LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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LIGO SURF 2016 - Progress Report #2 : Noise Hunting in Advanced LIGO

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Abstract

The Laser Interferometer Gravitational-wave Observatory (LIGO) is designed to detect gravitational waves from energetic astrophysical sources in the universe. During its first observing run, LIGO detected two gravitational wave signals from binary black hole mergers, opening up a new path to astronomy. In order to improve LIGO?s detection rate, continuous efforts are made to characterize sources of noise and thereby improve LIGO?s sensitivity. This project investigated ground motion as a source of non-linear noise at the LIGO observatories. We observed that high winds with an excess velocity of 20 mph have an impact on the Alignment Sensing and Control (ASC) control loops. We found an increase in ASC noise amplitude at three distinct frequency bands. Time frequency analysis indicated the prevalence of glitches, or transient noise, with a central frequency of 5 Hz during periods of high wind. These results will enable commissioners to isolate and eliminate this effect, improve data quality, and enhance the interferometers? performance and stability.

1 Introduction

On September 14, 2015, for the first time in history, the Advanced LIGO detectors observed a gravitational wave signal from a binary black hole merger (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]. Gravitational waves were first predicted in 1916 by Albert Einstein, stemming from his theory of General Relativity, which was published in 1915. Gravitational waves are ”transverse waves of spatial strain that travel at the speed of light, generated by time variations of the mass quadrupole moment of the source” [3]. Due to the small amplitudes of gravitational waves, detecting them requires instrumentation of unprecedented sensitivity. LIGO, a modified Michelson Interferometer with Fabry-Perot resonant cavities, achieved the required sensitivity to make the detection of a gravitational wave possible. One of the major challenges in enhancing LIGO’s sensitivity consists in identifying, and eliminating or isolating sources of noise - both environmental and instrumental.

Commissioning efforts in characterizing noise and improving strain sensitivity allow LIGO to further enhance its detection range [4]. This enhancement will enable LIGO to detect gravitational waves at a higher rate, from smaller mass sources, and deeper into the Universe. Ground motion is investigated in this study as a potential source of non-linear seismic noise during the first observing run. We find that high winds, which exceed 20 mph, have an impact on the Alignment Sensing and Control (ASC) control loops. The control loops are part of a feedback control loop system which are designed maintain the mirrors in a locked state. Maintaining lock allows the laser to be in resonance within the interferometer’s cavities, and maintain the readout photo-detector at the dark fringe.

Amplitude Spectral Density (ASD) taken for lock stretches that contain periods of both high and low wind, show an increase in the level of noise. Furthermore, time frequency analysis indicated the prevalence of glitches, or transient noise, at about 5 Hz during periods of high wind. These results will enable commissioners to isolate and eliminate this effect, thereby improving the interferometer's performance and stability.

2 Overview of ongoing work and progress

2.1 Weeks 1 - 3

The first two weeks were dedicated to getting 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 [5]. The corresponding times were used to compute the ASD for sixteen ASC control loops. These control loops are responsible for sensing and aligning two of the interferometer's degree of freedom, CARM and DARM for both SOFT and HARD modes, and for the transmitted power at the X and Y end stations. Initially, LIGO DV Web was used in order to obtain the spectra for the control loops for the identified lock stretches. Our data indicates a correlation between high wind speeds and an increase in noise in the ASC control loops for the following specific frequency ranges: 0 - 1 Hz, 4 - 20 Hz, and 20 - 40 Hz. The following days listed below correspond to an observational lock stretches which coincided with periods of both high and low wind:

Date	High Wind Time Segment (UTC)	Low Wind Time Segment (UTC)
September 27, 2015	00:30 - 06:00	15:00 - 16:30
October 09, 2015	17:00 - 21:30	07:30 - 11:00
October 11 - 12, 2015	18:00 - 22:00 (10/11/15)	02:00 - 5:00 (10/12/15)
November 05, 2015	17:30 - 19:30	16:00 - 17:00
November 12, 2015	17:00 - 18:15	15:00 - 16:30
December 14, 2015	17:30 - 19:30	05:00 - 07:00
December 18, 2015	17:00 - 20:00	10:00 - 15:00
December 20, 2015	18:30 - 19:00	00:00 - 12:30

The correlation observed between high wind and an increase in noise for the ASC control loops for frequency bands 0 -1 Hz, 4 - 20 Hz, and 20 - 40 Hz, can be seen in Figures 1 and 2.

