Noise Line Searches for LIGO S6

Michael Coughlin, Carleton College
for the LIGO Scientific Collaboration and VIRGO Collaboration

Introduction

The general theory of relativity predicts that all accelerating massive objects produce gravitational waves. These gravity waves should be detectable, for example, when very massive objects such as black holes undergo acceleration. Their direct observation would both validate Einstein's theory and lead to new areas of cosmology. LIGO (the Laser Interferometer Gravitational-Wave Observatory) is one of the handful of detectors searching for gravity waves.

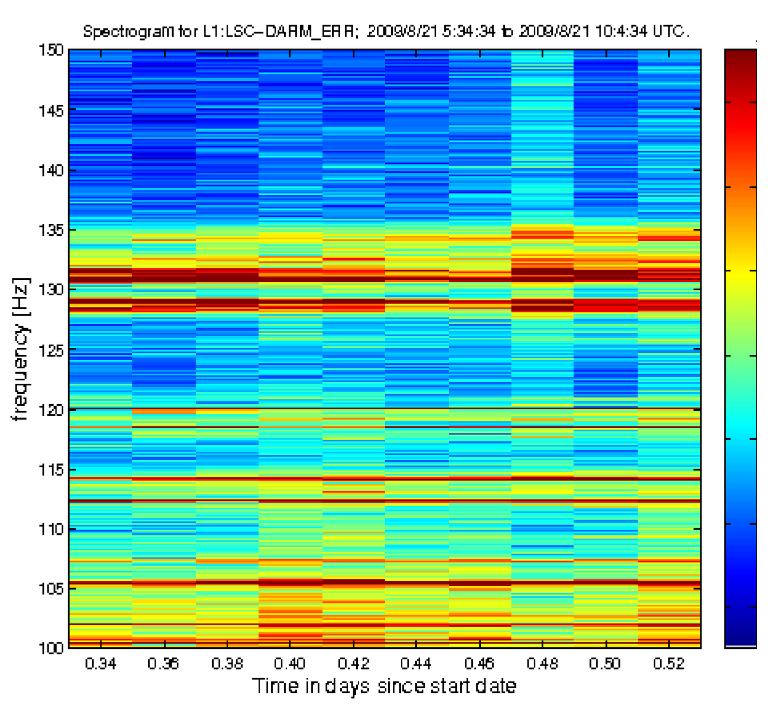
The interferometers at Hanford, Washington (LHO) and Livingston, Louisiana (LLO) each have perpendicular arms with light travelling down each of them. When a gravity wave passes through the detector, one arm should lengthen and one should contract by a very small amount. The difficulty arises from the fact that not only gravity waves but also other natural phenomena such as magnetic fields and ground tremors can mask these deviations.

The main goal of this project is to determine at what frequencies the data coming into the detectors can be considered "safe." We analyze the data from the gravitational wave channel, LSC_DARM_ERR (**L**ength **Sensing** and **C**ontrol - **D**ifferential **Arm Err**or) and the other sensors searching for noise caused by the environment, looking for sharp spectral lines at which there is a coincidence and thus try to determine the cause of significant lines in LSC_DARM_ERR.

Background

• The LSC Continuous Wave Group has developed a program (Named Fscan) which takes raw data from all of the sensors and Fourier Transforms (FT) the data, reducing it into its frequency components. In this process, each frequency is assigned an "Fscan Power" based on how strongly and how often it appears in the data.

1.)



2.)

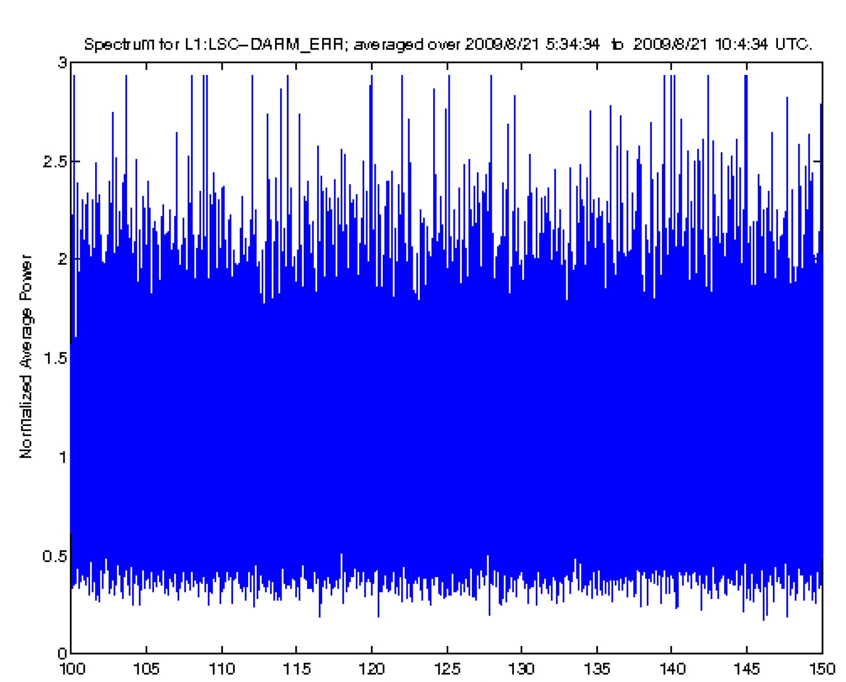


Figure 1: A spectogram based on the data from the FT's. The colors correspond to the Fscan Power associated with each frequency over the given time interval.
Figure 2: A spectrum plot based on the average Fscan power for the given frequencies over the course of the entire day.

