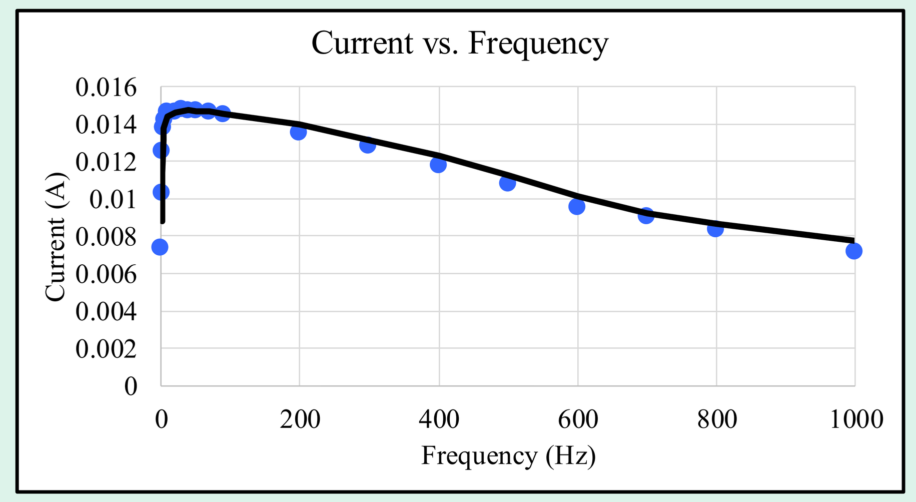

Figure 4: Data for calibrating the coil. Understanding current as a function of AC voltage frequency

2. The amplifiers. The kinds of amplifiers we use affects what kind of signal we get back. Transimpedance amplifiers are important for our use because of their flatter frequency response, in contrast with normal amplifiers, which could saturate our data because of resonance. One of the amplifiers used in our testing is the Thorlabs AMP 102 for its cleaner noise floor on low frequencies (1Hz-10Hz).

3. The location. The power lines in the United States use 60Hz AC which show up on our highly sensitive magnetic equipment. These power lines create peaks at every 60n Hz in our measurements. This is the reason why our 2022 tests were set up in the forest away from power lines. Using the coil like a metal detector and a map, we scouted out a location on campus that was close enough to our lab for convenient testing, and that was far away enough from the power lines to limit our signal noise. The chosen location for our testing was in the "back forty" on the campus, detailed in figure 5.

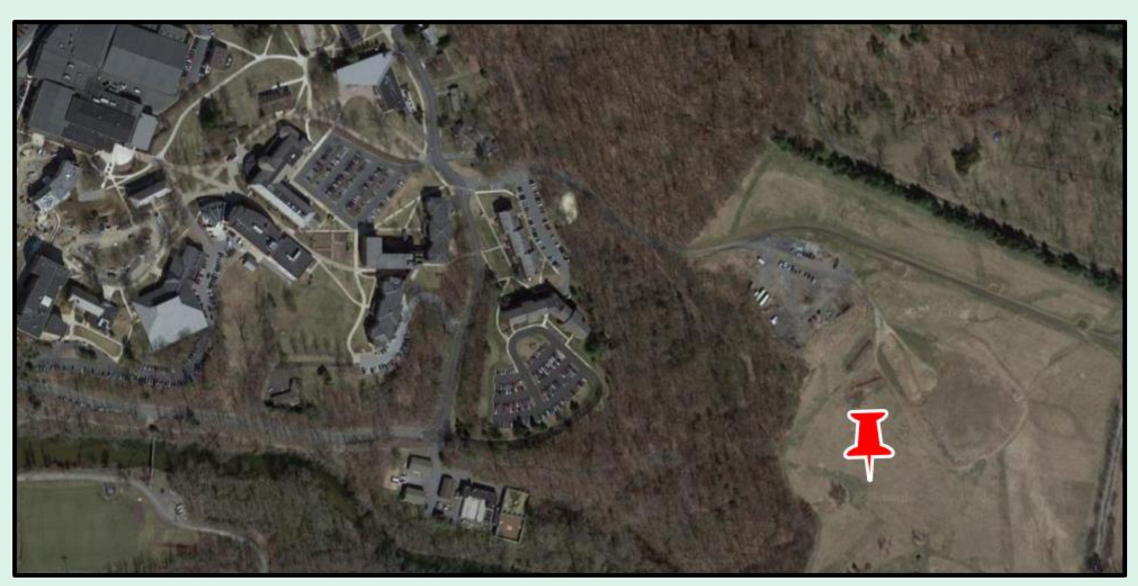

Figure 5: Satellite Image of Selected Testing Location Pinpointed With a Red Tack

Results/Discussion

On April 22nd, our team went to our designated area located in the "back forty" on the Messiah University campus where we set up our equipment using our updated procedure. We measured the current through the circuit and voltage response in the coil as a function of frequency over a period of 10 minutes. We found that we had much better sensitivity and a lower noise threshold for the circuitry, but still more progress needed. Our results show that our sensitivity above 10Hz is greatly improved, but between 1-10Hz, we need more sensitivity. Compared to our data from 2022, our sensitivity is improved by about a factor of 3 around the 1-10Hz range. Above 10Hz, our improvement is more noticeable. Unfortunately, we're looking to search in the 1-10Hz range, rather than the higher ranges. The noise was significantly improved as well because of our updated amplifier configuration. Comparing the signal data from the Oberlin site in 2022 to this, we see all these new improvements. With all of the updated equipment and polished data to back it up, we look forward now to doing a longer coordinated Science Run with the other teams like the one in 2022.