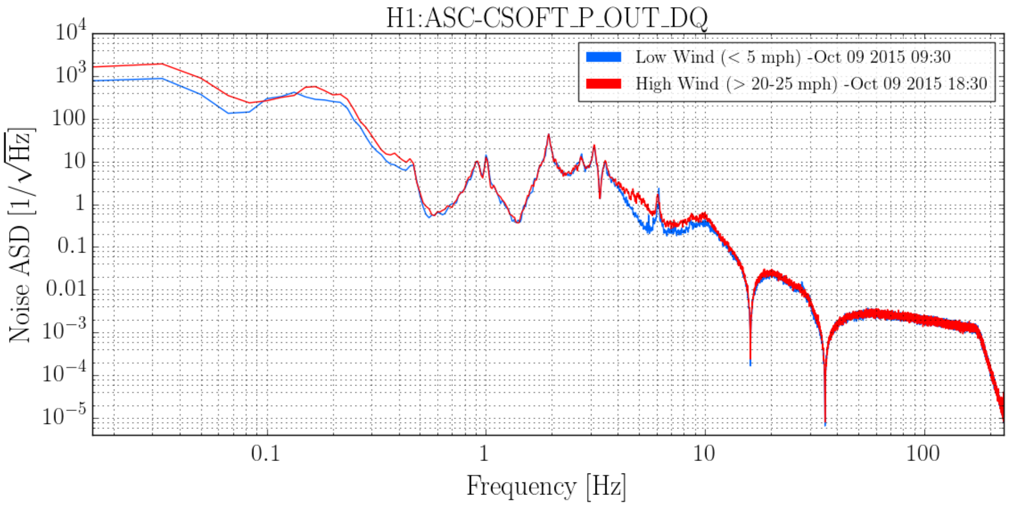

Figure 1: ASD plot. Alignment Sensing and Control channel for CARM soft mode pitch angular motion at Hanford Observatory. Low wind in blue, high wind in red. Increase in amplitude is evident for 0.02 Hz to 0.4 Hz frequency range.

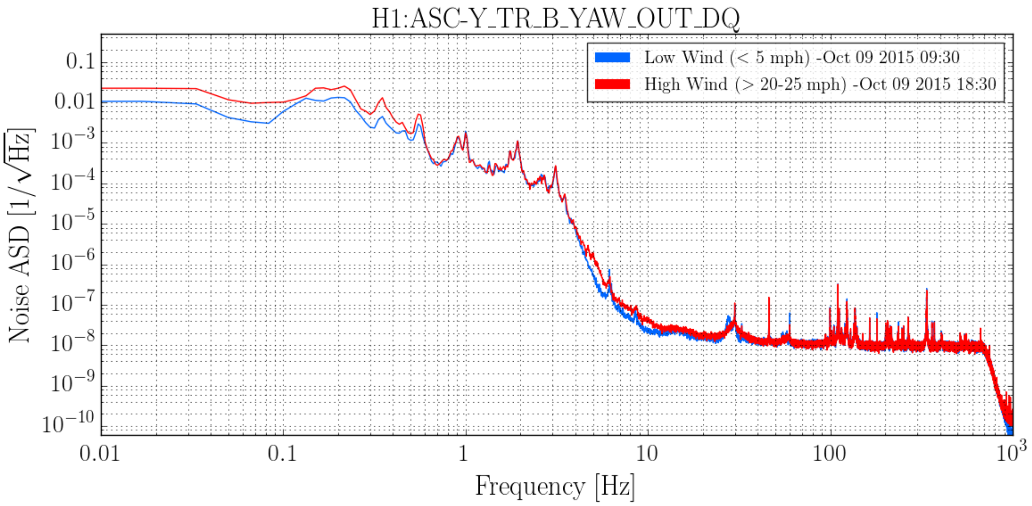

Figure 2: ASD plot. Alignment Sensing and Control channel for transmitted power at Y end station at Hanford Observatory. Increase in amplitude occurs at 4-10 Hz and 20-40 Hz.

