Study of Non-linear Seismic Noise and Wind in the first Advanced LIGO Observing Run

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Abstract

The Laser Interferometer Gravitational-Wave Observatory (LIGO), is an instrument designed to detect gravitational waves from various astrophysical sources in the Universe. On September 14, 2015, for the first time in history, the Advanced LIGO detectors directly observed a gravitational wave signal (GW150914) [1]. A second gravitational wave signal (GW151226) was detected on December 26, 2015, paving the way for a new era of gravitational-wave astronomy [2]. Commissioning efforts in characterizing noise and improving strain sensitivity will allow LIGO to further enhance its detection range [3]. This enhancement will enable LIGO to detect gravitational waves at a higher rate, from smaller mass sources, and deeper into the Universe. One of the major challenges in enhancing LIGO's sensitivity consists of eliminating or isolating sources of noise, both environmental and instrumental. Wind is investigated in this study as a potential source of non-linear seismic noise during the first observing run. Possible correlations were observed between high winds and elevated noise in LIGO's Alignment Sensing and Control channels. These correlations are to be further investigated.

Introduction

Gravitational waves were first predicted in 1916 by Albert Einstein, stemming from his theory of General Relativity. Such sources include but are not limited to: a pair of coalescing black holes, a pair of coalescing neutron stars, and core-collapse supernovae. Due to their small amplitude, detecting gravitational waves requires instrumentation of unprecedented sensitivity. LIGO, a modified Michelson Interferometer with Fabry-Perot resonant cavities, achieved the required sensitivity to make the detection of gravitational waves possible. This project aims to help improve the sensitivity of the Advanced LIGO interferometers through the characterization of non-linear seismic noise.

Overview of ongoing work and progress

The first two weeks were dedicated to getting software installed – gwpy, macports, pip – troubleshooting, and familiarization with the GWpy package for Python, LIGO DV Web, and LIGO's Summary Pages.

During week three, the time segments for lock stretches that coincided with winds over 20 mph and under 5 mph were identified using the summary pages [4]. The corresponding times were used to compute the amplitude spectral density (ASD) for sixteen different Alignment Sensing and Control (ASC) channels. These channels are responsible for keeping the optical cavities locked, and correspond to two of the interferometer's degrees of freedom: the Common Arm (CARM) and the Differential Arm (DARM); and the pitch and yaw motion of the mirrors in the interferometer's X and Y arm. Initially, LIGO DV Web was used in order to obtain the spectra for the selected times for sixteen different ASC channels. Data indicate a possible correlation between high wind speed and an increase in amplitude in the ASD spectra for the following frequency ranges: 0.02 Hz to 0.2 Hz; 4 Hz to 10 Hz; and 20 Hz to 40 Hz. The following days listed below correspond to an observational lock stretch which coincides with periods of both high and low wind:

- September 09, 2015
- October 09, 2015
- October 11, 2015
- November 11, 2015
- November 12, 2015
- November 15, 2015
- December 14, 2015
- December 18, 2015
- December 20, 2015

A correlation was observed between high wind and an increase in amplitudes of the ASC channels for frequency ranges of 0.02 Hz to 0.2 Hz; 4 Hz to 10 Hz; and 25 Hz to 35 Hz. Figures 1 and 2 are representative of the observed correlation.

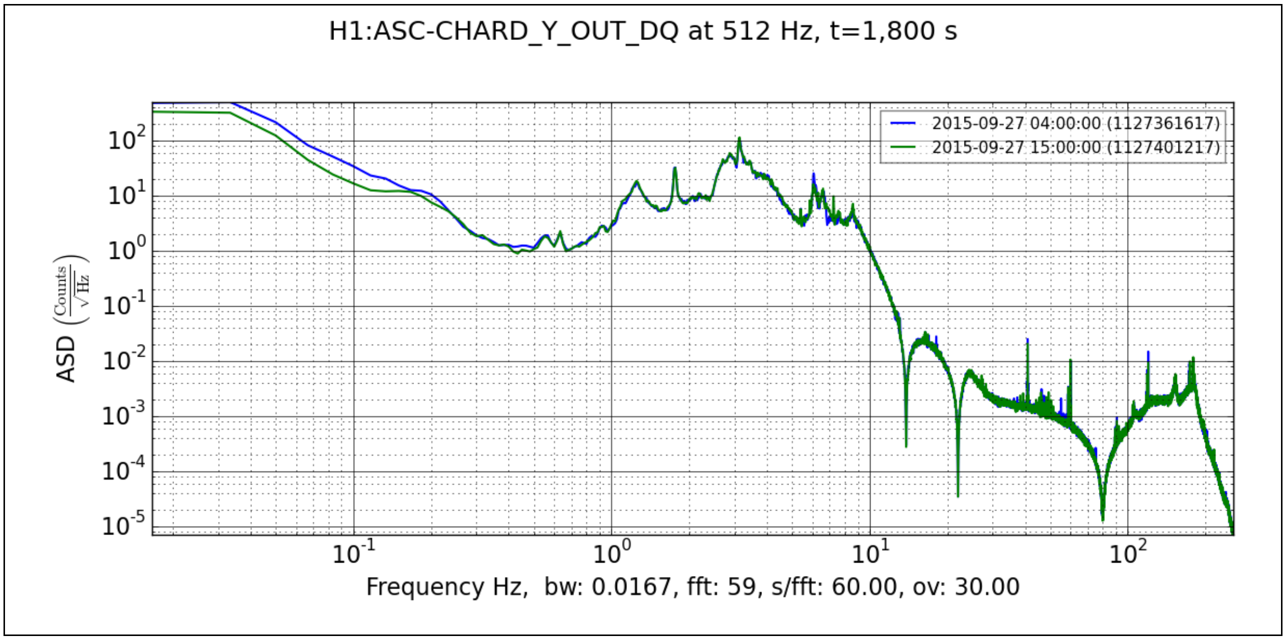

Figure 1. – ASD plot. Alignment Sensing and Control channel for CARM hard mode in the Y arm at Hanford Observatory. Low wind in green, high wind in blue. Increase in amplitude is evident for 0.02 Hz to 0.2 Hz frequency range.

