# Developing a Sensor Array and Applying Seismic Localization to Determine the Source of 4.2 and 15 Hz Features at LLO

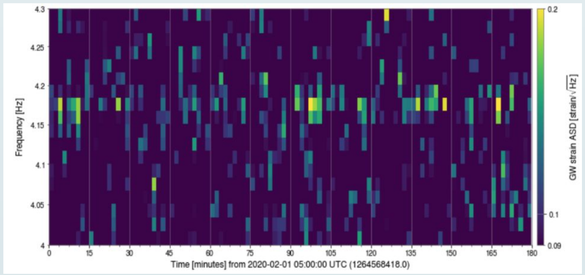
Priti Rangnekar
Stanford LIGO Group
DCC G2101868

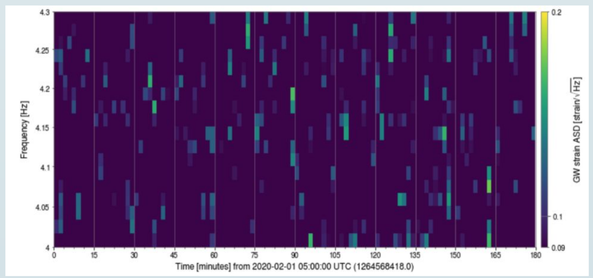
## Abstract

We have identified two low-frequency features present at LIGO Livingston Observatory. We have first applied detector characterization techniques to understand the feature's frequency and amplitude over time, as well as its relative prominence at different parts of the detector. In this current research project, we create our own array of L-22 3-component sensors and dataloggers for use at the LIGO Livingston site. In addition, we apply seismic localization methods, such as beamforming, and transfer functions to identify the directionality of the feature.

## Introduction

Spectrograms for the BRS_ITMX_Y (top) and BRS_ITMY_X (bottom) channels show that the 4.164 Hz feature is only observed in the ITMX_Y channel. Thus, we are led to believe it is caused by a Rayleigh wave moving in the x-direction, which aligns with an oil pipeline underground at the site.



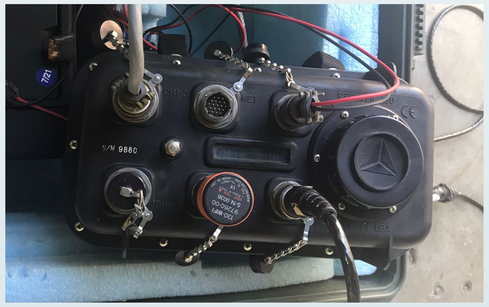




## Sensor Array

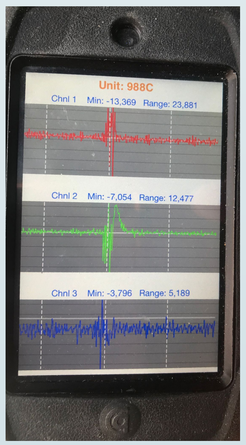
**Overall Setup**
15 stations located across the Livingston site (4.2 Hz) or only at the corner stations (15 Hz)
- 1 RefTek 130 data logger (left)
- 1 L22 3-component sensor (right)
- 200 samples per second


**Supplemental Equipment**
- Power for data logger
  - 12 V. car battery and car battery charger
  - Solar panel
- Garmin GPS for data logger
  - Supplied by PASCAL
- WiFi adapter for use with data logger iFSC app on iPod Touch

Setup of data logger with connections to supplemental equipment (below)



**Data Analysis**
- Completed through PASSCAL's PASSOFT software package - NEO
- Allows for comprehensive waveform analysis
- Real-Time Monitoring - sample stomp test at Stanford (right)
  - Shows higher amplitude on all 3 L22 channels



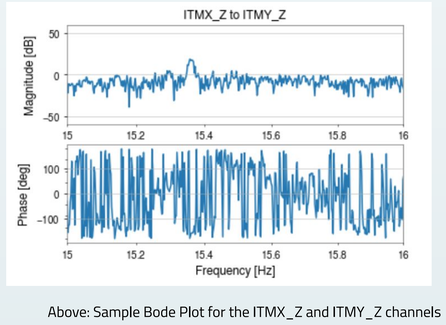

**Logistics**
- Setup will be done in Winter 2021 or Spring 2022
- Will require weekly or bi-weekly check-ins to switch Compact Flashes for data collection
- Locate the data logger deployment box and L22 in appropriate locations
  - Louisiana soil and rain

## Seismic Localization

**Generating Transfer Functions**
- Allows for investigating how a signal transfers between one sensor/channel on the interferometer and another
- Methodology
  a. Choose time in which feature(s) are prominent
  b. Acquire time series
  c. Calculate transfer function - output over input
     - Repeated for all combinations - STS_ITMX_Z, STS_ITMY_Z, STS_HAM5_Z
  d. Make Bode Plot for magnitude and phase

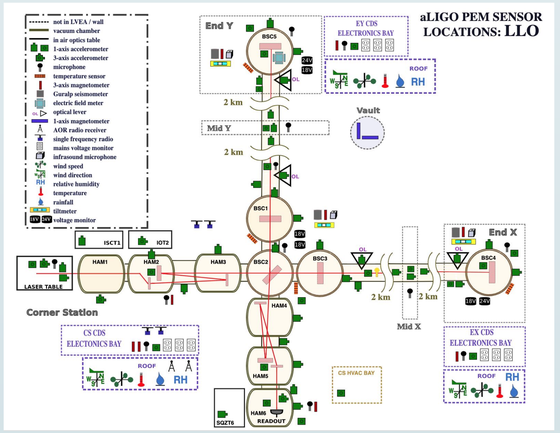
```
csdData = ch1.csd(ch2, fftlength=450, overlap=225, window='hann')
ch2psd = ch2.psd(fftlength=450, overlap=225, window='hann')
txfr = csdData / ch2psd
```

Above: Code for transfer function calculation in gwpy




Above: Sample Bode Plot for the ITMX_Z and ITMY_Z channels

**Ascertaining the Time Difference Between Channels**
- Get transfer function value corresponding to a particular frequency using indexing
- Convert the complex number to a phase
  a. +/- possibilities -> 2 possible answers for time difference
- Using the phases for various transfer function combinations for all of the channels, possible to find the time difference
  a. Find relative distances and locations of channels of interest through the PEM Channel Info or LLO Interferometer Map in SolidWorks




## Conclusion and Further Steps

**Sensor Array Setup at Stanford University**
- Conclusions
  - Current setup with data logger, sensor, GPS, solar panel, and car battery is functional
- Next Steps
  - Acquire data on compact flash and visualize it on a computer

**Seismic Localization**
- Check for consistency of transfer function at various times when the features are dominant
- Acquire phase values for more transfer functions, in both 4.2 Hz and 15 Hz cases
  - 15 Hz feature - focus on microphones, which detect the feature as a sound wave (benefit of knowing the wave speed)
- Work on localization using phase values and distances between channels

**Sensor Array Usage at LLO**
- Largely dependent on situation at LLO regarding weather and COVID-19
- Next Steps
  - Decide on exact location of the 15 stations (to be influenced by seismic localization analysis)

## Acknowledgements

LSC LIGO Scientific Collaboration

LIGO

NSF

Dr. Beverly Berger
Dr. Brian Lantz
Stanford LIGO Group
UBC LIGO Group
LIGO Seismic Group
Arnaud Pele
Michael Ross
PASSCAL Instrument Center