During week three, a Python script was 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.

2.2 Weeks 4 - 7

Weeks four and five were dedicated to producing time lapses of changing ASD as wind speed increased. The lock stretch for October 9th was selected as the most representative example in order to construct the time lapses due to the fact that the vast majority of ASC control loops showed an increase in noise for the three frequency bands for this particular date. Using this criteria raised the question as to why this date showed higher noise levels for the ASC control loops compared to the other dates. After comparing data for our lock stretches, it was found that the noise levels on ASC control loops showed greater displacement for lock stretches where low wind preceded periods of high wind, in contrast to high wind precededing periods of low wind. A plausible explanation is that the ASC control loop system requires time for the noise level to settle down to lower values.

Using the targeted lock stretch date, channels representative of the sensors and control signals of the ASC control loops were selected in order to create animations on how noise levels changed as wind speeds changed: The selected channels are:

- H1:ASC-CSOFT_P_OUT_DQ
- H1:ASC-DSOFT_P_OUT_DQ
- H1:ASC-X_TR_A_PIT_OUT_DQ
- H1:ASC-Y_TR_B_YAW_OUT_DQ

Here we present stills of the videos for the four channels which demonstrate the increased noise levels. For access to the videos, please visit the following link which contains a summary of this report and the time lapses.

- https://wiki.ligo.org/DetChar/LHOWindASCStudies

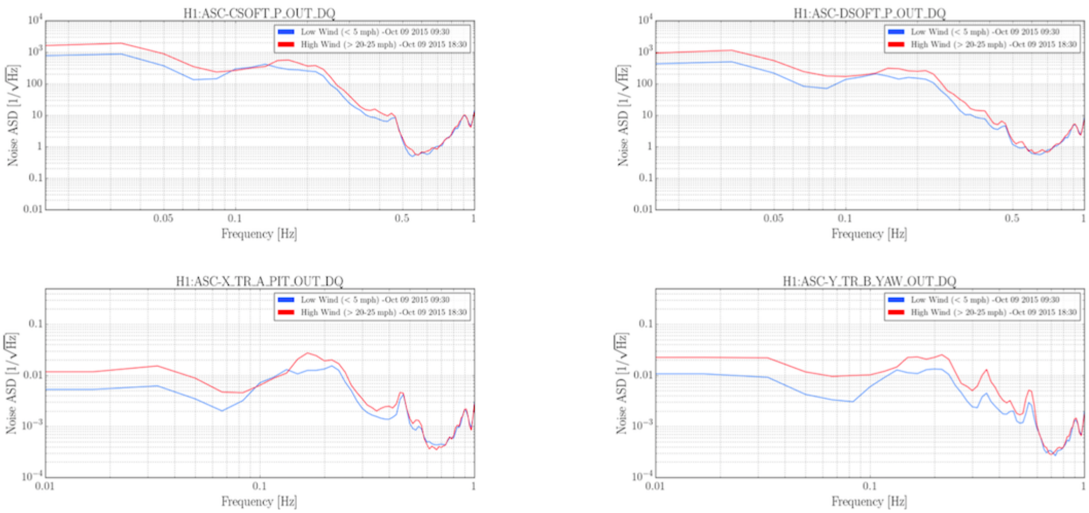

Figure 3: ASD plots of four ASC channels for 0 -1 Hz band.

