LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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Seismic Cloaking for LIGO

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1 Introduction

Laser Interferometer Gravitational-Wave Observatory (LIGO) is an observatory with locations in Hanford, WA, and Livingston, LA, with the goal of developing gravitational wave (GW) astrophysics through the detection of cosmic GW. LIGO works with a laser interferometer system. A laser enters the system and is split into two parts, which each go down one of the two 4km long arms (separated by 90 degrees). If a merger event occurs, spacetime is slightly altered, and one of the two beams is out of phase with the other. When the two beams recombine, they form an interference pattern [1]. LIGO was originally expected to detect mainly neutron star-neutron star (NS-NS) mergers, as binary black hole (BBH) mergers were thought to be more difficult to detect. However, of the six detections that LIGO has so far achieved, only one, GW170817, was of a NS-NS merger, while the others have all been BBH mergers.

Seismic noise is a persistent issue for highly precise interferometers, such as gravitational wave detectors. Natural causes of seismic waves are mostly ocean waves and wind, while artificial causes are usually traffic and construction [2]. This noise can affect GW detectors by artificially shaking the arms of the detector, causing false signals. Seismic waves can propagate in all directions, and at different velocities and frequencies, making detecting legitimate signals difficult. Seismic noise comes in at 20 Hz and below, while supermassive black holes (SMBH) and binary neutron stars (BNS) also spend time in the 10-20 Hz band. SMBH produce 10-20 Hz signals when merging and BNS spend a lot of time in the same 10-20 Hz band. Lowering noise in that band will allow for clearer detection of signals for SMBH and earlier detection of BNS and the ability to point telescopes at BNS mergers before they happen. Implementing seismic cloaking can allow seismic noise to pass by instrumentation without affecting it, enabling better accuracy in signal detection.

This project aims to see if trees can be used as natural seismic metamaterials to reduce seismic noise. Columbi et al (2015) [3] theorized that resonance in forests could be used to attenuate seismic waves. This project will combine theoretical and experimental work by modeling how seismic waves are affected by forests, and measuring different types of trees to discover resonant frequencies. The goal of this project is to determine if planting trees around the LIGO-Livingston detector will be an effective method of seismic cloaking, and hopefully explore what types of trees or cacti could be used at LIGO-Hanford.

2 Methods

Much of this project depends on verifying the results of the Columbi paper (2015). Columbi found with experimental and numerical methods that forests could be modeled as locally vertically resonant metamaterials.

2.1 Theoretical Work

The focus of the theoretical work will be to understand how seismic waves transfer energy into trees. Since trees have their own resonant frequencies, we will first model them as simple harmonic oscillators and then progress to more complex models. As an introduction, we will understand seismic waves in one dimension. We will model the simple harmonic oscillator in python, then link together multiple oscillators to model individual trees as a forest. Modeling seismic waves as one-dimensional while varying the spacing, Q factor, resonance, etc. of the trees will allow us to determine how these parameters affect cloaking. This will help us understand how reflection and transmission works with metamaterials. COMSOL will then be used for multi-dimensional analysis of seismic waves, which will allow for more precise work.

2.2 Experimental Work

The experimental part of the project will be measuring how trees can affect seismic noise. This can be done in a few ways. Seismometers can be used to measure waves propagating along the ground or in trees, or vibrometers could be attached to multiple points in the tree to determine resonant frequencies. While travel to LIGO-Livingston or LIGO-Hanford is unlikely for this project, the Los Angeles County Arboretum has a large diversity of plant species and could be used to measure the different types of trees. This location would require a portable data logger for vibrometers. The goal of the experimental work is to confirm the theoretical work and begin a plan for how to use trees as seismic metamaterials.

3 Schedule

Below is a rough schedule of the project.

Before Arriving

Gain familiarity with software tools (Python and COMSOL) and background of seismic waves and metamaterials. Determine what type of experimental measurements to take and order measurement tools.

Weeks 1-2

Model one-dimensional waves and understand the parameters affecting cloaking. Once measurement tools have arrived, begin setting up how measurements will be taken.

Weeks 3-4

Build a COMSOL model to begin making predictions for trees near LIGO-Livingston. Begin measuring trees around Caltech. Identify sites to compare between environments with and without trees.

Weeks 5-6

Travel to sites to make comparisons on the effects of cloaking on the ground. Continue to measure the resonances of the trees and compare to the COMSOL modeling.

Weeks 7-8

Continue measuring trees and modeling seismic waves to understand how they affect each other. Continue iterating the measurements and modeling until they are well-tuned.

Weeks 9-10

Combine theoretical and experimental work to make a recommendation on whether trees can feasibly used as seismic metamaterials for the LIGO detectors.

References

[1] "About — LIGO Lab — Caltech."

[2] Stanford Exploration Project, "What is seismic noise ?," 2005.

[3] A. Colombi, P. Roux, S. Guenneau, P. Gueguen, and R. V. Craster, "Forests as a natural seismic metamaterial: Rayleigh wave bandgaps induced by local resonances," *Scientific reports*, vol. 6, p. 19238, 2016.