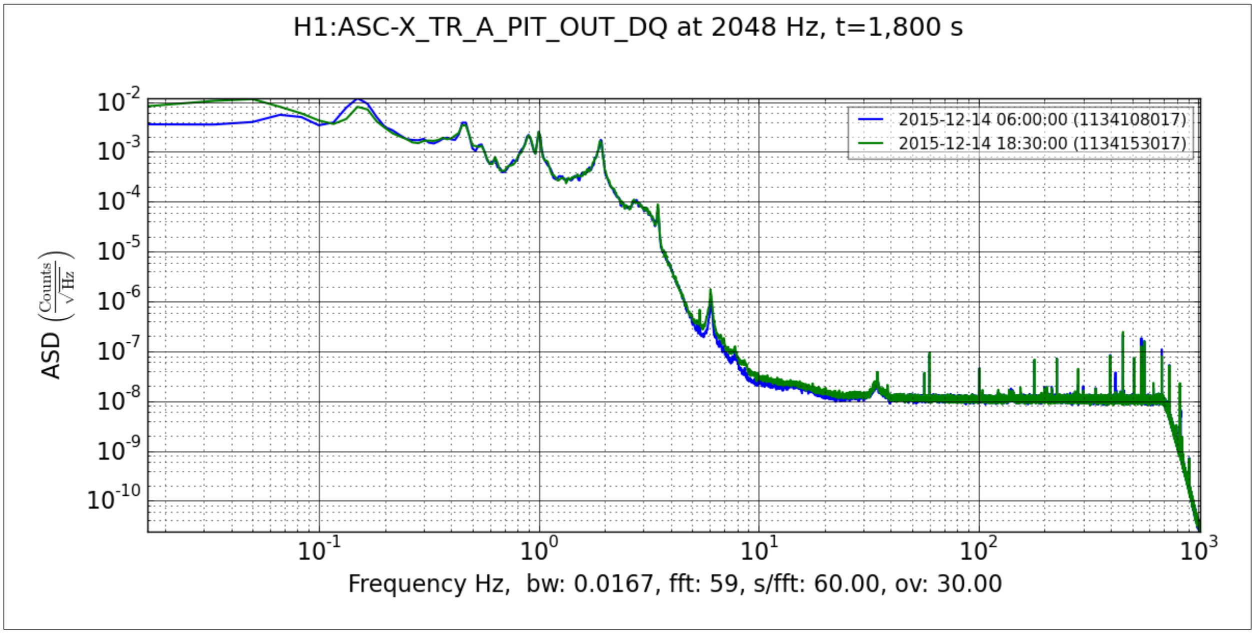

Figure 2. – ASD plot. Alignment Sensing and Control channel for pitch motion of optics in the X arm at Hansford Observatory. Low wind in green, high wind in blue. Increase in amplitude is at 4 Hz to 10 Hz; and possibly 30 Hz to 40 Hz.

In addition, a Python script has been coded which retrieves the necessary data, plots ASD spectra, and saves it with a specified file name. This script automates most of the plot generating labor.

The short term goals consist of more precisely measuring the amplitude increase in frequencies of interest. The threshold for the wind velocity at which the ASC channels are affected will also be identified. Ideally, this evolution of ASC control loop response to wind will be shown as a movie. In addition, a plan of action will be further developed for the larger goal of creating a matrix of all possible permutations of all degrees degrees of freedom and channels analyzed.

Challenges and Problems

It is expected to encounter bugs while installing software coding scripts. One of the major challenges is the length of time required to download the required data. The script written successfully downloads the data, generates 16 plots and saves them, at best, in one hour, and at worst, in four hours. This presents a setback when it comes to efficiency in productivity. This raises a major issue – making a movie for each channel per day will require multiple frames – and this will be a time consuming process. Therefore, a sacrifice will perhaps need to be made, videos for certain dates or channels may not come to fruition.

Resources

The following resources will be required:

- Software that can use .png files as frames to create a movie
- Video editing software for minor changes (if needed)
- Access to clusters

- Mentor’s guidance
- General blue prints of LIGO’s infrastructure and instrumentation in order to better understand how wind is coupling in to the interferometer’s optics, and access to more specialized and detailed blue prints would be ideal.

References

[1] B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration). Characterization of transient noise in Advanced LIGO relevant to gravitational wave signal GW150914. arXiv:1602.03844 (2016)

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[3] LIGO Scientific Collaboration. Advanced Ligo. arXiv:1411.4547 (2014)

[4] LIGO’s Summary Pages, Hanford site. https://ldas-jobs.ligo-wa.caltech.edu/~detchar/summary/