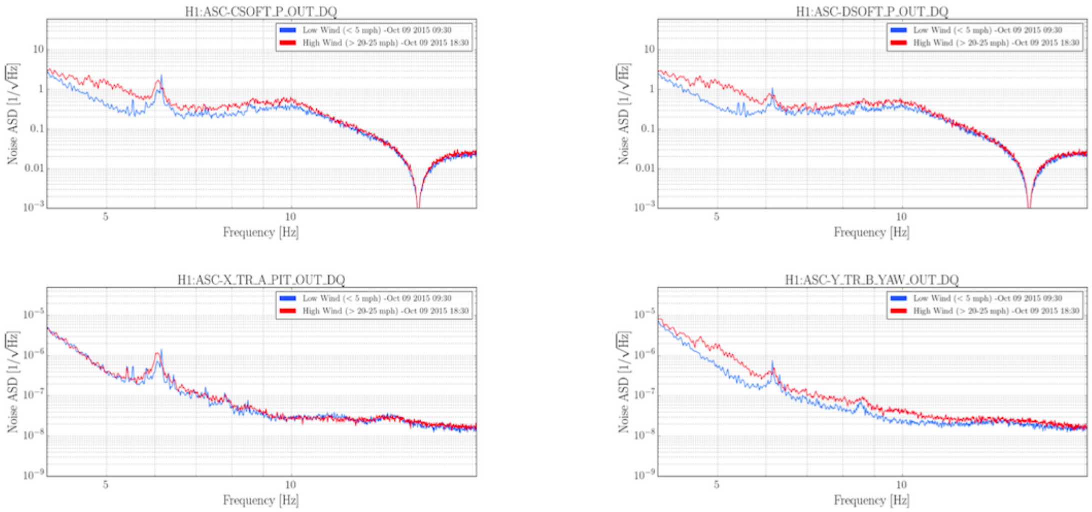

Figure 4: ASD plots of four ASC channels for 4 -20 Hz band. 5 Hz glitches occur in this frequency band.

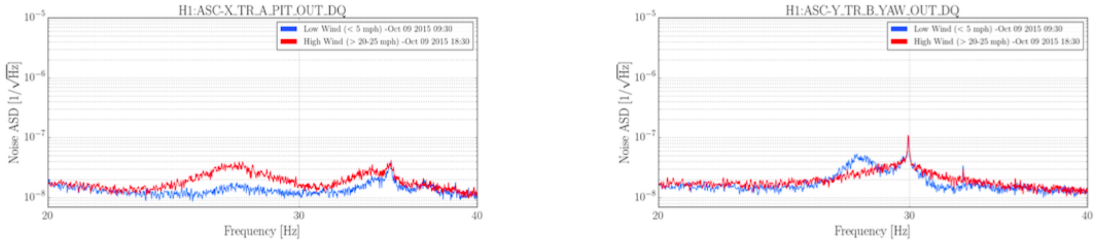

Figure 5: ASD plots of two ASC channels for 20-40 Hz band. At this frequency band, changes in noise levels were observed only for the transmitted power at the X and Y end stations.

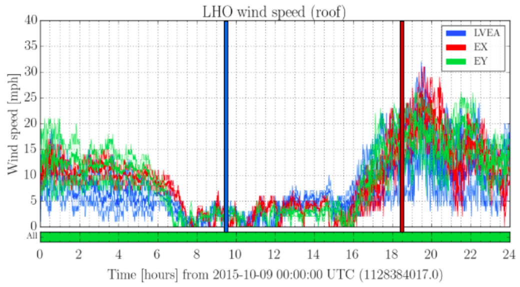

Figure 6: Time series for wind speed at Hanford on October 9, 2015. Blue and red markers indicate times of low and high wind as seen in the ASD plots.

The results up to this point were presented at UC Fullerton, where it was pointed out by Josh Smith that the behavior observed in the 4-20 Hz frequency band is caused by glitches. This was confirmed by looking at spectrograms centered at the 18:20 (UTC) time period which showed features of a localized and transient noise, which are characteristic of the morphology of a glitch as seen in Figure 7. It was suggested to me that a cause for this glitching could be caused by saturations in the photodetectors.