Cutting Data

Our task is to read in the results of Fscan and search for significant lines that appear. We first remove all of the lines whose sources are known, including calibration lines, violin mode, power line and harmonics.

Line Searching

Based on the number of frequencies that would remain after cutting, we determined that analyzing frequencies with Fscan Powers greater than 3 and 4, with coincidence windows of .1, .01, and .001 Hz would be the most beneficial.

Channel Names	Power Threshold: 3 Coincidence Window: .001	Power Threshold: 3 Coincidence Window: .01	Power Threshold: 3 Coincidence Window: .1
H1_LSC-DARM_ERR	177 / 177	177 / 177	177 / 177
H0_PEM-BSC10_MAGZ	0 / 177	5 / 177	7 / 177
H0_PEM-BSC9_MAGZ	1 / 177	4 / 177	6 / 177

Figure 4: A sample table containing some of the coincidence statistics produced for each channel analyzed. For example, the bottom right statistic corresponds to the comparison between H1_LSC-DARM_ERR and H0_PEM-BSC9_MAGZ after both of the data sets have had any lines below a Fscan Power of 3 removed. H0_PEM-BSC9_MAGZ is a magnetometer attached to a vacuum chamber housing one of the suspended mirrors. The program then checks for how many of the significant H1_LSC-DARM_ERR lines there is a significant H0_PEM-BSC9_MAGZ frequency within a .1 Hz window.

After we compare a channel's lines with DARM_ERR's, we develop a page checking for lines that have come up as significant that day and compare it to the significant lines of yesterday for that channel, in an effort to determine when something new and interesting has arisen in that channel. We again use coincidence windows of .1, .01, and .001 Hz for comparison.

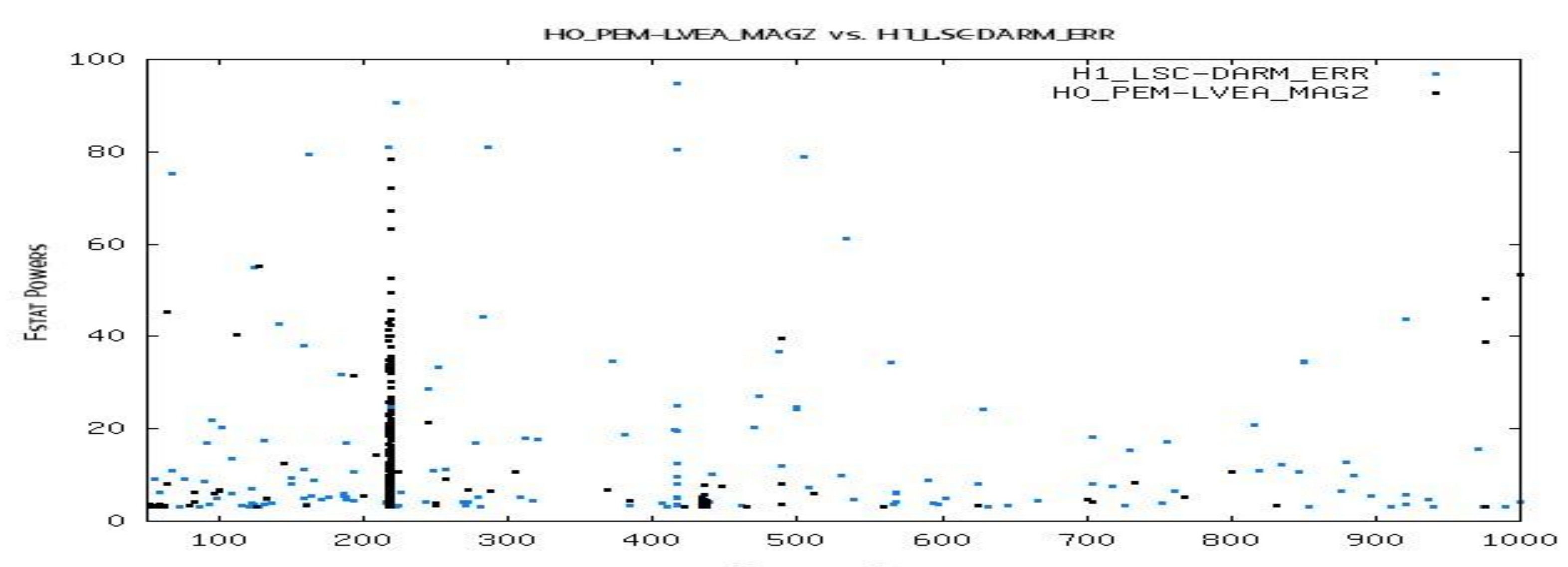


Figure 5: A graph plotting the significant lines and their corresponding Fscan powers for H1_LSC-DARM_ERR and a environmental monitoring channel (in this case, a magnetometer).