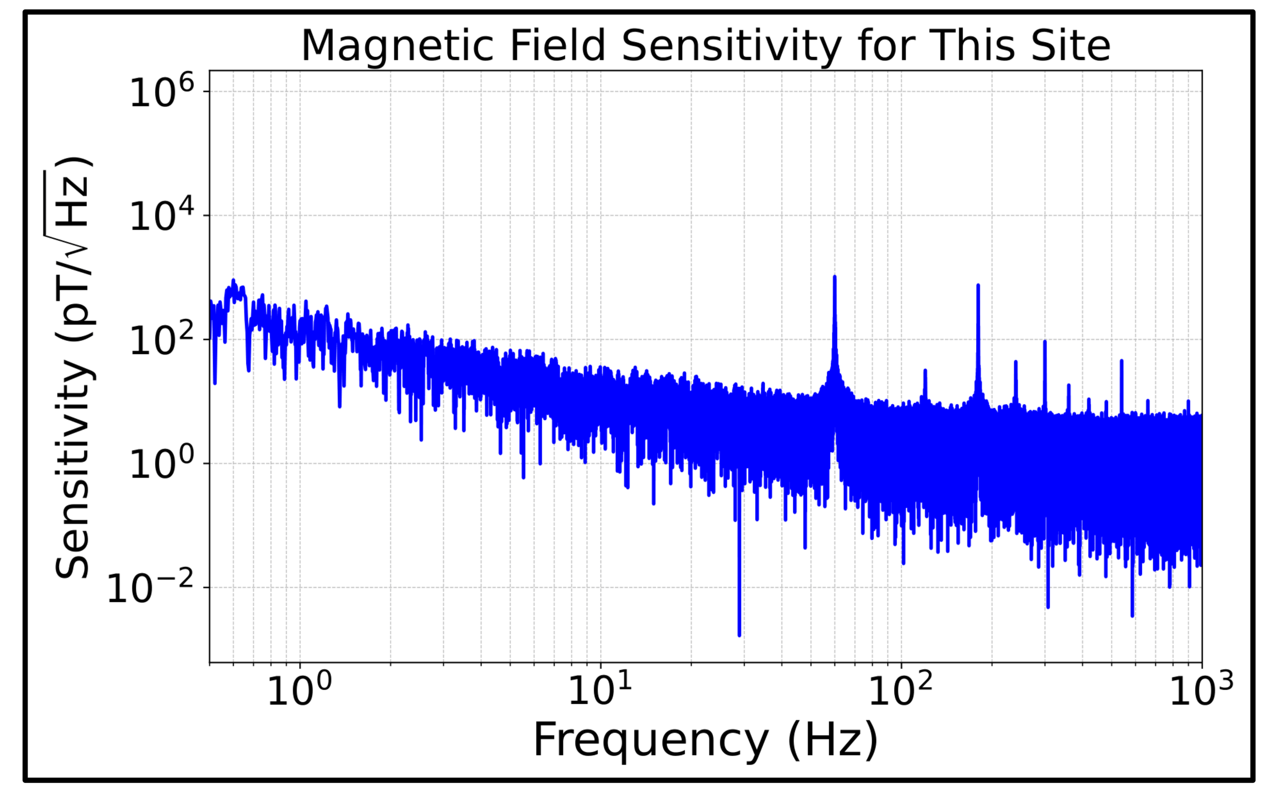

Figure 6: Back 40 10-Minute Field Sensitivity Data

Conclusions

Using our new techniques and equipment, we were able to improve our previous sensitivity results by a factor of ~ 3 with more prominent low-end frequency data and significantly reduced noise output in our measurements. Considering this, our research team is planning to coordinate with the other experimental teams and perform another synchronized run this summer.

Acknowledgments

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References

[1] Sulai, I.A., Kalia, S., Arza, A., Bloch, I.M., Muñoz, E.C., Fabian, C., Fedderke, M.A., Forseth, M., Garthwaite, B., Graham, P.W., Griffith, W., Helgren, E., Interiano-Alvarado, A., Karki, B., Kryemadhi, A., Li, A., Nikfar, E., Stalnaker, J.E., Wang, Y., Kimball, D.F.J. (2023). A Hunt for Magnetic Signatures of Hidden-Photon and Axion Dark Matter in the Wilderness. arXiv preprint arXiv:2306.11575.