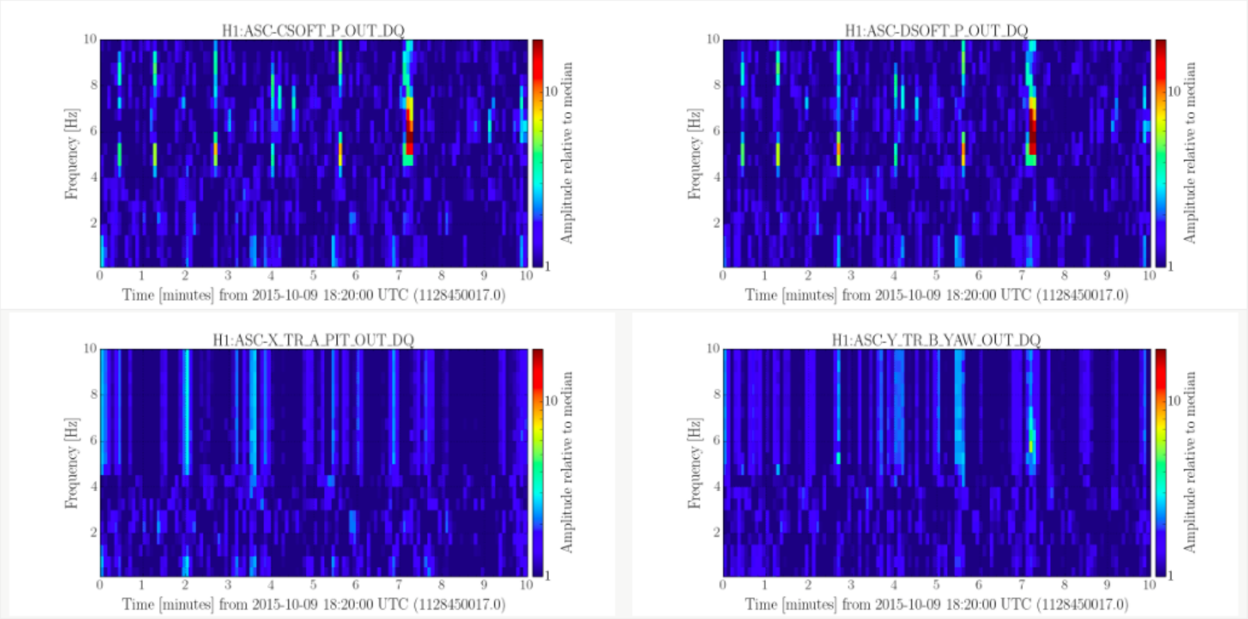

Figure 7: Spectrograms (GWpy) for high wind time segment which demonstrate glitching with a central frequency of 5 Hz

In addition, OmegaScans, a feature on LigoDV web, were also used to focus on a single glitch in order to have better resolution on the morphology of the glitch - see Figure 8.