Finding the Source of the Lines

In an attempt to determine where the significant lines in the LSC_DARM_ERR channel are coming from, we keep track of the data that has been produced over the last seven days. If a line in LSC_DARM_ERR has come up as significant every day over the past week, it goes into a table, along with the number of times that line appears in all of the other channels over the past week.

LLO, LHO, and Virgo Comparisons

Fscans for LHO, LLO, and Virgo h(t) data are made daily, weekly, and monthly. There are now comparisons of significant lines among the sites. We will continue to monitor the lines that show up as significant at all three sites as these have the greatest potential for disrupting the gravity wave search.

Coherence and Other Line Finding Methods

Our coherence code calculates the coherence between the gravitational wave channel and all the available channels in the reduced data set (RDS) using a python program called pycoh. A followup code then parses the information to help human investigation. It first clusters lines above a predetermined threshold to find significant lines so as to capture wide structures. It then finds coincident channels for each significant line, where coincidence is defined as any overlap between clustered lines between a pair of channels.

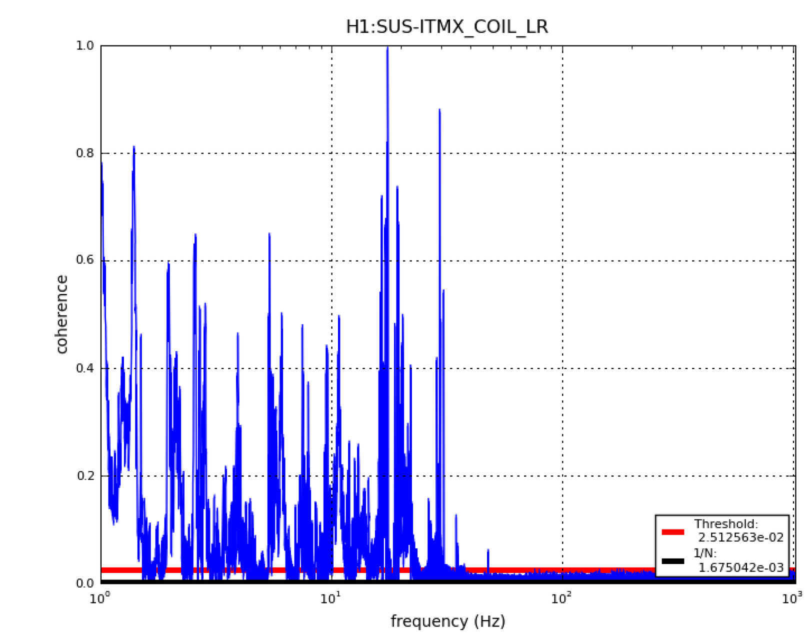


Figure 5: A plot of the coherence vs. frequency for an example channel.

In general, when searching for a line, we first look at the comparisons between the H1/L1/Virgo data for significant lines. If we see an unidentified significant line in coincidence among any combination of two or all three detectors, we can turn around and search the Fscans for the environmental channels at LHO and LLO in an attempt to find the source of the lines. There are a few other methods we use in our line search. First of all, LIGO's Continous Waves Group reports lines from search pipelines, such as PowerFlux and Einstein@Home, that are contaminating those searches and need identification. For troublesome frequencies like these, we create wiki pages, modifiable by all members of LIGO, containing information such as environmental channels that Fscan and other methods see in coincidence with that line. We also compare lines seen in Fscan with Coherence. When lines in coherence are seen for a specific environmental channel, Fscan is used to search not only that channel for those lines but other related channels, which can give us an idea of the cause of the line. Recently, a database containing both Fscan and Coherence lines was introduced for ease of comparing the line search methods.

Future Work

The most pressing goal to be accomplished in the near future is to identify the source of the many unidentified lines. A related goal is to begin finding significant lines in the spectograms and make it possible to identify "wandering lines," which are lines which move between frequencies over the course of a day. With the current method, these frequencies get washed out due to the averaging technique.

References

"All-Sky LIGO Search for Periodic Gravitational Waves in the Early Fifth-Science-Run Data", B. Abbott *et al.* (LIGO Scientific Collaboration), Physical Review Letters **102** 111102 (2009).

"LSC-Virgo White Paper", LIGO Scientific Collaboration and Virgo Collaboration. https://dcc.ligo.org/public/0004/T0900389/001/main09Public.pdf

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coughlim@carleton.edu