Advanced Lab Project Proposal: The Red Line Noise Curve

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We propose an experiment to characterize the seismic noise induced by the Chicago Transit Authority light rail trains which pass by the Lake Shore Campus of Loyola University Chicago. We discuss the motivation for such a measurement, a brief literature review, a timeline for construction and investigation of the experiment, the methods for collecting and processing data, and the potential utility of products generated by this work.

I. MOTIVATION

The physics department of Loyola University Chicago (LUC), located in Cudahy Science Hall (CSH), has no working astronomical telescope installed in the dome which sits atop the building. From conversation with faculty in the department[4], we have learned that this is in part due to the vibrations from the nearby Chicago Transit Authority (CTA) train line. Specifically, this vibrational noise would constantly throw off the delicate calibration required for imaging of distant bodies unless an additional, expensive suspension system was installed to mitigate it. Having access to hands on learning with astronomical equipment and observations would provide a deeper learning experience for the undergraduate students at LUC, so working towards the future installation of such a telescope would potentially be beneficial to the department.

As such, we are motivated to begin the first step towards this end goal, which is to create a detailed characterization of the vibrational noise present in CSH. We plan to construct three separate, GPS enabled, vibration detectors around the Arduino Uno R4 Wifi microcontroller in order to create a frequency dependent noise plot from spatially separated probes. It is important to note that this characterization is our primary goal for this work and that we do not claim to currently be able to implement our findings into the installation of any telescope in CSH. However, we will suggest in this proposal potential future prospects for the data and instruments created.

II. BACKGROUND

Measurement of the vibrational noise from CTA trains is not a new concept. A quick internet search for "chicago transit authority vibration measurements" provides listings of different memorandums on the environmental effects via noise and vibration, specifically for their Red Line trains. In particular, we consider Appendix D-5 of the Red-Purple Bypass Project Environmental Assessment[1], as it provides a relatively recent, distance dependent measurement of the vibrational noise when CTA trains are passing by. In summary, table 4-4 of reference 1 shows that at 12.5 Hz, the vibration velocity level ($L_{v,Max}$) ranges from 55 VdB at 300 feet from the source, to 72 VdB at 25 feet from the source. Per the Metropolitan Council, "The threshold of human perception to LRT and freight rail vibration is approximately 65 VdB" (Ref. 3), suggesting that more sensitive devices (like a finely tuned telescope) will "feel" the effects of a CTA train passing by at 300 feet and beyond. Additionally, the CTA claims on page 138 (C-4) of Reference 1 is less than 50 VdB. This implies that, in principle, we should be able to a difference in ground vibrational noise when trains pass by compared with a standard background level.

Component	Amount	Estimated Price
Arduino Uno R4 Wifi	3	$82.50
Arduino Ethernet Shield 2	3	$89.40
Arduino MKR GPS Shield	3	$123.90
SW 420 Motion Sensor	5	$5.88
DFR0027 Vibration Sensor	3	$15.24
D7S-A0001 Vibration Sensor	3	$64.52
Micro SD Card (64 GB)	3	$29.99
Total (Retail)	N/A	$411.43
Total (actual)	N/A	$239.53

TABLE I. Price summary for required components of the experiment.

III. DESIGN

Our group will design and construct three seismic sensors based around the Arduino Uno R4 Wifi microcontroller. These are our processors of choice because they have been supplied by LUC. We intend to use these combined with the Arduino Ethernet Shield 2 (also provided by LUC) for the additional storage it provides, and the Arduino MKR GPS Shield for recording accurate time and location data. We will also need both a rechargeable battery for each setup and some type of (likely 3D printed) protective case for each detector. Our group does not yet have a vibration sensor of choice, so we intend to purchase multiple options and compare them for best performance. Current options for these will be detailed in table I along with the rest of the required components.

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IV. METHODS

The completed detectors will be placed at three separate locations, with varying distances to the CTA train line near Loyola's Lake Shore Campus (LSC). Our current choices for these locations are; adjacent to the train line, inside the dome of CSH, and a location roughly halfway between these (perhaps inside of the Damen Student Center). Then, they will simultaneously record their location, time, and vibration sensor data to the SD card installed in the Ethernet Shield 2. We currently choose an offline recording method due to its simplicity and reliability, although in principle this data could be recorded to a computer offsite. We will also manually note the times that trains pass by the Loyola Red Line stop, so that we can more easily flag both "background" noise and train induced noise in our analysis. This data will be recorded over the course of multiple days to provide sufficient data for power spectral density (PSD) estimation. This also allows for us to compare the noise level during school days and weekends, potentially allowing for the cancellation of the added vibrations from foot traffic.

Once this data is collected, we will clean and align the vibration data along the time axis in Python. Then, we will use the Welch method included in the Python package SciPy[5] to compute an estimate of the PSD for each detector from the time series data. We describe the utility of such a PSD and Welch's method for its estimation below.