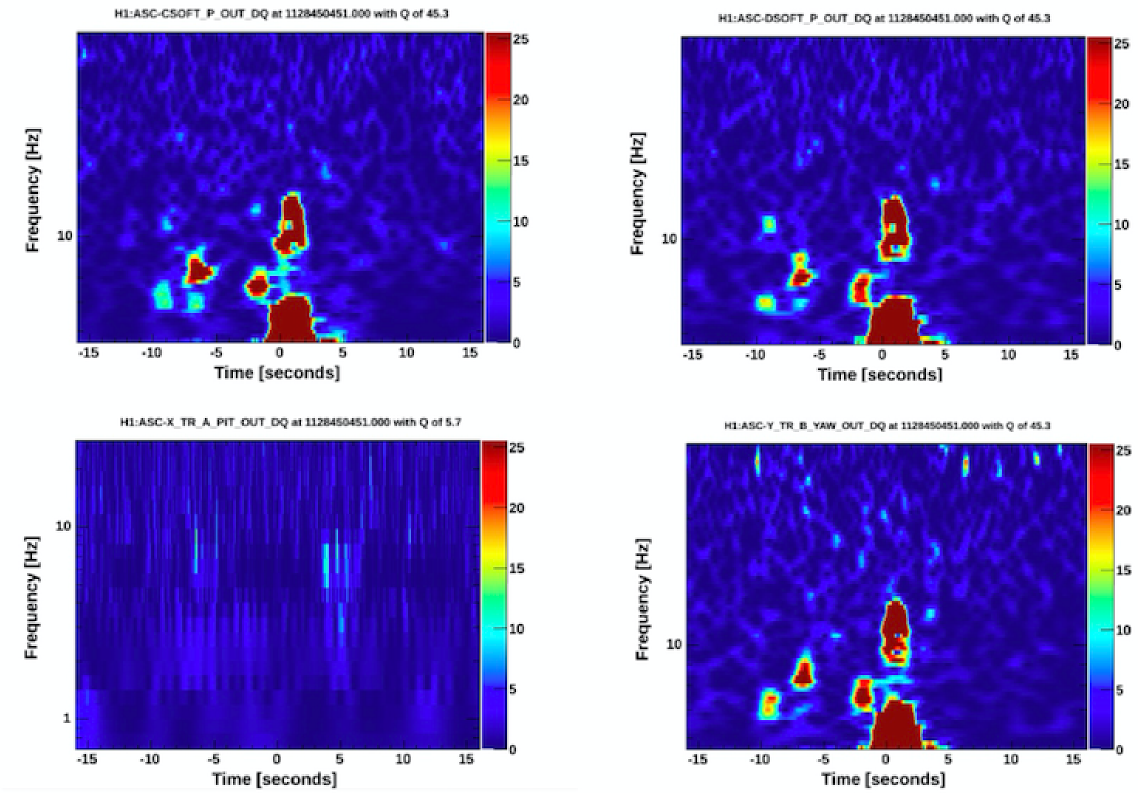

Figure 8: Spectrograms (OmegaScan) for high wind time segment for a single glitch

The result up to this point were presented during the LIGO detector characterization (DetChar) working group teleconference and the LIGO seismic isolation working group teleconference the week of July 25. During the DetChar call, Peter Saulson suggested to zoom in on the glitch on the OmegaScan in order to see if the glitch's morphology corresponds to glitches caused by scattered light.

2.3 Future Work and Goals

- Zoom into glitch using OmegaScan to see if the glitch's morphology corresponds to glitches caused by scattered light.
- Look at other lock stretches identified to see if there are glitches with a central frequency at 5 Hz in order explain if these glitches occur in only some cases or if they occur for all lock stretches with high wind.
- Obtain BLRMS of control loops which is a better indicator of glitching than 30 minute averaged ASDs.
- Obtain full OmegaScans for h(t) and other interesting channels.
- See the effect on the inspiral range during periods of high wind.
- Continue to work on identifying interesting features in the ASD for Length Sensing and Control loops for PRCL and SCRL during periods of elevated ground motion.
- Obtain time lapse for pitch and yaw motion for ASC SRC2 for October 9, 2015.
- Update summary report on the wiki page.
- Continue making updates on the aLog.
- Generate new ASDs that correct the 30 minute average to 15 minute average.
- Sync GIFs on the wiki page.
- Present results and submit a final report.
- Upload python scripts into DCC

3 Challenges and Problems

One of the major challenges which was amount of time in downloading data was fixed with the suggestion from Jess McIver which instructed me to add to my python script the following command: host = 'nds.ligo.caltech.edu'. This development allows for the creation of more videos in a significantly smaller amount of time. Another challenge is understanding complexity of the instrumentation in its fullest detail; how all the pieces fit together and interact with each other. This ranges from the interconnection between the mechanical, optical systems, and electronics to the feedback control loop systems, generation of data, and software systems that analyze the raw data.

4 Resources

My resource continue to be python, LigoDV web, access to computer clusters, guidance and feedback from my mentors, and feedback from other LIGO Detector Characterization team members.

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)

[2] B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration). Observation of Gravitational Waves from a 22 Solar Mass Binary Black Hole Coalescence. *Phys. Rev. Lett. 116.241103* (2016)

[3] B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration). Observation of Gravitational Waves from a Binary Black Hole Merger. *Phys. Rev. Lett. 116.061102* (2016)

[4] LIGO Scientific Collaboration. Advanced LIGO. *arXiv: 1411.4547* (2014)

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