A PSD plot, in plain terms, describes the strength of some signal in terms of its frequency components. In signal analysis, these facilitate the recognition of resonant or dominant modes in a signal, which is especially useful for analysis of noise signals. One example of a PSD plot is the noise budget plots for the LIGO detectors in its fourth observing run[2], shown in figure 1. Here, any signal at a given frequency is detectable if it its strain is larger than the corresponding value on the noise plot. Displaying the detector noise in this frequency dependent way allows for easy, intuitive understandings of the areas where each detector will perform better or worse in.

In a similar way, we plan to use a PSD plot to analyze the dominant parts of the seismic noise signal at the LSC. These will be calculated, as stated above, through the `scipy.signal.welch` function included in the SciPy Python library. This function takes a time series signal and breaks it up into overlapping segments, to which it applies a window function. Then, it computes the magnitude squared of the discrete Fourier transform of each segment, normalizing by the width of the segment. These results are then averaged to estimate the power density at each frequency, producing a PSD plot. For a more detailed explanation, see the original paper in reference [6].

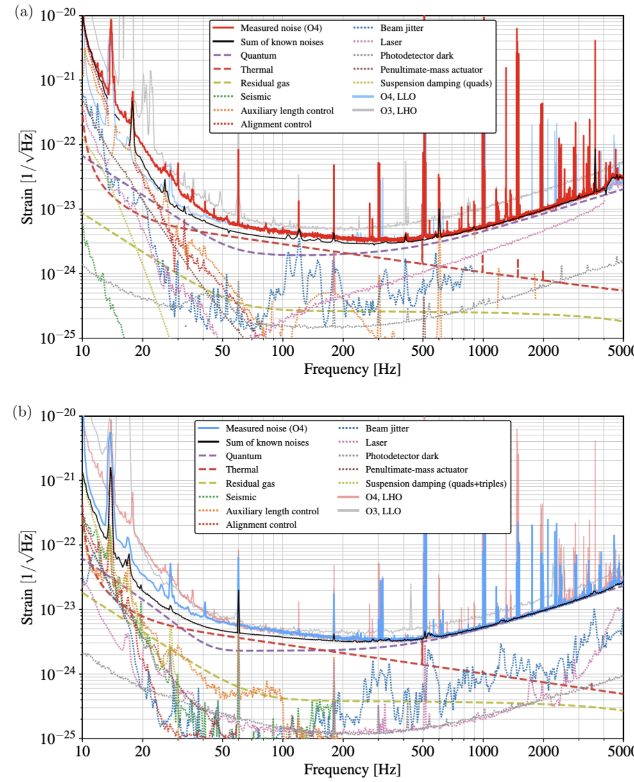

FIG. 1. The noise budget for the LIGO Livingston (lower) and LIGO Hanford (upper) detectors for the fourth observing run. Taken from reference [2].

V. PROJECT TIMELINE

Our group plans to spend the first two to four weeks conducting a more extensive literature review of experiments which measure seismic activity using microcontrollers similar to the Arduino boards we will employ. At the same time and guided by the things we learn, we also plan to spend this time making final designs for the detectors themselves and constructing them, although this could take as long as six weeks depending on what difficulties come up and how testing the vibration sensors goes. This process will include calibration of the sensors themselves and the development of software to collect and extract the data from the detectors. Once the development stage of the project is complete, we can almost immediately begin collecting data and performing analysis. These battery powered detectors will be largely hands-off while running, so we expect to collect a large amount of data from this experimental run.

Once we have collected our data and created the corresponding PSDs, we plan to prepare our results and instruments for future use by LUC. Specifically, we see potential value in the use of this data to train a machine learning model to predict the noise pattern in CSH given the locations of CTA trains nearby. This could then, in principle, inform the design of a future telescope suspension system to make it more cost effective. Even in absence of future construction inspired by this work, we see value in the spectral characterization of the CTA train vibrational noise as, to our knowledge, no such information exists or is publicly accessible.

VI. CONCLUSIONS

We have proposed a short term experiment, with potential for continuation, which aims to characterize the seismic noise generated by the CTA trains that pass by Loyola's LSC. This project is motivated by previous issues this seismic noise has caused, as well as the CTA's determination that the vibrations are detectable 300 feet away from the source. We have also detailed the design of the detectors based around Arduino Uno R4 Wifi boards, with the associated cost of all required components. Finally, we briefly defined the key data products to be generated, our methods for doing so, and the expected timeline for the project to be completed on with potential future use cases noted.

[1] Chicago Transit Authority. Red-purple bypass project: Noise and vibration technical memorandum. Technical report, Chicago Transit Authority, 2015.

[2] E. Capote et al. Advanced ligo detector performance in the fourth observing run. *Phys. Rev. D*, 111:062002, Mar 2025.

[3] Metropolitan Council. Vibration fact sheet, 2015. Accessed on January 21, 2026.

[4] Loyola Physics Department. Conversation with professor. In-person Conversation, 2025. Personal Communication.

[5] Pauli Virtanen et al. SciPy 1.0: Fundamental Algorithms for Scientific Computing in Python. *Nature Methods*, 17:261–272, 2020.

[6] P. Welch. The use of fast fourier transform for the estimation of power spectra: A method based on time averaging over short, modified periodograms. *IEEE Transactions on Audio and Electroacoustics*, 15(2):70–73, 1967.